THE ENGINEER'S FINEST MODE OF EXPRESSION

BY

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This article was submitted, by permission of the Editor of Engineering, *by the Author who was, until recently, Chief Technical Adviser in the Department of Naval Ordnance.*

Although results of scientific or experimental work in the form of reports, analyses, papers, diagrams, etc., are quite effective media for the transmission of thought from one man to another, they are only a preliminary step in the creation of any new product. Even a detailed specification is only a description of an idea. Drawing is the only medium for the transfer from thought to material in our work. In some activities such as wood carving, jewellery, or model making, an idea can be expressed in material by its creator without passing through the design stage. In practically all engineering work, however, manufacture depends upon detail drawings, covering the shape, size, material, etc., of every component part.

In these drawings the preliminary thought, specifications and calculations, the consideration of alternative designs, research, and experimental work, are processed into a form in which they can be materialized in hardware. Whether the final product actually embodies the principles it was intended to include depends upon the quality of thought put in at the design stage on the drawing board ; and in this stage the realities (as opposed to the potentialities) of the idea are determined. Manufacture presents few difficulties, and is usually quite capable of producing all the qualities of a good design as expressed in the working drawings. Faulty manufacture is usually the very last cause of failure ; the weak spot is almost invariably design—the transition from the thought to the working drawings.

Although drawing is the only effective medium in which design can be expressed, design is not just drawing, neither is good drawing necessarily good design. The relations between drawing and design are not unlike those between hand-writing and poetry or literature. First-class drawing may be—and often is—wasted on a shoddy or inadequate design. A first-class design may be expressed in poor drawings, though this is not usual ; a good designer will encourage good drawing.

There are many kinds of drawings, but those referred to here are constructive drawings, as issued for manufacture, with the dimensions, limits, etc., as required shown on them. These drawings determine the quality of the product. Drawings and diagrams of the type usual in patent specifications and handbook illustrations are a different matter altogether. They are descriptive or illustrative drawings. They have some value in manufacture and assembly, but they have no influence on the quality of the product.

ILLUSTRATIVE AND CONSTRUCTIVE

Oddly enough, men engaged on illustrative drawings, which have no influence on the quality of the product, but merely show how it is meant to work, are often paid more highly than those men on constructive drawings, whose work determines the quality and character of the product. The engineer should be able to do both kinds of drawing. His powers will be greatly increased thereby.

The difficulty of seeing, in the working drawings, evidence of the mental effort, research, or creative ability behind them, has tended to upset the balance between the ' scientific ' and the engineering aspects of design. There is no real conflict between these two aspects : each is the necessary complement of the other, and success can only be achieved by the full development of both.

The quality of draughtsmanship is measured by the clarity of expression of exactly what is required to be made, without regard to its assembly, testing, and use. It includes such matters as whether the dimensions shown can be readily achieved in manufacture. The quality of design, on the other hand, is measured by the performance of the whole machine, of which the items drawn form components. It includes fitness for purpose, ease of manufacture, absence of unnecessary operations, facility of erection, and performance in every meaning of the word. Maintenance and weather protection aspects are included, as well as materials, limits, surface treatment and finish, and other factors. The manufacture of any item is helped by good drawing, just as the pleasure of reading a sonnet is enhanced by its being well spaced and set up in a good fount of type. But good drawing, however good it is, can never turn a bad design into a good one.

Take care of the design and the manufacture will take care of itself. If the design of anything is really well done there is usually little difficulty in getting it made, and almost all defects in performance, and most cases of delay in

manufacture, are mainly due to lack of proper attention in the design or drawing-board stage. Neglect in this stage can never be made up by any subsequent activity. It usually means hasty alterations to material already made. This work, usually carried out under difficult conditions and in a hurry, is one of the most expensive and time-wasting activities imaginable (not to mention loss of temper and morale). The only remedy is to go back to the drawing-board stage and do it better.

A common weakness in establishments dealing with design is to pay too much attention to draughtsmanship, and drawing as such, too early in the design stage. First layouts can be very rough, done freehand, using a soft pencil. They should include as many different ways of doing the job as possible. There are usually many ways of approach to a good solution, and the best is not always found first. One should browse over these alternatives, imagining one is trying out a machine built on these lines. Differences in behaviour and in the way that stresses and loads are carried become apparent. This process demands experience as a background, but all design (except for a genius) needs a background of experience as a basis for judgment. Design is an art which must be developed by practice, rather than a science which can be taught, or learned by study.

Judgment is one of the most important qualities to cultivate, and next to this, perhaps even more important, is complete sincerity. A man of strong character can force his views on his fellow men so that they almost believe him. It is not possible to force material things to do anything they do not like doing. We often hear some such remark as ' This machine must be made to work.' With suitable design modifications this may well be possible ; but the important thing is whether it works at all, or well, or badly, is not so much a matter of the machine itself, which must blindly follow the laws of gravity, friction, dynamics, etc., as whether the design is such as to allow it to work. An unsatisfactory design cannot be ' made to work ' ; the design must be such that it cannot help working as intended, and doing so easily.

It is natural that personal preferences or departmental policies should be reflected in design ; one may prefer a mechanical, the other an electrical solution. Either may give an equally good solution, but to push a preference beyond the limits of impartial judgment and complete sincerity is fatal. This may seem to demand too much from human nature, but no design is better than its designer ; a sound basis of simple ethics is the best foundation for research and design. This is merely another way of describing the attitude of mind reflected in the phrase ' the scientific approach.' The same idea is expressed in St. Paul's saying :—' Prove all things : hold fast that which is good.' What better advice could be given to any engineer or designer ?

In design work, one of the first lessons to be learned is that you should not believe a word of what anybody tells you, no matter who he is, unless you are personally satisfied that it is so. If you are not satisfied, keep an open mind. It may be so, or it may not ; but sure enough, if you believe it, and act on that belief without fully understanding it, you will be let down, not by anyone else but by yourself.

ROUGH DRAFTS

A common weakness in many departments and industrial establishments is the relation between engineers or scientists, and draughtsmen. The engineer is usually responsible for design, but the execution is often left entirely to draughtsmen, the engineer or scientist criticizing the result, but not giving much of a lead as to how the thing should be done. In all too many cases we have the ' sketch on the back of an envelope ' given to the draughtsman to knock into shape, so that the originator can criticize it. This does not seem good leadership

to me. If the engineer cannot make his own rough draft, with enough detail for preliminary consideration, he is no leader. Leadership involves, not so much telling people what to do, as showing them, by precept and example, how to do it. New ideas usually involve consideration of many alternatives, and the engineer or scientist should be able to do some of these first outlines himself much better and quicker than any of his draughtsmen.

It is hard enough to express one's own ideas clearly ; it is beyond reason to expect others to express them for you. Professor M'Ewen, in a recent address, commented on the better training that architectural students received than engineers, in that, in the former case much more attention was given to drawing. It was well said. The engineer who cannot draw is in much the same state as would be a man engaged in clerical work who could neither read nor write.

It has been said that the engineer or scientist cannot afford to waste his time and talents on a drawing board. This is nonsense. The engineer must be a master of his only medium of expression ; and unless he can draw he will not be able to give proper consideration and guidance to other men's drawings. In many cases some faintly squared paper and a soft pencil, and a large piece of indiarubber, are all that is needed. Not only should sketching and drawing be practised and used regularly as a working tool by all engineers ; neat figuring and lettering show that thought has been given to the sole purpose of the drawing or diagram, namely, that someone else should be able to read it easily. It is worth hours of spare time practising a plain formal lettering and script. I believe no Continental engineer would sit for his examination until he had mastered this simple and useful art.

A properly organized drawing office is the place where creative ability and talent are best recognized and developed. Its success in this respect is a measure of the quality of the organization of which it forms a part. It should be regarded as an essential recruiting and training ground for designers and engineers. All too often, however, we find it forms a backwater, detached from the main stream, with very small prospects of promotion in it. In some way or other the idea has grown up that ' working on the board ' is below the dignity of an engineer or scientist, in contrast to the more sensible attitude of the architect.

The sooner this idea is dropped the better. How else does the engineer expect to express his ideas ? Read the obituary notices in the technical journals of eminent engineers : in almost every case we find that the subject worked in a drawing office. A recent biography of Sir Frank Whittle states that he had spent most of his working life on the drawing board. There is nothing surprising in this : where else could the creation of the jet engine—or any other engineering achievement—have been done ?

IMPORTANCE OF DETAIL

It is often said that senior men should not concern themselves with detail, this being left to juniors. This is a serious fallacy. The whole design is only an arrangement of details. Once a real design is in hand, the general principles have usually been accepted long ago, and can be taken for granted. The detail is the matter of supreme importance ; the whole thing, in fact. An error of judgment in respect of one single detail may, and often does, make all the difference between success and failure. No detail is too insignificant for the leader's attention. When many thousand details are involved in one job this looks formidable, but he should look at every single one. One can size up in a few seconds whether attention is needed or not, and give it further thought, without losing track of the overall design. Mechanical engineering detail is usually of great importance ; alterations after trial are difficult to make. This

is not to say that the chief designer or project leader should check every dimension. But there has been a tendency in recent years to neglect meticulous checking, with disastrous results in wasted time in the shops. The time of the most experienced man in the drawing office is well spent in checking the work of others, combining this, naturally enough, with advice and guidance to juniors.

The philosophy of engineering design as outlined above applies equally well to, say, the circuit diagram of a radar system, and its subsequent development. This circuit diagram work is a wizardry of its own, and everything depends on it ; but it only defines the potentialities, not the realities of performance. It may be a complete medium of expression from one radar expert to another, but not to the man (or men) who is to make it, and it does not define the actual performance in any way. The diagram is symbolized thought, like a mathematical expression : it needs interpreting in working drawings before it can be made in other than a ' bread-board ' form, and this interpretation needs an ability of the same order as the formulation, though different in kind.

This brings up a very important matter—the bread-board or demonstration model, which seems to be a necessity in the design stage of radar gear, where the idea must be tried out before real design, or so-called 'engineering' can be started. In other directions, however, the bread-board model may be a danger. One occasionally sees trial models rigged up ' to illustrate a principle ', without much regard to a proper manufacturing design. A model of this type may work quite well, up to a point, by virtue of its defects. A recast of the design and more accurate manufacture may result in the thing refusing to work at all.

Small models of cardboard, or Meccano, can be of very great value, and may be essential in the development of ideas, or complete scale models may be needed for structural tests ; but here again, only the potentialities of the idea, and not all of them, are covered. The realities lie in the design as expressed, not in fancy pictures, but in the working drawings.

I end with a quotation from Dr. Ing. J. Roemmelt, one of the senior design engineers of Krupps. He writes in English, and I only wish that my German was as good as his English. At the end of his *Practical Hints on the Design of Naval Gun Mountings*, he says :—

' Moreover, the designs cannot all be treated in an abstract way, but often can only be made with feeling, experience, and estimation. A good designer therefore must be possessed of a high degree of technical sensitiveness and creative spirit. The leader of a designing department must act as a clear-sighted pioneer, and on no account must he leave the work to subordinate collaborators. Thus the work of the leading engineer must take up the whole of his activity, and not only provide him with the means necessary for his livelihood, since otherwise the creative spirit is lost.

' Moreover, the superior must draw the attention of his collaborators to the fineness and beauty of work and awaken their interest even in simple tasks, which, by the way, sometimes cause more efforts than many a part which appears important at first sight.

' Anyhow all persons engaged in such an intensive work must devote themselves to their task with real ardour, and according to the poet's saying they must feel in their very bones what they create with consideration and good judgment.

' It is only in this way that a good efficiency can be obtained.'