Report OEM 1

Survey of STUDIES and COMPUTER PROGRAMMING EFFORTS

for

- RELIABILITY
- MAINTAINABILITY
- SYSTEM EFFECTIVENESS

September 1965

Office of the Director of Defense Research and Engineering

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FOREWORD

This report represents a preliminary, limited survey of efforts under way or recently completed for computer programming or techniques that are adaptable to computer operations in the areas of system analysis for reliability, maintainability, availability, system effectiveness, cost-effectiveness, system simulation, circuit analysis, and failure mode and effects analysis.

The rapid change in technology and quick obsolesence of the material in this survey has lead to the printing of the report despite the survey limitations. The information is being provided for possible use by the Defense Department and Industry project managers, designers, and any other personnel such as support specialists in reliability, maintainability, systems analysis, systems effectiveness, computer programming, etc. The data referred to in the survey briefs are intended to reflect available data, techniques, and studies reflecting current technology. The industry contributors take no responsibility in the use of such data, programs and techniques; similarly, these data have no contractual status on the part of the Department of Defense.

Recipients are solicited to offer information similar to that contained in the survey briefs for similar studies, efforts and available computer programs. Based on the number of new project briefs submitted, consideration will be given to the issuance of an expanded version of this report. Please send your project briefs to the Office of the Director of Defense Research and Engineering, Office of Assistant Director (Engineering Management), Pentagon, Washington, D. C. (20301).

It is preferred that the project briefs be limited to one page and be prepared in the same format as those contained herein. In forwarding your data, please include your company or agency approval for release to print by the Government with the purpose of making the data available to both industry and government personnel.

James W. Roach

James W. Roach
Assistant Director

SURVEY OF STUDIES AND COMPUTER PROGRAMMING EFFORTS FOR RELIABILITY, MAINTAINABILITY AND SYSTEM EFFECTIVENESS

Survey of efforts under way or recently completed for computer programming or techniques that are adaptable to computer operations in the areas of system analysis for reliability, maintainability, availability, system effectiveness, cost-effectiveness, system simulation, circuit analysis, and failure mode and effects analysis.

The main sources of information for this survey were Navy Applied Science Laboratory, Bureau of Ships, Air Force Rome Air Development Center, ARINC Research Corporation, Autonetics Division of North American Aviation. Other activities queried were Office of Naval Research, Army Research Office, and National Bureau of Standards.

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SECTION I - SURVEY OF MATHEMATICAL AND SIMULATION MODELS

Title: Survey of Mathematical and Simulation Models as Applied to Weapon System Evaluation

Abstract: A survey of 32 organizations (DoD Contractors) resulting in 56 abstracts of models identifying name of agency having done study, name of sponsoring agency, description of model and references to documentation.

Sponsor: Air Force Aeronautical Systems Division

Contract: AF 33(616)-7317

Contractor: University of Michigan

Status: Completed

Reports: ASD Technical Report 61-276 dated October 1961 (Defense Documentation Center No. 269-235)

SECTION II - RELIABILITY PREDICTION

Title: System Reliability Prediction by Function

Abstract: Phase I. A technique was developed for predicting the reliability of ground electronic systems prior to the actual design of the systems. Reliability data from 51 systems representing over two million system operating hours were analyzed to develop prediction equations based on generalized system parameters such as complexity, power consumption, and frequency. The prediction equations are of the form $\ln \hat{\theta}$ equals b_o plus b_1X_1 plus b_2X_2... plus b_nX_n, where $\hat{\theta}$ is the predicted system mean life and the X_i are measures of equipment characteristics. The coefficients b_i were determined by multiple regression analysis. Approximately 40 possible characteristics were investigated. The technique also allows the estimation of confidence intervals for $\ln \hat{\theta}$. With the use of new data, the prediction technique can be updated at any time by the computation of new regression equations.

Phase II. As a follow-on effort the techniques developed for Phase I (ground electronic) will be expanded for use relative to Airborne Electronics and to predict both Reliability and Maintainability in the planning and initial design phases. The techniques will be based on correlations of MTBF and MTTR with the airborne functions of line replaceable units of the B-58 aircraft for which ARINC is presently collecting data. This data will be supplemented by ARINC's library on electronic functions of other aircraft, e.g., B-47, B-52, F-100, F-105 and some Navy aircraft. Phase II started 1 April 1964, and will be completed 4 September 1965.

Note. The importance and greatest value of this "function" prediction technique is in the early feasibility study and design stages.

Sponsor: Air Force, RADC

Contract: Phase I - AF 30(602)-- 2838
Phase II- AF 30(602)-- 3387

Contractor: ARINC Research Corporation

Status: Phase II active

Reports: Computer Program for Phase I predictions included in appendix of report

Computer: IBM-1401/Fortran II

Title: System Reliability Prediction by Function

Abstract: This study consisted of an effort to develop techniques for predicting the reliability of electronic equipments and systems during the early system planning stages. The techniques were to be based on correlation factors which would relate system, equipment or subequipment functions by specific characteristics such as peak power to reliability levels achievable within the existing state of the art.

The correlation studies performed were categorized into three areas: radar, ground communication and data processing. A number of applicable radar and ground communication systems were studied, and definite correlation was found between functional characteristics and actual field MTBF. The results of these correlation studies led to the development of prediction techniques for both the radar and ground communication categories.

Verification of these techniques was accomplished through their application to other systems within the appropriate category and comparison of the resultant predictions with those calculated from actual field data. The satisfactory results obtained led to the conclusion that the prediction techniques were sound.

Sponsor: Air Force, RADC

Contracts: AF30(602)-2687
AF30(602)-3288

Contractor: Federal Electric Corp.

Status: Report 2687 completed FY63
Report 3288 completed FY65

Reports: RADC TDR 63-146
RADC TDR 65-27

Computer: Can be programmed for any general purpose computer

Title: Reliability Prediction - Mechanical Stress/Strength Prediction

Abstract: This effort involves the study and investigation required to refine and reduce to practice the strength/stress interference theory technique for designing to and predicting the quantitative reliability of mechanical parts under fatigue or constant loading. The statistical nature of both the strength and stress indicate that the results of this study will be amenable to computer manipulation.

Sponsor: Air Force (RADC)

Contract: Awarded March 1965

Contractor: University of Michigan

Status: Under way

Report:

Computer:

Title: Reliability Prediction (Mechanical Systems)

Abstract: Evaluation of alternate designs and prediction of inherent reliability utilizing basic failure mechanisms, of parts and materials, related to Service application environments.

Sponsor: Navy BuShips

Contract: NObs-88628

Contractor: American Power Jet Company

Status: Under way

Reports:

Title: Updating of MIL-HDBK-217A "Reliability Stress and Failure Rate Data for Electronic Equipment"

Abstract: An effort to update part failure-rate data and application data used in prediction of Reliability using a part failure rate computation. This does not include parameter drift considerations; it is limited to basic catastrophic failure modes and mechanisms. The prediction computation is not necessarily done by computer but can be for complex systems or circuit configurations.

Sponsor: Navy, BuWeapons (NAD Crane)

Contract: NAD Crane Contract

Contractor: Radio Corporation of America

Status: Completed - May 1965

Reports: Final Product is in process of tri-Service co-ordination

Computer: Not applicable. Data may be put into any general purpose computer.

Title: CRAM (Computerized Reliability Assessment Method)

Abstract: CRAM is a computer method which is used to predict system reliability. It permits the user to proceed in an orderly manner from a complex block diagram of a system whose components may fail in many modes to a final reliability prediction for the system.

Computations which can be almost impossible to carry out manually, become strictly a routine procedure of entering the proper data as program inputs.

To use CRAM, the engineer, having defined the level of detail of the analysis, draws a reliability diagram in an appropriate manner. The diagram is routinely converted into a computer program input. Component failure rates and any modifying factors are also used as inputs to arrive at the desired results.

Note: Principal areas of improvement in the existing program lie in increasing the size and complexity of the systems which can be evaluated, and improving the efficiency of certain sub-routines to reduce computer running time.

Sponsor: NASA, Marshall Space Flight Center

Contract: NAS-8-11087

Contractor: ARINC Research Corporation

Status: Under way

Reports: ARINC Monograph No. 11 by D. E. van Tijn and ARINC Report 294-02-14-444

Computer: IBM 1401, 16K Memory/AUTOCODER

Title: Beam Pattern Degradation (Sonar Arrays)

Abstract: Simulation program for the analysis of sonar transducer arrays to determine performance degradation as a function of inoperative transducer elements. The program defines system mode failures within the framework of the allowable system performance degradation for the applicable mode. A program has been developed for cylindrical arrays and a new contract effort is planned to develop a computer program for application to conformal and planar arrays (extension of AN/SQS-26 model).

Sponsor: Navy, BuShips

Contract: Nobsr-91039

Contractor: Tracor Inc.

Status: The program has been completed for the AN/SQS-23 and AN/SQS-26 Sonars and will be used in the reliability prediction techniques applied to AN/SQS-26 production contracts. Efforts are under way to initiate similar studies in connection with Conformal/Planar Arrays Development Programs.

Reports: Series of Tech. Reports prepared by Tracor Inc. relative to AN/SQS-26

Computer: CDC 3200/CDC-160A(Fortran)

Title: Reliability Simulation Model (APOLLO Mission)

Abstract: A Reliability Simulation Model that simulates the operation of a vehicle for a large number of missions, and determines the number of mission successes and mission failures by the application of a Monte Carlo technique.

In applying the simulation model, logic diagrams are constructed to define the combination of components required to complete each function of each phase of a mission. The failure density distribution for each of these components is obtained from test data or estimated failure rates, and the component time of failure is determined by the application of the Monte Carlo technique.

When mission failures occur, the model becomes a decision-making device, as it determines what form of an alternate mission is to be initiated. The form of alternate mission is a function of the combination of component failures at the time of mission failure. The alternate mission may be a continuation of the mission with lesser mission objectives or a return mission to enhance the safety of the crew. Thus, the model provides the probability of both mission success and crew safety.

The Reliability Simulation Model, while applicable to any form of equipment and/or mission configuration, was designed primarily for the reliability analysis of the APOLLO Lunar Landing Mission.

Sponsor: NASA

Contract: APOLLO Project

Contractor: North American Aviation (Space and Information System Div.)

Status: Active

Reports: Proceedings 10th National Symposium Reliability and Quality Control

Computer: IBM-7094

Title: SOAR-II

Abstract: Special purpose program tailored to the APOLLO mission simulates failures using Monte Carlo technique to evaluate and predict probability of "Mission Success" and "Abort Success." Inputs are both random and fixed and outputs are averages of success probabilities for every 500 trials.

Sponsor: NASA, Office Manned Space Flight

Contract: APOLLO Project

Contractor: General Electric - Tempo

Status: Active

Reports: NASA, OMSF Tech Memo
M-TJ-6300.001 (RA-10)

Computer: Not known

Title: **Mechanised Aircraft Reliability Analysis Model**

Abstract: Method for reliability evaluation of alternate system configurations for selection of an optimum system design and measurement of reliability growth. Computer program for rapid calculation enabling timely decisions and configuration control.

The emphasis is toward a consistent and realistic reliability evaluation that measures the achieved reliability and monitors the reliability growth throughout the development and operational life of airborne systems.

Sponsor: Lockheed - Georgia

Contract:

Contractor:

Status:

Reports: Proceedings 10th National Symposium on Reliability and Quality Control (Page 560)

Computer:

Title: Prediction of Circuit Drift Malfunctions of Satellite Systems

Abstract: The purpose of this study was to evaluate existing statistical analysis methods for determining the probability of malfunction of transistor circuits due to degradation of component part parameters during operating life. Circuit output parameters are expressed as functions of several part parameters characterized by probability density functions, which may be determined from test operation of part samples for the required time.

Analytical results are evaluated by comparison with results obtained from test operation of circuit samples for the required time. Comparison of both the number of drift malfunctions and the distribution of circuit parameters are made. Test sampling error and measurement errors are considered. The results lead to the following conclusions:

- Accurate estimates of the distribution of circuit output parameters - voltage levels and transient response times can be obtained during test operating life.
- The probability of drift malfunction of circuit output parameters during test operating life can be estimated accurately.
- Experience with the reduction of component part test data to derive probability density functions for part parameters suggests that further improvement in accuracy and refinement of analytical methods can be achieved through part tests which are designed specifically to yield statistical analysis data.
- Each of the three analysis methods investigated - combination of distributions, regression, and Monte Carlo - has advantages which merit consideration in any particular application; however, for general use, the Monte Carlo has fewer limitations.

Sponsor: Air Force, RADC

Contract: AF 30(602)-2418,

Contractor: IBM, Owego, New York

Status: Completed 1963

Reports: RADC TDR62-227

Computer:

Title: Mathematical Simulation for Reliability Prediction

Abstract: Phase I. A study program for the development of techniques for predicting the reliability of electronic systems from statistical information about the performance of system components. The problem of determining initial system performance and system performance over a time period, given changes in component characteristics in time, is analyzed. The prediction of the reliability of systems whose performance is measured on a continuous scale and which are subjected to degradation type failures is emphasized. Catastrophic failure models including repair and redundant elements are also discussed.

Phase II. The second phase of the study relates to the transfer functions which have been developed in this phase which are mathematical models of the actual systems to be evaluated. They are used to determine system performance when component characteristics vary from nominal values as a result of (1) manufacturing and handling, (2) degradation due to age, (3) internal and external random stresses. Form of output is magnetic tape and plot.

The circuits analyzed in this report will not only serve as vehicles to substantiate the findings of the Phase I, but will in addition serve as a nucleus for a library of preferred designs with defined lifetime characteristics.

Sponsor: Air Force, RADC

Contract: AF 30(602)-2376,

Contractor: Sylvania Electronic Systems Division

Status: 1960-63 effort, completed

Reports: Phase I, RADC-TR-61-299 "Math Simulation for Reliability Prediction".
Phase II, RADC-TR-63-87 "Transfer Functions in Math Simulation for Reliability Prediction"

Computer: Sylvania Model 9400

SECTION III - MAINTAINABILITY PREDICTION

Title: M Prediction by Function

Abstract: This is a current effort scheduled for completion in September 1965, and being conducted in conjunction with a "System Reliability Prediction by Function" study. It will provide a technique for establishing a quantitative relationship between equipment (LRU) Line Replaceable Unit function, i.e., transmitter, receiver, scope, recorder, data processor, display, etc., in terms of M design characteristics expressed as an influence on MTTR. Such M features as skill level, packaging, accessibility, adjustments, depth of-penetration, etc., will be included. The findings will be organized in a manner convenient for use (math model/equation_ in predicting equipment (LRU) M during planning stages when required function and some performance parameters (weight, volume) only are known and during early design before circuit detail has been decided.

Sponsor: Air Force, RADC

Contract: AF 30(602)-3387

Contractor: ARINC Research Corporation

Status: Under way

Reports:

Computer: IBM 1401/Fortran

Title: OPTIC

Abstract: A mechanization of elemental maintainability design information to translate maintenance source data into maintenance procedural instructions. Iterative process of analyzing maintainability design and the output is a set of procedural maintenance instructions optimized from a time and cost standpoint.

Sponsor: Republic Aviation Corporation

Contract:

Contractor:

Status: Active

Reports:

Computer: General Purpose Digital Computer

Title: Criteria for Discard-at-Failure Maintenance

Abstract: A mathematical model was developed serving as a design decision tool describing the relationships between module size, maintainability, and total resource cost. The model is adaptable for use during early design phases of a development program by minimizing the number of variables and maximizing use of cost factors which are constant. It is flexible to allow for variations in maintenance planning and up-dating of values furnished for the factor constants. The model is capable of defining which of the two alternates, repair-at-failure maintenance or discard-at-failure-maintenance is most economical, and capable of determining the optimum discard-at-failure module part density. Resource costs considered included manpower, materials, facilities, test equipment expenditures at the various maintenance echelons. The model is a difference equation which can be manually applied.

Sponsor: Air Force, RADC

Contract: AF 30(602)-2681,

Contractor: IBM, Owego, New York

Status: 1962-63 effort completed

Reports: AD-405779 (RALC TDR-63-140)

NOTE: See current Validation Effort AF Contract AF30(602)-3336 (P. III-4)

Title: Validation of Criteria for Discard-at-Failure Maintenance

Abstract: The mathematical model developed under previous contract AF-30(602)2681 (see Page III-3) was revised to more exhaustively reflect all pertinent cost and design factors. The finalized mathematical model was validated empirically by comparing actual resource costs for an existing operational equipment design in repairable RAFM (Repair at Failure Maintenance) form with projected resource costs for an identical equipment redesign on paper in accordance with DAFM (Discard at Failure Maintenance) criteria. The results of this work provide definite criteria for judging the relative cost merit of RAFM vs DAFM in a given equipment or system situation.

Sponsor: Air Force, RADC

Contract: AF(30)(602)-336

Contractor: Radio Corporation of America, Camden, New Jersey

Status: Completed July 1965

Reports: RADC-TR-65-214

Computer: In a form to be programmed for any general purpose computer.

Title: Refinement of M Prediction Technique

Abstract: The study has provided a technique for quantifying the relationship between circuit design features and M. Use of empirically derived repair times in conjunction with a circuit design feature diagram provides guidance early in equipment design for selection of circuit configurations which could satisfy a repairability requirement. The technique will also facilitate the evaluation of existing off-the-shelf circuitry to predict the associated repair time and determine the extent of redesign necessary to provide the greatest M improvement. The M design criteria is applicable to all repairable conventional and semi-conductor circuitry found in aerospace and ground electronics. The criteria are graphically presented for ease of application and expressed quantitatively, relating circuit design to malfunction diagnosis, repair, and checkout. It is significant to note that although only 16 basic circuit types were studied, the technique permits the evaluation of MTTR for any circuit employing any combination of the nine basic design features.

Sponsor: Air Force, RADC

Contract: AF 30(602)-3033

Contractor: Vitro Labs, Silver Spring, Maryland

Status: 1963-1964 effort; completed

Reports: AD-610073
RADC-TDR-64-308 "Circuit MTTR as a Function of Design"

Computer:

Title: Maintainability Prediction Program

Abstract: This program implements the prediction technique developed by ARINC Research Corporation. Inputs to the program, in the form of equipment characteristics, are converted by the computer to distributions of active repair times and system down times.

The inputs are typified by such characteristics as numbers of components, flight line replaceable components, spares, test points, and readouts; and failure rates, mission length and maintenance policies. A major advantage of the output is the fact that it is in the form of a distribution rather than a point estimate.

Improvements in the program must be predicated on refinement of the basic prediction technique.

Sponsor: Air Force, WPAFB (AFSC - Dir. Strategic and Tactical)

Contract: AF 33(657)-10594

Contractor: ARINC Research Corporation

Status: Completed

Reports: ARINC Report 267-02-6-420

Computer: IBM 1401 and 7090
Programs available at ARINC for 1401 and at WPAFB for 7090

Title: M Techniques Study

Abstract: Furnishes quantitative measurement of ground electronic system/equipment M through use of a prediction technique which provides an estimate of equipment downtime through measures of M design. Complementary to the prediction technique, design analysis methods were formulated to permit M design selection decisions to be made during equipment development.

Sponsor: Air Force, RADC

Contract: AF 30(602)-2057

Contractor: RCA Service Company, Camden, New Jersey

Status: 1960-63 effort; completed

Reports: RADC TDR-63-85 "Maintainability Technique Study", Vol. I
AD-404899
AD-404898 "Maintainability Engineering", Vol. II

Computer:

SECTION IV - SYSTEMS EFFECTIVENESS

Title: Availability Evaluation Program (NARSE-I)

Abstract: This program permits the efficient repetitive evaluation of the reliability, maintainability or availability of a system as variations are made in failure or repair characteristics, or in system configuration.

Once a reliability block diagram has been established for a system, the program can calculate for any specified time the reliability and/or availability of the system. The failure and repair times for the individual blocks can have exponential normal or log-normal distributions or can be entered as probabilities. The program can handle partial, time dependent, and standby redundancy.

Note: As presently written, this program is limited to evaluation of reliability, maintainability, and availability. Additional effort should be directed toward the inclusion of capability characteristics so that total system effectiveness can also be treated.

Sponsor: Navy, Applied Science Lab, New York

Contract: N-140-(62462) 76790B

Contractor: ARINC Research Corporation

Status: Current. Program available from NASL.

Reports: Report No. 321-01-1-468 of 31 January 1965 (Confidential)

Computer: IBM 1401-16K

Title: System Effectiveness and Design Adequacy

Abstract: Analytical model related to System Effectiveness and Design Adequacy simulation and evaluation. Applicable to aircraft systems with eight or less subsystems and eight or less system functions and assuming no inflight repair; also, unit performances are independent. Printed output states effectiveness as a probability.

Sponsor: Air Force; Aeronautical Systems Division

Contract: AF 33(657)-10594

Contractor: ARINC Research Corporation

Status: Complete for single systems; to be extended

Reports: ARINC Publication 267-01-7-419

Computer: IBM 1401/Fortran II

Title: System Effectiveness Evaluation

Abstract: During the course of ARINC Research Corporation's efforts for WSEIAC, a computer program was developed for employing the System Effectiveness evaluation procedure recommended by Task Group II of WSEIAC.

The basic program provides for analytic combination of the three elements of Effectiveness; i.e., availability, dependability, and capability. (These elements must be represented by vectors or matrices in order to consider the multiple system states which are possible).

For specific systems, variations in the basic program are made. Programs were written and employed for Evaluating the specific systems discussed in the following:

(1) Section V, Volume II, Task Group II Report
(2) Example A, Volume III, Task Group II Report
(3) Example C, Volume III, Task Group II Report

While some variations did exist, in general, the computer accepted as inputs the reliability, maintainability, and capability indices of the equipments comprising the systems; from these, it computes the elements of the several vectors and matrices; and finally, it multiplied the vectors and matrices to obtain Effectiveness. Automatic parameter variation (i.e., several values of mean-times-between failure for each equipment) can be included and the resulting Effectiveness values computed.

Areas in which improvements are required will best be uncovered when the program is applied to actual, as opposed to the hypothetical, systems evaluated to date.

Sponsor: ARINC Research Corporation in-house effort in connection with Air Force Weapon System Effectiveness Industry Advisory Committee (WSEIAC) Study.

Status: Program available from ARINC

Report: WSEIAC Report Task Group II, Vol. II

Computer: IBM 1401-1bk

Title: SEA (System Effectiveness Analyzer)

Abstract: The program is intended to have capabilities for evaluation (prediction) and optimization of systems in terms of their systems effectiveness or cost effectiveness attributes. Optimization can be performed either as a selection problem among a postulated set of alternatives or as an allocation problem.

The program contains several features that make it suitable for the solution of a wide variety of problems while requiring only a simple set of rules for the direction and execution of tasks. This is accomplished by means of a routine whereby various organizational (structural) and functional relationships that govern system operation and behavior, at various levels of interest, are stored on tape and called for as needed. In addition, a command and definition language has been developed which enable the user to communicate his problem in simple terms. Provision is also made for revision and updating of the various libraries and for storage and recall of analyzed configurations. Capability also exists for modifications and altering systems during analysis as well as assessment of sensitivity of various parameters to selected effectiveness measures.

Sponsor: Naval Applied Science Laboratory, New York

Contract: N140(62462)-77459B

Contractor: Computer Applications Inc.

Status: Active, users language, system of function libraries developed

Report: User Language Available, also Program Reports 30 November 1964 and 31 January 1965

Computer: CDC 6600 (Control Data Corp.)

Title: (SEE/AN) System Effectiveness Evaluation Analyzer

Abstract: A Steady-State Effectiveness Model. SEE/AN involves a steady-state system effectiveness model that computes equilibrium distributions of effectiveness characteristics. It is most useful for large systems composed of 10 to several hundred subsystems in which sustained operations, including real-time maintenance, is required.

This model, when implemented with the aid of a computer program, will show the effects of malfunction, scheduled and unscheduled maintenance, logic and time of detection, localization, fall-back, and recovery upon the performance distributions that form the program outputs. System degradation requires particular attention during transitions in system operating modes. The SEE/AN-I program, which is used to perform the final computations, requires inputs that include the following:

(1) Definitions of groups of functionally interchangeable subsystems that exist in the system.

(2) The mean-up-time (MUT) and mean-down-time (MDT) for the subsystems of each group, measured or calculated from formulae in the associated program documents.

(3) The number of subsystems that are in each group.

(4) Definitions of states, and groups of states of interest. All states that are unspecified are automatically placed together with the null state (all subsystems Down).

(5) Values of state performance parameters. As many as 10 performance parameters may be specified. These may be of either the additive type (more are better, e.g., capacity) or the time-descriptive type (fewer are better, e.g., service time). These parameters differ in the automatic corrections that are made for system recovery time, and for non-performance in the null state.

(6) Values of thresholds. Thresholds allow the distributions of the performance parameters to be compared with specified performance values.

Program outputs include: (1) the probability of each state specified on input, (2) the mean-time spent in each of the states specified on input, (3) probability distributions for each performance parameter specified on input, and (4) comparison of the performance parameter distributions with the specified threshold values.

Also see (SEE(SIM)) Simulation Program (P. IV-6).

Sponsor: DCA

Contract: DCA Contract SD-194

Contractor: Auerbach Corporation

Status: Currently being used in the Autodin Project for Proposal Evaluation, Design Prediction and System Progress during production.

Reports: (a) Spec MIL-A-55246 (EL-Autodin)
(b) IEEE Paper "System Effectiveness" Philadelphia Section, 10Feb65

Computer: Philco S-2000, IBM-7090, Fortran II

Title: SEE(SIM) System Effectiveness Simulation

Abstract: SEE(SIM) was developed in support of SEAHAWK and PACED. It is capable of simulating the effectiveness characteristics of a wide class of systems. The Simulator generates failures and repairs of subsystems (units) in Monte Carlo fashion in accordance with prescribed probability distributions. The program also allows for consideration of task priorities and inclusion of recognition times (mean and variance of times necessary to recognize a failure) and adjustment times (specification of alternate modes of operation of the system upon recognition of a failure and mean times required to accomplish adjustments). The program outputs include the following:

(1) Tables that show the number of times the system was not performing at a specified level for a specified length of time.

(2) The mean duration of an occurance, and deviations from the tabulated mean.

(3) Probability of achieving given levels of performance.

Also see (SEE(AN) Analyzer Program P. IV-5)

Sponsor: Navy, BuShips

Contract: Nobsr-91244

Contractor: Auerbach Corporation

Status: Current-being used

Reports:

Computer: IBM-7090/7094(GPSS II Language)

Title: ASW Mission Effectiveness

Abstract: Program to (a) evaluate the contribution of each sub-system to over-all mission requirements, (b) establish contribution of each sub-system to over-all mission effectiveness, and (c) provide means for optimization of tactics.

Does not consider factors such as false alarms, sonar interference, countermeasures, cost, manning, etc.

Work done is support of DE-1052 Advanced ASW Ship.

Sponsor: Navy, BuWeapons, Navy Weapons Laboratory

Contract: N178-85-44

Contractor: ARMA

Status: First phase completed. Currently being programmed and updated. Computer program will be available for exercise 1 July 1965.

Reports: Phase I - 9 partial reports each covering sub-model

Computer: Stretch (IBM-7030)/Stretch Language (Fortran 4)

Title: Evaluation of the System Effectiveness of the E2A/ATDS

Abstract: A program has been developed to assess the effectiveness over relatively long periods of time of a system capable of operating in several different modes. The system capability is a function of the system state at a particular time; the system state, in turn, is a function of the condition of the equipments comprising the system. The measure of effectiveness is the integrated capability of the system over the total mission time.

In the system under study, a simulation approach was employed because of the difficulties involved in analytically describing the multiple state transitions which could occur.

The simulation considers such variables as the number of systems available for patrol duty, reliability of the components of the system, maintenance policy, times required to restore failed units, and various operational parameters such as refuel times, launching and landing times, and the number of aircraft allowed in the air simultaneously. The program allows variation of these parameters and shows the relationship between system effectiveness and the various parameters.

Improvements in the program to permit inclusion of such factors as logistic considerations, shop maintenance, and maintenance efficiency as fleet experience is obtained should be incorporated.

Sponsor: Navy, BureauWeapons

Contract: NPOLA-N-123(61756)-50249A

Contractor: ARINC Research Corporation

Status: Completed February 1965

Reports: ARINC-322-01-2-470

Computer: IBM-7090

Title: Techniques for Prediction of System Effectiveness

Abstract: The purpose of this effort was to investigate and develop a mathematical model capable of predicting the effectiveness for any given operational environment. The model was expected to be able to account for the influence of all important parameters of hardware and environment, such as reliability, redundancy, man-made and natural environments, etc., and to express the effectiveness of the system in terms of a single figure of merit.

The SPAN (System Performance Analysis) Model developed in the course of the study utilizes both physical and mathematical modeling techniques and is derived from probability and information theory and the energy flow equations of Laplace and Helmholtz. By transforming system and environmental parameters into SPAN language and appropriate effectiveness numbers, the system is simulated by electrical networks. As an example, transmission phenomena are represented as "T" networks in which the values of the series arms represent the lossy transmissions of both energy and information, and the values of the shunt arms represent the transfer ratios. The initial values of resistance are determined by the product of the effectiveness numbers and a constant resistance determined by the simulation equipment used. The total system effectiveness in this type simulation is represented as an output power which can be optimized by varying the resistances of the simulator. The new resistance values, when translated back into real system parameters, then represent the most effective system configuration.

Contained in this report are a series of transforms for the conversion of parameters to SPAN language and effectiveness numbers, and a demonstration of the simulation technique for the case of a hypothetical system.

Sponsor: Air Force, RADC

Contract: AF 30(602) 273

Contractor: Nortronics

Status: Completed

Reports: RADC TDR 62-540

Computer:

Title: Techniques for Prediction of System Effectiveness

Abstract: The broad problem of the prediction of system effectiveness is investigated with the objective of determining the kind of mathematics, mathematical models or mathematical procedures capable of supporting a significant amount of the required applications. Special attention is given to those problem areas in which the computation of effectiveness indices can not exclude consideration of reliability and maintainability. For such problems it is concluded that feasible solutions, capable of the timely and economical generation of needed results, exist only in terms of hybrid Monte Carlo and analytical simulation programs for digital computers (requiring, in some cases, minor analog support) which must be generated by the computer itself by virtue of a compiler type automatic programming language. The existing languages are investigated and found unsuitable because of lack of suitable logic, protracted programming time or lack of usability by other than specially trained professional programmers. Some of the difficulties encountered are demonstrated by the construction of a working program for the prediction of system effectiveness for a simple system for which reliability and maintainability are considered. Suggestions for the structure of a suitable language are set forth.

Sponsor: Air Force, RADC

Contract: AF30(602)-2718

Contractor:

Status: Completed 1963

Report: RADC TDR 63-407 (available through DDC)

Computer: IBM 1620

Title: Effectiveness Simulation

Abstract: Computer program developed for analysis and prediction of Reliability, Availability, Maintainability and System Effectiveness for an Airborne equipment with four independent units.

Printed output indicates for every Kth flight number of complaints, number verified, number successfully repaired, start status probabilities and individual unit characteristics.

Program is written to show general utility of simulation program. Test run of 500 flights yielded no-complaint probability of 0.484 as compared to0.491 obtained analytically.

Note. Limited to Airborne system of 4 independent units - effort needed to revise program to handle variable number of units.

Sponsor: Air Force - WPAFB (AFSC-Dir.Strategic and Tactical)

Contract: AF 33(657)-10594

Contractor: ARINC Research Corporation

Status: Completed end of 1963 - thinking was input to WSEIAC Study

Report: ARINC 267-01-7-419

SECTION V - COST EFFECTIVENESS

Title: Cost-Effectiveness Studies

Abstract: Cost-effectiveness studies for advanced Sea Based Deterrance

Sponsor: Navy, Special Projects Office

Contract:

Contractor: Stanford Research Institute

Status: Active

Reports: Vol. I and II "Weapons Systems Synthesis and Technical Evaluation for Advanced Sea Based Deterrance" (Classified Reports)

Special Report I - Notebook of Cost Effectiveness Studies for Advanced Sea Based Detterance (Classified Report)

Computer: IBM-7090

Title: Evaluation Criteria for Associative Memories

Abstract: A method for evaluating the relative cost-effectiveness of a series of computer memories relative to performance per unit of total cost.

Note: The underlying assumptions and approach are being held proprietary but the actual memory analyses and computations are included in the report of Phase I of the effort.

Sponsor: Air Force RAWID, Rome Air Development Center

Contract: AF 30(602)-3108

Contractor: Hollander Associates

Status: Completed

Reports: Phase I, Report 209-1 dated 28 December 1963

Title: Criteria for Systems Trade-Offs

Abstract: Phase I. Determine whether correlation exists between both development cost and time, and the ranges of system performance characteristics for a given class of systems.

Phase II. If correlation exists, develop general relationships equating the appropriate design characteristics to over-all system development cost and system development time.

Sponsor: Air Force, RADC

Contract: AF 30(602)-3702
AF 30(602)-3722

Contractor: Sylvania
ARINC

Status: Active

Reports:

Computer:

NOTE: The approaches to the problem are different in each case:

Sylvania

Approach - Actual system design, development time and cost information, will be studied and retraced in detail for several systems, each representative of a type in wide usage, to realize the objectives above (Case history approach). In addition computer simulation procedures will be utilized to determine design vs cost parameters for hypothetical systems of a given type.

ARINC

Approach - Actual system design, development time and cost data will be collected from a large group of systems. Pertinent information will be extracted, analyzed, correlated and supplemented by engineering theory to realize the goals of the objective.

Title: Economics of Ownership

Abstract: The economics of ownership program is designed to study system optimization with respect to cost and reliability. This program simulates the operation of weapon systems as a function of reliability and maintenance capability and, in turn, computes the availability. The effectiveness of any system is a function not only of its tactical capability, but also of its operational reliability and availability. Trade-off studies are made between initial cost and total maintenance cost. In addition, optimum spares investment and allocation can be determined along with maintenance personnel and facility requirements.

Sponsor: Autonetics Division of NAA (In-House)

Contract:

Contractor:

Status: Program currently being used.

Reports: No reports available

Computer: IBM-7094

Title: Cost and Availability Program

Abstract: A program developed and employed under a Navy contract provides reliability, maintainability, and availability indices at various levels of hardware complexity. Coupled with these, it provides several costs associated with the system's operation and support.

The program accepts as inputs such observed characteristics as system operating time; number of failures at system, equipment and part levels; maintenance times; technician rating; echelon(s) at which repairs are made; replacement part costs; system and initial spares costs; and system life and utilization rate.

The program provides as outputs:

Reliability, maintainability, and availability indices at various hardware complexity levels.

Costs, per operate hour, of

(1) Initial procurement

(2) Operation

(3) Maintenance (labor and parts)

Costs, per maintenance action, of

(1) Labor

(2) Parts

The program has recently been adapted to accept data provided by an existing military activity (NATSF).

Additional effort in improvement of this program could be devoted to inclusion of broader support costs, such as buildings, major facilities, costs of personnel above squadron level.

Sponsor: Navy - Bureau Weapons

Contract: N123(61756) 32994A(PMR)

Contractor: ARINC Research Corp.

Status: Completed

Reports: ARINC Report 285-01-4-467 (Confidential)

Computer: IBM - 1401

SECTION VI - SYSTEMS EVALUATION

Title: G.P.S.S. (General Purpose System Simulator)

Abstract: G.P.S.S. is a technique that provides a means of evaluating a proposed system. The systems' characteristics and behavior are modeled by a computer program which reacts to various operating conditions in a similar manner as the proposed system would react.

Results are used to establish feasibility, compare alternatives and to gain insight as to the effect on system performance of a change in equipment parameters.

Sponsor: IBM (In-House)

Contract:

Contractor:

Status: Operating

Reports: Available from IBM

Computer: 7090 Series/Fortran — 32K Memory
7040 " " — 32K Memory (GPSS III only)

Title: GOSSIP (General Operating Systems Simulation Program)

Abstract: GOSSIP is a general program for simulating a number of states and activities with the operation of a complex system over a specified mission interval. It will simulate operating time in both normal and degraded modes, unit and system failures, corrective repair and influences of all of these on supply support effectiveness.

The program can handle very large networks (i.e., complete POLARIS Submarine). The outputs possible are (1) complex system reliability as a function of unit reliability, (2) availability and readiness analysis at given performance levels.

Used basically as a design tool for determination of logistics requirements.

Sponsor: Navy Special Projects Office

Contract:

Contractor: General Electric Tempo

Status: Active

Reports: Available

Computer: IBM-7090/Fortran and Kab

Title: Weapons Simulation

Abstract: Program to evaluate performance as a function of varying inputs.

Long range program, will not complete most models until sometime after 1970.

Sponsor: BuWeapons

Contract:

Contractor: NOTS(P)

Status: Active

Reports: Status Report due April 1965

Computer: AN/USQ-20B(Digital); EA(Analog)

Title: Sonar Simulation

Abstract: Complete programming of direct path, bottom bounce and convergence zone sonar modes of operation. The model considers environmental and other sub-system inputs. It can be used for surface or submarine sonars.

Sponsor: Navy, Naval Electronics Lab/BuShips

Contract:

Contractor: NEL, In-House

Status: Active, ready for excercising 1 July 1965

Reports: NEL Report September 1964 on bottom bounce simulation; March 1965 for convergence zone and direct path operation.

Computer: AN/USQ-20A/MELIAC(International Algo(58) Compiler)

Title: Simple Digital Device Simulator

Abstract: Simulate the operation of digital computers. Output is the state of all storage elements.

Sponsor: Air Force, AFSC

Contract:

Contractor: AMF

Status: Completed

Reports: "A Simple Digital Device Simulator", Rubin and Hickey, AMF Company

Computer: IBM 7090/1

SECTION VII - CIRCUIT ANALYSIS

Title: E.C.A.P. (Electronic Circuit Analysis Program)

Abstract: Analysis to determine effect of environment, aging and production tolerances of parameters on circuit performance. User oriented program capable of yielding a thorough D.C., A.C. or transient circuit analyses.

Sponsor: IBM (In-House)

Contract:

Contractor:

Status: Program available and being used. Program being modified for IBM-7090/4.

Reports: IBM-1620 Electronic Circuit Analysis Program

Computer: IBM-1620, 40K Memory
Fortran II

Title: NET-1

Abstract: Circuit Design model to evaluate circuit performance for design optimization from past performance electrical inputs. A utility routine, it accepts system - descriptions and part - specifications as inputs and produces system behavior as outputs. Iterating voltages and currents at all modes of operation are available as output for both transient and steady state.

Sponsor: Los Alamos Scientific Laboratory

Contract:

Contractor: Sandia Corporation

Status: Active

Reports: NER-1 Analysis Program - Doc LA-2853 Los Alamos Scientific Laboratory

Title: Statistical Circuit Analysis

Abstract: Programs provide a method of determining the statistical distribution of a circuit's output variables. Circuit output variables include voltages, currents, powers, gains, etc. The output variables determine the distribution of a circuit's DC operating points and frequency response. Most of the programs use a Monte Carlo method which simulates the random construction of a circuit from parts described by their distributions. The distribution of the output variables is determined by analyzing a large number of these circuits. The moment method program is an analytical technique which uses the propagation of variance formula to predict the mean and standard deviation of a circuit's output variables. These programs have been used to determine the probability of a circuit failing due to the components tolerance buildup.

Sponsor:

Contract: Company and Contract Funds

Contractor: Autonetics Division of NAA

Status: Programs currently being used

Reports: Autonetics Report "Reliability Analysis of Electronic Circuits" being reproduced by Defense Documentation Center.

Computer: IBM-7094 for several programs
Autonetics RECOMP II for one program

Title: Parameter Variation Circuit Analysis Techniques

Abstract: Parameter variation programs that vary the parameters of a circuit in some predetermined manner to provide the engineer with useful design data. Worst case analysis programs provide absolute maximum and minimum values of circuit's outputs. These worst case programs were particularly useful in determining the power ratings of resistors and transistors, voltage rating of capacitors and other component stress ratings.

Some of the variational programs are used to determine the effects on circuit performance when one or more parameters is varied through a range of values. For examples these programs have been used to determine the frequency response of a circuit for several different values of a component. This type of program helps the engineers to design more reliable circuits.

Sponsor:

Contract: Company and Contract Funds

Contractor: Autonetics Division of NAA

Status: Program currently being used

Reports: Reports available from Autonetics

Computer: IBM-7094
Autonetics RECOMP II

Title: Transient Analysis

Abstract: Transient circuit analysis programs are used to study the behavior of circuits as a function of time. Of primary concern are the peak part stresses that are associated with transients and the over-all time response.

Several programs are available to supply this information to design engineers. The "DEE" (Differential Equation Evaluator) program gives the time response for a set of simultaneous equations written in terms of the LaPlace transforms. SCAN transient analysis programs solve simultaneous differential equations by the finite difference method. This program has the added capability of being able to handle non-linear components. The "TRUMP" (Transient Response Using Matrizant Procedures) finds the transient response of linear and non-linear circuits using matrizant procedures to solve the simultaneous differential equations.

Sponsor:

Contract: Company and Contract Funds

Contractor: Autonetics Division of NAA

Status: Programs currently being used

Reports: Reports available on some programs from Autonetics

Computer: IBM-7094

Title: Radiation Analysis

Abstract: The "TRAC" (Transient Radiation Analysis by Computer) program analyzes the effects of nuclear radiation on semiconductor circuits. In its present form, TRAC is oriented toward the specific area of pulsed ionising radiation, but is capable of including permanent damage/displacement/effects and E-M pulse effects. This program can simulate a radiation profile of a nuclear device more realistically than can be duplicated in a laboratory. The TRAC program is basically an advanced transient circuit analysis program with the additional capability of including radiation effects.

Sponsor: Autonetics Div.of NAA

Contract:

Contractor:

Status: Program currently being used

Reports: A paper available from Autonetics

Computer: IBM-7094

Title: Failure Mode Analysis

Abstract: Failure mode circuit analysis programs simulate catastrophic part failures to analyze the fail-safe characteristics of circuits. They are also used to determine if associated parts will be over-stressed and fail. They provide information which can be used in defining test point allocation, and in preparing fault isolation and repair procedures. "SYCATE" was developed as an aid in the preparation of maintenance manuals. The "AMAP" failure mode analysis program is designed to fail all components of a DC circuit to determine their effects on circuit performance. The "ACFM" program is used to study the primary and secondary failure modes of AC circuits.

Sponsor:

Contract: Company and Contract Funds

Contractor: Autonetics Div. of NAA

Status: Programs currently being used

Reports: Autonetics report in preparation

Computer: IBM-7094

Title: Logic Circuit Evaluation

Abstract: Analysis of cost-effectiveness of high-speed computer circuits.

Note: The underlying assumptions and approach are being held prepietary but the actual analysis and computations will be included in the report.

Sponsor: Army

Contract: DA(18)-119(SC)2461

Contractor: Hollander Associates

Status: Under way

Reports:

Title: Statistical Data Analysis

Abstract: The "ECAP" (Electronic Component Analysis Project) computer program is an integrated system of analysis programs used to analyze electronic part parameter data. The statistical methods, techniques, and computer programs are applicable to the majority of engineering test data. This program was developed to analyze the extensive reliability life test data generated in the Minuteman Reliability Improvement Program.

The program had the following objectives:

(1) Improve reliability by obtaining failure mode data and feedback for design and process improvement.

(2) Completely characterize reliability of electronic parts.

In addition to this integrated program, there are numerous statistical computer programs written for particular problems. These programs perform regression analyses, develop pictorial computer output, and perform such statistical operations as determining the chi-squared function and Weibull distributions.

Sponsor: Air Force

Contract: Minuteman Project

Contractor: Autonetics Div. of NAA

Status: Programs currently being used

Reports: Minuteman Contract Report available through Air Force

Computer: IBM-7094

Title: A.C. and D.C. Circuit Analysis Program

Abstract: This program enables an analyst familiar only with basic techniques for circuit analysis to obtain a complete analysis of a circuit. The analysis options are (1) one-at-a-time parameter variation and sensitivity test to determine the effect of the input parameter change on circuit performance; (2) worst-case solutions with all components at their drift limits; (3) Monte Carlo analysis to determine what the large volume production spread of circuit performance might be; and (4) special solutions with specified combinations of limits on components. The method has been labeled a cookbook approach.

The program can be used either as a design tool for optimizing circuit performance or for determining the reliability of given circuits.

Note: Two major areas in which further development is needed are (1) incorporation of capability for transient analysis, and (2) eliminate the need for the analyst to write the loop equations (which can be a major source of error) and incorporate these into the computer program for equivalent circuits.

Sponsor: Navy - NOTS, China Lake, Calif.

Contract: N123(60530)-51224A

Contractor: ARINC Research Corporation

Status: Complete with efforts planned for computer generation of equations and to cover transient analysis.

Reports: (a) Proceedings of 11th National Symposium Reliability and Quality Control, Pages 12-21
(b) Service to NOTS and no formal contract reports

Computer: 7090/94 Fortran II

Title: Master Parameter Variation Program

Abstract: Designed to perform statistical analyses of electronic circuits, particularly digital logic circuits. Program is capable of performing virtually all engineering and statistical analysis. Elements modeled are circuit parameter variation analysis and reliability. Output is in form of plotted histograms, various numeric values for currents, voltages, relative sensitivity, etc. Features of the program are: Monte Carlo parameter variation, multiple parameter distributions (maximum of 22 different distributions); high efficiency, handles switches and circuits. Major difficulty is in programming specific circuit for analysis.

Sponsor: AFSC - Mfg Tech Laboratory - Research & Technology Div.

Contract: AF (33)657-8785

Contractor: ARINC Research Corporation

Status: Complete

Reports: ARINC Report 234-02-10-466 "Final Report on Investigation of Factors Affecting Early Exploitation of Integrated Solid Circuitry" December 1964.

Computer: IBM-7090 or 7094/Fortran IV

Title: Application of Von Neumann Redundancy Techniques to the Reliable Design of Digital Computers

Abstract: The study described herein consists of two parts: (1) a critical analysis of the engineering problems that arise in the attempt to implement various redundant information-processing concepts, and (2) a detailed development, design analysis, and reliability analysis of the application of functional majority logic to the redesign of an ADDER used in a space guidance computer.

The analysis of the engineering problems arising in the implementation of various information-processing redundancy concepts includes an evaluation of all such applicable concepts developed to date, and the implementation problems associated with each. Applicability of these concepts to the mechanization of all the logic and control functions normally required in a digital computer is investigated, and a qualitative evaluation of the practical potential of the various methods is presented herein.

One such concept, functional majority logic redundancy (FMLR), is the subject of application and analysis in the design of a real computer element, an ADDER used in an aerospace guidance computer. Basic functionally-redundant AND-NOT and OR-NOT modules are developed, and the ADDER logic is redesigned to make the most efficient use of the module. An analysis of the comparative physical characteristics of the redundant and non-redundant ADDER is provided for evaluating the space/ weight/ power trade-offs required in the effort to achieve increased reliability in digital systems. The redundant design is the subject of a detailed reliability analysis, which attempts to keep at a minimum the simplifying assumptions which often dilute the applicability of theoretical or conceptual studies to the design of real hardware.

It became apparent in the course of the study that the value of the redundant design was affected as much by the mode as by the frequency of part failure. Statistically valid information of a general nature on part failure modes does not exist. In the absence of such information, ARINC Research has developed a mathematical reliability model which defines the sensitivity of the design concept to the failure modes of its constituent parts. This approach has a twofold value: (1) when statistically valid data on part failure modes become available, the value of the functional redundancy design concept can be assessed from the families of reliability curves provided in this report; and (2) the model demonstrates the value of developing piece-part fabrication processes which will control failure modes.

Sponsor: Air Force, RADC
Contract: AF 30(602)-2419
Contractor: ARINC Research Corporation
Status: Completed
Report: RADC TDR-62-228
Computer: IBM-7090 Fortran II

SECTION VIII - FAILURE MODE AND EFFECTS ANALYSIS

Title: Mathematical Automated Reliability and Safety Evaluation (MARSEP) Program

Abstract: A computerized failure mode and effects analysis program. The program accepts as input (a) the description of the system composed of various electrically or mechanically connected components, and (b) a definition of system success. The computer then determines which combinations of component events are required for system operation or system failure in all modes of operation.

Methodology based on work done for Sandia Corp.

Comment: This program does not provide a means for quantitatively predicting Reliability or Safety. It results in a failure mode and failure effects analysis.

Sponsor: Mathematica, Princeton, New Jersey (In-House)

Contract:

Contractor:

Status: Unsolicited presentation

Title: Thermal Analysis

Abstract: Programs are available which can solve a wide variety of thermal problems. Most of these programs are used to treat a unique thermal analysis problem. The transient analysis of heat transfer through an ablative material is an example of one of these programs. Two thermal programs, written by Autonetics, were used in support of the Minuteman program. One simulates the thermodynamic behavior of multi-layer boards with attached integrated circuits. The other studies the temperature distribtuion within an integrated circuit to determine average and "Hot Spot" temperatures for reliability considerations.

Sponsor:

Contract: Company and Contract Funds

Contractor: North American Aviation (Autonetics and other Divisions)

Status: Programs currently being used

Reports: Autonetics In-House Thermal Design Analysis Manual (Not presently available for distribution)

Computer: IBM-7094

Title: Study of Failure Theory (Metal Film Resistors)

Abstract: Study of the principal mechanisms of failure in deposited metal film resistors (precipitation and oxidation). A mathematical model of resistor behavior, involving at this time oxidation and precipitation, has been investigated and programmed for IBM-7090 computer.

Results to date show poor correlation with test data; this is attributed to effects and mechanisms not yet incorporated in the model, and data available for validation studies represent mean value data for hundreds of resistors. The study is being continued.

Sponsor: Air Force, RADC

Contract: AF 30(602)-3251

Contractor: IIT Research Institute

Status: Study continuing as follow-on to Phase I studies

Computer: IBM-7090