Design

The ability to design well is both an obligation and an opportunity.

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Until rather recently, in terms of the history of engineering, the designer did the analysis himself and was directly influenced by it during the very process of designing. Only about 60 to 80 years ago the picture began to change; the amount of knowledge continually being accumulated began to demand a separation of the engineering activities into design and other, mostly analytical, disciplines.

In the analytical areas this development occurred with increasing momentum and called for considerable specialization. Only through such specialization was it possible to achieve the enormous advancements of the last decades. It would be wrong to consider this specialization and the split into various disciplines a fashion, or unfortunate. In its growth from the all-encompassing design to its present form, the development was an entirely natural process.

The importance of analytical engineering is not an isolated phenomenon. We are living in an era of analysis, involving everything from sewer lines to religions. It is necessary to emphasize, however, that analysis is not and should not be done for its own sake. Analysis as such is worthless unless conclusions are drawn from its results and used constructively.

When one considers design-related activities today, one finds that the determination of the strength of a structure has become a highly developed analytical process; information about materials has grown into material sciences; dynamic processes are beginning to be better understood and predictable owing to the development and improvement of pertinent analytical tools. The same is true in other related areas. Libraries are well supplied with many studies of these developments.

The exactly opposite situation pertains with regard to design. Little has been written about it, and those few papers discuss structure which is the result of, but not the process of, designing. We may assume this reflects the fact that design in its essence is the opposite of analysis. I do not believe that there will ever be a substantial change in this situation because the design process is elusive, depends on, and expresses very personal qualities, and at best is subject to rather general rules.

What Is Design?

We can say that design establishes and defines solutions to and pertinent structures for problems not solved before, or new solutions to problems which have previously been solved in a different way. This means that design encompasses all activities from finding a first concept to the production of hardware drawings. This also means, however, that the mere adaptation of a known solution to new requirements cannot be called design in the strict sense. It should also be noted here that, consequently, the frequent use of the word "design" in literature dealing with the determination of sizes, numbers, or shapes of structural elements (for example, the various kinds of shells, or springs, and so forth) is indeed a misuse; because it is evident that such information is needed for design, but not equivalent to it.

The design process is performed in three phases, each with clearly distinct characteristics. The first phase begins with an idea and ends with concepts; it brings into existence something which had not existed before and is therefore taking place in the border area between imagination and reality. We can say this phase begins with opening the mind for a scanning of possibilities; some of these possibilities will assume forms which are at first unclear, but gradually become defined. Of all the design phases, this first phase makes the highest demand on one's imagination and intuition. This reaching into the unknown and attempting to consolidate and formulate an idea can be a very heavy burden for the designer; but at the same time, it is perhaps his greatest challenge (*1*). The work performed here is truly creative and, in an almost radical sense, personal. This is the situation and condition where the unexpected, the unpredictables—the breakthroughs and inventions—are born. It is evident that, in their essence, this phase and the designer's role in it are close relatives to the arts and to artists.

For the moment, we will omit the second phase and examine the other end of the spectrum—the hardware design phase: the final definition of the structure in its last detail, followed by its documentation for fabrication. This phase requires complete adjustment of the emerging structure to available technologies, and the methods of fabrication. An intimate knowledge of a wide variety of engineering facts is essential, along with the ability to select and match them with the desired form. This necessarily different emphasis is by no means indicative of a routine process or an engineering activity of less importance. The third phase has at least as much influence on the quality, function, and economy of the product as the previous phases. In addition, this is the only phase which gives an engineer insight into the truly merciless demands of hardware production and its need for precise and complete information and final decisions. Whoever believes himself to be qualified for design work in any of the other phases without having first worked here for a good while is badly mistaken. Quite naturally, part of this phase consists of work dealing with all the aspects and burdens of formal documentation, regulations, procedures, and so forth. As far as design is concerned, this is an appendix. It is routine work; an important link for the proper flow of information, but not pertinent to our present subject.

In between the two phases just described, that is, between conceiving a structure and its final documentation, extends a period which is perhaps the most delightful of the entire design process. It is the phase in which the structure is developed and given form. There are no longer the labor pains of giving birth to a concept, and the de-

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signer is still free of the requirements of the hardware phase. The result of this phase could be called the pure structure. The phase is highly dynamic, permits an almost playful weighing of possibilities and alternatives, and, to an ever-increasing extent, demands clarification of all influences affecting the structure. At this point, the active support of all related disciplines becomes involved. It is the designer who converts such inputs into structural form and who, by knowing the limits to which he can bring his structure, combines, weighs, and balances incoming demands. What indeed applies to all three phases is most clearly visible here: the designer should be the central figure. If he fails he will deliver a poor conglomerate, a committee design; if he succeeds he will form all inputs into a natural, homogeneous whole. For this reason, and with all due respect for the analytical disciplines, we can say that the designer is the *primus inter pares.*

Design should be understood and performed in the sense just outlined. It cannot be overemphasized that design is primarily a mental activity with a close relationship to the arts. It produces something new and is therefore never routine work. Drawings are necessary to support the thinking process and serve as a means of communication and documentation. Design, as described here, can be performed at all levels of complexity. This means that even apparently simple or unimportant parts can and should be "designed." Finally, it is evident that design is not the exclusive domain of the "designer"; a member of any other discipline functions as a designer whenever he contributes an idea concerning either a detail or a whole system.

Similarities with the Arts

At this point I should like to mention some intangible qualities which are involved in design. Simplicity, for instance. It can neither be defined nor predicted; it cannot be documented, but we recognize it when we see it. It is not the product of blind accident. Any mediocre engineer can produce a complicated solution; in fact, such is usually the case. Only excellence achieves simplicity. There is no question that simplicity is relative; it can exist at all levels of complexity. Therefore, simplicity is not inherently opposed to refinement and sophistication.

We may also include a few words about beauty. In strictly technical structures, beauty is neither planned nor directly intended. I am therefore excluding here the planned beauty which is the realm of architects and industrial designers. I am concerned here with what could perhaps be called the natural beauty. Consider, for example, sailing ships, or guns, or bridges. Their beauty is not automatically obtained, not necessarily present: many ships, guns, bridges, and other structures have been designed which lack structural beauty. Beauty is the by-product of good design, not the result of analyses, which give us loads, dimensions, and so forth.

Beauty may exist in the general configuration of a product and may not be matched by its major or minor details. The exact opposite is also possible, of course, because fine details can be found, at times, on otherwise poorly designed structures. Although the achievement of continuity in structural beauty is certainly no easy task, it is most certainly possible. The participation or contribution of details seems to depend largely on their size. As they become smaller in succeeding subassemblies, their potential is inherently reduced. At the extreme end we find a rivet head, for example, and there can hardly be any relevant discussion about it. However, already the rivet or bolt pattern does, undoubtedly, influence the appearance of the structure.

Since these considerations are made from an engineering point of view, we are including not only the outside appearance of a structure; any well-designed bracket or other small part located in the darkest inside corner does definitely contribute to the beauty of the structure.

For most of these considerations we could have replaced the word "beauty" with "elegance." Both beauty and elegance are matters of taste, and, therefore, time-dependent. In contrast thereto, simplicity is ageless. I have found over the years that the attributes of beauty and elegance are given to the structures which represent the most up-to-date engineering at a certain time. Airplanes are good examples. What elegance was in the bombers and fighter planes of the last war! Now, in the jet age, they begin to remind us of medieval knights in armor. We must note, however, that the relationship between good design and beauty or elegance is irreversible. Beauty is the result of good design; the desire to make something beautiful will hardly produce a good design. Admittedly, such thoughts are of secondary importance as far as design itself is concerned. However, they influence personal attitudes and reactions to structures and engineering in general, to engineering and design as professions, and eventually, to technology as a whole; and they are, therefore, well worth considering.

Education

The entire complex outlined above can really be taught only in colleges. We find, however, that the student receives everything he can absorb in analyses, mathematics, utilization of computers, but no education in design of equal quality. The result is a striking imbalance in the education for two facets of engineering which have to work intimately together (or, at least, are supposed to) in practical life. On one hand, analytical disciplines are developed to the very borders of our present knowledge; on the other hand, design is practically left to develop according to the natural ability of the individual. (There are indications that even the analytical education is somewhat losing touch with the realities of engineering life.) The economical aspects of this situation will be discussed later because we are concerned here primarily with the student and his education. First of all, the present system is unfair to the student because it deprives him of insight and guidance into a career which permits, and indeed requires, the free use of creativity and imagination in addition to his logical capabilities. Consequently, whether this is intended or not, he is left with the impression that design is a low-grade activity, unworthy of academic attention.

It is only natural that this attitude is carried over into the ensuing years of practical engineering life, where it enters a vicious circle which, by now, has made the drawing board the most dreaded negative status symbol (*2*).

It is up to the college to help the student see these requirements in proper perspective and to develop his talents as a designer. Only at the college will he find the opportunity, the time, and the intellectual climate needed for such development. In addition to providing all the "learnable" elements of his profession, this environment will develop the one thing the student must furnish himself—talent. This process needs a climate that expects (not only permits) experimentation, variation, and expression of the personality but also one that provides guidance and tempering by a mature realism. It needs little teaching, but mostly cultivating, fostering, encouraging, and proper trimming of a growing, widening mind and ability.

Any institution willing to respond to this challenge must accept a change in the curriculum. Two main courses would be introduced: one would deal with structural elements and structures in their dependence on materials and manufacturing processes; the other would consist of actual board work in which design problems of increasing complexity and difficulty would be solved. This second course would be the focal point of a designer's education. It would provide the challenge to develop his imagination, flexibility, creativeness and, by applying his increasing knowledge in analytical areas, he would learn to understand the interplay between them and a developing structural concept.

To make room in the curriculum for design courses, some of the theoretical courses would have to be reduced or deleted. I am aware this is likely to cause objections. Once we realize, however, that the emphasis in a design education is naturally different to some degree from that of an analytical one, this proposition will be acceptable and easy to carry out.

A necessary further step is the introduction to actual, practical engineering through direct contact with industry, which exposes the student to the challenges, demands, and limitations of engineering life. The local situation will suggest the most suitable means of presenting these opportunities to students.

Economy

The imbalance of analytical and design education, discussed above with regard to the student, affects industry and economy in an exaggerated form. This should not be a surprise when we realize again that a structure is designed by people who learned just about everything else but the actual process of designing, who have natural talent, and who get their advanced training on the job. Their counterparts in the analytical departments, however, have available the most up-to-date knowledge in their respective fields. They can make almost any design work, whatever its quality. This expertise is a doubtful blessing because many people blindly consider a design good if it results in a workable structure. Let me use an example to illustrate this point: If someone has to convey information by way of a letter, he can use poor grammar, misspell words, forget about proper punctuation—and still fulfill his original intention. That, however, is by no means proof that he could not have written a much better letter; and it does not eliminate the true need for correct grammar, spelling, and punctuation.

In other words, to the same extent that we acknowledge the need and, more than that, the obligation to write well, to that very same extent we must demand corresponding obligations to design well. These are personal matters as far as writing is concerned; but with regard to design they are oriented toward society as a whole because of their direct influence on economy. There is no doubt that several factors, all eventually affecting the finances as well as the reputation of an organization, are strongly influenced by the quality of the design of its products. Furthermore, there is only slight exaggeration if we consider the flourishing of such activities as quality, reliability, value, and safety engineering as another consequence of a decaying design capability. For these reasons one should expect industry to be keenly interested in receiving from the colleges not only highly educated analysts but also equally well-prepared designers.

Training on the job, as mentioned earlier, is undoubtedly an important factor. Whether this factor has a positive or a negative effect depends on circumstances. It is a very positive factor for those fortunate enough to work under a man who is not only an outstanding designer but who also holds a corresponding organizational stature. Under such rare circumstances the young, and the not-so-young, engineer can observe how structures attain their specific characteristics, and how such a personality is able to form and cast a structure into an organic entity. In the other cases the young engineer will be exposed to what we may call the local techniques—in all the various interpretations. As we know, furthermore, the emphasis in industry is on production, on output, on schedules—and rightfully so. Consequently, the conditions necessary to develop an existing talent cannot generally be provided within the practical atmosphere of a profit-motivated company. It seems to me that it is even unfair to expect that.

Experience, finally, is a fruit that grows more or less automatically with time and is therefore sometimes overemphasized. It is a very valuable increase in our stock of tools. But who would equate tools and ability?

In the relation between economy and the three phases of design, we find that the third, the hardware phase, is by far the dominant one. It requires the largest amount of manpower, is therefore the most visible, and its activities occupy substantial floor space; it becomes involved in all the problems which develop during manufacturing and the subsequent use of the product, and it is the phase most intimately interwoven with all other disciplines. By comparison, the first two phases are small quiet activities visible only to a relatively small group of people. That there is usually not enough time allotted to these first phases to do a thorough job is rarely acknowledged. To a certain extent we find an explanation—though no excuse—for this in the fact that, as just illustrated, the hardware phase seems so prominent that to the superficial observer it becomes synonymous with "design." Unless one understands the basic importance of the first phases, the schedule slips and financial problems which appear during the hardware phase are not easily understood; usually the blame is then placed on hard-to-penetrate technicalities and the designer must take responsibility for the mistakes which were made by the manager in the first place. Such situations result from the shift away from the influence of the designer toward emphasis on analysis. In this manner the designer eventually tends to become an extended arm or service function of the analyst. This unhealthy inversion of responsibility deprives the organization, and through it the economy of a whole country, of the one outstanding creative force in the entire process.

All this is visible to those few who understand the natural interdependence of the three phases of design. Meanwhile, a mistaken attempt was made to replace the missing creative phases by an analytical process. This approach, which is one of the meanings of the ambiguous term "system analysis," has an inherent contradiction that prevents it from growing beyond the stage of an attempt.

It is a fact that there currently exist no definition, no measure, and no criterion for good design. As a partial remedy for this absence of points of reference there are the well-known attempts to narrow the field by establishing weight, cost, material, or other limitations. It cannot be denied, however, that none of these has or provides absolute values, because within each of them there is still a rather wide variety of possible solutions. Accordingly, it is very important that we realize that, with regard to design, we must still rely on very subjective judgment. There is grim irony in this situation because more often than not the inputs for such judgment come from engineers who have not really been educated to make such inputs.

Conclusion

In the foregoing discussions we have seen how strongly good design depends on very personal qualifications. This qualification consists of a combination of extensive engineering knowledge and creativity, plus—not to be overlooked—an open, unbiased mind. By its nature, design should be the "first among equals" in its cooperation with the analytical disciplines. We know, however, that in both education and practical engineering emphasis has shifted in recent years toward these analytical disciplines. This is not surprising as there is a general trend in that direction. It should be a matter of concern, however, that such a shift is frequently interpreted as a reduced importance of design. What has actually happened is that other engineering disciplines have increased their contributions, thus reducing the *relative* difference between themselves and design, but not the *absolute* value of design. That thinking should be reinstated in our educational institutions and reinforced and kept alive in all fields of practical engineering.

Two aspects not discussed above should be briefly mentioned here: computer-aided design and a graphological analogy. The former, with all its enormous potential, is a tool and therefore of no pertinence to our present theme. The latter is an interesting subject of definite, though secondary, relevance. It is enough to say that a drawing indeed reflects the personality of the designer, which is understandable once we comprehend that design exists only through personal expression.

The increased capabilities of the analyses are creating an image which implies that in just about any case we can find an answer through mathematical formulation. Those of us, however, who grew beyond their *Sturm und Drang* periods will know that there is much around us which does not submit to formulation and formulas, in our professions as well as in our lives. It behooves us to acknowledge that we shall continue to be confronted with phenomena we cannot formulate. From this insight we gain enormously as human beings; because it is only the unformulated that challenges and calls upon some of the most unique human qualities—our intellect, our imagination, and our creativity.

Notes

1. Generally speaking, the term "design engineer" would probably be expected here. However, the word "designer" does not only have a somewhat degrading connotation but also is used to indicate high creative capability (as the designer of bridge *X*, or airplane *Y*, and so forth). Of course, very few engineers will ever reach such levels. The implication of similar high qualities is intended whenever the word "designer" is used in this article.
2. In no way do I want to imply that we do not still have good and excellent designers. However, their high qualification is due more to their innate talent than to a specific education.

NEWS AND COMMENT

Energy Crisis: Environmental Issue Exacerbates Power Supply Problem

"An abundant supply of low-cost energy is the key ingredient in continuing to improve the quality of our total environment." — LEE A. DUBRIDGE, presidential science advisor, in testimony before the Joint Committee on Atomic Energy

"In other words, those zealots who propose going on without electrical energy or without increasing electrical energy are not speaking for you or for most of the people in the country."—CHET HOLIFIELD, chairman of the Joint Committee

"They are not speaking for themselves, either, because they go home and turn on the air conditioner."—DUBRIDGE

Two powerful forces now at work in American society are headed for a collision that could do damage to both. The first force is the nation's seemingly insatiable appetite for energy to run its factories, commercial establishments, transportation systems, air conditioners, electric toothbrushes, and the whole gamut of labor-saving gadgetry and "modern" conveniences that the American consumer now regards as his birthright. The second force—probably less powerful than the first—is the environmental movement, which seeks to save mankind from smothering in the waste products that result from the generation of energy and from other activities of an industrial civilization. The two forces are not necessarily irreconcilable, but they are already coming into conflict. The resolution of that conflict will determine whether the nation goes through a severe energy crisis, a worsening environmental crisis, or both.

The nation is already experiencing an energy crisis of sorts. It is a crisis which affects virtually all forms of energy, and it cannot be blamed primarily on opposition from the environmentalists. The fact of the matter is that for the past few years the consumers of energy have been escalating their demands faster than the producers of energy can boost their outputs. The supply of natural gas, a relatively "clean" fuel, is dwindling. For the past 2 years production of gas has outrun new discoveries, thus eating into the nation's proved reserves. Coal suppliers, meanwhile, are failing to meet commitments, with the result that stockpiles at some plants have fallen to a mere 10- to 15-day supply as against the 60- to 90-day supply considered desirable. Residual fuel oil is also said to be tight. And nuclear power, once hailed as a panacea, is coming into use at a much slower rate than was predicted just a few years ago.

The energy crisis is particularly apparent in the electric power industry, which uses such primary fuels as coal, oil, gas, uranium, and water power to produce the electrical energy that keeps many of the nation's offices, homes, and factories humming. Overall energy consumption has grown by 5 percent a year since 1965, an explosive jump over the 2.8 percent growth rate that pre-