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THE FUNCTION OF DESIGN IN AN ADVANCED TECHNOLOGY INDUSTRY

W. J. Schimandle

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
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This paper discusses an advanced technology industry and describes design as it exists in that industry. The characteristics of an ideal designer are presented and his development charted. These characteristics are then related to the training of students who intend to enter this profession.

I. INTRODUCTION

When I first agreed to prepare this paper for Tom Woodson I was positive that I clearly understood the meaning of the term "Advanced Technology Industry." But, after trying out a few definitions on Henry Fuchs, Russell Keim, Jim Adams, and others, I found that a precise definition of this concept is probably not possible. As with definitions of God, pain, love, and art, opinions as to the existence and nature of an advanced technology industry vary according to the experience, personality, and point of view of the listener. In like manner, many definitions of "Design" have been put forward by people who have thought about the subject at great length. Enough different opinions exist so that I would like to describe the design operation in today's advanced technology industry rather than attempt to defend a specific definition.

II. ADVANCED TECHNOLOGY INDUSTRY DEFINED

I would like to start this paper with two examples. The first deals with a problem faced by cave men and the second deals with a problem faced by a group of advanced technology engineers last winter.

Long ago in the valley of either the Nile or the Tigris, early man lived, hunted, and died. His social activity was limited and his initial survival was probably due more to his ability to reproduce prolifically than to his ability to understand and control the environment in which he lived. His first battle was for survival. At first his tools and weapons consisted of sticks and stones picked at random, but because of climatic change, population pressure, or other factors, he was forced to improve their effectiveness by selecting them more carefully. One day, while looking at the first three sticks shown in Fig. 1, he recognized (for some reason which he could not explain) that one seemed better

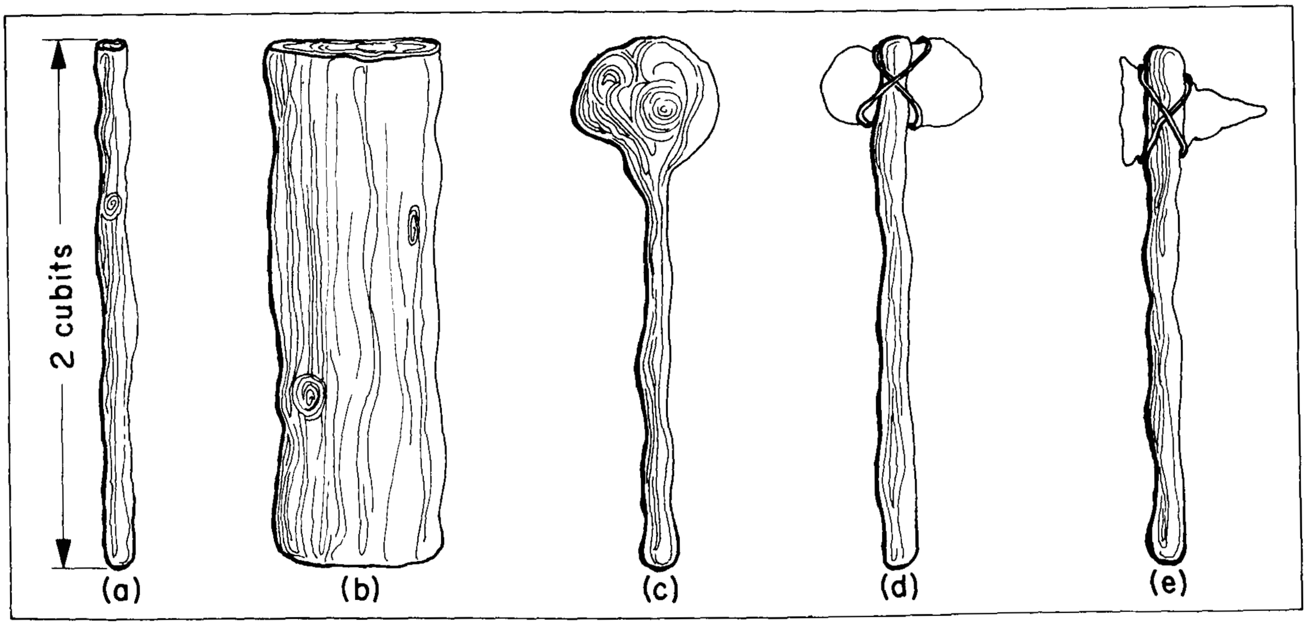

Fig. 1. Caveman clubs

than the others. Homo sapiens, man the thinker, had begun to climb. He knew nothing of stress analysis, dynamics, physiology, or the material properties of wood. What he did know was that it took a certain stick, swung at a given speed (usually as hard as possible) to kill the game he needed. He had found by trial and error which diameter best fit his hand (a), but he also found that this stick, when of convenient length, was not heavy enough to deliver a fatal blow. He also knew that if he used a stick which was thick enough to be weighty (b), it could not be handled properly. He looked at the last stick he had used, now broken, which was small at one end and had a large knot at the other (c). This one had seemed very effective so he came to the conclusion that since he could not find one of these "good" sticks he would try to make one. Slowly, over the years, he learned not only to fashion such a stick, but to substitute a stone for a knot (d), and to substitute a sharp rock for the dull stone (e).

Let us change the time to October of 1961, and the scene to the Jet Propulsion Laboratory. We had just been asked to develop a spacecraft which could investigate interplanetary space and make surface temperature measurements of Venus. It was required that this job be accomplished by the summer of 1962.

Our first problem was to pick a boost vehicle which was capable of lifting a meaningful payload and which could be readied in time. Our second problem was to determine if we could reduce the sophistication of an early prototype sufficiently to permit it to meet the payload constraints dictated by the selection of the boost vehicle. A study program was conducted, and in two weeks, enough work had been done by many people of varying technical disciplines to indicate that a payload of approximately 450 lb could be made ready in time to meet the launch constraints. This device was called the Mariner 1 and is shown in Fig. 2.

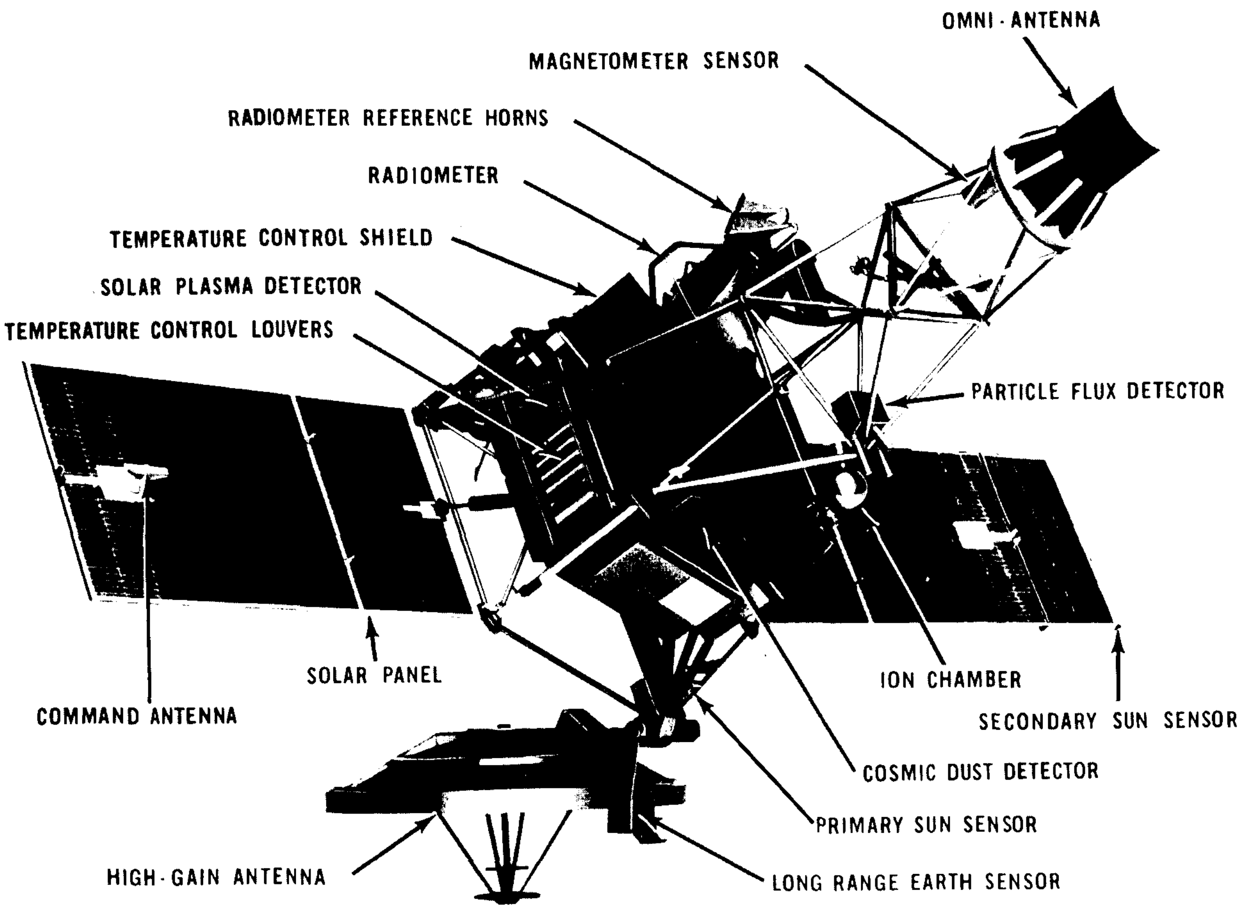

Fig. 2. Mariner 1 spacecraft

It is a complex device capable of carrying a set of instruments from the launch pad to the vicinity of Venus. Its design involves such disciplines as structures, communications, guidance and control, dynamics, materials, propulsion, physics, and many others. But the spacecraft, though a system in itself, is only a small portion of the vast systems required for injection into an interplanetary trajectory and subsequent data recording.[1]

An attempt to launch Mariner 1 was made on July 22, 1962, but it failed because the guidance equations which were used could not handle a nonstandard operating condition. At the time of this writing, the second vehicle and spacecraft are being prepared at Cape Canaveral for the next attempt.

I ask each one of you to examine your feelings. Which of these examples best describes advanced technology? Is it described only by the group of modern technologists working vigorously to solve a problem in space exploration, or is it also represented by the cave man's having solved a more basic need. I think they both serve as examples because the cave man, too, become Homo faciens,[2] man the maker (as differentiated from Homo sapiens, man the thinker), when he decided to reconstruct nature in order to solve the problem which faced him.

Our second example deals with a much later and more complex time, but the problem is the same. Man wishes to accomplish a task and he must do it with the most advanced ideas at his disposal. The situation may require disciplines, skills, and tools of conventional technology, but it also represents a dynamic situation which will change as new techniques, new ideas, and new

[1]A detailed description of the design can be found in "Mechanical Design of Spacecraft," Astronautics Information, Seminar Proceedings, Jet Propulsion Laboratory, Pasadena, California, March 28 to May 23, 1962.

[2]See Bibliography, R. J. Forbes.

needs develop. An advanced technology industry, then, is simply one in which a major share of the activity is dictated by the newest technological advances. This definition may seem too elementary but it does work.

III. CHARACTERISTICS OF AN ADVANCED TECHNOLOGY INDUSTRY

If we now understand what an advanced technology industry is, and understand that it changes with time, what are the things which characterize such an industry today? The space industry serves as a model. It is not unique but it is convenient.

(a) NONPRECEDENTED
(b) MULTIDISCIPLINED
(c) REQUIRES SIGNIFICANT ECONOMIC AND HUMAN RESOURCES
(d) MASS DEVELOPMENTAL
(e) SUCCESS AT THE BEGINNING
(f) ADVANCED MANAGEMENT TECHNIQUES
(g) GEOPOLITICAL
(h) THE GENERALIST APPROACH

Fig. 3. Characteristics of an advanced technology industry

Figure 3 presents a list of the outstanding characteristics and each of the items can be described in brief detail as follows:

(a) An advanced technology industry is one in which the majority of its activities have no precedent. It may use a considerable amount of conventional technology, but by its very nature, its chief efforts represent attempts to do things which have not been done before.

(b) Such an industry is multidisciplined. It is multidisciplined because technology has progressed and expanded to such an extent that no single individual can possibly master the diversity or depth of disciplines required to accomplish the task.

(c) Such an industry requires significant economic and human resources. This is necessary because the task to be accomplished is so difficult. The resources required of the cave man in his selection of weapons were small because his task was small.

(d) Such an industry is mass-developmental[3] as opposed to mass-productional. The term "mass developmental" implies that large groups of people and resources are brought together to accomplish one or a few tasks as opposed to bringing a large number of people together to produce a great volume of products. Each man's input is crucial to the mass-developmental process, whereas the failure of a

[3]Private communication, N. Sirri

man in a mass-production industry may result in the rejection of a small quantity of parts.

(e) Such an industry is required to be successful with each new task because of the great cost entailed. The costs are so great that it is not possible to take a chance on an initial design which might fail.

(f) Advanced management techniques are required. This is necessary because of the mass-developmental nature of the industry. The number of variables involved in management problems have increased to such an extent that the simple balance sheet and profit and loss statement are no longer sufficient to assure success. Such techniques as PERT and PEP are the forerunners of tools which management must learn to use if it is to be successful in dealing with the new problems.

(g) The industry is geopolitical in nature. In general, these projects are so large that they involve not only internal economic and political problems but they also involve foreign nations. Such a simple requirement as placing an antenna on the soil of a foreign nation can require tedious negotiations.

(h) The generalist approach is required of all members of the mass-development team. This is required because every component at the smallest level can greatly affect the outcome of the over-all program. It is therefore necessary that each specialist engaged in this type of activity be cognizant of the effects which his work will have on that of others.

We have discussed here the characteristics of an advanced technology industry. We should not pass to a discussion of where design fits in that industry without pausing for a moment to realize that the characteristics which are applicable to advanced technology industries today will represent the foundations on which the conventional industries of tomorrow will be built.

This year we saw a startling example of how this can occur when the Telstar satellite began to broadcast live pictures of people in Europe describing their continent. If you felt awe while watching the doors of the Sistine Chapel swing open and seeing the genius of Michelangelo revealed in your homes, think how you will feel many years hence when the fruits of today's work are available for other uses.

IV. DESIGN IN AN ADVANCED TECHNOLOGY INDUSTRY

Where does design fit into all of this? Again, I would like to return to the cave man analogy. When our cave man decided that he wanted something different, he set in motion a process which has been continually perfected since that time. If we may borrow a term from the biologist and Morris Asimow[4] we might describe it as the Ecological Cycle of Use.

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[4]See Bibliography, M. Asimow

This cycle, shown in Fig. 4, starts with a need. Man designs a solution to this need. He builds or otherwise executes his solution, and then uses it. He observes the results, and this in turn, often generates a new need. He proceeds in this fashion--need begetting need--ad infinitum.

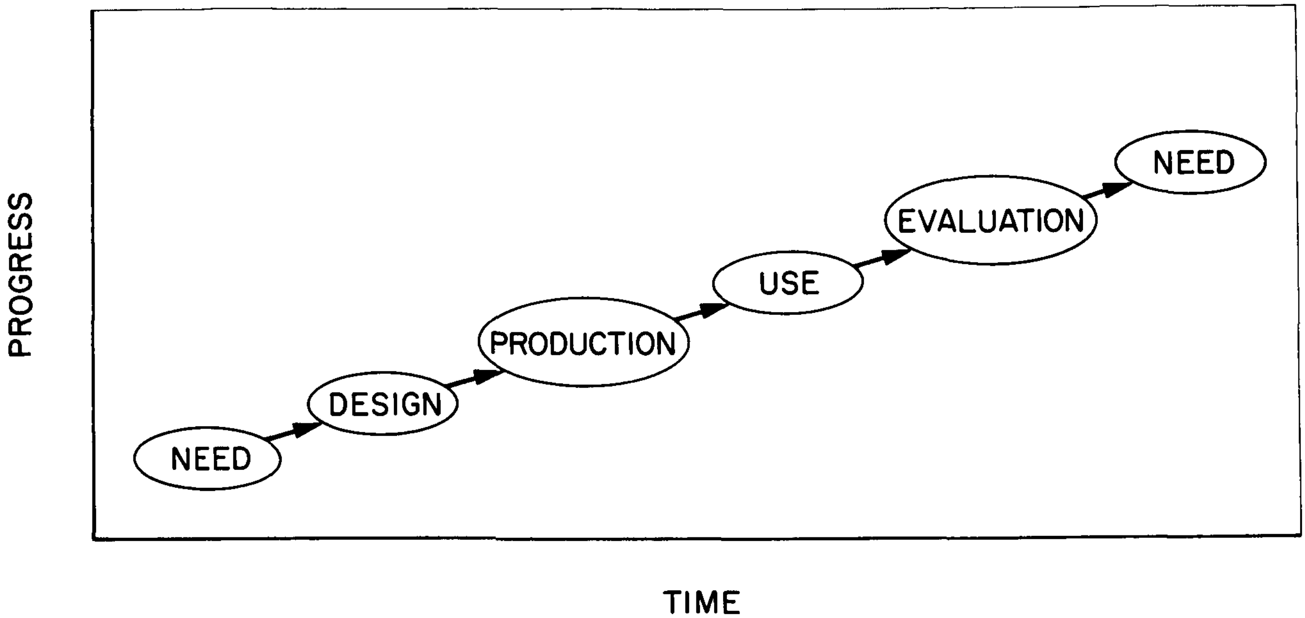

Fig. 4. Ecological cycle of use

In this ecological process, design shows up as the second step. It starts with a need and ends when the designer has decided what to do. In its simplest form, design is deciding what to do. Each term of the definition is important and should be examined.

The term <u>decides</u> implies that the designer should examine the facts, judge that the need is real, and reach conclusions. He may use any of a number of approaches and tools to reach his conclusion, but he should recognize that decision making is a key element which cannot be avoided.

The term <u>what</u> is important, also, for it is necessary for the designer to describe and define not only his problem, but his solution or solutions. In describing the need, he again uses various tools such as words, mathematics, physical models, drawings, specifications, or sketches on the backs of old envelopes. Any tool should be used which aids in making this description more precise or acceptable. One of the most important functions of the designer is to make his results intelligible to the people who must construct or execute his solutions.

The last term, <u>to do</u>, implies that action should be taken. The action may result in dropping the project since, upon examination, the need may prove to be unreal. On the other hand, the action may involve initiation of a significant project. In any case, it is the designer's responsibility to see that his design either satisfies or eliminates the need.

In the preceding discussion we have talked a little about the tools used by the designer in an advanced technology industry. It is important to point out that just because an industry is advanced does not necessarily mean that conventional techniques should not be used or applied to the solution of a problem. It is the designer's responsibility to use that tool which is most effective in solving the particular problem at hand.

A recent problem from JPL can be used to illustrate this point. Figure 5 shows a model of a study spacecraft with folded solar panels. Figure 6 shows the same model with the solar panels in the extended position. The problem was to determine the location of a single hinge axis for each panel which would meet these two end conditions. Many methods could have been used to solve

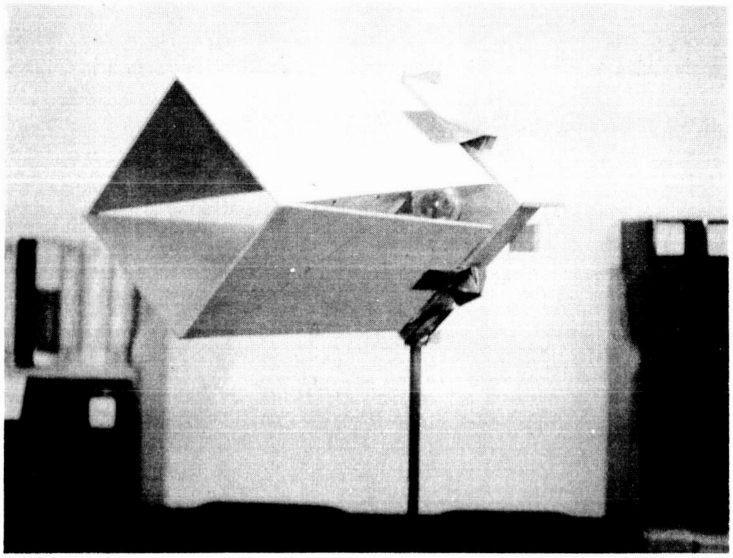

Fig. 5. Spacecraft model, solar panels in folded position

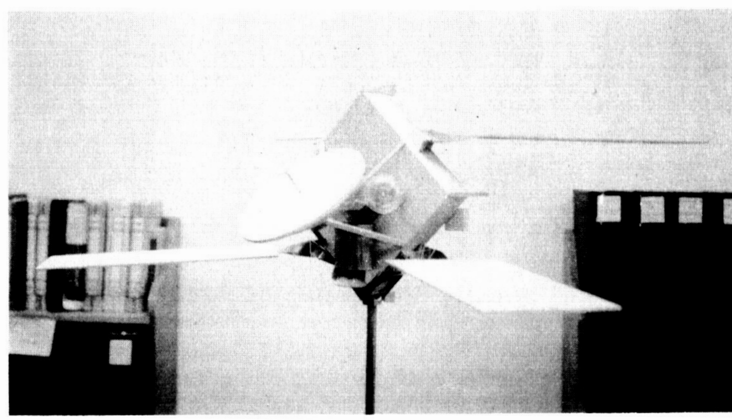

Fig. 6. Spacecraft model, solar panels in extended position

Fig. 7. Engineers using "paper dolls" approach to solve hinge axis problem

this problem. A computer program could have been written or the problem could have been solved graphically. The actual solution was obtained by the application of simple modeling techniques, as shown in Fig. 7. There are people who might say that such work could be left to technicians or other non-professionals, but the fact that these engineers were trained, and were not ashamed to use the most effective tool at their disposal, permitted a very large advanced technology program to proceed with a minimum of delay.

V. THE DESIGNER

The modern designer can be called by many names depending on his training and the position he holds in the industry. He may be called a mechanical, electrical, thermal, aeronautical, dynamics, electronic, or communications engineer. He may also be called a project manager or systems engineer. All of these functions are deeply involved in deciding what should be done.

It is interesting to attempt to describe the characteristics of an ideal designer (see Fig. 8). The following represents such an attempt:

(1) A designer must be trained to a high level of technical competence in his field. This necessitates a sound grounding in the fundamentals of engineering and in the principles of design.

(2) He must be creative in applying the engineering and social tools at his command, for he is working in an area which is multidisciplined and nonprecedented.

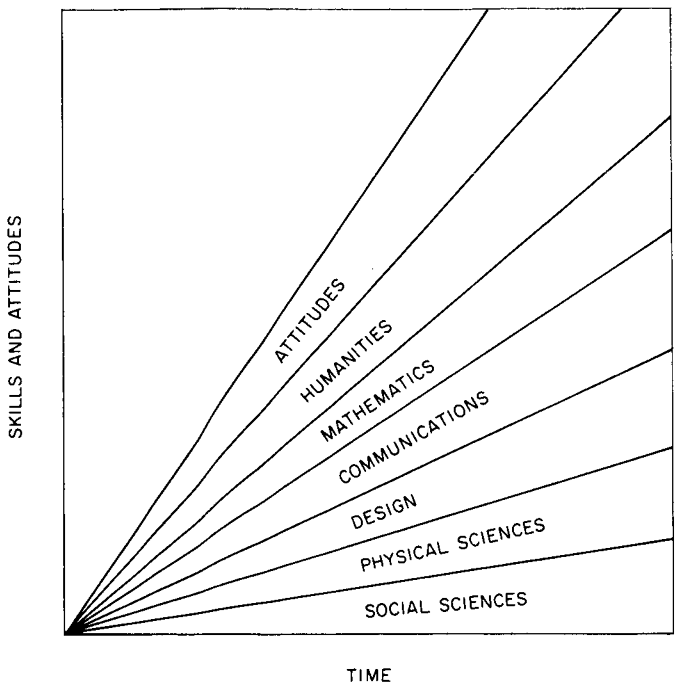

Fig. 8. Ideal design-engineer's development

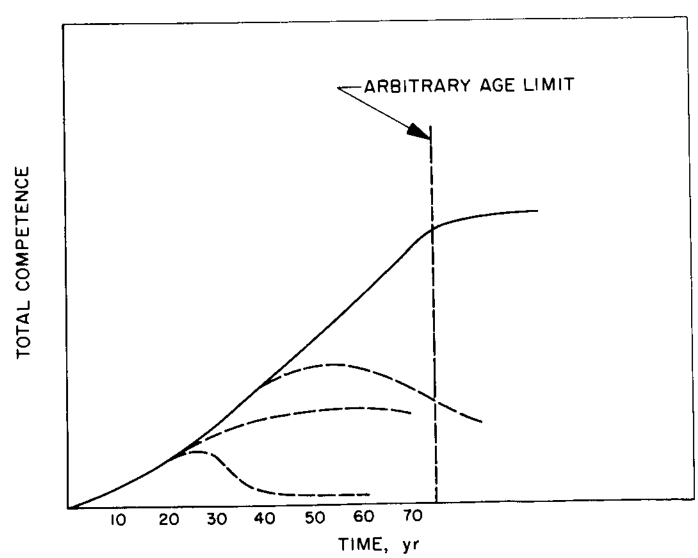

Fig. 9. Engineering competence vs. time

(3) He must develop an ability to work with and direct others. The very multiplicity of disciplines in the advanced technology industries requires this skill.

(4) He should understand the humanities and social sciences if he is to function effectively. In particular he should understand economics, political science, history, and psychology.

(5) He must have a proper attitude about accomplishment: a belief that things can be done even if the answer is not neatly placed before him.

(6) He must have a natural curiosity about the nature of things and a willingness to learn continually as he develops his profession.

This is admittedly a long list of characteristics, and it cannot be attained by any man in school. However, it is important to note that ATI's have been steadily increasing their standards for technical employment. At the beginning of World War II a man with a B.S., ranking in the upper 25% of his class, could look forward to a good future. At present this same man requires an M.S. and his ranking must be in the upper 10%. Recruiters are already strenuously bidding for the Ph.D., and the time will come when engineers without this degree will feel seriouslv handicapped.

An attempt to look at this problem subjectively is presented in Fig. 9. Here a man's total competence is plotted as a function of his age. It is assumed that the ideal designer will continue to learn and be able to accomplish increasingly better things until some arbitrary age, say 75. It is interesting to observe what happens to other people. Some will certainly come to a peak earlier, and others will improve but little after graduation. In fact, it has been observed that the competence of some will degrade rapidly unless the learning process is continued.

Figure 10 represents another subjective look at the problem. It examines the school years in more detail and is intended to show that each level of education should represent a higher level of total development than that preceding it.

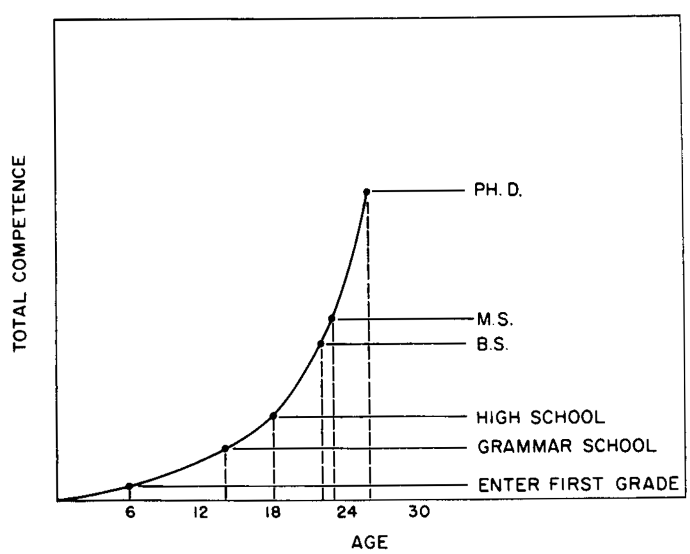

Fig. 10. Total competence vs. age for school years

If the student is to fit into the total development pattern, two things are required:

(1) He must be trained to a minimal level of engineering competence at each step where he may enter society.

(2) The student must be infused with a desire to learn on his own and be shown how this learning can be accomplished.

The first requirement stipulates that when the engineer leaves school with his B.S. he should have the ability to perform at some level of competence. He should have some basic tools and he should be indoctrinated with a philosophy of design. He should have experienced the second step in the ecological use cycle, a little at a time, by using cases which are gradually increased in difficulty as he develops. If he works toward his M.S., his technical tools should be sharpened, but he should also continue to sharpen his understanding and use of the design process. The same holds true for the Ph.D. except in this case he should demonstrate special excellence in his discipline.

If these approaches are pursued, the student, at graduation, will be capable of moving to the final step of his development: learning his profession. This final step has, for most engineers, been the most difficult for three reasons. First, the training he generally receives now does not warn him sufficiently that engineering is an inexact art at best. He is accustomed to solving closed-end problems and giving answers in examinations that his professor wants to hear or that are contained in the answer book. He is not generally used to being asked to synthesize the problem or expected to put his career on the line when he has little real information to go on.

Second, he has generally been spoon-fed by being given too many prepared notes and other over-constrained aids. He generally is not aware of the fact that he is going to have to spend time in the library, on the phone, with vendors, and with other associates if he expects to accomplish his job on time. For there is never enough time or money to do a complete verification job even in industries such as ours.

Third, we have just begun to understand the needs for the additional academic training of mature men who have interrupted their work at the B.S. or M.S. level. Many avenues of approach need to be pursued in order to find ways of giving these men opportunities so that they can return to school or study on the job.

VI. SUMMARY

In summary, I believe that: (a) advanced technology has been with us since man first was able to reshape nature to take care of his needs; (b) design is a vital step in the ecological use cycle which should be recognized as such and taught as an integral part of all discipline programs; (c) a designer's development should not end with his graduation; and (d) means should be provided to permit him to continue his work and study as he develops his profession.

He is in your hands for the most critical time in his life. I recommend that you shape him well, for he will shape our future.

PRIVATE COMMUNICATIONS

Dr. James L. Adams	Jet Propulsion Laboratory
Prof. John E. Arnold	Stanford University
Dr. Henry O. Fuchs	Univ. of Calif., Los Angeles
Prof. Allen S. Hall	Purdue University
Dr. S. Russell Keim	Univ. of Calif., Davis
Prof. A. K. Oppenheim	Univ. of Calif., Berkeley
Norri Sirri	Jet Propulsion Laboratory
Prof. Robert F. Steidel	Univ. of Calif., Berkeley

BIBLIOGRAPHY

Antonov, A. K., "'Book Learning' Engineers," Aviation Week and Space Technology, Vol. 76, No. 30, July 23, 1962, p. 75.

Asimow, Morris, Introduction to Design, Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 1962.

Buhl, Harold R., Creative Engineering Design, Ames, Iowa, Iowa State University Press, 1960.

Clausen, Hugh, "Engineering Design," The Engineer, Vol. 205, No. 5343, June 20, 1958, pp. 920-22.

de Malherbe, M. C., and Oppenheim, A. K., "Changing Structure of Engineering Education," The Engineer, Vol. 212, No. 5526, December 22, 1961, pp. 1025-28.

de Malherbe, M. C., "Some Reflections on Engineering Education in Europe," paper presented at the Annual Meeting, American Society for Engineering Education, Colorado Springs, July 16-20, 1962.

Draper, C. S., "Modern Engineering--Some Examples from Flight Guidance," paper presented at the Annual meeting, American Society for Engineering Education, Colorado Springs, July 16-20, 1962.

BIBLIOGRAPHY (Cont'd)

Forbes, R. J., Man the Maker, London and New York, Abelard-Schuman Limited, 1958.

Francis, A. J., "Science and Design in Engineering Education and Practice--No. 1, Engineering Education and Engineering Practice," The Engineer, Vol. 211, No. 5496, May 26, 1961, pp. 848-52.

Grillo, Paul Jacques, What is Design?, Chicago, Paul Theobald and Company, 1960.

Kavanau, Lawrence, "Competence in Engineering," paper presented at the Annual Meeting, American Society for Engineering Education, Colorado Springs, July 16-20, 1962.

Marples, D. L., "The Decisions of Engineering Design," Engineering Department, Massachusetts Institute of Technology, Cambridge.

Rosenstein, Allen B., English, J. Morley, and Buhl, Harold R., "Machine Design Manufacturing Bulletin," paper presented at the Annual Meeting, American Society for Engineering Education, Colorado Springs, July 16-20, 1962.

Steg, Leo, "The Changing Roles of the Engineer and the Scientist," paper presented at the Annual Meeting, American Society for Engineering Education, Colorado Springs, July 16-20, 1962.