AUTHENTIC INVOLVEMENT IN INTERDISCIPLINARY DESIGN

PROCEEDINGS

THIRD CONFERENCE ON ENGINEERING DESIGN EDUCATION

AUTHENTIC INVOLVEMENT IN INTERDISCIPLINARY DESIGN

JULY 12 and 13, 1965

AT CARNEGIE INSTITUTE OF TECHNOLOGY - PITTSBURGH, PENNA.

SPONSORED BY THE CARNEGIE INSTITUTE OF TECHNOLOGY
AND THE COMMISSION ON ENGINEERING EDUCATION

FOREWORD

The Third Conference on Engineering Design Education was held at the Carnegie Institute of Technology on July 12 and 13, 1965. The theme of the Conference, "Involvement in Interdisciplinary Design," reflects the fact that design is a universal ingredient in engineering activity—and illustrates the view of the Conference organizers that design education is most effectively accomplished where students are confronted with an authentic involvement in a design experience.

The first two Conferences on Engineering Design education were held at the Case Institute of Technology in 1960 and the University of California at Los Angeles in 1962.* Their respective themes were devoted to the "definition of Engineering Design, the Engineering Design Process, and the Engineering Designer," and to a diverse group of papers on "Research in Design," design theory and pedagogy, and examples of industrial experience.

The Third Conference focused its attention on a critique and dissemination of results of the NSF-sponsored Design Laboratory Workshops held at Carnegie, Case, Dartmouth, M.I.T., University of California, Berkeley, and U.C.L.A. during the summer of 1965. The primary goal of the Workshops was faculty development—to determine whether faculty, many inexperienced in engineering design education, could successfully guide their own students through unstructured design projects. Workshop participants described their experiences, and four experts in design-related fields who had visited the Worshops presented their impressions of the program. One session of the conference was devoted to a discussion of the Case Study approach to design education being developed at Stanford. Several invited guest lecturers described how interdisciplinary design is accomplished in some of the nation's major industries.

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* Copies of the *Proceedings* of the 1960 Conference are available from the American Society for Engineering Education, 1346 Connecticut Avenue, N.W., Washington, D.C. A very few copies of the *Proceedings* of the 1962 Conference are still available from the Division of Engineering at U.C.L.A.

The Conference was sponsored jointly by the Carnegie Institute of Technology and the Commission on Engineering Education through its Committee on Authentic Involvement in Design. The Conference Committee was composed of:

Lawrence N. Canjar, Chairman
Richard B. Barnhart
William W. Ellis
Stephen L. Rosen
Wilfred T. Rouleau

all of Carnegie Institute of Technology.

The Committee on Authentic Involvement in Design is composed of:

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The proceedings of the Conference have been compiled and edited by Peter Z. Bulkeley, Stanford University. Following initial distribution, copies are available from the Commission on Engineering Education, 1501 New Hampshire Avenue., N.W., Washington, D.C, 20036. Inquiries for further information about any of the Design Laboratory Workshops should be directed to the Director(s) of the Workshop(s) involved, or to any of the visiting faculty participants in the Workshop program.

The Committee on Authentic Involvement in Design and the editor are grateful to Mrs. Jean P. Moore, Commission on Engineering Education, for her assistance in preparing copy and in developing the format of these Proceedings.

Peter Z. Bulkeley
September 17, 1965

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PART I—INTRODUCTION

Today's technology has resulted in a vigorous upgrading of engineering education in pure and applied science and mathematics. The emphasis on science, however, has been made at the cost of Design and practically oriented subjects. Courses whose material is largely "state of the art" have lost favor with many engineering educators.

Recently, however, there has been an awareness that Design is an essential characteristic of the engineering curriculum and may be in fact the distinguishing characteristic. Design embraces the diversity of analytic knowledge obtained from engineering science courses. This was emphasized by Dr. H. Guyford Stever, President of Carnegie Institute of Technology, in his welcoming comments to the participants in the Third Conference on Engineering Design Education:

> "I once was one of those who believed that the only important part of engineering education had to do with engineering science. Now I'm completely convinced that an engineer's education just isn't education . . . unless it has not only a lot, but a very powerful portion of it in design. In fact, that's the unique part of engineering education."

These comments keynote the fact that Design cannot be subjugated entirely to science or analysis or mathematics.

Many opinions exist about how best to teach Design. The mixture of pedagogical components used in design courses vary markedly from school to school. One approach, that of involving the student in an actual design experience in the laboratory, has received acceptance and is the subject of much experimentation. In his welcoming comments to the participants in the Third Conference on Engineering Design Education, Dr. B. Richard Teare, Jr., Dean of the School of Engineering and Science at Carnegie Institute of Technology, said this about involvement in design: "If you agree that students learn by what they do, then they have to be involved directly in design themselves." Few argue that this is not a desirable objective in the design portion of an engineering curriculum. However, the depth and intensity of involvement and the way in which it is introduced into a student's coursework is still the subject of considerable discussion. The Third Conference on Engineering Design Education was intended to be an expository display of the involvement practiced at a few leading schools.

Preliminary to the conference, with National Science Foundation support, Workshops in Design-Education, each representing a slightly different view of involvement in design, were held at Carnegie Institute, Case Institute, Dartmouth, M.I.T., University of California, Berkeley, and U.C.L.A. The approaches taken by these schools formed the primary basis for the Conference discussions.

Each of the Workshop host schools adopted a project format for much of its program, although the projects varied from broad system concepts to detailed hardware to the writing of individual case histories. Characteristics common to all projects included their broad interdisciplinary structure, reflecting contemporary engineering practice. In addition each project was a design response to a verifiable need. They were not merely contrived exercises. These two facts demonstrate evolution from the "paper design" projects in mechanical design commonly used in years past. Today's design experiences are at once more catholic in scope and more authentic in formulation.

There was common agreement at the Carnegie Conference that involvement is an essential ingredient of effective design education. However, the different points of view presented indicate that no standardized approach best fits the needs and local environments of all schools. In particular, different opinions were expressed about the following:

Level — At what level should design be introduced into the engineering curriculum? Should it weave a continuing thread throughout a student's undergraduate and graduate years or should it be applied in a discrete package?

Structure — Should a step-by-step morphology of design be emphasized or should a design "way-of-thinking" evolve from students working in design situations?

Lectures — Should design-oriented courses rely on formally structured lecture programs, or should lecturers be used only where there is a "need-to-know" apropos a specific project?

Projects — What type of projects are best suited to teaching of design? Do those with broad system implications have greater educational value than those with specific hardware orientation? Or is it more effective to use case studies in partial substitution for project type work? Should the choice of project be left to the student, or should a common project be enforced upon all? Should the instructor look to industry as the source of projects, or should the faculty and/or students generate their own topics?

Group Size — Should students be encouraged to work singly on projects or collectively in small groups? Should student groups be mixed, combining disciplines and classes?

Authenticity — To what degree should projects be contrived by the faculty? Should they comprise actual experience in an on-going design (research) effort, or should they be ad hoc artifacts derived by the instructor? Should the involvement be with a "paper design" or in an actual confrontation with nature in the laboratory?

Realizability — How far into practical realization should a project go? Is the manufacture of a prototype an essential component of the design experience?

The Carnegie Conference highlighted several areas of agreement among its participants. Foremost was the feeling that Design is not the parochial property of a single discipline. Rather, it freely crosses boundaries of conventional departmental organization. It was encouraging to note the eagerness with which the elements of design experience are being accepted by and adapted to the individual needs of many different curricula.

The need for outstanding staff in design education was expressed by many conference participants. It appears that the main concern of engineering educators is no longer whether to teach design, but how best to teach it and by whom. Thus the primary problem has become one of identifying, training and/or recruiting that staff technically and psychologically prepared for engineering design instruction. A recent hope that industry itself could be a significant source of engineering practitioners qualified and willing to teach has not materialized. The search for such people must go on, but clearly the yield will not be adequate to the needs of engineering design education. The substantial burden of design teaching inevitably must be borne by faculty members having little actual professional design experience.

The Workshops this past summer successfully demonstrated one technique for augmenting the competence of faculty normally familiar with the content and techniques of more parochial, engineering science analytical subjects. Faculty otherwise unfamilar with design education could and did, in a short space of a few weeks, undertake with their own students a wide variety of engineering design project work.

In the type of "involvement" practiced at the NSF-sponsored workshops, the student and his instructor either jointly or in liaison approached the design problem. This required the intensive personal involvement of the instructor—a time consuming but often exhilarating job. Concern was expressed by virtually all participants that this type of effort, while of obvious educational merit, requires special administrative study—how can the staffing requirements of project involvement and interdisciplinary design be reconciled to the exigencies of engineering science-oriented curricula and academic budgets?

There is no question that this type of design education demands more student contract hours than those commonly encountered in lecture course work. However, the nature of the engagement for the professor is quite different. Lectures demand careful preparation; homework, quizzes and final examinations as integrated elements of an educational process require much preparation, grading, and discussion time. However, in the involvement type of design education, the professor, together with his students, is confronted with a nouveau situation; inordinate preparation by the professor destroys the novelty and spontaneity of the educational experience for the student. Thus, the total time committed to disciplinary subjects, including preparation and grading, may not be significantly different from the total time committed to design.

The real value of the education derived from this experience must be equated in terms of effectiveness compared to cost. Cost is the more easily qualified, but in the long-run effectiveness establishes the quality of an education and, in turn, the character of that education.

In Part II of these Proceedings each of the Workshops is described in detail by one of its own participating faculty. The philosophy and organization of each Workshop is unique—yet they all derive from the tenet that involvement is essential to design education. The value judgment of which version of involvement best suits his own environment is, of course, left to the reader. However, a brief comparison of the various Design Workshops is included at the end of the section—together with a sampling of comments which arose concerning them at the Carnegie Conference.

These Proceedings of the Third Conference on Engineering Design Education include two components in addition to discussion of the NSF Design Workshops. The first of these, Part III of the Proceedings, is a discussion of the "Case Method" approach to engineering education, particularized here to design education. The results presented derive partly from the Berkeley Workshop and partly from an NSF-funded program in case development at Stanford University. Part IV of the Proceedings contains, in whole or part, the texts of invited papers presented at the Carnegie Conference by several speakers from industry.

PART II—DESIGN LABORATORY WORKSHOPS

In response to problems imposed on educators by accelerating technological sophistication in engineering, the Boulder Conference of August, 1961, proposed the establishment of a Commission on Engineering Education whose charge, in part, was

> "To develop . . . effective programs for faculty development in . . . the processes of instructing and learning relative to engineering education." *

Prominent among the topics discussed by the conferees was Engineering Design:

> "The design process and its elements need to be studied, improved, and above all, taught to student engineers. Student engineers need the opportunity to participate in design experiences which are optimum when authentic . . ." *

Following the Boulder meeting, a committee was established under the auspices of the Commission: the Committee on Authentic Involvement in Design. Its name describes its primary objective—to implement the ideas expressed in the quotations excerpted above.

Meeting in Hanover in 1963, the Committee pondered on the experience of an Engineering Design Education Workshop, presented by and held at M.I.T. under sponsorship of NSF in the summer of 1962. This Workshop, attended by 75 educators from the United States, Canada and Great Britain, emphasized lecture presentations of design projects and design analyses, normally done by students under faculty counsel. During the Workshop the faculty attendees were also encouraged to carry out projects on their own, much as they would ultimately expect their own students to do. The propensity of the attendees at the Workshop was to listen rather than to involve themselves in design. This foretold the subsequent, rather disappointing transfer of the design education techniques carried back to the home campuses of the visitors.

The next step was clear—to involve faculty with their *own* students in authentic engineering project situations at sponsor institutions, under the guidance and support of faculty experienced in this type of design education. It was hoped, if visiting faculty could successfully negotiate their own students through an unstructured situation under the friendly auspices of the host institution, these same faculty would have a high probability of successfully transplanting some of the techniques learned to their home environments. This was the basic philosophy underlying the Design Laboratory Workshops held during the summer of 1965.**

The host schools for the Workshops reflected the membership of the Committee on Authentic Involvement—they were Carnegie Institute of Technology, Case Institute of Technology, Dartmouth College, Massachusetts Institute of Technology, and the Univer-

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* Boulder Conference proceedings are contained in the *Journal of Engineering Education*, vol. 52, number 9, May 1962, pp. 624-641.

** The Workshops were originally planned for 1964, but were postponed to insure a wider selection of faculty applicants.

sity of California, both Berkeley and Los Angeles campuses. While each of these schools submitted its own proposal for NSF support, they were combined and processed as a unit. Coordination of the over-all program and direction of its common aspects was assumed by the Commission on Engineering Education.

Following a widely disseminated general description of the program and solicitation of candidates, the faculty participants, and subsequently their students, were selected for each of the six Workshops. A planning session brought the visiting faculty to his host school prior to the beginning of the Workshops. The Workshops themselves comprised four weeks in late June and early July followed immediately by a terminal meeting to exchange and reinforce the Workshop experiences. This terminal meeting was combined with and constituted a major part of the Third Conference on Engineering Design Education held at Carnegie Institute on July 12-13, 1965.

The Workshop experiences in "authentic involvement" were augmented by lectures given by four experts in avant-garde "design theory" disciplines. These experts spent two days at each host school, lecturing on their specialty and participating in Workshop activities in whatever ways were found most useful. The experts and their topics were:

S. A. Coons, *Massachusetts Institute of Technology;*
Computer-Aided Design
R. L. Prince, *Lockheed Aircraft Corporation;*
Optimization in Design
E. E. Smith, *Serendipity Associates;*
Decision-making, Approached from the Psychological Point of View
L. A. Schmit, Jr., *Case Institute of Technology;*
Automated Optimum Design of Structures

In the sections to follow, each of the Workshops is described in detail by members of its host faculty. Included in each is a commentary on objectives and general remarks on the effectiveness of this mode of design education. Following the Workshop descriptions is a brief section comparing the Workshops, with comments based upon interviews and correspondence with Workshop participants, and excerpted remarks from participants at the Carnegie Conference.

CARNEGIE INSTITUTE WORKSHOP

By R. R. Rothfus

The Workshop at Carnegie shared, with the other Workshops, the common goal of "demonstrating that authentic design opportunities can be created and undertaken successfully in an academic setting." It also shared as a central theme "the direct personal involvement of the students in original engineering design situations." More specifically, however, the program at Carnegie addressed itself to the realistic and pressing question of how the expanding need for involvement in design can be met when the number of faculty having had actual design experience is seriously limited. The need for faculty must outstrip the supply of experienced people if design activity is to assume its rightful priority in engineering curricula. For this reason relatively inexperienced teachers must be called on to perform meaningfully in the design area.

* The Dartmouth proposal differed somewhat from the general format and was processed individually. Their Workshop was nine weeks long, straddling the Carnegie Conference and they did not participate in the "visiting experts" program.

Several items are of immediate concern. *First* is the development of proper concepts and attitudes in the student. It is a valid goal to produce a graduate who can transfer basic concepts to useful application and who recognizes and accepts his legitimate responsibilities as an engineer; however, to do this he must develop some conceptual judgment about the processes with which he deals and some confidence in his ability to obtain useful results when the situation is incompletely structured. *Second* is to make the faculty member's involvement in design an authentic experience. In general, this means that he cannot work as an authority out of a particular center of competence. Rather he must become involved with total problems, as a designer, thus opening a dialogue which is a profitable learning experience for him and his students alike. *Third* is the development of honest respect for engineering end-points by the faculty member and his associates. Only to the extent that individual teachers feel their involvement in design represents a respectable level of personal accomplishment will they spread genuine enthusiasm for design to the rest of the faculty and to the students.

The Workshop at Carnegie sought to clarify an approach to these concerns. A design situation was evolved to demonstrate that inexperienced faculty and ordinary students, with only the usual facilities of an academic setting, can mutually gain valuable concepts of the nature of design and also the confidence and enthusiasm necessary for a successful engineering career.

The Faculty

Dean L. N. Canjar, the initial director of the project, and Professor R. R. Rothfus, who later directed it, are chemical engineers by training and experience. Both have been involved in the design of chemical processes and equipment in both industrial and academic contexts. Except in a substituting role, however, neither was involved personally with day-to-day instruction during the workshop.

The five participating faculty members, each responsible for supervising a group of four or five students, and their fields of major interest were as follows:

Donald A. Gall, Assistant Professor, *Carnegie Institute of Technology*, control systems engineering.

Arthur C. Haman, Assistant Professor and Acting Head of the Department of Mechanical Engineering, *University of Detroit;* thermodynamics and combustion engineering.

Leo A. Padis, Associate Professor, *Virginia Polytechnic Institute;* kinematics, vibrations and machine design.

Roger W. Schiller, Instructor, *Pennsylvania State University;* mechanical design, kinematics and dynamics of machinery.

Theodore A. Terry, Assistant Professor, *Lehigh University;* machine design, mechanics, thermodynamics, control.

All had experience in industrial employment, consulting, or course development in addition to normal teaching experience.

In summary, the participating faculty had a solid background of experience, coupled with special competence in one or more of the usual areas of mechanical engineering. It is important to note, however, that in no case could the faculty member be considered an expert in the type of design being done.

The Students

There were twenty-four students in the Workshop, about an equal number from each of the five colleges represented by the participating faculty. Fifteen of the students were upperclass undergraduates, six had just received baccalaureates, and three were graduate students. As for their major fields, sixteen were mechanical engineers, three were chemical engineers, one was in a five-year program of arts and mechanical engineering, and there was one representative from each of the aeronautical, aerospace, electrical and industrial engineering disciplines.

On the whole, these students had earned above-average academic records at their respective schools. It is fair to say that they came to the Workshop with a more variable history of motivation than of scholastic ability.

Most of the students with a mechanical engineering background had taken what might be called the standard courses in kinematics, dynamics and the like. Those who had completed the baccalaureate had, usually, taken a senior project course concentrated in the machine design area. Students in other curricula had taken corresponding courses. Only a very few of the students in any discipline had ever been involved in a design project having an open-end solution. None had participated in a design situation similar to that of the Workshop.

The students were divided into four groups of five and one group of four persons, each group under the supervision of a member of the participating faculty. In arranging group assignments before the start of the Workshop, selections were based on the idea that each group should be as heterogeneous as possible internally. In addition, the predicted abilities of the groups relative to one another were balanced as well as the available information would permit. None of the groups brought any special knowledge or ability into the solution of its problem; nor did any instructor have any pre-established rapport with the majority of students under his supervision.

The Problems

At the planning meeting of faculty members and staff, Professor P. Conley of Carnegie proposed that certain problems in the realm of public interest might lend themselves to the Workshop experiment. His suggestion was accepted. It was decided to concentrate on the general subject of the disposal of solid wastes; in particular, the following five areas:

Household trash
Junk autos
Building demolition wastes
Snow removal
Incinerator design

Although they could be handled as separate problems, these items were interconnected by a common overlay, and some were closely enough related to breed arguments and opposing views of the same situation. On the other hand, they were different enough to be useful in demonstrating that the design process involves common factors, regardless of the details of the problem at hand.

In each case the problem area was of current interest and was the subject of recent literature. Little more than this fact was stated to the groups initially. The students were therefore left with the necessity of seeking the design problem as a starting point.

Conduct of the Workshop

An important part of the Workshop's impact was to come through comparison of how people with different backgrounds attack the same or different design situations. It was, therefore, of first importance to keep lines of communication open from group to group and from person to person. Each group met by itself in a separate workroom with the services of the instructor available at all times. Individuals and groups were free to communicate with one another and were encouraged to do so. In addition, there was a joint meeting of all the groups at the end of each week to present oral progress reports and to exchange information. This fostered a spirit of competition without setting groups directly against one another. The housing of students was arranged to promote easy communication in the evening hours; a significant amount of work was accomplished on this overtime basis.

The relationship of the faculty and students was not specified beforehand. Rather, each instructor was encouraged to seek for himself the kind of mutual involvement needed to make the design opportunity valuable in terms of its ultimate objectives. Daily discussions were carried on between the Director and the instructors and there was a free exchange of experiences among the faculty. The faculty members were provided with office space in the same immediate area and this proved to be a worthwhile means of keeping the lines of communication open.

The instructors were alert, interested, and open-minded. Consequently, they readily relinquished their traditional role of control of their groups in the interest of the project and acted, instead, as guides and advisors. Sometimes they offered suggestions which the students could accept or reject; sometimes they were the conscience of the group; sometimes they represented the public, the profession, or the client, to emphasize a point of ethics or responsibility. It was a healthy relationship and the students reacted well to it.

In addition to the weekly progress meetings, the groups met jointly for guest lectures and for a final report meeting on the last day of the Workshop. Each group submitted a complete, written report of its total project. The instructors saw to it that everyone shared in giving the oral progress reports, so each student was called on at some time to defend his views at a joint meeting. Otherwise, the groups were free to organize as they saw fit and to distribute the work load according to their own evaluation of their associates. It turned out that the variety of personalities within the groups was fortuitous; many good arguments and discussions lasted far into the night.

The general facilities at Carnegie, including laboratories, shops, computers, and libraries, were made freely available to the students. In no case, however, were any special aids employed which would not ordinarily be available on their home campuses. The students were permitted and encouraged to make contacts with industrial, governmental, and academic sources for pertinent information. Some of the groups arranged meetings with city and county officials and visited working installations in the area.

Progress of One Group

It is impossible to deal with all of the projects here, but the experiences of the group concerned with household trash can be considered as an example. This group, under the supervision of Professor T. A. Terry, contained four mechanical engineers and one aeronautical engineer; two students were undergraduates, two were newly graduated, and one was a graduate student. Each of the five came from a different participating school.

When the group was initially faced with the prospect of devising a proposal for dealing with household trash, their first response was to "blue sky" the topic ineffectually. Their second response was to find out something substantive about household trash by going to the literature. This uncovered some real needs for dealing with the problem, but it also pointed up extreme technical and socio-economic difficulties associated with it. At this point frustration prevailed; it took careful handling to keep the group from embracing the easy refuge of current practice. Gradually, obstacles were cleared away and, although there remained an occasional tendency to retreat, a valid appraisal of the problem unfolded.

An analysis of current practices was made in three areas: collection, transport, and disposal. A classification of refuse was developed. The average composition of refuse was considered, along with the characteristics which determine how trash is handled in various localities. In short, an overview of the household trash disposal system and variables was developed. To complete the data,the cost distribution of present methods was examined. The group looked at future trends in refuse disposal, both from the standpoint of predicted quantities and from the standpoint of suggested methods for dealing with them.

Having defined the problem and examined a broad range of possible approaches, the group reduced the alternative solutions to three. These were really extensions of existing processes, but their choice was now a valid one in view of the time constraints and the available data; it no longer represented a simple retreat from a difficult decision. The three proposals were then evaluated, basing judgment on a cost analysis applied to an actual city suitable for use as a general model.

At this point the problem had been rendered tractable; the decision about which proposal to pursue in depth could be made on a rational basis. Specifically, attention was directed toward the design of a disposal-type of unit for home installation which would accept the normal daily volume of trash, grind and flush it into existing sanitary sewers. Further work was directed toward the areas of feasibility, mechanical design, and public appearance.

The group made a careful investigation of the modifications which might be required in sewage lines and treatment plants. The idea of dumping ground-up refuse into the existing sewage system was repeatedly challenged by the students in other groups. The effect was good—the household trash people extended themselves in order to prove their contention. First they met with treatment plant officials of the Allegheny County Sanitary Authority to get opinions about line capacities and overload problems. Then they examined experimental data obtained by the Los Angeles County Sanitary Authority and by people interested in solids pipelines. Still not satisfied, the group went to the laboratory and ran an actual experiment.

They could find no information about how chopped tin cans and broken glass might behave in a sewage line. To answer the question, they set up a model flow channel and ran tests with solid materials of various sizes, shapes, and densities. Using parameters of average particle size, slope of the channel, and average linear velocity of the flow, they established the limits of the flow, transitional, and no-flow regimes. Their results indicated that metal chips should pose no special problem when disposed of in a sewage line which handles other typical solids satisfactorily.

The mechanical design of a household unit was undertaken in the light of constraints developed by the group, since they felt that only a design study would determine the feasibility of a home-sized unit. A reasonable machine was designed which included some small but significant innovations having to do with safety. A sequence of operations was evolved and the necessary control system was devised. Materials were specified and complete weight and cost estimates were developed. Including a water saving device and allowing for a reasonable profit for the manufacturer, the price of the proposed unit was just under four hundred dollars, quite a realistic figure.

As the final step in their solution, the group considered problems having to do with acceptance and public relations. Recommendations were made for introducing the proposed unit in certain types of residential areas and for modifying associated services appropriately. Comments were also made about publicity, centralized units, and the time pattern conversion to the new scheme.

Reaction of Students

Most of the students (and faculty, too, for that matter) were surprised by the Workshop, since they had expected to deal with relatively well-defined problems of machine design. On the whole the Workshop was considered a worthwhile experience, with implications for their future work in engineering. Most pointed out that they came to realize that the formulation of a design problem is a difficult matter not stressed in their previous courses.

It is clear that the students were initially frustrated by the lack of structure and by the open-ended characteristics of their problems. A few never quite recovered, but the majority entered with good effect into the business of defining the problem and making it tractable. As they went along, their confidence increased remarkably, and with it their enthusiasm for the job at hand. At the end, a large majority of the students expressed the opinion that unstructured problems can be used effectively in design courses. About sixty per cent of the students favored long design problems over short ones because more complete involvement is implied. There was general agreement that with ordinary time constraints there should be some short problems emphasizing particular factors but also a long project covering the whole design sequence. The point here is that the students recognized a need for being involved in a complete design opportunity.

The majority of students were completely satisfied with their relationship to the instructor during the Workshop, and with his role in the project. A few were quite disturbed by the fact that the instructor brought no special competence to the group and did not occupy the traditional seat of authority. Almost all of the students were well pleased with the chance to work in a heterogeneous group. They particularly like the vigorous exchange of ideas which kept individuals from stagnating.

Conclusion

It is clear that the Workshop actually attained those of its objectives which can be demonstrated promptly. Whether long-range value is achieved rests squarely with the continued response of the faculty to the design experience.

The five instructors entered the activities of the Workshop with some trepidation. One cannot state surely and completely what the effect of involvement will be. It undoubtedly includes some insecurity regarding success—they are professional men with a professional sense of responsibility. It can be concluded firmly on the basis of valid external indications, however, that the participating faculty did a remarkable, competent job, worthy of the highest commendation.

CASE INSTITUTE WORKSHOP

J. B. Reswick
Case Institute

Introduction

The Design Laboratory Workshop at Case was divided into two forms of participation. The entire group of students and faculty assembled almost every morning for a series of lectures. In the afternoon they met in four separate design teams in rooms equipped for design office functions. At a planning meeting in May, the four professors from the visiting schools met with their faculty counterparts from Case Institute and began to organize to attack four separate problems. These may be summarized as follows:

Project Description	*Visiting Faculty*	*Case Faculty*
Design of a Laser Window Tapping System	R. A. Wyant Clarkson College	W. B. Johnson
Design of a Thermally Regenerative Fuel Cell	O. A. Arnas Louisiana State Univ.	J. C. Angus
Design of a Miniaturized Low-Pressure Transducer	B. Webb, Jr. University of Arkansas	C. K. Taft
Design of Medical Instrumentation for Metabolic Studies	J. N. Krueger University of North Dakota	J. B. Reswick

Eight Case junior students (seniors in 1965-66) were selected and divided among the four visiting teams. The design teams quickly organized and subdivided the task into parts for individual members. In each case the object was actually to build a device to be evaluated. Hence, there was a good deal of scouting around for parts and materials in addition to doing calculations and drafting. Fairly extensive experimental evaluation was possible in several projects.

On the last day of the Workshop final oral and written reports of the four groups were presented to a jury composed of engineering managers from some Cleveland industries. The jury judged the projects on the basis of originality, presentation, and engineering competence. The prize, a "Serendipper" mounted on a plaque, was won by the Clarkson group for their laser window tapping project.

The lectures consisted of a series on engineering synthesis, optimization, and decision theory. The visiting experts occupied two days out of each week.

A great deal of interest developed in the Case 1107 computer and the use of Algol 60. Following an expressed desire of the Workshop, arrangements were made for Professor F. Way of the Computing Center to give a brief series of lectures on programming with Algol 60. He was able in the space of a few hours to bring most of the group to the point where they could run simple programs. He then arranged for the facilities of the Computing Center to be made available to all members of the Workshop. Several analyses relating to the design tasks were run on the computer.

Individual reports by the visiting faculty on their projects follow.

Design of a Laser Window Tapping System

R. A. Wyant
Clarkson College

The object of this project was to design a system to detect and monitor noises in a room. This was to be done by making observations of the vibration of a glass pane in a window of the room. An original requirement of the project was to utilize a beam of light from a laser as a means of observing this vibration from a distance.

A system was designed and constructed to split the beam of light from a gas laser into two parallel beams a short distance apart and to project these perpendicular to the window pane. The reflected beams were picked up and passed through a modified Michelson interferometer to give an interference pattern when there was a difference in length of path traveled by the two beams. Vibration of the window pane produced a minute flexure or bending of the glass, thereby producing a difference in the length of path traveled by the two beams. The resulting interference pattern was analyzed by means of a photomultiplier tube whose output was amplified and applied to either a pair of headphones or a tape recorder. The system was tested by exposing the pane of glass to various sounds, including the human voice and music, and recording the output on tape. The tape was then played back for comparison with the original input sound. The results were remarkably successful and indicated that the system was functioning as predicted.

The most important example of creativity during the course of the project was the conception of the idea of using two closely spaced parallel beams of light. By this technique the difference in length of path traveled by the two beams could be less than a half-wave-length of light, thereby producing a relatively simple change in interference pattern which could be easily detected and interpreted. Greater differences in path length produce more complicated changes in interference pattern. It was believed that previous attempts to extract information from a vibrating window pane had failed for lack of this idea.

The experimental work was limited to a "pane of glass" consisting of a back-surfaced mirror. A brief attempt to use an ordinary piece of window glass was unsuccessful due to its low reflectivity and to the problem of reflection from both surfaces of the glass. The work was also limited to a relatively short distance, above five feet between the light source and the glass. While the technique developed in this project may have distance limitations for "window tapping" purposes, it does show considerable promise as a means for detecting and evaluating the minute distortion of a reflecting surface.

Due to lack of time the project proved to be more of an exercise in experimental engineering than a "design problem." It did prove the technical feasibility, however, of using a beam of light from a laser for "window tapping" purposes. The project provided little opportunity for application of theories pertaining to decision making, design, optimization, reliability, etc. Such opportunities would only come with continuation of the project leading to a final design suitable for construction of a prototype of a commercial model.

Design of a Thermally Regenerative Fuel Cell

O. A. Arnas
Louisiana State University

The project undertaken by the Louisiana State University was the design and construction of a working model of a "Continuous Gas Concentration Cell as a Thermally Regenerative Fuel Cell." Two subgroups were formed: one elected to use iodine and lead iodide as their basic substances and the other used mercury and mercuric-mercurous chloride. The over-all objective was to give the students a chance to think creatively and to design and build a working model to prove the energy conversion capability of cells of this type. The project was unusual in that it included concepts from chemistry, electro-chemistry, thermodynamics, strength of materials, manufacturing processes, economics, and other design concepts. From this point of view, we believe that the project fitted very well the objectives of the "Committee on Authentic Involvement in Design."

The morning lecture sessions, arranged prior to the start of the Workshop, proved, in general, to be of little immediate value to the participants. One reason for this result is the fact that the students from L.S.U. were all sophomores, the youngest group among the participants. The afternoon schedule was rather interesting. The first few days were devoted to lectures by Dr. Angus on the electro-chemical and thermodynamic aspects of the project. After this introduction, the group split into two subgroups and started the actual design of the cells. As an incentive to work harder, a prize of $100 was offered to whichever group got the first working model. The students made much progress in actual design during the first week and a half, deciding on materials to be used and the size of the model. However, this was followed by a stagnant and frustrating week and a half in which the participants tried to obtain needed materials, most of them exotic in their physical characteristics.

Acquisition of these materials had a lot to do with the end result of the project. During this time, the students themselves manufactured the stainless steel parts of their cells and waited in an unproductive fashion, in the sense of building of the model, for the rest of the materials. While waiting, however, the report was started so that it would be finished by the end of the four-week period. The final week was interesting. Everyone was writing, machining, and trying to get everything put together. However, in the end the project was not completed due to the missing materials. One of the participants continued to work on this project through the remainder of the summer.

We believe that a lot was accomplished in this short period of time, particularly since the participants had no previous knowledge of the technical aspects of the project. During the Workshop, the faculty members acted as consultants. They were available at all times for questioning, consulting, or any other help that the participants requested. In this way, the faculty gave the participants a chance to think for themselves, to make mistakes, and to learn by these mistakes. This could not have been accomplished in any other way.

The result was that at the end of the four weeks, two models with certain pieces missing had been built. As far as could be deduced at that time, both of these models would work if completed. This has been confirmed by a recent report from Dr. Angus, demonstrating, therefore, that the objective was almost totally attained.

Design of a Miniaturized, Low-Pressure Transducer

B. Webb, Jr.
University of Arkansas

The primary objective of this design problem was to provide a vehicle for training in design methodology, using the medium of designing to satisfying a particular need. In the development of miniaturized fluid control systems there is a need for low-pressure transducers having specifications not met by commercially available devices. The problem undertaken was the design of a miniaturized, low-pressure transducer which would meet this need. The entire design procedure followed a typical design methodology, beginning with the recognition of a need, stating the problem in terms of specifications, investigating several known alternatives, deciding on the best of these alternatives, making a preliminary design, analyzing and altering the preliminary design, and constructing and testing a prototype.

The size of the transducer was not to exceed a circular probe area with diameter of 0.060 inch. The sensor was not to obstruct or disturb the fluid flow, thus limiting its motion to a maximum of 0.001 inch. The pressure range was to be 0.0-0.2 p.s.i. with a resolution of one part in one hundred. It needed to be sensitive to a bandwidth of 0-5 kc. and have a d.c. signal read-out.

Several methods of detecting pressure were studied and the limiting factors noted. Among those considered were: semi-conductor devices whose conduction characteristics change under pressure; conductors whose resistance change with pressure; pressure-sensitive dielectrics; and use of a deflecting diaphragm to control light hitting a photocell, to control arc-breakdown, and, when used as one plate of a capacitor, to control spacing.

Of the methods of detection considered, the use of a metal diaphragm to form one plate of a variable capacitor was chosen. The design began by determining deflection characteristics of different types of thickness of metals. Having selected a particular thickness of aluminum to give the most sensitive deflection without exceeding the maximum allowable, the variation in capacitance was calculated over the deflection range as determined by the pressure range. The calculated capacitance change was very nearly linear and of an amount sufficient to assure acceptable design of a detecting circuit utilizing the variable capacitance. While no detection circuit design was realized within the time period, different forms were considered, and an analysis was made for a circuit using amplitude modulation with series resistance, inductance, and capacitance. This type of circuit was determined to provide the best means of detection.

A diaphragm test set-up was arranged to measure static characteristics. The change in capacitance over the frequency range was nearly linear and near the computed variation. A dynamic analysis was made, but a test was not possible since there is no known source of varying pressure of 5 kc. The preliminary design and tests made indicated that a miniaturized, low-pressure transducer employing the variable capacitor method could be obtained.

Design of Medical Instrumentation for Metabolic Studies

J. N. Krueger
Univ. of North Dakota

The project undertaken by the Bio-medical-electronics group was concerned with instrumentation for the metabolic studies being conducted at Highland View Hospital in Cleveland, Ohio. The problem was divided into three parts: transducer design, data telemetering, and data acquisition.

The transducer problems were concerned with lead breakage between transducer and telemeter transmitting due to movement of the patient, and with the development of a more reliable transducer for detecting pulse rate.

The lead breakage problem was solved by designing a stretchable lead that could be elongated to over 150 per cent of its original length without damaging the lead wires contained therein. The transducer used to detect pulses for pulse rate measurement was based on EKG signals received by conventional EKG electrode pick-ups. To improve upon this, several different designs using various devices to detect pulse pressure were investigated. All posed the same major problem: to distinguish between pulse signals and random signals that were introduced by body movement. A barium titanate crystal appeared to show promise as a detecting device, but due to the short time we had for the entire project we could not obtain a full evaluation of the device.

The second part, data telemetering, necessitated an evaluation of the existing FM transmitter-receiver system being used in the studies. Tests on this system as to its accuracy, reliability, and ruggedness showed that it was entirely adequate and satisfactory for the system.

The third part, data acquisition, involved designing a device to prevent jamming of IBM data cards in the IBM 026 card punch machine recording the data. This was achieved by designing and building a device that measured the cards going into the card punch, and the cards coming out of the card punch. A logic circuit detected any difference in these two and sounded an alarm if a card entered the machine and did not come out within a very short, predetermined time.

All three of the phases of the project were conducted simultaneously with all of the results combined in a 36-hour test on one of our group as a "patient" at the end of the workshop. This test proved that the system was workable and reliable and the objectives of lead breakage, telemeter accuracy and reliability, and data card jam warning system had been achieved.

DARTMOUTH COLLEGE WORKSHOP

by
R. C. DEAN, JR.
P. T. SHANNON
S. R. STEARNS

The purpose of the Dartmouth Workshop was to acquaint the visiting faculty with the philosophy and techniques employed by the Thayer School to teach engineering practice (i.e. design). Of particular concern was the regular sophomore course, "Introduction to Engineering, ES-21."

A clear separation between the Workshop and the sophomore course will be made here. It is emphasized that the Workshop's purpose was to *teach teachers*. The sophomore course, ES-21, was used by the Workshop as a living teaching experience.

Participants

During the Spring of 1965, six participants were selected from twenty-six applicants.

DOUGLAS W. BRADBURY, Professor and Head, Graphics Department, *Clemson University;* MSE 1959; ten years teaching graphics and machine design; consulting.

WILLIAM S. CHALK, Assistant Professor, General Engineering, *University of Washington;* MSME 1961; six years teaching freshman graphics and design; seven years engineering practice; consulting.

MARSHALL M. LIH, Assistant Professor, Chemical Engineering, *The Catholic University of America;* Ph.D. 1962; one year teaching chemical engineering and transport phenomena; three years engineering practice; consulting.

THORTON W. PRICE, Professor and Head, Mechanical Engineering, Assistant Dean, *Arizona State University;* Ph.D. 1952; twelve years teaching thermodynamics, transport phenomena, and design; three years engineering practice; consulting.

FREDERICK G. SHEPPARD, Instructor, Civil Engineering, *Duke University;* BS 1957; one year teaching graphics and mechanics of materials; five years engineering practice; consulting.

WILLIAM SHEWAN, Professor and Head, Electrical Engineering, *Valparaiso Unversity;* MS 1952; eight years teaching electrical systems; one year engineering practice; consulting.

Each participating faculty member brought four of his students. In all but two cases, the faculty member taught a heterogeneous group of students, rather than those from his own school.

Workshop Description

The most important objective of this Workshop was to provide a stimulating experience in the teaching of the *totality of engineering* with particular emphasis upon creativity under real time, money, and practicality restraints.

There is and was no presumption that Thayer School's methods have universal application. Rather they are examples of *one* method of teaching engineering practice. We and the participants fully realized that these methods must be modified and sometimes replaced in other situations.

Another Workshop objective was to acquaint the participants with modern methods in engineering. This was done in two ways: first, by engaging the participants in their own engineering project, ORIGO, directed by the Thayer School faculty, and, secondly, by exposing them to a large number of experts and practitioners in various branches of engineering and science. (Table I.)

The Workshop ran for nine weeks. One week after the faculty, the students arrived to concentrate on ES-21 for the regular eight-week summer term.

The method of operating the Workshop is a direct analogy to Thayer School's methods of teaching design. The participants were completely responsible for the teaching of course ES-21; they seemed particularly appreciative of this authority. And just as they were expected to coach their student "companies," the Dartmouth faculty coached the Workshop participants.

The visiting faculty met each day in executive session concerning the operation of ES-21. Immediately thereafter a seminar was held with the Dartmouth faculty where problems of teaching the course and design in general were discussed. An essential part of our modus operandi was to criticize the teaching of the Workshop participants and their students' response.

Table I—Lecturers

Computers in Design	Brice Carnahan, Professor of Chemical Engineering, University of Michigan
Optimization	Alvin O. Converse, Associate Professor of Engineering, Thayer School
Technical Entrepreneurship	*Ralph Crump, Vice President, Frigitronics Inc.
Marketing Considerations and Procedures	*Kenneth Davis, Professor of Marketing, Tuck School, Dartmouth College
PERT and Methods of Innovation	*Robert C. Dean, Jr., Associate Professor of Engineering, Thayer School
Contracts, and Patents and Records	*Frederick D. Goode, Attorney at Law, Manchester, N. H.
Organizational Politics	*Ed. J. Hegarty, Lecturer on Human Relations in Management
Engineering Planning in a Large Organization	*Frederick J. Hooven, Director, Research Planning, Ford Motor Company
BASIC (instruction in Dartmouth computer language)	Thomas E. Kurtz, Associate Professor in Mathematics; Director Computation Center, Dartmouth College
Instrumentation	Sidney Lees, Professor, Thayer School
Military Systems Engineering	David F. Moyer, Head, Systems Analysis Department, The Mitre Corporation
Computers in Engineering	Paul T. Shannon, Associate Professor, Thayer School
Design, Practice and Education	George N. Soulis, Director, Institute of Design, Associate Professor of Engineering, University of Waterloo
Teaching Creativity, Stimulating Creativity in Practice, Legal and Economic Aspects of Engineering	George A. Taylor, Professor of Engineering and Management, Thayer School

Formulations of Information Theory; Engineering Education; Thermodynamics	Myron Tribus, Dean, Thayer School
Cost and Market Surveys; Corporate Finance	Richard S. White, President, Automation Engineering Laboratory, Inc.
Technical Report Writing	*Donald R. Woods, Professor, Chemical Engineering Department, McMaster University

*also lectured to ES-21

ORIGO immersed the faculty in an engineering project made as realistic as possible. Most of the participants, and indeed most of the applicants for this Workshop, have had little responsible experience in industry. (We emphasize the word *responsible* because only in such a position does a man come to appreciate the entirety of doing engineering.)

ORIGO was completed during five and a half days of the second week with a total time input of 416 hours by nine men. Dartmouth faculty members served as engineering managers; the six Workshop participants served as staff. The weighing of hospitalized patients in bed was the human need to be resolved.

Intensive study of the problem and a market survey were carried out very rapidly by the staff. The local hospital provided direct observation, expert advice, and economic data. By heavy reliance upon the telephone, many potential customers were contacted all across the United States.

Because of the short time span, careful and detailed planning was required. The project went through the usual steps: problem definition planning, specification, innovation of alternatives, evaluation, selection, engineering analysis, experimentation, detailed design, report preparation and presentation with all of the interactive loops of a real project.

The staff presented the results before their ES-21 students and others, including hospital administrators. The medical fraternity judged the results worthwhile, and asked that the solution be carried to a finished product.

We believe that not only did this project effectively acquaint the Workshop participants with the process of engineering, its vital factors, and the kinds of decisions which must be made, but it also gave them a preview of exactly the sort of problems their students would face in ES-21. The students, too, got a useful and timely preview of what they had before them.

Each Workshop participant kept a notebook containing his personal notes and all written communication with his students. Although the Dartmouth faculty intended to criticize these notebooks each week, only one serious critique was made during the sixth week of the course, due to understaffing.

Three Thayer School faculty were involved in this Workshop; Professors Dean and Shannon were half-time and Stearns one-quarter time. We learned that two half-time men are not equivalent to one full-time. We would recommend for the future that one faculty member be involved full-time with nothing but the Workshop, supported by another half-time faculty member. We did not elect this scheme because we did not want to emphasize the opinion of one man. However, the advantages of a diversity of opinion were probably outweighed by practical disadvantages.

The one extensive written critique made a major contribution to the Workshop. It was followed by long conferences with each faculty participant which came early enough so that he could make some alterations in his method of operation. These critiques ran to five pages on the average, requiring four to five hours of study and writing to prepare. Preparation of six critiques followed by six one- to two-hour conferences was a full week's work.

The Guinea Pig Course ES-21

This course was first taught in 1962. Its intention is to provide beginning engineering-science students with an awareness of their future profession, its manifold scientific, technical, economic, organizational, and human aspects, and an understanding of the relationship of their scientific education to engineering.

The specific course objectives are to provide:

1. an authentic experience in resolving a real human need in a useful way,
2. practice in inductive reasoning,
3. development of the courage and capability to attack problems without routine answers,
4. creative opportunities,
5. practice in scientific problem solving,
6. practice in selection of appropriate analytical and experimental tools,
7. an opportunity to build and test hardware,
8. practice in project planning and control,
9. practice in written and oral communication,
10. practice in use of information sources, and
11. an awareness of the non-technical aspects of engineering.

ES-21 commences with the statement of a human need. In the summer, 1965, the need was for devices to enhance the mobility of the crippled.

The class was organized into groups of four (twelve to fifteen regularly) students called "companies." The faculty advisor served as a consultant rather than as a taskmaster. He suggested possible approaches, methods of decision-making, organization, sources of information; he instructed on technical matters when needed.

The first task of each "company" was to get organized. The next step was to define carefully the problem which had purposely been stated vaguely. A proposal was then submitted. When acceptable the "company" was "contracted" to continue by a client firm made up of non-coaching faculty. The third step was to design a plan of action involving the scheduling of activities, reservation of facilities, etc.

The fourth step was to carry out the manifold activities including: the gathering of information, conception and evaluation of alternate solutions, choice of a system, final design, construction, and testing of prototypes.

Each student reported on his work weekly in a detailed progress report which was criticized, both technically and as a communication, by his faculty "consultant."

A final report was prepared by the group; parts were written by individual students. The "companies" defended their solutions before their peers and a Board of Evaluators composed of practicing engineers, business men, and experts in the problem subject.

A postmortem generalized the lessons learned by students and faculty.

Results

While incidental to the Workshop, ES-21 worked out very well with non-Dartmouth students. The projects were unusually successful, probably because of the larger effort per student (360 hours versus 150 during the regular academic year). Several very promising devices were developed and tested, including practical curb-climbing and transfer-board-arm attachments for wheel chairs, and a portable patient hoist.

At the end of the Workshop, the participants answered a questionnaire from which we draw the following comments:

1. They were positive (9.8/10) that attending this workshop was their most profitable way to spend the summer.
2. The ORIGO experience was most valuable (10/10).
3. The daily seminar was not very effective (6.5/10).
4. Bringing one's own students to the Workshop was important (9.5/10).
5. In teaching design the use of a realistic project is vital (9.7/10).
6. The importance of authentic design courses compared to applied science courses for undergraduate engineers was rated 7.8/10.
7. The first design course should be in the sophomore year.
8. The participants felt that about 54% of an engineering faculty should be practicing engineers.
9. ES-21 was rated 9.7/10 in over-all effectiveness as an introduction to engineering.
10. The importance of the emphasis on economics in ES-21 was rated 9/10.
11. This Workshop program should be repeated (9.8/10).
12. They intend to start something like ES-21 at their college (9.3/10).
13. Finally the participants summed up, answering the question: How effective has your entire Workshop experience been in:
    a) improving your over-all ability to teach engineering practice? (8.6/10)
    b) increasing your understanding of the totality of engineering? (9/10).
    c) encouraging you to pioneer new educational methods at your own school? (9.5/10).
    d) increasing your emphasis on design in contrast to science in education? (6/10).

Generalization and Recommendations

Concerning only the operation of future similar Workshops, we offer the following comments:

1. The coaching host faculty must devote at least one-and-a-half full-time men to six Workshop participants.
2. The principal host faculty member should do nothing other than direct and coach the Workshop during its span.
3. Written critique followed by conference with the participants is extremely valuable if done with care and sympathy, and *particularly* if done early enough so that the participant may modify his behavior during the course of his teaching.

4. The Workshop is a very effective vehicle for rapidly communicating the methods and philosophies of a given institution.
5. One Workshop cannot display a universal approach to the teaching of design.
6. Direct involvement of the Workshop participants in teaching of a course is critical to their learning.
7. A four-week Workshop is probably inadequate because it is impossible to teach a real course in such a short time.
8. Workshops in Design Education should be continued.

M.I.T. WORKSHOP

by

R. W. Mann

Goals of the Program

The basic purpose of the M.I.T. Design Laboratory Workshop was the development of faculty competence in design instruction, and the enhancement of their confidence while doing so. In addition the effort was directed towards the design of a sophomore-level subject to coalesce those activities normally associated with either design subjects or laboratory exercises.

A design subject should confront the student with a broadly defined goal and exercise his ability to develop specifications for pertinent tasks and to innovate ideas (concepts) for possible solutions. Tests and refinements of the concepts through processes of visualization, mathematical modeling, and analysis follow. Finally the student must specify, present, and defend his particular, solution. In undergraduate education, this process is usually conducted entirely on *paper.*

By contrast, the primary role of the laboratory should be to confront the student with *nature,* directly and experimentally.

Our Workshop undertook an integration and fusion of these traditional roles. Thus, a criterion for student projects would require paper studies with graphical descriptions and mathematical analyses combined with appropriate experimental investigations including design of experimental apparatus and experimental procedures.

Optimum solutions to design goals are intrinsically interdisciplinary. This conviction—coupled with the fact that sophomore-level students, even if they have identified with an engineering department, have had little opportunity for course work exclusively identified with that department—made mandatory an interdisciplinary theme and a cross-department mix of faculty and students.

Engineering (and therefore design) is fundamentally a sometimes collaborative, sometimes competitive endeavor. The engineer (and student) must learn to work cooperatively as a team member toward a common goal while also explaining and defending his approach in competition with alternative solutions.

Planning

To provide an appropriate source of projects and to bring about the sought-for social interaction, the visiting host faculty at the Spring Planning Meeting decided on a common theme to focus and integrate what would ultimately be a number of projects each undertaken by teams comprised of several students. Transportation Mobility in High Population Density Regions, i.e., the Northeast Corridor, was chosen over other themes dealing with oceanography, ecology, pollution, etc., primarily because transportation was deemed closer to the direct experience of the students.

Further pre-planning consisted of:

defining a number of possible permutations of student groupings, varying size, engineering disciplines, class, school of origin, and faculty advisors,
scheduling a tentative series of discussion and brain-storming sessions in which the student groups would define the goals, concepts, and research tasks pertinent to the theme,
planning a set of short introductory laboratories,
setting out a list of possible lecture topics including the already scheduled visits of the itinerant "design theory" experts.

Participants

Faculty applicants to our Workshop substantially exceeded our resources. Selection criteria were derived from the over-all goals of the nationwide Workshop Program and from the particular objectives of the M.I.T. program as set out above, resulting in the selection of a

Professor of Electrical Engineering from the University of Oklahoma
Professor of Mechanical Engineering from the Davis campus of the University of California
Professor of Mechanical Engineering from Bradley University in Peoria, Illinois
Professor of Agricultural Engineering from Purdue University

In addition to these NSF sponsored faculty, an instructor in Electrical Engineering from, and sponsored by, Rensselaer Polytechnic Institute was with us throughout the program and assumed the same responsibilities as the other faculty. During the last week of the Workshop a professor of Mechanical Engineering from Cornell joined us and a Senior Lecturer in Mechanical Engineering from Cambridge University, Cambridge, England, was with us during the second week.

The participating students were a mix of class, engineering fields, and schools, including:

five mechanical engineering students who had completed their junior year,
one mechanical engineering student who had completed his sophomore year,
two agricultural engineers who had completed their junior year,
two agricultural engineers who had completed their sophomore year,
one civil engineering student who had completed his junior year,
one industrial engineering student who had completed his junior year,
eight M.I.T. students who had completed their freshman year.

Whatever their ultimate degrees in science, engineering, humanities, social science, management or architecture, all M.I.T. students have a common first year and need not designate their departmental choice until as late as the junior year. Of the eight M.I.T. students, two had indicated a prospective choice of Mechanical Engineering, while the remainder were uncommitted.

The Workshop Program

It is axiomatic that the outcome of an authentic design experience cannot be known in advance. And in the same sense, the detail of the Workshop Program was subject to evolution and alteration as the timing and relevance of different features came under the scrutiny of experience. The planning items outlined above were arranged into a well-delineated format for the first several days. Beyond this, the program, except for the pre-scheduled visits of the itinerant "design experts," became more vague. After the fact, however, the program as experienced provided a basis for commentary on aspects of the program.

Design/Laboratory Integration

The theme posed a truly comprehensive problem obliging the students to define carefully the goals and criteria by which the satisfaction of the goals could be evaluated. Their familiarity with transportation in its present various modes and the advantages and limitations thereof greatly facilitated and reinforced their identifying and defining relevant aspects. This common base of experience subsequently helped (certainly in no way inhibited) the "brainstorming" group discussions of the goals of transportation the first morning and alternate new approaches to travel in the growing megalopolis the second morning.

The short but intense experience of small-group generation of ideas followed by reports to general meetings led quite naturally into the third morning's task—students' compilation of a great number (over 70) of possible research tasks. Through their identification of these engineering-science-based research tasks, the students themselves directly and naturally coupled a systems design experience with disciplinary subject knowledge. And, by defining their own source of tasks and going on to design the equipment and experiments to prosecute that task during the remaining three weeks, they truly integrated a design and laboratory experience.

Introductory labs occupied the afternoons of the first week. The students were assigned in groups of three to lab tasks pre-arranged as to topic, somewhat pre-arranged as to equipment, but which left many implementation decisions to the students. In prosecuting these labs the students became familiar with the lab space, facilities, and staff, and they (and the faculty) developed the student-faculty advisor relationship which would persist throughout the Workshop. And in presenting their introductory lab results, the students experienced sharp, critical faculty (and fellow students') review of the adequacy and clarity of their verbal and visual descriptions of their effort.

Thus, by the end of the first week the students defined a range of possible research tasks and, through the introductory labs, had some direct experience with those physical and time constraints* which could guide their choice of task. The lab experience, the growing student-faculty relationship, and the reactions to their lab presentations provided the students with a concrete idea of what would be expected from them. The self-selected groups of students then proceeded to define and refine research tasks—nine groups in all.

The goal-orientation of the theme demanded that the relevance of all aspects of each research task be demonstrable. Ultimately, at the conclusion of the program, the theme provided a cohesive matrix into which the nine separate investigations could be integrated and evaluated.

* An economic restraint took the form of a maximum budget of $100 per research task; the actual average expenditure was a fraction of this.

Interdisciplinary Character

The theme selection and the mix of professional orientations of faculty and students ensured an interdisciplinary experience, attested to by the variety of research tasks selected and performed by the students.

Student Interaction

The social aspects of the students' effectiveness were exercised and disciplined in a variety of ways. The six-man "brainstorming" goals, concepts, and research groups were faculty selected to represent mixes of schools, fields, and classes; their experience was one of collaborative, reinforcing discussions followed by condensation and presentation to the entire Workshop. The three-man Introductory Lab groups were also assigned as deliberate mixes.

The longer tenure, research tasks groups were self-selected; seven of the nine composed of mixes of students from different schools.

Through both lab experiences, the group-brainstorming sessions, the several presentations, and the editorial functions which culminated in the student-prepared 200-page final report, the students learned how to relate one to another, how to distribute equitably a job among colleagues, how to combine individual and group outputs into fluent, integrated presentations.

A number of opportunities, prior to the final presentation, were created to require the students to present, debate, and defend their ideas, programs, and conclusions to peer groups and to the faculty. These included the reports of the "brainstorming" goals, concepts, and research sessions, reports on the Introductory Labs, initial definitive and progress reports on the nine research tasks. The final presentation was completely student-organized and conducted on a formal, professional level to an audience which included experts from various aspects of transportation-related-research who had not otherwise been involved in the Workshop.

Student Responsibility

Prior discussion herein stresses the extent to which the responsibility for making decisions was thrust upon the students. Stripped of its particulars, every engineering (design) venture reduces to this essential—an intertwined array of *decisions* which must be rationally resolved so as to be consistent with the constraints of nature's laws and best compromise society's desires and resources. In the Workshop the students were responsible for discovering, defining, selecting, exploring, and integrating. The several organizational arrangements provided opportunities for individual students to assume various degrees of group leadership. A four-man student Editorial Board assumed over-all coordination of the entire program. They started planning the final report during the first week, augumented their membership as new tasks were defined, worked out details of deadlines, editing, illustrating, and reproduction, and had a well-organized, coherent, respectable 200-page report ready for distribution on the last day of the Workshop!

The Role of Lecture

After the initial flurry of lectures of the first week, the time committed to lectures decreased, especially if one excludes the lectures of the "design theory" experts whose schedule had been pre-arranged. The justification of lecture in design education depends upon the extent to which the material is appropriate and timely to the project *currently* under student scrutiny. Pertinence may result from particularly relevant content or from general information presented in a fashion directly useful to the students' needs. The lectures on similitude, error analysis, and technical report writing were good examples of direct relevance. Those on computer-aided design and creativity were more general but were concretely illustrated with examples through which the student could relate generalities with his particular experience. But even pertinence palls as time passes and their own projects monopolize the students' valuable time. Then formal lecture must be dropped and available common meeting times used either for individual or group effort or for general progress reports and critiques.

The Role of the Faculty

A perusal of the Workshop as described thus far highlights much student activity and responsibility with little accentuation of the role the faculty played in the program. This is as it should be if design education is, in fact, confronting and involving the *student* in an authentic engineering situation.

However deliberately inconspicuous they may be, though, the presence of the faculty is absolutely vital; how they play their role is the prime determinant of the realizability and efficacy of this sort of education. In fact, the fundamental reason for the Workshop program was the creation of opportunities for faculty to experiment with and exercise themselves in student-involvement-based design.

From the outset the visiting faculty were established as the responsible advisors of student groups in the brainstorming sessions, the introductory labs, the research tasks, the editorial groups. The M.I.T. faculty acted only as consultants and back-up.

The faculty advisor's role is one of guide, provocateur, even agnostic, and intermediator. He proposes goals, but then avoids delineating them, transferring leadership as rapidly as possible to the students. As the momentum of their own interaction increases, he maintains an open-minded, flexible position on student ideas but assumes the role of questioner to force on the student that self-criticism which leads to clarity of understanding. As student self-confidence mounts, faculty incredulity becomes more insistent, perhaps to the point of openly wondering whether dramatically different approaches might not be superior.

He encourages the ideas of reticent students lest their notions and confidence be lost under the enthusiasm and forcefulness of natural leaders. When necessary, the faculty becomes the intermediary between student and the "establishment" as, for example, when schedules should be changed or equipment borrowed, and he arbitrates between student and student, and student and system when irreconcilable situations occur.

The faculty role vis-à-vis the student is more of tutor, critic, even colleague, than it is pedant or even lecturer.

In addition to the formal contacts of lecture and general meetings, and the informal exchanges of group meetings, lab discussions, and personal talks, the visiting and M.I.T. faculty scheduled a regular discussion each afternoon for recapitulation and planning of the Workshop, trouble-shooting, and technical and professional exchange. As part of this, the visiting faculty were familiarized with a number of government- and industry sponsored, faculty-supervised, graduate- and undergraduate-staffed research and development projects in the Engineering Projects Laboratory.

The Final Report

The limited space available herein precludes reporting details of individual student group results or over-all Workshop performance. The 200-page report* prepared by the students represents a surprisingly comprehensive and readable compilation of the results of the nine research task groups and of the goals, concepts, and research alternatives which posed the specific tasks undertaken. Research results are related back to the theme and recommendations for further study are made.

The report also includes student appraisals of the educational goals of the Workshop program and their collective evaluation of its effectiveness in meeting these goals. Appendices to the report include biographies of the faculty and students, student reports on the Introductory Labs, notes on lectures, presentations, schedules, etc. Finally, appended to the report are week-by-week summaries and critiques of the program independently prepared by the visiting faculty.

The Research Tasks

A brief mention of the research tasks, however inadequate as descriptions of the challenge-frustration, success-failure, experience-maturation of the students thus employed, can suggest the significance level of what was accomplished.

One group designed, built and tested (on a test facility of their own design and fabrication) a polyphase linear, induction motor. Another team studied power transfer from guideway to vehicle at speeds representative of truly high speed systems, with electrical loads simulating representative power units, and including plasma as well as sliding contact interfaces.

Another group studied the hazard to foundations near a subterranean right-of-way due to shock and vibration transmitted through subsoil. They designed and built an apparatus for evaluating the transmissibility of sand, including a suitable excitation device and acceleration detectors.

Suspension problems of a vehicle-in-a-tube intrigued the largest number of research groups. Optimum geometries for air-cushion support were studied by one group—balancing load carrying capacity against power consumed for air compression. Another group studied the feasibility of using the forward motion of the vehicle, and resultant stagnation of the incident air, as the source of pressurized gas suspension. The best choice of guideway and vehicle cross-section to enhance lateral stability for gas support absorbed the attention of a third group. A fourth suspension team experimented with magnet support, built and tested successfully a greatly (overly) simplified version and then failed dramatically on an elaborate version of their concept.

The fluid mechanics, and in particular the drag, of a vehicle in a tube, an as-yet obscure field, was explored through similitude experiments over a wide range of speeds, vehicle-to-tube diameter ratios, vehicle length-to-diameter aspect ratios, and vehicle leading and trailing geometry.

Finally, one group questioned whether switching vehicles in tubes at speed might be done pneumatically, built and tested a rig which performed successfully but opposite to their analytical predictions, and then had to reformulate their theory to fit reality.

* Within practical limits of staff and budget, individual copies of the document will be sent upon written request to Professor Robert W. Mann, Department of Mechanical Engineering, M.I.T.

Epilogue

The educational outcome of the Workshop is attested to by the tangible research report and by the more important enthusiasm, accomplishment,* and concomitant self-confidence exhibited by the students and faculty. The students themselves were the instigators and implementors of a significant and authentic engineering endeavor and the faculty demonstrated to themselves their competence in effectively discharging their vital role in engineering education.

From the point of view of sophomore-level design laboratory subject design, the outcome was revealing and reassuring. Sophomores are less inhibited than their upper-class colleagues in enthusiastically embarking on ambitious themes and they display no disciplinary bias. However, they must be encouraged to match their limited technical knowledge to appropriate investigations where they can acquire the essential background rapidly. The guiding faculty assumes a special responsibility in anticipating regious of ignorance on the part of the students and providing appropriate resource information and tutoring if necessary. A student-faculty ratio not exceeding 1:12 seems manageable.

Grading** was no problem at all. By the end of the Workshop the faculty had a surfeit of information on each student to provide the basis of a fair and equitable grade.

Extrapolation of the four week full-time Workshop to an equivalent one of four subjects during a 15-week semester poses some problems. On the one hand, the unalloyed concentration and ready accessibility of the faculty and fellow students, many of whom lived on campus in one of the dormitories, cannot all be carried over to the regular semester. On the other hand, the incessant tempo of the Workshop left little time for reflection and cogitation and unmercifully compressed the analyses, equipment design, and experimental phases of the investigation, in some cases unduly precipitating the fabrication of equipment. The more leisurely pace of a regular semester would permit a better distribution of effort.

On balance, the prospects for such a sophomore subject looks promising and one based on this Workshop experience will be offered to all M.I.T. sophomores, irrespective of department, in the spring of 1967.

* One interesting manifestation of this was the removal by several students of their research apparatus back to their home campuses for further work.

** M.I.T. and visiting students received grades and 12 hours of M.I.T. credit for their Workshop performance.

UNIVERSITY OF CALIFORNIA, BERKELEY WORKSHOP

by

R. F. STEIDEL, JR.

The Division of Mechanical Design of the Department of Mechanical Engineering, at the University of California, Berkeley, has developed a comprehensive graduate program in Mechanical Design in line with the role of the University in the state system of higher education in California. Although the development of this program has been the direct result of deliberate efforts by the University to establish firm graduate areas of study, the Mechanical Design staff is convinced that engineering design education can best be accomplished at the graduate level.

The academic program in Mechanical Design at the University of California, Berkeley, has five main areas:

1) Mechanical Design
2) Mechanical Control
3) Mechanical Behavior of Engineering Materials
4) Experimental Mechanics
5) Metal Processing

The Workshop was directed toward the first three subject areas.

The format of the Workshop was a series of lecture-seminars by the staff in the morning followed by the review and discussion of mechanical engineering projects in the afternoon. The Case Study method was applied to review projects, with the object of establishing the criteria on which basic design decisions were made. The process of synthesis in engineering design was examined as it bears on each project.

Philosophy

The guest experts were scheduled to lecture for four hours in the mornings of two successive days. This interrupted the pattern of lecture-seminars by the regular staff, but did not interrupt the afternoon discussions. In our schedule, Dr. Smith, of Serendipity Associates, arrived at Berkeley during the first week, and his lectures were very valuable in awakening the design process in the Workshop participants. Dr. Schmit and Prof. Coons arrived at the end of the second and the beginning of the third weeks, respectively, when the format of the Workshop was well established. The visit of Mr. Prince occurred at the end of the Workshop while the participants were writing and revising the Case Studies. As a result, the lectures of Mr. Prince were informative but did not affect our Case Studies.

To introduce the subject of Case Studies, Dr. Fuchs, Dr. Pefley, and Mr. Vesper each discussed a Case Study on which he had worked. The degree of student participation varied. This introduction lasted for the first two weeks of the Workshop. At the beginning of the third week the student participants were placed in groups under the guidance of one of the faculty participants and each group visited a preselected industrial site. Our objective was to develop a Case Study within the time remaining at the Workshop.

Workshop Staff and Faculty Participation

The Workshop staff consisted of the four faculty from the University of California. Although all four were involved in the lecture-seminars, only two, Professors Steidel and Costanza, were involved in the Case Studies.

Staff

Professor Robert F. Steidel, Jr., Director
Mechanical Design

Professor James L. Costanza
Mechanical Control

Professor Joseph Frisch
Mechanical Design

Professor Frank E. Hauser
Mechanical Behavior of Engineering Materials

Faculty Participants

Professor Henry O. Fuchs

Department of Mechanical Engineering
Stanford University

Professor William C. Monday
Mechanical Engineering Department
Kansas State University

Professor Richard K. Pefley
Department of Mechanical Engineering
University of Santa Clara

Professor Robert S. Vail
Department of Aerospace
and Mechanical Engineering
The University of Arizona

Student Participation

The students selected to participate in the Workshop from the Berkeley campus were candidates for the Master of Engineering Degree and their participation in the Workshop partially fulfilled the requirements for that degree. All students enrolled in the Workshop were allowed to enroll in the first summer session for three units of credit in course Mechanical Engineering S 298, Master of Engineering Seminar, provided that they were bona fide graduate students in mechanical engineering. Students selected from institutions other than the University of California, Berkeley, were expected to be matriculating for a graduate degree at that institution.

Twenty-three students participated in the Workshop. Of these, twenty-one were graduate engineers and two were senior undergraduates in Mechanical Engineering. Of the twenty-one graduates, nine had completed the Bachelor's degree in June of 1965. The remainder were in the midst of graduate work leading to an advanced degree. Four from the University of Cailfornia had completed all of the requirements for the Master of Science degree except for the completion of an engineering project and had received permission to use the preparation of a Case Study in lieu of completion of a thesis. One man was in the final year of his program for a Doctorate.

Nineteen students were graduates of Mechanical Engineering courses. One was a graduate in Civil Engineering and one was a graduate in Electrical Engineering.

Participants

University of California

Mr. John Brewer
Mr. D. C. Chiang
Mr. R. C. Desai
Mr. R. M. Desai
Mr. Keshab Dutta
Mr. A. K. Goyal
Mr. Anwar-ul Karim
Mr. N. M. Sevak
Mr. A. R. Vora

University of Arizona

Mr. Jay Abramowitz
Mr. James K. Needham
Mr. Rex W. Shumway
Mr. Kenneth Steffan

Kansas State University

Mr. Ramgopal Battu
Mr. Thomas Eagles
Mr. Richard Leung

Stanford University

Mr. John Alic
Mr. Allan Krauter
Mr. Oivind Lorentsen

University of Santa Clara

Mr. R. A. Becker
Mr. E. W. Mabie
Mr. E. C. Matis, S. J.
Mr. G. J. Scatena, Jr.

Case Studies

Eight Case Studies were prepared by the students participating in the Workshop. The students were divided into groups of three and four. Preference was given to those from a specific school who wished to remain together.

The students were introduced to the case which they were to study on Monday afternoon, June 28. They were allowed several days to digest their thoughts about this visit. On Wednesday afternoon, June 30, the entire Workshop made a site visit to the Hydrogen Bubble Chamber of the Lawrence Radiation Laboratory. This was studied as a project in engineering design by a group of three graduate students in the spring semester. The report was made available to all. On Thursday afternoon the student participants were released to work on the Case Studies.

On Thursday afternoon, July 8, each group presented their results orally to the Workshop. On Friday morning written drafts were submitted. The following Case Studies were prepared:

1. "An Automatically Controlled Experimental Test Facility at the Rucker Company, Oakland," Part I

   Faculty Supervisor: Professor J. L. Costanza
   University of California, Berkeley

   Student Participants: Mr. J. Brewer, Mr. D. C. Chiang, Mr. R. M. Desai, Mr. N. M. Sevak

2. "An Automatically Controlled Experimental Test Facility at the Rucker Company, Oakland," Part II

Faculty Supervisor:	Professor J. L. Costanza University of California, Berkeley	
Student Participants:	Mr. J. Brewer Mr. D. C. Chiang	Mr. R. M. Desai Mr. N. M. Sevak

3. "Liquid Level Control at the Quality Casting System Company, Berkeley"

Faculty Supervisor:	Professor Robert F. Steidel, Jr. University of California, Berkeley	
Student Participants:	Mr. R. Battu Mr. K. Dutta	Mr. A. Karim Mr. A. R. Vora

4. "Liquid Level Detection at the Quality Casting System Company, Berkeley"

Faculty Supervisor:	Professor W. C. Monday Kansas State University	
Student Participants:	Mr. R. C. Desai Mr. T. W. Eagles	Mr. A. K. Goyal Mr. R. H. Leung

5. "Development of the Parallel Groove Clamp Tool"

Faculty Supervisor:	Professor R. P. Vail University of Arizona	
Student Participants:	Mr. J. Abramowitz Mr. J. Needham	Mr. J. Shumway Mr. K. Steffan

6. "Preliminary Study for the Design of a Probe to be Used in Determining the Thermal Properties of the Soil"

Faculty Supervisor:	Professor Richard K. Pefley University of Santa Clara	
Student Participants:	Mr. R. A. Becker Mr. E. W. Mabie	Mr. E. C. Matis, S.J. Mr. G. J. Scatena, Jr.

7. "A High Acceleration Centrifuge at the Rucker Company, Oakland"

Faculty Supervisor:	Professor H. O. Fuchs Stanford University	
Student Participants:	Mr. Ö. Lorentsen	Mr. A. Krauter

8. "The Design of a Tapewriter at Dymo Industries, Berkeley"

Faculty Supervisor:	Professor H. O. Fuchs Stanford University	
Student Participant:	Mr. J. A. Alic	

Lectures

The lectures given by the Berkeley staff formed an important component of the Workshop program. To complete the description of the Berkeley session the lecture topics are listed below, in order given and with some indication of their content.

June 14

Introduction and Objectives of the Workshop in Mechanical Design. (S)*

Formalizing the Process of Design. An introduction to the process of design when viewed as an iterative procedure, employing both analysis and synthesis techniques. The basic motivation for dealing with abstractions (mathematical) of physical system components will be discussed. (C)

June 15

Some Particular Types of Abstraction. The development of models for physical systems which are sufficiently accurate as to allow the prediction of operating characteristics. Model methods and their present limitations. (C)

June 16

Integrated Systems. A continuation of the June 15 seminar with the logical result being an assessment of those factors which determine the conditions for which an interconnection of physical systems has a stable operating characteristic. (C)

June 17

Structure of Metals, Polymers, and Ceramics. Atomic bonding; ionic, covalent and metallic crystals; molecular solids, elastic properties. (H)

Time and Frequency Domain Analysis. Here are developed two particular abstractions which are suitable for design application when the relevant system performance factors are expressed in either the time domain (i.e., transient overshoot) or frequency domain (i.e., system bandwidth).

Optimization of Central Power Systems for Cost. (S)

June 18

Imperfections in Crystals. Vacancies, dislocations, grain boundaries; diffusion; plastic deformation; effect of temperature and deformation rate on mechanical properties. (H)

Systems of Automatic Control. Application of the previous topics to the design of an automatic control system. Prime mover selection, instrumentation, and controller action will be discussed. (C)

Introduction to Optimization and Reliability in Design. General review of basic concepts of statistics. Gaussian, Weibull and exponential distributions, density functions, hazard rate. (F)

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* The letter in parenthesis following each lecture description, C, F, H, or S, refers to the lecturer, Professor Costanza, Frisch, Hauser, or Steidel, respectively.

June 21

Imperfections in Crystals (continued) (H)

Graphical and Mathematical Methods for Determining Confidence Levels for Gaussian and Exponential Distribution Functions. Application to design information. (F)

June 22

Alloying. Solid solutions, precipitates, and binary phase alloys; effect of alloying on mechanical properties. (H)

Application of Variance Theory to Mechanical Design and Product Performance. (F)

Optimization of Central Power Systems for Performance. (S)

June 23

Optimization of Central Power Systems for Performance. (S)

Use of Statistical Information in Developing Failure Pattern Models and Factors of Safety. Outline of optimizing equations for mechanical elements under normal, redundant, and incompatible specifications. (F)

June 24

Application of Two- and Three-Dimensional Variation Diagrams to the Optimization of Mechanical Elements. (F)

June 25

Reliability Concepts, Failure Modes, and Reliability Functions. Wear out and chance failures. (F)

June 28

Reliability of Series, Parallel and Mixed Systems. Application of Poisson distribution and Bayes theorem. (F)

June 29

Reliability of Stand-by Systems and Redundancy in Time Dependent and Time Independent Situations. (F)

June 30

System Performance. The relevant factors of system operation discussed as they relate to the selection of meaningful criteria of performance. Specific examples drawn from the areas of process control positioning servomechanisms, and spacecraft attitude control. (C)

Feasibility Predictions and Reliability Allocations. Influence of equipment maintenance and availability. (F)

July 1

System Optimization. (1) Static optimization via the theory of ordinary maxima and minima. Linear programming methods and a simplified version of Bellman's dynamic programming will be discussed in connection with system parameter optimization. (C)

Fatigue, Fracture, and Creep. Fundamental mechanism governing fatigue, brittle and ductile fracture, high and low temperature creep. (H)

July 2

System Optimization. (2) Dynamic optimization in the context of minimizing a chosen performance index which defines a penalty (cost) function during transient modes of system operation. (C)

Fatigue, Fracture, and Creep. (Continued) (H)

July 6

Sensitivity Analysis. The interplay between a degraded component and overall system performance. A basic introduction to the "after design" aspects of malfunction detection and diagnosis. (C)

Principles of Material Selection. Carbon steels, low alloy steels, Al alloys, Cu alloys, Mg alloys, "exotic" materials; modification of mechanical properties by heat treatment. (H)

July 7

Computation in Design. The basic modes of computation as they relate to the design process. Analog and digital techniques are discussed in the context of aiding in the development of prototype systems. (C)

Principles of Material Selection. (H)

U.C.L.A. WORKSHOP

by

A. B. ROSENSTEIN
W. B. HEINZ

Engineering Design—One School's View

Engineering 4B at U.C.L.A. is a second semester, freshman year, lecture-laboratory Engineering Design course. It is part of the single, unified undergraduate curriculum that is taken by all engineering students to obtain their B.S. in Engineering. The course is part of a Design Sequence that has been planned to meet the professional needs of the future practicing engineer.

In this context, Design has been taken to mean the overall process that begins with a recognition of a need and ends with the disposal of waste products and the retirement of the worn out or obsolete device. Design itself has been defined as an "iterative decision-making process to conceive and implement systems to optimize the value of society's resources."

The major needs of the engineering students that Engineering 4B attempts to satisfy are twofold:

1. to prepare students for their future careers as professional engineers who will carry collectively the responsibility for a vital sector of our society—namely, the physical environment in which that society lives and the physical resources which it employs, and

2. to offer the students a comprehensive view of engineering and to relate each facet of their education to their careers as engineers.

The constraints that act to limit and often eliminate professionally oriented courses for the undergraduate curriculum are important and must be understood. Four that apply to Engineering 4B are worth listing:

1. the limited engineering, science, and mathematics preparation of the undergraduate and particularly of the freshman,

2. the increasing pressure on the undergraduate program for more science and mathematics,

3. the rapid changes in technology that tend to make obsolete specific material,

4. the limited number of years available for formal higher education.

Since a set of universal truths that would govern all of Engineering Education has not yet been accepted in all quarters, we have assumed a hierarchy of "truths" which in turn form the foundations of our design program. Engineering 4B is based upon the following six assumptions:

1. We assume that design in its broadest sense is the essence of engineering.

2. We assume that the discipline of Engineering Design possesses a logic and a methodology. In this sense, design is analogous to mathematics which in itself consists of logic and methods. Mathematics, we must remember, is not a science. As Bertrand Russell has stated, "There are no truths in mathematics."

3. We assume that the logic and methodology of design can be described.

4. We assume that the design process can be taught. The design process may be compared to a forest. It possesses an overall form composed of various areas that are linked by well-defined trails. Professor Asimow has called this structure the *Morphology of Design*. At the same time, the structure is composed of elements which are repeated over and over again. Professor Rosenstein has called the elements of the design process that are repeatedly employed, the *Anatomy of Design*. We have assumed that it is important for the engineering student to be thoroughly familiar with both the Morphology and the Anatomy of Design.

5. We assume that the design process should be introduced at the beginning of the engineering student's undergraduate program and threaded throughout the four years. This is consistent with the presentation of the methods of mathematics which are also introduced in the freshman year and exercised throughout the four years.

6. We assume that teaching the design process without a design laboratory experience would be a futile exercise. Conversely, a design laboratory experience without the benefit of a coherent presentation of the design process would be repudiation of the responsibility of educators to organize and generalize man's knowledge and experience for greater understanding and insight.

The corollary assumptions of Item 6 are particularly important since they clearly point to the main purpose of the summer design Workshops. Our colleagues in Mathematics and Science have done a superb job of developing sophisticated mathematical models to describe and manipulate the great generalizations they have produced to explain the behavior of the physical world. The usefulness and power of these methods and generalizations demand their place in the engineering curriculum. Professional courses will be able to maintain their position in the same engineering curriculum only to the extent that the methods and generalizations of the design process are as powerful and useful as their competitors'.

Learning by doing is an important part of the educational process. However, *the student cannot discover for himself in the laboratory all of man's accumulated knowledge.* His professors bear the responsibility for continuously seeking the most powerful methods and the most penetrating generalizations, and for making them available to students. The engineering professor's responsibility for the formalization of design methodology is certainly as great as his responsibility for the transmittal of a well-integrated understanding of mathematics and science. The teaching of design simply through vicarious laboratory experiences is patently too inefficient and too demanding of the student to be practical. The ideas of engineering design are quite sophisticated. We cannot expect the student to develop more insight and more useful generalizations in design on his own than he can in mathematics or science where the generalizations have been carefully collected.

We have assumed that Design is the essence of Engineering and that the design process can be described by the Morphology and Anatomy of Design. Again we note that the Morphology identifies a detailed sequence of phases, while the Anatomy presents the basic steps in the process which are repeated over and over again in each of the phases of the Morphology.

Professor Asimow describes the Morphology of Design in seven phases that follow after a primitive need has been recognized.

Morphology of Design

Phase I	Feasibility Study
Phase II	Preliminary Design
Phase III	Detailed Design
Phase IV	Planning for Production
Phase V	Planning for Distribution
Phase VI	Planning for Consumption
Phase VII	Planning for Retirement

Each phase in turn is composed of a number of steps that lead to a decision or series of decisions that form the outcome of the phase.

Professor Rosenstein has collected the basic steps in each phase of the design morphology into the anatomy in order to gain a better understanding of the fundamental methods, knowledge, and skills that the engineer requires to efficiently discharge his design responsibilities.

Anatomy of Design

1. Identification of needs (needs analysis)
2. Information collection and organization

3. Identification, modeling and statement of variables and parameters
   a. Inputs
   b. Outputs
   c. Transforming means
   d. Constraints
4. Criteria development—value system to determine the best
5. Synthesis of feasible alternatives using criteria of
   a. Physical realizability
   b. Economic worthwhileness
   c. Financial realizability
   d. Producibility
   e. Reliability
   f. Maintainability
6. Test, evaluation and prediction (analysis)
7. Decision making
8. Optimization—to obtain the best of the feasible
9. Communication, implementation and presentation
10. Iteration

The Anatomy provides another way of reviewing the content of a curriculum. For instance, if Design is always an "iterative, decision-making process," we might wonder if all engineering students shouldn't have an introduction to modern Decision Theory in their required undergraduate program.

If the proposed structure along with the Anatomy of Design does indeed give a good description of the material that the engineer must master, then the reasons for many existing courses in engineering curricula becomes clear and the lack of others becomes obvious. We would turn to the social sciences and humanities to understand the *constraints* that society places upon our engineering designs and also as a source of the *value system* we must develop in order to *optimize* these designs.

Studies in the physical sciences and life sciences give an understanding of the constraints that nature places upon our *material* and *energy resources*. Information is now recognized as a *resource* and a commodity. Courses are beginning to be required of engineers in information theory, communications, and machine information processing (computer theory). The lack of courses dealing with *space* or *people* as *resources* is quite noticeable.

The *methods* of *analysis* needs of the engineer are well served by this preparation in mathematics. Laboratory courses should prepare him to utilize the *methods* of *experimentation*. The lectures of the Design courses offer the student an understanding of the *methods* of *design*. The design laboratories should allow him to develop some skill in design and the application of the design methodology.

The details of the material presented in Engineering 4B are given below. Briefly, the course serves as an introduction to Engineering Design. The complete design process is described in terms of the Morphology and Anatomy. The first three phases of the Morphology are explored in detail and carried out in the laboratory through at least the Preliminary Design. In terms of the elements of design tested in the Anatomy, lecture-laboratory hours are largely devoted to need analyses, communication, syntheses, modeling, and optimization.

The level of the Engineering 4B lectures and laboratory projects must, of course, be geared to preparation of the students. It is obvious that the mathematical and physical background of freshmen students is limited. However, if anything, their creative talents seem to equal or exceed those of older students. Since the course is concerned with the presentation of a methodology, it is not necessary to call upon systems requiring sophisticated models to explain the design methodology.

Content of the Workshop

The U.C.L.A. Workship program comprised basically the presentation of the course Engineering 4B, "Introduction to Design." Substantially its full content was presented during the four weeks of this workshop. The forenoons were principally devoted to lectures, and the afternoons to group work on projects, cooperatively chosen by students and professors. Each professor worked only with those students from his own school.

The "principal" 4B lectures were delivered usually by Ben Ostrofsky, who elaborated upon the design morphology as set forth by Asimow* and expanded by Woodson.** Communication lectures were based upon the work of Rosenstein.*** The visiting professors attended all the lectures, which they were thus able to interpret, expand upon, and apply during the afternoon lab sessions with their students.

Four formal reports were required during this course. These consisted, as mentioned in the Course Description, of a Project Proposal, a Feasibility Study, a Preliminary Design Report, and a Detailed (Final) Design Report. The general philosophy of the sequence was to simulate a real situation in which the engineering was performed and presented to management for decision about commitment of manpower and funds for the next steps.

Substantial amounts of student and faculty time were devoted to defining objectives, to Mathematic Modeling, to developing of Criterion Functions, and to Optimization. These subject areas were used as bases for digital computer experience.

Considerable stress was applied to techniques for constructing and using mathematical models for identifying optimum combinations of project parameters in rather abstract form before alternative physical concepts had been advanced far enough to make comparisons among them. Much time was spent in constructing numerous combinations of possible design parameters and corresponding value weighings, and in computer summing of their products into numerical values of a criterion function. The optimum design approach was then regarded as that producing the maximum value of the criterion function.

Attached is the course outline upon which the Workshop was based.

The course provides two hours per week lecture on design methodology and the tools of information retrieval, synthesis, math modeling, graphics, computer programming, and communication. In addition there is a three-hour lab period per week for the prosecution of a student project, the vehicle and the measure of the course. Under the close guidance and counsel of a professionally oriented instructor, the student validates

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* Asimow, M., *Introduction to Design*, Prentice Hall, Englewood Cliffs, New Jersey, 1962.

** Woodson, T. T., *Introduction to Engineering Design*, Engineering 4B Syllabus, U.C.L.A. Printing and Production. (McGraw-Hill Book Co., New York available July 1966.)

*** Rosenstein, A. B., R. R. Rathbone, W. F. Schneerer, *Engineering Communications*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1964.

needs and proceeds through a feasibility study, a preliminary design and a detail design, terminating with a prototype or partial implementation. While engaged in his design, the student writes three- to ten-page monthly progress reports and is individually counselled by an editor on his communication effectiveness. The IBM-1620 computer is taught by auto-instructional material written for the purpose and the computer lab is run "open shop." About half of the students put their design alternatives on the computer in selecting their "optimum" design. Individual oral presentations of the projects close the course.

Course Outlined—U.C.L.A.—Engineering 4B

Week	*Lecture and Discussion Topic*
1.	The Engineer and Design; Science vs. Engineering; Information Sources and Interpretation
2.	Problem Solving in Design; The Design Process-Morphology
3.	Communication—Sender Receiver; Channel Diagram Communication—Starting the Technical Report
4.	The Design Process; Anatomy-Needs Analysis; Computers. (General Homework Due: Proposal Report)
5.	Computers: Programming; Free Hand Sketching; Isometrics; (General Homework Due: Computer Problem No. 1)
6.	Fundamentals of Orthographics: The Point, Auxiliary Plane, True Length, Point View of Line. (By means of auto-instructional text.)
7.	Edge View, True Size, True Angle, Piercing Point, Intersections
8.	Feasibility Study—Input/Output Analysis; Alternative Solutions; Creativity (Patents); (General Homework Due: Feasibility Study Report)
9.	Estimation and Order of Magnitude Analysis; The Engineer and Money: Guest Engineer from Industry
10.	The Preliminary Design; Math Modeling; Variety of Models: Iconic, Analog, Symbolic
11.	Symbolic Modeling; Formulating the Criterion Function; Sensitivity and Compatibility Analysis
12.	Optimizing: Subjective, Graphic, Analytic
13.	Digital Computers and Design; Engineering Checking; (General Homework Due: Preliminary Design Report)
14.	The Detail Design: Revision, Implementation; Oral Communication—Visual Aids
15.	Guest Engineer; Review; (General Homework Due: Detail Design [and prototype if any])

AN OVERVIEW OF THE WORKSHOPS

by

P. Z. BULKELEY

Funds for a "reporter-editor" were provided in the Commission's portion of the Workshop budget. His task, envied by few, was to prepare the final report of the Workshops (these Proceedings) with editorial comment based on visits to the host schools and talks with workshop participants.* This section, then, of the Proceedings is the editor's overview of the entire operation, comprising planning meetings, Workshop sessions, and Carnegie Conference. It is gleaned from endless hours of listening and probing, from volumes of correspondence with Workshop participants, and from tape recordings made of the terminal conference.

The Workshops—A Comparison

It is evident, from reading the Workshop descriptions, that no two were alike. Instead, each reflected the environment peculiar to its host institution, and the biases ingrained in its staff. Indeed, it is remarkable that six activities outwardly so different from one another could find a common home under the banner of "Authentic Involvement." Before seeking the common thread wound through all of the Workshops, consideration of their external differences is in order.

To start with, actual designing was not the main activity at each Workshop. Berkeley, for example, concentrated most of its time on the study of engineering cases and in their preparation. At Case a great deal of time was spent in building and experimenting and checking-out—more of development than of devising.

The basic approach to the designing done differed markedly from school to school. At U.C.L.A. a formally structured programming of the design process was overseer of the daily routine. Dartmouth devised an entrepreneurial flavor by requiring total project planning at the outset and by stressing continuous attention to the economic consequences of design alternatives. The M.I.T. program was goals oriented—methodology was not explicitly imposed.

The posture of the faculty vis-à-vis the students varied markedly. The coach-confidant role espoused by the Dartmouth faculty was adopted by some of the participants at each Workshop, though not by all (even at Dartmouth). Classical trans-lectern relations between teacher and student usually prevailed at those Workshops having a substantial component of formal lecture, as at Berkeley, for example.

The M.I.T. experience best answered the question—should students work singly or in groups? It obviously depends on the job at hand. Ambitious tasks are better handled by groups while simple ones can be prosecuted successfully by single students; however, the best mix of classes, disciplines, and schools showed much variation from Workshop to Workshop. At Berkeley, U.C.L.A., and Case each visiting faculty member worked with his own students.** Some also did at Dartmouth, but other groups were mixed.

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* Each host school was visited twice, once before the Workshop started (at two schools this was during the planning meeting), and once while the Workshop was in session.

** Augmented in the Case Workshop by students from Case.

No artificial categorizing can completely describe the basic differences found in the projects undertaken at the Workshop. At Case and M.I.T. the projects were strongly oriented toward laboratory involvement with instrumentation and hardware. Carnegie directed itself more toward paper studies of a highly complex systems problem. At U.C.L.A. the tasks undertaken were more modest—reflecting their students' individual or paired efforts and interests. Berkeley experienced design vicariously through the preparation of cases obtained in local industry.

There were two sources for the involvement project problem—the faculty and the students. In almost every instance, the students defined the problem on which they worked within a framework established by the faculty ("solid waste disposal" at Carnegie, for example). The tangible results of the students' designing were usually less impressive when their problem area was imposed on them by a faculty member (invariably one of the visitors).*

Communication between the various working groups was usually good at each Workshop. Common housing of students and relatively frequent joint activities were the reasons. However, where various groups worked at some distance from each other, as in separate buildings, it was evident that many students didn't know what was going on except in their own area. M.I.T., where all student groups shared a large common laboratory area, had, perhaps, the best inter-student communication.

Faculty communications among themselves were good or bad depending on the school and individual. They were best where there were regular meetings, however informal (luncheon). They deteriorated whenever host faculty became distracted by interests other than the Workshop. The esprit among the visiting faculty at Dartmouth and U.C.L.A. was exceptional.

The lecture program offered by each school reflected its home environment and its philosophy of design. Carnegie, Dartmouth, and M.I.T. had little lecturing to the students, except for the visiting experts—"need to know" apropos the projects was the general criterion which governed selection of lecture topic and its timing. Berkeley and Case had substantial lecture programs, the core of each being assorted topics in design analysis. U.C.L.A.'s lecture program was central to their course and reflected their detailed structuring of the design process.

That all engineering students must have a component of design in their course work is absolute gospel to the host faculty of the Workshops; however, differing views are held about when they should start getting it. Freshmen are considered ideal fodder at U.C.L.A. Dartmouth and M.I.T. began their offerings at the sophomore level. Berkeley concentrates its effort on graduate students.

As can be seen, each of the Workshops was different from the others. In fact, in fine structure, the number of individual approaches to design equaled the total number of participants. However, interlaced through all of the Workshops were some common features and philosophy.

In the first place, each project undertaken, or case written, was wholly new to both student and visiting faculty. Thus, decisions rendered by the instructor were most often based upon judgment and experience, rather than upon recourse to a detailed body

* Excepting the Case experience where internal comparisons are hard to make. There the project areas were carefully pre-selected to blend into existing on-going research projects.

of knowledge. This implies that the teacher's credibility was tied psychologically to the confidence he had in his own ability and resourcefulness. Inevitably, errors of judgment on the part of faculty members did occur. Frequently, these could be traced to a lack of flexibility and willingness to approach questions not answered by prior experience.

Education by confrontation with reality, the essential ingredient of "authentic involvement," is a teaching method that cannot be transmitted effectively without actual experience in doing it. Thus, the students were essential in comprising the arena for demonstrating this approach to design education. Some faculty adapted readily, others did not. However, all of the host schools provided, by example and in program structure, the freedom required to acquire the viewpoints needed in "authentic involvement."

However carefully they are contrived, all bona fide design problems are open-ended. The projects of the Workshops were, additionally, unstructured. There was, in no instance seen by the editor, a clear-cut pathway visible to the student which led from his problem definition to its ultimate solution. This fact manifests itself in more than ordinary frustration and anxiety among the students. It would clearly, to them, require more than brute force to complete their projects satisfactorily—if, indeed, they were completed at all. A new dimension of uncertainty as to outcome had been introduced into the educational process.

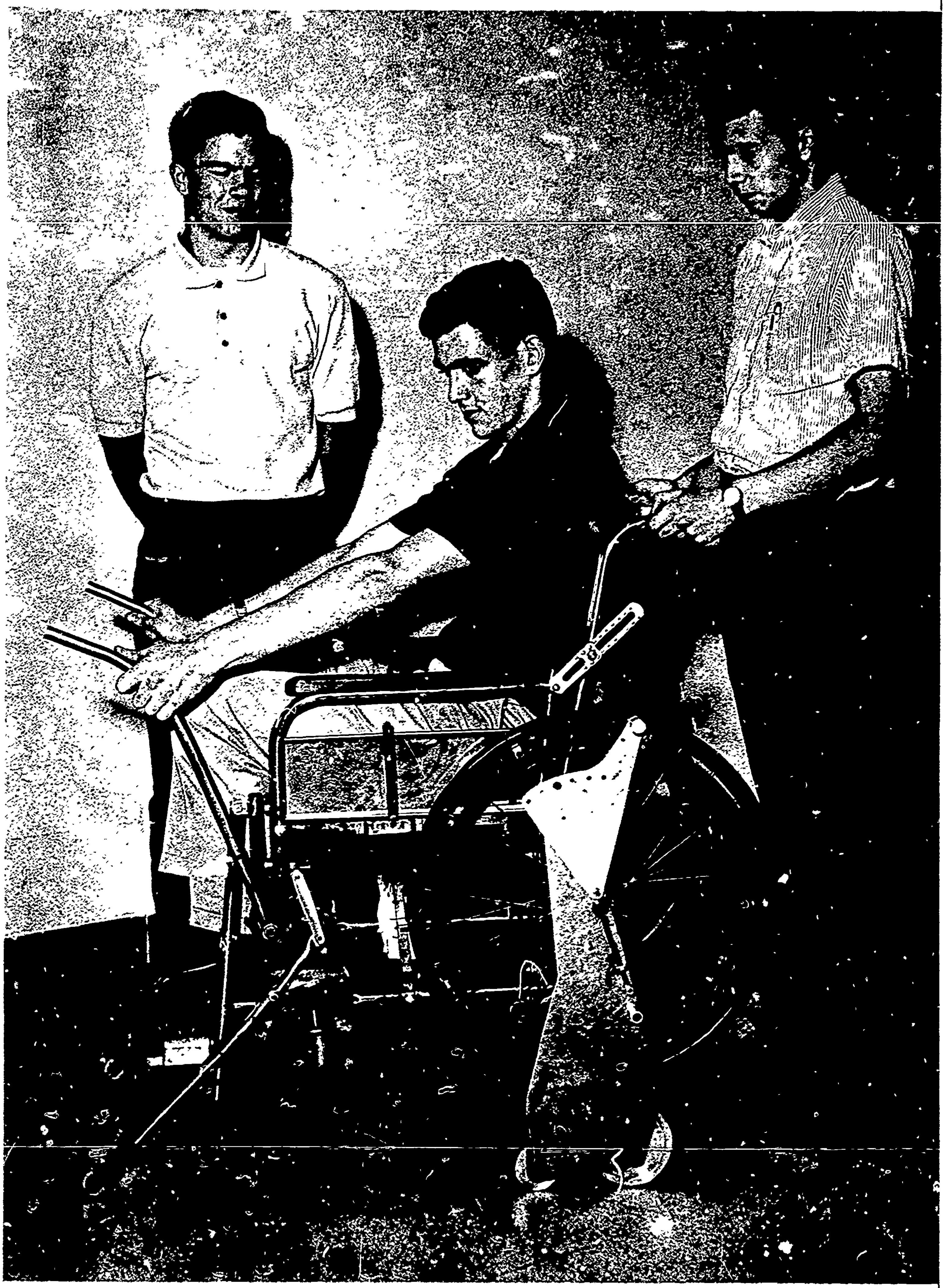
The projects undertaken themselves freely crossed boundaries of conventional engineering curricula. The Workshops, without exception, demonstrated that design is a priori interdisciplinary—the historical anomaly of its association with mechanical engineering, i.e., through machine design, can no longer govern the approach educators take to the teaching of design.

The Visiting Experts

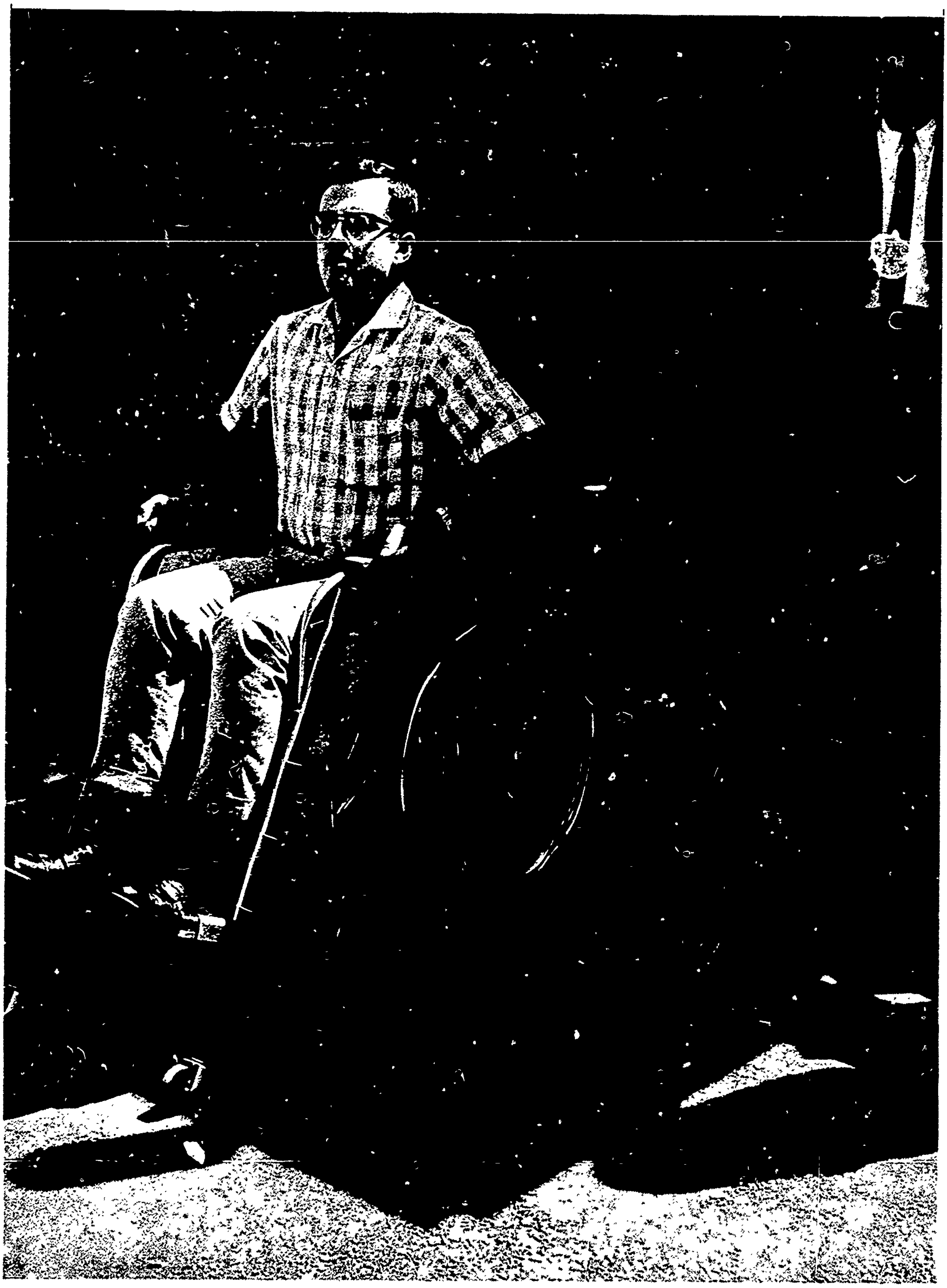
The guest "experts" mentioned earlier spent two days at each host school (excepting Dartmouth which they did not visit). They gave several lectures at each Workshop, and otherwise were available to students and staff for consultation and advice. Subsequently, they participated in one of he round-table discussion sessions at the terminal Carnegie Conference.

The reception of the experts varied from Workshop to Workshop. However, generalizations about their effectiveness can be had from correspondence with Workshop participants. With rare exceptions, the experts were accepted as what their name implies—expert at some aspect of design theory. However, this expertise infrequently blended with Workshop activities. Most often the timing of their visits did not make optimum use of their talents at the most appropriate stage in an individual Workshop program. In addition, their relative sophistication could outstrip the capacity of the students to understand—some of what a senior could grasp a freshman could not. This is summed up in a comment, by R. R. Rothfus, ". . . that much of the value of the lectures was lost on the students. They simply did not have the perspective needed to fit each subject into its proper place and to pursue fully its connection with the problems they were in the midst of solving." One of the guest experts expressed a more general reaction to this experience by saying, ". . . the traveling speakers were sometimes seen as distractions and not a part of the 'real' design activity." The overwhelming response of Workshop directors and participants indicates their reluctance to consider having expert lecturers in future programs of this type.

M. I. T. WORKSHOP
The feasibility of switching high speed vehicles in tubes by means of pneumatic tubes was established.



DARTMOUTH COLLEGE WORKSHOP
Device for climbing curbs with a wheelchair.



DARTMOUTH COLLEGE WORKSHOP
Device for climbing curbs in a wheelchair.

CASE INSTITUTE WORKSHOP
Channel bio-telemetry system as re-designed by the North Dakota University Workshop group.

The Vaccination—Did it Take?

The Committee on Authentic Involvement recognized, in organizing the Workshops, that each host school could hope to influence, through this program, only a few other institutions. Thus, the number of participating schools was purposely kept small, many fewer than applied. It was thought that participants would return to their home environments with new ideas and viewpoints of design education. After a suitable gestation period using the approach of "authentic involvement" they would be encouraged by success to organize similar Workshops. Thus we ask, what is the fallout of the Workshop program? Is there evidence that the "vaccination took"?

While the Workshops were in session, the editor asked the visiting faculty whether they would be greatly influenced by the experience, and they all, of course, answered yes. The tenor of their remarks, however, was flavored by the host school involved—two patterns of response emerged. At those schools having little program superstructure, the answers typically were of the variety, "I'll use these ideas, but I'm not quite sure yet how." Where activities were highly organized as at U.C.L.A. and, in part, at M.I.T. and at Dartmouth, there was a tendency to want to jump right in—to transfer directly and unchanged large components of the program.

In later correspondence it is evident that a shift in scenery has tempered some of these initial judgments. Portions of each Workshop are being taken over into new housing at other institutions—but are being conditioned by the local environment. In general, where a particular technique or device will lend new vitality to existing courses there is immediate transference; virtually all participants are experiencing this.* The more significant goal, that of making long term changes in the philosophy of design education, remains to be tested.

It was originally thought by the Committee on Authentic Involvement that some of the 1965 visiting faculty would have their own schools as host institutions in a second round of Workshops. There wasn't enough time after the 1965 effort to plan and submit proposals for 1966, but there is a possibility for 1967. However, an initial survey of the 1965 visiting faculty shows only small interest in preparing immediately to host their own Workshops (with two exceptions). Instead, they prefer to wait—and to develop their own "muscle" at "involvement" before passing it on to other schools and faculties. For this reason the promulgation of the authentic involvement philosophy in a 1967 round of Workshops will require some continued participation of the 1965 hosts—if not the schools themselves, at least the faculty. This group can, of course, be augmented by other practitioners of authentic involvement who were not hosts or visitors in the 1965 Workshops.

The Carnegie Conference

A verbatim transcript of the round-table discussions at the Carnegie Conference reads like patternless glossolalia. Few excerpts, taken from context, can add to what has been written by the Workshop directors—yet the whole, in sheer volume, would only contribute monstrous tedium to the reading of these Proceedings. Some of the flavor of the meeting, and what the editor feels was the consensus of participants, can, however, be gotten from a very few quotations from the transcript. These are given here.

* Many specific examples can be cited. For example, at Arizona State in ME 102, "Introduction to Engineering," T. W. Price reports changes "which certainly show traits inherited from E.S. 21 at Dartmouth."

About the teacher-student relationship, R. C. Dean, Jr., said:

> *"I think it's very important to take the role of a coach—to stand on the sidelines. Otherwise it's very difficult to see how the game is going."*

And L. Harrisberger said:

> *"This design environment has a tremendous potential for the development of self-confidence. One of the ways we can give good reinforcement is to put the students in league with the instructor and not pitted against him."*

About the effect on students of an experience in authentic involvement, W. J. Schimandle said:

> *"It is frustration which offers the students the opportunity to try to search for new ideas."*

And R. C. Dean, Jr., said:

> *"A very definite objective of this kind of course is to get the student committed to practical engineering, and we feel that this commitment is far higher if he picks up a project in which he is very interested and which he wants to solve rather than being trained in a project which he is forced to solve."*

About staffing, R. W. Mann said:

> *"Concern most properly must be directed at the generation of the staff who can carry through the kind of design education that we are talking about."*

About the outcome of the Workshop, D. B. Welbourn said:

> *"The value of these courses is that the young men had a chance to educate themselves for a change instead of being systematically trained."*

And, finally, W. B. Diboll, Jr., said:

> *"The consensus is that design is the essence of engineering."*

PART III—CASE METHOD WORKSHOPS

by

KARL H. VESPER
Stanford University

The intent of the Case Method Workshops was to demonstrate, as clearly as possible, some approaches to the use of cases in teaching engineering. There were five separate Workshops, each of one hour duration. These Workshops were each repeated once so that every Conference participant had the opportunity to attend two of them. Each Workshop was conducted by a professor who had experience in using written cases. In it he discussed how he used a specific case or cases and he presented his views on the results of their use.

In the book, *Plain Words*, Sir Ernest Gowers lists "case" as one of the most overworked words in the English language—so it isn't surprising that considerable disagreement exists about defining "case methods" and "case" when we talk about the pedagogy of engineering education. No ubiquitous meaning exists for these terms. For the purposes of the case study Workshops, "case" did not mean simply a "student design project." Rather, it referred to an excerpt from, or critical instant in, an actual engineering project in industry. The cases discussed are historical in part, but they are not "case histories" which simply tell of events completed in the past. Typically, each case stops its story at some crucial point, leaving a definite problem to be solved. The student then is expected to complete the history by his own work. Supplements to the case may describe what course of action was actually adopted by the company involved. The cases are not like journal articles, focusing on detailed exposition of a technical problem and its supporting rationale. Rather the case descriptions describe who said what to whom and also who did what, showing the surrounding circumstances and mentioning the failures as well as the successes which were achieved.

There are some common features among the cases which were discussed. All of them were written descriptions of problem situations in engineering, situations which actually occurred in industry outside of the classroom. However, they go beyond simply describing a problem and its solution—and may be considered as clinical examples of engineering practice as it really occurs. A brief description of each case Workshop, written by its moderator, follows. The numbering system "ECL . . ." refers to catalog numbers at the Engineering Case Library, Design Division, Department of Mechanical Engineering, Stanford University. Copies of these cases as well as a bibliography describing a number of others are available upon request.

WORKSHOP MODERATOR: P. Z. Bulkeley, Associate Professor, Stanford University

CASE DISCUSSED: "Task Corporation—Hiring Engineers and Draftsmen," ECL-8

The nonfictional Task Corporation, a manufacturer of electrical motors and some allied hardware, uses a test of dimensioning skills to screen applicants for jobs as engineers and draftsmen. This test, together with some background material describing the Task Corporation, its operations, and its products, form the case—which is *not* a case history, but is a collection of descriptive material.

This example was chosen for presentation at the Workshop session because it shows the diverse uses which can be made of a single case. It has been used by the moderator with groups large and small, at all levels of the academic spectrum, having been presented to classes as follows:

115 students, predominately freshmen and sophomores, in introductory engineering drawing;
60 students, predominately sophomores, in introductory engineering drawing;
18 senior students in mechanical design;
22 graduate students in analytical design.

In addition, "Task Corporation" was written by Mr. Karl Vesper, which illustrates the fact that one need not write a case himself in order to utilize it effectively.

A typical assignment of "Task Corporation" would follow the pattern:

1. Case is assigned for reading overnight. The students are expected to read and re-read the document until they are thoroughly familiar with its contents.
2. The dimensioning test is taken by the students and its solution is discussed with them. This discussion can be directed in a variety of ways, depending on the intent of the instructor. Possible directions include:
   a. Exploration of the need for paying meticulous attention to detail in carrying forward any engineering task.
   b. The extensive interaction between mechanical design and manufacturing processes.
   c. The details of mechanical analysis related to the objects to be dimensioned in the test.
   d. Tooling for production and its related economics.
   e. The interaction of electrical criteria of performance and detailed mechanical design in electro-mechanical devices.
   f. Personnel practices in small corporations.
   g. Study of the diverse products available from this small corporation.

Discussion is moderated by the instructor and is aimed at detailed description and analysis of one or several of the areas listed above. Discussion is Socratic—the students and instructor together approach the "Task Corporation."

The Workshop sessions at the Carnegie Conference devoted much of their time to discussing the type of student involvement associated with this type of case study and the pedagogy of its use. The involvement in "Task Corporation" is a simulation of a real situation through the medium of the dimensioning test, leading into a more general discussion which the instructor can direct toward any of several objectives listed. The essential feature of the pedagogy used with this case is the simultaneous confrontation of student and instructor with a practical situation, the test, in which they together have the opportunity to explore, at any depth desired, the problem surroundings.

WORKSHOP MODERATOR: H. O. Fuchs, Professor, Stanford University

CASE DISCUSSED: "Development of an Oil Well Tubing Stripper Rubber," ECL 1-13
"FMC Corporation, A thru D," ECL-17

The first of the cases discussed, the Stripper Rubber, consists of two parts: a formal engineering report which Paul Bickel submitted to the Ohio State Board of Registration, and his story of what "really" happened as he developed this device. This case has been used previously in senior courses in Mechanical Design at U.C.L.A. and at Stanford, and in a freshman course in Engineering Graphics at Stanford.

The second of the cases, the FMC Corporation, concerns a sophisticated optical-electronic mechanical device for sorting white rice from pecky (spotted) rice. The four parts of the case describe the conception, design of the first prototype, field failures of the first production model, and re-design of the rice sorter, as handled by FMC's Central Engineering Laboratory and one of its manufacturing divisions. This case was written by graduate students employed as case writers at Stanford. Previously it had been described in a graduate seminar on Engineering Operations.

Both cases were used primarily to show that engineering is done by individual engineers—humans with judgment, temperament, idiosyncrasies, limitations—so that students can identify with the person who must do the job and so that they may have an antidote to the erroneous impressions created by rigorous impersonal texts.

The students at the Berkeley Design Workshop were assigned a number of problems connected with these cases:

List decisions chronologically and rank them in order of importance.
Compare the design process as related in a case to the process outlined by FMC.
Identify problems and sketch solutions.
Sketch improved hoppers for rice.

At the conclusion of the class meetings devoted to these cases, the students were asked to consider how easy it is, with the wisdom of hindsight, to find fault with the work done by engineers, and to temper their future judgments by this consideration.

Discussion at Pittsburgh Conference concerned such points as grading (subjective), structuring case discussions (little for graduates, strongly for freshmen), and the place of cases in instruction. On this last point my view is that textbooks, projects, and cases each have unique virtues, that a balance of the three is desirable, that in design courses the balance should favor projects and cases more than textbooks and lectures, that time used for cases will provide a great amount of breadth to complement the depth achieved by a project and will introduce a human element into engineering instruction.

WORKSHOP MODERATOR: R. K. Pefley, Professor, University of Santa Clara

CASE DISCUSSED: "Temperature Control. A Case History of the Mariner Spacecraft," R. K. Pefley, J. M. 33-189, J. P. L.; also ECL-43

The case discussed was prepared by the moderator as an instructional vehicle while he was at JPL on sabbatical leave.

The case is written so that it can be supplied to the students in sections. This is to simulate the progressive unfolding of features and interface constraints in real design work. At the end of each section are student challenges. The succeeding sections of the case describe the real design evolution and allow the student to contrast his ideas and analyses, which he has completed prior to receipt of the follow-on section, with the actual design.

The case was exposed to the Design Conference attendees as it would be to the students. They read the first section and then we spent the remainder of the hour with them, performing in ambivalent roles of students and teachers. The basic parameters and design philosophy for spacecraft temperature control were established by group discussion while having a thorough discussion of best methods of exposing these ideas.

If the writer correctly sensed the consensus of the group, it is that a case can best be presented by the author of the case. This is particularly so, if the author wrote it from firsthand observations. So much of the color of personalities and circumstances are strained from the presentation if it is presented from secondhand awareness that the case loses a significant portion of its appeal.

Based on the experience of the writer with this case and having observed the presentation of several other cases under variety of circumstances, the writer concludes:

a) Cases provide the closest approach to real design experience that a vicarious exposure can provide.

b) The exposure is most likely maximized if the case writer presents the case to the students, i.e., firsthand presentation.

c) Some sort of funding should be available to allow the authors of outstanding case examples to visit different schools and present their cases to the student groups to verify the above impressions.

WORKSHOP MODERATOR: R. F. Steidel, Jr., Professor, University of California, Berkeley

DISCUSSED: "Program on Case Studies"

The University of California, Berkeley, is now making use of case studies in engineering as a pedagogical tool which increases the cooperation between engineering education and industry.

In developing and using case studies for classroom use, two groups benefit. The first group consists of students who are using case studies as text or source material to bring the real world of engineering into the classroom. The professional benefits of this are recognized. The second to benefit are the case writer or case writers who develop the case study. At the University of California, Berkeley, in the Division of Mechanical Design, our attention has been directed to the latter.

In the Spring of 1965, a graduate seminar in Engineering Case Studies was held as an organized course. This was the pilot effort, which we hope will result in a sustained program. Six students enrolled. In the first six weeks of the 15-week semester, these students read and discussed several of the case studies that had been developed by Mr. Vesper and Professor Fuchs of Stanford University, and Professor Pefley of the University of Santa Clara. These represented a diversity of material and did give the students a general idea of the objectives of a case study. This is important. Graduate students who have never seen or read a case study expect the formal problem solution that is so familiar to engineering education. Their surprise was somewhat traumatic.

During the last nine weeks of the course, with the first interviews coming even earlier, the students explored and developed a case study of their own choosing. Three students developed a case study on the Design of the Liquid Hydrogen Bubble Chamber at the Lawrence Radiation Laboratory in Berkeley. The other three students developed a Case Study on the Hydro-Constant Pump, which was developed, manufactured, and marketed by the FMC Corporation in Santa Clara. The first represented a design problem of a national laboratory. The second represented a venture of a profit-making organization. The students contrasted the differences in objectives and purposes of the two designs.

At the Case Studies Workshop during the Conference, the purposes of this approach to Case Studies in engineering were discussed. The Bubble Chamber Case Study was distributed to those attending the Workshop session. The Hydro-Constant Pump was not completed, but has since been mailed to all who desired copies. Those in attendance at the Workshop questioned the mechanics of such an operation and asked such questions as:

1) How were the seminars carried out?

2) How were grades assigned?

3) Of what references did the students make use?

4) Did the students have any opportunity to criticize?

The last question invoked considerable discussion, since the students were not given an opportunity to criticize the design or engineering of the case under study. The students were also not given any opportunity to test their own approach to the design in the laboratory (involvement). There was considerable discussion on the educational value of a study of a completed design, in which the student has only objective interest. Such objective interest cannot substitute for laboratory or clinical involvement, but it is an educational vehicle used in law and medicine, and not now used in engineering.

One result of the discussion was a change in format at Berkeley. This summer, our seminar in Case Studies was repeated in the second Summer Session of 1965 for one group of four students. These students were given the opportunity to criticize the engineering design that they studied. This criticism was beneficial, although it seemed mostly a catharsis, and it will remain as part of the objective of future studies.

Our experience with case studies reinforces our opinion that graduate work in developing a case study is an excellent alternative to a thesis or graduate project in engineering design.

WORKSHOP MODERATOR: K. H. Vesper, Director of Case Development, Stanford University

CASE DISCUSSED: "Radonics," ECL-27

The Radonics case consists of three chapters describing the design of a fixture for use in heliarc welding. The first chapter gives background of the desire for the device and introduces the student to the company for which it is to be designed. It also introduces him to the engineer who has been asked to do the job and gives the student essentially the same information the company engineer was given for doing the design. This part of the case was handed out as a one-night assignment at the Berkeley Design Workshop, and students were asked to come prepared the next day to present sketches showing the general concept for a design plus an estimate of the total number of man-hours required to carry the design through to a working model.

When student solutions to the problem were presented before the class the next day, no attempts were made to criticize them, although questions were asked to clarify their descriptions. After these presentations, the second chapter of the case, which describes the procedures followed by the company engineer and the resulting design, was given to the students and they were asked to evaluate critically his efforts. By being allowed to criticize the professional's design rather than each other's, it was felt that students could learn from the critical process without condemning their own creative efforts. In their critique, students were asked to predict difficulties to be expected with the professional's design.

The third chapter was given out following the critique session so students could see the final outcome and costs of the company's design. This allowed them to check their forecasts and judgments.

PART IV—SPEAKERS FROM INDUSTRY

The awesome rate of technological change emphasizes the interdependence between the practice of engineering in industry and the source of engineers, the educational establishment. Nowhere in the engineering curricula is this interdependence more obvious than in the field of design, and at no interface between school and industry will effective rapport bring about greater bilateral advantages. Elsewhere in these Proceedings, interaction and cooperation between industry and design education has been apparent. An inspection of the participant list discloses many representatives from industry. It was therefore, most appropriate that invited speakers from industry share the rostrum, providing the audience with several exciting examples of current technology.

These speakers gave papers before the Third Conference on Engineering Design Education during the afternoon of the second Conference day and at its banquet. The texts of these addresses are included here with one exception. The comments of Mr. R. H. Fields, Westinghouse Electric Corporation, were not recorded, and he did not follow a written script. However, his topic, "A Rapid Transit System," is presented in a similar way in a paper by William J. Walker and John K. Howell, both of Westinghouse, entitled "Transit Expressway . . . A New Mass-Transit System." This appeared in the July, 1965, issue of *Westinghouse ENGINEER* and is now available from Westinghouse at 3 Gateway Center, Box 2278, Pittsburgh, Pennsylvania, 15230, as Reprint Number 6322.

THE COMPLEAT AUTOMOTIVE DESIGN ENGINEER

HAROLD C. MACDONALD
Ford Motor Company
Dearborn, Michigan

Before I get into my subject for this evening, I'd like to mention that, exactly one month ago, educators in mechanical engineering from fifty universities attended our 1965 Engineering Forum held in Dearborn. Now, these poor fellows were subjected to a week of after breakfast, after lunch, and after dinner speeches by Ford engineers and other executives. If any of you here tonight are refugees from that forum, and if you didn't realize you were going to hear another speech by a Ford engineer, you are free to leave the room right now—quietly and no questions asked.

The title of my talk tonight was suggested by Izaak Walton's classic 17th Century treatise on the art of fishing, called "The Compleat Angler." In it, the author dispenses some good advice about fishing with frogs that all of us after dinner speakers could apply to our audiences: "Use him," Walton cautions, "as though you loved him; that is, harm him as little as possible, that he may live the longer."

Gentlemen, let me emphasize at the outset that I am here tonight to discuss the process of developing design engineers at Ford. I am not here as another outside "expert" on education. We have only to look around at the amazing diversity of skills and talent among the 12,000 engineers, scientists, and technicians in our Research and Engineering Center to realize that no technical curriculum can be all things to all people.

We, therefore, recognize an obligation to provide a continuous learning environment for the young man coming to us, to facilitate his transition into our world—a world that has a nasty habit of posing non-linear situations and requiring as much ingenuity in economics as in kinematics. If Herb Misch were here tonight, I'm sure he would agree with me that we *are* getting the caliber of young men in our organization that we want.

When I went through engineering school, just before World War II, the curriculum was based on the assumption that technology would not change very much within an engineer's lifetime. Well, I, and many fellows like myself, have been running to catch up with the technology explosion ever since we came back from the war.

We have ceased to wonder at this explosion, and now we are talking a lot about system engineering and the major breakthroughs to come from *between* disciplines rather than within them.

I'm sure you men are aware that the automobile industry, despite its economic impact on our society, has—technologically speaking—just recently graduated into the world of sophisticated science and engineering. I can tell you it's exciting to be here! We don't do business in Detroit and Dearborn the way we used to. The intense marketing pressures generated by an eight to nine million car market is one reason. But another very basic reason is our new technology—which is characterized by widening computer applications, and increased reliability testing in a realistic laboratory environment.

However, one thing has *not* changed in our industry: That old, old formula that still separates success from failure and extinction: you must bring the right *product* into the right *market*, at the right *time*, and at the right *price*!

In this formula the importance of the automotive design engineer is today—as it *always* has been—absolutely critical!

Regarding the right product: traditionally, it has always sold primarily on its styling. Today, styling is still the the *major* appeal, but reliability, durability, performance, freedom-from-maintenance, comfort, and safety are becoming increasingly important to our customer.

Regarding the right market: Now that the domestic automobile market—and not even counting the growing overseas market—is on its way from eight to nine million car sales a year, people are finally beginning to understand why in a multi-billion-dollar industry the automotive designer must be so cost conscious . . . why he must think in fractions of a cent, like a paper clip manufacturer.

Regarding the right time: Most consumer items get refined by a painstaking, time-consuming process—but not the automobile. The industry puts a heavy requirement on its engineers to be right the *first time*—not only in design, but in the test and development criteria used to assure required reliability in the required time. And, gentleman, our development time continues to shrink away!

Regarding the right price: Holding the line on rising costs of the product and product improvements through ingenuity is a terribly important responsibility of the designer. He is called on, not only to improve the product, but to do it at equal or less cost than the design it replaces. There are numerous exceptions to this, of course, when the added cost can be well justified.

I would like to repeat—the design engineer is critically important to the automobile business. Much of what he needs to know we must teach him. But whether we are able to do so or not is largely up to you.

Dean Teare suggested to me that a profile of a typical Ford automotive design engineer might interest you gentleman tonight. One young fellow—let's call him Jim Bates—immediately comes to mind because he would be welcome anywhere in Ford Research and Engineering. Jim is an extraordinary fellow, and I'd like to tell you about him:

Jim came to us from a school highly regarded in mechanical engineering. He was among the three out of four engineers who don't have an advanced degree when they join Ford Engineering. He then spent two years in the Ford training program, in which young college men move from division to division in search of that tailor-made job in which they can *go*. It didn't take him long to conclude that he needed more specialized engineering courses; and by the time he finished his training program, he was well along at night school toward a master's degree. Recently, we have started to send promising fellows like Jim to full-time graduate day school for their master's degree—and at full pay. Currently, 50 per cent of our engineers are enrolled in college-level courses, on their own or on company time.

Jim's first choice as a permanent assignment was the area of Applied Research. Like many young fellows, research meant to Jim "Imagineering" with a capital "I." Jim saw himself as a sensitive man of ideas, an innovator working magic at the outer state-of-the-art. Leave the crass details of manufacturing cost and feasibility to those clods down on the ground!

Jim's first project didn't turn out too well. He teamed up with a young electrical engineer to design a new ammeter. Of itself, the ammeter was a watchmaker's dream. The only trouble was that it required 28 more feet of wire and 20 more connections to install than the old one—but Jim learned something he never forgot. He learned that an improvement in one area of the vehicle may be a big step backward in another area. He learned that he had to work on his own small part of the whole vehicle with a broad viewpoint, a perspective, and that he would have to get the essential interface requirements himself. No one was going to hold his hand.

Jim's second project came off much better. He came up with a new cooling fan design, a fan with flexible blades, whose pitch decreased as a function of engine speed. This eliminated the expensive and repair-prone viscous "slip" clutch long required on cooling fans in air conditioning systems. It remained for other product design engineers to develop life-of-car durability into his research model, but no one was prouder than Jim when his fan finally went into production. It was about this time—after he had seen the changes in his design and some of the critical production steps being ironed out at the supplier's plant—that Jim began reassessing his view of *the design-for-now-engineer*—that is, the product designer.

He concluded, for example, that if he had done a better job of estimating attainable manufacturing tolerances in the early design stages, prior to prototype testing, his research model would have gotten into production with less development work. He was beginning to realize the difference between a brilliant designer, whose designs are successful as they were conceived, and the journeyman, whose design has to be cobbled and changed, freighted down with expensive "fixes," or thrown out entirely for a new start.

Meanwhile, Jim had been boning up at night on courses in computer applications. His special interest was constructing math models to predict performance of component systems, such as cooling systems, axle ratios, and vehicle suspension and handling dynamics.

He had an opportunity to put his homework to use when he joined the Vehicle Concepts Department. The only research engineers authorized to construct entire vehicles, this group sifts and evaluates concepts that appear to be feasible for vehicles a decade or two away. Here, Jim demonstrated an ability to step back and take fresh new views of an old problem, rather than start where the other fellow had left off. This, plus the ability to sift out the feasible from the unfeasible on the computer before going to expensive hardware, meant he was developing professionalism.

Ford's Superhighway Gas Turbine Truck is an advanced concept vehicle designed to both answer and raise questions concerning truck transport of the 1970's over the federal interstate highway system now under construction. Aside from its compact 600 horsepower turbine, one of the huge truck's true innovations is a second or additional suspension between the cab and chassis that does an excellent job of isolating the cab from road and chassis vibration. This was Jim's contribution to the truck;

it marked his entry into the "art" of engineering—that is, to the inductive processes of invention, problem-solving, design *and* development the automotive designer uses in performance of his assignment.

Jim enjoyed his "imagineering" in Vehicle Concepts, but, by this time, he had decided he didn't want to wait 10 or 20 years to see what he had—by definition as an engineer—produced "for the use and convenience of man."

By this time, Jim had asked himself a question that every young man who enters Ford Motor Company should ask himself—and the sooner the better. That question is: What do I want to be doing 10 years from now, 20 years from now? Jim understandably concluded that he'd like to be doing as well as he possibly could. He concluded that he had the balance of technical ability and personal traits to become a good engineering manager. He also observed that the men with the management skills in Ford Engineering were the men with the broadest perspective—so he moved at every opportunity, but only *after* he had mastered each job.

Jim moved from research into the General Parts Division to learn more about electrical and engine accessory development. Here he came up with another fresh answer to an old problem. This time it was contact points—a humble and prosaic component that hadn't changed in years. Jim sharply increased reliability and decreased manufacturing costs by eliminating about seven of the fifteen parts used in conventional points. He did this by going to aircraft-type points, which operate off a cantilever spring arm, thereby eliminating the complicated pivot mechanism. The accomplishment of bringing cantilevered points to the automobile industry resulted in points equal or better in quality than aircraft points. The manufacturing cost was not only drastically lower than aircraft points, it was a third lower than Ford's conventional points! Jim had won his badge as a sharp product designer.

Jim learned some new facts of product design life in the General Parts Division. He really learned, for the first time, what it means to design for mass production under the constraints of equal or decreased cost versus equal or increased reliability, durability, and functional efficiency. He learned the hard fact that no prior design analysis is as accurate as records of performance in the customer's hands—which is long after the manufacturer is committed to the design. He learned that no analytical prediction of behavior—computers notwithstanding—is any more accurate than the assumptions made about the range of operating conditions a vehicle or component will encounter in the field. And he learned that these conditions can only be inferred statistically for mass-produced components from the characteristics of the component itself. And he learned what designers of military equipment have known for years: If human nature and a new design don't mesh, it may not be easy to change the design, but it's easier than changing human nature.

Jim found, for example, that, after a few thousand miles, the pre-load tension on the cantilever spring arm of his pivotless points was dropping below what mechanics were used to reading on the conventional pivot points. On frequent field trips during his prove-out program, he found that many fleet mechanics were replacing perfectly good points if the spring arm tension had dropped a bit.. Well, you can't get all the mechanics to read all the service literature. So Jim had to minimize the tension drop by lowering the original pre-load spring rate. He did this by going from sixteen thousandths gauge spring steel to thirteen thousandths, but the details of how he accomplished this with the necessary reliability is a whole story in itself.

Jim's work on the advanced concept turbine truck had, meanwhile, attracted the attention of the product designers in Ford truck engineering. The truck engineers were girding up for an assault on a competitor's light truck several years hence. The competitor's light truck had independent front suspension with the advantages of a soft ride. Ford's light truck had a solid front axle suspension, which connotated ruggedness and durability—but also a harsher ride.

Our new man in truck engineering came up with a front suspension that retained the ruggedness—and just as important—the rugged image of the solid axle that so many light truck owners have in their minds. But, in addition, it offered the improved ride and handling and lower steering effort of independent front suspension. Called Twin-I-Beam, the new suspension features two I-beam axles of forged steel, which allow one front wheel to absorb impacts without affecting the other wheel. It was introduced this year on Ford's F-100 and F-250 line of light trucks, and has been a potent shot in the arm to the Ford Division's truck sales. For the manner in which Jim's design resolved the conflict—both engineering and saleswise—between ruggedness and good ride and handling qualities, it was considered by his colleagues to be an "elegant solution." It was based on a principle used in a French luxury car, called the "Unic," back in 1935, but had never been successfully applied by anyone else until Jim did it.

Jim himself did not consider the Twin-I-Beam a difficult design job. "The tough part," he'll tell you, "was the development work on each part in the suspension to get good enough dynamic functional and structural characteristics out of the design."

Jim's development program covered 30,000 miles in two test vehicles just to establish design feasibility. Later, 13 prototype vehicles went a total of 400,000 miles over all kinds of test roads, of which 34 per cent were run on severe gravel roads in Arizona. The "severest use" mileage was used to set durability criteria for the lab tests by measuring impact forces from various maneuvers along the pothole roads.

The lab test hours on the Twin-I-Beam alone totaled 11,000 hours—the equivalent of 12 million road miles. All lab test bogies were for the heavier F-250 truck, and laboratory development on this truck totaled 59,000 hours. In this assignment, Jim demonstrated the capability in development work that a designer must have if he is to perceive the functional and economic consequences of his chosen approach to design problems.

While the lab work was very costly, it paid for itself three times over by optimizing use of costly materials. For example, out of the lab work came kingpins of high aircraft quality steel with 30 per cent less bearing pressure developed inside . . . strength of the steering arm was raised 2½ times by increasing its weight one per cent . . . a conventional stamped bracket that initially went 4,000 test cycles, ended up going well over one million cycles without failure. Jim's lab data correlated beautifully with results from the 400,000 general durability test miles I referred to previously.

At each stage in its development, the Twin-I-Beam was checked by impartial computer experts, who analyzed energy inputs into the suspension, peak loading and load frequencies, chassis stresses, and other factors. As the man responsible for the development timetable of his design, Jim was not only prepared to submit his design to such periodic computer checks on schedule, he was able to conduct a sort of continuing analysis in his mind as he went along. Therefore, the modifications resulting from the analytical checks on the Twin-I-Beam were not wasteful or extensive.

After describing Jim Bates' career in Ford Research and Engineering thus far, it should be no surprise to you that today, at age 41, he is executive engineer responsible for the chassis designs of all the company's passenger car lines. Jim is responsible for integrating production designs of all chassis components into one "package." The package includes major vehicle systems, such as suspension, steering, brakes, exhaust, frame, body and engine mounts, clutch, speed controls, heating and air conditioning.

These complete chassis packages, incidentally, then move into my organization, where we marry chassis, bodies, engines and powertrains, then begin prove-out of complete vehicles.

Jim now manages an organization of 237 people. To help prepare him for this job, Ford management sent him to M.I.T. for a year, where he earned a master's degree in industrial management. His resposibilities have, of course, broadened into administrative areas of cost and weight objectives, budgeting, scheduling, and resolving design problems with the manufacturing people. He is not as close to specific design problems these days as he would like to be, but he does have some solid job satisfactions over and above a good salary. He has earned an excellent company reputation for "bringing in" chassis packages with efficient use of manpower, tooling, laboratory and test track facilities, and dollar resources. Much of the sweeping change that characterizes the 1965 line of Ford-built cars bears his stamp. And, judging by the warranty and policy records of his products, this stamp says "QUALITY."

As you have probably concluded by now, Jim Bates is not one man, but a composite of fine design engineers in our organization. However, if any of you gentlemen know of a young man who can match Jim's qualifications, please contact me after tonight's program.

As much as we would like to develop the complete automotive design engineer like Jim Bates, we recognize that with today's proliferating technologies, this is becoming less and less likely. Nevertheless, the automotive designer is still valuable in proportion to his broad knowledge, not in proportion to his degree of narrow specialization, which can turn into mere provincialism. Skills are *still* reasonably transferable from one area to another within automotive engineering—our talented designers are not trapped into an ever-narrowing spiral of specialization.

Gentlemen, in my opinion, the automobile industry is the world's finest post-graduate training school for the young design engineer. There are engineers who can design excellence into a product at a 10 per cent increase in cost or weight . . . there are engineers who can always find a way to cheapen a product . . . but the fellow who can come up with the elegant solution . . . more excellence at less cost, less redundance . . . with an element of beauty and the unexpected . . . the flavor of ingenuity transcending the obvious and commonplace . . . this is a designer's designer! And he is so recognized by his intensely competitive counterparts across town!

I cannot conceive of concluding this address tonight without citing the late Henry Ford as *the* classic example of "The Compleat Automotive Design Engineer." There are some conflicting opinions as to his technical ability in this or that precise area. But there is no disagreement on the fact that he was the best all-round man—the complete design, development, and manufacturing engineer—of the automobile industry. In 1914, Henry Ford was far out-producing everybody else from the world's finest plant in Highland Park, Michigan, because of his superior skill in integrating product design with the very latest manufacturing techniques. The next car that could even approach the $500 Model T in quality cost $450 more!

Mr. Ford's lesson in economics was not lost on our friends across town. But the cemetery is filled with auto companies, which over the past half century failed to learn from him . . . failed to deliver a product which millions of people can afford to buy, a product whose reliability must rival those with almost no cost limit . . . companies which engineered unnecessary costs into vehicles, for which the buyer paid but received no value.

I would like to emphasize one more thing about Henry Ford, which has been obscured by the passage of time, and perhaps by memories of his declining years: He himself built the earliest Ford automobiles because he was a born engineer. But he built Ford Motor Company because he had the ability to get other outstanding engineers to work with him—and work hard!

These engineers were not meek "yes men" by any means. They were intelligent, strong-minded, rugged men pioneering in an infant company and industry. But Henry Ford had the priceless ability for diffusing his new ideas, his perception, his enthusiasm, throughout the machine shops and assembly lines on a man-to-man basis.

Ford management puts a heavy premium on the talented design engineer who, in a more formal organization, can do the same things today. For ideas still remain the most fragile of things . . . and introducing new ones into an engineering organization still remains a most fascinating—and rewarding—art.

THE HUMAN FACTOR IN MODERN DESIGN *

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It is with great pleasure that I meet with you again to talk about design. As most of you know, the Mariner shown in Figure 1** will begin its pass by Mars tomorrow evening. If all goes well, by 8:30 p. m. the probe will have taken 21 pictures of the Martian surface. It will then begin the occultation experiment.

If both these experiments are successful, man will have significantly improved his knowledge of Mars and greatly improved our chances of landing successfully on that planet in 1971.

Good flashback technique requires that we dissolve to the beginning of the story, find out how it started and how we managed to proceed from an idea to a completed fact. It would be easy to tell the story in that way; in fact, that is the way it is usually told. With this paper, I hope to do something more. I hope to enlist the support of each of you to relive an experience with me. What I am trying to do is

* This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NASA 7-1000, sponsored by the National Aeronautics and Space Administration.

** Figures are at the end of the paper.

to have you experience the design process as it actually took place and, from this experience, gain an appreciation and a curiosity about an increasingly important ingredient in design, "the human factor."

The General Problem

In the summer of 1962, it became apparent that the Centaur vehicle, which was scheduled to carry a large payload to Mars during the 1964 opportunity, would not be developed on time. This meant that if the 1964 opportunity were to be used, a lighter payload launched by an Atlas-Agena would have to be developed. In early August, first cuts at the design indicated that the minimum payload which could be built weighed in the neighborhood of 540 lbs. At that same point in time, the weight carrying capability of the Atlas-Agena was considerably less. This discrepancy could not be relieved by ordinary means, which would have consisted of reducing the flight payload by the appropriate amount. A dual attack was made on this problem. The first was a performance improvement in the Atlas-Agena. This improvement, while expensive, would produce a payload potential of approximately 560 lbs. These improvements, however, had never been flight tested and considerable risk had to be accepted in using that number as a design parameter. This risk was accepted.

The second was a drastic reduction in the weight of the Mariner. During October, the realities of the Mariner were beginning to be understood, as shown in Figure 2. The spacecraft had been steadily climbing and had reached 580 lbs. At the worst, a weight discrepancy of 100 lbs. existed. At best, a weight discrepancy of 20 lbs. existed. The first situation would scrap the mission; the second would permit only 20 lbs. for science, half the intended payload. This was considered too small when measured against the expense of the mission.

The Technological Position

Also by October, JPL had gained considerable experience with solar panel technology. Early Rangers had used photovoltaic arrays and the Mariner II was on its way to Venus using solar panels made of stiffened aluminum structure. Ranger 3 had also used a similar structure. The best structural weights achieved to that point were 1.15 lbs. per sq. ft. on the Mariner II and 1.08 lbs. per sq. ft. on an advanced Mariner prototype.

In addition to solar panel technology, JPL had been investigating the use of a small damper for the reduction of resonance loads in large structural elements. These dampers were crude. consisting of an annular space between two sliding concentric tubes. The space was filled with a high viscosity silicone grease. A damper of this type was developed in an emergency to reduce resonance on the Mariner II Earth tracker. The damper was non linear and could not be subjected to good analysis, but worked under test and, as a consequence, was used. This design was invented by Bill Layman, of the Mechanisms Group, and he was permitted to continue work on a small scale during 1962.

In early May of that year, when we suspected that damping structures might be required for Mariner IV, he was asked to experiment with two versions of solar panel damping; tip-mounted dampers which were mounted at the tip of the solar panels and quarter-point dampers, which were mounted at the one-fourth point on the panel structure. We wanted some sample hardware produced which could be used in case of an emergency.

The Organizational Relationship

We cannot examine the human factors unless we understand the people and their relationship with one another. Each of the individuals involved saw a different picture, had different technical capabilities and different value judgments.

We start by examining the formal organization chart in Figure 3.

At that time, the Laboratory was set up as a matrix organization. The Project Office was responsible for the over-all performance of the mission. It controlled the design and the monetary resources. The Technical Divisions were responsible for a specified technical area.

Of interest to this discussion is the Engineering Mechanics Division and the Guidance and Control Division.

The Guidance and Control Division was assigned the responsibility for spacecraft power, in addition to other responsibilities including guidance sensors, autopilots, and electronic sequencers.

The Engineering Mechanics Division was assigned the responsibility for structures, dynamics, thermal control, materials, packaging and cabling.

The Solar Panel was assigned to the Guidance and Control Division as a deliverable item. Their job was to design the power system, using photovoltaic cells, to apply these cells to the structure furnished by the Engineering Mechanics Division, and to qualify the entire assembly for flight.

The Engineering Mechanics Division was assigned the responsibility of developing a spacecraft configuration which included approximately 80 sq. ft. of solar panels. In addition, it was assigned the responsibility of designing, fabricating and testing the solar panel structure and delivering it to the Guidance and Control Division for further processing.

The detailed organization within the Guidance and Control Division is shown in Figure 4 and the Engineering Mechanics Division in Figure 5.

Schedule and Contracting Requirements

The schedule is shown in Figure 6. Preliminary design was to occur during the last five months of 1961. Hard design during five months of 1963 with the delivery of the first completed solar panel made to the Guidance and Control Division was planned for June of 1963. To meet the overall schedule, 32 additional panels had to be delivered by December.

The number of units required and their rate of delivery dictated that the panels be bought on subcontract. JPL had bought the Mariner II and Ranger III panels from Ryan and considerable experience was established in working with that contractor. We knew, however, that we would have to go out on competitive bid and that this decision would have to be made by November 1, 1962, if the schedule were to be met. Ryan Aeronautical, of San Diego, California, won the bid and, after final negotiations, work was commenced.

The Emergency

In this general context, significant weight had to be cut from the spacecraft designs. How could this be accomplished and still meet the design and schedule requirements? What would *you* have done if it were *your* responsibility? How would you have sized up the risks? What could you have taught a student which would have prepared him for this moment?

The Solar Panel

The element set aside for a large potential weight saving was the solar panel. Layman had shown that if resonance loads could be reduced through the use of point dampers, the structural weight could be cut roughly in half (.50 lb. per sq. ft.).

A summary of all elements bearing on the problem is given in Figure 7. After considerable discussion within Division 35, Jim Wilson approached me with a tentative decision to go for the lightweight panel. This decision was based on the following:

A. There would not be a mission unless we made a major weight contribution (the payoff was large).
B. While not amenable to analysis, the dampers had worked on Mariner II and Ranger (we had confirming similar performance).
C. If we moved fast we could test a representative set of equipment by December (it would be possible to verify our performance).

In disagreement with these arguments were the following:

A. This approach was a significant extension of our present technology.
B. The schedule was very short and an attempt to set up a contractor to do this work on this complex a structure could cause serious delays.
C. If the panels failed, we would have to scrap the mission after committing some $50 to $60 million.
D. Significant opposition was building up without our own division, particularly on the part of our dynamicists, who felt that it was too risky to accept questionable test results in lieu of analysis.

A tentative decision was made to proceed and money was allocated to build a test set of hardware which would be delivered in December. Procurement action was initiated on the flight panels with four contractors. The situation was explained to the Spacecraft Systems Engineer and he concurred. It was the end of October, 1962. As with any decision, mixed feelings resulted. Many things would happen before this solar panel was to fly. The following are a few of the problems:

A. When the first sample section was tested in an acoustic chamber, all spot welds cracked. The panel had to be converted to a bonded structure.

B. The power people became concerned about the amount of heat sink available on the spars for their zener diodes. The spars had to be thickened.

C. Ultrasonic tests to determine the integrity of the bonded structure caused pitting of the magnesium fittings and all had to be replaced.

D. During testing the solar panel exhibited a torsional vibration mode which coupled with the spacecraft bus. Torsional stiffeners had to be added to the box beams.

E. During flight acceptance testing, a failure occurred in the corrugations of the skin .003 *AL*. It was determined that this was due to excessive material removal in a chemical mill bath. Each panel had to have a double row of doublers bonded to the corrugations on both sides of the spars.

In spite of the difficulties, this panel did meet its schedules and was finally qualified. It was truly an exciting experience when I received a call at Harvard that told me the panel had passed its final qualification test. The final flight weight was .58 lb. per sq. ft., the lightest solar panel array yet flown.

What can we learn from this?

First: This is just a simple example of a problem which was not decided on purely technical grounds.

Second: The decision process in this simple area was a very complex one involving many different people of many different points of view.

Third: To be effective, the engineer who works on an interdisciplinary team must have a knowledge of his fellow engineers and of the fundamental interpersonal forces which make them work together if he is to achieve his objective.

Fig. 1. MARINER IV S/C

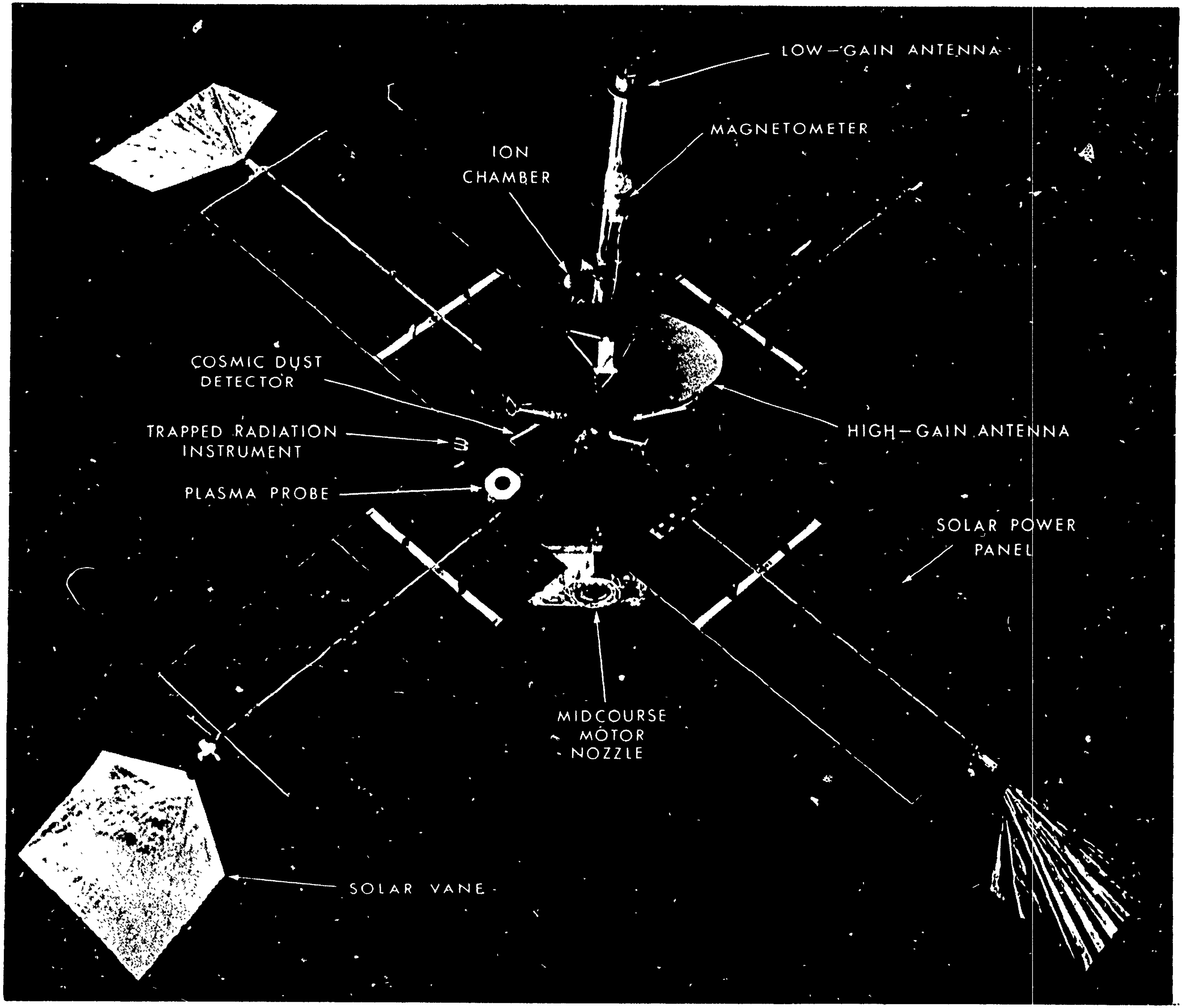


FIGURE 2

PAYLOAD WT AS A FUNCTION OF TIME

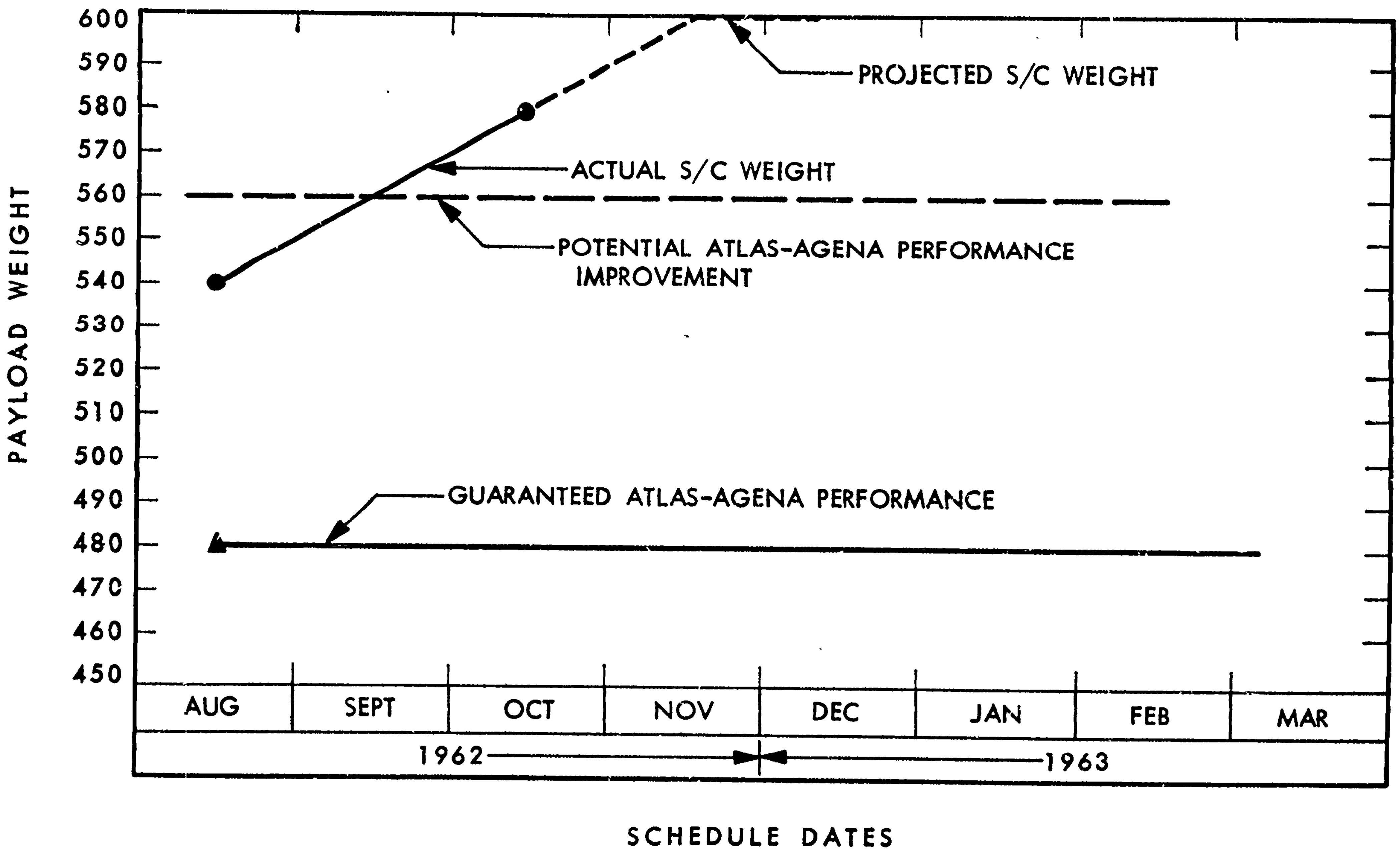


FIGURE 3

OVERALL JPL ORGANIZATION CHART (1962)

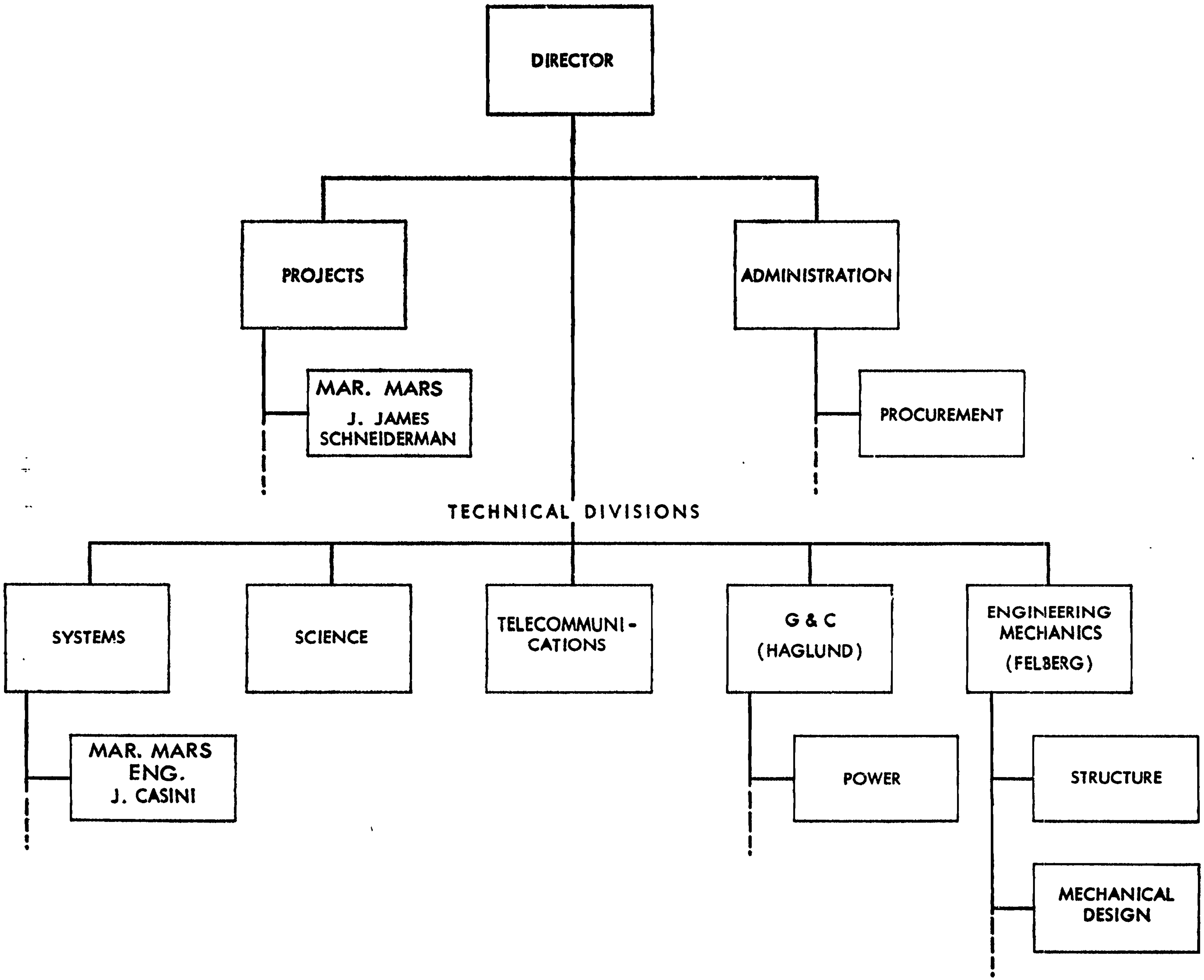


FIGURE 4

GUIDANCE AND CONTROL DIVISION

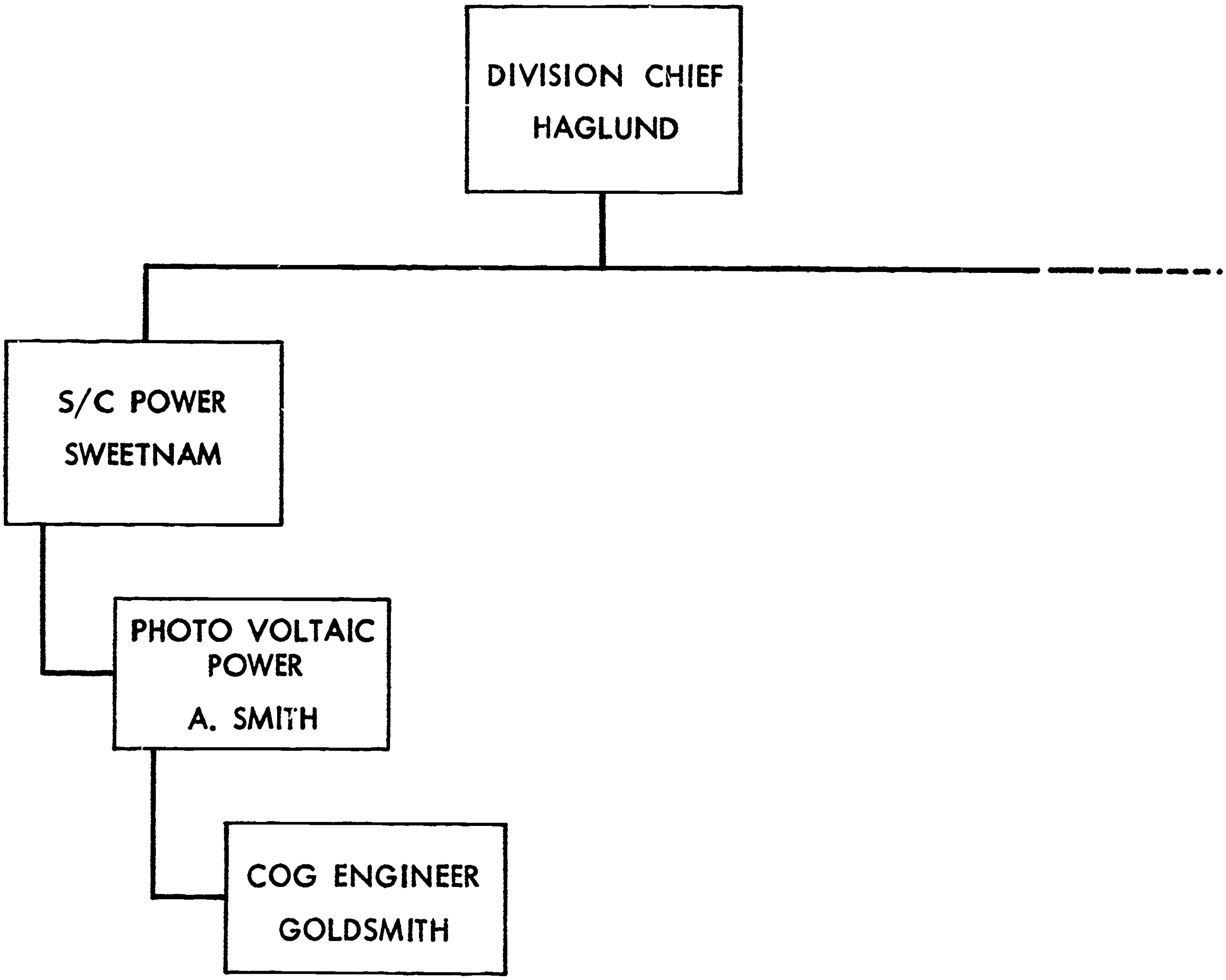


FIGURE 5

ENGINEERING MECHANICS DIVISION

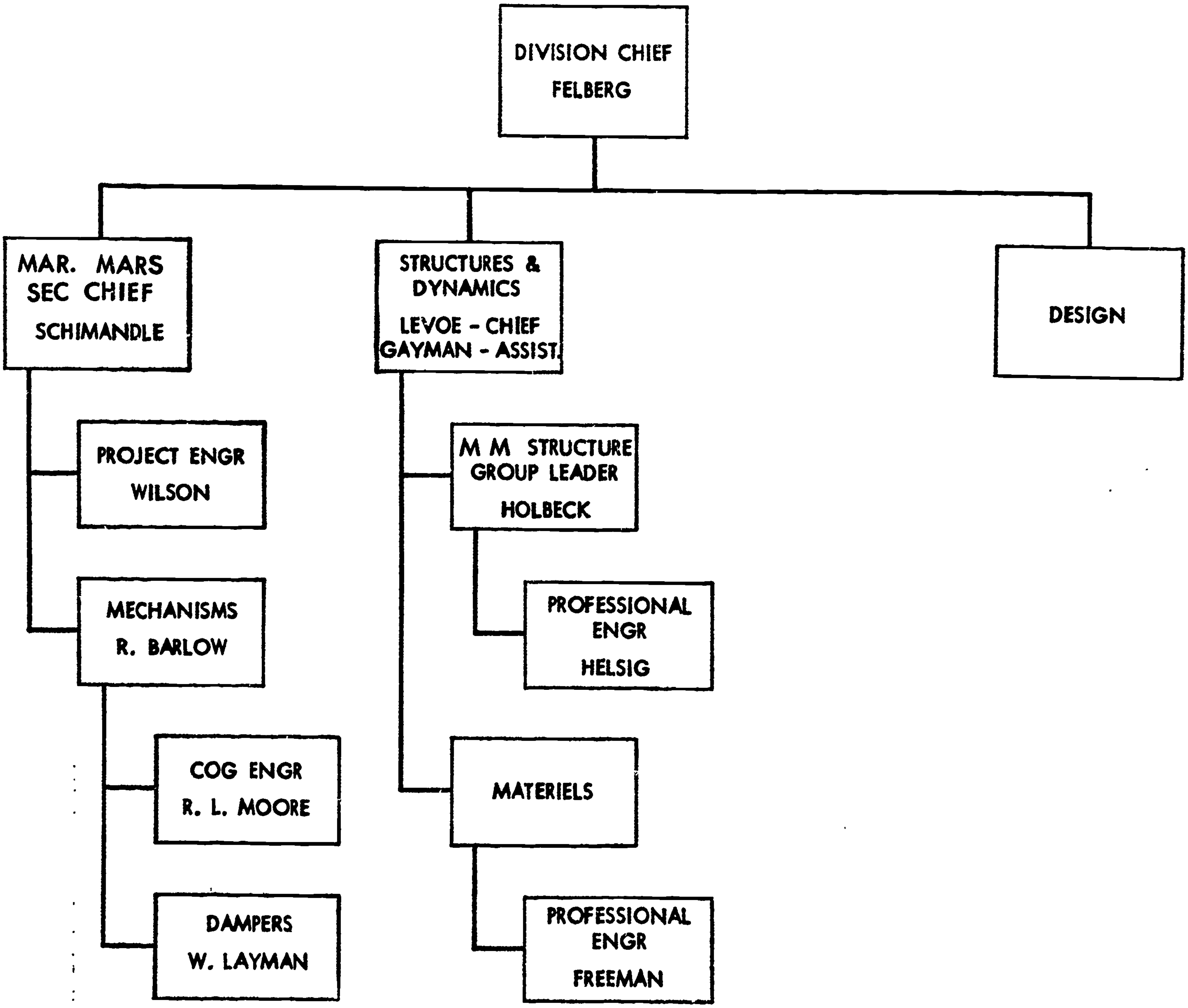


FIGURE 6

MARINER IV SCHEDULE

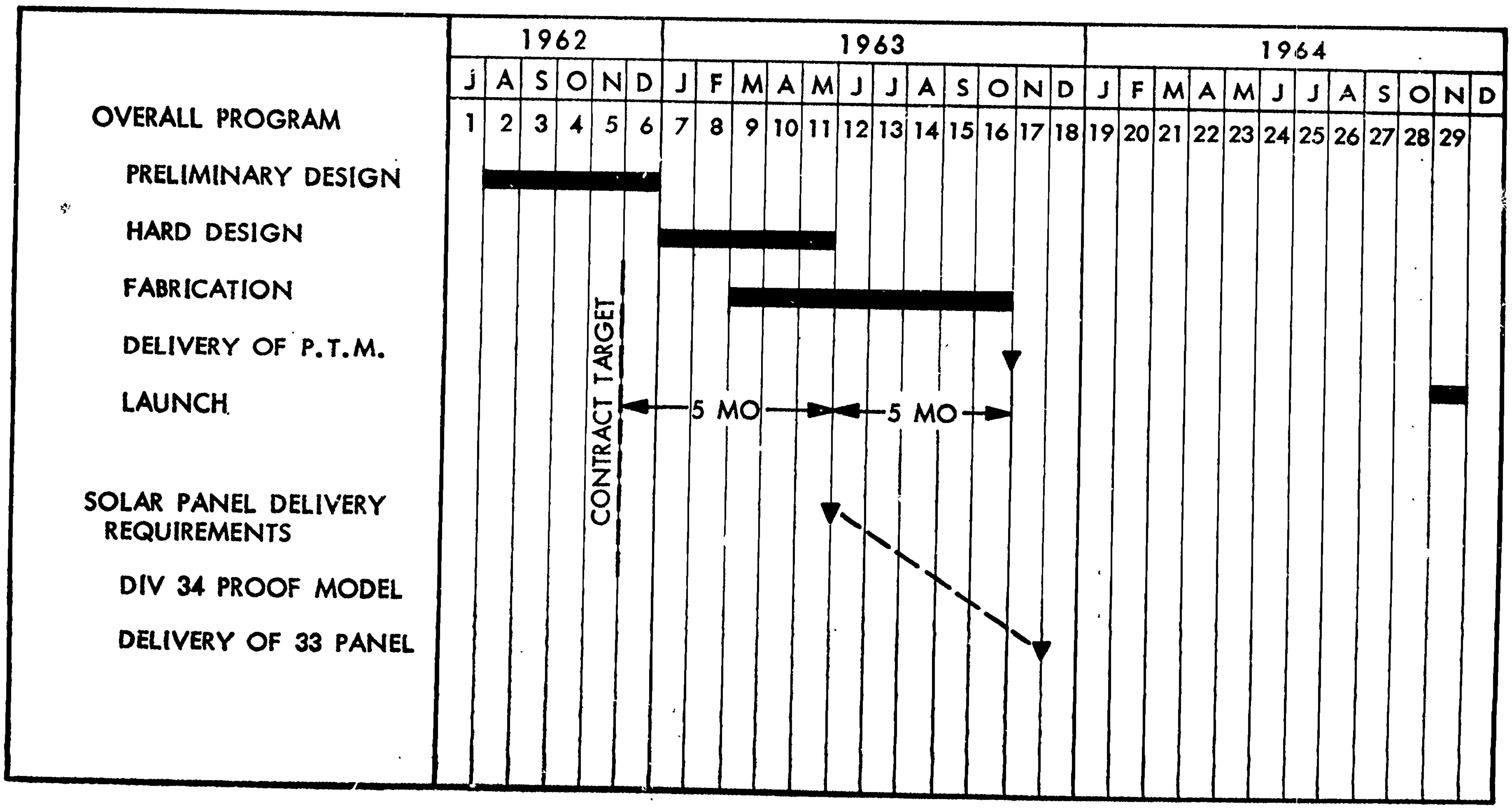
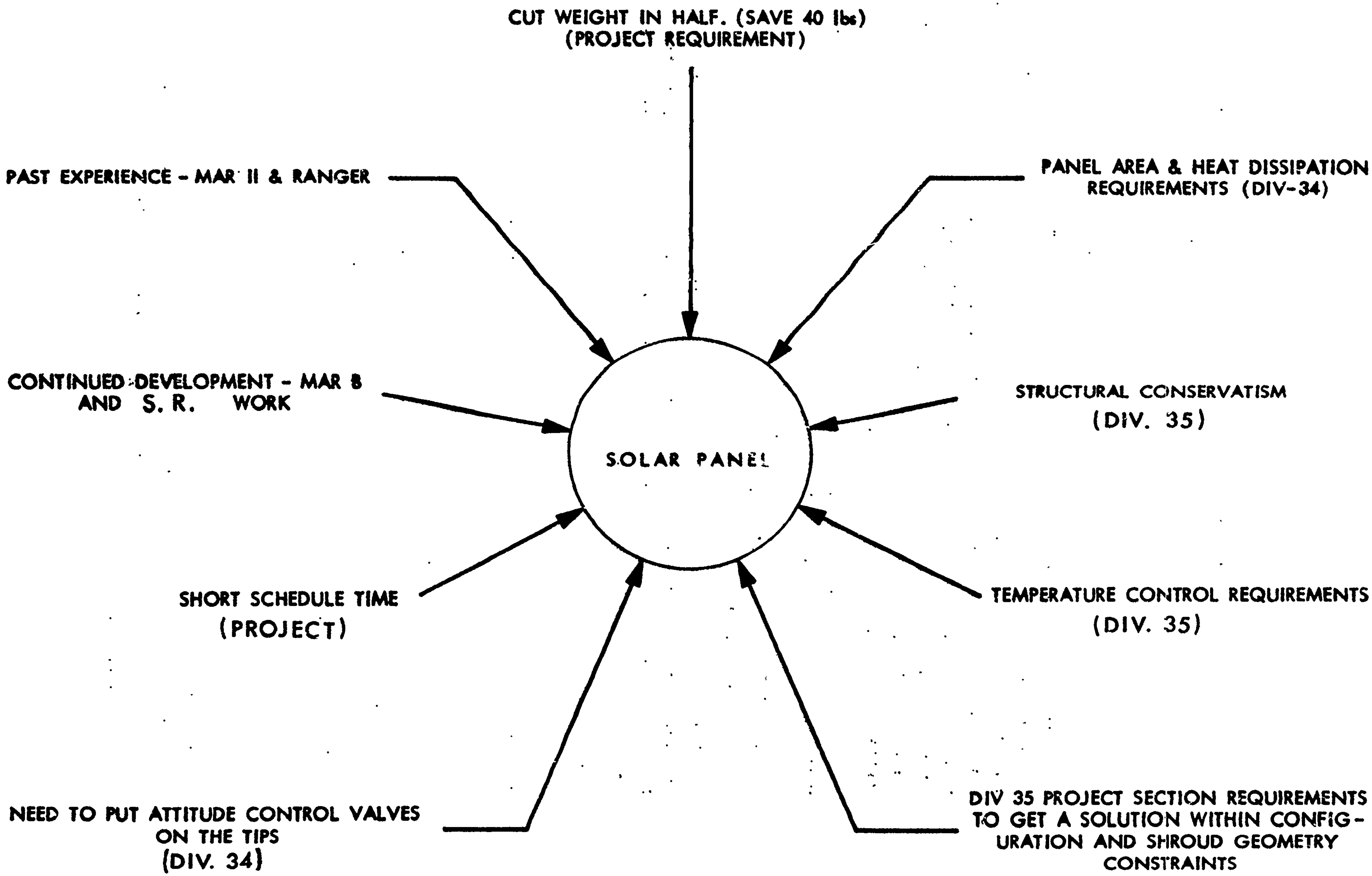


FIGURE 7

FACTORS BEARING ON THE SOLAR PANEL



MECHANICAL ENGINEERING DESIGN IN THE CHEMICAL PROCESS INDUSTRIES

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Mechanical Engineering Design in the chemical process industries is significantly different from that encountered in the normal manufacturing industries. This is primarily due to the fact that the end item is a chemical or petro-chemical product rather than a piece of mechanical hardware. Accordingly, in these industries, it is expected as a matter of routine that hardware is designed to properly perform its required functions. Special consideration, however, is given to items of mechanical equipment when these make the difference between a process being possible or impossible, or where the mechanical equipment significantly affects the cost of the chemical product.

The work of mechanical engineers in the chemical process industries falls into three very broadly defined categories, namely:

(1) Design and Application Engineering
(2) Economic Engineering
(3) Development Engineering

It should be mentioned that when I speak of the work of mechanical engineers, I am referring to people working as mechanical engineers, not to their specific degree. In the chemical process industry, as in many other industries, people may well be working in areas other than that of their educational specialty.

Design and Application

Most engineers are working in this first category, and here they operate with many more constraints on their work than is generally apparent to the average engineering student.

1. Design: This involves the design of pressure vessels, heat exchangers, tanks, furnaces and piping. In addition to meeting their service requirements, these designs must conform to many codes and specifications such as the ASME, API codes, and local codes. Also, the user's specifications, and in the case of a contracting company the contractor's specifications, must be complied with.
2. Selection of Equipment: Many engineers are engaged in the selection of pumps, compressors, filters, valves, etc., from the offerings of various manufacturers. These selections must not only be able to properly perform their required functions, but must meet Company and customer specifications and code requirements.
3. The third area of activity is in the preparation of estimates and proposals. Here considerable use is made of design charts and computer programs for calculations. In many cases, design charts are preferable to computer programs because they yield the accuracy required in substantially less time and at lower cost.

Economic Engineering

A major activity involves design studies to insure that the final system design will be the most economic possible.

1. General Design Studies: For example, in a typical plant, the cost of pumps and compressors may range between 20 and 25 percent of the total material cost. Piping and piping components are also generally between 20 and 25 percent of the total material cost. Because of this, it is of considerable importance to insure that a proper balance is arrived at between the size of the piping used and the cost of the pumping power and of the pumps and drivers. Here, studies in depth are made to develop general guide lines for use by designers.
2. Specific System Design: A specific consideration that arises in many plant designs is the determination of the balance between the elevation of a vessel and the net positive suction head available for a pump taking suction from such a vessel. Raising the vessel elevation increases the vessel support cost but increases the available NPSH and, hence, reduces the pump cost. An economic balance is required and is generally arrived at by discussions between the pump, piping and vessel designers concerned with the installation in question. In this category we also find specific studies of plant energy balances, involving optimization of the use of waste heat for steam generation, the use of extraction steam for process heating, balances between water- and air-cooled heat exchangers, etc., all designed to minimize the cost of the final product.
3. Design Standards: Much effort is devoted to the development of design standards. These not only have the advantage of insuring that the designs are economical, they also save engineering time and unify the work of the Company. Design standards, however, must be continuously reviewed and revised to insure that they represent the best in current technology and reflect current economics.

Development Engineering

In the chemical process industries (since there are no mechanical products as such) necessity is, indeed, the mother of mechanical inventions. New designs, when developed, are either those that are required to permit a chemical process to be operable or that materially influence the manufacturing cost of the chemical product.

I should like, at this time, to discuss a specific design in this category. Our Company had developed a batch-type continuous process which involved four reactors, three onstream in series at any time with the fourth being either charged or unloaded. In order for this process to work, it was necessary to have valves that could isolate any one of these reactors during the period when this specific reactor was offstream. A customer was anxious to have us build this plant, and time was of the essence. These valves, however, had very severe service requirements. The valves had to be very large as they were to go into a 40-inch OD by 24-inch ID internally insulated pipe line. The flowing gases varied in temperature between 200 degrees Farenheit and 1600 degrees Farenheit, with a possible short time temperature of 1800 degrees F. The gases were highly combustible containing a high percentage of hydrogen; and they were dirty, containing fine solids. These valves were required to seal against a pressure of up to 50 psig, with temperatures ranging from 200 degrees Farenheit to 1600 degrees Farenheit at each side, and to open and/or close under all combinations of these temperature and pressure conditions.

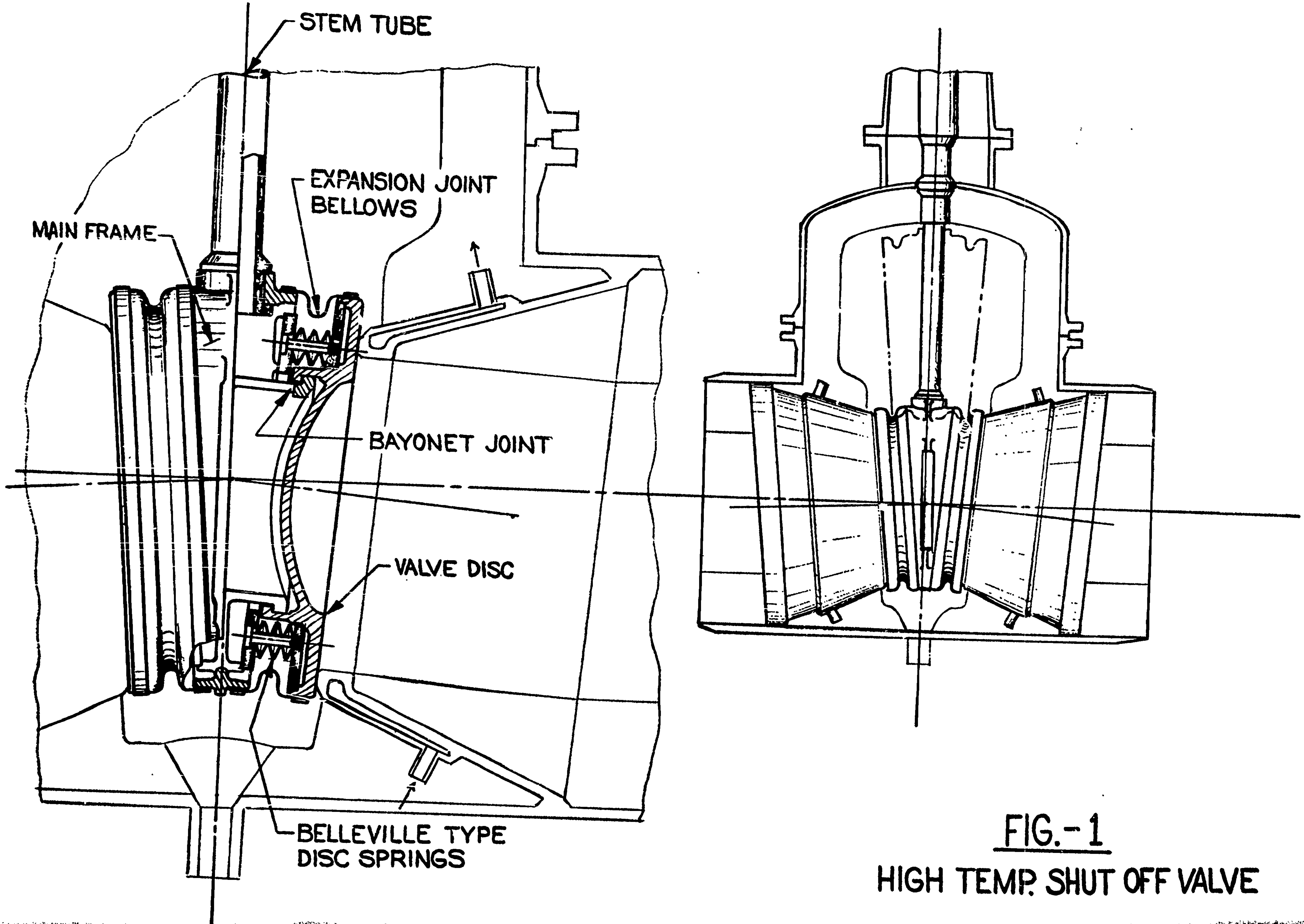

FIG.-1

HIGH TEMP. SHUT OFF VALVE

Our first approach was to determine if such a valve was commercially available. After finding that this was not the case, we next investigated the possibility of modifying an existing valve. When this failed, we attempted to find a manufacturer willing to undertake the design and construction of such a valve. When this also failed, we had no choice but to design the valve ourselves.

By this time it became necessary to develop the design of this valve very rapidly if we were to meet our customer's desire for the plant start-up date. Accordingly a group of senior engineers were gathered together to design this valve.

On the basis of the service requirements, the following general specifications were set:

1) The valve discs and seats should be water-cooled. This would minimize thermal distortion of the valve, thereby insuring better sealing, and reducing any tendency to jam. Also, it would permit the use of carbon or low alloy steel for the valve.
2) The valve should have wedge-type double disc construction, with relatively independent discs. Wedge-type construction would insure tight closure, double discs would result in two independent sealing surfaces in series, and independent discs would reduce the effects of different temperatures on each side of the valve on the valve sealing.
3) In closing, the discs should slide, under pressure, across the seat face. The sliding action would tend to clean the valve seats as the valve closed, thereby minimizing the possibility of leakage due to trapping dirt between the disc and seat.

A preliminary layout of the valve was made and heat transfer analysis and mechanical design proceeded concurrently. Since the work was done by a small group in close consultation with each other, it was possible to revise the thermal design and mechanical details when required as the over-all design progressed, thereby ensuring thermal and mechanical compatibility of the final design.

Some of the important design details are shown in Figure 1, along with an overall view of the valve. The sectioned view of the valve shows the water-cooled seats, the internal baffles required to give the proper flow patterns, however, are not shown. The disc guides, not shown, were also water-cooled. Each disc is attached to the main frame by means of a bayonet joint, permitting the disc to move relative to the main frame. The belleville springs between the disc and frame are preloaded such that the force on the disc, at its maximum displacement from the main frame, exceeds the force on the disc produced by the maximum anticipated gas pressure. In order to contain the cooling water inside of the main frame, the discs are connected to the main frame by means of bellows expansion joints, thereby sealing the internals from the flowing gases. The hollow stem tube contains two passages, one for the water supply to, and the other for the water leaving the disc assemblies. The water pressure adds to the spring force in keeping the discs against the seat when the valve is in the closed position. In order to reduce the thermal load on the disc assembly, the discs are dished in the center with the dished volume filled with insulation. The valve is operated by means of a hydraulic ram connected to the stem tube.

After the design was completed, a valve manufacturer was found who would build the valve to our design. The manufacturer, however, would only guarantee workmanship and materials, with the operability and suitability of the valve remaining our own responsibility. I am pleased to be able to report that these valves have now been in service for over five years and have operated without any difficulty.

APPENDIX I—CONFERENCE PROGRAM

Monday, July 12

8:30 a.m. **Registration**

9:00 a.m. **Welcome**

Dr. B. Richard Teare, Jr., presiding
Dean, College of Engineering and Science
Carnegie Institute of Technology

Dr. Horton Guyford Stever, President
Carnegie Institute of Technology

Professor Robert W. Mann
Massachusetts Institute of Technology

9:30 a.m. **Round-Table Discussion**

"Design Laboratory Workshop Programs"

Dr. B. Richard Teare, Jr., Moderator

Selected participants of the Design Workshops conducted at Dartmouth, M.I.T., Case, U.C.L.A., Berkley, and Carnegie

Professor Ozer A. Arnas
Louisiana State University

Professor D. W. Bradbury
Clemson University

Professor Robert C. Dean
Dartmouth College

Professor W. B. Diboll, Jr.
Washington University

Professor Robert W. Mann
Massachusetts Institute of Technology

Professor James B. Reswick
Case Institute of Technology

Professor A. B. Rosenstein
University of California, Los Angeles

Professor Robert R. Rothfus
Carnegie Institute of Technology

Professor Edward J. Smith
Rensselaer Polytechnic Institute

Professor Robert F. Steidel, Jr.
University of California, Berkeley

Professor Theodore A. Terry
Lehigh University

Professor Robert P. Vail
The University of Arizona

10:30 a.m. Coffee Break

11:00 a.m. Round-Table of Design Workshops continued

12:30 p.m. Luncheon

2:30 p.m. Round-Table Discussion

"The Role of Design Theory in the Workshop Program"

Professor Robert W. Mann, Moderator
Massachusetts Institute of Technology

Selected Participants of Workshop Program

Professor Peter Z. Bulkeley
Stanford University

Professor Steven A. Coons
Massachusetts Institute of Technology

Professor Donald Gall
Carnegie Institute of Technology

Professor William C. Monday
Kansas State University

Professor Frederick C. Munchmeyer
University of Hawaii

Professor Thornton W. Price
Arizona State University

Dr. Robert K. Prince, Jr.
Lockheed—California Company

Professor H. B. Ratcliff
Bradley University

Professor Roger W. Schiller
Pennsylvania State University

Professor Paul T. Shannon
Dartmouth College

Dr. Ewart E. Smith
Serendipity Associates

Professor Robert A. Wyant
Clarkson College of Technology

3:30 p.m. Coffee Break

4:00 p.m. Round-Table on Design Theory Continued

5:30 p.m. Cocktails

6:30 p.m. Banquet

Dr. B. Richard Teare, Jr., presiding
Dean, College of Engineering and Science
Carnegie Institute of Technology

Speaker:

Mr. Harold C. MacDonald
Assistant Chief Engineer—Vehicles
Ford Division, Ford Motor Company

"The Compleat Automotive Design Engineer"

Tuesday, July 13

9:00 a.m. The Case Study

Mr. Karl H. Vesper, presiding
Director of Case Development
School of Engineering
Stanford University

After Introductory Remarks each person attended one of five workshop sessions of his choice conducted by Professors Bulkeley, Fuchs, Pefley, and Steidel and Mr. Vesper. Each session discussed a particular case, considering its nature as a pedagogical tool and ways of using it in teaching.

10:30 a.m. Coffee Break

11:00 a.m. Repetition of five workshop sessions so each person could participate in a second session of his choice.

12:00 Noon Critique of the Case Study

12:30 p.m. Luncheon

1:30 p.m. The Industrial Point of View

Professor Robert R. Rothfus, presiding
Carnegie Institute of Technology

Mr. W. J. Schimandle
Jet Propulsion Laboratory
"The Mariner 'C' Solar Panel"

Mr. R .H. Fields
Westinghouse Electrical Corporation
"A Rapid Transit System"

3:30 p.m. Coffee Break

Mr. Stanley E. Handman
M. W. Kellogg Company
"Mechanical Engineering Design in the Chemical Process Industry"

APPENDIX II—PARTICIPANTS IN THIRD CONFERENCE ON ENGINEERING DESIGN EDUCATION

Name	*Company*	*City State*
Arnas, Ozer A.	Louisiana State University	Baton Rouge, La.
Au, Tung	Carnegie Institute of Technology	Pittsburgh, Pa.
Baumann, Dwight M.B.	Massachusetts Institute of Technology	Cambridge, Mass.
Beardsley L. Robert	University of Mississippi	University, Miss.
Blesser, William	Polytechnic Institute of Brooklyn	Brooklyn, N. Y.
Bollinger, John G.	University of Wisconsin	Madison, Wis.
Borgmann, Carl W.	Ford Foundation	New York, N. Y.
Bosma, Robert	Princeton University	Princeton, N. J.
Bradbury, D. W.	Clemson University	Clemson, S. C.
Brighton, J. A.	Carnegie Institute of Technology	Pittsburgh, Pa.
Bulkeley, Peter Z.	Stanford University	Stanford, Calif.
Calvert, Floyd O.	University of New Mexico	Albuquerque, N. Mex.
Canjar, Lawrence N.	University of Detroit	Detroit, Mich.
Chalk, William S.	University of Washington	Seattle, Wash.
Church, Austin H.	New York University	Bronx, N. Y.
Coberly, Camden	University of Wisconsin	Madison, Wis.
Constantinides, C.	University of Oklahoma	Norman, Okla.
Conti, James J.	Polytechnic Institute of Brooklyn	Brooklyn, N. Y.
Coons, Steven A.	Massachusetts Institute of Technology	Cambridge, Mass.
Costanza, James L.	University of California	Berkeley, Calif.
Crossley, F. R. E.	Georgia Institute of Technology	Atlanta, Ga.
Cunningham, R. G.	Pennsylvania State University	University Park, Pa.
Curtis, Gerald	International Textbook Company	Scranton, Pa.
Daniel, L. R.	Louisiana State University	Baton Rouge, La.
Davis, Ralph M.	Westinghouse Electric Corporation	Pittsburgh, Pa.
Dean, Robert C., Jr.	Dartmouth College	Hanover, N. H.
Del Bene, J. V.	Carnegie Institute of Technology	Pittsburgh, Pa.
Derbenwick, F.	Manhattan College	Bronx, N. Y.
Diboll, W. B., Jr.	Washington University	St. Louis, Mo.
Dieter, George E.	Drexel Institute of Technology	Philadelphia, Pa.
Dobrovolny, J.	University of Illinois	Urbana, Ill.
Ennis, Robert	United States Naval Academy	Annapolis, Md.
Eshghy, Siavash	Carnegie Institute of Technology	Pittsburgh, Pa.
Fax, David	Westinghouse Electric Corporation	Pittsburgh, Pa.
Felling, William E.	Ford Foundation	New York, N. Y.
Fields, Raymond H.	Westinghouse Electric Corporation	Pittsburgh, Pa.
Finzi, Leo A.	Carniege Institute of Technology	Pittsburgh, Pa.
Fleck, William	Carniege Institute of Technology	Pittsburgh, Pa.
Forbes, M. A.	Broome Technical Community College	Binghamton, N. Y.
Foster, Truman G.	Ohio State University	Columbus, Ohio
Frisch, Joseph	University of California	Berkeley, Calif.

Name	*Company*	*City State*
Frounfelker, R.	Tennessee Technological Institute	Cookesville, Tenn.
Fryling, Glenn R.	Combustion Engineering Inc.	Princeton Junction, N. J.
Fuchs, Henry O.	Stanford University	Stanford, Calif.
Gall, Donald A.	Carnegie Institute of Technology	Pittsburgh, Pa.
Garcia, Bert H., Jr.	North Carolina State University	Raleigh, N. C.
Gerde, Clifford S.	Purdue University	Lafayette, Ind.
Golden, Robert G.	Newark College of Engineering	Newark, N. J.
Goode, Henry	Cornell University	Ithaca, N. Y.
Gouse, S. William	Massachusetts Institute of Technology	Cambridge, Mass.
Hale, Harry P.	Wayne State University	Detroit, Mich.
Handman, Stanley	M. W. Kellogg Company	New Market, N. J.
Hanus, John	Newark College of Engineering	Newark, N. J.
Hauser, Frank E.	University of California	Berkeley, Calif.
Harrisberger, Lee	Oklahoma State University	Stillwater, Okla.
Hartenberg, R. S.	Northwestern University	Evanston, Ill.
Heinz, Winfield B.	University of California	Los Angeles, Calif.
Hill, Percy H.	Tufts University	Medford, Mass.
Howell, Glen H.	Wayne State University	Detroit, Mich.
Hoyaux, Max	Carniege Institute of Technology	Pittsburgh, Pa.
Johnson, H. L.	Georgia Institute of Technology	Atlanta, Ga.
Jones, J. B.	Virginia Polytechnic Institute	Blacksburg, Va.
Karplus, Alan	Wentworth Institute	Boston, Mass.
Ketchum, Gardner M.	Union College	Schenectady, N. Y.
Knott, K.	Pennsylvania State University	University Park, Pa.
Krueger, Jack N.	University of North Dakota	Grand Forks, N. Dak.
Lambert, Joseph M.	Drexel Institute of Technology	Philadelphia, Pa.
Leipzger, Stuart	Institute of Gas Technology	Chicago, Ill.
Li, Kun	Carnegie Institute of Technology	Pittsburgh, Pa.
Lichty, William H.	General Motors Institute	Flint, Mich.
Lih, Marshall M.	The Catholic University of America	Washington, D. C.
Linke, Simpson	Cornell University	Ithaca, N. Y.
MacDonald, Harold C.	Ford Motor Company	Detroit, Mich.
Mann, Robert W.	Massachusetts Institute of Technology	Cambridge, Mass.
McKee, R. B.	University of Nevada	Reno, Nev.
McNeill, Joseph G.	State University of New York Maritime College	Bronx, N. Y.
Mercer, Samuel, Jr.	Drexel Institute of Technology	Philadelphia, Pa.
Modrey, Joseph	Purdue University	Lafayette, Ind.
Monday, William C.	Kansas State University	Manhatan, Kan.
Monrad, Carl C.	Carnegie Institute of Technology	Pittsburgh, Pa.
Morse, Ivan E., Jr.	University of Cincinnati	Cincinnati, Ohio
Mote, C. D.	Carnegie Institute of Technology	Pittsburgh, Pa.
Munchmeyer, F. C.	University of Hawaii	Honolulu, Hawaii
Murphy, Arthur T.	Pennsylvania Military College	Chester, Pa.
Muster, Douglas F.	University of Houston	Houston, Tex.
Osborn, Robert E.	Cornell University	Ithaca, N. Y.
Ostrofsky, B.	University of California	Los Angeles, Calif.

Name	Company	City State
Owen, W. Miller	Caterpillar Tractor Company	Peoria, Ill.
Patrick, W. L.	Virginia Military Institute	Lexington, Va.
Paul, Igor	Massachusetts Institute of Technology	Cambridge, Mass.
Paxton, H. W.	Carnegie Institute of Technology	Pittsburgh, Pa.
Peart, R. M.	Purdue University	Lafayette, Ind.
Pefley, Richard K.	University of Santa Clara	Santa Clara, Calif.
Pelan, Byron J.	Rutgers University	New Brunswick, N. J.
Peterson, Thorwald	United States Military Academy	West Point, N. Y.
Price, Thorton W.	Arizona State University	Tempe, Ariz.
Prince, Robert K., Jr.	Lockheed-California Company	Burbank, Calif.
Quevedo, Carlos	Carnegie Institute of Technology	Pittsburgh, Pa.
Ratcliff, H. B.	Bradley University	Peoria, Ill.
Reswick, James B.	Case Institute of Technology	Cleveland, Ohio
Rosen, Stephen L.	Carnegie Institute of Technology	Pittsburgh, Pa.
Rosenstein, A. B.	University of California	Los Angeles, Calif.
Rothfus, Robert R.	Carnegie Institute of Technology	Pittsburgh, Pa.
Salamon, Robert	Newark College of Engineering	Newark, N. J.
Schiller, Roger W.	Pennsylvania State University	University Park, Pa.
Schimandle, W. J.	Jet Propulsion Laboratory	Pasadena, Calif.
Schnelle, Karl B., Jr.	Instrument Society of America	Pittsburgh, Pa.
Shannon, Paul T.	Dartmouth College	Hanover, N. H.
Shaw, Milton C.	Carnegie Institute of Technology	Pittsburgh, Pa.
Shen, C. N.	Rensselaer Polytechnic Institute	Troy, N. Y.
Sheppard, Frederick G.	Duke University	Durham, N. C.
Sheridan, Marlin L.	Bucknell University	Lewisburg, Pa.
Shewan, William	Valparaiso University	Valparaiso, Ind.
Siddall, J. N.	McMaster University	Hamilton, Ontario, Canada
Smith, Edward J.	Rensselaer Polytechnic Institute	Troy, N. Y.
Smith, Ewart E.	Serendipity Associates	Chatsworth, Calif.
Starkey, Walter L.	The Ohio State University	Columbus, Ohio
Steidel, Robert F., Jr.	University of California	Berkeley, Calif.
Stelson, T. E.	Carnegie Institute of Technology	Pittsburgh, Pa.
Stever, H. Guyford	Carnegie Institute of Technology	Pittsburgh, Pa.
Teare, B. Richard, Jr.	Carnegie Institute of Technology	Pittsburgh, Pa.
Upthegrove, W. R.	The University of Texas	Austin, Tex.
Vail, Robert P.	The University of Arizona	Tucson, Ariz.
Vesper, Karl H.	Stanford University	Stanford, Calif.
Webb, Bryan, Jr.	University of Arkansas	Fayetteville, Ark.
Welbourn, D. B.	University of Cambridge	Cambridge, England
Williams, Gordon C.	University of Louisville	Louisville, Ky.
Wyant, Robert A.	Clarkson College of Technology	Potsdam, N. Y.
Yang, An Tzu	University of California	Davis, Calif.
Yerazunis, Stephen	Rensselaer Polytechnic Institute	Troy, N. Y.
Zorowski, Carl	North Carolina State University	Raleigh, N. C.

APPENDIX III—WORKSHOP PARTICIPANTS

Only the principal participating faculty of each host institution is listed.

At the Carnegie Institute of Technology:

Carnegie Faculty:
- L. N. Canjar, Project Director
- R. R. Rothfus
- D. A. Gall

Visiting Faculty:
- A. C. Haman, University of Detroit
- L. A. Padis, Virginia Polytechnic Institute
- R. W. Schiller, Pennsylvania State University
- T. A. Terry, Lehigh University

At the Case Institute of Technology:

Case Faculty:
- J. B. Reswick, Project Director
- J. C. Angus
- W. B. Johnson
- C. K. Taft

Visiting Faculty:
- O. A. Arnas, Louisiana State University
- H. Goode, Cornell University (observer)
- J. N. Krueger, University of North Dakota
- B. Webb, Jr., University of Arkansas
- R. A. Wyant, Clarkson College

At Dartmouth College:

Dartmouth Faculty:
- R. C. Dean, Jr., Project Director
- P. T. Shannon
- S. R. Stearns

Visiting Faculty:
- D. W. Bradbury, Clemson University
- W. S. Chalk, University of Washington
- A. K. Karplus, Wentworth Institute (observer)
- M. M. Lih, Catholic University of America
- T. W. Price, Arizona State University
- F. G. Sheppard, Duke University
- W. Shewan, Valparaiso University

At the Massachusetts Institute of Technology:

M.I.T. Faculty:
- R. W. Mann, Project Director
- D. Baumann
- S. W. Gouse
- I. Paul

Visiting Faculty:

C. Constantinides, University of Oklahoma
S. Linke, Cornell University (observer)
R. M. Peart, Purdue University
H. B. Ratcliff, Bradley University
E. J. Smith, Rensselaer Polytechnic Institute (observer)
D. B. Welbourn, University of Cambridge (observer)
A. T. Yang, University of California, Davis

At the University of California, Berkeley:

University of California Faculty:

R. F. Steidel, Jr., Project Director
J. L. Costanza
J. Frisch
F. E. Hauser

Visiting Faculty:

H. O. Fuchs, Stanford University
W. C. Monday, Kansas State University
R. K. Pefley, University of Santa Clara
R. P. Vail, University of Arizona

At the University of California, Los Angeles:

U.C.L.A. Faculty:

A. B. Rosenstein, Project Director
W. B. Heinz
R. B. McKee (on leave)
B. Ostrofsky

Visiting Faculty:

L. R. Beardsley, University of Mississippi
F. O. Calvert, University of New Mexico
W. B. Diboll, Jr., Washington University (St. Louis)
F. C. Munchmeyer, University of Hawaii