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1960**

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ENGINEERING DEPARTMENTAL REPORTS AND THESES 1960

*Abstracts of Engineering Departmental Reports and Titles of Theses of the
University of Illinois College of Engineering*

Edited by

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THE ENGINEERING EXPERIMENT STATION OF THE UNIVERSITY OF ILLINOIS, URBANA, ILLINOIS, 1961

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CONTENTS

INTRODUCTION	5
AERONAUTICAL ENGINEERING	7
AGRICULTURAL ENGINEERING	8
CERAMIC ENGINEERING	13
CHEMICAL ENGINEERING	16
CIVIL ENGINEERING	17
ELECTRICAL ENGINEERING	24
MECHANICAL ENGINEERING	33
MINING AND METALLURGICAL ENGINEERING	35
PHYSICS	35
THEORETICAL AND APPLIED MECHANICS	36
AUTHOR INDEX	44
SUBJECT INDEX	46

INTRODUCTION

This publication provides bibliographical data and abstracts of research reports published by individual departments of the University of Illinois College of Engineering during the fiscal year 1959-1960. The purpose of the bibliography is to make known to interested individuals the existence and nature of papers written by the research staff, papers which may not be available in form other than that of a departmental publication. In general three peculiarities characterize these reports: (1) a number of the papers are written as graduate theses; (2) many of them are edited for journal publications, and a few may appear as Experiment Station bulletins; and (3) in all instances the reports in the form described herein are available only for limited distribution by the individual department. In some cases, these reports are restricted to qualified personnel.

It is not the aim of this bibliography to give a definitive account of all research reports. For the most part, the departments represented here have a standard method of publishing reports by staff members in series form. Engineering departments which do not adhere to a departmental series or other consistent departmental publication but do publish a significant number of articles are Aeronautical Engineering, Agricultural Engineering, Ceramics, Chemical Engineering, Mining and Metallurgical Engineering, and Physics.

The large number of journal publications evolving from research projects, although not listed here, are listed by title under the description of their respective research project in A Summary of Engineering Research, 1960, University of Illinois Engineering Experiment Station. Also, progress reports of a tentative nature are not listed, but those which terminate a specific phase of research have been included. Unless they are departmental reports, graduate theses are given here merely by title, since Ph.D. dissertation abstracts can be obtained from the periodical Dissertation Abstracts published by the Ann Arbor Press.

To facilitate requisition of those papers which are available, an attempt has been made to include all descriptive bibliographic information known at the time of the bulletin's publication. Abstracts are listed under the title of the project which the reports describe, but thesis titles are alphabetized by author under the department in which they were written. All entries are referred to in both an author and subject index.

Inquiries concerning copies of the abstracted reports should be sent to Engineering Publications Office, 114 Civil Engineering Hall, University of Illinois, Urbana, Illinois.

AERONAUTICAL ENGINEERING

A numbered series is not published by this department. Most available research information is disseminated in professional journals. The following are abstracts of reports published through the department for the sponsors' distribution.

BARTHEL, H. O. "High Strength Shocks," Aeronautical Engineering, Sandia Corporation Purchase Order 51-4370, July 16, 1960. 29 pp. 18 figs.

This report describes the efforts expended during the previous year to convert the 4- by 15-inch conventional single-diaphragm shock tube with Mach 2.5 capability to a double-diaphragm, combustion driven shock tube having a Mach 20 capability when the test section is at 1 mm Hg. pressure. The converted tube is to be used to study shock structure and process by interferometric, spectroscopic and mass-sampling techniques for shocks in air with shock Mach numbers between 10 and 20.

KRZYWOBLOCKI, M. Z. v. "A Study of Special Interplanetary Flight Problems," Aeronautical Engineering, Report No. 2, Contract No. DA-11-022-ORD-2835, June 1959. 190 pp. 19 figs.

Report No. 2 constitutes the second volume of the study of special interplanetary flight problems performed for U. S. Army Ordnance under the contract No. DA-11-022-ORD-2835. In particular, the present report contains discussions and presentations of various items pertinent to the subject of orbit mechanics and interplanetary trajectories in the solar system. These items are discussed in detail with the final results presented in a mathematical form. This collection of various technical details of a mathematical nature was performed with a special goal in mind. It was desired to select the items which were best suited to adequately describe interplanetary trajectories between the Earth and Mars. These items will be treated in Report No. 3.

KRZYWOBLOCKI, M. Z. v. "A Study of Special Interplanetary Flight Problems," Aeronautical Engineering, Report No. 3, Contract No. DA-11-022-ORD-2835, April 1960. 155 pp. 13 figs.

Report No. 3 contains the following items: mathematical formulation of the boundary conditions referring to the trip to Mars, extension of the boundary conditions to a more general case, calculation of the terminal orbital velocities and acceleration, derivation of the equations of motion, and the variational approach.

KRZYWOBLOCKI, M. Z. v. "A Study of Special Interplanetary Flight Problems," Aeronautical Engineering, Report No. 4, Contract No. DA-11-022-ORD-2835, June 1960. 146 pp. 1 fig.

Report No. 4 in the series of the study of special interplanetary flight problems contains the mathematical aspects of the problem and a discussion of various possible methods of solution available today. Chapter II contains a long list of references of a mathematical nature, pertinent to the problem in question. It is pointed out that with the use of methods and techniques available today there is little hope that a rigorous solution or even an acceptable approximate solution can be found.

KRZYWOBLOCKI, M. Z. v. "A Study of Special Interplanetary Flight Problems," Aeronautical Engineering, Report No. 5, Contract No. DA-11-022-ORD-2835, June 1960. 127 pp. 19 figs.

The present volume, the fifth in the series of the study of special interplanetary flight problems, consists of three chapters. Chapter I contains reviews of some papers and reports referring directly to the problem of navigation during interplanetary flight. Chapter II contains reviews of some papers pertinent to the general problems of interplanetary flight, and from this standpoint may be considered as a supplement to Volume I of the present series. Chapter III deals with the possible methods of correctional maneuver in space by using either high impulsive thrust or low continuous thrust. Various cases will be discussed there.

HILTON, H. H. "The Divergence of Supersonic Linear Viscoelastic Lifting Surfaces Including Chordwise Bending," Aeronautical Engineering, Hughes Aircraft Co. Technical Report S. F. 3.3-4, September 1959. 36 pp. 7 figs.

An elastic-viscoelastic analogy is developed for the creep deformations of lifting surfaces. It is applicable to chordwise bending and torsional divergence analyses. The general linear viscoelastic stress-strain relationships are used and the analogy is derived in terms of Fourier and Laplace transforms. An illustrative example for the case of torsional divergence is included and the contributions of the various parameters influencing creep deformations are discussed. It is further shown that analyses based on linear viscoelastic stress-strain relations will not lead to divergence of the lifting surface in a finite time. However, the deformations can become exceedingly large in a relatively short time and alternate methods for the determination of maximum lifetimes are presented.

8 DEPARTMENTAL REPORTS AND THESES

An expression is derived for the effective polar moment of inertia for an arbitrary cross section. It is shown that for a homogeneous linear viscoelastic body it is identical to the expression for an equivalent homogeneous elastic body.

AERONAUTICAL ENGINEERING THESES

Ph. D.

None

M. S.

Baud, K. W. "Evaluation of a Hydrazine Monopropellant, Air-Turbo-rocket Power Unit," R. W. McCloy, advisor. August 1960.

Chang, E. Y. "On the Interaction of a Plane Uniform Shock Wave with an Unrestrained Plate," H. S. Stillwell and H. O. Barthel, advisors. August 1959.

Chenoweth, D. R. "Exact Calculation of Steady Compressible Diabatic Flows," B. L. Hicks, advisor. October 1959.

Culver, A. C. "An Experimental Investigation of the Torsional Instability of Open-Section Columns," J. M. Coan, advisor. August 1959.

James, W. R. "On a General Method of Solution to the Nonlinear Equations of Magnetogasdynamics," M. Z. v. Krzywoblocki, advisor. February 1960.

Lundry, J. L. "On the Interaction of a Weak Plane Expansion Wave with a Shock Wave Generated by a Supersonic Conical Body," A. I. Ormsbee, advisor. October 1959.

Meyer, P. A. "Experimental Development of a Two Stage Direct Current First Stage and Three Phase Alternating Current Second Stage Plasma Generator," A. I. Ormsbee, advisor. June 1960.

Pierce, D. J. "The Development of the University of Illinois 2-Inch Diameter Combustion Shock Tube and Shock Wave Detection Apparatus for Studying the Attenuation of Strong Shock Waves," H. S. Stillwell, advisor. August 1959.

Shao, Tzu-Sien "On the Brachistochronic Flight of a Rocket in the Interplanetary Space," M. Z. v. Krzywoblocki, advisor. February 1960.

Stahl, W. H. F. "Approximate Solution of the Boundary Layer Equation for Fully Developed Turbulent, Compressible Two-Dimensional Flow Applied to a Diffuser," R. W. McCloy, advisor. February 1960.

Walsh, E. L. "The Effects of Thermal Stresses on the Torsional Response of Thin Flat Plates Subjected to Torsion Using Viscoelastic Stress-Strain Relationships," H. H. Hilton, advisor. August 1959.

AGRICULTURAL ENGINEERING

Agricultural Engineering publishes large quantities of research reports through its own publications office and in professional journals. The reports included here have been read as ASAE papers, but they are distributed also through the University of Illinois Agricultural Experiment Station.

REPLOGLE, J. A. "Critical Flow Criterion in Open Channel Computations," Agricultural Engineering, ASAE Paper 59-710, Agr. Exp. Station Project No. 10-315, December 1959. 16 pp. 8 figs.

Many flows in open channels can be described by the concept of critical depth. Critical depth is the condition of maximum discharge for minimum energy. For channels with subcritical slope, the specific energy equation minimizes to produce the critical depth expression $\frac{V^2}{2g} = \frac{D}{2} \cos \theta$ (1) where, V is velocity, g is the acceleration of gravity, D is the mean depth and θ is the channel slope.

In a long channel with a free overfall, such as at a culvert or tile outlet, the point of minimum energy is near the brink section due to frictional losses. This section should be the true critical section and thus the point of measure for flow calculations. This is true only for mild slopes producing subcritical velocities.

Equation (1) assumes straight, parallel, non-viscous flow with hydrostatic pressure distribution. Since none of these assumptions are valid in the region of the overfall section, three corrections must be applied to the equation. These corrections are the velocity distribution coefficient a , the pressure coefficient a' , and the drawdown coefficient a'' . The velocity distribution coefficient a , can be determined by using methods described in King's Handbook of Hydraulics. It varies from about 1.04 to 1.15.

The pressure coefficient, a' , is required because of the acceleration components produced by the curvilinear flow at the overfall. It can be shown that $a' = \frac{1}{Qy} \int_0^A hvy \, dA = 1 + \frac{1}{Qy} \int_0^A cr \, dA$ (2) where Q = discharge, y = depth of flow, h = true piezometric height, v = velocity, A = area, c = static piezometric height minus h , and r = radius of curvature. For the condition at an overfall this can be approximated by $a' \approx 2 - a$ (2a).

The Drawdown coefficient, a'' , is required by the reduction in pressure at the open end of the channel. This produces an increase in velocity and thus a decrease in depth in this region. The drawdown coefficient is evaluated from a momentum expression written for the pressure conditions at the brink section and a section upstream. The upstream section is chosen so that it corresponds to the critical flow criterion for straight, parallel flow with hydrostatic pressure distribution.

These momentum expressions are implicit functions of the brink depth, d_b , and the upstream critical depth d_c . The drawdown coefficient, $a'' = \frac{d_c}{d_b}$, was solved by trial and error for triangular, rectangular, and circular channels. The values are constants for triangular and rectangular channels and nearly constant for circular channels. They are $a'' = 1.28$, $a'' = 1.46$, and $a'' = 1.35$ for triangular, rectangular and circular channels respectively. The general trapezoid does not bear the same geometrical relationship to the flow at all depths, so the value of a'' is not constant.

With these three corrections the critical flow expression becomes $a \frac{V^2}{2g} = a' a'' \frac{D}{2} \cos \theta$ (3). Combining this with the continuity equation we obtain $Q = \sqrt{\frac{a'g}{a}} \cos \theta AD^{1/2}$ (4). The quantity $AD^{1/2}$ is called the section factor for critical flow computation and is designated by Z_c . Thus equation (4) becomes $Q = \sqrt{\frac{a'g}{a}} \cos \theta Z_c$ (4a). For triangles and rectangles respectively $Z_c = \frac{\sqrt{2}}{2} z d_c^{2.5} = \frac{\sqrt{2}}{2} z (a'')$ (5) and $Z_c = b d_c^{1.5} = b (a'' d_b)^{1.5}$ where z is the side slope ratio, horizontal to vertical. Circles are more conveniently worked with graphical solutions or tables to determine Z_c .

Laboratory measurements of the pressure distribution and the velocity distribution were conducted. The pressure profile at the overfall section was found to be parabolic. It was zero (atmospheric) at both top and bottom and .175 times the depth near the interior region. The velocity distribution coefficient a for the triangular section was 1.08. The a values for the other sections were not measured directly.

The experimental rating curves made on the different channel sections are nearly coincident with the theoretical curves over all ranges tested. Deviation was less than one percent.

HOLT, R. C., R. R. YOERGER and J. A. Weber. "Why Early Tractor Intake Valve Failure?" Agricultural Engineering, ASAE Paper No. 60-140, Agr. Exp. Station Project No. 10-342, June 1960. 10 pp. 8 figs.

Nine engine loading tests were conducted to determine the effects of improper repair practices, use of valve rotators and the use of valve seals on the early failure of tractor engine intake valves. Improper repair practices including small and excessive tappet clearances, use of oversized valve guides, grinding the valve seat out-of-round and the use of weak valve springs were imposed upon the engine according to a statistical design. Each engine test was 125 hours in duration and was cycled to more nearly simulate field operation. Measurements of temperature during operation, deposit weight accumulated during each test, changes in the size of valve stems and guides caused by wear or deposits and the valve face roughness were made for each treatment. Grinding the seat out-of-round was found to be the greatest cause of early intake valve failures in the test. However, no valve failures were encountered when rotators were used. Oversized guides, weak springs, and valve seals did not affect the temperature, deposit weight or stem size of the intake valves.

HUANG, B. K. Y., and R. R. YOERGER. "Maceration As a Pretreatment to Hay Wafers," Agricultural Engineering, ASAE Paper No. 60-119, Agr. Exp. Station Project No. 10-392, June 1960. 9 pp. 10 figs.

A major problem in the use of hay wafers, a product that can be readily handled, transported and fed with mechanical equipment, has been the development of an economical machine to satisfactorily produce wafers under the widely varying conditions encountered in the field. Contrary to the usual experience in forming hay wafers from high moisture material, satisfactory cohesion of alfalfa stem material ranging up to 49 per cent in moisture content was obtained when the stems were compressed between flat plates. Microscopic inspection revealed a severe lacerating or more nearly a macerating action on the stem walls that destroyed much of the mechanical structure and liberated adhesive protoplasm. A laboratory machine designed to breakdown the plant stem wall structure without chopping or destroying the plant stem fiber was used to treat the hay just prior to wafers. With this pretreatment stable wafers were obtained by compression in a closed-end cylinder from alfalfa hay ranging up to 35 per cent in moisture. The energy requirements, pressure-volume relationships and wafer handling durability are discussed.

PICKARD, G. E., and R. R. YOERGER. "Tractor Engine Exhaust For Pumping Agricultural Fluids," Agricultural Engineering, ASAE Paper No. 60-106, Agr. Exp. Station Project No. 10-330, June 1960. 8 pp. 10 figs.

There are many applications in agriculture where exhaust gas back pressure from a tractor engine can be used to pressurize an air tight tank and develop sufficient head to eliminate the need for a transfer pump. The performance of hydraulic systems utilizing exhaust gas back pressure and the effect of exhaust restriction on engine operation are discussed. The performance characteristics of a spark ignition engine operated with exhaust back pressures up to 26.5 pounds per square inch and a diesel engine operating up to 49 pounds per square inch were studied. Indications of the influence of exhaust back pressure on maximum power output, exhaust temperature and pumping capacity were obtained. Two types of exhaust pressure regulators were developed for use on tractors. Tests also indicated that engine exhaust pressure could be used with the gravity system of liquid fertilizer application and permit the use of several row applicators from a single tank even on rolling terrain.

YOERGER, R. R. "Dimensional Analysis in Farm Machinery Development," Agricultural Engineering, ASAE Paper 59-633, December 1959. 8 pp. 4 figs.

The application of some of the techniques of dimensional analysis to the design and performance testing of farm equipment is demonstrated by a detailed example. The test program presented is designed to obtain a single equation to predict the power requirement characteristics of a roller-crusher mechanism for reducing the size of corn cobs making them suitable for use as animal bedding, litter, mulch and industrial raw products. The twelve machine design and material property variables are combined into dimensionless and independent P_i terms thereby reducing the number of variable quantities to nine. The significant engineering properties pertaining to the quartering action are evaluated. Component equations are determined for each dependent P_i term and these equations are then combined to form a general prediction equation for the power requirement of the operation. Further application of dimensional analysis and model study technics to machinery development is discussed.

KAMPE, D. F. "Harrow Flexibility by Means of Linkage," Agricultural Engineering, SAE Paper No. 96W, S. A. E. National Farm Construction and Industrial Machinery Meeting, September 1959. 5 pp. 7 figs.

This paper is a discussion of a linkage system developed to provide for relative motion between the tractor and a disc harrow attached to the tractor's 3-point hitch system. The tractor 3-point hitch system does not provide for roll motion of an implement nor does it provide for free pitch motion.

The provision for these two types of motions was incorporated in the tractor implement combination by using the specially developed linkage in the attaching system. This linkage system consists of two main draft links and a stabilizing top strut connected between the tractor hitch "A" frame and the harrow frame. The analysis of this linkage is similar to the analysis used for any 4 bar linkage with both motion and force considerations involved. Implement roll and pitch are possible while still providing for transport lift and implement stability while working.

The linkage has application to a tractor mounted disc harrow and also to a wheel-mounted pull-type harrow.

SHOVE, G. C., and K. K. HARSHBARGER. "Mechanized Feeding of Complete Rations to Dairy Cows," Agricultural Engineering, ASAE Paper 59-838, Agr. Exp. Station Project No. 10-373, December 1959. 3 pp. 4 figs.

The Departments of Agricultural Engineering and Dairy Science, University of Illinois and the Farm Electrification Research Branch, United States Department of Agriculture are cooperating in a new project to study automation in feeding dairy cattle. Earlier feeding experiments at the Illinois Agricultural Experiment

Station indicated dairy cows can be fed satisfactory with mixed roughage and concentrate rations. These experiments also gave evidence that dairy cows can be self-fed a complete ration by grouping and feeding the cows according to milk production level.

Facilities to study group feeding of cows have been installed at the University of Illinois Dairy Farm. Mechanical equipment automatically blends and processes shelled corn, oats, and soybean meal. The blended concentrate mix is metered in a preselected amount onto chopped hay and the complete roughage and concentrate ration conveyed to a feed bunk. The cattle feed free-choice and although they have shown some tendency to separate out the grain particles eventually clean up the mixed ration placed before them.

Automatic electrical controls for the feeding system were designed by Hoyle B. Puckett, agricultural engineer of the Farm Electrification Branch. The time of day and length of each feeding period is preselected by adjustment of time clocks.

JEDELE, D. G. "Lagoon Disposal of Liquid Hog Manure," Agricultural Engineering, ASAE Paper No. 60-401, June 1960. 5 pp.

This report deals with the adaptation of the lagoon method of sewage treatment to disposal of liquid hog manure.

Hogs are being raised in confinement in ever increasing numbers. Cleaning the buildings and disposing of the waste is the most vexing problem in this system of raising hogs. Therefore much attention is being given to the use of lagoons.

A method of manure disposal was needed at the Moorman Breeding Research Institute on the University of Illinois South Farm where 20 new swine buildings are being erected. Manure from these buildings will be discharged into lagoons of varying sizes. One provides about 20 square feet of surface area per hog, another about 30 square feet per hog and the third provides about 50 square feet per hog.

Experience with lagoons for animal waste disposal is limited and results are not available from the test lagoons. But the potential appears to be good for the use of lagoons in conjunction with large confinement live-stock enterprises.

UGGERBY, O., and K. HINCHCLIFF. "Panelized Farm Homes of Native Materials Using Farm Labor," Agricultural Engineering, ASAE Paper No. 60-429, Agr. Exp. Station Project 10-377, June 1960. 13 pp. 13 figs.

The goal of this project was to combine the advances gained in urban construction techniques with the special advantages offered by the modern farm. These advantages include: a supply of native building materials, natural construction skills of most farmers, more off-season time for self-help building due to time gained from mechanization, farm power equipment for moving building components, and farm structures suitable for building and storing building components prior to erection.

Although not all farmers have their own timber supply, this first study made use of native lumber as much as possible. The house design took advantage of the unique architectural features of the rough timber rather than merely substituting for accepted commercial products.

The structural system was developed using post and beam framing and prefabricated floor, wall and roof panels. A scale model was built to check the design and finally a full sized portion of a house was erected to check construction techniques.

Even though good power tools were utilized, it was found that the weight and hardness of the native oak made fabrication and erection time consuming. Difficulties were encountered in lining up panels because of variations in dimensions of the rough sawn lumber, and it appeared that dressing or more accurate sizing of the lumber would be very important if this method of building were adopted.

Results thus far indicate that the wall panels of native material could be utilized very well. Floor and roof panels could use native material for framing, but plywood sheathing would be much preferred over native lumber sheathing.

Since a complete house has not been built, there has not been an opportunity to check the details of finishing this type of house on the inside.

RODDA, E. D., and E. L. HANSEN. "Concrete Rigid Frames for Farm Buildings," Agricultural Engineering, ASAE Paper No. 59-807, Agr. Exp. Station Project No. 10-372, December 1959. 4 pp. 3 figs.

This paper discusses the application of ultimate strength design to the critical section at the knee joint of a reinforced-concrete gable frame and outlines a test program in progress to verify the design assumptions.

HERUM, F. L. "Performance of Screw Conveyors At Rates Less Than 2500 Pounds Per Hour," Agricultural Engineering, ASAE Paper 59-916, Agr. Exp. Station Project No. 10-344, December 1959. 8 pp. 6 figs.

Screw conveyors are well suited to a variety of conveying applications and are being permanently installed as integral parts of farmstead continuous-flow feeding systems. In any such system, usually including screw conveyors operating at a number of speeds and angles of inclination, it is likely that most are operating to some degree below their maximum capacities. In some situations, other devices restrict the rate of feed flow.

Tests of screw conveyors, previously performed, have been made with the conveyor freely removing material from a bulk supply and operating essentially full. Such data did not appear to accurately reflect the characteristics of auger conveyors operating at less than maximum rate. Since accurate performance data at partial capacities are required to design an efficient and dependable system of conveyors, a series of tests were conducted to obtain such data.

A commercially produced screw conveyor, nominally four inches in diameter, was tested with provisions for adjusting and measuring the input rate, conveyor slope, and screw rotational speed. Input power was determined with a cradled driving motor. All combinations of four variables were tested: six rotational speeds from 50 to 400 revolutions per minute, six slopes from 0° to 90° , one to four input rates, and three different feed materials. Data were plotted as horsepower per 10 feet of conveyor length versus input rate, with separate curves for each rotational speed.

The test results provide the desired estimates of power requirements for nominal 4-inch screw conveyor at low conveying rates.

PUCKETT, H. B., "Progress Report, Performance of Medium-Pressure Conveying System," Agricultural Engineering, ASAE Paper No. 59-911, December 1959. 11 pp. 24 figs.

This paper reports the progress of a four-year study on small-pipe pneumatic conveying systems for automatic feed distribution on a livestock or poultry farm.

A medium-pressure pneumatic conveyor (operating at pressures of 2-20 pounds per square inch) shows much promise for fully automatic distribution of dry granular feed on the farm. The system is easy to install in existing buildings and to operate automatically. As in all pneumatic conveyors, all operating equipment can be concentrated at one location with conveying tubes extended to the delivery points. This simplifies maintenance. Valves suitable for automatic operation can be placed in the conveying lines to divert the material flow to any one of several possible locations. Only one location can be serviced at one time.

The higher pressure available with this conveyor system not only permits the use of smaller pipe but increases the solids to air ratio. This reduces the dust problem at the discharge end. A large cyclone type dust collector is not required. A few cubic feet of space in the top of the material receiver with a muslin dust filter for the small amount of air to escape through is adequate for most farm installations. The higher pressures available with positive displacement blowers permits the use of valves to control the flow of material which are simple in construction and easy to operate automatically.

The performance information of a medium-pressure pneumatic conveyor under farm conditions was needed to design and select equipment for an automatic system. Tests were conducted to gather information on the effect on pressure drop and on the following: type of material conveyer, diameter of conveying pipe, volume of air used per minute, rate of conveying, length of system, elbow radius, orientation of elbows, location of elbows in pipe (distance from inlet), and direction of conveying (up and down).

One-inch pipe was used in all tests to reduce the volume of data in this study. Pipe diameter will be studied in detail later.

The data collected on the remaining eight variables show their interdependence. They also show the losses to be expected in the design of a medium-pressure pneumatic conveying system.

Two automatic feed-preparation and distribution systems using medium pressure pneumatic conveyors have been field tested. The older system is located on the University of Illinois Agricultural Experiment Station Swine Farm. The other is on the farm of a cooperator. The latter system is preparing and distributing more than 70 tons of poultry feed per month. It delivers 1200 pounds per hour of feed a distance of 400 feet with 30 cubic feet a minute of air at 7.25 pounds per square inch through a one-inch pipe. The conveying compressor draws approximately two horsepower under these conditions. Both systems have operated very satisfactorily.

PUCKETT, H. B., D. R. DAUM, F. W. ANDREW, and A. V. NALBANDOR. "Light-Intensity Control Chamber," Agricultural Engineering, ASAE Paper No. 59-903, December 1959. 8 pp. 7 figs.

This light-intensity control chamber was designed and constructed to study photonus in rats and other laboratory animals. It could be used for other applications requiring a cycle of varying light intensity.

The light intensity in the chamber is controlled by power operated shutters. The shutters are controlled by adjustable timers to provide increasing and decreasing light-intensity cycles ranging from 4 to 96 hours.

The light source is divided into two banks of 21 and 28 incandescent lamps each. The two banks may be operated simultaneously or one at a time. The light-intensity range can be altered by using lamps with different lumen outputs. A maximum intensity of 22 foot candles was produced with 25-watt lamps; when 60-watt lamps were used the maximum intensity increased to 84 foot-candles.

AGRICULTURAL ENGINEERING THESES

M. S.

Farnan, E. H. "Improved Efficiency Tests of Automotive Dry-Type Air Cleaners Including Air Sampling," J. A. Weber, advisor. August 1959.

Haugh, C. G. "Head Losses in Polystyrene Insert Fittings," W. Bowers and G. E. Pickard, advisors. September 1959.

Holt, R. C. "Early Failure of Tractor Intake Valves," R. R. Yoerger, advisor. April 1960.

Huang, B. K. Y. "Maceration as a Pre-Treatment to Hay Wafering," R. R. Yoerger, advisor. January 1960.

McMunn, J. C. "Pulsating Pressures in the Induction System of an Internal Combustion Engine," R. R. Yoerger, advisor. May 1960.

Pigg, D. L. "Peak Runoff and Rainfall Analyses for Two Agricultural Watersheds," B. A. Jones, Jr., advisor. October 1959.

Rodda, E. D. "An Investigation of the Strength of Reinforced Concrete Subjected to Combined Bending, Axial Load, and Shear," E. L. Hansen, advisor. February 1960.

Roll, W. M. "The Compression Characteristics of Hay as Related to Hay Wafering," G. E. Pickard, advisor. October 1959.

Smith, M. R. "An Investigation of Moldboard Plow Attachments for Plow Sole Application of Anhydrous Ammonia," B. J. Butler and G. E. Pickard, advisors. August 1959.

CERAMIC ENGINEERING

The following reports from Ceramic Engineering represent only a small portion of the total staff publications. But these are department publications having limited distribution to qualified personnel. The progress reports included here are considered to be of a conclusive nature.

BERGERON, C. G., A. L. FRIEDBERG, R. C. ANDERSON, V. E. BRADFORD, D. M. MARONEY, and R. W. BOHL. "Protective Coatings for Refractory Metals," Ceramic Engineering, AF Contract 33(616)-5734, Project No. 7350, January 1960. 44 pp. 13 figs. 8 tables.

Preliminary experiments of a probing nature demonstrated that oxygen-free atmospheres, but not high vacuum conditions, were required for the successful application of ceramic coatings on tungsten.

Tests with tungsten encapsulated in evacuated fused silica tubes demonstrated that glassy materials were indeed impermeable to oxygen at temperatures above 3000° F. for long periods of time, as evidenced by the non-oxidation of the encased tungsten.

In order to avoid the excessive oxidation and extremely rapid rate of volatility of the tungsten oxides at coating processing temperatures, experiments were carried out by processing zirconia-containing vitreous-bonded coatings in an argon atmosphere.

Experiments with siliconized tungsten wire indicated that silicide coatings are most protective in regions where glass formation at the surface of the coating had been well developed. Because of the silicide "pest" and the brittleness of the silicide, such coatings may not alone be satisfactorily protective.

14 DEPARTMENTAL REPORTS AND THESES

High temperature testing using the direct resistance heating of tungsten indicated that ceramic coatings consisting of admixtures of zirconia and glass provided protection of tungsten wire for several hours at temperatures in the range of 3000° - 3500° F.

WILCOX, D. L., C. G. BERGERON, P. F. SCHWARZLOSE, and A. L. FRIEDBERG. "High-Temperature Electrical Insulating Inorganic Coatings on Wire," Ceramic Engineering, WADC Technical Report 58-12, Part III, Contract No. AF 33(616)-3943, Project No. 7371, May 1960. 68 pp. 12 figs. 27 tables.

The program on high-temperature electrical insulation on wire, in its third and final year, covered the work on flexibility of coated wire, coating trials on clad copper wires, firing procedure for two coats of 58C on copper wire, vitreous silica and boron nitride mill additions to glass coating 58C, and vitreous coatings sheathed with organics. Also as a part of the last year's effort, test data were obtained on high-temperature insulated wire supplied by various manufacturers.

Flexibility studies indicated the ratio of coating thickness to wire diameter and the cooling cycle were important factors affecting flexibility of the coating. It was demonstrated that a heat treatment of the coating may increase coating flexibility. Contrary to what was expected, coatings on inconel-clad copper wire did not show an increase in flexibility over coatings on plain copper wire.

The results of coating trials on inconel-clad, stainless steel-clad (Oxalloy), nickel-clad (Kulgrid), silver-clad, and aluminum-clad copper wires are given. A firing study of coating 58C resulted in the optimum firing procedure for two coats of 58C on copper wire.

It was demonstrated that additions of vitreous silica and boron nitride to the mill formula of coatings 58 and 58C enhance the electrical properties of the resulting coating.

Sheathing of vitreous coatings with organics showed promise as a method of retaining the flexed vitreous coating on the wire. It was thought that in service the organic coating may burn off at a temperature where the vitreous coating could be capable of sealing itself.

Electrical tests of flexed coated specimens indicated that room temperature dielectric constant and dissipation factor were not sensitive to the first fine cracks which appeared.

BART, R. K., R. J. HERBST, and A. W. ALLEN, "Thermal Conductivity and Thermal Diffusivity of Ceramic-Metal Combinations," Ceramic Engineering, September 1, 1959. 76 pp. 23 figs. 4 tables.

A study of the thermal conductivity and thermal diffusivity of ceramic-metal combinations generally of a "macro-cermet" type fabricated by Department 865 of Bendix Products Division, Bendix Aviation Corporation, South Bend, Indiana is the subject of this report. These are materials either in current production, under development or in the case of nickel-magnesia and molybdenum-magnesia series, cermets formulated to study the role of metal additives to metal oxides in defining thermal properties.

Work accomplished in the period September 15, 1957 to September 1, 1959 is summarized.

The general effect of the metal phase is to raise the thermal conductivity and the thermal diffusivity of the combinations at all temperatures studied. In the range to about 1100° F. the thermal conductivity is related linearly to the reciprocal of the absolute temperature, the constants being dependent on the volume per cent of the constituents and showing a pronounced discontinuity in this dependency at fifty per cent by volume of the metal phase. Above 1100° F. when the metal constitutes one-third or more by volume, the thermal conductivity approaches the value of the metal alone as a limit. Less than one-third by volume of metal alters the conductivity of the oxide, but the high-temperature dependency is more characteristic of the oxide alone.

The relation between thermal diffusivity and composition has not been as clearly defined because: a) the boundary conditions assumed in the derivations of the experimental techniques are not realized over the entire range of diffusivity values encountered, b) the pronounced influence of skin effects have been evaluated in only a qualitative manner. The technique developed is quite satisfactory for the high ceramic compositions having a relatively low thermal diffusivity, but, must be altered for accurate determinations on high metal content cermets.

WILLMORE, T. A., P. D. ZIMMERMAN, and A. W. ALLEN. "Fundamental Study of Properties of Refractories as Related to Service in a Steel Pressure Casting Process," Ceramic Engineering, February 1, 1960. 105 pp. 22 figs. 16 tables.

The synthesis of magnesium aluminate from heavy magnesium carbonate or magnesium oxide and aluminum hydrate has been accomplished in a laboratory process which produces refractory grain of suitable physical characteristics for use in bonded refractory compositions.

Studies of the effects of various mineralizers in the temperature range 2500° - 3000° F. have shown that a material such as titania or calcium fluoride in amounts of one-half to two per cent is necessary for grain densification. The actual amount of spinel formed has been shown to be independent of the mineralizer, but densification by grain growth during sintering is activated at lower temperatures by its presence. The interpretation of the kinetics of this mineralization by the use of x-ray diffraction and electron micrography has been presented.

The properties of twenty-three refractory compositions utilizing spinel grain have been determined. The properties of a number of these indicate their potential for use in steel foundry practice.

An automated apparatus to evaluate the erosion and corrosion of refractory materials in contact with wheel steel at 2900° F. has been constructed, and a procedure perfected by means of which tubular specimens can be repeatedly immersed in molten steel. This test is anticipated to be a potentially useful simulated service test for a wide variety of refractory materials.

A number of service projects, completed at the request of the sponsor, have been enumerated.

HAERTLING, G. H., K. N. PARIKH, H. R. THORNTON, H. G. LEFORT, J. H. LAUCHNER, and D. G. BENNETT. "Research on Elevated Temperature Resistant Inorganic Structural Adhesives," *Ceramic Engineering*, Final Summary Report, WADC TR 55-491, Part V, AF Contract 33(616)-6192, Project No. 7340, February 1960. 91 pp. 19 figs. 1 table.

Glassy bond and air setting adhesives were developed and studied. High temperature (to 2000° F.) strength, ductility and moisture were targets.

Methods of attack included metal and metal oxide powder additions, crystallization of gold nucleated bonding glasses, study of metal surface roughness function and evaluation of stress-strain relations in metal-adhesive composites.

In a study of moisture resistance, additions of about 33 per cent of Fe_3O_4 were made to selected air setting or low temperature curing adhesives. Tensile shear values of the order of 1350 pound per square inch at room temperature and 1150 pound per square inch 800° F. were obtained but the adhesives disintegrated after a 3 1/2-hour boiling water treatment. When duplicate specimens were given a preliminary heat treatment of one hour at 1000° F., shear strengths were reduced by about 50 per cent, but they were essentially unchanged by the 3 1/2-hour boiling water treatment.

In glassy bond adhesives, stainless steel and phosphatized carbonyl iron powder additions gave improved strength, still increasing at 1000° F. Crystallized bonds gave higher strengths at the higher test temperatures. An optimum metal surface roughness value was noted. High order residual stresses (desirable to remove) were found in some metal-glassy bond composites.

CERAMIC ENGINEERING THESES

Ph. D.

Bratschun, W. R. "Metal Ion Substitution in the Sodium Niobate Lattice," R. L. Cook, advisor. October 1959.

Deadmore, D. L. "Thermal Decomposition of Some Inorganic Fluorides," A. W. Allen, advisor. February 1960.

Johnson, E. L. "A Kinetic Study of the Reactions Occurring in the Glass Preparation Process," F. V. Tooley, advisor. June 1960.

M. S.

Amin, R. B. "Low Temperature Lead Enamels Containing Molybdenum and Bismuth Oxides," R. L. Cook, advisor. June 1960.

Bart, R. K. "Thermal Conductivity of Ceramic-Metal Combinations," A. W. Allen, advisor. August 1959.

Bradford, V. C. "Quantitative Evaluation of Oxidation Resistant Coatings on Tungsten," A. L. Friedberg, advisor. August 1959.

Haertling, G. H. "Correlation of Physical Properties with Crystalline Phases in High Purity Steatite," R. L. Cook, advisor. February 1960.

Herbst, R. J. "Evaluation of a Technique for Measuring the Thermal Diffusivity of Cermets," A. W. Allen, advisor. February 1960.

16 DEPARTMENTAL REPORTS AND THESES

- Maroney, Doris M. "Zircon and Zirconia Recrystallizing Glasses," A. L. Friedberg, advisor. February 1960.
- Parikh, K. N. "Studies of the Formation of Magnesium Aluminate Spinel," A. W. Allen, advisor. August 1959.
- Wilcox, D. L. "Stresses and Flexibility of Vitreous Coated Wire," A. L. Friedberg, advisor. August 1959.

CHEMICAL ENGINEERING

The Chemical Engineering Division of the Department of Chemistry and Chemical Engineering contributes regularly to professional journals. No departmental reports have been printed for the 1959-1960 fiscal year. Therefore, only thesis titles are included here for the Division.

CHEMICAL ENGINEERING THESES

Ph.D.

- Benjamin, J. E. "Bubble Growth in Boiling Mixtures of Glycol and Water," J. W. Westwater, advisor. June 1960.
- Chen, J. W. "Nitrogen Dioxide and Dinitrogen Tetroxide Simultaneous Reactions with Water," M. S. Peters, advisor. October 1959.
- Dunskus, T. "Trace Additives in Boiling Liquids," J. W. Westwater, advisor. February 1960.
- Eppler, R. A. "The Effect of Pressure on Impurities in Alkali Halides," H. G. Drickamer, advisor. February 1960.
- Gaertner, R. F. "Population of Active Sites in Nucleate Boiling Heat Transfer," J. W. Westwater, advisor. August 1959.
- Hershman, A. "The Effect of Liquid Properties on the Interactions Between a Turbulent Air Stream and a Flowing Liquid Film," T. J. Hanratty, advisor. June 1960.
- Keating, K. B. "The Effect of Pressure on Internal Transitions," H. G. Drickamer, advisor. June 1960.
- Koval, E. J. "Influence of Nitric Oxide on Aqueous Nitrogen Dioxide Reactions," M. S. Peters, advisor. February 1960.
- Rosen, E. M. "Effect of Heat Transfer on Flow Field at Low Reynolds Numbers in Vertical Tubes," T. J. Hanratty, advisor. October 1959.
- Wiederhorn, S. "The Effect of Pressure on Phase Transitions," H. G. Drickamer, advisor. June 1960.

M.S.

- Ghosh, D. N. "Driving Forces in Mass Transfer," D. D. Perlmutter, advisor. February 1960.
- Govindan, T. S. "The Drying of Granular Solids in a Quasifluidized Bed," J. A. Quinn, advisor. June 1960.
- Gregg, D. W. "The Effect of Pressure on Phosphor Decay," H. G. Drickamer, advisor. August 1959.
- Layton, G. R. "Catalytic Dehydrogenation of Isopropanol to Acetone," M. S. Peters, advisor. October 1959.
- Samara, G. A. "The Effect of Pressure on Molecular Crystals," H. G. Drickamer, advisor. June 1960.
- Scheele, G. F. "The Effect of Heat Transfer on Transition to Turbulent Flow in a Vertical Tube," T. J. Hanratty, advisor. October 1959.
- Thomas, L. J. "Motion at Solid-Liquid Interfaces During Phase Change," J. W. Westwater, advisor. June 1960.
- Tischer, R. E. "A Bomb for High Pressure-High Temperature Research," H. G. Drickamer, advisor. June 1960.

Westerheide, D. E. "Isothermal Growth of Hydrogen Bubbles During Electrolysis," J. W. Westwater, advisor. June 1960.

Youngquist, G. R. "Kinetics of Methylcyclohexane Dehydrogenation to Toluene," M. S. Peters, advisor. June 1960.

CIVIL ENGINEERING

Included here are reports published directly by the Department in its own series of Studies. The bulk of Civil Engineering work is published in journals and bulletins.

FRIEDERICY, J. A., and A. S. VELETOS. "Bending of a Rectangular Plate with a Stiffening Edge Beam," Civil Engineering Studies, Structural Research Series No. 179, August 1959. 40 pp. 11 figs. 5 tables.

This report is concerned with the bending of a uniformly loaded rectangular plate which has two opposite edges simply supported, one edge fixed, and the other supported on a flexible beam. It is assumed that the beam does not restrain the plate against rotation.

By application of Newmark's moment distribution procedure, numerical solutions are obtained for a number of plates having different ratios of sides and different ratios of beam to plate rigidities. The quantities evaluated include deflections, bending moments and reactions. The results are summarized in a series of tables and the most significant trends are depicted graphically. Poisson's ratio for the material in the plate is taken to be 0.3.

MAYES, G. T., M. A. SOZEN, and C. P. SIESS, "Tests on a Quarter-Scale Model of a Multiple-Panel Reinforced-Concrete Flat Plate Floor," Civil Engineering Studies, Structural Research Series No. 181, September 1959. 83 pp. 98 figs. 3 plates.

This report describes a phase of an investigation of the behavior and strength of various types of reinforced-concrete floor slabs. The first stage of studies of a series of tests on a quarter-scale flat plate slab are reported. The model slab, which was nominally 1.75 inches thick, comprised 9 panels, each 5 feet square, arranged 3 by 3. The exterior edges were supported by beams of 2 different sizes, one beam being 2 by 5 1/4 inches while the other 4 by 2.75 inches. The beams were located so that the structure was symmetrical about the diagonal. The slab was supported on 16 columns which extended only below the slab and were pinned at their bases. The slab reinforcement consisted of 1/8 inch square bars and the longitudinal beam and column reinforcement of 1/4 inch round bars. A small-aggregate concrete was used.

About 40 individual tests at various levels of loading and with various loading patterns were carried out on the structure. Reinforcement strains were measured at some 300 locations and deflections at 33 locations. In addition to the applied load, the three components of each of the 16 column reactions and crack patterns were recorded.

At working loads, the maximum stress measured in the reinforcement was on the order of 20,000 pounds per square inch and the maximum deflection 0.1 inch. In tests with dead load plus 2 live loads, the maximum stress reached the yield stress of about 40,000 pounds per square inch at several critical sections. During this test the maximum deflection was about a quarter of an inch. The structure collapsed by punching through one of the interior columns after general yielding of the slab at a total load of 360 pounds per square foot. This corresponds to an over-all factor of safety of 2.3 in relation to the design load.

GAUS, M. P. "A Numerical Solution for the Transient Strain Distribution in a Rectangular Plate with a Propagating Crack," Civil Engineering Studies, Structural Research Series No. 182, Contract NObs 65790, September 1959. 179 pp. 138 figs. 4 tables.

A physical model that approximates a continuous material and is suitable for the investigation of transient two-dimensional strain-wave propagation is described herein. The lattice model reduces the continuous material into a series of rigid bars and deformable connections. This model also can represent a crack type of dis-

continuity and is used in this report to investigate the transient strain redistribution associated with a crack propagating through a rectangular plate.

Equations are developed for equilibrium of the lattice model in terms of displacements using plane-stress conditions. Equations could also be developed for plane-strain conditions or for non-linear elasticity by introducing an appropriate stress-strain relationship in place of the plane-stress relationship that was used. A complete set of equations is given to cover all cases of boundary conditions that ordinarily would be encountered in applications of this lattice model. Several examples of statically loaded plates are analyzed with the lattice model and the results compared with an energy-method solution. The comparison shows that excellent results are obtained with the lattice model.

The differential equations expressing the dynamical behavior of the lattice model are developed and numerical solution of these equations is discussed. Application of these equations to a steady-state condition, the calculation of natural frequencies of lattice models, is illustrated. Several examples of the transient strain redistribution associated with a crack propagating through a plate in finite jumps are presented. Two methods of numerical integration that are suitable for transient solutions of the differential equations are described; in one case the two methods are applied to the same problem and the results compared. It was found that both methods of numerical integration provided a satisfactory solution to the problem.

An immense amount of calculation is involved in solving transient strain-wave propagation problems with the lattice model, and a high-speed digital computer is virtually a necessity for numerical solution of problems of any complexity by this method. Further studies of fracture propagation using this method are planned.

BARTON, F. W. and W. J. HALL. "Studies of Brittle-Fracture Propagation in Six-Foot-Wide Steel Plates with a Residual-Strain Field," Civil Engineering Studies, Structural Research Series No. 183, Contract NObs 65790, October 1959. 92 pp. 57 figs. 1 table.

This investigation was undertaken to study the propagation of a brittle fracture in 6-foot-wide steel plates containing a residual strain field; primary emphasis was placed on a determination of the fracture speeds and strains associated with a moving crack. This pilot study is in effect a continuation of the earlier investigation of 2-foot-wide prestressed plates made as a part of this program.

Five plates were prepared and tested in which the residual-strain field was produced by welding tapered slots cuts in the edge of the specimen. The tests clearly show that the high residual tensile strain at the initiation edge aided the fracture initiation. For specimens with no external applied load, the fractures arrested before completely crossing the specimen; for specimens with external applied loads, even though low in magnitude, the fracture propagated completely across the plates.

The recorded fracture speeds were much lower than any previously noted in tests of 6-foot-wide plates, ranging from about 4000 feet per second near the initiation edge to as low as 50 feet per second in the compressive-strain region. The strain response as measured by gages located at various points across the plate showed that the peak strain magnitudes and the strain field associated with the moving crack tip diminished as the fracture propagated through the compressive-strain field at reduced speeds.

CORLEY, W. G., M. A. SOZEN, and C. P. SIESS. "A Study of Time Deflections of Prestressed Concrete Beams," Civil Engineering Studies, Structural Research Series No. 184, October 1959. 62 pp. 28 figs. 4 tables.

The object of this report was to analyze the results of time deflection tests on four prestressed-concrete beams in order to determine a reliable method of predicting their behavior, and to apply this method to the investigation of the time-deflection problem in a typical highway bridge.

Each of the four beams was 4 by 6 inches in cross section with an over-all length of 7 feet 6 inches and a clear span of 6 feet. The concrete strength was about 4000 pounds per square inch. Each beam had 0.18 square inches of straight tension reinforcement. Two beams, MU-1 and MU-2, had no externally applied loads. These two beams were designed for a nominal stress of 2000 pounds per square inch in the top fiber. Beam ML-1 was loaded at the third-points with a total load of 4000 pounds. This load was intended to reverse the stress conditions of the beams under prestress alone and result in a nominal stress of 2000 pounds per square inch in the top fiber and zero in the bottom fiber throughout the center third of the span. Beam ML-2 was loaded at the third points with a total load of 2000 pounds. This load was intended to produce a nominal stress of 1000 pounds per square inch over the depth of the cross section throughout the center third of the span.

For each beam, twelve 6- by 12- inch cylinders were cast for use in determining the strength of the concrete. Four 4- by 16- inch cylinders were also cast for each beam. Two of these cylinders were used to determine the shrinkage of the concrete under zero external load. The other 2 were stressed to a nominal 2000 pounds per square inch in order to determine the time deformation properties of the concrete under constant load.

The duration of the test period was 16000 hours (about 2 years) during which time the beams were stored at a constant temperature of 75° F. and a constant relative humidity of 50 per cent.

For the beams tested, 80 per cent of the 2-year time deflection took place in the first 3 months of loading and 95 per cent took place in the first year. The results of other tests indicate that it would have taken an additional 20 years to increase the deflections of the beams tested by another 10 per cent of the 2-year time deflection. The ratio of creep strain to instantaneous strain measured in cylinders ranged from 2.1 to 3.6 after 2 years.

Two methods, the "rate of creep" and the "superposition" methods, were used to analyze the time deflections of the beams. In view of the many variables having uncertain effects on time deflections, both methods were found to give satisfactory solutions to the problem.

Because of its relative simplicity, the "rate of creep" method was used to investigate the creep deflections of an interior beam of a typical prestressed-concrete bridge design. The bridge analyzed was made up of prestressed I-sections with a depth of 28 inches and a clear span of 35 feet. The roadway consisted of a 6 1/4 inch-thick uniform slab with 24 feet clear between curbs. Deflections were computed considering a creep strain of three and four times the instantaneous strain. Separate computations were made considering the slab cast at 30, 60, and 90 days after the release of prestress.

The effects of varying the ratio of creep strain to instantaneous strain had little effect on the computed time deflection for the structure considered. It should also be noted that the 2-year deflections computed for this member are very nearly the same whether the slab is cast at 30, 60, or 90 days. The computations indicated that nearly all the time deflections would take place within the first 2 months after the slab was cast.

HALL, W. J., S. T. ROLFE, F. W. BARTON, and N. M. NEWMARK. "Brittle-Fracture Propagation in Wide Steel Plates," *Civil Engineering Studies, Structural Research Series No. 188, Contract NObs 65790, January 1960. 51 pp. 20 figs. 1 table.*

This fundamental fracture-mechanics investigation has been concerned with studies of the propagation of brittle fractures in wide steel plates. In this investigation an attempt has been made to delineate many of the parameters associated with a propagating fracture, and in particular to study the strain field surrounding a propagating brittle fracture.

The experimental phases of the program involved tests of 3/4 inch-thick structural-steel plate specimens, either 2 feet or 6 feet in width. In most cases the plate specimens were stressed uniaxially to about 19,000 pounds per square inch, cooled to about 0° F., and a fracture started with the notch-wedge-impact method of fracture initiation. Measurements of the strain distribution on the surface of the plate, and the crack speed, were made as the fracture traversed the plate. Of particular interest was the fact that for gages oriented perpendicular to the crack path near the fracture, the recorded strains remained elastic even though the peak magnitudes, in some cases, exceeded 5000 microinches per inch. The majority of the recorded fracture speeds ranged from 2000 to 4000 feet per second, although higher and lower values were observed in the course of the investigation. From the measured strain data it was possible to portray the strain distribution on the plate surface in the form of strain contours during the time a crack was propagating. The studies indicated that for the particular specimen geometry used and associated test conditions, the strain field surrounding the tip of an advancing fracture remains essentially unchanged after traversing about one-third the width of a 6-foot-wide plate.

Late in the program exploratory studies were made of the propagation of brittle fractures in prestressed plates. The recorded fracture speeds in these tests were much lower than any previously recorded in tests of 6-foot-wide plates made as a part of this program; the measured speeds ranged from about 4000 feet per second in the region of high tensile strain near the initiation edge to as low as 50 feet per second in the compressive-strain region. Also, studies of the strain response in this case showed that the peak strain magnitudes and the strain field associated with the moving crack tip diminished as the speed of the fracture decreased. The results of this series of tests indicated clearly that a residual-strain field does have a marked effect on the initiation and propagation of a brittle fracture.

From the analytical standpoint studies of plate response were undertaken by representing the plate as a lattice-type structure, in which the plate was replaced by a series of perpendicular rigid bars connected at their points of intersection by a deformable node and interconnected at their midpoints by a shear element. Studies of plate response for both static loadings, and symmetrical and unsymmetrical propagating fractures, were undertaken with the plate analog. Although the grid was rather coarse, as dictated by available computer facilities, the studies indicated that the lattice representation was a promising method of studying plate response during fracture propagation.

The more significant results of the studies made as a part of this investigation are summarized in this final report. A list of reports, papers and theses originating from the investigation is included at the end of the report.

As a result of the work on the noted program, a new study concerned with low-velocity fracture recently has been inaugurated under sponsorship of the Ship Structure Committee.

LEWITT, C. W., E. CHESSON, JR., and W. H. MUNSE. "Studies of the Effect of Washers on the Clamping Force in High-Strength Bolts," Civil Engineering Studies, Structural Research Series No. 191, March 1960. 42 pp. 18 figs.

Forty-six tests of individual bolts were made to evaluate the effect of washers on the clamping force developed in high-strength bolt assemblies. Also, nine fatigue specimens, all four-bolt double-lap joints, were included in the program to determine whether there would be any change in the fatigue life of the joints if the washers were omitted. All bolts used in these tests were 3/4-inch diameter, except for those in one of the fatigue specimens, which had 1-inch bolts. The bolts were tightened by a turn-of-the-nut method. Several nut and head sizes were employed.

The bolt tests have indicated that there is no great or significant difference in the clamping force that is developed either with or without washers. The joint tests suggest that the fatigue lives of specimens without washers are generally as great as those for specimens with washers.

DEPAIVA, H. A. R., and W. J. AUSTIN. "Behavior and Design of Deep Structural Members, Part III: Tests of Reinforced-Concrete Deep Beams," Civil Engineering Studies, Structural Research Series No. 194, Contract AF 29(601)-468, Project 1080, March 1960. 126 pp. 64 figs. 17 tables.

Tests of 11 reinforced-concrete deep beams subjected to slowly applied, uniform loading are described in this report. Studies of the strength and behavior of simply supported, reinforced-concrete deep beams are made, and procedures for the prediction of the static load-deflection behavior of such members up to flexural failure are presented.

UNTRAUER, R. E. "Behavior and Design of Deep Structural Members, Part IV: Dynamic Tests of Reinforced-Concrete Deep Beams," Civil Engineering Studies, Structural Research Series No. 195, Contract AF 29(601)-468, Project 1080, May 1960. 103 pp. 65 figs. 6 tables.

Tests of simply supported reinforced concrete deep beams subjected to rapidly applied loads are described in this report. Five beams were tested under a triangular-shaped pulse and three beams were tested under a flat-top pulse of 'infinite duration.' Five beams were tested statically to serve as control beams for the beams tested dynamically. Studies of the relationships of the sum of the measured reactions to deflections, steel strains and concrete strains are made. Data concerning the effect of strain rate on the behavior are presented.

FELDMAN, A. "Behavior and Design of Deep Structural Members, Part V: Resistance and Behavior of Reinforced-Concrete Beams of Normal Proportions Under Rapid Loading," Civil Engineering Studies, Structural Research Series No. 196, Contract AF 29(601)-468, Project 1080, March 1960. 169 pp. 81 figs. 16 tables.

The object of this investigation was to obtain information on the strength and behavior of reinforced-concrete beams subjected to rapid loading. To this end, 33 beams of various strengths, 6 by 12 inches in cross section and 9 feet or 12 feet 8 inches in span were tested under static and dynamic loads. Three percentages of tension reinforcement were employed using intermediate-grade steel. Some beams also had compression and/or shear reinforcement. Concrete strength, beam width and depth, and yield strength of reinforcement were essentially constant.

Eight of the two-point loaded beams were tested statically, requiring from about 2 to 6 minutes each to reach collapse deflection. In the dynamic tests of the other 25 beams, loads were applied from 0.1 to 0.8 times the natural period of vibration of the beam. Some of the dynamic loads were of "infinite" duration, while others were terminated at from 1/2 to 3 times the beam period. The load levels varied from less than static yield capacity to more than dynamic ultimate capacity.

The analysis of the test results consists of determining the dynamic-resistance characteristics of the test beams. This was accomplished by considering the beam to be a single-degree-of-freedom system and analyzing its behavior on an analog computer. The measured load pulse was fed into the computer along with an arbitrary resistance function for the beam. This resistance function was then changed until its response matched the response measured in the test. Dynamic resistance functions were also determined using the strain rates measured in some of the tests together with the available results of dynamic tests of coupons of reinforcing bars. The resistance functions determined with the analog computer are compared with the computed functions and with the static load-deflection characteristics. An analytical procedure for the determination of the dynamic resistance of reinforced concrete beams is proposed which involves the use of the deflection rate at yield.

The most important conclusions concern the direct relation between the dynamic yield level of a reinforced-concrete beam and the yield strength of the tension reinforcement under dynamic loading; the apparently small effect that dynamic loading has on the collapse deflection of reinforced-concrete beams; and the feasibility of using established formulas, developed in connection with static tests, for the prediction of dynamic resistance provided proper account is taken of the increase in yield strength of the reinforcing steel.

KEENAN, W. A. and A. FELDMAN. "Behavior and Design of Deep Structural Members, Part VI: The Yield Strength of Intermediate-Grade Reinforcing Bars Under Rapid Loading," Civil Engineering Studies, Structural Research Series No. 197, Contract AF 29(601)-468, Project 1080, March 1960. 91 pp. 54 figs. 3 tables.

The object of this investigation was to determine the influence of rapid loading on the yield strength of deformed reinforcing bars of intermediate-grade steel. Thirty-four specimens consisting of 2-foot coupons cut from No. 6, No. 7, and No. 9 bars were tested at room temperature under uniaxial tension. The static yield strengths ranged between 40, 500 to 48,900 pounds per square inch. The dynamic yield strength varied from 102 to 149 per cent of the static yield strength and was related to the strain rate during yielding. Load and strain data for each bar tested are presented in graphical and tabular form.

HATCHER, D. S., M. A. SOZEN, and C. P. SIESS, "An Experimental Study of a Quarter-Scale Reinforced-Concrete Flat Slab Floor," Civil Engineering Studies, Structural Research Series No. 200, June 1960. 134 pp. 121 figs. 17 tables.

This report describes the analysis of the results of several tests on a quarter-scale flat slab floor. The tests were part of one phase of an investigation of the behavior and strength of multiple-panel reinforced concrete floor slabs.

The test structure was a quarter-scale model of a typical flat slab floor designed by the provisions of the 1956 ACI Building Code. The floor consisted of 9 panels arranged 3 in each direction. The panels were 5 feet square and a nominal slab thickness was 1.75 inches. The slab reinforcement consisted of 1/8 inch square bars and the beam and column reinforcement of 1/4 inch round bars. A small-aggregate concrete was used. Strains were measured on the reinforcing bars at some 300 locations, and deflections at 33 locations. The applied load, the 3 components of each of the 16 column reactions, and the crack patterns were also recorded. An extensive series of tests were carried out on the structure at various levels of load with various combinations of loading.

In the test at design loads, the maximum steel stresses were on the order of 25,000 to 30,000 pounds per square inch in the slab reinforcement. The maximum deflection was about a quarter of an inch. Cracking was extensive on both the top and bottom of the slab. Local yielding of the slab reinforcement occurred at about one and a half times the design live load.

Measured moments in the slab were generally higher than the design moments prescribed by the ACI Building Code (318-56). In the interior panel, the ratio of measured to design total moment was 1.22. The distribution of moments within the individual panels also differed with the design requirements. The greatest difference was at the interior negative moment section of the middle strip. In all panels, the average measured moment at a given section was much higher than the average design moment for that section. In some cases this ratio was as large as 2. There was a large discrepancy between measured and design moments at the discontinuous edges. The measured moments perpendicular to the beams were much less than the design moments. The useful ultimate load carried by the slab represented an over-all safety factor of 2.

THORNBURN, T. H., and W. R. LARSEN. "A Statistical Study of Soil Sampling," Civil Engineering Studies, Soil Mechanics Series No. 2, October 1959. 13 pp. 4 figs. 3 tables.

This is a study undertaken to determine the number of samples needed to obtain reasonable correlations between pedologic soil types and their engineering properties. Data from 4 DeWitt County, Illinois, soils give a quantitative indication of the value of pedologic information in planning, designing and constructing highways and airports in Illinois.

CORLEY, W. G. "Bibliography on Time-Dependent Effects in Plain and Reinforced Concrete," Civil Engineering Department Publication, December 1959. 41 pp.

This bibliography has been prepared in order to furnish, as nearly as possible, a complete listing of work that has been done on time-dependent effects in plain and reinforced concrete. All known publications on the subject are included. The range of time covered dates from 1868 through October, 1959.

References are listed in chronological order by date of publication with the publications in each year arranged alphabetically by author or by title when no author is given.

This bibliography has been compiled from available previous bibliographies on the subject and from the resources of the University of Illinois Library.

IRELAND, H. O., W. E. FISHER, and P. G. HOADLEY. "The Dynamic Bearing Capacity of Soils," Civil Engineering Department Publication, June 1960. 211 pp. 55 figs. 20 tables.

This report describes a test program conducted to study the factors affecting the ultimate load-carrying capacity of a soil subjected to transient loading and the effect that the size of the footing may have on the performance of the footing.

The field-test program involved two test structures. The interior footing structure involved 6 test footings that were loaded through a system of roof beams and supporting girders and columns. All the footings were within one excavation and at the same elevation below the ground surface. The location of the excavation was chosen to give an anticipated ground-surface peak overpressure of 30 pounds per square inch from a nuclear explosion. The test footings included 1- by 1-, 2- by 2-, and 3- by 3- foot square footings at an expected bearing pressure of 56 tons per square foot and 2- by 2- foot square footings at pressures of 18, 56, and 160 tons per square foot.

The exterior or wall footing structure involved 2 wall footings that were loaded through a series of roof beams and supporting reinforced-concrete walls. Both footings were within one excavation and at the same elevation below the ground surface. The location of the excavation was chosen to give an anticipated ground surface peak overpressure of 150 pounds per square inch from the same nuclear explosion mentioned previously. The test footings included one 10- by 0.67 foot wall footing and one 10- by 1.83 foot wall footing subjected to expected bearing pressures of 150 and 54.5 tons per square foot, respectively.

The instrumentation of both test structures consisted of electronic load and deformation-time measurements on each of the test footings. A system of mechanical load and deformation measurements to "back up" the electronic equipment and a soil survey containing 4 load-bearing tests were also included in the project.

CHANG, Y. C. "Annotated Bibliography of Lateral Loads on Piles," Civil Engineering Department Publication, Project IHR-22, February 1960. 54 pp. 22 figs.

Within the last decade or two, highway engineers have been quite concerned about the lateral stability of retaining walls and abutments, because a number of failures have occurred. Some of the abutments moved so much that their bearings had to be reset and some of these were supported by pile foundations. While the piles may not have been basically responsible for these failures, it is possible that further study of laterally loaded pile behavior may reduce the number of failures. Very few, if any, abutment failures specifically attributed to excessive lateral loads on piles have been recorded and published in available literature. In view of the lack of information on laterally loaded pile behavior and a suitable design criteria, this bibliography has been prepared to assist in determining the present status of this problem.

The literature now available, while by no means adequate for our needs, can be divided into two categories: the laterally loaded single pile, and pile groups in a monolith subjected to lateral loads.

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Mayes, G. F. "Tests on a Quarter-Scale Model of a Multiple-Panel Reinforced-Concrete Flat-Plate Slab," C. P. Siess, advisor. October 1959.

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ELECTRICAL ENGINEERING

The varied work in Electrical Engineering is very often published in departmental reports. As many of these reports as are conclusive in nature have been included here. As far as possible they are listed according to the laboratory section in which they were written. Electrical Engineering projects in the Digital Computer Laboratory have also been listed in this section. Other work is printed in professional publications.*

DESCHAMPS, G. A., and W. L. WEEKS. "Use of the Smith Chart and Other Graphical Constructions in the Magnetoionic Theory," Electrical Engineering Antenna Laboratory, Scientific Report No. 1, AF Contract 19(106)-5565, April 26, 1960. 52 pp. 22 figs.

The complex refractive index of a magnetoionic medium for various directions of propagation is evaluated graphically. Most of the constructions make use of a Smith Chart on which the scales have been suitably relabeled. The directions of propagation considered are longitudinal, quasi-longitudinal, transverse, and quasi-transverse with respect to the applied magnetic field. The losses are taken into account. The energy transferred to the medium is characterized by conductivity coefficients that are also evaluated graphically. By using an overlay the refractive index is converted into the reflection coefficient at a plane boundary of the medium.

DASGUPTA, S. "A Study of the Coma-Corrected Zoned Mirror by Diffraction Theory," Electrical Engineering Antenna Laboratory, Technical Report No. 40, Contract AF 33(616)-6079, Project No. 9-(13-6278), July 17, 1959. 105 pp. 34 figs. 2 tables.

A coma-corrected zoned mirror has previously been shown by parageometrical optics to possess no spherical aberration and no third order coma. However, geometrically defined aberrations provide no information about the diffraction pattern structure which may be of importance in microwave applications. In this investigation a study using a more rigorous boundary-value approach has been made of a zoned mirror with emphasis on its effectiveness in coma correction. Because a cylindrical mirror has no astigmatism or other higher types of aberration (according to Nijboer's classification), and because the mathematical analysis is simpler, a two-dimensional zoned mirror was chosen for analysis.

The image patterns (the field-intensity distributions on the focal plane for various incident angles as commonly used in optics) as well as the main features of the radiation pattern (minor lobe level, gain and beam width for various scan angles as commonly used in antenna engineering) are obtained. These features are compared with those of a smooth parabolic cylinder with same focal length and aperture. It is found that for a system with small F number and nearly uniform illumination, the zoned mirror is much superior to the smooth parabola in coma correction. The gain, minor lobe level and beam width of the radiation pattern for a zoned mirror are relatively constant for a scan angle up to 25° , while those for the corresponding smooth parabola change considerably. The ratio of the two secondary maxima of the intensity distribution in the focal plane (a function of the coma aberration only) is substantially equal to unity in the case of a zoned mirror whereas it changes drastically for a smooth parabola.

Calculations of the diffracted fields are based upon three different orders of approximation for the induced current on the mirror; (1) geometrical optics current distribution, (2) a distribution taking into account the effect of the edges, and (3) a distribution taking into account both the edge effect and the first order coupling between zones.

It is found that the field intensity on the focal plane (and by reciprocity, the far field) obtained by using (2) and (3) are not significantly different. Results obtained by using approximation (1) follow those obtained by (2) and (3) quite closely. Thus the simple and straight-forward physical and optics solution seems to offer a result of good accuracy even with a large number of discontinuities in the diffracting surface as in the present case. However for higher accuracy the edge effect should be considered.

BALMAIN, K. G. "The Radiation Pattern of a Dipole on a Finite Dielectric Sheet," Electrical Engineering Antenna Laboratory, Technical Report No. 41, Contract AF 33(616)-6079, Project No. 9-(13-6278), August 1, 1959. 65 pp. 18 figs. 6 tables.

When a metallic antenna is "printed" on the surface of a dielectric sheet, the original radiation pattern is altered by the presence of the dielectric. This report considers the case of a half-wave dipole antenna mounted on the surface of a thin, rectangular dielectric sheet. For this case, the pattern changes due to the dielectric are found to be quite large, even for very thin sheets. Theoretical radiation-pattern calculations are presented and they agree with the experimental patterns for thin sheets. The results obtained provide a basis for estimating the radiation-pattern perturbations due to the dielectric for a fairly wide range of dielectric constants and sheet dimensions.

* The Digital Computer Laboratory is administered by the Graduate College. Those projects listed here are in cooperation with Electrical Engineering.

MITTRA, R. "The Finite Range Wiener-Hopf Integral Equation and a Boundary Value Problem in a Waveguide," Electrical Engineering Antenna Laboratory, Technical Report No. 42, Contract No. AF 33(616)-6079, Project No. 9-(13-6278), October 1, 1959. 38 pp. 3 figs.

The finite bifurcation problem in a rectangular waveguide has been formulated in terms of a finite-range Wiener-Hopf integral equation. The solution of this equation has been obtained by analytic means. The case when the septum is semi-infinite has also been included and a connection between the methods of solution for the finite and the infinite case has been provided, the finite case being an extension of the infinite one. The problem of numerically calculating the mode coefficients has been discussed briefly. The technique presented here is general and is applicable to other finite-range Wiener-Hopf integral equations for which the kernel can be expanded as a series of exponentials of the type $e^{-9n[z - z_0]}$ where z and z_0 are the variable coordinates.

DESCHAMPS, G. A. "Impedance Properties of Complementary Multiterminal Planar Structures," Electrical Engineering Antenna Laboratory, Technical Report No. 43, Contract AF 33(616)-6079, Project No. 9-(13-6278), November 11, 1959. 33 pp. 11 figs.

Booker has shown that Babinet's principle, properly extended to electromagnetic fields, leads to a simple relation between the impedances of two planar complementary structures. A relation, which generalizes this result, is found between the impedance matrices of two complementary n -terminal structures.

This relation is applied to the particular n -terminal structures having n -fold symmetry and to those that are also self-complementary. In the latter case the impedance matrix is real and entirely determined by the number of terminals. It is therefore independent of the exact shape of the elements composing the structure and of the frequency. By connecting in groups the terminals of such a structure various impedance levels, all frequency independent and real, may be achieved.

Structures having their terminal pairs in different locations in the plane are also considered. A self-complementary two-port structure is found to be equivalent, from the impedance point of view, to a length of lossy transmission line having a characteristic impedance of 60π ohms.

MITTRA, R. "On the Synthesis of Strip Sources," Electrical Engineering Antenna Laboratory, Technical Report No. 44, Contract AF 33(616)-6079, Project No. 9-(13-6278), December 4, 1959. 18 pp.

The report considers the mathematical problem of synthesizing an infinite strip source when the space factor of the radiation pattern is specified as a function of the angle of radiation.

The report shows how the problem of synthesizing the source can be handled through the use of the technique of Lagrangian interpolation. This approach is basically different from ones based on the sampling theorem, which has been used by other authors. The present technique can lead to expressions which are more general than those obtained by others.

In the second part of the paper the case of a continuously specified space factor is considered and a solution to this problem is presented. The solution is obtained by dealing directly with the integral equation associated with the problem.

TANG, C. H., and Y. T. LO. "Numerical Analysis of the Eigenvalue Problem of Waves in Cylindrical Waveguides," Electrical Engineering Antenna Laboratory, Technical Report No. 45, Contract AF 33(616)-6079, Project No. 9-(13-6278), March 11, 1960. 39 pp. 22 figs.

The waves in a cylindrical waveguide are found from solutions of the two dimensional differential equation $\nabla^2 u + k^2 u = 0$ (1) where u is a function of the coordinates in the transverse plane and k is a constant. The Dirichlet boundary condition, $u = 0$ on the boundary of the cross section, corresponds to transverse magnetic modes and the Neumann boundary condition, $\partial u / \partial n = 0$ on the boundary, corresponds to transverse electric modes. In (1) k is the wave number, and the function u , which is independent of the longitudinal coordinate z , represents the component of electric-(TM-case) or magnetic-(TE-case) field intensity along a longitudinal direction. The time dependence is assumed to be of the form $e^{-i\omega t}$ in this formulation.

The permissible values of k are also called eigenvalues of the differential equation (1) and u is the eigenfunction. Since the wave is confined to a finite region, the spectrum of the eigenvalues $[k_n]$ is a discrete set. According to mode theory, these eigenvalues $[k_n]$ determine the cut off frequency of each mode propagating along the waveguide. It is necessary only to find the resonant frequency of the two-dimensional problem defined by the guide boundary since there is no axial variation at cut off; all energy does propagate back and forth in the transverse plane.

The exact solution of (1) with prescribed boundary condition can be obtained only when the given boundary constitutes a (or a set of) coordinate surface of the separable coordinate system. It has been shown only few regular cross sections can be treated by the method of separation of variables. Waveguides with odd cross section, yet valuable in practical use (such as folded waveguide and ridged waveguide), demand the result for engineering design.

DYSON, J. D., and P. E. MAYES. "New Circularly Polarized Frequency-Independent Antennas with Conical Beam or Omnidirectional Patterns," Electrical Engineering Antenna Laboratory, Technical Report No. 46, Contract No. AF 33(616)-6079, Project No. 9-(13-6278), June 20, 1960. 31 pp. 14 figs.

A conical beam may be obtained from balanced equiangular spiral antennas by constructing an antenna with more than two spiral arms and symmetrically connecting these arms to provide a suppression of the radiated fields on the axis of the antenna. The angle of this conical beam can be controlled and with proper choice of parameters it can be confined to the immediate vicinity of the azimuthal ($\theta = 90^\circ$) plane.

An antenna with four symmetrically spaced arms can provide a radiation pattern that is within 3 db of omnidirectional circularly polarized coverage. The standing wave ratio of this antenna referred to a 50 ohm coaxial cable is less than 2 to 1 over the pattern bandwidth.

This four-arm version retains the wide frequency bandwidths of the basic conical log-spiral antenna, and it provides a coverage which heretofore has been difficult to obtain even with narrow-band antennas.

HAKIMI, S. L., and J. B. CRUZ. "On Minimal Realization of RC Two-Ports," Electrical Engineering Circuit Theory Group, Interim Technical Report No. 18, Contract No. DA-11-022-ORD-1983, March 4, 1960. 25 pp. 5 figs. 1 table.

From a given RC-realizable open-circuit voltage transfer function, some lower bounds are obtained for the minimum possible number of elements in the network. In the case of bilinear and biquadratic functions, network realizations have been tabulated which are minimal although not all realizable biquadratic functions are covered. In the case of an n-pole transfer function with symmetrically clustered zeros, a realization involving at most two elements more than the minimum requirement is obtained using Guillemin's parallel ladder procedure. The effects of interchanging the input terminals and interchanging the R's and C's in a network are also considered.

CRUZ, J. B. "On the Synthesis of Time-Varying Linear Systems," Electrical Engineering Circuit Theory Group, Technical Note No. 9, Contract No. AF 49(638)-63, Project No. 47501, August 7, 1959. 96 pp. 25 figs.

It is shown that any multi-input -- multi-output linear system may always be represented by a set of single-input -- single-output linear subsystems connected properly. Attention is focused on some properties of single-input -- single-output linear systems which are generally time varying. These properties are exploited in developing synthesis procedures for time-varying linear systems with specifications in the time domain, frequency domain, and general λ domains.

In connection with synthesis in a general λ domain, compatible systems are defined. The techniques for fixed linear systems in the frequency domain apply to compatible time-varying linear systems in an appropriate λ domain.

The characterization or system functions for all the models considered belong to the class of separable functions first treated by Bendat. Necessary and sufficient conditions are derived for the exact realization of certain classes of functions. However, a much wider class of specified system functions may be expanded in terms of a set of orthogonal and realizable functions. It is well known that if the series is truncated, the approximation is best in the sense of minimum integral square error.

The basic time-varying element used in most of the models is a time-varying gain amplifier. The approximation of the time-varying gain amplifier by periodically operated switches, sinusoidal time-varying amplifiers, and sequentially gated amplifiers is discussed.

MYERS, B. R. "Two Theorems in Multi-Weighted Sums, and Their Application in the Stability Analysis of Active Linear Systems," Electrical Engineering Circuit Theory Group, Technical Note No. 10, Contract No. AF 49(638)-63, Project No. 47501, November 5, 1959. 17 pp. 4 figs.

The first theorem in this paper shows that the collection of all normalized, nonnegatively multiweighted sums of a finite set of vectors belonging to an arbitrary finite-dimensional vector space is contained in the convex hull of the vertex vectors of the normalized weights.

The second theorem states a sufficient condition under which the collection is complete, i.e., such that there is no point in the convex hull which is not a point of the sum. Two corollaries of this theorem identify particular types of sums for which the collection is complete.

Application of the theorems in the stability analysis of active linear systems with multi-parameter variance results in a useful graphical method which might be described as a generalization of Nyquist's criterion for stability.

FU, K. S. "Synthesis of Double-Terminated Active Networks," Electrical Engineering Circuit Theory Group, Technical Note No. 11, Contract No. AF 49(638)-63, Project No. 47501, March 4, 1960. 29 pp. 29 figs.

Methods are given for the synthesis of double-terminated active networks for zeros of transmission at zero, infinity, on the imaginary axis, and also for complex zeros of transmission. The network configuration used is a bridge-type active network containing negative impedance converters.

KARNI, S. "The Approximation of Network Functions Using Tchebycheff Polynomials," Electrical Engineering Circuit Theory Group, Technical Note No. 12, Contract No. AF 49(638)-63, Project No. 47501, March 18, 1960. 61 pp. 24 figs.

Approximation is accomplished by expanding the prescribed response function and an assumed network response function in series of Tchebycheff polynomials. Matching a finite number of terms in the two series determines the desired network function, and the error of approximation. The results represent an extension of a method due to Darlington. The extensions include a method for the derivation of Pade approximants from the Tchebycheff polynomials series expansion of the prescribed gain, a procedure for the reduction of network complexity, and a technique for the matching of the power series expansions of the derivative of a prescribed gain function with that of a network function.

The theoretical developments are supported by step-by-step procedures for use in design problems. Included are realizability tests, various tabulations, and graphs. The methods are illustrated by the following examples: (1) the equalization of gain distortion resulting from one or more poles on the negative real axis by means of all-pole network functions, (2) a method for the exact equalization of gain distortion in the approximation band, (3) the approximation of the so-called "brick wall" and the linearly decreasing gain functions by means of biquadratic network functions, and (4) the reduction of the degree of a given network function.

EPLEY, D. E. "New Techniques in Switching Circuit Synthesis," Electrical Engineering Circuit Theory Group, Technical Note No. 13, Contract No. AF 49(638)-63, Project No. 47501, May 1, 1960. 98 pp. 27 figs.

Three new switching-theory concepts and methods analogous to electrical-network-theory methods are defined and applied to problems in switching-circuit synthesis. The first, the removal synthesis technique, is used to synthesize transmission contact networks with p input terminals and q output terminals. Transmission contact networks are synthesized to realize a transmission matrix containing switching functions between each input-output terminal pair. The method is extended to synthesize asymmetric transmission networks whose transmission from input to output is different than transmission from output to input. These networks realize two transmission matrices. A right-angle product condition is used to detect undesirable sneak paths; this determines whether or not ideal diodes must be used and where they should be placed.

The second new concept introduced is the 0, 1-configuration of a switching function. Using this representation of switching functions and a mapping procedure, a new method of finding the minimum sums of a given function is developed. The method is similar to the Harvard chart in size and construction but is superior because it includes the prime implicant chart of McCluskey.

The third concept, sensitivity of a contact circuit to contact errors, is used to design circuits with error protection. Two different sensitivities, contact and condition, are defined. Contact sensitivity is used to develop a design procedure for the single-contact error and equally likely input-combinations case. Condition sensitivity is used in a similar design procedure applicable to multiple-contact-error case and which includes differences in likelihoods of occurrence of input combinations. The approach of both procedures is to synthesize an economical circuit first and then to add the series and/or parallel redundant contacts which give maximum amount of error protection. The circuits realized either satisfy a probability of circuit-error specification or give complete single- or multiple-error protection.

TANG, D. T. N. "Rational Approximation of Arbitrary Real Functions with Specified Weights," Electrical Engineering Circuit Theory Group, Technical Note No. 14, Contract No. AF 49(638)-63, Project No. 47501, May 1, 1960. 93 pp. 10 figs.

The problem of obtaining the Tchebycheff approximation of a real continuous function in a closed interval by a polynomial or a rational function is treated. Solutions of such problems are obtained by numerical methods involving iterative procedures which may be carried out by modern computing machines.

The effect of shifting a zero or several zeros of an error function on the weighted error function itself is obtained by multiplying the amount of shift by the sensitivity, defined as the partial derivative of the weighted error function with respect to the zero shifted. Various techniques are used to equalize (and hence minimize) the extreme of the weighted error. The knowledge of the zero shifting effect on the weighted error is used to determine the amount of shifts in different cases.

The successive equalization of the weighted error function at the points of extreme gives an iterative procedure with assured convergence of the process. In the case of polynomial approximation, this method yields a set of linear simultaneous equations to be solved in each cycle. In the case of rational function approximation, it results in a set of non-linear simultaneous equations which can be solved by certain special techniques. Special cases such as the approximation with equal-ripple relative error and an approximating polynomial with specified cutoff slope are investigated.

When the function to be approximated is only piecewise continuous with a transition interval specified for each discontinuity, the zero shifting technique can still be used to obtain an error function which is equal rippled in each remaining connected interval in $[a, b]$. If a certain integral measure of error is chosen, the solution of approximation is obtained by solving the set of simultaneous equations (non-linear except the polynomial approximation in least squares sense) obtained upon taking partial derivative of the corresponding error measure with respect to all available parameters of the approximating function.

Cases with constraints due to the realizability requirements of different network functions or different network configuration such as symmetry requirements, specified poles, specified cutoff slope, etc. are also investigated.

HAYDEN, E. C., et al. "Wullenweber-Type Antenna Array," Electrical Engineering Radio Direction Finding Section, Interim Engineering Report No. 7, Contract No. Nobsr 64723, Index No. NE-070154. June 15, 1959. 128 pp. 57 figs.

The purpose of this contract is to develop an antenna array for a radio direction finder of the Wullenweber type, to fabricate and install the array, and to evaluate the direction-finding system consisting of this array and suitable terminal equipment.

This report covers a major portion of the evaluation period. During this period, an attempt was made to obtain at least some information about nearly all aspects of the performance of the individual components of the system, and of the system as a whole. While none of the evaluation studies are entirely completed, it appears that they have progressed to the point where a fairly useful picture of the performance is emerging. Thus, this report might be considered as a sort of "final" report on the preliminary stages of the evaluation program. For the sake of presenting a reasonably complete picture, a small amount of information reported previously has been summarized and included in this report.

SHUBERT, H. A. "Evaluation of a Laboratory Model Injection-Type RDF Receiver," Electrical Engineering Radio Direction Finding Section, Technical Report No. 12, Contract Nonr 1834(02), ONR Project No. NR 371-161, March 31, 1959. 45 pp. 19 figs.

Contained in this report are descriptions and data on the construction and operation under laboratory conditions of a two-channel RDF receiver matched in phase and gain automatically. The channels are matched by means of a signal-injection system.

Schematic diagrams, explanations of operation, and photographs and analysis of results are presented.

In the first section a review of the general principles of operation of a direct-reading RDF system with emphasis on the details pertinent to this project is given. An attempt has been made to show why the requirements on the receiver are very rigid.

Section two outlines the principles of operation of the injection system for channel matching, and gives an explanation of the construction of system used.

In section three is presented an analysis of results obtained, in which the results are compared to theoretical calculations and curves.

Section four is a summary and conclusion.

BAILEY, A. D., and R. L. SYDNOR. "An Investigation of Signal Amplitude to Bearing Deviation Correlation as a Function of Time in High-Frequency Radio Direction Finding," Electrical Engineering Radio Direction Finding Section, Technical Report No. 13, Contract Nonr 1834(02), ONR Project No. NR 371-161, July 1, 1959. 14 pp. 10 figs.

The investigation is based on the application of a method described by Licklider and Dzendolet and extended by Sugar. Statistical scatter diagrams of the signal amplitude vs. bearing deviation of high-frequency radio direction-finder signals may be displayed on a cathode-ray oscilloscope. Photographs of the display for selected intervals of display time permit an investigation of the correlation parameter as a function of display interval.

The spinning goniometer radio direction finder lends itself particularly well to such studies of bearing deviation by means of simple adaptive circuits. A DAU-type radio direction finder was modified to obtain the necessary data for the correlation study.

A comparison is made between the actual data and that of plausible idealized Rayleigh-Gaussian distributions. The results have application in the optimum use of small-aperture radio direction-finding systems.

KELLUM, E. E. "The Development and Evaluation of a Panoramic Radio Direction Finding Receiver," Electrical Engineering Radio Direction Finding Section, Technical Report No. 14, Contract Nonr 1834(02), ONR Project No. NR 371-161, September 25, 1959. 56 pp. 21 figs.

A multitude of systems have been devised to determine the direction of arrival of radio signals. Virtually every type of antenna has been used for radio direction-finding purposes. Since this report is concerned only with a matched twin-channel receiver used in conjunction with a crossed-Adcock antenna, a description is not given of the various systems. The purpose of this project was to determine the performance of the receiver when used for direction finding.

WYMER, F. J. "Bearing Averaging Using Two or More Spinning Goniometer RDF Systems," Electrical Engineering Radio Direction Finding Section, Technical Report No. 15, Contract Nonr 1834(02) ONR Project No. NR 371-161, December 24, 1959. 93 pp. 51 figs.

R. L. Smith-Rose suggested averaging bearings in 1929, when it was found that night effect could be reasonably eliminated by taking a number of readings and averaging the indications over time. This is not suitable for obtaining bearing indications when the signal is transmitted for only a short period of time. By using two or more Adcock antenna arrays, and averaging the indications from each one, an "instantaneous" average bearing can be obtained.

The equipment used in this investigation was designed to perform the algebraic manipulations determining the bearing indication, and was used to show the validity of the analysis. It was tested in the laboratory using two channels to represent two RDF systems.

The problem, then, was to develop equipment which would average the bearing indications from two Adcock antenna arrays. The purpose was to show that this system could be used to reduce the errors in bearing indications due to interfering components at the carrier frequency. The development of an optimum distribution of arrays was also desired, and for this purpose, the effects of various parameters on the averaged bearing indication was desirable.

PASK, G., and H. VON FOERSTER. "A Predictive Model For Self Organizing Systems," Electrical Engineering Research Laboratory, Technical Report No. 4, Contract Nonr 1834(21), ONR Project No. NR 049-123, June 30, 1960. 87 pp. 18 diagrs.

There are 2 pieced of experimental work which are in progress at this time. The first of these, which is examined in Part I of the paper is called a Social Interaction Experiment, in which the players are human subjects who interact with one another. Their interaction is, however, restricted by certain constraints, which change as a function of the interaction, and in particular by a limited supply of a commodity called "money", which players must use in order to "purchase" the channels of communication via which they interact. Here, it seems, there is little objection to the game analogy, but one might reasonably doubt the outcome of our assumptions about the players, for example, that they learn a preference ordering over a set of possible outcomes of play.

The second set of experiments, which are examined in Part II of the paper, concern artefacts. In the simplest case players are replaced by automata. It is felt that the rationality assumptions are irrefutable, but that the choice of the game analogy might be rejected. All the same, it is hoped to uphold the choice (expecially in the case of electrochemical self-organizing systems with no differentiated components), and to advance it as a method of describing the activity within learning (and evolutionary) systems.

CHEN, C. L., C. C. LEIBY, and L. GOLDSTEIN. "Electron Temperature Dependence of the Recombination Coefficient in Pure Helium," Electrical Engineering Research Laboratory, Scientific Report No. 7, Contract AF 19(604)-2152, Project No. 4156, September 1, 1959. 149 pp. 63 figs.

Recombination of oppositely charged particles of a helium-gas discharge plasma is studied in this work. Attention has been focused especially on investigating the law governing the variation with electron temperature of the recombination coefficient, characterizing the process of recombination of free electrons with positive ions in decaying plasmas produced in pure helium. The technique of microwave interaction with a plasma and the simultaneous observation of the afterglow light intensity were employed. These yield some of the characteristic plasma parameters. In addition to the total visible light intensity, two characteristic spectral lines of helium: 5876°A ($3^3\text{D} - 2^3\text{P}$) and 3888°A ($3^3\text{P} - 2^3\text{S}$) have also been studied. Measurements were made on the amount of quenching of the total visible light intensity as well as those of the above two spectral lines, due to selective heating of the electron gas in the plasma by adsorption of microwave energy. It is found that the recombination coefficient α_{er} of electrons with molecular helium ions varies inversely with the three-halves power of the

temperature of the electron gas, which was varied from 300°K. to approximately 1500°K. The value of a_{er} at room temperature ($\sim 300^{\circ}\text{K.}$) is found to be $(8.7 \pm 0.3) \times 10^{-9} \text{ cm}^3/\text{ion-sec}$ for decaying plasmas established in pure helium and is independent of the gas pressure.

The momentum transfer cross section, Q_m , for electron collisions with helium atoms is found to be $(5.59 \pm 5\%) \times 10^{-16} \text{ cm}^2$. The mobility of molecular helium ions in helium $\mu(\text{He}_2^+)$ has a value of $17.8 \pm 0.8 \text{ cm}^2/\text{volt-sec}$ referred to 0°C. and 760 mm Hg gas pressure. The fractional excess energy loss factor G of electrons to helium atoms, determined from the light quenching experiments is found to be $\sim 2.7 \times 10^{-4}$ and is very close to the classical value.

Decaying plasma in helium-neon mixtures have also been investigated with helium as the main gas. Three different percentages of neon concentrations were used. They are 2×10^{-4} , 52×10^{-4} and 1300×10^{-4} per cent. Within the precision of these measurements, no detectable change of Q_m is observed, while the value of a_{er} at 300°K. is found to increase from $2 \times 10^{-8} \text{ cm}^2/\text{ion-sec}$ to $40 \times 10^{-8} \text{ cm}^3/\text{ion-sec}$ as the neon concentration increases from 2×10^{-4} to 1300×10^{-4} per cent.

The mobility of Ne^+ in the admixed gases is found ranging from 21.9 to $24.9 \text{ cm}^2/\text{volt-sec.}$ The charge transfer cross section of molecular helium ions to a neon atom is found to be $Q_{\text{conv}} \cong 2 \times 10^{-16} \text{ cm}^2$.

A better treatment to the guided wave propagation in a waveguide filled with ionized gases has been given, which is believed to give more accurate determination of the fundamental parameters in a gaseous discharge plasma confined in the geometry used.

In the determination of the electron temperature, correction due to thermal conduction has also been included in an approximate way. The effective coefficient of thermal conductivity given by Landshoff and by Spitzer and Härm is adopted in this analysis since Goldstein and Sekiguchi have demonstrated experimentally the applicability of their theory even in a partially ionized gas.

POPPELBAUM, W. J., and N. E. WISEMAN. "Circuit Design for the New Illinois Computer," Digital Computer Laboratory, Report No. 90, AEC Contract AT (11-1)-415, August 20, 1959. 106 pp. 73 figs.

This report describes the theoretical background involved in the design of the new very high-speed computer at the University of Illinois. Chapters are devoted to the general design philosophy of ILLIAC II, and it is shown under what circumstances a parallel asynchronous computer is preferable to the synchronous serial type.

Hardware parameters as specified by the manufacturers are discussed in terms of circuit performance, and it is shown what ranges of values are acceptable if the requisit conditions of speed, stability, and absence of drift are to be met.

Subsequent chapters go into the details of circuit design. Specific circuit tricks such as the provision of last moving points, dc compensation, gating by breaking into feedback loops, and flow-gating are discussed.

Complete drawings of a set of circuits to be used in this computer in circuit design and a procedure for optimizing the tolerance conditions is given.

A final chapter is devoted to the use of a computer in circuit design and a procedure for optimizing the tolerance conditions is given.

RAY, S. R. "Design of the Core Storage Unit," Digital Computer Laboratory, Report No. 91, AEC Contract AT (11-1)-415, August 20, 1959. 32 pp. 19 figs.

This report describes the design of a magnetic-core memory whose principal specifications are that it contain 8192 words of 52 bit length capable of random access at the maximum rate feasible.

The principal engineering considerations which were encountered in the course of the design are described. It is concluded that a two-core-per-bit, word-organized, destructive readout, switch-core driven memory having a single wire digit-sense line is the best compromise. The memory cycle time is in the 1.5 to 2 microsecond range.

WHEELER, D. J. "The Arithmetic Unit," Digital Computer Laboratory Report No. 92, AEC Contract AT (11-1)-415, August 21, 1959. 28 pp. 2 figs.

This report describes the general philosophy in design and operation of an asynchronous arithmetic unit using logical elements developed by the circuits group.

Design requirements included high-speed operation and low cost. Also, the unit is intended primarily for floating point operations with the additional requirement that the accumulator should hold results to double precision.

Registers selected for the main arithmetic unit are described, and measures to insure speedy operation are discussed.

KUNIHIRO, T. "On the Dynamic Design of Non-Regenerative Transistor Switching Circuits," Digital Computer Laboratory, Report No. 94, AEC Contract AT (11-1)-415, November 19, 1959. 39 pp. 23 figs. 1 table.

In designing a computer, the switching time of a circuit is one of the major considerations. It is directly related to the "economy" of the system. Let W , τ , and c be the total work to be done by a machine (in bits per second), the switching time of a logical element (in seconds per bit), and the cost of a logical element (in dollars), respectively. Then the total cost of the machine, C_T , will be roughly estimated $C_T = W\tau c$ dollars. Therefore the cost per unit work to be done by the machine, i. e., the "economy" of the system is $C_T/W = \tau c$ (1). Equation (1) demonstrates the economical aspect of the switching time.

In this report, firstly, the transfer function of a non-regenerative, base-driven transistor circuit is derived by applying the linear equivalent circuit method. The results are experimentally verified. Secondly, the idea of the inverse-gain bandwidth is introduced as the criterion of the dynamic design. Thirdly, the stability factor is explained. Finally, it is shown that a system constructed by various types of transistor switching circuits is reduced to a long train of unit chains formed by delay units and wave-shapers, and the maximum allowable number of delay units in a unit chain is discussed. The results given here are consistent with the design procedures for transistor switching circuits established in the Digital Computer Laboratory, i. e., the emitter-follower logical circuits associated with restorers and flipflops.

BARTKY, W. S. "A Theory of Asynchronous Circuits III," Digital Computer Laboratory, Report No. 96, ONR Contract Nonr-1834(27), January 6, 1960. 52 pp. 9 figs.

This report is a continuation of the development of asynchronous circuit theory the first part of which was presented in Digital Computer Laboratory Reports 75 and 78, and published in Proceedings of an International Symposium on Theory of Switching (1957), Annals of the Computation Laboratory, Harvard University.

Mr. Bartky's report deals specifically with a subclass of speed-independent circuits and with various representations of such circuits and methods of synthesis.

TAKAHASHI, S. "Separate Carry Storage Adders," Digital Computer Laboratory, Report No. 97, March 7, 1960. 12 pp. 2 figs. 1 table.

In the past, attempts to increase the speed of arithmetic operations in parallel digital computers have been limited ultimately by the necessity to let the carries propagate during each addition.

The idea of storing carries instead of propagating them was at first restricted to the additive steps of a multiplication. The extension of the separate carry storage concept from one operation to a sequence of operations involving an accumulator with separate carry storage results in several problems.

In this particular study the problem of designing a psuedo-adder of any base with carry storage was discussed. For simplicity, a base 4 adder was used since the arithmetic unit in the new Illinois computer will use base 4 representations.

AVIZIENIS, A. "A Study of Redundant Number Representations for Parallel Digital Computers," Digital Computer Laboratory, Report No. 101, May 20, 1960. 76 pp. 2 figs.

This dissertation presents the results of an investigation of redundant number representations for arithmetic operations in parallel digital computers. The development of digital computers for high-speed computation focuses attention on the representation of numbers and the execution of arithmetic operations. Time-honored methods employed by human computers must be adapted for use in computing machines or replaced by methods developed especially for the computing machinery.

In a parallel digital computer all digits in a number representation simultaneously become available to the arithmetic unit which performs arithmetic operations. If the conventional representations of numbers are employed, the requirement for carry formation and propagation to the more significant digits imparts a serial

aspect to the addition or subtraction of two numbers. Carry propagation partially cancels the high-speed capability of a parallel arithmetic unit and therefore is an undesirable property of the conventional number representations.

This investigation is based on the studies of the elimination of carry propagation during arithmetical operations by J. E. Robertson and G. Metze of the University of Illinois. These studies develop the fundamental concept of redundant-number representations and extend carry-free arithmetic operations to a sequence of operations in the arithmetic unit. To avoid conversion between two representations, the use of the redundant representation of the coincident carry-borrow type is then extended throughout the entire computer.

The objective of this investigation is to explore the effects of redundancy in each digital position of a number representation without the use of a carry-borrow identification. The approach used is to postulate initially a method of addition which has the desired properties, and to derive from this description the properties of a number representation which permits the postulated method of addition.

A totally-parallel mode of addition is defined and postulated to be the required characteristic of a number representation. A class of signed-digit number representations which permit totally-parallel addition is then developed. Various significant properties of these signed-digit representations are then developed and the existence of methods for the execution of arithmetic operations is demonstrated. Finally, the logical design of an adder circuit for totally-parallel addition of two numbers in signed-digit representation is discussed. The conclusions present a summary and evaluation of the results of this investigation.

ELECTRICAL ENGINEERING THESES

Ph. D.

- Arzbaeher, R. C. "Servomechanisms with Force Feedback," G. H. Fett, advisor. June 1960.
- Avizienis, A. A. "A Study of Redundant Number Representations for Parallel Digital Computers," J. E. Robertson, advisor. June 1960.
- Babcock, M. L. "Reorganization by Adaptive Automation," H. Von Foerster, advisor. February 1960.
- Bitzer, D. L. "Signal Amplitude Limiting and Phase Quantization in Antenna Systems," M. E. Van Valkenburg, advisor. February 1960.
- Buchta, J. C. "A Study of Optimum and Near Optimum Contactor Servomechanisms Using Phase Space Techniques," G. H. Fett, advisor. October 1959.
- Chen, C. L. "Electron Temperature Dependence on the Recombination Coefficient in Pure Helium," L. Goldstein, advisor. October 1959.
- Criss, D. E. "A Study of the Behavior of a Two-Phase Servo Motor with Modulated Excitation," G. H. Fett, advisor. October 1959.
- Cruz, J. B. "On the Synthesis of Time-Varying Linear Systems," M. E. Van Valkenburg, advisor. October 1959.
- Das Gupta, S. "A Study of the Coma-Corrected Zoned Mirror by Diffraction Theory," E. C. Jordan, advisor. October 1959.
- Davis, C. F. "A Mathematical and Experimental Analysis of a Harmonic Oscillator Containing Multiple Non-linearities," G. H. Fett, advisor. June 1960.
- Epley, D. L. "New Techniques in Switching Circuit Synthesis," M. E. Van Valkenburg, advisor. June 1960.
- Karni, S. "The Approximation of Network Functions Using Tchebycheff Polynomials," M. E. Van Valkenburg, advisor. February 1960.
- Liu, R. W. "Nonlinear Differential-Equation Solution by Dynamic Analogy," G. H. Fett, advisor. February 1960.
- Murti, V. G. K. "Driving-Point Function Synthesis by Transformation of the Brune Network," M. E. Van Valkenburg, advisor. February 1960.
- Sather, R. O. "A Linear Network Method for Compensating a Nonlinear Servomechanism," G. H. Fett, advisor. June 1960.
- So, H. C. "Realization of Loop-Resistance Matrices," M. E. Van Valkenburg, advisor. February 1960.

- Steier, W. H. "Magnetodynamic Dipolar Ferrite Modes," P. D. Coleman, advisor. February 1960.
- Swago, A. W. "Frequency Multiplication Circuits," P. D. Coleman, advisor. September 1959.
- Tang, T. N. "Rational Approximation of Arbitrary Real Functions with Specified Weights," M. E. Van Valkenburg, advisor. June 1960.
- Weissman, I. "Resonant Binary Shifting Register," A. T. Nordsieck, advisor. February 1960.
- Wishner, R. P. "On Markov Processes in Control Systems," M. E. Van Valkenburg, advisor. June 1960.

M. S.

- Armstrong, M. E. "The Use of Solar Radio Noise for Calibrating Radio Receiving Systems," H. D. Webb, advisor. August 1959.
- Balmain, K. G. "The Radiation Pattern of a Dipole on a Finite Dielectric Sheet," P. E. Mayes, advisor. August 1959.
- Kellum, E. E. "The Development and Evaluation of a Panoramic Radio Direction Finding Receiver," H. D. Webb, advisor. October 1959.
- Poeschel, R. L. "An Experimental Investigation of Magneto-Plasma Dynamics," A. A. Dougal, advisor. June 1960.
- Wymer, F. J. "Bearing Averaging Using Two or More Spinning Goniometer RDF Systems," H. D. Webb, advisor. February 1960.

MECHANICAL ENGINEERING

The Mechanical Engineering series publications are numbered according to their respective projects or as M. E. Technical Notes or Reports. Other Research work not listed here can be found in journal articles.

BROWN, E. J., and B. W. HRYKEWICZ. "Investigation of Year-Around Air Conditioning in Research Residence No. 4 During the 1958-59 Heating Season," Warm Air Heating Research Series FWA-12A-1, February 1960. 23 pp. 14 figs. 8 tables.

The split-level home has progressed in the past decade from a rarely-seen structure to one that is commonplace to most new neighborhoods. The differences in elevations of the various floors of this type of house create a potential for movement of warm air to the upper levels and for cool air to the lower levels. Such movement of air is aided by the open-between-levels construction that usually is found in this type of house.

Research Residence No. 4 incorporates that heating problem along with a number of others. The Residence has three levels. The upper level includes an open landing which permits the free exchange of air between the upper level and the other levels. The lower level has uninsulated, concrete-block exterior walls with large windows and a concrete-slab floor. The middle level has large windows, including a sliding glass door, and is built over a crawl space.

This report on the 1958-59 heating season is concerned with four major phases: 1) the room-to-room temperature balance achieved with a perimeter air-conditioning system and the effect of interchange of air between levels on the temperature balance, 2) the comparative performance characteristics of perimeter air-conditioning systems during heating using two summer-cooling air-flow rates and an air-flow rate consistent with CAC requirements, 3) the effect of the number and location of the return air inlets on the room-air temperature differentials, 4) the general performance characteristics of a combination high sidewall and perimeter system.

BROWN, E. J., and B. W. HRYKEWICZ. "Investigation of Year-Around Air-Conditioning in Research Residence No. 4 During the 1959 Cooling Season," Warm Air Heating Research Series SC-6A-1, May 1960. 18 pp. 11 figs. 9 tables.

Research Residence No. 4 is representative of split-level houses which incorporate a variety of constructions under a single roof. Wall constructions vary from well-insulated frame to uninsulated concrete

block. The levels of the house are connected by open stairwells which allow free movement of air from one area of the house to another. The construction and layout of the house present potential air-conditioning problems which were the basis for the 1959 summer-cooling investigation. The investigation was a continuation of a parallel investigation conducted during the 1958-59 heating season. During both investigations, the year-around air-conditioning unit was controlled by a single thermostat and satisfactory temperatures were maintained throughout the Residence by the proper adjustment of the system supply outlets.

This report discusses the five major phases of the experiment: 1) the room-to-room temperature balance achieved with a full-perimeter air-conditioning system and the effect of air interchange between levels on the temperature balance, 2) the comparative performance characteristics of a full-perimeter system and a combination high-sidewall and perimeter system, 3) the comparative effects of cyclic and continuous blower operation on temperature balance, air interchange between levels and the moisture removed from the Residence, 4) the performance of three types of perimeter supply outlets and one type of high-sidewall outlet, and 5) the sensible and latent cooling load of each conditioned level and of the total conditioned space.

CHOW, W. L., H. H. KORST, and C. C. TSUNG. "Truncated Cone in Supersonic Flight at Zero Angle of Attack," ME Technical Note 392-6, January 1960. 4 pp. 9 figs.

This report contains the results of calculations to determine pressure distributions over truncated-cone shaped afterbodies in supersonic flight with zero angle of attack. The numerical computations were carried out on the Illiac (electronic digital computer at the Engineering Research Laboratory, University of Illinois) as a side activity in connection with a comprehensive research program on jet-slipstream interaction pertaining to jet engines and missiles flying at supersonic speed. The calculations were based on the Method of Characteristics for axially symmetric supersonic flow and the oblique shock relations, disregarding the vorticity behind the curved shock front. The results cover half-cone angles up to 20 degrees (at 5 degrees intervals) at Mach Numbers of 1.5, 2.0, 2.5, 3.0 and 3.5.

KORST, H. H., W. L. CHOW, G. W. ZUMWALT. "Research on Transonic and Supersonic Flow of a Real Fluid at Abrupt Increases in Cross Section," ME Technical Report 392-5, Contract No. AF 18(600)-392, December 1959. 151 pp. 72 figs.

A general theory for pressures and temperatures in separated transonic and supersonic flows is developed using a physically perceptive model composed of simplified flow components. The principle of interaction between dissipative and free stream flow regions, already utilized in ME-TN-392-2, allows one to distinguish between inviscid flow configurations and superimposed jet mixing region. Treatment of the latter is based on concepts developed in ME-TN-392-1, and on tabulated results (including theoretical Stanton Numbers and Drag Coefficients) for fully developed isoenergetic (ME-TN-392-3) and non-isoenergetic (ME-TN-392-4), constant pressure, turbulent ($Pr_t = 1$), compressible two-dimensional mixing regions.

A great variety of problems in internal and external flow is analyzed theoretically, ranging from the classical base pressure problem to the performance of supersonic ejectors and the detailed study of the jet-slipstream interaction (afterbody) problem in jet-engine and rocket propulsion.

SOO, S. L., "Transport Processes Involving a Moving Rotating Disk in a Low-Density Gas," ME Technical Note, 9725-1, Engineering Experiment Station, University of Illinois, March 1960. 10 pp. 9 figs.

An analytical method is presented for studying the compressible boundary-layer motion over a rotating disk including axial forced flow. Some existing incompressible flow data can be utilized. The range considered includes free-molecule flow, slip flow, and high-density gas flow. A new correlation for treating disk-friction data is suggested. General aspects of friction and heat transfer are discussed. Results suggest the rotating disk as a suitable tool for experimental study of mechanics of a rarefied gas.

This has recently been published as Paper No. 60-WA-154 in the transactions of the ASME Journal of Basic Engineering.

MECHANICAL ENGINEERING THESES

Ph. D.

Li, H. L. "Local Temperature at Tool Flank and Frictional Energy Distribution at Chip-Tool Interface (With a new procedure for solving ill-conditioned equations)," B. T. Chao, advisor. October, 1959.

M. S.

Bhattacharyya, A. "Cutting Performance on Controlled Contact Cutting Tools," K. J. Trigger, advisor. August 1959.

DeCamp, R. E. "Pin Positioning Times for an Indexing Fixture," L. C. Pigage, advisor. June 1960.

Willer, E. M. "Population Stereotypes in the Movement of Manual Controls," L. C. Pigage, advisor. February 1960.

MINING AND METALLURGICAL ENGINEERING—PHYSICS

The Mining and Metallurgical Engineering and Physics staffs contribute regularly to professional journals. No departmental series publication is maintained for the purpose of having copies available for limited distribution. Therefore, only thesis titles are included here for both departments.

MINING AND METALLURGICAL ENGINEERING THESES

Ph. D.

- Chakraverty, N. "A Laboratory Study of the Influence of Metallic Additives on the Carburization Properties of No. 6 Seam Illinois Coal," R. G. Wuerker, advisor. June 1960.
- Enrietto, J. F. "Strain Aging and Fatigue of Columbium," C. A. Wert, advisor. February 1960.
- Stanley, J. T. "Internal Friction and Diffusion in Iron Vanadium Alloys," C. A. Wert, advisor. October 1959.

M. S.

- Becker, W. T. "A Study of Impact Characteristics of Alpha Brass," R. W. Bohl, advisor. February 1960.
- Class, W. "Isothermal Effects in Beta Phase Gold-Cadmium," D. S. Lieberman, advisor. January 1959.
- Hanafee, J. E. "A Determination of the Austenite-Martensite Crystallography in a High-Purity Fe-Cr-C Alloy," C. M. Wayman, advisor. November 1959.
- Hren, J. A. "A Study of Some Properties of Vanadium Between 77° and 300° K.," C. M. Wayman, advisor. February 1959.
- Kamber, K. T. "The Interaction of Interstitial Carbon and Nitrogen with Dislocations in Deformed Alpha Iron," C. A. Wert, advisor. February 1960.
- Mukherjee, K. "Quenching Effects in Beta-Phase Gold-Zinc," D. S. Lieberman, advisor. October 1959.
- Schleicher, A. R. "Application of Electrokinetic Effects for Radial Fluid Flow Systems," N. Street, advisor. February 1960.
- Stewart, P. R. "An Electrokinetic Investigation of Potentials at Interfaces," N. Street, advisor. June 1960.
- Sunay, H. N. "Influence of Additives on the Coking Properties of Illinois Coal Seam No. 6," R. G. Wuerker, advisor. February 1960.
- Fara, H. "On the Effect of Non-Equilibrium Vacancies on the Kinetics of Kirkendall Diffusion," T. A. Read, advisor. June 1959.

PHYSICS THESES

Ph.D.

- Bobone, R. "Transverse Polarization of Conversion Electrons Following Beta-Decay," H. Frauenfelder, advisor. June 1960.
- Bredt, J. H. "A Study of Low-Temperature Electrical Resistance Recovery in Cold Worked Copper Crystals," J. S. Koehler, advisor. June 1960.
- Burnham, D. C. "Photoconductive Hall Effect in Silver Bromide," F. C. Brown, advisor. October 1959.
- Coover, R. E. "Surface Magnetoconductivity Experiments on Silicon" J. Bardeen, advisor. June 1960.
- Dyal, P. "Cross Sections for the B⁺ (γ , π^-) C⁺ and B⁺ (γ , π^-) B⁺ Reactions," J. P. Hummel, advisor. August 1959.
- Emrick, R. M. "The Effect of Hydrostatic Pressure on the Anneal of Quenched-In Vacancies in Gold," D. Lazarus, advisor. June 1960.
- Fox, J. D. "The Photoneutron Cross Section Near Threshold," P. Axel, advisor. February 1960.

- Hanson, R. C. "Hall Effect for Holes in AgBr," R. J. Maurer, advisor. June 1960.
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- Mieher, R. L. "Quadrupolar Nuclear Relaxation," C. P. Slichter, advisor. February 1960.
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M. S.

- Libchaber, J. A. "Electrical Properties of a Cleaned Germanium Surface," P. Handler, advisor. October 1959.
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THEORETICAL AND APPLIED MECHANICS

Research done in T&AM is consistently published in a department research series. A separate series for material not yet released by the sponsor for general distribution is maintained by the department. Only the series available to qualified requestors is given here.

WORLEY, W. J. "The Effects of Inelastic Action on the Resistance to Various Types of Loads of Ductile Members Made From Various Classes of Metals," T&AM Report No. 149, Contract No. AF 33(616)-5658, Project No. 7360, March 1959. 20 pp. 11 figs. 3 tables.

This is the final report on the photoelastic study of I-Beams, and covers the period from May 1, 1958 to March 1959.

The data presented are intended to supplement the data presented in WADC TR 56-330 Part VII under contract No. AF 33 (616)-2753. Report VII presented information on the fully plastic strength while the present report discusses the elastic stress distribution in the web section of I-Beams with various shapes of elliptic-type web cutouts.

The prediction of the location of the fully plastic hinges using the shear difference method is discussed for one shape of web cutout. The method shows reasonable agreement when compared with available data on the actual aluminum alloy I-Beam.

BOWMAN, C. E. "A Simplified Elastic Load Measuring Ring," T&AM Report No. 150, July 1959. 15 pp. 7 figs. 1 table.

A type of simplified load-measuring ring that has high sensitivity and accuracy is described in this article. A number of these rings have been designed, with slight modification in dimensions, to satisfy a wide range of load-measuring requirements. The ring is similar to other commonly used elastic calibration devices, such as the Morehouse Proving Ring, but is designed to simplify fabrication by eliminating the usual integral lugs on each end.

Several typical applications are cited at the end of this article to illustrate the use of the rings.

BOWER, J. E., and I. M. VIEST. "Shear Strength of Restrained Concrete Beams Without Web Reinforcement," T&AM Report No. 151, August 1959. 45 pp. 12 figs. 8 tables.

Tests of two series of reinforced-concrete beams without web reinforcement were made to investigate the behavior in shear of restrained beams. One series was designed as a study of the effects of variations in the ratio of maximum negative moment to the maximum positive moment (moment ratio). The other series was concerned with the effects of variations in the ratio of maximum moment to shear (moment-shear ratio).

The tests have shown that the effect of shear on the behavior of restrained beams is essentially the same as that observed for simple beams: the shear affects the load-deformation characteristics and the capacity of a beam through the formation of diagonal tension cracks. The first diagonal tension crack forms at a section subjected to both moment and shear and located between the point of contraflexure and the section of maximum moment. An analysis of the test data has shown that the initial diagonal tension cracking strength is a function of the moment-shear ratio rather than of the length of the shear span.

Large variations were found in the load-carrying capacity beyond the initial diagonal tension cracking loads even for companion specimens. This finding supports earlier suggestions that the strength in excess of the diagonal tension cracking load is of little practical value.

Equations are presented for the initial diagonal tension cracking strength and for the shear-moment capacity.

ROBERTSON, J. M., J. C. F. CHOW, and M. E. CLARK. "Transition Stimulation for Terminal Velocity Reduction in Water-Exit Studies," T&AM Report No. 152, Contract No. 1834(10), Project NR 062-202, November 1959. 28 pp. 12 figs.

A technique for reducing the terminal velocities of small buoyant bodies rising through water is described and its experimental verification indicated. Sand-grain patches to induce premature transition of the flow in the boundary layer from laminar to turbulent were used in the (length) Reynolds-number range of 10^5 to 10^6 . A method of designing the sand patches in terms of known information on transition, roughness effects, and laminar boundary-layer growth is detailed. Experimental evidence of the achievement of transition stimulation in an air tunnel, via hot-wire anemometer boundary-layer studies and drag tests, is presented. Finally, it is shown that an appreciable reduction in terminal velocity was obtained in the actual water-exit tests.

ROBERTSON, J. M. "Hydroballistic Calculations of the Rise and Water Exit of Buoyant Bodies," T&AM Report No. 153, Contract No. 1834(10), NR 062-202, November 1959. 72 pp. 29 figs.

Problems associated with the vertical rise and passage through a water-air interface of small buoyancy-propelled bodies are considered. In general the methods of analysis are approximate, and sometimes even crude, but the results are considered indicative of what may occur. Calculations are limited to consideration of prolate ellipsoids and usually to those of fineness ratio equal to 4. The terminal velocity and length of rise required to approach it closely are calculated in Chapters II and III. Comparison with experiment indicates fair agreement. It is further shown that above a diameter of 2 inches the Froude number no longer increases appreciably with body size. A rough analysis of the added-mass variation of ellipsoidal bodies as they pass through the free surface is developed in Chapter IV. This later estimate is used to indicate the expected velocity and acceleration changes of exiting bodies in Chapter V. These are shown to diverge somewhat from those found experimentally. Besides the effect of added-mass variation, buoyancy and drag changes as the body exits are also shown to have an important effect on the velocity-distance and acceleration-distance profiles. Finally, in Chapter VI the effect of entrained water, as has been experimentally observed, is considered. Calculations of the displacement volume of the boundary layer on the body are shown to be in fair agreement with the measured entrained-water volumes. This permits some consideration of this entrainment effect at other scales of water-exit occurrence -- the effects of Reynolds number and transition from laminar- to turbulent-boundary-layer flow are shown to be significant. Consideration of this estimate of the entrained water permits a revision in the calculated velocity and acceleration profiles; in Chapter VI this is shown to lead to closer agreement with observation. The entrained water is thus found to have an important effect on the water-exit behavior of the bodies, a fact which has been suspected since the first observations of this occurrence.

SIDEBOTTOM, O. M., S. DHARMARAJAN, J. L. GUBSER, and J. D. LEASURE. "The Effects of Inelastic Action on The Resistance to Various Types of Loads of Ductile Members Made from Various Classes of Metals." Part XII, Eccentrically Loaded Tension Members and Columns Made of 17-7PH Stainless Steel and Ti 155A Titanium Alloy and Tested at Various Temperatures, T&AM Report No. 154, Contract No. AF 33(616)-5658, Project No. 7360, October 1, 1959. 74 pp. 44 figs. 4 tables.

Experimental data were obtained from eccentrically loaded columns made of 17-7PH stainless steel and Ti 155A titanium alloy and tested at room temperature, from eccentrically loaded columns made of 17-7PH stainless steel and tested at 1000° F., and from eccentrically loaded tension members and columns made of Ti 155A titanium alloy and tested at 800° F. In most cases the creep tests were limited to 30 minutes. At the elevated temperatures the inelastic deformation was time dependent for the 17-7PH stainless steel and was mostly time independent for the Ti 155A titanium alloy.

The theoretical analysis of room-temperature test data obtained from Ti 155A titanium-alloy members tested at 800° F. was based on the interaction curve-moment-load curve theory. The arc-hyperbolic-sine theory was used in the analysis of data obtained from 17-7PH stainless-steel members tested at 1000° F. In all cases good agreement was found between theory and experiment.

LIU, H. W. "Crack Propagation in Thin Metal Sheet Under Repeated Loading," T&AM Report No. 155, Contract No. AF 33(616)-5153, Project No. 7024, December 1959. 88 pp. 50 figs. 2 tables.

Fatigue fracture involves two processes: crack initiation and crack propagation. The effect of range, mean, and state of stress appears to be different for crack initiation and crack propagation. Therefore, to understand basic damage phenomena it is advantageous to separate the studies of crack initiation and crack propagation.

An experimental and analytical investigation was undertaken to study the fundamental factors of crack propagation in a thin metal sheet under repeated axial loading.

Sheet specimens of 2024-T3 aluminum alloy 4 inches wide containing a central hole were used in the experimental investigation. Stress range and mean stress were the controlled variables. Time-lapse photography was used to record the crack length and the number of cycles of loading at regular intervals. The crack length was then measured from the recording film.

The experimental results indicated that the propagation life consisted of 3 periods. In the initial period, the cracks propagated sporadically and slowly. In the middle period, the relationship between the crack length and the number of cycles of loading was well represented by an exponential function. In the final period, crack propagation was greatly accelerated, leading rapidly to fracture.

An expression for crack length was derived, based on the concept of geometrical similarity of crack configuration, for a semi-infinite sheet subjected to repeated loads consisting of a constant-stress range and mean stress. The expression is in terms of a stress-dependent propagation factor and an exponential function of the number of cycles of loading. This expression was in good agreement with the experimental results for the middle periods of the propagation lives. The propagation factor was related experimentally to the stress range and the mean stress.

The expression for a semi-infinite sheet was modified for the effect of increasing-stress range and mean stress as the crack propagated in a specimen of finite width. Accurate prediction of the propagation life was possible using the modified equation.

Photomicrographic observations indicated that the size of the plastic zone increased as the crack propagated and that the crack often branched along the path.

The equation by Head and the hypothesis by Paris were used to analyze the experimental data. However, the results indicated that, without further development, the analyses by Head and Paris et al. were not as promising as the analysis developed in this investigation.

WEINSTEIN, D., G. M. SINCLAIR, and C. A. WERT. "The Strain Rate and Temperature Dependence of the Ductile to Brittle Transition in Molybdenum Subjected to Torsional Loading," T&AM Report No. 156, Contract No. AF 33(616)-5153, Project No. 7024, December 1959. 16 pp. 7 figs.

Brittle failure in annealed arc-cast molybdenum in torsion was studied as a function of strain rate and temperature. Strain rates ranged from a maximum of 12.5 per second to a minimum of 0.005 per second. The temperature dependence of the yield point for these different strain rates was used to calculate a heat of activation for the yield point. The heat of activation was not a constant but was approximately a linear function of the stress at yield. The value extrapolated to zero stress is 36,000 calories per mole. This is close to the reported value of 33,400 calories per mole for C diffusing in molybdenum. It is proposed that the rate effect in yielding is determined in part by diffusion of C (or other interstitial atom) in the metal.

BENNETT, P. E., and G. M. SINCLAIR. "An Analysis of the Time and Temperature Dependence of the Upper Yield Point in Iron," T&AM Report No. 157, Contract No. AF 33(616)-5153, Project No. 7024, December 1959. 28 pp. 15 figs.

Torsion tests were conducted on ingot iron using strain rates of 12.5, 0.25, and 0.0001 per second over a temperature range of 77° K. to 525° K. The magnitude of the upper yield-point shear stress was the dependent variable in all of the tests.

The results of the tests show that the yield strength exhibits a rapid increase as the temperature is lowered. The yield strength also increases as the strain rate is increased. The dependence of the yield point on strain rate and temperature can be explained on the basis of a locking interstitial mechanism.

An activation energy ΔH can be associated with this embrittlement mechanism. This energy is influenced by stress and it appears from these tests that this relationship can be described by an equation of the form: $\Delta H = \overline{\Delta H} \left(\frac{\bar{\tau} - \tau}{\bar{\tau}} \right)^b$. If this relation is used in conjunction with a modification of the Boltzman

equation, the following result is obtained: $\log \left(\frac{\dot{\gamma}}{\dot{\gamma}_1} \right) = M \frac{\overline{\Delta H}}{RT_1} \left(\frac{\bar{\tau} - \tau_1}{\bar{\tau}} \right)^b \left[1 - \frac{T_1}{T} \left(\frac{\bar{\tau} - \tau}{\bar{\tau} - \tau_1} \right)^b \right]$. This

equation quite accurately describes the experimental data.

In all of the torsion tests conducted on ingot iron, the fracture occurred in a ductile manner. From these results and the tests conducted by Weinstein on molybdenum, it appears that there is a critical tensile stress which must be exceeded before brittle fracture can occur. The state of stress is an important factor in determining whether this tensile stress can be reached before yielding takes place. Torsion tests effectively reduce the tensile stress in comparison with the shear stress and thus enhance the chances for ductile behavior.

At sufficiently elevated temperatures, the embrittlement mechanism no longer holds and the yield stress loses its strong time and temperature dependence. This is reasonable if the dependence is assumed to be a consequence of locking mechanism. At elevated temperatures the interstitial atoms have sufficient energy to move freely through the lattice and no longer effectively lock dislocations.

WILSON, P. E., and A. P. BORESI. "Annotated Bibliography of Selected References on the Theory of Elastic Plates," T&AM Report No. 158, Contract No. NR 1834(14), Project NR 064 413, January 1960. 21 pp.

In the problems of buckling and of post-buckling behavior of thin plates, the Kirchhoff-Love approximation is usually employed. This approximation implies that the transverse shearing strains have negligible effect on the buckling and on the post-buckling deformation of thin plates. In the case of small deflections of thin plates, the effect of transverse shear has been incorporated in the theory by E. Reissner. However, in the case of thick plates, the approximations of thin plate theory are unreliable, and it becomes necessary to resort to the theory of three-dimensional elasticity.

In view of the present importance of buckling and of post-buckling behavior of thin plates, sandwich plates, etc., in modern aircraft, missiles, etc., it is desirable to relax the restriction of the Kirchhoff-Love approximation; that is, it is desirable to extend the buckling theory and the post-buckling theory of plates to include the effects of shear deformation. Furthermore, effects of anisotropy, heating and nonhomogeneity play an important role in current plate problems. Accordingly, as a first step in an evaluation of the status of current plate theories, this list of selected references has been compiled and annotated. Particular emphasis has been placed on those theories which include one or more of the following effects: (1) nonlinear effects in the strain-displacement relations, (2) transverse shear stress, (3) transverse normal stress, (4) anisotropy, (5) heating, (6) nonhomogeneity (sandwich plates), (7) viscoelasticity.

Since many of these phenomena are of particular importance in practice, a number of recent papers have been devoted to studies of their effects. However, no attempt has been made here to include the numerous papers on applications of the various plate theories. Rather, emphasis has been given to those papers which we believe contribute most to the formulation of a plate theory which may be used in the buckling and post-buckling problems of plates, including the effect of transverse shear.

MILLER, R. E., and A. P. BORESI. "Strain Energy Expression For a Circular Cylindrical Shell Including Transverse Shear Effects," T&AM Report No. 159, Contract No. NR 1834(14), Project NR 064 413, February 1960. 28 pp. 1 fig.

In problems of buckling and of post-buckling behavior of circular cylindrical shells, restrictive assumptions which reduce the three-dimensional elasticity problem to a two-dimensional problem are usually employed. A common approximation is that due to Kirchhoff-Love which implies that transverse shearing strains have negligible effects on the large deflection and on the buckling and post-buckling behavior of very thin shells. However, in modern structural problems of moderately thin shells, the effects of transverse shear may be important. Hence, in theories of large deflection and of buckling and post-buckling behavior of moderately thin shells, it is desirable to relax restrictive assumptions which discard the effect of transverse shear.

The strain energy expression derived in this report is based on the exact expressions for the strain-displacement relations of three-dimensional elasticity theory. However, the displacement components are represented as polynomials in the thickness coordinate z . The Kirchhoff-Love approximation (stating that normals to the middle surface of the shell remain straight, normal and inextensional under the deformation) is discarded. Temperature terms are included in the stress-strain relations. The material is assumed to be linearly elastic, isotropic and homogeneous.

The principal results are left in a form suitable for digital-computer computations. However, to explore numerical difficulties involved in the application of the equations, the relatively simple case of plane strain of a circular cylinder subjected to internal pressure was solved using a ten-place desk computer. The resulting computations did not prove prohibitive.

STEPHENS, R. I., and G. M. SINCLAIR. "A High-Temperature, Vacuum, Axial Fatigue-Testing Machine," T&AM Report No. 160, Contract No. AT (11-1)-67, Project 20, March 1960. 19 pp. 9 figs.

This paper describes fatigue equipment which was developed to test thin-walled refractory metal specimens in a vacuum under repeated axial loading at temperatures up to 2100° F. The machine is of the constant displacement type and incorporates an eccentric and crank mechanism which allows the alternating stress, mean stress, and frequency of cycling to be varied. The stresses in the specimens are easily calculated from $\sigma = P/A$, where P is the axial load measured by a ring dynamometer and A is the cross-sectional area of the specimen. The test specimen is uniquely heated by placing a tungsten heating element inside the thin-walled tubular specimens. The evacuated test chamber is completely visible through the use of a pyrex bell jar seated on an O-ring seal. Axial motion is transmitted into the vacuum chamber through a copper-alloy bellows. Preliminary results of fatigue tests on commercially pure arc-cast molybdenum specimens subjected to fully-reversed stresses at 1700° F. and 875 cycles per minute, are included in this paper.

LIND, N. C. "The Stress Concentration at Radial Outlets in Spherical Pressure Vessels," T&AM Report No. 161, Contract No. NOBS 72069, March 1960. 29 pp. 10 figs.

This paper outlines a simple method to determine the elastic stress-concentration factor of axial outlets from spherical and other symmetrical vessels subjected to internal pressure.

The computed values of the stress-concentration factor are compared with the results of photoelastic tests, showing good agreement ordinarily within the limits of experimental accuracy.

COOK, R. D. "Correlation of Variables in Photoelastic Stress Freezing," T&AM Report No. 162, April 1960. 34 pp. 17 figs.

The experimental work shows how the material (Araldite 6020 epoxy resin cured with phthalic anhydride) deforms and behaves photoelastically at various temperatures. Quantitative relationships between strain, fringe order, stress, time and temperature are determined experimentally. These relationships are explained upon the theory that the material contains two types of bonds in its molecular structure, one of these types being van der Waal bonds which become ineffective at high temperature, the other type being covalent bonds which retain their effectiveness at both high and low temperatures. The temperature of maximum optical sensitivity is found, and the temperature below which the properties of the material are not time dependent is determined. It is shown that above the temperature of maximum optical sensitivity, Young's modulus increases and the optical sensitivity decreases with increasing temperature, while the figure of merit remains constant. It is shown that the distribution of fringes in a photoelastic model will change if the model is loaded at a temperature at which the properties of the material are time dependent, and evidence is presented which indicates that the stress-freezing technique cannot help but be in error by a small amount.

ENRIETTO, J. F., G. M. SINCLAIR, and C. A. WERT. "Mechanical Behavior of Columbium Containing Oxygen," T&AM Report No. 163, Contract No. AT (11-1)-67, Project 20, April 1960. 24 pp. 12 figs.

It has been shown that columbium is extremely susceptible to strain aging, both in tension and in fatigue when small amounts of oxygen are present in solid solution. The temperature at which maximum strain aging occurs is apparently a function of the strain rate (frequency of loading in fatigue), and for the rates used in the present experiments maximum strengthening occurred at 500° C. in tension and 400° C. in fatigue. The stress magnitude of the strain-aging peak for both tension and fatigue is dependent upon the oxygen concentration. Strengthening due to strain aging increases very rapidly with increasing oxygen content up to approximately 0.02 per cent by weight which corresponds to one oxygen atom per dislocation per atom plane, in the severely deformed metal. Oxygen in excess of 0.02 per cent by weight contributes relatively little additional strengthening at the temperature of maximum strain aging.

BOWMAN, C. E., and T. J. DOLAN. "Biaxial Fatigue Studies of High-Strength Steels Clad with Stainless Steel," T&AM Report No. 164, Contract No. NOBS 72143, Final Report, May 1960. 24 pp. 12 figs.

This research was conducted to determine the resistance to cyclic mechanical loading of the bond between stainless steel clad to carbon-steel backing plate. It was originally contemplated that a cyclically loaded plate specimen subjected to a state of biaxial stress would be the most suitable test specimen. During the course of the research, however, it was determined that bending fatigue and static-bend specimens were not developed in well-bonded clad plate; the only bond failures that were developed were in plate that was considered by the supplier to have a faulty bond.

It was demonstrated that there was no correlation between the indication of a sound bond by ultrasonic means and the resistance of the bond to cyclic mechanical loading. That conclusion was based upon the test of one steel of roll-bonded backing plate.

"First Student Symposium on Engineering Mechanics," faculty advisor JODEAN MORROW, T&AM Report No. 165, June 1960.

The papers in this volume were presented on June 4, 1960 at the University of Illinois. Seniors in the Engineering Mechanics curriculum take a sequence of two advanced-problems courses, T&AM 293 and T&AM 294, which are intended to give them an opportunity to do independent research and analysis. Four faculty members were assigned to these two courses. Professor W. J. Worley was in charge of T&AM 293, Professor JoDean Morrow was in charge of T&AM 294, and Professors R. E. Miller and C. E. Bowman participated as occasional lecturers and consultants to the students. Other members of the T&AM staff assisted individual students and are acknowledged in the separate papers. The papers reproduced in the volume were chosen for presentation from the term problems which were completed in T&AM 294. Other papers prepared for this class are listed by title and author at the end of the volume.

CARLSON, D. E. "Free Torsional Vibration of an Elastic Cylindrical Bar Mounted in a Continuous Elastic Support," 18 pp. 1 fig.

This paper presents a solution for the free torsional vibration of an elastic cylindrical bar mounted in a continuous elastic support. Solution was for a bar having one end fixed and given an arbitrary initial twist.

The completeness of the solution of the differential equation of motion is discussed and its uniqueness proved.

The special case of the bar being given an initial twist at the free end is solved.

TULER, F. R. "A Discussion of the Triaxial State of Stress in an Extremely Thin Brazed Joint." 12 pp. 4 figs.

The variation of the tensile strength of a thin brazed joint with joint thickness can be divided into three regions. For the region of extremely thin joints the stresses are nearly elastic up to fracture. A Fourier solution is specialized to find the state of stress at the center of the joint where fracture is assumed to initiate. It is found that the stresses are independent of joint thickness and that the state of stress in the joint has an appreciable hydrostatic tension component. An estimate can be made of the cohesive strength of the metal used in the joint.

JOBARIS, J. E. "The Effect of Biaxial Stresses on Rapid Crack Propagation." 9 pp. 4 figs.

Present theories on rapid crack propagation in thin sheets state that stresses parallel to the crack length can be neglected. This is a report of tests intended to investigate the validity of this assumption. The specimens were prepared from brass shim stock 0.001-inch thick.

A series of uniaxial tension tests under a constant load was used to determine the critical crack length for that load. Biaxial tension tests were then made on specimens with a crack of this critical length present to determine any effects of an added stress-field parallel to the induced crack.

The experimental results indicate that the effects of stresses parallel to the crack length are far from being insignificant. The biaxially stressed specimens withstood loads about 190 per cent of the uniaxially stressed specimens before spontaneous brittle fracture occurred through the crack.

Thus, it appears that the accepted theory does not adequately describe rapid crack propagation in very thin sheets stressed biaxially. It seems that further tests should be conducted on the basis of this report.

MELVIN, J. W. "The Soap Film and Its Applications." 19 pp. 10 figs.

This paper presents a general treatment of soap films, their behavior and their uses in science. By first describing the reasons for the formation of soap films, a basis for understanding the phenomena peculiar to soap films is established. The information is used to explain and describe applications of soap films to scientific problems.

COLLINS, W. H. "Analysis of the Influence of Initial Crookedness on Column Strength." 29 pp. 16 figs.

This paper presents the theoretical and experimental results of an investigation to determine the influence of initial crookedness on column strength. A numerical method was developed to use interaction curves for obtaining load-deflection relationships for straight and crooked, rectangular columns under various loading conditions. Ten 2024-T4 aluminum-alloy columns were tested. Five loading conditions were used. In most cases, good agreement existed between theory and experiment. The influence of initial crookedness was not appreciable, provided that the eccentricity with respect to the mid-height was the same for the crooked and straight columns.

HALFORD, G. R. "Specific Work as a Criterion for Simple Shear-Strain Definition." 9 pp. 4 figs.

The definitions of shear strain are discussed. It is shown that $\gamma = \tan \phi$, where ϕ is the shear angle, is the shear-strain definition which satisfies the energy relation $V \int \tau d\gamma = \int \bar{T} d\theta = \text{Total work done}$. V is the volume of uniformly stressed material, τ is the shear stress, T is the torque, and θ is the angle of twist. On this basis, it is recommended that $\gamma = \tan \phi$ be used as the definition of shear strain.

SCHWIEBERT, P. D. "Free Vibration of a Continuum with Damping Characteristics." 16 pp. 8 figs.

This paper presents the general equations for the free vibratory response of a one dimensional medium. The medium is assumed to be characterized by either a Kelvin or Maxwell stress-strain-time relation.

The resulting equations have been specialized for specific initial strain and velocity distributions.

Computer techniques have been used to solve the equations for a simplified Kelvin body approximation of the medium. A plot of these results serves to illustrate the general response of the more complex system.

A short discussion on the use of an electrical analogy is also presented.

STERN, M., and E. V. WILMS. "Analysis of Missile Launchers," Part G, Phase 1, Ballistic Equations for Free Flight Rockets, T&AM Report No. 166, Contract No. 57-4341, DA-11-070-508-ORD-593, Ord. Project No. Tu2-7D (TW-205), July 1960. 34 pp. 6 figs.

This report contains a restatement of the equations governing the exterior ballistics of a free-flight rocket in a form suitable for solution by high-speed digital computers. Neither the notation nor the definitions conform to any particular reference, hence they are clearly stated in the development of the equations of motion. The equations, along with the necessary notation, are collected at the end of the report for easy reference.

KUGEL, R. "The Highly Stressed Volume of Material as a Fundamental Parameter in the Fatigue Strength of Metal Members," T&AM Report No. 169, June 1960. 18 pp. 8 figs.

A study was made of the influence of geometric factors on the fatigue strength of several metals. Size and shape effects as found in existing data on steel and aluminum-alloy specimens subjected to different types of loading were reviewed. A simple analysis based on the fact that a decrease of fatigue strength accompanies an increase of volume of material subjected to 95 per cent and more of the maximum stress was found to account for these effects. A linear relationship was found between the logarithm of the maximum stress and the logarithm of the appropriate volume, which was equally valid for both smooth and notch bar members. This line exhibited the same slope for each of the materials that was evaluated. This linear relationship with a ± 10 per cent scatter band, included 96 per cent of the experimental fatigue limit determined from small laboratory specimens (0.25 inches in diameter).

THEORETICAL AND APPLIED MECHANICS THESES

Ph.D.

Keim, S. R. "Elastic Stability of Radially Non-Homogeneous Rings Under Uniform Pressure," H. L. Langhaar, advisor. June 1960.

Liu, H. W. "Crack Propagation in Thin Metal Sheet Under Repeated Loading," H. T. Corten, advisor. October 1959.

Miller, R. E. "Theory of Non-Homogeneous Anisotropic Elastic Shells Subjected to Arbitrary Temperature Distribution," H. L. Langhaar, advisor. May 1960.

M. S.

- Carlson, R. E. "Primary and Secondary Creep Deflection of Two Types of Indeterminate Beams," O. M. Sidebottom, advisor. August 1959.
- Chen, C. S. C. "Effect of Approximations Upon Theoretical Buckling of Circular Elastic Rings and Arches," H. L. Langhaar, advisor. February 1960.
- Chow, J. C. "On the Hydrodynamics of an Elongated Body Approaching a Free Surface," J. M. Robertson, advisor. October 1959.
- Cioth, N. "Strain Aging and Reproducibility of Yield Points in Molybdenum and Steel," G. M. Sinclair, advisor. June 1960.
- Cook, R. D. "Correlation of Variables in Photoelastic Stress Freezing," C. E. Taylor, advisor. June 1960.
- Fisher, D. R. "Analysis of the Fracture Behavior of a Ceramic-Coated Metal System," H. T. Corten, advisor. August 1959.
- Leasure, J. D. "Theoretical and Experimental Analysis of Eccentrically Loaded Columns of 17-7PH Stainless Steel and Ti 155A Titanium Alloy at Room Temperature," O. M. Sidebottom, advisor. February 1960.
- Lee, S. K. "Gyroscope with Sinusoidal External Couples Applied to the Gimbals," H. L. Langhaar, advisor. February 1960.
- Pfeifer, D. W. "Bond and Anchorage Characteristics of Welded Wire Fabric in Concrete," C. E. Kesler, advisor. February 1960.
- Pocs, E. "The Effect of End Conditions on the Collapse Load of Columns," O. M. Sidebottom, advisor. June 1960.
- Shan, S. "Comparisons Between Herbert's Equation for the Outer Fibers of the Beam and the Stress-Strain Diagram of Douglas Fir," J. O. Smith, advisor. August 1959.
- Stephens, R. I. "A High Temperature Vacuum, Axial Fatigue Testing Machine," G. M. Sinclair, advisor. February 1960.
- Wang, I. C. "Determination of the Cyclic Speed Variation of a Six-Cylinder Diesel Engine with Damping," P. G. Jones, advisor. February 1960.
- Willem, R. A. "Cyclic Stress-Relation of U-700 and R-41 at Elevated Temperature," J. Morrow, advisor. June 1960.
- Wozniak, R. S. "An Investigation of the Neon Method of Determining Airy Polynomial Stress Functions," A. P. Boresi, advisor. June 1960.

AUTHOR INDEX

- Allen, A. W.--14
 Amin, R. B.--15
 Anderson, R. C.--14
 Andrew, F. W.--12
 Appleton, J. H.--22
 Armstrong, M. E.--33
 Arzbaeher, R. C.--32
 Austin, W. J.--20
 Avizienis, A.--31, 32

 Babcock, M. L.--32
 Bailey, A. D.--28
 Balmain, K. G.--24, 33
 Bart, R. K.--14, 15
 Barthel, H. O.--7
 Bartky, W. S.--31
 Barton, F. W.--18, 19, 23
 Baud, K. W.--8
 Becker, W. T.--35
 Benjamin, J. E.--16
 Bennett, D. G.--15
 Bennett, P. E.--38
 Bergeron, C. G.--14, 15
 Bhattacharyya, A.--34
 Bitzer, D. L.--32
 Bobone, R.--35
 Bohl, R. W.--14
 Boresi, A. P.--39
 Bower, J. E.--37
 Bowman, C. E.--36, 40
 Bradford, V. E.--14, 15
 Bratschun, W. R.--15
 Bredt, J. H.--35
 Brown, E. J.--33
 Buchta, J. C.--32
 Bunte, W. F.--23
 Burnham, D. C.--35

 Campbell, D. B.--23
 Carlson, D. E.--41, 43
 Chakraverty, N.--35
 Chang, E. Y.--8
 Chang, Y. C.--22
 Chen, C. L.--29, 32
 Chen, C. S. C.--43

 Chen, J. W.--16
 Chenoweth, D. R.--8
 Chesson, E., Jr.--20
 Chow, J. C. F.--37, 43
 Chow, W. L.--34
 Cioth, N.--43
 Clark, M. E.--37
 Class, W.--35
 Collins, W. H.--41
 Cook, R. D.--40, 43
 Coover, R. E.--35
 Corley, W. G.--18, 21
 Criss, D. E.--32
 Cruz, J. B.--26, 32
 Culver, A. C.--8

 Das Gupta, S.--24, 32
 Daum, D. R.--12
 Davis, C. F.--32
 Deadmore, D. L.--15
 DeCamp, R. E.--34
 dePaiva, H. A. R.--20, 23
 Deschamps, G. A.--24, 25
 Dharmarajan, S.--37
 Dineen, R. L.--23
 Dolan, T. J.--40
 Dunskus, T.--16
 Dyal, P.--35
 Dyson, J. D.--26

 Egger, W.--22
 Emrick, R. M.--35
 Enrietto, J. F.--35, 40
 Epley, D. L.--27, 32
 Eppler, R. A.--16

 Fara, H.--35
 Farnan, E. H.--13
 Feldman, A.--20, 21, 22
 Fisher, D. R.--43
 Fisher, W. E.--21
 Fleming, C. J.--23
 Fluhr, W. E.--22
 Fox, J. D.--35
 Friedberg, A. L.--14, 15

 Friedericy, J. A.--17
 Fu, K. S.--27
 Fulton, R. E.--22

 Gaertner, R. F.--16
 Gaudy, A. F.--22
 Gaus, M. P.--17, 22
 Ghosh, D. N.--16
 Goldstein, L.--29
 Govindan, T. S.--16
 Gregg, D. W.--16
 Gubser, J. L.--37

 Haertling, G. H.--15
 Hakimi, S. L.--26
 Halford, G. R.--42
 Hall, W. J.--18, 19
 Hanafee, J. E.--35
 Hansen, E. L.--11
 Hanson, R. C.--36
 Harshbarger, K. K.--10
 Hart, H. R.--36
 Hatcher, D. S.--21
 Haugh, C. G.--13
 Hayden, E. C.--28
 Herbst, R. J.--14, 15
 Herrington, C. G.--23
 Hershman, A.--16
 Herum, F. L.--12
 Hilton, H. H.--7
 Hinchcliff, K.--11
 Hoakley, P. G.--21
 Holt, R. C.--9, 13
 Hren, J. A.--35
 Hryekewicz, C. W.--33
 Huang, B. K. Y.--10, 13

 Ireland, H. O.--21

 Jackson, J. J.--36
 James, W. R.--8
 Jedeke, D. G.--11
 Jobaris, J. E.--41
 Johnson, E. L.--15

Kamber, K. T.--35
 Kampe, D. F.--10
 Karni, S.--27, 32
 Keating, K. B.--16
 Keenan, W. A.--21, 23
 Keim, S. R.--42
 Kellum, E. E.--29, 33
 Korst, H. H.--34
 Koval, E. J.--16
 Krzywoblocki, M. Z. v.--7
 Kugel, R.--42
 Kunihiro, T.--31

Larsen, W. R.--21
 Lauchner, J. H.--15
 Laurance, N. L.--36
 Layton, G. R.--16
 Leasure, J. D.--37, 43
 Lee, S. K.--43
 Lefort, H. G.--15
 Leiby, C. C.--29
 Lewitt, C. W.--20
 Li, H. L.--34
 Libchaber, J. A.--36
 Lind, N. C.--40
 Liu, H. W.--38, 42
 Liu, R. W.--32
 Lo, Y. T.--25
 Lundry, J. L.--8
 Lycan, D. L.--22

Maroney, Doris M.--14, 16
 Mayes, G. T.--17, 22
 Mayes, P. E.--26
 McDonald, D.--23
 McDonough, G. F.--23
 McMunn, J. C.--13
 Melvin, J. W.--41
 Meyer, P. A.--8
 Mieher, R. L.--36
 Miller, R. E.--39, 42
 Misiaszek, E. T.--23
 Mittra, R.--25
 Morrow, J. D.--41
 Mukherjee, K.--35
 Munse, W. H.--20
 Murti, V. G. K.--32
 Myers, B. R.--26

Nalbandor, A. V.--12
 Newmark, N. M.--19
 Nordell, W. J.--23

Olson, R. E.--23

Parikh, K. N.--15, 16
 Pask, G.--29
 Pfeifer, D. W.--43
 Pickard, G. E.--10
 Pierce, D. J.--8
 Pigg, D. L.--13

Pols, E.--43
 Poeschel, R. L.--33
 Poppelbaum, W. J.--30
 Puckett, H. B.--12

Ray, S. R.--30
 Replogle, J. A.--8
 Robe, J. K.--36
 Robertson, J. M.--37
 Rodda, E. D.--11, 13
 Roden, N. C.--23
 Rogers, K. T.--36
 Rolfe, S. T.--19
 Roll, W. M.--13
 Rosen, E. M.--16

Sahgal, R. K.--23
 Samara, G. A.--16
 Sather, R. O.--32
 Scheele, G. F.--16
 Schleicher, A. R.--35
 Schwarzlose, P. F.--15
 Schwiebert, P. D.--42
 Shan, S.--43
 Shao, T. S.--8
 Shaw, R. W.--36
 Shove, G. C.--10
 Shubert, H. A.--28
 Sidebottom, O. M.--37
 Siess, C. P.--17, 18, 21
 Simmons, W. W.--36
 Sinclair, G. M.--38, 40
 Smith, M. R.--13
 So, H. C.--32
 Soo, S. L.--34
 Sozen, M. A.--17, 18, 21
 Stahl, W. H. F.--8
 Staley, J. A.--23
 Stanley, J. T.--35
 Steier, W. H.--33
 Stephens, R. I.--40, 43
 Stern, M.--42
 Stewart, P. R.--35
 Stockdale, W. K.--23
 Summerbell, Alice A.--36
 Sunay, H. N.--35
 Sutcliffe, S.--23
 Swago, A. W.--33
 Sydnor, R. L.--28

Takahashi, S.--31
 Tang, C. H.--25
 Tang, D. T. N.--27, 33
 Thomas, L. J.--16
 Thornburn, T. H.--21
 Thornton, H. R.--15
 Tischer, R. E.--16
 Triandafilidis, G. E.--23
 Tsung, C. C.--34
 Tuler, F. R.--41

Uggerby, O.--11
 Ullman, J. D.--36
 Untrauer, R. E.--20

Veletsos, A. S.--17
 Viest, I. M.--37
 Von Foerster, H.--29

Walls, W. A.--23
 Walsh, E. L.--8
 Wang, I. C.--43
 Warwaruk, J.--23
 Weber, J. A.--9
 Weeks, W. L.--24
 Weinstein, D.--38
 Weissman, I.--33
 Wert, C. A.--38, 40
 Westerheide, D. E.--17
 Wheeler, D. J.--30
 Wiederhorn, S.--16
 Wilcox, D. L.--15, 16
 Willem, R. A.--43
 Willer, E. M.--34
 Willmore, T. A.--14
 Wilms, E. V.--42
 Wilson, P. E.--39
 Wiseman, N. E.--30
 Wishner, R. P.--33
 Worley, W. J.--36
 Wozniak, R. S.--43
 Wymer, F. J.--29, 33

Yoerger, R. R.--9, 10
 Youngquist, G. R.--17

Zimmerman, P. D.--14
 Zumwalt, G. W.--34

SUBJECT INDEX

- Adhesives, inorganic--15
- Aerodynamics--7, 8
- Aeroelasticity--7
- Air conditioning--33
- Alloys--35
- Annealing of metals--35
- Antenna systems--26, 28, 32
- Arches--43
- Astronautics--7, 8
- Auger--12
- Automation
 - adaptive--32
 - feeding dairy cows--10
- Bars
 - reinforcing--23
 - yield strength--21
- Beams
 - analysis of--36, 37, 43
 - concrete--18, 20, 22, 23
 - steel--22
 - timber--43
- Bearing averaging--33
- Boiling--16
- Bolts, high strength--20, 23
- Boron compounds--35
- Bound strength, concrete--43
- Boundary layers--8
- Brittle fracture--18, 19, 23
- Buckling--8
- Catalytic dehydrogenation
 - of isopropanol--16
 - of methylcyclohexane--17
- Ceramic
 - coatings--14, 15, 43
 - metal combinations--14, 15
- Circuit
 - frequency multiplication--33
 - switching, synthesis of--27, 32
 - synthesis, brune network--32
- Coal, properties of--35
- Columbium--40
- Columns
 - eccentrically loaded--37, 43
 - end conditions--43
 - initially crooked--41
 - reinforced concrete--23
- Concrete
 - beams--20, 22, 23
 - flat slab--17, 21, 22
 - prestressed--18, 23
 - reinforced--13, 17, 21
 - reinforced beams--20, 23
 - reinforced columns--23
 - reinforced, slabs--22
 - rigid frame--11
 - time-dependent effects in--21
- Conductivity
 - electrical--36
 - thermal--14, 15
- Construction, farm houses--11
- Control systems--32, 33
- Conveyors--12
- Copper--35
- Crack propagation--17, 18, 19, 22, 23, 38, 41, 42
- Creep--43
- Crystallization in glass--16
- Crystalline phases, in ceramic bodies--15
- Dehydrogenation
 - catalytic, of isopropanol--16
 - catalytic, of methylcyclohexane--17
- Differential equation solution, nonlinear--32
- Diffraction theory--24
- Diffusion--36
- Diffusivity, thermal--14, 15
- Digital computer
 - arithmetic unit--30
- asynchronous circuits--31
- circuit design--30
- core storage unit--30
- redundant number representations--31, 32
- storage adders--31
- transistor switching circuit--31
- Dimensional analysis, farm machinery design--10
- Dipole, radiation pattern of--24, 33
- Dislocations in metals--36
- Dispersion--36
- Drying of granular solids--16
- Dynamics--23
 - structural--23
- Eigenvalue problem in cylindrical waveguides--25
- Elastic
 - plates--39
 - stability--42, 43
- Electrolysis, growth of hydrogen bubbles during--17
- Electrons--35
 - scattering--36
- Farm machinery--10, 13
- Fatigue--38, 40, 42
 - alloy steels--43
 - effect of notches--23
 - testing machine--40, 43
- Feedback control systems--32
- Ferroelectrics--15
- Flow
 - channel--8
 - head losses in plastic fittings--13
 - supersonic--34
 - transonic and supersonic--34

- Fluid flow, electrokinetic effects--35
 Fluid mechanics--16
 Fluidized beds, drying with--16
 Fluorides--15
 Functions, arbitrary real--33

 Gases, rarefied--34
 Germanium--36
 Gold--35, 36
 Gyroscope--43

 Hall effect--35, 36
 Hay wafering--10, 13
 Heat transfer--16
 Helium--36
 recombination coefficient--29, 32
 High pressure, see pressure
 Hydrology--13

 Indium--36
 Insulation, electrical--15
 Interfaces, potentials at--35
 Ions--36
 Iron--38
 Isopropanol, dehydrogenation of--16

 Joints, brazed--41

 License plates--23
 Light, control chamber--12
 Linear systems
 stability analysis of--26
 time varying--26, 32
 Liquid properties--16
 Low temperature research--36

 Machine design, farm machinery--10
 Magnesium aluminate--16
 Magnetogasdynamics--8
 Magnetoionic theory, graphical constructions--24
 Magneto-plasma dynamics--33
 Mass transfer, driving forces in--16
 Matrices, loop resistance--32
 Measuring, load--36
 Metal cutting--34
 Metals--35
 and alloys--35
 at low temperatures--35
 defects--35, 36
 Methods time analysis--34
 Methylcyclohexane, dehydrogenation of--17
 Mirror, coma-corrected zoned--32

 Modes, magnetodynamic dipolar ferrite--33
 Molybdenum--38

 Network
 active double terminated--27
 functions, Tchebycheff polynomials--27, 32
 Neutrons--35
 Nitrogen oxide reactions--16
 Notches, effect of--23
 Nuclear
 magnetic resonance--36
 relaxations--36

 Oscillator, harmonic--32

 Panelizing, farm houses--11
 Phase changes, effects of solid-liquid interface during--16
 Phase transitions, effect of pressure on--16
 Photoconductivity--35, 36
 Photoelasticity--36, 40, 43
 Photons--35
 Piles, lateral loads on--22
 Planar structures, complementary multiterminal--25
 Plates, analysis--17, 22
 Polarization, electricity--35, 36
 Porcelain enamels
 low temperature coatings--15
 on wire--16
 Potassium bromide--36
 Pressure--35
 bomb for high temperature studies--16
 effect of impurities in alkali halides--16
 effect on molecular crystals--16
 internal transitions with--16
 phase transition effects with--16
 phosphor decay with--16
 vessels--40
 Propellants--8
 Pumping, using tractor exhaust--10

 Radio direction finding
 bearing averaging--29, 33
 panoramic receiver--29
 receiver--33
 receiver, injection-type--28
 signal amplitude to bearing deviation correlation--28
 R C two-ports--26

 Reactions, glass--15
 Real functions, rational approximation of--27
 Refractories--14
 Refractory coatings--14, 15
 Register resonant binary shifting--33
 Resistance, electrical--35
 Rings--42, 43
 Road design--23
 Rockets, free flight--42

 Self organizing systems--29
 Semiconductors--35, 36
 Servomechanisms--32
 Servomotor--32
 Sewage disposal, hog manure--11
 Shear strain, energy criteria--42
 Shells--22, 23, 39, 42
 Shock
 transmission--22
 waves--7, 8
 Silicon--35
 Silver bromide--35
 Slabs, concrete--22
 Soap films--41
 Sodium
 chloride--36
 niobate--15
 Soils
 bearing capacity of--21, 23
 foundation settlement--23
 illite--23
 laterally loaded piles--22
 properties of--23
 sampling--21
 Solar radio noise--33
 Solids, drying of--16
 Stainless steel--37, 40, 43
 Steatite--15
 Steel
 behavior--23
 stainless--37, 40, 43
 Stress
 Airy functions--43
 concentrations--40
 thermal--8
 Strip sources, synthesis of--25
 Structures, buried--23
 Surfaces--35, 36

 Temperature dependence
 fatigue--40, 43
 strain aging--40
 yield point--38
 Tension members, eccentrically loaded--37
 Thermal stress--8, 42
 Titanium--43
 alloy--37

48 SUBJECT INDEX

- Tractor
 - air cleaners--13
 - intake pressures--13
 - pumping--10
 - valves--9, 13
- Traffic surveys--23
 - license plates--23
 - road design--23
 - vehicular speed--23
- Tungsten--15
 - protective coatings for--14
- Ultraviolet rays--36
- Valves, tractor--9
- Vehicular speed--23
- Vibration
 - damping--42
 - diesel engine--43
 - torsional--41
- Viscoelasticity--7, 8
- Water
 - exit ballistics--37
 - open channel flow--8
 - terminal velocity in--37, 43
 - treatment--22
- Wave propagation--23
- Waveguides--25
- Welded wire fabric--43
- Wiener-Hopf integral equation
 - 25
- Wire
 - coatings for--15, 16
 - fabric reinforced--43
- Yield point--38
 - molybdenum steel--43
- Zircon--16
- Zirconia--16

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