

NATIONAL BUREAU OF STANDARDS REPORT

10576

PROJECTS and PUBLICATIONS
of the
APPLIED MATHEMATICS DIVISION
A Semi-Annual Report
July through December 1970



U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT

205.0

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U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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^oOnly unclassified material is included in this report.

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¹ Separated from the Division, October 16, 1970.

Status of Projects

1. MATHEMATICAL ANALYSIS

RESEARCH IN MATHEMATICAL ANALYSIS

Task 20540-12-2050141/55-57

1550-11

Origin: NBS
Manager: H. J. Oser
Full task description: July-September 1954 issue, p. 27

Authorized 9/1/54

Status: CONTINUED.

Continuing further with the exploration of a macroscopic theory of materials based on a single-integral representation of the constitutive equation, J. T. Fong completed a manuscript entitled "Some New Results on the Isothermal Bernstein-Kearsley-Zapas Theory of Elastic Fluids (1963) and its Generalizations to Include Anisotropic Solids with Memory", with co-author Dr. John A. Simmons, Metallurgy Division, IMR, in July 1970, and submitted it to an outside journal for publication in December 1970. These results apply to an experimental study of the mechanical response of real materials such as: (a) a test for the suitability of adopting the BKZ fluid model to fit several sets of experimental data, based on the theoretical result that the BKZ scalar potential is separable as the sum of two identical functions with different matrix arguments:

$$f(\underline{A}) = f(\underline{1} \det \underline{A}) + f(\underline{A}^\circ),$$

where \underline{A} denoted the matrix argument which must be non-singular, and \underline{A}° is a unimodular matrix defined by $\underline{A}^\circ = (\det \underline{A})^{-1} \underline{A}$; and (b) a technique of characterizing nonlinear, anisotropic and memory-dependent mechanical behaviors of composite materials, based on a single-integral constitutive equation with a scalar potential instead of the multiple-integral theories currently available.

New results on the non-equilibrium thermodynamic theory of the BKZ fluid were derived by J. T. Fong in collaboration with Dr. E. A. Kearsley, Mechanics Division, IBS. Specifically, an interpretation of the notion of the single-integral entropic functional based on non-equilibrium statistical mechanics was obtained, and the weakening of two hypotheses in the BKZ theory without altering its basic structure was proved. A manuscript entitled "A Non-Equilibrium Thermodynamic Theory of Solid Materials with Memory and Anisotropy Based on a Single-Integral Representation of the Entropic Functional" is being prepared for future publication.

Seymour Haber has obtained the following result: A family of functions F is said to have a "simple quadrature" if there exist coefficients a_1, a_2, a_3, \dots and distinct abscissas x_1, x_2, x_3, \dots such that

$$\int_0^1 f(x)dx = \sum_{n=1}^{\infty} a_n f(x_n)$$

for every f belonging to F . S. Haber showed that if ω is any increasing continuous function with $\omega(0) = 0$, the family $F(a) = \{f : |f(x_1) - f(x_2)| \leq C(f) \omega(|x_1 - x_2|) \text{ for all } x_1, x_2 \in [0,1]\}$ has a simple quadrature. In particular, $C^1(0,1)$ has a simple quadrature.

In collaborative work with the Optical Physics Division, R.S. Kraft made considerable progress in analyzing the integral equation of "light inter-reflections". The kernel of the integral equation has been shown to describe a contraction mapping. This property greatly simplifies the mathematical analysis and clarifies the physical content of the integral equation. A paper describing this work is in preparation; also, a computer program to calculate the solution for a particular geometry that is of technical interest is being developed.

A method for extending Riemann's method of integration for linear hyperbolic equations has been found. Riemann's method is generalized in such a way that representation formulas can now be found for boundary-initial problems instead of only the pure initial value problems treated by the classical Riemann method. A paper describing this is under preparation. R.S. Kraft delivered a talk on the subject of "Existence of a solution to a Cauchy problem for a linear transport equation" at the Fall SIAM Meeting in Boston, Mass.

Publications:

- (1) Numerical Evaluation of Multiple Integrals. S. Haber. SIAM Review, Vol. 12, pp. 481-526, (1970).
- (2) The Error in Numerical Integration of Analytic Functions. S. Haber. To appear in the Quarterly of Applied Mathematics.
- (3) On Certain Optimal Quadrature Formulas. S. Haber. To appear in J. of Research, NBS.
- (4) Convergence of semi-discrete approximations of a linear transport equation. R.S.Kraft. To appear in J. of Math. Anal. and Appls.

FORTRAN LIBRARY IMPROVEMENT AND ALGORITHM DEVELOPMENT

Task 20501-2053587

1550-23

Origin and Sponsor: NBS
Manager: H. J. Oser

Authorized 4/27/70

Status: CONTINUED

Testing of the FORTRAN library functions has confirmed several suspicions about the EXEC II library. In addition, it has given numerous insights into how a successful testing philosophy can be best developed and implemented.

A. Philosophy of testing. In order to certify the accuracy and performance of a given subroutine, one has to separate first the possible sources of error: (1) The input error due to conversion from decimal to octal. (2) The argument error due to prior calculations, as in $\sin(2x-1)$. (3) The error in the subroutine itself, which is composed of the truncation error in the approximation and the propagated error resulting from carrying out the arithmetic operations in the subroutine. (4) The output error caused by conversion from octal to decimal.

Errors (1), (2), and (4) can be separated from the errors in (3) which are genuinely affecting the working of the subroutine itself. This separation is effected by supplying the subroutine with exact octal arguments rather than going through I/O conversion. Moreover, the effect of an inaccurate argument is amenable to classical analysis and should not enter the discussion of performance of an algorithm. Error (3), which is made up of two components, the truncation and roundoff error, is genuinely affecting the performance of the subroutine. It is these two errors that we address ourselves to in this analysis.

Comparing two subroutines against one another, one first has to make sure that both have been supplied with exactly the same argument down to the last binary bit. Second, the "better" function value should be assured to be correct within the allowable rounding in the last digit. When checking a single-precision routine, the double-precision values are used for comparison. The double-precision values are checked against values obtained from a variable-precision package that calculates with 40 and 50 decimal (or octal) places in decimal (or octal) arithmetic and then correctly truncates to the length of the machine word [20 octals for the fraction, 4 octals for exponent and sign].

The choice of arguments was dictated by the recognition that although the frequency distribution of the arguments used would probably peak around exponent zero, errors would more likely be found at the extremes of the range of arguments and that therefore testing merely for a random set of arguments on $[0,a]$ or $[-a,a]$ would not be sufficient to detect trouble. E.g., the probability that a routine that fails badly for $x \in [10^{-36}, 10^{-38}]$ would show any trouble at all if 10,000 random arguments are used on $[0,1]$ is about 10^{-32} , in other words the chance of detection is nil*. We therefore chose to place a few arguments in each exponent range ("bicide" as we call it). Another point is that many times a routine fails because of peculiar bit configuration in the argument. We therefore decided to include such fractions as (i) all binary ones and (ii) one bit in the first position followed by all zeros. Other fractions are obtained randomly if so desired. The design of this testing philosophy is a result of joint efforts by the algorithm group (Lozier, Maximon, Oser, Sadowski, Sookne). The variable precision package was developed by L. Maximon.

B. Test results for the single precision FORTRAN library on the EXEC II system. The present FORTRAN library was found to be rather bad in several respects: Sine and cosine functions suffered from incorrect argument reduction procedures near zero where all accuracy was lost for the sine function subroutine. I.A. Stegun discovered this fault and recommended a fix for it. The hyperbolic sine and tangent functions use the exponential function below $x = 0.5$ and all accuracy is lost as x drops below 10^{-8} . (The same difficulty occurs for the double-precision functions). Better routines will replace these bad ones in the near future. The double-precision tangent also suffers loss of accuracy for small arguments.

* That assumes that the random numbers are uniformly distributed on the interval $[0,1]$.

The manufacturer of the UNIVAC 1108 computer has been aware of the deficiencies of the present library for some time and has developed a new FORTRAN library to be used with the EXEC VIII operating system. We have applied our tests to this new library (not yet released) and, while the overall design of the new library is vastly superior, we did find difficulties at the extremes of the argument range though considerably less severe than with the old library. The manufacturer has been responding to our criticism with numerous changes that should eliminate these troubles. (For example DEXP and DCOSH would not work for $x = 0$.)

C. New Algorithms. W.L. Sadowski and D. Lozier have applied F.W.J. Olver's algorithm to integrals of the type $\int_{-1}^{+1} e^{-a^2 x^2} T_{2n}(x) dx$ with excellent results. They have also studied the feasibility of using series-economization techniques for calculating various Bessel functions. A priori error estimates have been obtained for this algorithm. D. Sookne applied Olver's algorithms to the computation of Bessel-functions $J_n(x)$ and $I_n(x)$ for both real and complex x .

The activities in the Operations Research Section on the improvement of the linear programming package are reported under project 2050153.

MATHEMATICAL METHODS IN PLASMA PHYSICS

Task 20504-12-2050140/59-422

1540-11

Origin: NBS
 Manager: Walter L. Sadowski
 Full task description: October-December 1961 issue, p. 12
 Status: CONTINUED

Authorized 10/13/61

Walter L. Sadowski and Daniel W. Lozier have investigated the convergence properties of the eigenfunction solution of the Vlasov equation in the Fourier-Chebyshev representation. The free-stream solution for a periodic model with fundamental length L is given as a function of time by the expression

$$f(x,v,t) = \sum_n \sum_m 2e^{inkx} e^{-s^2 v^2 / 2} J_m(nkst) T_m(v)$$

where J_m is the Bessel function of integer order m , $k = \frac{2\pi}{L}$ and s is the scale factor that allows the representation of velocities over the range $-s \leq v \leq s$ in terms of Chebyshev polynomials defined on the interval $-1 \leq v \leq 1$.

The knowledge of the free-stream solution in its analytic form allows a check on the truncation error in the free-stream regime of the computer program.

The use of Chebyshev polynomials makes it possible to represent the function over half of its range which in turn permits the doubling of the time range over which the solution can be integrated with a given number of polynomials.

The use of Chebyshev polynomials is also advantageous because it restores the conservation quantities as computational checks. The eigenfunction expansion did not allow this. The Fokker-Planck term was added to the equation as a physically meaningful way of truncating the number of polynomials needed to represent the velocity space.

Walter Sadowski has developed a way of generating a stationary solution of the fully non-linear Vlasov equation on the computer. In addition to indicating convergence properties of the non-stationary solution for the same set of parameters, it is expected to check out an important and hitherto unsuspected source of computation errors inherent in polynomial expansions of solutions.

Two algorithms have been developed as an outgrowth of the plasma work. One of these is a method of evaluating certain integrals of the Maxwellian multiplied by Chebyshev polynomials. A manuscript has been prepared but not yet submitted for publication in the open literature. The other is a way of generating the free-stream solution to the Vlasov equation via series economization.

A talk was delivered by W. L. Sadowski at the School of Mines, University of Nancy, Nancy, France on August 4, 1970 entitled "Use of Symbolic Methods in Computational Physics".

2. OPERATIONS RESEARCH

CONSULTATION IN MATHEMATICAL OPERATIONS RESEARCH

Task 205-12-2050151

Origin and Sponsor. NBS

Authorized 12/30/60

Manager: A.J. Goldman

Full task description: October-December 1960 issue, p.3

Status: CONTINUED.

(1) Many activities of types previously recorded under this heading will henceforth be reported under Project 2050586 (q.v.)

(2) Demand for miscellaneous consulting and advisory services continued heavy. Section staff provided such services in 86 recorded instances, 58 involving assistance to NBS staff. The 86 instances totalled to 402 man-hours. Other agencies assisted included the Business Defense Supply Agency, National Science Foundation, NASA, AEC, Defense Communications Agency, and Naval Research Lab. Requests from universities, industries, professional groups and journals were also met so far as possible.

(3) J. Gilsinn continued collaboration with the Information Processing Technology Division in a study, for the Federal Aviation Authority, to improve air traffic designation procedures. Additional schemes for assigning radar-beacon codes to airplane flights were evaluated, and project work was documented. (Reported here for convenience; supported under Project 6505453.)

(4) W.G. Hall continued assistance to the Army Data Field Systems Command relative to a new tactical artillery fire-control system. He also completed collaborative work in a preliminary study of the urban renewal process (at both Federal and local levels) relative to the feasibility of automation of certain Local Planning Agency operations. Also of interest were the improvement of data flow between HUD and the LPA's, and the quality and relevance of data at both levels. (Reported here for convenience; supported under Projects 6505425 and 4004110 respectively.)

(5) R. Traub utilized ring theory to construct an example of a stationary ergodic process which is not a function of any finite Markov chain. He studied paradigms of certain goal-seeking processes, and also analyzed the optimization of certain queuing situations suggested by air-traffic-control contexts.

(6) A.J. Goldman completed service as Vice-Chairman of the Operations Research Society of America's Transportation Science Section, and continued as Associate Editor of the associated journal. He served on ORSA's Lanchester Prize Selection Committee, and has organized a session on "Systems Analysis in the Federal Government" for the Spring 1971 National Meeting of ORSA.

Publications

- (1) R.H. Jordan, (Div. 431), J. Gilsinn, A.J. Goldman et al. Systems analysis of inland consolidation centers for marine cargo. NBS Technical Note 530 (11/70).
- (2) A.J. Goldman. Systems analysis and urban problems (discussion). Pp. 93-103 in Systems Analysis for Social Problems, A. Blumstein, M. Kamrass and A.B. Weiss (ed.), Washington Operations Research Council, Washington, D.C. (1970).
- (3) A.J. Goldman. The adequacy of management science technology for non-military applications in the Federal government. To appear in Proc., Amer. Soc. Public Admin. Workshop on Management Science in the Federal Government (11/69).
- (4) W.A. Horn. Some fixed point theorems for compact maps and flows in Banach spaces. Trans. Amer. Math. Soc. 149 (1970), 391-404.
- (5) W.A. Horn. Convex homotopy. Submitted to a technical journal.
- (6) P.R. Meyers. Contractive semigroups and uniform asymptotic stability. Journal of Research NBS 74B (1970), 115-120.
- (7) P.R. Meyers. Contractifiable semigroups. Journal of Research NBS 74B (1970), 315-322.

COMBINATORIAL METHODS

Task 205-12-2050152

Origin and Sponsor. NBS

1540-11

Authorized 12/30/60

Manager: A.J. Goldman

Full task description: October-December 1964 issue, p.3; April-June 1962, p.15

(1) J. Gilsinn and C. Witzgall (Boeing Scientific Research Labs) continued documentation on the comparison of shortest-path algorithms.

(2) A.J. Goldman continued studies relating to the optimal location of facilities in a region. He showed that if a subregion both generates sufficiently much of the total flow, and admits entry via prescribed "gateways" without excessive circuitry, then it both contains near-optimal locations, and has all (strictly) optimal locations "not too far" from it.

(3) W.A. Horn studied several problems concerning optimal routings and coverings in trees (connected acyclic networks).

Publications

- (1) J. Edmonds and O. Shisha. Acute bijections. To appear in J. Combinatorial Theory.
- (2) A.J. Goldman and C. Witzgall (Boeing Scientific Research Labs). A localization theorem for optimal facility location, Transp. Sci. 4 (1970), 406-409.
- (3) A.J. Goldman. Optimal center location in simple networks. To appear in Transportation Science.
- (4) W.A. Horn. Optimal design of sorting networks. Submitted to a technical journal.
- (5) W.A. Horn. A simple algorithm for minimizing delay (cost) in a sorting(decision) network. Submitted to a technical journal.

LINEAR AND NON-LINEAR PROGRAMMING

Task 205-12-2050153

Origin and Sponsor: NBS

1540-11

Authorized 12/30/60

Manager: W.G. Hall

Full task description: October-December 1960 issue, p.3

Status: CONTINUED.

(1) W.G. Hall and P. Saunders "polished", debugged, and documented a subroutine for the ordinary simplex method. Modifications to the earlier version were primarily to improve the user orientation, and included simplification of the calling sequence, provision for a variety of optional outputs, and redefinition of storage. The code is core-limited and will handle problems with less than 44,000 matrix entries. Work on user-oriented subroutines for both the revised simplex method and a quadratic programming method are under way. (Largely supported under Project 2053587, funded by the NBS Computer Services Division.)

(2) A.J. Goldman and P.R. Meyers continued study of a "minimax error" approach to imputing values to incompletely determined data.

Publications

- (1) W.A. Horn. Some recent theoretical work on accessibility in transportation systems. NBS Report 10 500 (12/70).
- (2) W.A. Horn. Optimal container inventory and routing. To appear in Transportation Science.
- (3) J. Levy and M.H. Pearl. A comparison of control policies for an intersection of two traffic streams. NBS-NECTP Working Paper No. 16 (9/70).
- (4) C. Witzgall (now of Boeing Scientific Research Labs). On complementary polar conical sets. Journal of Research NBS 74B (1970), 99-113.

OPERATIONS RESEARCH SERVICES FOR TECHNICAL ANALYSIS DIVISION

Task 205-12-2050586

Origin: NBS (Div. 431)
Sponsor: NBS, various other agencies
Manager: A.J. Goldman

Authorized 7/15/70

Objective: This project, set up for cost-accounting purposes, covers collaborative and supporting activities for a number of projects in the Technical Analysis Division (Div. 431).

Background: The pattern of joint work by the Operations Research Section (205.02) with the Technical Analysis Division (431) has shifted from a few larger activities, for which individual Division 205 projects could be set up, to a greater number of smaller tasks, requiring the present project for accounting purposes.

Status: NEW

(1) Project 4314427: L.S. Joel (project leader) along with A.J. Goldman, W.A. Horn, J. Levy, M.H. Pearl and R. Traub participated in this study for the FAA, which explored approaches to evaluating the effects of "VFR towers" on flow and safety at medium-activity airports. Principal outputs of the first phase were: (a) a mathematical model to help study a tower's role in reducing delay by permitting pilots to exploit "no conflicting traffic ahead" information; (b) a statistical analysis using a modified sign test, by J. Filliben (205.03), of the collision rates at tower and non-tower airports; and (c) development of a computer program to calculate a pilot's time-varying field of visibility, as a step toward assessing his need for additional safety-related information supplyable by a tower.

(2) Project 4314569: J. Gilsinn (project leader) along with A.J. Goldman, W.A. Horn, D. Klavan, J. Levy and M.H. Pearl participated in this study for the FAA, which continued previous work on capacity and delay estimation for airport runways and runway-complexes at large airports. A simulation model (DELCAP), especially tailored for the efficient estimation of throughputs and delays at airports, was developed and programmed. A previous capacity model for a stream of arrivals at a single runway was further elaborated and analyzed (this required extending existing asymptotic treatments of Markov renewal processes), and applied to short-takeoff-and-landing (STOL) aircraft. The capacity model was extended to a dual-use runway, and the theoretical foundations were laid for its application to more complex configurations.

(3) Project 4314549: J. Gilsinn and A.J. Goldman participated in this study for HUD, to aid in estimating the consequences of transport changes for concentrated urban-activity areas. Gilsinn examined algorithms for finding undominated multi-attribute paths in networks, and also joined in developing a model to produce plausible patterns of truck movements consistent with available data.

(4) Project 4314553: J. Gilsinn, A.J. Goldman and J. Lagarias are participating in this study to arrive at modal flow estimates for the Department of Transportation's National Network Simulation. A minimax error estimation approach developed under Project 2050153 is being applied to estimate origin-to-destination pipeline flow volumes. A new traffic assignment algorithm for congestion-prone networks (developed at Johns Hopkins U. under an NBS contract) received initial computer implementation.

(5) Project 4314561: P. Saunders continued participation in this development of a simulation (SARSIM) of the Coast Guard's search and rescue operations, contributing to model modification, computer implementation, and documentation.

(6) Project 4314542: J. Gilsinn and W.A. Horn are participating in this study, to automate the Interstate Commerce Commission's tracing of shortest paths in the U.S. rail network as an aid in rate evaluation.

(7) Project 4310900: A.J. Goldman participated in a number of project and document reviews for the sponsoring division.

(8) Under various project numbers, W.G. Hall lectured on linear programming to several groups (Civil Service Commission training courses, General Accounting Office staff, etc.).

Publications

- (1) J. Gilsinn and R. Ku (Div. 431). A model to simulate truck movements in lower Manhattan. NBS Report 10 358 (11/70).
- (2) A.J. Goldman. A capacity concept for runway and final-approach path airspace. Navigation 17 (1970), 253-259.

3. PROBABILITY AND MATHEMATICAL STATISTICS

RESEARCH IN PROBABILITY AND MATHEMATICAL STATISTICS

Task 20503-12-2050131/63-1259
6030-11

Origin: NBS
Manager: Joan Raup Rosenblatt
Full task description: July - December 1962

Authorized 10/1/62

Status: CONTINUED. Janace A. Speckman, in collaboration with J. M. Cameron (Office of Measurement Services) and W. H. Clatworthy (State University of New York at Buffalo), has continued work on the preparation for publication of the revised and expanded version of "Tables of Partially Balanced Designs with Two Associate Classes" by Bose, Clatworthy and Shrikhande. Professor Clatworthy completed most of the introduction and, in collaboration with Morris Newman, settled some of the open questions about multiplicity of solutions (up to isomorphism) for certain designs. Miss Speckman determined the nature of the duals of some of the tabled designs.

Roy H. Wampler has continued his study of the accuracy of linear least squares computer algorithms. A number of ill-conditioned problems have been run on (1) the OMNITAB program which uses a classical Gram-Schmidt algorithm (with reorthonormalization), (2) A FORTRAN program using the modified Gram-Schmidt algorithm of Björck, and (3) a FORTRAN program using the Householder transformation algorithm of Björck and Golub. The latter two programs, both of which use an iterative refinement scheme involving both coefficients and residuals, generally obtained equivalent accuracy. In some problems this accuracy was appreciably better than that of OMNITAB.

Publications:

- (1) The percent point function. James J. Filliben. Submitted to a technical journal.
- (2) An author and permuted title index to selected statistical journals. Brian L. Joiner, N. F. Laubscher (National Research Inst. for Math. Sciences, South Africa), Eleanor S. Brown, and Bert Levy (Harry Diamond Labs., U. S. Army). NBS Special Publication 321, September 1970.
- (3) Some properties of the range in samples from Tukey's symmetric lambda distributions. Brian L. Joiner and Joan R. Rosenblatt. To appear in J. Amer. Statist. Assoc.
- (4) Analysis of information -- An alternative approach to the detection of a correlation between the sexes of adjacent sibs in human families. H. H. Ku. To appear in Biometrics.
- (5) A report on the accuracy of some widely used least squares computer programs. Roy H. Wampler. J. Amer. Statist. Assoc., Vol. 65 (1970), pages 549-565.
- (6) On the analysis of multi-dimensional contingency tables. H. H. Ku, R. Varner and S. Kullback (G.W.U.). To appear in Journal of the American Statistical Association.

DEVELOPMENT OF "OMNITAB"

Task 20503-12-2050131
6030-11

Origin and Sponsor: NBS
Managers: David Hogben, Sally T. Peavy
Full task description: July - December 1968

Authorized 11/1/68

Status: CONTINUED. David Hogben, Sally T. Peavy, Ruth N. Varner, and Shirley G. Bremer continued work on the documentation of the OMNITAB II computing system. A complete parcel was released to the National Technical Information Service for sale to the public. The parcel, described in NBS Magnetic Tape 1, consists of a magnetic tape and suitable documentation. The tape contains four files consisting of the master program, data for test problems, information for implementing the system, and test results. The documentation consists of four publications which contain the source listing of the master program, a guide for implementing OMNITAB II, test problems and results, and a user's manual. The documentation is available, separately, from the Government Printing Office. The documentation is complete, except for PART C of the manual. Preprints of PART A (Beginner's OMNITAB) and PART B (The OMNITAB Computing System) of the manual were distributed to users with newsletters 7 and 8, respectively. The entire documentation was prepared using computers. A terminal with text-editing capability was used to prepare camera-ready copy of all text material from start to finish and computer output was prepared with computer assisted photo typesetting.

Publications:

- (1) OMNITAB II Magnetic Tape and Documentation Parcel. David Hogben, Sally T. Peavy and Ruth N. Varner. NBS Magnetic Tape 1, October 1970. National Technical Information Service.
- (2) Test Problems and Results for OMNITAB II. Ruth N. Varner and Sally T. Peavy. To appear as NBS Technical Note 551, October 1970.
- (3) A Systems Programmer's Guide for Implementing OMNITAB II. Sally T. Peavy, Ruth N. Varner and Shirley G. Bremer. NBS Technical Note 550, November 1970.
- (4) Source Listing of OMNITAB II Program. Sally T. Peavy, Ruth N. Varner and David Hogben. To appear as NBS Special Publication 339, December 1970.

4. STATISTICAL ENGINEERING SERVICES
COLLABORATION ON STATISTICAL ASPECTS OF
NBS RESEARCH AND TESTING

Task 13911-612050950/51-1
9500-11

Origin: NBS

Authorized 7/1/50

Managers: H. H. Ku, J. R. Rosenblatt

Full task description: July - September 1950 issue, p. 60

Status: CONTINUED. This is a continuing project involving cooperation with other Bureau scientists on the statistical aspects of their investigations. These services vary from short (one-hour) sessions to extended collaborations involving several man-months; and are concerned primarily with statistical design of experiments, analysis and interpretation of data, and the use of computers in statistical analysis of data. Typical examples of the services performed are the following.

Brian L. Joiner has been collaborating with John Dean and Jim Brennan (Cryogenic Metrology Section, Cryogenics Division) on the evaluation of cryogenic flow meters and the simultaneous evaluation of the cryogenic flow facility. The evaluation has provided a good example of the non-standard statistical situations that are virtually always encountered in the design and analysis of real experiments.

Brian L. Joiner and Peter V. Tryon are collaborating with Glen Engen, Manley Weidman, and Ralph Desch (Active Standards Section, Electromagnetics Division) toward evaluation of the "power equation" method of calibrating bolometer mounts that are used for making radio frequency electrical power measurements. During a series of experiments some of the factors that affect systematic errors and imprecision have been identified.

Joan R. Rosenblatt has collaborated with Arthur I. Rubin (Applied Acoustics and Illuminations Section, Building Research Division) in the analysis of paired comparison experiments that were conducted to study the measurement of relative "unpleasantness" of different types of automobile tires with respect to noise. Preference judgments are made for pairs of 5-second tape-recorded sounds. The first series of experiments was based on noise recordings made with tires running on a laboratory endurance wheel. These results have been correlated with results from a second experiment based on noise recordings made as automobiles coasted by a microphone set up near a highway (closed to other traffic). The derived preference scores for tires at various speeds are related to physical measurements of noise (peak value, dB(A) scale).

David Hogben, using OMNITAB, analyzed data for W. C. Wolfe (Building Research Division) on the bond strength (p.s.i.) of overlay to cement mortar cubes. Two treatments, clean and greasy, were applied to five different systems.

H. H. Ku collaborated with John K. Taylor and Ernest E. Hughes (Microchemical Analysis Section, Analytical Chemistry Division) in the certification of the Standard Reference Material SRM 1625, sulfur dioxide permeation tubes designed for the calibration of air pollution monitoring apparatus. Each tube was individually calibrated over the range of 20°C to 30°C. A group of these tubes will be maintained at NBS as reference standards.

Joan R. Rosenblatt served on a committee of NBS staff members that conducted a study of the role of the Bureau in, and its relation to, the nation's private voluntary standardization organizations (principally the American National Standards Institute and the American Society for Testing and Materials). She chaired a subcommittee that planned and executed a survey of NBS staff members who participate in the work of voluntary standardization committees.

STATISTICAL SERVICES

Task 20503-40-2050132/58-346
5040-11

Origin: Various Agencies

Authorized 3/31/58

Sponsor: NBS

Manager: J. R. Rosenblatt

Full task description: January - March 1958 issue, p. 45

Status: CONTINUED. This is a continuing project which involves providing, upon request, statistical services to other governmental agencies, universities, industrial organizations, and other non-governmental agencies. Approximately 30 such requests are handled per month ranging from short conferences to collaboration involving several days work.

Upon request of Dr. Henry J. Pratt, Biophysics Laboratory, Edgewood Arsenal, Harry Ku analyzed wound severity data of about 400 servicemen injured by M-26 grenades in Vietnam summarized as 3- and 4-way contingency tables. An interesting feature displayed by the data is the entirely different patterns of injuries exhibited by the Army and by the Marines. The effects of protection of body armour and helmets, however, were not clearly demonstrated.

Peter V. Tryon is consulting with J. H. Allen (National Oceanographic and Atmospheric Administration Magnetic Observatory) on plans to evaluate the long-term stability of an experimental gradiometer for use in geologic observations (e.g., earthquake prediction). The initial problems are those of data collection and sampling rates.

Publications:

- (1) Randomization and the draft lottery. Joan R. Rosenblatt and James J. Filliben. To appear in Science.

RESEARCH IN NUMERICAL ANALYSIS AND RELATED FIELDS

Task 20501-12-2050110/55-55

1540-11

Origin: NBS
 Manager: Morris Newman
 Full task description: July - September 1954 issue, p. 1

Authorized 8/29/54

Status: CONTINUED. M. Newman has shown that if the k arithmetic progressions $\{n_i x + a_i, x \geq 0\}$, $1 \leq i \leq k$, form a partition of the non-negative integers, and if n is the maximum of n_1, n_2, \dots, n_k , then n occurs at least p times among the n_i , where p is the least prime dividing n .

Let x, y be generators of the finite group G such that $x^p = y^q = (xy)^n = 1$, where p, q, n are integers > 1 , $(p, q) = 1$, and n is the true order of xy . Then if $\mu = nt$ is the order of G , M. Newman has shown that $n \leq pq t^p$. This result is used to show that a Fuchsian group of genus 0 generated by 2 elliptic elements of coprime order and with 1 parabolic class possesses only finitely many normal subgroups having a given number of parabolic classes.

M. Newman has determined the genus of certain groups of linear fractional transformations, and has shown the connection between this and the binary quadratic form class number. As a consequence, all hyperelliptic subgroups of the modular group of a certain type were determined.

With M. Newman, J. Lehner is investigating the representations of the triangle groups by subgroups of $SL(2, \mathbb{C})$. Questions of reality and faithfulness have been settled. There remains the problem of discreteness.

K. Goldberg continued to compile tables for a forthcoming booklet on the elementary combinatorial numbers: binomials, Stirling numbers, Bernoulli and Euler numbers, various multinomials and partitions.

F.W.J. Olver has constructed a new error theory for the method of stationary phase and made applications to a number of representative examples.

R. Merris and W. Watkins proved a number of theorems for group algebras. Applying a standard representation, they obtained new theorems for symmetry classes of tensors.

R. Merris considered the following question: Let $A = (A_{ij})$ be an mn -square partitioned positive semidefinite Hermitian matrix, where A_{ij} is an n -square submatrix of A , $1 \leq i, j \leq m$. For what functions f_1, f_2 taking n -square matrices to k -square matrices is it true that the nk -square partitioned matrix $(f_1(A_{ij})) - (f_2(A_{ij}))$ is positive semidefinite Hermitian? A large class of pairs of functions was found to have this property.

Publications:

- (1) Normal subgroups of the modular group. L. Greenberg and M. Newman. J. of Research NBS, 74B, No. 2, 121-123(1970).
- (2) Some results on solvable groups. L. Greenberg and M. Newman. Arch der Math., Vol. 21, No.4, pp. 349-352(1970).
- (3) Bounded matrix groups. M. Newman and S. Pierce. To appear in the Journal of Linear Algebra.
- (4) On the Smith normal form. M. Newman. To appear in the J. of Research, NBS.
- (5) Units in cyclotomic number fields. M. Newman. To appear in J. Reine Angew Math.
- (6) A dominance theorem for partitioned hermitian matrices. R. Merris. Submitted to a technical journal.
- (7) Trace function I. R. Merris. Submitted to a technical journal.
- (8) Elementary divisors of higher degree associated transformations. R. Merris and S. Pierce. Submitted to a technical journal.
- (9) A class of representations of the full linear group. R. Merris and S. Pierce. To appear in J. Algebra.
- (10) Conjecture and theorem on permanents. R. Merris. Submitted to a technical journal.
- (11) An improvement of the Fischer inequality. R. Merris. Submitted to the J. of Research, NBS.
- (12) The Bell numbers and r-fold transitivity. R. Merris and S. Pierce. To appear in the J. Comb. Theory(A).
- (13) Isomorphic symmetry classes of tensors. R. Merris and W. Watkins. Submitted to a technical journal.
- (14) Group algebra ideals and symmetry classes of tensors. R. Merris and W. Watkins. Submitted to a technical journal.
- (15) Monotonicity of positive semidefinite hermitian matrices. R. Merris and S. Pierce. Submitted to a technical journal.
- (16) Multiplicative maps of matrix semigroups over Dedekind rings. S. Pierce. Submitted to a technical journal.
- (17) Orthogonal groups of positive definite multilinear functionals. S. Pierce. To appear in Pacific Jour. of Math.
- (18) Two characterizations of $(A_q(U))^*$. M. Sheingorn. Submitted to a technical journal.
- (19) A property of the triangle groups. J. Lehner. To appear in the J. of Research, NBS.

BIOMEDICAL IMAGE AND LANGUAGE PATTERN PROCESSING

Task 20500-2050404

1550-22

Origin: NBS

Authorized: 1/21/64

Sponsor: National Institutes of Health

Manager: Russell A. Kirsch

Full task description: January-June issue 1964, p.19

Status: CONTINUED. The set of programs available for image processing in the LISP language now provides an almost complete set of image processing and list processing tools. New programs added this period include several assembly language programs for high speed bit manipulation and many LISP level functions.

At the LISP level a complete morphological analyzer enables us to decompose scanned images into many different partitionings of the image field corresponding to covers of a morphological decomposition tree. This program was used to produce resynthesis of several scans of nerve cells. Analyses of structural parts of the images were obtained along with high quality reproductions on an ink jet printer.

A careful metrological analysis of the scanning microscope confirmed that reproducibility of scanning as well as stage positioning is within a single resolution element at the highest magnification customarily used which becomes 0.2×10^{-6} meters in the object plane for scan position and stage position in the z direction, and 0.6×10^{-6} meters for stage position in x and y and for skewness of the scan and stage directions in x and y.

The high quality of the scanned images produced encouraged us to produce 3-dimensional serial section reconstructions from thick (4×10^{-5} meters) tissue sections.

Among equipment developments there was further construction of the optical bench scanning system; connection of a line printer to the PDP-8; completion of construction of scan axis drivers; and installation of a TV monitor for remote microscope viewing.

SCANNING MICROSCOPE PROCESSING

Task 20500-2050408

1550-22

Origin: NBS

Authorized: 6/18/68

Sponsor: National Institutes of Health

Manager: Russell A. Kirsch

Full task description: July-December issue 1968, p.14

Status: CONTINUED. Progress during this period included items mentioned under 2050404 as well as the following.

Some help was given in the development of a cell population dynamics model for solid tumor growth.

Scans were made and analyzed for white blood cells to study some nuclear fine structure problems.

CHEMICAL BIOLOGICAL INFORMATION PROCESSING

Task 20500-2050410

1550-22

Origin: NBS

Authorized: 6/27/68

Sponsor: National Institutes of Health

Manager: Russell A. Kirsch

Full task description: July-December issue 1968, p.14

Status: CONTINUED. Advisory work continued on Chemical Biological Information Handling techniques. Advisory capacity consisted of evaluation of submitted research proposals from various corporations and institutions as well as periodic site visits to review project and research proposals in connection with the development of a Chemical Biological Information Processing system. Studies were continuing of proposals for the development of computer graphics and data management systems for use in pharmacology.

MATHEMATICAL AIDS

Task 20500-40-2050121/57-216

Origin and Sponsor: NBS

Manager: I. A. Stegun

Full task description: July-December 1964 issue, p.4.

Status: CONTINUED. Work continued on providing a library of ASA FORTRAN programs for special functions. It is planned that this library in its aims will parallel the library of elementary functions-supply functional values within machine accuracy and bounds. Limiting values of the functions will be supplied. The computing methods will be given in sufficient detail for easy possible recoding for specialized computers. Efforts are being directed to those functions not well covered in available programs and of more general need in scientific computation. Presently a paper is being prepared on the computation of the exponential integral. Comments on the prior paper on the error, probability and related functions will be taken into account.

Consultations continued at the rate of about eight per month with staff of NBS, other government agencies, industry and universities. Topics covered included computer programs and tables of special functions, matrix computations, computing techniques and pitfalls.

Corrections were submitted for the 9th printing of AMS 55- the Handbook of Mathematical Functions. Checking continued on questionable formulas and values.

Publications:

- (1) Mathematics Bibliography. Irene A. Stegun and Constance Carter (Library of Congress). To appear as Section 1A of the American Institute of Physics Handbook, 3rd Edition.
- (2) Automatic Computing Methods for Special Functions. Part 1. Error, Probability and Related Functions. Irene A. Stegun and Ruth Zucker. J. of Research NBS, 74B, 211-224 (1970).

Lectures and Technical Meetings

Papers and Invited Talks

Presented by Members of the Staff at Meetings of Outside Organizations

GOLDMAN, A. J. Modal Split. George Washington University (Course in Traffic Flow Theory and Transportation Analysis). July 3.

GOLDMAN, A. J. Optimal Center Location in Simple Networks. Fall 1970 National Meeting of Operations Research Society, Detroit, October 30.

HABER, S. The Use of the Theory of Numbers to Design Algorithms for the Numerical Evaluation of Integrals. University of Maryland, Catonsville, Md. November 18, and November 25.

HALL, W. G. Linear Programming: Some Problems and Their Solutions. Atlanta, Georgia. October 17.

HOGBEN, D. Recent Developments in OMNITAB II. American Statistical Association, Detroit, Michigan. December 27.

JOINER, B. L. OMNITAB - And An Example in Data Analysis. Gordon Conference on Statistics in Chemistry and Chemical Engineering, New Hampton, N. H. July 9.

JOINER, B. L. The Computing Needs of the Statistical Consultant. 14th Annual Technical Conference, Chemical Division, Amer. Soc. for Quality Control, and Section on Physical and Engineering Sciences, Amer. Statist. Assoc. Rochester, N.Y., October 8.

JOINER, B. L. Panel Discussion on "Computers: Creative Use in the 70's". Amer. Soc. for Quality Control and American Statist. Assoc., Rochester, N. Y. October 8.

KRAFT, S. R. Existence of a Solution to a Cauchy Problem for a Linear Transport Equation. Fall SIAM Meeting, Boston, Mass. October 12.

KU, H. H. Recent Developments in Contingency Table Analysis. Washington Statistical Society, October 29.

NEWMAN, M. Results on Solvable Groups. University of Arizona, Tuscon, Arizona. October 29.

NEWMAN, M. Solving Equations Exactly. University of Maryland, College Park, Maryland. November 11.

SADOWSKI, W. Use of Symbolic Methods in Computational Physics. University of Nancy, Nancy, France. August 4.

WAMPLER, R. H. An Evaluation of Linear Least Squares Programs. Amer. Soc. for Quality Control and American Statist. Assoc., Rochester, N. Y. October 9.

WAMPLER, R. H. Panel Discussion on "Computer Statistical Packages: Present and Future". Washington Statistical Society, October 14.

WAMPLER, R. H. A Report on the Accuracy of Some Widely Used Least Squares Computer Programs. Washington Section, American Society for Quality Control. November 10.

Applied Mathematics Division Lectures

SHISHA, Oved (Aerospace Research Laboratories, Wright-Patterson Air Force Base, Ohio)
Approximation by Landau Polynomials. November 20.

Mathematical Analysis Section Meeting

BRIGHT, Herbert S. (Computation Planning, Inc.) Significance Arithmetic Experimental Package.
November 23.

Applied Mathematics Division Seminar

KAYEL, Robert G. (Computer Center, Stevens Institute of Technology, Hoboken, New Jersey).
A Statistical Approach to Numerical Linear Algebra. November 9.

Applied Mathematics Division Expository Seminar Series

ROBERTSON, Baldwin (Office of the Director, Institute for Basic Standards). Classical Mechanics and
Quantum Statistical Mechanics. September 16.

RUBIN, Robert J. (Office of the Director, Institute for Materials Research). Brownian Motion,
Thermal Conductivity, and Harmonic Crystals. October 21.

SENGERS, J. V. (Institute for Molecular Physics, University of Maryland and Heat Division,
Institute for Basic Standards). Integral Equations in the Theory of Transport
Properties for Moderately Dense Gases. November 17.

MOUNTAIN, Raymond D. (Statistical Physics Section, Heat Division, Institute for Basic Standards).
Thermodynamics - A Statistical Mechanical Construction. December 16.

Mathematical Statistics Seminar

GASTWIRTH, Joseph L. (Johns Hopkins Univ.) The Effect of Dependence on Common Statistical Procedures.
July 8.

Statistics Seminar

HALL, W. B. (C.S.I.R.O., Australia) Cyclic Designs in Experimentation. October 12.

Publication Activities

1.0 PUBLICATIONS THAT APPEARED DURING THIS PERIOD

1.2 Manuals, Bibliographies and Indices

An Author and Permuted Title Index to Selected Statistical Journals. Brian L. Joiner, N. F. Laubscher (National Research Inst. for Math. Sciences, South Africa), Eleanor S. Brown, and Bert Levy (Harry Diamond Labs., U. S. Army). NBS Special Publication 321, September 1970.

1.3 Technical Papers

A Capacity Concept for Runway and Final-Approach Path Airspace. A. J. Goldman. Navigation 17, 253-259 (1970).

Normal Subgroups of the Modular Group. L. Greenberg and M. Newman. J. of Research NBS, 74B, No. 2, 121-123 (1970).

Some Results on Solvable Groups. L. Greenberg and M. Newman. Arch der Math., Vol. 21, No. 4, pp. 349-352 (1970).

Some Fixed Point Theorems for Compact Maps and Flows in Banach Spaces. W. A. Horn. Trans. Amer. Math. Soc. 149, 391-404 (1970).

Contractive Semigroups and Uniform Asymptotic Stability. P. R. Meyers. J. of Research NBS, 74B, 115-120 (1970).

Contractifiable Semigroups. P. R. Meyers. J. of Research NBS, 74B, 315-322 (1970).

Automatic Computing Methods for Special Functions. Irene A. Stegun and Ruth Zucker. J. of Research NBS, 74B, No. 3, 211-223 (1970).

A Report on the Accuracy of Some Widely Used Least Squares Computer Programs. Roy H. Wampler. J. Amer. Statist. Assoc., Vol. 65, 549-565 (1970).

On Complementary Polar Conical Sets. C. Witzgall (now of Boeing Scientific Research Labs.). J. of Research NBS, 74B, 99-113 (1970).

1.4 Notes

Systems Analysis and Urban Problems (Discussion). A. J. Goldman. Systems Analysis for Social Problems. A. Blumstein, M. Kamrass and A. B. Weiss (ed.), Washington Operations Research Council, Washington, D. C. (1970), pp. 93-103.

A Localization Theorem for Optimal Facility Location. A. J. Goldman and C. Witzgall (Boeing Scientific Research Labs.). Transportation Science 4 (1970), 406-409.

Systems Analysis of Inland Consolidation Centers for Marine Cargo. R. H. Jordan, (Div. 431), J. Gilsinn, A. J. Goldman et al. NBS Technical Note 530, November 1970.

A Systems Programmer's Guide for Implementing OMNITAB II. Sally T. Peavy, Ruth N. Varner and Shirley G. Bremer. NBS Technical Note 550, November 1970.

1.5 Books

Convexity and Optimization in Finite Dimensions, I. J. Stoer (U. Wurzburg) and C. Witzgall (now of Boeing Scientific Research Labs.). Springer-Verlag ("Grundlehren", V. 163), New York, 1970.

1.6 Magnetic Tape

OMNITAB II Magnetic Tape and Documentation Parcel. David Hogben, Sally T. Peavy and Ruth N. Varner. NBS Magnetic Tape 1, October 1970. National Technical Information Service.

2.0 MANUSCRIPTS IN THE PROCESS OF PUBLICATION

2.3 Technical Papers

The Percent Point Function. James J. Filliben. Submitted to a technical journal.

Optimal Center Location in Simple Networks. A. J. Goldman. To appear in Transportation Science.

Optimal Design of Sorting Networks. W. A. Horn. Submitted to a technical journal.

A Simple Algorithm for Minimizing Delay (cost) in a Sorting (decision) Network. W. A. Horn. Submitted to a technical journal.

Analysis of Information -- An Alternative Approach to the Detection of a Correlation Between the Sexes of Adjacent Sibs in Human Families. H. H. Ku. To appear in Biometrics.

On the Analysis of Multi-Dimensional Contingency Tables. H. H. Ku, R. Varner and S. Kullback (G.W.U.). To appear in J. of the American Statistical Association.

A Property of the Triangle Groups. J. Lehner. To appear in the J. of Research, NBS.

Conjecture and Theorem on Permanents. R. Merris. Submitted to a technical journal.

An Improvement of the Fischer Inequality. R. Merris. Submitted to the J. of Research, NBS.

Monotonicity of Positive Semidefinite Hermitian Matrices. R. Merris and S. Pierce. Submitted to a technical journal.

The Bell Numbers and r -fold Transitivity. R. Merris and S. Pierce. To appear in the J. Comb. Theory (A).

Isomorphic Symmetry Classes of Tensors. R. Merris and W. Watkins. Submitted to a technical journal.

On the Smith Normal Form. M. Newman. To appear in the J. of Research, NBS.

Units in Cyclotomic Number Fields. M. Newman. To appear in J. Reine Angew Math.

Randomization and the Draft Lottery. Joan R. Rosenblatt and James J. Filliben. To appear in Science.

2.4 Notes

The Adequacy of Management Science Technology for Non-Military Applications in the Federal Government. A. J. Goldman. To appear in Proc. Amer. Soc. Public Admin. Workshop on Management Science in the Federal Government (11/69).

Test Problems and Results for OMNITAB II. Ruth N. Varner and Sally Peavy. To appear as NBS Technical Note 551, October 1970.

2.5 Books

Source Listing of OMNITAB II Program. Sally T. Peavy, Ruth N. Varner and David Hogben. To appear as NBS Special Publication 339, December 1970.

NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards¹ was established by an act of Congress March 3, 1901. The Bureau's overall goal is to strengthen and advance the Nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the Nation's physical measurement system, (2) scientific and technological services for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau consists of the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Center for Computer Sciences and Technology, and the Office for Information Programs.

THE INSTITUTE FOR BASIC STANDARDS provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of a Center for Radiation Research, an Office of Measurement Services and the following divisions:

Applied Mathematics—Electricity—Heat—Mechanics—Optical Physics—Linac Radiation²—Nuclear Radiation²—Applied Radiation²—Quantum Electronics³—Electromagnetics³—Time and Frequency³—Laboratory Astrophysics³—Cryogenics³.

THE INSTITUTE FOR MATERIALS RESEARCH conducts materials research leading to improved methods of measurement, standards, and data on the properties of well-characterized materials needed by industry, commerce, educational institutions, and Government; provides advisory and research services to other Government agencies; and develops, produces, and distributes standard reference materials. The Institute consists of the Office of Standard Reference Materials and the following divisions:

Analytical Chemistry—Polymers—Metallurgy—Inorganic Materials—Reactor Radiation—Physical Chemistry.

THE INSTITUTE FOR APPLIED TECHNOLOGY provides technical services to promote the use of available technology and to facilitate technological innovation in industry and Government; cooperates with public and private organizations leading to the development of technological standards (including mandatory safety standards), codes and methods of test; and provides technical advice and services to Government agencies upon request. The Institute also monitors NBS engineering standards activities and provides liaison between NBS and national and international engineering standards bodies. The Institute consists of the following technical divisions and offices:

Engineering Standards Services—Weights and Measures—Flammable Fabrics—Invention and Innovation—Vehicle Systems Research—Product Evaluation Technology—Building Research—Electronic Technology—Technical Analysis—Measurement Engineering.

THE CENTER FOR COMPUTER SCIENCES AND TECHNOLOGY conducts research and provides technical services designed to aid Government agencies in improving cost effectiveness in the conduct of their programs through the selection, acquisition, and effective utilization of automatic data processing equipment; and serves as the principal focus within the executive branch for the development of Federal standards for automatic data processing equipment, techniques, and computer languages. The Center consists of the following offices and divisions:

Information Processing Standards—Computer Information—Computer Services—Systems Development—Information Processing Technology.

THE OFFICE FOR INFORMATION PROGRAMS promotes optimum dissemination and accessibility of scientific information generated within NBS and other agencies of the Federal Government; promotes the development of the National Standard Reference Data System and a system of information analysis centers dealing with the broader aspects of the National Measurement System; provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world, and directs the public information activities of the Bureau. The Office consists of the following organizational units:

Office of Standard Reference Data—Office of Technical Information and Publications—Library—Office of Public Information—Office of International Relations.

¹ Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.

² Part of the Center for Radiation Research.

³ Located at Boulder, Colorado 80302.

