FINAL REPORT

DEVELOPMENT OF AN INTERDISCIPLINARY SYSTEMS ENGINEERING PROGRAM

(GRANT GE 2532)

National Science Foundation

FOR THE PERIOD SEPTEMBER 1963 TO NOVEMBER 1968

Prepared by

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PROJECT DIRECTOR

NOVEMBER 1968

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA
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</tr>
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<td>-----------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Stan Aaronson</td>
<td>Assistant Professor</td>
</tr>
<tr>
<td>D. O. Covault</td>
<td>Professor</td>
</tr>
<tr>
<td>S. L. Dickerson</td>
<td>Associate Professor</td>
</tr>
<tr>
<td>J. L. Hammond</td>
<td>Professor</td>
</tr>
<tr>
<td>W. W. Hines</td>
<td>Professor</td>
</tr>
<tr>
<td>Eugene Harrison</td>
<td>Professor</td>
</tr>
<tr>
<td>Joseph Krol</td>
<td>Professor</td>
</tr>
<tr>
<td>R. N. Lehrer</td>
<td>Director</td>
</tr>
<tr>
<td>Joseph Talavage</td>
<td>Assistant Professor</td>
</tr>
<tr>
<td>H. M. Wadsworth</td>
<td>Professor</td>
</tr>
<tr>
<td>T. M. White</td>
<td>Professor</td>
</tr>
<tr>
<td>Pranas Zunde</td>
<td>Associate Professor</td>
</tr>
</tbody>
</table>
Systems Engineering Advisory Committee
1968-69

School of Aerospace Engineering
School of Ceramic Engineering
School of Chemistry
School of Civil Engineering
School of Electrical Engineering
School of Engineering Mechanics
School of Industrial Management
School of Industrial Engineering
School of Information Science
School of Mechanical Engineering
School of Military Science
School of Nuclear Engineering
School of Physics
School of Psychology
School of Textiles
Water Resources Center

Representatives
Professor D. W. Dutton
Professor W. E. Moody
Professor W. H. Eberhardt
Professor D. O. Covault
Professor J. L. Hammond
Professor Jose Villaneva
Professor R. E. Green
Professor D. E. Fyffe
Professor Lucio Chiaraviglio
Professor S. L. Dickerson
Colonel Wayne W. Bridges
Professor J. D. Clement
Professor E. T. Patronis
Professor Carr Payne
Professor R. K. Flege
Professor J. Earnest Flack
I. **Objectives and History of the Systems Engineering Program.**

A study of the impact of systems engineering on engineering curricula, with a view to designing a program of study in this area, was begun at the Georgia Institute of Technology in 1961. In August 1963, Georgia Tech received a one-year grant from the National Science Foundation for the design of a typical undergraduate program of courses in systems engineering. The grant was extended for two years and ran until 1966. A further extension of the grant continued the program until November, 1968.

This study has two general objectives, namely:

1. The definition and design of a program of courses covering those aspects of systems engineering which can be appropriately presented at the undergraduate level at most universities and
2. The practical evaluation of such a program through teaching of the courses at the Georgia Institute of Technology which is typical of a state university with strong engineering disciplinary divisions.

The following more specific objectives have also been established.

1. The program should be at the undergraduate level.
2. The program should provide elective courses which supplement rather than replace the more conventional disciplinary training.
3. The courses should be interdisciplinary and emphasize the general aspects of classes of systems without domination by any one of the participating disciplines.
4. Students from most of the engineering schools and some from the science schools would participate.
5. A student should be able to select courses which provide a background for later advanced study.
6. The major emphasis in all programs should be on engineering design, although much of the underlying material will be of a mathematical analysis nature.
(7) For an area of systems engineering to be included in the program it should: (a) constitute a body of knowledge which can be quantitatively formulated, (b) consist of knowledge which is useful in more than one of the engineering disciplines and (c) involve mathematical models which are of such a nature that they can be mastered by undergraduates.

(8) This course of study should be developed as a model program and information on it should be disseminated to other schools and interested persons.

The reasons for selecting these objectives has been outlined in previous annual reports especially the first report on this study issued May 13, 1964. A program of elective courses which seems to accomplish these objectives was formulated to the extent of naming eleven courses these courses were approved by the undergraduate curriculum committee in 1965 and were incorporated into the official undergraduate catalogue. These courses are identified by name, number, and credit hours and are listed below for reference purposes:

<table>
<thead>
<tr>
<th>Course No.</th>
<th>Course Name</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sy. E. 380</td>
<td>Systems Engineering I</td>
<td>2-3-3</td>
</tr>
<tr>
<td>Sy. E. 381</td>
<td>Systems Engineering II</td>
<td>3-0-3</td>
</tr>
<tr>
<td>Sy. E. 390</td>
<td>Computer Methods in Systems Engineering</td>
<td>2-3-3</td>
</tr>
<tr>
<td>Sy. E. 410</td>
<td>Systems Analysis I</td>
<td>4-0-4</td>
</tr>
<tr>
<td>Sy. E. 411</td>
<td>Systems Analysis II</td>
<td>4-0-4</td>
</tr>
<tr>
<td>Sy. E. 412</td>
<td>Systems Analysis III</td>
<td>4-0-4</td>
</tr>
<tr>
<td>Sy. E. 413</td>
<td>Systems Analysis IV</td>
<td>4-0-4</td>
</tr>
<tr>
<td>Sy. E. 416</td>
<td>Optimization of Systems</td>
<td>3-3-4</td>
</tr>
<tr>
<td>Sy. E. 417</td>
<td>Modeling and Measurement</td>
<td>3-0-3</td>
</tr>
<tr>
<td>Sy. E. 420</td>
<td>Physical Systems Laboratory</td>
<td>1-3-2</td>
</tr>
<tr>
<td>Sy. E. 415</td>
<td>Case Studies in Systems Engineering</td>
<td>2-6-4</td>
</tr>
</tbody>
</table>
Appendix A contains the descriptions and other information for the courses in the Systems Program as listed in the official catalogue for 1968-1969 for the Georgia Institute of Technology.

II. Discussion of Progress During the Report Period (1963-1968)

The primary objective of the work during the report period has been to design the elective courses in detail and to evaluate as many as possible through committee discussions and through actual teaching experience. The general approach being employed in designing the courses as a part of the overall program consists of development in four stages: a preliminary design stage, two intermediate stages, and a final stage. These stages will be referred to as stages 1 through 4 and they are defined as follows:

Stage 1 - A course which has been designed on paper as to detailed content by a committee of several persons, usually from different disciplinary areas.

Stage 2 - A course which has been (a) taught once to an interdisciplinary class, (b) evaluated by the instructor and the Systems Engineering Committee, (c) and modified.

Stage 3 - A course which has been (a) usually taught by a second instructor (b) to an interdisciplinary class, (c) evaluated by the instructor and the Systems Engineering Faculty, (d) and modified.

Stage 4 - A course which is an integrated part of the complete Systems Engineering Program. The notes for these courses are usually well developed.

A review of existing text material has indicated that, with a few exceptions, appropriate texts for many of the planned courses are not presently available. Thus, notes have been prepared for most of the courses, and the work of preparing these notes typically extended over all four steps in the development of each course. For the benefit of students existing texts are being used for supplementary reference material.
The current status of each course in the Systems Engineering Program is indicated in Table 1. As can be noted from the table, nine courses have reached stage 4; and two courses are at stage 1. All courses which have reached stage 3 or greater have been taught one or more times. Because of limited demand Sy. E 412 and 413 have not been taught to date but it is expected that these courses will be taught as the Systems Engineering Program grows and matures.

Some of the course design effort should be classified as research into system engineering theory, rather than routine course development. Systems Engineering 411 and 416 are the only courses where some text material is being used. All of the remaining courses are being developed extensively with notes. Several copies of the notes for each course reaching stage 4 are included with this report as supplementary material.

Programs of Study. As can be noted from Appendix A, two programs of study can be pursued by the student. These programs have been designated Program A and Program B. Program A consists of the following courses:

Program A

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sy. E 380</td>
<td>Systems Engineering I</td>
</tr>
<tr>
<td>Sy. E 381</td>
<td>Systems Engineering II</td>
</tr>
<tr>
<td>Sy. E 425</td>
<td>Case Studies in Systems Engineering</td>
</tr>
</tbody>
</table>

A total of ten credit hours constitute Program A. This program is taken by the student who desires a broad coverage of systems engineering courses.

Program B consists of the following courses:

Program B

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sy. E. 380</td>
<td>Systems Engineering I</td>
</tr>
<tr>
<td>Sy. E. 410</td>
<td>Systems Analysis I</td>
</tr>
<tr>
<td>Sy. E. 411</td>
<td>Systems Analysis II</td>
</tr>
<tr>
<td>Sy. E. 425</td>
<td>Case Studies in Systems Engineering</td>
</tr>
</tbody>
</table>

A total of 15 credit hours constitute Program B. This course of study can be elected by the student who wishes a more mature mathematical treatment of Systems Engineering than can given by Program A.
<table>
<thead>
<tr>
<th>Course</th>
<th>Stage of Development (As of Nov., 1968)</th>
<th>Stage of Notes</th>
<th>Times Taught as of Nov., 1968</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sy.E. 380 Systems Engineering I: 2-3-3</td>
<td>4</td>
<td>X</td>
<td>12</td>
<td>X  See supplementary notes for detailed course content</td>
</tr>
<tr>
<td>Sy.E. 381 Systems Engineering II: 3-0-3</td>
<td>4</td>
<td>X</td>
<td>5</td>
<td>X  See supplementary notes for detailed course content</td>
</tr>
<tr>
<td>Sy.E. 390 Computer Methods</td>
<td>4</td>
<td>X</td>
<td>2</td>
<td>X  See supplementary notes for detailed course content</td>
</tr>
<tr>
<td>in Sy.E. 2-3-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sy.E. 410 Systems Analysis I: 4-0-4</td>
<td>4</td>
<td>X</td>
<td>4</td>
<td>X  See supplementary notes for detailed course content</td>
</tr>
<tr>
<td>Sy.E. 411 System Analysis II:</td>
<td>4</td>
<td>X</td>
<td>4</td>
<td>X  See supplementary notes for detailed course content</td>
</tr>
<tr>
<td>4-0-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sy.E. 412 System Analysis III:</td>
<td>1</td>
<td></td>
<td>-</td>
<td>OUTLINE ONLY</td>
</tr>
<tr>
<td>4-0-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sy.E. 413 System Analysis IV:</td>
<td>1</td>
<td></td>
<td>-</td>
<td>OUTLINE ONLY</td>
</tr>
<tr>
<td>4-0-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sy.E. 416 Optimization of Systems. 3-0-3</td>
<td>4</td>
<td>X</td>
<td>-</td>
<td>X  See supplementary notes for details of course content</td>
</tr>
<tr>
<td>Sy.E. 417 Modeling and Measurement. 3-0-3</td>
<td>4</td>
<td>X</td>
<td>1</td>
<td>X  See supplementary notes for details of course content</td>
</tr>
<tr>
<td>Sy.E. 420 Physical Systems Laboratory 1-3-2</td>
<td>4</td>
<td>X</td>
<td>1</td>
<td>X  See supplementary notes for details of course content</td>
</tr>
<tr>
<td>Sy.E. 425 Case Studies in Systems</td>
<td>4</td>
<td>X</td>
<td>2</td>
<td>X  See supplementary notes for details of course content</td>
</tr>
<tr>
<td>Engineering. 2-6-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Development of the Systems Engineering Program at the Georgia Institute of Technology: Since the inception of the Systems Engineering Program at the Georgia Institute of Technology in 1963 many difficulties with the committee method of dealing with problems peculiar to the program became apparent. These problems ranged from the development of student interest in the program to the obtaining of faculty to teach the courses and to perform committee work. Consequently, in March, 1967, the structure of development and administration on the Systems Engineering Program was changed. Basically the changes that were submitted to A. G. Hansen, Dean of Engineering, were as follows:

1. The Systems Engineering Program would operate as a department within the School of Industrial Engineering.

2. Two faculties, each with responsibilities and prerogatives dealing with their own areas of (a) Industrial Engineering and (b) Systems Engineering would be appointed.

3. The Systems Engineering Faculty would be new, and will be composed of full and part-time members selected by the Systems Engineering Committee for initial organization from: (a) the System Engineering Faculty (b) from interested Industrial engineering faculty and (c) recruited from other sources.

4. A member of the Systems Engineering Faculty will be appointed as Chairman of the Systems Engineering Programs. This person will serve as administrative officer for the program and will be responsible to the Director of the School of Industrial Engineering.

5. An Advisory Committee to provide general guidance to the Systems Engineering Faculty and Director of the School of Industrial Engineering shall be appointed. The objectives of such an arrangement are to help insure a cross-disciplinary flavor within the Systems Engineering Program and to encourage the cross-campus interchange of attitudes and to facilitate responsiveness of the Systems Engineering Faculty to the needs and desires of other academic units. Advisory committee membership will be open to meet representatives from each interested Engineering School and academic department on the Campus. The committee will meet for the purpose of review of the Systems Engineering activity and to recommend ways in which better cross-disciplinary endeavors can be encouraged and facilitated.
6. The School of Industrial Engineering plans to change its designated name to the Schools of Industrial Engineering and Systems Engineering or alternatively to the School of Industrial and Systems Engineering.

The Systems Engineering Program has started to operate with the changes which are proposed above. A more vibrant and effective program which can better meet the needs of students and attract qualified faculty is developing with these changes.

III. Current Status and Planned Directions of Course Development:

The current stage of development of each course is given in Table 1. The purpose of this section is to summarize the detailed content of each course, to discuss its role in the overall program and to indicate specific directions of future work. This summary will be made for each course under four headings: (1) Objective of course and its relation to the overall program (2) Topical outline (3) Considerations in evaluation of course content and (4) Future plans.

SY.E 380 Systems Engineering I, 2-3-3:

Objective and Relation to Overall Program: Sy.E 380 is intended to introduce the student to systems engineering as a professional area and also to introduce him to some of the theoretical activities of systems engineering upon which other courses will develop in much greater detail. The course presents qualitative and quantitative concepts of systems engineering and can be taken by the student as early as the third quarter of the Sophomore year and has differential equations as a mathematics corequisite.
## Topical Outline

<table>
<thead>
<tr>
<th>No. of Periods</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>General System Theory and System Science</td>
</tr>
<tr>
<td>1</td>
<td>Systems Science and Related Disciplines</td>
</tr>
<tr>
<td>3</td>
<td>The Nature of Man-Machine Systems</td>
</tr>
<tr>
<td>3</td>
<td>Biotechnology and Human Engineering</td>
</tr>
<tr>
<td>3</td>
<td>To Systems Design</td>
</tr>
<tr>
<td>3</td>
<td>The Nature of Models</td>
</tr>
<tr>
<td>3</td>
<td>Economic Aspects of Systems Evaluation</td>
</tr>
<tr>
<td>2</td>
<td>Const. Considerations in Systems Analysis and Design</td>
</tr>
<tr>
<td>3</td>
<td>Decision Making in Systems Engineering</td>
</tr>
<tr>
<td>2</td>
<td>in Systems Design</td>
</tr>
<tr>
<td>2</td>
<td>Some Advanced Optimization Techniques</td>
</tr>
<tr>
<td>3</td>
<td>Computer Simulation Techniques</td>
</tr>
</tbody>
</table>

30 Total

**TEXT**

*Introduction to Design* by Morris Asimow.

A set of notes which were compiled by Dr. Joseph Krol are also being used for this course.
Considerations in Evaluation of Course Content: Some minor changes are still being made in this course which reflects the evaluation of thinking as to its proper content to meet the requirements of Program A.

Future Plans: The content of this course will vary somewhat as changes are made in its content to reflect changes which occur in other courses, especially Sy.E. 380. Some consideration is also being given to the inclusion of this course as a requirement in Program B.

Sy.E. 390 COMPUTER METHODS IN SYSTEMS ENGINEERING, 2-3-3: Objectives of Course and Relation to Overall Program: This course provides the student with a rudimentary background in analog and digital computer methods. The student will have sufficient knowledge of the computer after completion of this course to enable him to program analog and digital computers for problem solving involved in Sy. E. 425.

Topical Outline:

<table>
<thead>
<tr>
<th>No. of Periods</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Introduction to Analog and Digital Computation</td>
</tr>
<tr>
<td>4</td>
<td>Analog and Digital Notation</td>
</tr>
<tr>
<td>5</td>
<td>Illustrative Programs, Flow Diagrams</td>
</tr>
<tr>
<td>1</td>
<td>Analog, Simulation of Transfer Function</td>
</tr>
<tr>
<td>8</td>
<td>Digital Computers-Basic Language and Problem Solving</td>
</tr>
<tr>
<td>10</td>
<td>Analog Computer-Summing, Intergration, Multiply, Dividing, and Problem Solving</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
</tr>
</tbody>
</table>

Consideration in Evaluating of Course Content: There is considerable pressure to reduce the number of courses in the systems engineering sequence. Since basic computer technology is taught in several schools of the campus, and especially in the School of Information Science, this course cannot produce a unique service to the university.
Future Plans: This course as presently structured, was taught in the winter quarter, 1968 for the last time. This course will be reconstructed so that it becomes an advanced computer science course and other computer courses, particularly Information Science 151, will be used as a prerequisite.

SY.E. 410, 411, 412, and 413, SYSTEMS ANALYSIS I, II, III, AND IV, 4-0-4:

Objective of Courses and Relation to Overall Programs: These systems analysis courses are intended to present those mathematical tools of system engineering analysis which can be mastered at the undergraduate level. Sy.E. 410 presents mathematical tools for the analysis of linear deterministic systems with and without memory. Sy.E. 411 discusses the analysis of linear non-deterministic systems without memory. Sy.E. 412 will discuss tools for the analysis of linear non-deterministic systems with memory and Sy. E. 413 will be concerned with special techniques for deterministic systems. Also included in Sy. E. 413 will be a study of techniques for the analysis of nonlinear and distributed parameter systems.

Sy.E. 412 and Sy. E. 413 have not yet been planned in detail.

Outlines for Sy. E. 410, Sy. E. 411, Sy. E. 412, Sy. E. 413 are given below. Sy.E. 380 will be a prerequisite for Sy. E. 410 and each of the systems analysis courses will be a prerequisite for the next higher number.
### Topical Outline for Sy. E 410:

<table>
<thead>
<tr>
<th>No. of Periods</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Review of Sy. E 380</td>
</tr>
<tr>
<td>9</td>
<td>Matrix Algebra and Solution of Equations describing Linear Systems</td>
</tr>
<tr>
<td>10</td>
<td>Variation of Parameters and Laplace Transforms</td>
</tr>
<tr>
<td></td>
<td>Techniques for Solution of Differential Equations</td>
</tr>
<tr>
<td>8</td>
<td>Matrix Solution in the Laplace and Time Domain</td>
</tr>
<tr>
<td>2</td>
<td>System Response to Step, Impulse, and Sine Waves</td>
</tr>
<tr>
<td>9</td>
<td>Concepts in Feedback Systems</td>
</tr>
<tr>
<td>40 Total</td>
<td></td>
</tr>
</tbody>
</table>

### Topical Outline for Sy. E 411

<table>
<thead>
<tr>
<th>No. of Periods</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Introduction to Probability</td>
</tr>
<tr>
<td>3</td>
<td>One Dimensional Random Variables</td>
</tr>
<tr>
<td>3</td>
<td>Functions of One Random Variable and Expectation</td>
</tr>
<tr>
<td>3</td>
<td>Higher-Dimensional Random Variables</td>
</tr>
<tr>
<td>3</td>
<td>Important Discrete Distributions</td>
</tr>
<tr>
<td>3</td>
<td>Important Continuous Random Variables</td>
</tr>
<tr>
<td>4</td>
<td>The Normal Distribution</td>
</tr>
<tr>
<td>3</td>
<td>Markov Processes</td>
</tr>
<tr>
<td>9</td>
<td>Queuing Models</td>
</tr>
<tr>
<td>3</td>
<td>Simulations</td>
</tr>
<tr>
<td>3</td>
<td>Reliability Models</td>
</tr>
<tr>
<td>40 Total</td>
<td></td>
</tr>
</tbody>
</table>
### Topical Outline for Sy. E. 412 (Tentative)

<table>
<thead>
<tr>
<th>No. of Periods</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Introduction Types of Computers</td>
</tr>
<tr>
<td>9</td>
<td>Topics From Linear Algebra</td>
</tr>
<tr>
<td>9</td>
<td>Finite Difference Approximating</td>
</tr>
<tr>
<td>9</td>
<td>Numerical Matrix Operations</td>
</tr>
<tr>
<td>7</td>
<td>Numerical Solutions to Ordinary Differential Equations</td>
</tr>
</tbody>
</table>

40 Total

### Topical Outline for Sy. E. 413 (Tentative)

<table>
<thead>
<tr>
<th>No. of Periods</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Review of Probability</td>
</tr>
<tr>
<td>9</td>
<td>Basic Notions of Stochastic Processes</td>
</tr>
<tr>
<td>7</td>
<td>Density and Power</td>
</tr>
<tr>
<td>9</td>
<td>Markov Processes</td>
</tr>
<tr>
<td>9</td>
<td>Random Processes in Linear Systems</td>
</tr>
</tbody>
</table>

40 Total
Consideration in Evaluation of Course Content: As indicated in Table 1
Sy.E. 410 and Sy. E. 411 have been given several times. Because of substantial similarities Sy. E. 411 has been cross-listed with a course in the School of Industrial Engineering entitled, I.E. 335. Sy.E. 410 and Sy.E. 411 have undergone substantial revisions since their original teaching. The initial courses were centered around the teaching of the mathematics required to analyse various linear systems. Later versions of these courses concentrated on the systems engineering problems and the mathematical formulation of the problem was studied as an outgrowth of the stated engineering problem. Mathematics are used as a tool for the analysis of the systems problem and were appropriate computational methods are taught as a means to solve the systems engineering problem.

To implement the approach to teaching just discussed, a program of study into system types and their common mathematical models was begun. This study has shown that a useful system classification can be made on the basis of the following system properties: (1) The system variable i.e., input-output stages and time, (2) The type of space on which the variables are defined and (3) The type of input-output or state-output transformation. As a consequence, a system can be classified on the basis of a number of specific properties derived from these three categories. For example, the input-output variables of the system can be stochastic of deterministic, the spaces can be trivial, discrete, or continuous and the transformation can be linear, nonlinear, time invariant or time variable. Every class of system required a potentially different type of mathematical model.

The major distinctions in mathematical models seem to be associated with the type of input-output variables, i.e., whether deterministic or stochastic, and with the transformation in so far as it does or does
not have memory. These four categories have been used to obtain the
division of material between the four analysis courses which has been
stated previously.

Plans call for this classification being made in the analysis
courses to be followed throughout the elective program. This approach seems
to have the following advantages. (1) Duplication of effort will be avoided
because most theories and techniques apply to a particular class of
systems. (2) The similarities of systems within classes and dissimilarities
between systems of different classes will be displayed. (3) General
equations describing systems in a given class can be developed to
provide a standard description of various systems. (4) Identification of
a system can be aided by placing it in a specified class. (5) The
classification will aid in presenting a theory of systems so that the
properties of all systems in given classes can be developed.

Future Plans: Plans call for a continued effort in refining the
classifications discussed above. A concentrated effort will be made to
develop more illustrative examples and to introduce each mathematical
techniques as a tool for analysis of a given class of systems. Because
of lack of student demand, Sy.E. 412 and 413 have not been taught to
date. However, it is expected that these courses will be taught as the
Systems Engineering Program develops.

SY.E. 416 - OPTIMIZATION OF SYSTEMS, 3-3-4:

Objective of Course and Relation to Overall Program: Optimization
techniques are sufficiently important in systems engineering to concentrate
them in a separate course in the program. Because of the great
similarities in this course and a course, I.E. 334, entitled "Optimization
Methods, " which is presently taught in the School of Industrial
Engineering, I.E. 334, will be taken by students who desire credit for
Sy.E. 416. Four credit hours will be given for this course.
instead of three credit hours as initially envisioned for this course. This change was made because I.E. 334 is a four credit-hour course.

**Topical Outline:**

<table>
<thead>
<tr>
<th>No. of Periods</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Methods of Classical Calculus for Optimization</td>
</tr>
<tr>
<td>3</td>
<td>Finite Differences</td>
</tr>
<tr>
<td>20</td>
<td>Use of Linear Programming for System Optimization</td>
</tr>
<tr>
<td>4</td>
<td>Special Forms of Linear Programming</td>
</tr>
<tr>
<td>3</td>
<td>New Work Problems</td>
</tr>
<tr>
<td>3</td>
<td>Dynamic Programming</td>
</tr>
</tbody>
</table>

Total 40

Text: *Introduction to Management Science* by Daniel Teichroew, published by John Wiley and Sons, Inc. and course notes developed by Professor Stanley Aaronson.

**Consideration in Evaluation of Course Content:** Because of large similarities, Sy.E. 416 has been cross listed with the course, I.E. 334, "Optimization Methods." Because of this substantial similarity, little change is contemplated in I.E. 334 to accommodate students in systems engineering.

**SY.E. 417 MODELING AND MEASUREMENT 3-0-3:**

Objective of course and Relation to Overall Program: Sy.E. 417 is concerned with the problem of determining a mathematical model for a system or a system component through the use of observed or measured data. General characteristics of measurement instruments are developed and incorporated in the techniques of the formulation of models. A course such as this is required to a planned system program to provide information about physical systems and mathematical models which represent them.

The measurement instruments studied in this course, are in general, deterministic systems with memory and with potentially stochastic inputs.
The major emphasis in modeling is on linear time invariant deterministic systems. Sy.E. 410 and Sy.E. 411 are required prerequisites for this course.

**Topical Outline:**

<table>
<thead>
<tr>
<th>No. of Period</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
</tr>
<tr>
<td>3</td>
<td>General Structures of Measurement Instruments</td>
</tr>
<tr>
<td>3</td>
<td>Mathematical Description of Physical System</td>
</tr>
<tr>
<td>5</td>
<td>Noiseless Linear Measurement Instruments</td>
</tr>
<tr>
<td></td>
<td>a. Read-Out Component</td>
</tr>
<tr>
<td></td>
<td>b. Estimation System</td>
</tr>
<tr>
<td>4</td>
<td>Model Identification from Noise-Free measurements</td>
</tr>
<tr>
<td></td>
<td>a. Excitation from Identification</td>
</tr>
<tr>
<td></td>
<td>b. Identification Methods</td>
</tr>
<tr>
<td>4</td>
<td>Mathematical Models for Measurement System Errors</td>
</tr>
<tr>
<td>4</td>
<td>Measurement System Error</td>
</tr>
<tr>
<td>4</td>
<td>Noisy Measurement Instruments</td>
</tr>
<tr>
<td>2</td>
<td>Illustrative Practical Measurement Systems</td>
</tr>
</tbody>
</table>

30 Total

**Consideration in Evaluation of Course Content:** Because of the lack of students who have taken Sy.E. 410 and Sy. E. 411, this course is presently being offered without all of the required prerequisites. Consequently, approximately nine periods are presently used in this course to review mathematical tools for the analysis of deterministic and non-deterministic systems. It is anticipated that the prerequisite problem will be overcome when the program is more fully developed and matured.

**Future Plans:** The prerequisite problems discussed above will be overcome as the program is more firmly established.

**SY.E. 420 PHYSICAL SYSTEMS LABORATORY, 1-3-2**

**Objective of Course and Relation to Overall Program:** The physical systems laboratory is intended to provide some contact with actual physical systems and system components. Emphasis in this laboratory will be on mechanical
and electromechanical devices.

Sy E. 420 is planned for the senior year. This course has been taught one time to date and is essentially complete including the preparation of laboratory notes.

**EXPERIMENT NUMBER 1— MECHANICAL VIBRATION**

This experiment is concerned with demonstrating mechanical vibrations, and also with illustrating the use of frequency response techniques to determine mathematical models for relatively complex systems. A torsional vibrating system is part of the equipment available for this experiment.

**EXPERIMENT NUMBER 2— ROTATING COMPONENTS**

This experiment consists of transient and sinusoidal type tests of an interconnected group of rational mechanical components including a servo motor and gears connected in both an open and closed loop configuration. Electrical, hydraulic and mechanical components are also available for use in this experiment.

**EXPERIMENT NUMBER 3— PROCESS CONTROL**

The lab is equipped with a large water tank and controllers for both water level and water temperature. A simple on-off controller is used for water level and a three mode controller for temperature. This experiment demonstrates fluid and thermal systems and allows the student to become acquainted with the types of controllers used in the process industry.

**EXPERIMENT NUMBER 4— STATISTICAL PARAMETERS**

This experiment illustrates some of the principles of statistics and reliability. A Graeco-Latin model is used to determine the
statistically significant parameters that influence the outcome of an experiment, in this case the failure of a number of overloaded light bulbs. Additional equipment to measure the mean time to failure is also provided.

EXPERIMENT NUMBER 5- HUMAN FACTORS

This experiment is concerned with the problem of determining a mathematical model for a human operator performing a simple function. The experiment involves equipment consisting of two projectors and a screen. One of these projectors is programmed to give a predetermined motion to a projected image on a fixed screen. The other projector is manually operated and the operator is given the task of matching the programmed motion. After performing an experiment, a mathematical model is determined from the two recorded motions.

Considerations in Evaluation of Course Content: The considerations which have determined the experiments listed are the following: (1) The laboratory should expose the student to a variety of different types of physical devices and systems, (2) The lab should enable the student to gain experience in the use of modern laboratory measuring and recording equipment, and (3) The laboratory should provide the opportunity to apply some of the techniques learned in the previous systems courses.

Future Plans: The physical assembly of the laboratory is complete. Future offerings of this course will provide the student with well documented information and the experience of working with physical systems.

SY. E 425 CASE STUDIES IN SYSTEMS ENGINEERING, 2-6-4.

Objective of Course and Relation to Overall Program: Any complete elective program in systems engineering should contain some experience in actual
systems design. Some design problems can be included in courses such as Sy.E. 380 or the Systems Analysis sequence, but such problems must necessarily be of such limited scope. Each planned sequence of elective courses contains Sy.E. 425 to give each student the experience of making studies of all the aspects of a complete system.

As discussed elsewhere in this report, it has been necessary to offer students a great deal of flexibility in the amount of work in their elective programs. The Case Studies Course along with Sy.E. 380 and Sy.E. 381 has been chosen as an essential part of the minimum program A, and thus Sy.E. 380 and Sy.E. 381 as well as Sy.E. 390 followed by work in the systems analysis sequence are accepted as prerequisite material.

Presently this course has been taught two times, the first time during Spring Quarter of 1965 and for the second time during the Spring Quarter of 1966. A solution of a single large scale system was attempted during each offering. Although the students became involved in the solution of these large single system problems their experience was limited because time permitted them to work only on one project. Team effort was needed and emphasized in the solution of these problems.

Topical Outline

<table>
<thead>
<tr>
<th>No. of Periods</th>
<th>Topic Introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Work on a Systems Design Problem</td>
</tr>
<tr>
<td>20</td>
<td>Lectures on Important Topics in Systems Engineering (Decision making processes)</td>
</tr>
</tbody>
</table>

40 total

Considerations in Evaluation of Course Content: The project chosen for the system design problems should contain sufficient elements to give the student broad experiences in the design of a large scale system. Large complex systems should not be considered for this course unless the study is permitted to make simplifying assumptions. This type of problem should
also be discouraged because it tends to make the design problem unrealistic.

A large scale system design was initially attempted. During the Spring Quarter of 1967 the Sy. E 425 class joined a class of graduate students who had already worked one quarter on the design of a mass transportation system for the City of Atlanta.* This system was to be made capable of moving persons within the central business district of Atlanta after persons had disembarked from mass transit facilities which fed the city centers. The System Committee felt that this type of problem and its prior development led to a successful conclusion.

This course was taught by teachers and outside experts on a team basis so that the expertise of various disciplines could be used to help solve the complex system problem.

Future Plans: Future plans for the development of this course are concerned with the introduction of the Case Method of teaching. It is felt by the Systems Faculty that this teaching technique could prove to be quite valuable in this course. The Case Method of teaching has the ability to make the student think his way through a complex system design by considering the successes and failures of system design as illustrated by the Case Method. The Case Method will be employed when this course will be taught in the future.

IV. Conclusions from the Study to Date: Conclusions relative to the first general objective of the program: namely, that of determining the technical content of an elective program in systems engineering, are contained in the discussions of course content above and is summarized in Table 1. The purpose of this section is to discuss what has been learned so far with respect to the second general objective of evaluating

* See Downtown Atlanta Rapid Transit. A Graduate Project in Complex Systems Design. Completed by the students from the Georgia Institute of Technology, June 1967
the implementation of the elective program at a state university with strong disciplinary divisions.

The number of elective hours available to students in the different disciplinary schools at Georgia Tech varies from a minimum of 10 to a maximum of 33 quarter hours. Furthermore, each individual school presently holds tight control over most of these elective hours. Thus it is becoming more and more obvious that a change in the elective policies of the entire engineering college will be necessary to attract many students into a major fraction of the planned elective courses. The change would have to make it possible for students to substitute systems courses for what are now considered required disciplinary courses.

The Systems Engineering Program has already been adopted as an elective option within the School of Industrial Engineering and to some extent in the School of Electrical Engineering.

Thus rather than restrict the program to a fixed number of elective courses, the systems engineering faculty decided to offer the students a flexible curriculum with two major choices as to elective content. The elective programs resulted in the development of Program A and B and are shown in the appendix. In keeping with the fact that students are finding it difficult to free many hours for systems electives, the systems faculty made a critical examination of the planned courses with a view to eliminating those which are not exclusively systems oriented. This examination focused attention on Sy.E. 390, in the elective program. In addition course cross listings were considered. The study resulted in the cross listing of Sy. E. 416 with the already existing course, I.E. 334, Optimization Methods and the cross listing of Sy. E. 411 with the course, I.E. 335, "Applications to Probability"
The material contained in Sy. E. 390 is available in two other existing courses in the engineering college, Sy. E. 390 has been offered two times with a moderate degree of success. Future plans include extending the material in this course to build upon information obtained in more elementary computer courses offered on the Georgia Tech campus.

V. Other Activities of the Systems Engineering Committee: In addition to course development studies, the members of the Systems Engineering Committee also engaged in other types of activity which contributed to their professional competence and enable them to exchange ideas with persons from other universities and industry. In the past five years members of the Systems Engineering Faculty have attended and participated in numerous seminars and discussions which directly related to the systems engineering study at Georgia Tech. Members of the committee have also presented several papers dealing with the present study and other related topics to the subject of systems engineering.

VI. The Symposium on Systems Engineering: A Symposium was held on the Georgia Tech campus on October 23 - 24, 1968. The Symposium was concerned with a discussion of the following topics:

(a) Systems Engineering Program at Georgia Tech
(b) Systems Engineering Programs at Other Universities
(c) Systems Engineering and Systems Theory
(d) Role of Industry in Systems Engineering Education
(e) Systems Engineering and Design

The topics were discussed by leading authorities in various topics in systems engineering. A list of the speakers is as follows:
Speakers:

Dr. Harold Chestnut, Manager
Systems Engineering & Analysis Branch
General Electric Company
Schenectady, New York

Dr. Donald O. Covault
Professor of Civil Engineering
Georgia Institute of Technology
Atlanta, Georgia

Professor Arthur D. Hall, III
Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia

Dr. Arthur G. Hansen
Dean of Engineering
Georgia Institute of Technology
Atlanta, Georgia

Dr. Robert N. Lehrer, Director
School of Industrial Engineering
Georgia Institute of Technology
Atlanta, Georgia

Dr. Mihajlo Mesarovic
Head, Systems Engineering Division
Case Western Reserve University
Cleveland, Ohio

Dr. Allen B. Rosenstein
Department of Engineering
University of California
Los Angeles, California

Dr. A. Wayne Wymore
Department of Systems Engineering
University of Arizona
Tucson, Arizona

Professor Pranas Zunde
Chairman, Systems Engineering Program
Georgia Institute of Technology
Atlanta, Georgia
A copy of the Symposium program and persons attending the Symposium is shown in the Appendix B. Including the speakers and presiding officers, a total of 63 persons attended the Symposium. Eighteen of the participants were from various universities in the United States and the remaining represented various industries. These participants help to produce a very informative and stimulating program.

VIII. Plans for the Future: The purpose of this section is to summarize plans for the overall program. Reference to Table 1 gives the status of the courses in the Systems Engineering Program. As indicated by this table, all courses will have reached stage 4 in development with the exception of Sy. E. 412 and Sy. E. 413. It is estimated that when student demand develops these courses will be developed to stage 4.

On November 30, 1968, the grant from the National Science Foundation for the development of the Systems Engineering Program at Georgia Tech terminated. Georgia Tech will continue the program developed under the grant. Plans are now underway to develop the Systems Engineering Program as a formalized course of study with possible degree granting status. Various plans are also being developed with the School of Information Science in the offering of a graduate program in System Science. Tentative programs have also been suggested for a course of study in System Analysis. All of these proposals have been very tentative and the future development of the various ramifications of the present Systems Engineering Program to degree granting status is to some extent uncertain.

Placement of the Systems Engineering Program in the School of Industrial Engineering administrative structure has strengthened the program and has promoted a more secure basis of operation. This organization is expected to continue until the time the System Engineering Program reaches degree granting status and becomes a
department or school on the Georgia Tech campus.

The appointment of an interdisciplinary faculty will be encouraged and continued. In addition faculty will be acquired which will spend full time on systems engineering.

Dr. Pranas Zunde has been appointed Chairman of the Systems Engineering program. He replaces Dr. Donald O. Covault who was Acting Chairman of the Program.
Appendix A

Catalog Description of the Systems Engineering Program at The Georgia Institute of Technology

1968-1969
Systems Engineering Program

(Established in 1965)

The Systems Engineering program is administered by the School of Industrial Engineering, in conjunction with a campus-wide Committee which advises on the interrelationship between systems engineering and other engineering programs. It is an interdisciplinary activity dealing with systems implications of engineering, and may be elected as a planned option to supplement and complement curricula in any of the engineering schools. Dr. Pranas Zunde, Associate Professor of Systems Engineering and Information Science, serves as Chairman, Systems Engineering, and is available for consultation and advising students in planning Systems Engineering course work. A designated major in Systems Engineering is currently being planned.

What is Systems Engineering?

Systems engineering emphasizes the coordination of man and machines in complex arrangements. It is largely a development of the last 25 years and has received impetus from the building of defense systems and the rapid development of other forms of modern technology. Computers and automated equipment play a role in virtually all systems engineering efforts.

The concepts of systems engineering are as important today for civil engineers designing complicated highway systems as they are for electrical engineers devising sophisticated communication systems. Teams of engineers and scientists use systems engineering principles to build the systems that make possible flights of missiles, to develop transportation systems and many other complex jobs.

Planned Systems Engineering Programs

Two elective programs in systems engineering are offered. Program A consists of 10 quarter credit hours of course work. This program has been tailored for students who have a limited number of elective hours and who wish to obtain a basic knowledge of systems engineering. Program B involves a minimum of 15 quarter credit hours of course work and has been tailored for students who want to study more about the mathematical bases of systems engineering and who would like to go on to more advanced work in the field. An additional 20 quarter credit hours of advanced work is also available as part of this program.

Case Studies in Systems Engineering (Sy.E. 425) is contained in both Program A and B. This course gives the student an opportunity to design a system as a member of a design team, and illustrates the important team approach required in the solution of systems engineering problems.
PROGRAM A

Course                          Credit Hours
Sy.E. 380 Systems Engineering I ................. 2-3-3
Sy.E. 381 Systems Engineering II.................. 3-0-3
Sy.E. 425 Case Studies in Systems Engineering .... 2-6-4

Total .................................... 7-9-10

PROGRAM B

Course                          Credit Hours
Sy.E. 380 Systems Engineering I ................. 2-3-3
Sy.E. 410 Systems Analysis I ...................... 4-0-4
Sy.E. 411 Systems Analysis II ..................... 4-0-4
Sy.E. 425 Case Studies in Systems Engineering .... 2-6-4

Total .................................... 12-9-15

ADDITIONAL COURSES

Course                          Credit Hours
Sy.E. 390 Computer Methods in Systems Engineering.... 2-3-3
Sy.E. 412 Systems Analysis III ...................... 4-0-4
Sy.E. 413 Systems Analysis IV ....................... 3-3-4
Sy.E. 416 Optimization Methods ..................... 3-3-4
Sy.E. 417 Modeling and Measurement .................. 3-0-3
Sy.E. 420 Physical Systems Laboratory .............. 1-3-2

Total .................................... 17-9-20

Courses of Instruction

Note: 2-3-3 means 2 hours class, 3 hours laboratory, 3 hours credit.

Sy.E. 380. Systems Engineering I
2-3-3. Prerequisite: Math. 304, or concurrent.

As an introduction to the theory of systems engineering, this course is designed to acquaint the student with the scope of activities and the fundamental concepts and definitions involved in systems engineering.

Basic theoretic notions necessary for analytical treatment of engineering systems are presented. The concepts of systems, sub-systems, and components are defined; and illustrative systems, both deterministic and non-deterministic, from several fields are presented and analyzed.
Sy.E. 381. Systems Engineering II
3-0-3. Prerequisite: Sy.E. 380
A continuation of Sy.E. 380.
Topics in engineering economy, decision, theory, optimization of systems, system reliability evaluations, and network planning will be discussed. The construction of state equations for systems will be emphasized.

2-3-3. Prerequisite: Math 304
An introduction to the operational characteristics of analog and digital computers will be presented. Fundamental machine operations are discussed and related to the numerical solution of equations. Emphasis is placed on problem formulation. Elementary principles of machine programming will be given.

Sy.E. 410, 411, 412, 413. Systems Analysis I, II, III, IV
4-0-4. Prerequisite: Sy.E. 380 or consent of instructor.
This sequence of courses presents a unified treatment of analytical techniques for the analysis, design, and reliability evaluation of systems. Mathematical models will be developed which describe the characteristics of classes of linear and non-linear deterministic and non-deterministic systems. Analytical and numerical techniques for treatment of these models will be presented. Application will be made of such topics as linear algebra, operational mathematics, probability, statistics, and approximation methods. Input-output analysis, response and stability characteristics of systems will be stressed. (Sy.E. 411 is cross-listed with I.E. 335 Applications of Probability.)

Sy.E. 416 Optimization Methods
3-3-4. Prerequisite: Sy.E. 411
Techniques for system and subsystem optimization are presented with emphasis on methods yielding practical numerical procedures.

Specific topics include: linear and dynamic programming, steepest ascent or descent procedures, procedures using the calculus of variations, miscellaneous search techniques. (Sy.E. 416 is cross-listed with I.E. 334 Optimization Methods.)

Sy.E. 417. Modeling and Measurement
3-0-3. Prerequisite: Sy.E. 411.
Construction of mathematical models for systems using measured data will be discussed. The characteristics and use of physical measuring instruments and the statistical theory of measurements will be presented in a unified manner. The effect on the models of measuring instruments and errors in measurement will be studied.

Sy.E. 420. Physical Systems Laboratory
1-3-2. Prerequisite: Sy.E. 417.
This is a laboratory course designed to give the student experience with systems composed of components from several fields. The work will include experiments with mechanical, electrical, hydraulic, chemical, pneumatic, and human elements. The experiments will be designed to illustrate important concepts of systems engineering covered in prerequisite courses.

2-6-4. Prerequisite: Sy.E. 381 and Sy.E. 390 or equivalent and senior standing.
Selected engineering problems are to be solved using systems procedures and concepts. A multidisciplinary team will be assigned to each problem. Specific knowledge in component design and analysis techniques is required. The laboratory periods will be used for the design of a system and the lecture periods will be used to present specific systems engineering topics.
Appendix B

PROGRAM AND PARTICIPANTS
FOR THE SYMPOSIUM ON SYSTEMS
ENGINEERING

October 24-25, 1968

Held on the Campus of the
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia
Friday, October 25, 1968

Presiding: Herman E. Koenig

9:00 Problems of Defining a Systems Program at a Technological Institute
    Arthur G. Hansen

10:15 Coffee Break

10:30 The Role of Systems Theory and Systems Engineering in Systems Design - Allen B. Rosenstein

12:00 Lunch

Presiding: Lotfi A. Zadeh

1:30 The Role of Industry in Systems Engineering - Harold Chestnut

3:15 Coffee Break

3:30 Systems Engineering Concept - Its Extensions and Intentions
    Arthur D. Hall, III

4:30 Adjourn
PROGRAM FOR SYSTEMS ENGINEERING SYMPOSIUM

GEORGIA INSTITUTE OF TECHNOLOGY

Thursday, October 24, 1968

Presiding: Robert N. Lehrer

8:30 Registration

9:10 Welcome Address: Edwin Harrison

9:15 Remarks: Robert N. Lehrer

9:30 Systems Engineering Program at the Georgia Institute of Technology

Donald Covault

10:30 Coffee Break

Comments:

Joseph Hammond Sy. E. 380
Joseph Krol Sy. E. 381
Thomas White Sy. E. 390
Stephen Dickerson Sy. E. 410
William Hines Sy. E. 411
Stanley Aaronson Sy. E. 416
Joseph Hammond Sy. E. 417
Eugene Harrison Sy. E. 420
Donald Covault Sy. E. 425

Discussion

12:00 Lunch

Presiding: Richard F. Vidale

1:30 Survey of Systems Engineering Programs - Pranas Zunde

2:30 Model Curriculum in System Engineering and System Theory - A. Wayne Wymore

3:30 System Theory as an Academic Discipline - Mihajlo Mesarovic

5:00 Adjourn

7:30 Workshop on Systems Engineering
ATTENDANCE

SYSTEMS ENGINEERING SYMPOSIUM

October 24-25, 1968

GEORGIA INSTITUTE OF TECHNOLOGY

Atlanta, Georgia

1. Stanley Aaronson
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Atlanta, Georgia

2. H. L. Ablin
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Lincoln, Nebraska

3. O. S. Adams
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4. Gyan C. Agarwal
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Department of Systems Engineering
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Chicago, Illinois 60680

5. Cecil O. Alford
School of Electrical Engineering
Georgia Institute of Technology
Atlanta, Georgia

6. Robert N. Braswell
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Gainesville, Florida 32601

7. Herbert Callister
Picatinny Arsenal
Training Officer on Systems
Dover, New Jersey

8. Robert C. Chandler
Manager, Systems Engineering
Helicopter Dev. Dept.
Boeing Company
Philadelphia, Pennsylvania

9. Harold Chestnut
General Electric Company
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10. Chung Chiang
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Department of Mechanical Engineering
Houghton, Michigan 49931

11. Gilmoure N. Cole
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East Hartford, Connecticut 06108

12. Donald O. Covault
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Georgia Institute of Technology
Atlanta, Georgia

13. Jose B. Cruz
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Department of Electrical Engineering
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14. Jerry L. Dake
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Atlanta, Georgia

15. Margaret E. Dexter
School of Information Science
Georgia Institute of Technology
Atlanta, Georgia

16. Stephen Dickerson
School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, Georgia

17. Gary Draper
School of Industrial Engineering
Georgia Institute of Technology
Atlanta, Georgia

18. John J. Dunn
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20. Milutin Gavrilov  
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Atlanta, Georgia

21. E. B. Gibson  
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Lockheed-Georgia Company  
Marietta, Georgia  30060

22. P. C. Greenlee  
Department 72-08, Zone 460  
Lockheed-Georgia Company  
Marietta, Georgia  30060

23. Arthur D. Hall, III  
The Moore School of Electrical Engineering  
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Philadelphia, Pennsylvania  19104

24. Joseph Hammond  
School of Electrical Engineering  
Georgia Institute of Technology  
Atlanta, Georgia

25. Arthur Hansen  
Dean of Engineering  
Georgia Institute of Technology  
Atlanta, Georgia

26. Edwin Harrison, President  
Georgia Institute of Technology  
Atlanta, Georgia

27. Eugene Harrison  
Clemson University  
Clemson, South Carolina

28. William W. Hines  
School of Industrial Engineering  
Georgia Institute of Technology  
Atlanta, Georgia

29. Edward F. Howard  
Office of the Technical Director  
U. S. Navy Underwater Sound Laboratory  
Fort Trumbull  
New London, Conn.  06320

30. Jose Irastorza  
School of Industrial Engineering  
Georgia Institute of Technology  
Atlanta, Georgia

31. John Jarvis  
School of Industrial Engineering  
Georgia Institute of Technology  
Atlanta, Georgia

32. H. E. Koenig, Director  
Systems Science Program  
Michigan State University  
East Lansing, Michigan  48823

33. Melvin B. Kline  
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7620 Boelter Hall  
Department of Engineering  
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35. Richard Leatherwood  
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36. Robert N. Lehrer, Director  
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37. J. M. Liittschwager  
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