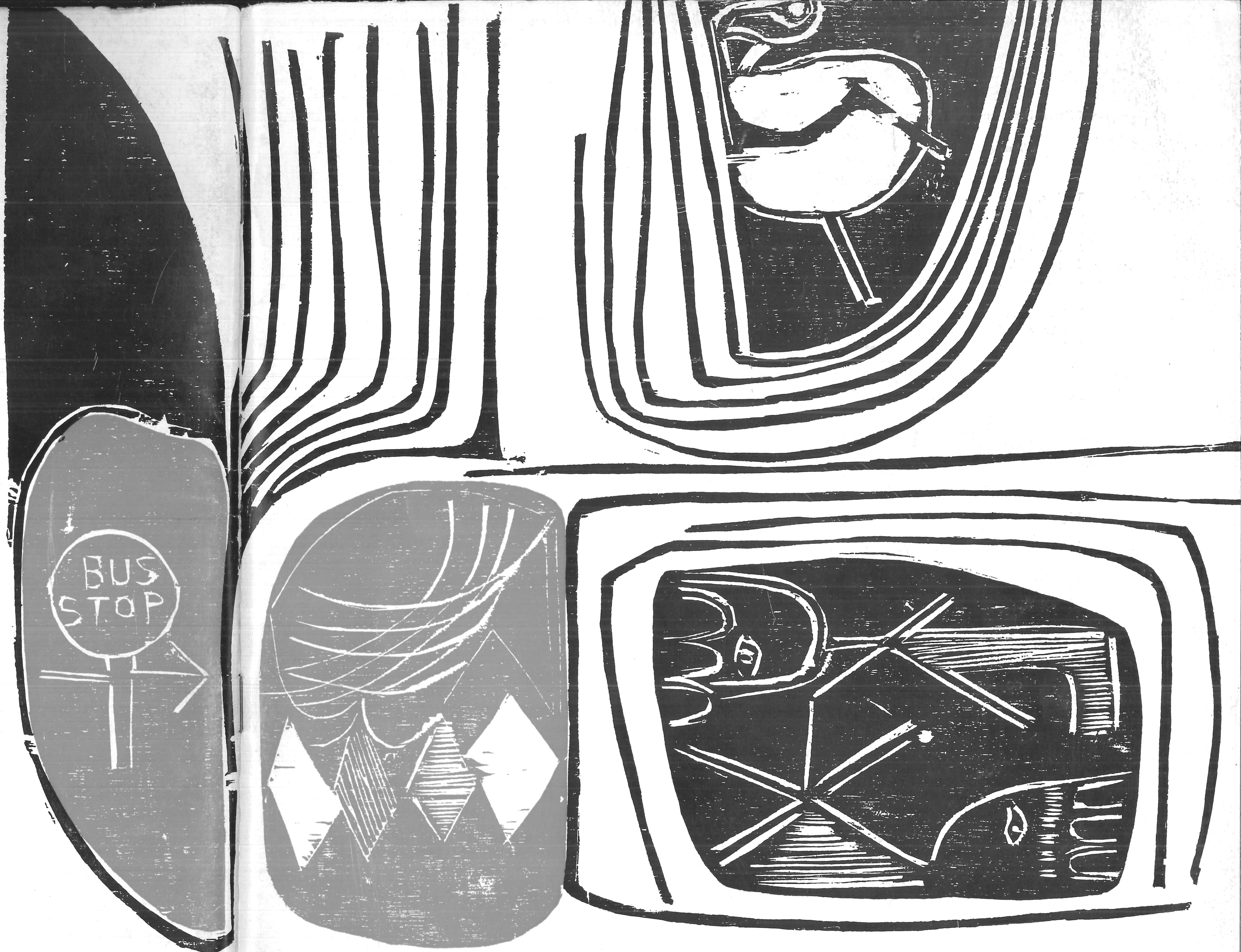

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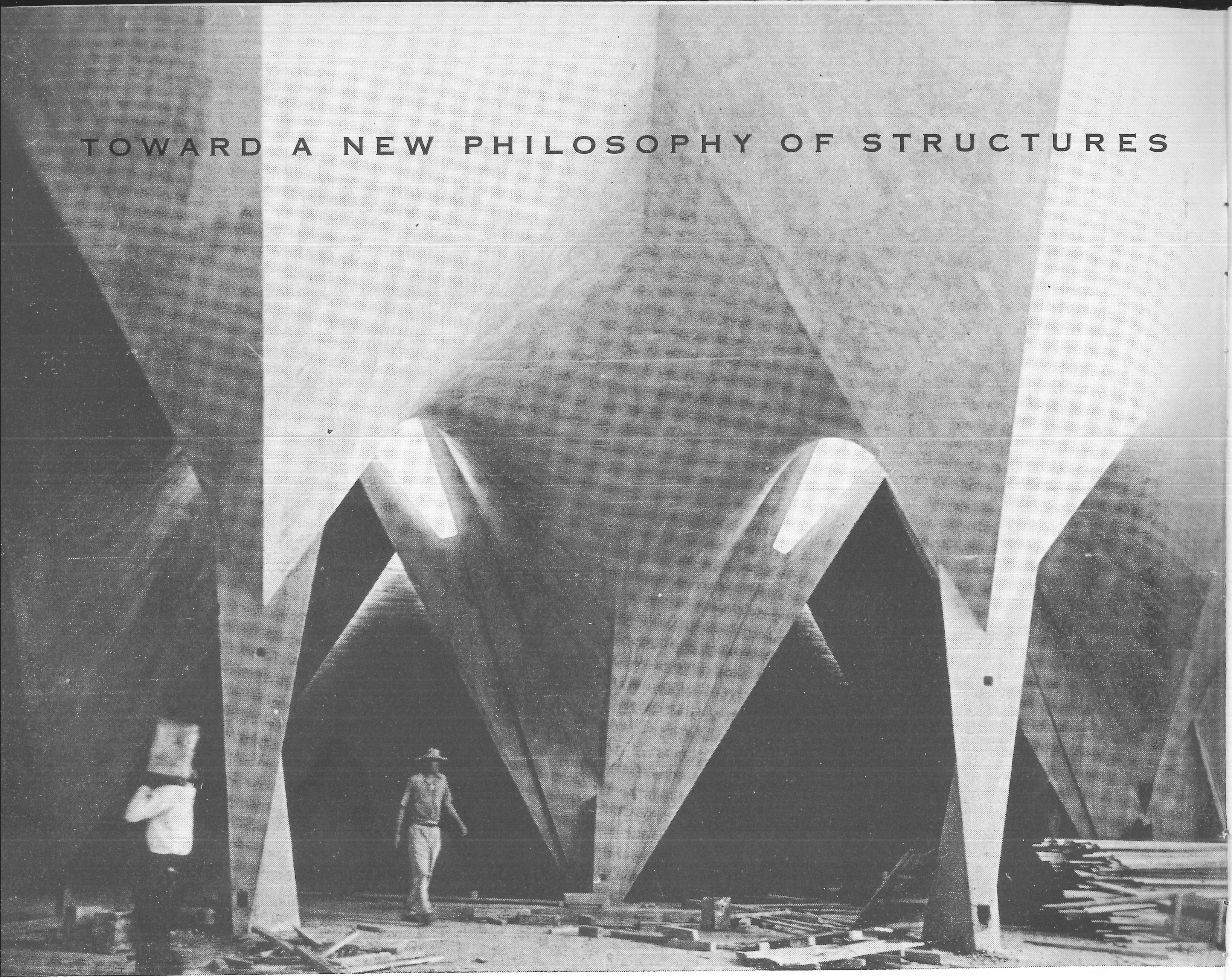


TOWARD A NEW PHILOSOPHY OF STRUCTURES

FELIX CANDELA

Born in Madrid, Spain, January 27, 1910 studied the career of architecture in the Escuela Superior de Arquitectura de Madrid, receiving degree in 1935. Resident of Mexico since 1939. Adopted Mexican nationality in 1941.
Professor of Building in the Escuela Nacional de Arquitectura, U.N.A.M. President of the firm "Cubiertas ALA, S.A.", specializing in the design and construction of laminar structures and concrete shells, having built with the firm more than ninety structures of this type in Mexico City over the past five years.

Translated from the Spanish by Dr. G. Poland,
Dept. of Modern Languages,
North Carolina State College

The 19th Century represents the triumph of pure science and especially its practical or technological application. It is the culmination of a period of unilateral lucidity of humanity, which had its beginning in the Renaissance, and in scarcely 500 years has continued to bring about a series of marvelous discoveries which could not even have been forseen in the previous thousand years. This lapse of time has been extraordinarily brief and even includes its gestation period that comprises most of it. In short, we find the astonishing fact of science and, particularly, its palpable results in a period of less than a century and a half, an instant in the evolution of humanity.

It is not strange, then, that enormous, though unjustified, arrogance characterizes modern man. He believes himself capable of continuing the process with equal rapidity and facility,* believing further that he has learned to dominate nature, forgetting, however, that it is first necessary to be able to dominate oneself, that without a similar development of the other sciences—moral, political and social—The germ that it carries within itself threatens to destroy all present civilization. Reckless technical hypertrophy will serve only, in the end, to give man more powerful arms with which he may more comfortably complete his own destruction.

But this is not the theme of our essay, nor are we capable of dealing with it. What interests us is to emphasize, for the time being, is the excessive esteem with which mathematics is regarded, as a natural consequence of superficial observation of the very important role it has taken in the rapid development of technology.

It is very significant that this final period begins precisely in the moment when present-day mathematics is completing its evolution and differential and integral calculus are becoming fully consolidated. It is perfectly natural for it to happen thus, since, without such an instrument, it would have been impossible to undertake the solution of the new problems, at least, in the form used. Who knows whether they could have been solved by other means? But the certain fact is that mathematical proceedings were employed from which we could conclude superficially—and so it was done in the 19th century—that all science reduces itself to the systematic application of mathematical reasoning and that through such a simple process one could arrive, if he had not already arrived, at discovering absolute truth, that is to say, at recognizing reality completely.

In the last century the fundamental position of man in relation to the world was his belief in the infallibility of science, or rather, in logical or mathematical reasoning and, by extension, in rationalist theories of all lines of thought including politics.

Thus the human intellect became so deformed that the most obvious and tested explanations of any physical phenomenon was rejected as it is, even today, as unscientific if not accompanied by an impressive display of mathematical formulas. However, the merest presence of complicated differential equations suffices to cause respect. We consider them intangible truths.

* The mere fact of the daily use of the utilitarian consequences of such scientific discoveries, the ease of obtaining them with our "money" gives us a totally erroneous feeling of domination over them. It has occurred to no one to stop to think how little each one of us has contributed personally to the development of science. The truth is that science is not the fruit of the cooperative work of all but the daughter of a gigantic work of a few.

Confusing thus, lamentably, the means with the end, it is forgotten that mathematics is only a means, an instrument, however precise it may be, but that the rigidity and precision of mathematical reasoning cannot guarantee us the exactness of the results of its application because we must always begin from a supposed arbitrary original. However evident the certainty of these primary hypotheses may seem to us on occasion, the reality is that we can never trust them completely because they are of our own making, of our senses, and above all, of our imagination, since our own senses are not to be trusted entirely.

"Seeing is believing" is not enough for us in the majority of cases since the objective examination of the facts is not sufficient or even possible. When one investigates or tests —the word itself indicates clearly the nature of the process—one always does it with the idea of proving a certain preconceived idea about the cause of the phenomenon that he is investigating. As Ortega y Gasset says: "For the very reason that it is impossible to know directly the fullness of reality, we can only construct a reality arbitrarily, supposing that things are of a certain manner. This gives us a scheme, that is to say, a concept of a network of concepts. With it, as by means of a graph, we see then; only then do we obtain an approximate vision of it. This is the scientific method. Furthermore, in this consists the full use of the intellect."

Along with this, it goes without saying that the important thing is the intellectual attitude toward the phenomenon. A single experiment can be interpreted in different ways and even in opposite ways depending upon the approach of the observer.

Hence, the enormous importance of hypotheses which, as a general rule, are only conventions which serve to fix ideas for us and are legitimate as long as they imply no contradiction with the results of the experiment, that is to say, as long as they permit logical explanations of said results. But they must be replaced by others better adjusted to reality as soon as they present too obvious incongruencies, which the conventions in use are not capable of explaining.

In this way experimental sciences advance by leaps and bounds. During the periods of creation, a series of basic ideas originate which must be useful to us throughout the periods of development. These periods are charged with verifying, completing and turning to practical advantage those fundamental ideas to the point of exhausting them, that is to say, until the presence of contradictions becomes intolerable, in spite of the repugnance for abandoning the precise, and generally ingenious, scientific tool chest, which for the practical application of those ideas, the latter periods have developed.

This resistance to dispensing with the convenience given by habitual methods of analysis is one of the principal causes of the inertia which characterizes the final periods of the development process.

Thinking always constitutes a painful effort, and, therefore, it is much more convenient for us to believe simply in the good criterion of those who have developed the processes in use and apply them to the letter of the law, however long and tedious the methods may be, rather than to stop and think a moment for ourselves.

But the technique can advance only as a consequence of scientific thought: Without it, without the investigative fervor, it becomes pure routine and degenerates until it becomes a fixed and immovable formula. Clearly any professional man needs a quantity of formulas for his personal use in daily problems brought up in his work. The sad thing is not the use of such formulas, but the belief in their infallibility and the consequent deadening of all initiative. It cannot be expected, obviously, that each technician will be an investigator, but it is necessary to have a certain degree of curiosity and preoccupation for the fundamental principles on which his technique is based.

The scientific process needs analysis and synthesis, or, said in another way, specialization and unification. The first activity, as a classification and report of investigations made, relates to the periods of development; the second, as an interpretation and panoramic examination of the results obtained, relates to the periods of creation. This is the manner of progress in scientific thought. Both processes are essential in normal progress which indicates that there must be a certain balance between them. When this balance is broken there is the risk that all the work will be useless, whether by excessive liberty in interpretive or imaginative work or by lack of content in verification and testing work.

It is a commonplace to say that we are in a period of specialization, but the very insistence on the phrase indicates that it lacks confidence, that the domination of specialist has ended since the vital corresponding cycle is completed. The ideas that gave it being are fully developed and to continue expressing them would be futile and senseless. They have already given all that can be expected of them and it is necessary to substitute for them other basic principles which will inject new wisdom into the tree of science if one wishes science to continue advancing. In the field of physics such transformation has already begun, or perhaps, it has never ceased, but the lesser sciences are still chained to fallen principles. The least that we can do is to realize the fall and prepare ourselves to accept new ideas.

And this does not mean to say that exhausted ideas are erroneous. This would be a senseless proposition since, to a certain degree, those ideas which would replace them would also be false. The important thing is that they help us to take one more step along the incalculable road of knowledge. The tragedy of Science is in working for a result that will never be reached. We must then be reconciled beforehand to closing, even though in a very small measure, the enormous circle within which we are trying to imprison reality.

All this preamble will seem out of proportion to what we are going to say later, but we wanted to recall some general ideas of what is understood by scientific process in order to apply the ideas to the present state of Structural Analysis which, in a way, can be considered a science, even though somewhat rough and coarse.

More properly it could be defined as a technique whose strict aim is to obtain a certain surety, within human limitations, that the constructions that we build will remain stable under all ordinary conditions. Having established this definition, we come face to face with the first uncertainty in it. What are "ordinary conditions"? The difficulty of determining them beforehand with certainty is well-known, since if it is easy to know the weight of the construction itself, the same does not occur with live loads and especially with their possible distribution. Even more uncertain are the conditions produced by the so-called secondary effects (variations of temperature, contraction in the bedding of concrete, settling of the soil, etc.) Which are in general difficult to predict. That is to say, omitting for the present the exactness of the methods of calculation, the problem can never have a single and exact solution. Recognizing implicitly this state of things, regulations fix some determined coefficients of safety, but if we hold exclusively to the letter of the norms, it seems as if these "coefficients of work" have as their end foreseeing possible failures of materials due to variance of quality inherent in the processes of obtaining or fabricating, taking for granted the precision obtainable in respect to the other variables that intervene.

It should be noted that this is not the case. In this connection it will help to comment on what such internationally recognized authorities as Professors Torroja, Ros, and Campus say in the introduction of the report presented by them in July of 1950, at the Reunion Internationale Des Laboratoires d'Essais et de Recherches sur les Materiaux et les Constructions (International conference of Laboratories Engaged in Testing and Research of Materials and Construction) about "The concept and calculation of the safety factor in Reinforced Concrete Constructions." If the loads to which the structure was to be subjected were known exactly, as well as the quality of the materials; if the execution were perfect; and if, finally, there were no possibility of any error in the calculations, the safety factor would be only a few decimals superior to the unit. Unfortunately, this is not the case. We can not have confidence in any of the aforementioned points. The causes of ruin are uncertain and their importance unknown, and we must increase the factor to obviate the probability that the actual conditions are worse than those predicted."

Since the number of variables and unknowns that come into any calculation is so large, we have to take as a basis statistics and the calculation of probabilities to determine the magnitude of said coefficients with which the strength of materials does no more than follow a process already accepted by the physical sciences, in which the notion of probability takes a role of great importance.

Referring, for example, to reinforced concrete, we see that it does not suffice to divide by a certain coefficient the breaking strength of the concrete and the iron to obtain the work coefficient, but that such a factor must be applied to the breaking conditions of the whole of the structure which we are analyzing. It is not even enough to consider the breaking of each section of each frame that goes to make up the whole.

Here is precisely where the usual methods of calculation are faulty. The theory of elasticity, the only one admitted in most regulations, is not capable of giving us even an approximate image of such a phenomenon so that the whole customary process of calculation totally lacks meaning. To obtain the resistence limit, we must extend the fundamental hypotheses of the theory, the most important of which is Hooke's Law or proportionality between stress and deformations and such extension would only be justified if the materials continue to behave elastically until the breaking point.

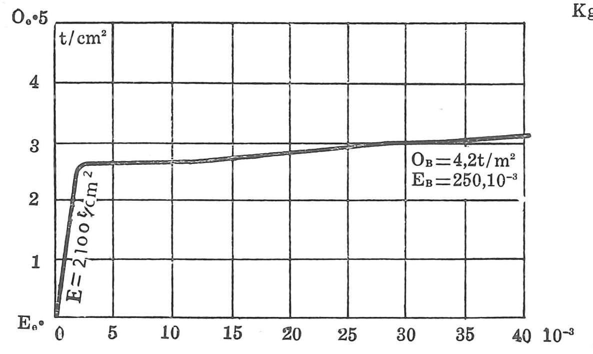


Fig. 1
DIAGRAM OF DEFORMATIONS
IN CONCRETE

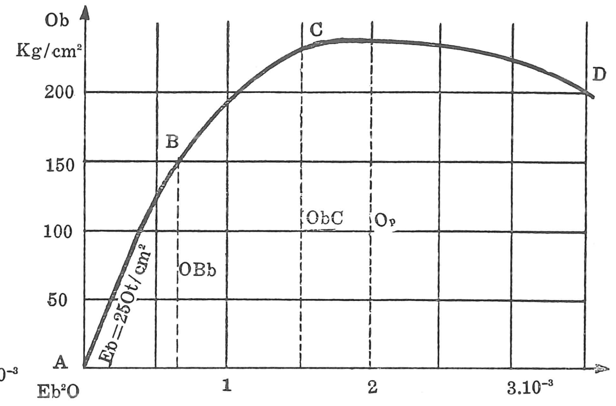


Fig. 2
DIAGRAM OF DEFORMATIONS
IN STRUCTURAL STEEL

This does not happen even in those materials like ductile steel which have a zone of proportionality or pure elasticity. With great loads this leads to breaking, proportionality disappears, the materials yield and deformation increases enormously for the slightest increase in load. This fact is shown graphically in the horizontal part of diagrams of deformation of materials under stress usually employed in construction and which represent the plastic or fluid period of the material (fig. 1 and 2).*

This period has a great importance in the new theories of calculation, because it is the origin of the "Metestasis" or transfer of stress from parts most sought to those less sought. In fact to this phenomenon is due the stability of most structures.

In this way we have sketched in the fundamental theme of our work; THE INSUFFICIENCY AND LACK OF LOGIC IN METHODS OF CALCULATION IN USE, BASED ON THE THEORY OF ELASTICITY.

It could be argued against such an affirmation that most structures that are raised according to these ideas are standing. Nevertheless, we have already indicated and we will try to demonstrate later that the principal reason for these constructions standing, although it seems paradoxical, is that materials do not adjust to the hypotheses of calculation. If, on the contrary, they were perfectly elastic, the collapse of the structure built with them would be inevitable with the varying of the conditions supposed in the calculations and, upon the deformations reaching the corresponding values of breaking strength, they would have

*Fig 1 and 2 from the book "Die Neue Theorie Des Stahlbetons" by Dr. R. Saliger had to substitute a long time ago the usual materials for others not having such dismal properties. Happily, structures, wiser than man, undertake not to fall down, and that permits us to continue deceiving ourselves with our innocent play.

Although the principles on which the mathematical theory of elasticity were based were sketched by Galileo and Hooke in the 18th century and were further strengthened by the investigations of Euler, Coulomb and the Bernouilli brothers, to cite only a few of the famous names of this period, their definitive formation was not possible until differential and integral calculus—their principal instrument—was developed fully. It is then at the beginning of the last century, in 1821, when Navier and Cauchy attained the basic differential equations of elasticity, that the evolution of the theory has been very rapid. We see, therefore, that it is an authentic product of the 19th century and of its mania for wanting to imprison reality within a mathematical frame. A very fertile mania, however, since without it the amazing discoveries that we see and enjoy today in all technical fields would not have been achieved;* but nevertheless it represents a completely outmoded point of view.

Allow us a parenthesis to insist on the similarity of the process which has given reason to rationalist theories in all walks of life. In the field of Architecture there was produced, although with something of a delay, the same phenomenon. Functionalist theories carried to their limit would presuppose a unique and unequivocal solution for each architectural problem once the initial premises and location or program were fixed. This solution would be, therefore, independent of the subject or producting agent. It would be perfectly possible in such a case to invent a machine by which through introducing at one end the architectural program, we would obtain at the other end the complete project including photostatic copies and building permits as was the case with the legendary Chicago machine which admitted live pigs at one end and sent out tasty sausages from the other.

If modern architecture were truly rationalistic, we could say that it was anachronistic. Its basic anachronism would be evident since it would relate to an intellectual proposition already outmoded at the time of its birth, that of believing in the infallibility and exactness of scientific reasoning.

Let this digression serve for considering other justifications for present architecture since apparently it is necessary to justify it, and explain it, and further, so that the student of architecture will stop asking unfailingly if a certain form is justified by the function. Something must be wrong with Plastic Arts when it is necessary to seek literary and rationalistic justification for them.

Turning to the theory of elasticity, it is necessary to recognize the very important role that it has played in the evolution of structural analysis as well as what it means in relation to the indispensable mental discipline for the training of engineers and architects. As a theory, it is irreproachable in the same way that mathematical reason is irreproachable. But, for the very reason that it is only a logical process, it cannot guarantee certainty of results beyond the degree of exactness of premises. There could be no objection to the

* Or perhaps they would have been achieved by another route. It would be very interesting to analyze this possibility in detail.

application of its deductions to the calculation of structures, if the materials with which the latter were built responded to the basic hypotheses of elasticity, but unfortunately this is not what happens.

It is certain that in order to be able to apply mathematical procedures to any physical phenomenon, a certain degree of idealization is always necessary and this idealization is also necessary to be able to see things with relative clearness;* taking the thing to the limit one forgets the end which is to interpret the behavior of materials in work with all imperfections inherent in the constructive process. One should remember frequently the characteristic lack of precision of such a process and compare the inevitable roughness of the resultant structures with the delicacy and exquisite exactness of mathematical procedures which pretend to give us an idea of the behavior of such structures under the action of the very uncertain loads.

But it happens that, when the imaginative effort which represents idealized or simplified physical properties is made, it requires a lot of work to undo what has been done and reconsider the fitness of one's premises. This is true, especially, when in the application of the mathematical process to such bodies, one has achieved more or less complicated results and formulas. Consequently, the very difficulty of obtaining these results causes them to seem definitive.

One must take into account, moreover, the spiritual satisfaction and feeling of perfection that the solution of any problem by purely mathematical means gives. The instrument is so clear and beautiful, that it constitutes an almost physical impossibility to renounce its results or even to doubt its uncertainty.

The fact is that the theory of elasticity refers to an ideal homogenous and isotropic material which, moreover, responds to Hooke's Law. Nevertheless, the usual materials lack a great deal in resembling such a hypothetical material, and reinforced concrete, which is actually a *(par excellence)* construction material, is heterogeneous by definition, and is alotropic since it contains steel only in certain zones and in determined directions and does not respond at all to Hooke's Law. The diagram of deformations in simple concrete has no straight fragment and the deformation of a section depends essentially on the quantity and disposition of the reinforcing steel.

But let us examine the real utility of the theory of elasticity in the analysis of structures composed of prismatic members.

When it is a question of estimating frames whose conditions of support permit them to be considered as statically determinate or isostatic, the equations of mechanical balance and the implicit consideration of Saint-Venant principal suffice to find the forces and moments which are active in any section of the frame.

* "All things by which science, whichever it may be, speaks, are abstract, and abstract things are always clear. The thing that is essentially confused, intricate, is vital, concrete reality which is always unique," says Ortega y Gasset, and also:

"Only the fantastic can be exact. The mathematical stems from the same roots as poetry, from the imaginative gift."

Once these forces and moments are known, the calculation of sections, and especially of reinforced concrete sections, requires from the beginning a procedure that has little to do with the theory of elasticity. The only memory of it, the triangular diagram of the zone included, is practically excluded in many regulations and only habit causes it to be used in others. Modern methods of calculation of sections are purely empirical and consider a rectangular distribution of pressure on the concrete corresponding to a coefficient of 0.85 of breaking on pressure gauges keeping in mind the plasticity of the concrete and of the iron to determine the limit capacity of resistance of the section.

That is to say, the theory of elasticity is used only for the analysis of continuous structures statically indeterminate or hyperstatic.

The usual procedures for obtaining the redundant forces or unknown hyperstatics are based on the application of the theorems of work. The most common, that of Castigliano, says: "The elastic work of deformation expressed as a function of the external work, is a partial derivative with respect to any one of these forces, giving us the projection along its direction of the displacement which is produced at its point of application." If we differentiate with respect to a moment we obtain similarly the rotation of the section on which it is applied. Repeating this process as necessary, we arrive at a system of linear equations, in number equal to the unknowns, whose resolution gives us the redundant forces sought. It is well known that the process was inapplicable in practice for moderately complicated structures until, in order to solve the system of equations, the method of successive approximations known as the "Cross Method" was conceived.

We see, then, that the fundamental thing in such a process is the expression of the elastic work of deformation obtained as an integral of the elementary work corresponding to the points of the limit of the surface of the body. In order for such an expression to become manageable it became necessary that, once the tensors of the elastic forces and deformations were defined, the relation between them be simple, in such a way that this relationship would depend solely on two coefficients (that of the longitudinal elongation "E" and that of the transverse strain "Ω", which is customarily used for the so-called Poisson's ratio) and, among other things, the homogeneous and isotropic nature of the material.

It would be difficult to find a clearer example of the premeditated stubbornness and falsification of the facts in order to make the slippery and complex reality fit a mold than the artificial process by means of which coefficients are eliminated, in the usual explanation of the case in point until they are reduced precisely to two.

Having once obtained in this manner, very ingenious to be sure, the mathematical explanation of the proportionality between stresses and deformations, the logical thing would have been to set out to find a material that would fulfill the supposed requirements. The fact that iron was relatively homogenous and isotropic and presented a zone of proportionality was enough for our grandfathers, with a spirit that we would call sporting today, to set out to develop a strictly mathematical and exact structural theory in which, nevertheless, the only thing that was never taken into account is the most important thing—since it is what one must try to avoid—the conditions producing breaking.

We could define such a theory in the following words, "Structural analysis is an exact science which being based on deliberately false hypotheses tries to determine in a single manner for each system of loads the forces to which any structure is subjected."

As reinforced concrete was invented after this theory was completely developed, they applied simply the results and formulas already obtained to structures built with the new material without stopping to think, apparently, that the new material was not related in any way to the basic supposition of the theory. But a hundred years have passed and we continue the same way. Will we have to shorten even more the creative period of which we were speaking at the beginning and leave it reduced, in so far as it refers to structural calculations, to thirty or forty years of the last century?

And this state of things is not justified by the fact that construction can be considered only a minor science, since it is, at the same time, one of the human activities consuming the greatest amount of collective effort. A greater fitness in the methods of calculation of structures which will result in economy of material and which will simplify the analysis of the material, means automatically a considerable reduction of human effort in this connection. Nevertheless, the theme that we are trying to set forth seems to be untouchable among professionals to judge from our personal experience and the slight impression that works already published by its few proponents for some years have had. Its proponents in recent times, treated it briefly and hastily*, recognizing in advance the futility of greater effort in the vain undertaking of fighting against the current.

In this connection the introduction to H. Cross's book, *Continuous Frames of Reinforced Concrete*, is of tremendous significance. It constitutes in itself an obvious mental reserve, a self justification, and renounces, beforehand, the responsibility that may fall on the author for the mistaken interpretation of his book that less clear minds may make. It seems as if recognizing implicitly the uselessness of setting forth the problem in all its ugliness, he is saying to us, "If in spite of everything, you want to continue along this road, if you have decided to continue practicing your ingenuous pastime, here is a tool which will save you effort."

Little or nothing can we add to his masterful and concise treatment of the topic. We will have to be satisfied with repeating it once more, following the line of our own reasoning.

Since the only usable procedure in practice for the elasticity analysis of hyperstatic structures is Cross's method which is universally known and accepted, we will naturally have to refer to it specifically to give greater clarity to this critique; but having it well-understood that objections will be laid at the door of the competence of the sources of the analysis and by no means that of the instrument.

* Thus, for example, the Swede, A. Holmberg, in a note on the calculation of "flat slabs" says, "in structures of reinforced concrete the problem does not necessarily have anything to do with the theory of elasticity. The only value of the calculation of stress for such a theory is that it describes a system in balance, but this balance can be achieved in many different ways".

According to A.M. Freudenthal,[23] "The methods that are applied to the calculation of structures are based on the supposition that materials are perfectly elastic; if they actually were, no structure would be safe, in even very normal conditions of use."

The point of departure for this analysis is to consider each structural member perfectly fixed at the ends since we consider the joints in the system to be rigid. Both fixed end moments are considered as unknown indeterminates, and therefore, the integral expression of the elastic work of each member becomes a function of the members. When the total section of concrete is constant along the length of the member, the moment of inertia (I) is considered invariable and is taken from outside the integral together with the coefficient of elasticity (E) of the section which is also assumed to be constant, obtaining, thereby, the so-called member constant, rigidity, transmission factor, and distribution factor.

Unfortunately, the values of E and I cannot be considered constant for reinforced concrete. According to Saliger, E varies for the same concrete from 285,000 Kg/cm^2 when the section is without cracks to a minimum of 40,000 Kg/cm^2 for a section working in flexure with cracks in the traction zone and a 0.3 percentage of reinforcement increasing this value until it approaches the first as the proportion of iron increases. For $p = 1.5$ percent, the value of E is 110,000 Kg/cm^2. That is to say, E depends not only on the quantity and disposition of the reinforcement but also on the stresses of the section, whether or not they are capable of producing cracks in the tension zone. Therefore, their variation limits are considerable in a single frame.

The values of I are even more indeterminate. Some of us consider the moment of inertia of the total section of concrete; others, that of the compression zone plus n times the area of steel. But if we could decide on either of the two definitions, the values of I would vary in agreement with the possibility that in T-beams, which are more usual, the slab may contribute as a compression head.

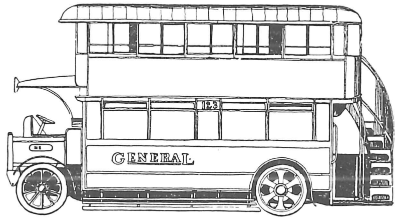
The usual argument that we do not need to know the exact values of E and I, since the only thing which interests us is the relative values, is nullified by previous considerations.

For the same reason it is possible to know beforehand the perfect embedding moments of each frame which are the points of departure for the distribution method, since obtaining it depends equally on the values that we attribute to the supposed constants E and I.

To sum up the preceeding reasoning, we could say in a few words that the methods of hyperstatic structures analysis are based on the consideration of the deformation and on its hypothetical proportionality with the loads, or with the stresses. But as they cannot be known beforehand, since they vary in a single section, there is no reason to suppose that the results of the process can offer us even an approximate representation of the actual working conditions of the structure and much less those of failure.

(continued in Vol. No. 6)

London Bus Design



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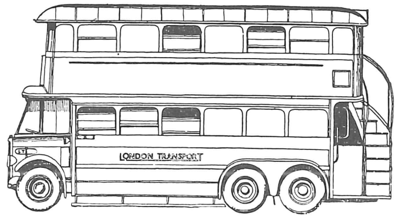

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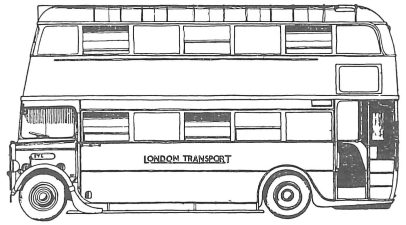

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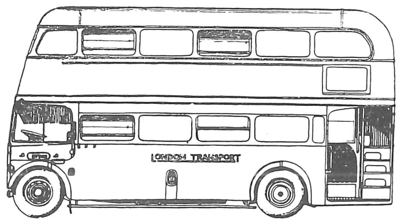

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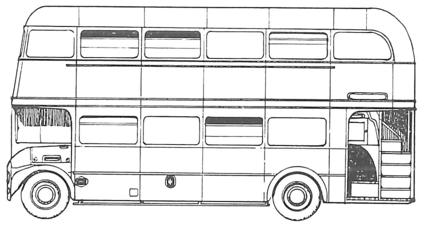


5 Routemaster, 1955

From The Editors

The following is reprinted, in part, from "Plan", (#5, 1949), Published by the students of the A.A., London, England. The design development of the RT3 model is presented here, although, it has been superceded by a later design, the "Routemaster". The work done by the London Transport Office "Design Group" on the design of the RT3 represents one phase of a constant process of refinement and is typical of the work carried on by the design group for the last twenty-three years.

HISTORY

Every year before the war London Transport needed between 600 and 800 buses. The London Passenger Transport Act of 1933, which provided for the formation of the LPTB, limited the number of buses which the Board could produce in its own workshops to 549 per year. The balance of the yearly requirement was made up by placing small orders with different builders as the need arose. Bus design was in the process of continual evolution and as a result production was in small batches of constantly changing design. None of the production runs were of sufficient size to warrant the heavy capital expenditure of tooling up a plant for mass-production. Any extensive standardisation of body components was thus out of the question and the resulting lack of interchangeability made maintenance a difficult and tedious business—stocks of spare parts grew to unmanageable proportions. When the war ended London Transport was faced with an extremely serious shortage of buses. Since 1939 the gradual replacement of equipment had become more and more difficult. 166 buses had been destroyed and 4456 damaged in air raids, and the all-important task of maintaining and repairing existing stock had been severely curtailed since the repair plant had been taken over for aircraft and other war production. Consequently, for the steadily expanding post-war London, buses were needed in thousands. The nature of this new problem demanded fast, efficient and imaginative methods and techniques if the need was to be met.

In 1945 the LPTB made a fresh start. A revolution took place. Most of the old production methods were scrapped and the mass-production of standardised components was decided on as the only solution both of the bus shortage and the maintenance problem. In the development of this new technique the experience of aircraft production gained during the war was invaluable. The size and nature of the problem made the new technique imperative, and it was the very size of the problem which made it feasible. Mass-production, which implies the standardisation of parts and thus immediately solves the problem of interchangeability, is only economic when applied to a large-scale production programme.

To carry out its policy the LPTB reorganized the pre-war design department and formed a new Design Group. This Group received directives from the LPTB in terms of operational economy and efficiency in relation to an overall policy for all types of transport in London, and from the Ministry of Transport Regulations in terms of public safety.

DESIGN REQUIREMENTS

Economy
Production costs must be low: the bus must be rapidly and efficiently maintained by the garage and repair staff: it must be hard wearing to reduce maintenance costs: its weight, size, and passenger capacity must be in the right economic relationship.
Comfort
For physical comfort the passengers and crew must have the best possible conditions for movement: manipulation of equipment: sitting: vision by day and night: recognition of destination: thermal and acoustic insulation: ventilation: freedom from engine fumes: freedom from engine and road vibration: hygiene. Psychological comfort demands brightness, cleanliness and gaiety: structural stability: pleasant textures on floors, internal panelling and handrails.
In addition to these requirements the bus must be waterproof and painted in durable colours. Since this particular bus is for short-range operation, ease of boarding and alighting is particularly important.

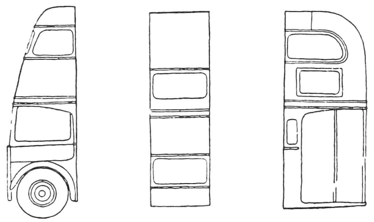
Safety
The bus must have emergency exits: stability on the road under all conditions of weather and loading: a suitable structure to withstand not only dead loads, but also the live loads due to its movement: non-splinter glass: careful insulation of electrical circuits: fireproofing to cover hazards from cigarettes, fuel, etc.

DESIGN METHOD

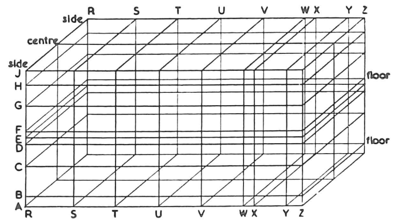
Structure of the Design Group
1. LPTB—the clients.
2. Design Team.
3. Interchangeability Section.
4. Technical Planning Section.
5. Contractors—Park Royal Vehicles and Weymanns.
6. Development Section.

WORKING METHOD

Organization: At first, in 1945, the design team consisted of a few men with pre-war and wartime engineering experience. As the work increased and extended into greater detail, the original design team expanded. Each member of it became the leader of one of the subsidiary sections which were formed to deal with the multiplication of the design problems. These subsidiary sections worked on the final design of the bus in detail. The interchangeability section co-ordinates the design in terms of dimensioning, standardisation, and tolerances.
The technical planning section similarly co-operates in the design from the point of view of overall production efficiency and manufacturing economy.
The development section has three functions: research on new ideas presented by the Design Group: research on operational problems concerning the repair and maintenance of current designs: research for long-term planning.
Administration: There are frequent and regular meetings of the whole Design Group. A design book is kept to record criticisms, decisions and design modifications made at these meetings, and in it priorities and progress can be checked against a time schedule. An index was made to deal with the library of over 3500 design drawings, parts lists and assembly schedules. A special feature of this index is that cards are made out which describe the production, use and position of the smallest component in relation to its neighbours wherever it occurs in the design. This simplifies, among other things, the problem of modifications, and keeping certain components in use over several designs although the design as a whole may be changed considerably.



5 The basic elements of the bus.



6 The three-dimensional grid of datum lines—location in space.

PRODUCTION METHOD

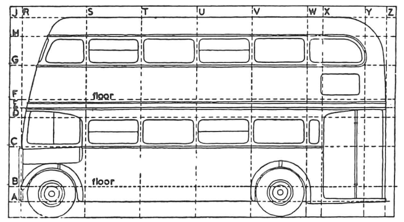
Lower Saloon
Detail parts: nuts, bolts, stampings, die castings, and other prefabricated components
Structure
Floor and staircase
Engine bulkhead

Assembly

Upper Saloon
Detail parts, etc., as in lower saloon
Structure
Floor (inter-roof) and roof
Destination equipment

Assembly of both saloons
External panelling, exterior mouldings, and joint plates
Body shell complete
All seating, interior electrical wiring, internal panelling, and installation of handrails
Body complete

DESIGN SEQUENCE

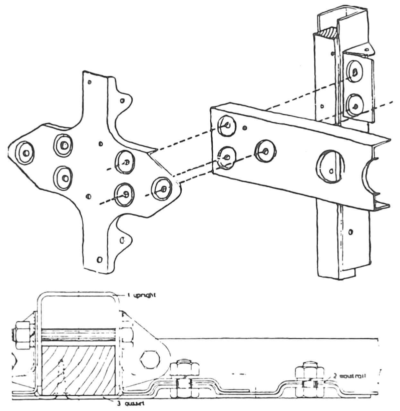


7 The datum lines applied to the side elevation of the bus—location on a plane.

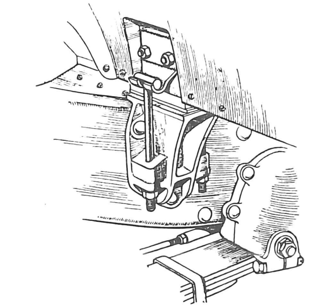
1. July 1945. The design team, working closely with the contractors and the operational and maintenance staff, made the first decisions on the materials, structure, and planning of the new bus. These decisions were based on a critical analysis of earlier designs and were closely related to the requirements of the new manufacturing process.
2. Designing began on the typical cross-section, **9**, the key to the whole design.
3. The design was elaborated in terms of the front and rear bays and a sequence of similar middle bays, **5**.
4. Datum lines were fixed as a three-dimensional reference for the whole design, **6, 7**.
5. The detail design began. For this purpose the datum lines divided the bus into three main parts (front, rear, and middle sections), and each of these was further divided into components. At this stage subsidiary design sections were formed to deal with these components.
6. By the end of 1946, working drawings, specifications and drawings showing the sequence of assembly were complete. Certain drawings were given priority so that tooling up of the production plant could be begun before this date in order to save time.
7. The bus went into production. Although lack of time made it impossible to build a prototype during the design process, the first bus came off the line in running order in May 1947 and was immediately put into service—a convincing demonstration of the accuracy and foresight of the Design Group's work.
8. Once the bus is in operation the regular Design Group meetings discuss modifications which become necessary in the light of operational experience. At these meetings the improvements to be expected from a modification are weighed against the waste of material in parts already produced, the dislocation of the production sequence and the loss of interchangeability which it may cause. Once the modification is decided on, it is given a degree of priority according to whether it is to be introduced immediately or, say, in a year's time; and its introduction into the manufacturing process, which may occur at several stages, is planned so that the production flow is not interrupted.
9. The process of change according to the basic idea of flexibility continues.

STRUCTURE

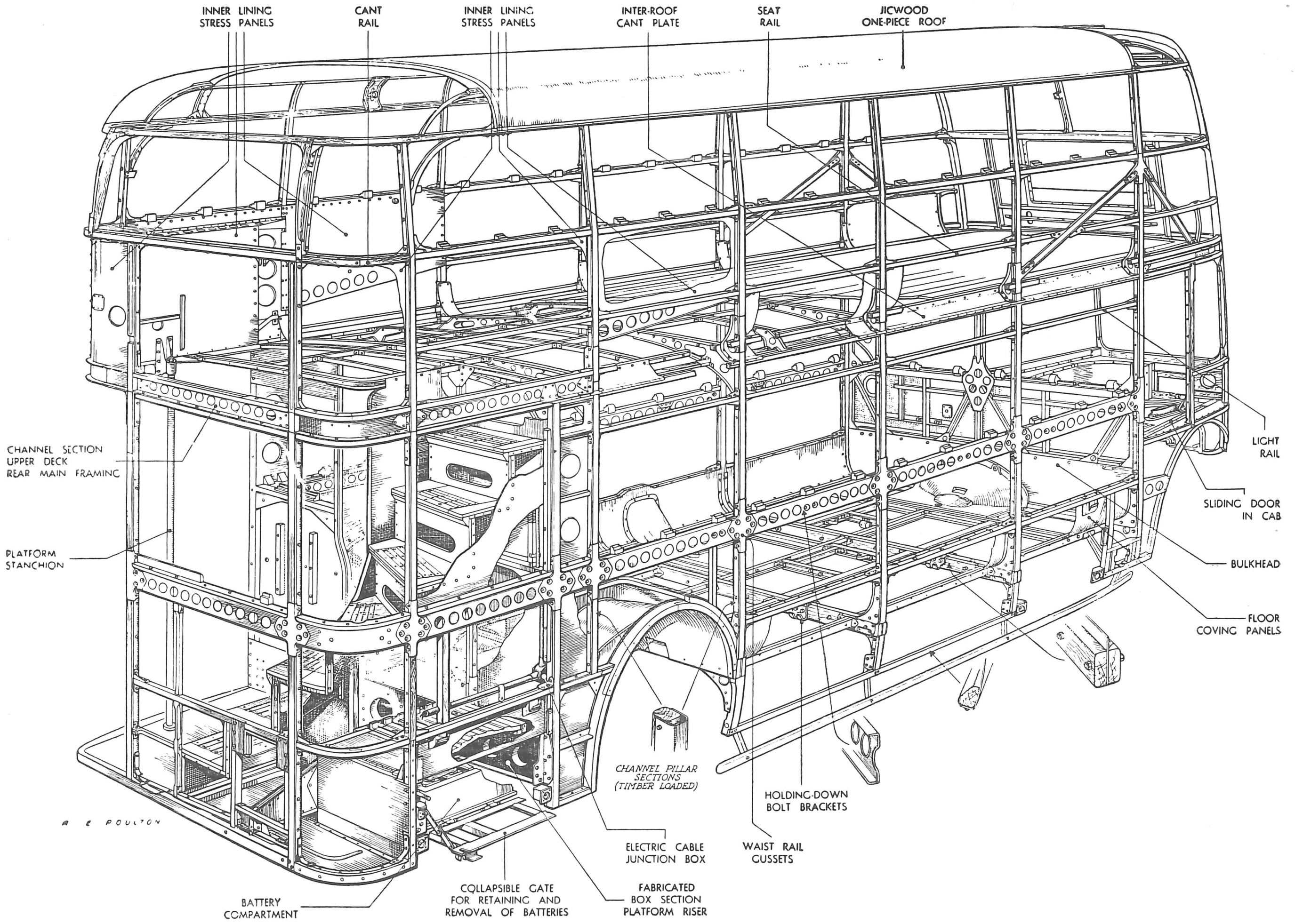
The structure, **16, 17a, b,** is essentially an assembly of small components with no long continuous members. This makes for easier replacement and is cheaper for mass production than the manufacture of large members. The body is structurally independent of the chassis and is itself a completely rigid self-supporting structure. This means that, although the strength of certain members could be calculated, the body as a whole had to be designed by means of deflection tests on full-scale cross-sections.
Material: Mainly steel for the precision demanded by mass production and interchangeability. The steel sections are loaded with timber for fixing and extra strength where required. The weight of panels and steel sections is reduced wherever possible by pressing large diameter holes out of the material. Steel structural members are fully finished and drilled on jigs before being bonderised, stove enamelled and coated with protective paint. This prevents corrosion either by oxidation or by contact with other metals, e.g., aluminium.
Bottom deck frame: A rigid platform: crossbars of timber with 1/8 in. nickel-steel flitch plate: longitudinal members of steel Y or ribbed U sections, timber loaded.
Lower side frames: Uprights of mild steel U sections, timber loaded, and rigidly connected to bottom deck crossbars with flanged steel gussets: the horizontal waist rail between the uprights is a 4 in. channel section with holes pressed out which add stiffness: the rigid connection, **14,** between the waist rail and the upright is formed by cruciform steel gussets bolted directly to the upright but connected to the waist rail by bolting through recessed dimples, which distribute the shear force at this joint over a wide area of metal and so reduce the stresses, on much the same principle as timber ring connectors.
Front bulkhead: Specially rigid: built up from L, Z, and top hat section steel members with diagonal bracing: welded gusset plates at all connections: front of bulkhead covered with a steel plate welded to the frame and perforated with 5/32 in. holes at 5/16 in. centres to prevent drumming and insulate the interior from engine vibration.
Rear platform support: The bottom deck frame terminates in a deep built-up box section beam which forms the step from the loading platform into the lower saloon, and from which the loading platform support brackets are cantilevered.
Positioning on chassis: The bottom deck frame is positioned through four body location brackets, one on each side of the chassis beneath the front bulkhead and beneath the transverse rear and support beam. The brackets are accurately positioned on the chassis—accuracy being checked on each chassis as it is delivered by means of a gauge—and are drilled to receive dowels similarly placed on the underside of the bottom deck frame. The hole in the front offside bracket closely fits its dowel, the other dowel holes are drilled to accommodate the lateral and longitudinal dimensional tolerances of the whole body assembly (see **Tolerances,** page 171). Once the body is in position the dowels are bolted to the brackets, and the body is further secured with T-headed bolts, **15,** connecting the side frames of the chassis to the intermediate members of the bottom deck frame. Wiring and pipelines between the body and the chassis are connected at junction boxes and one coupling point respectively, so that the removal of the complete body, involving the slackening of the T-headed bolts and the removal of the four body locating bolts can be done in fifteen to twenty minutes.
Upper deck frame: Longitudinal members of timber: cross-bars of mild steel U sections, timber loaded, (hoop sticks), connected to the uprights of the lower side frame by pairs of flanged steel brackets: these brackets are also connected to a steel cant plate, (inter-roof crib rail), which runs the whole length of the body frame to provide lateral rigidity, **16, 17a.**
Upper side frames: Uprights and waist rails of mild steel U sections, timber loaded.



14 The lower side-frame assembly—an exploded view of the rigid connection between waist rails and upright, and a horizontal section showing the shear dimples.



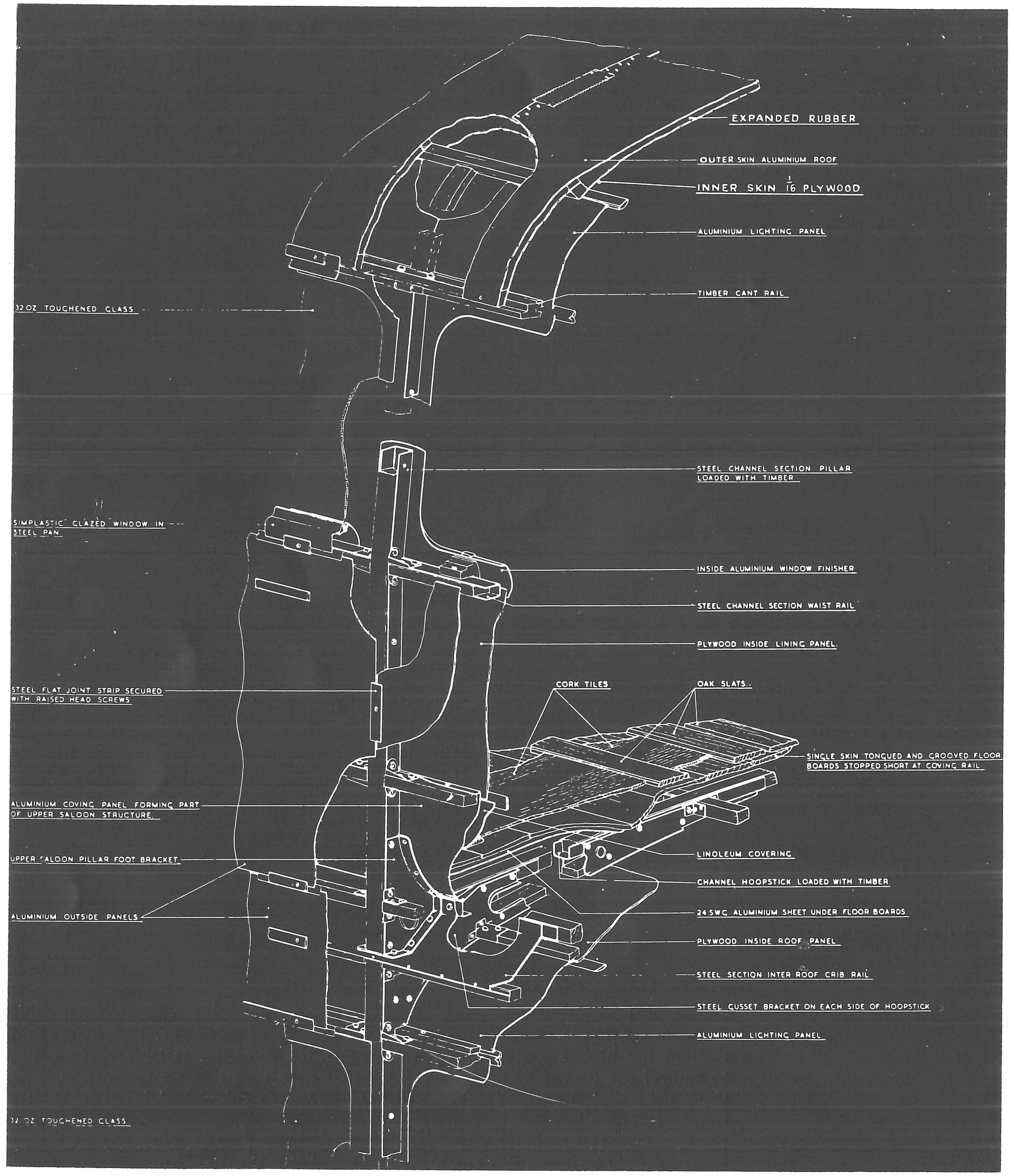
15 One of the quickly removable T-headed bolts securing the body to the chassis.



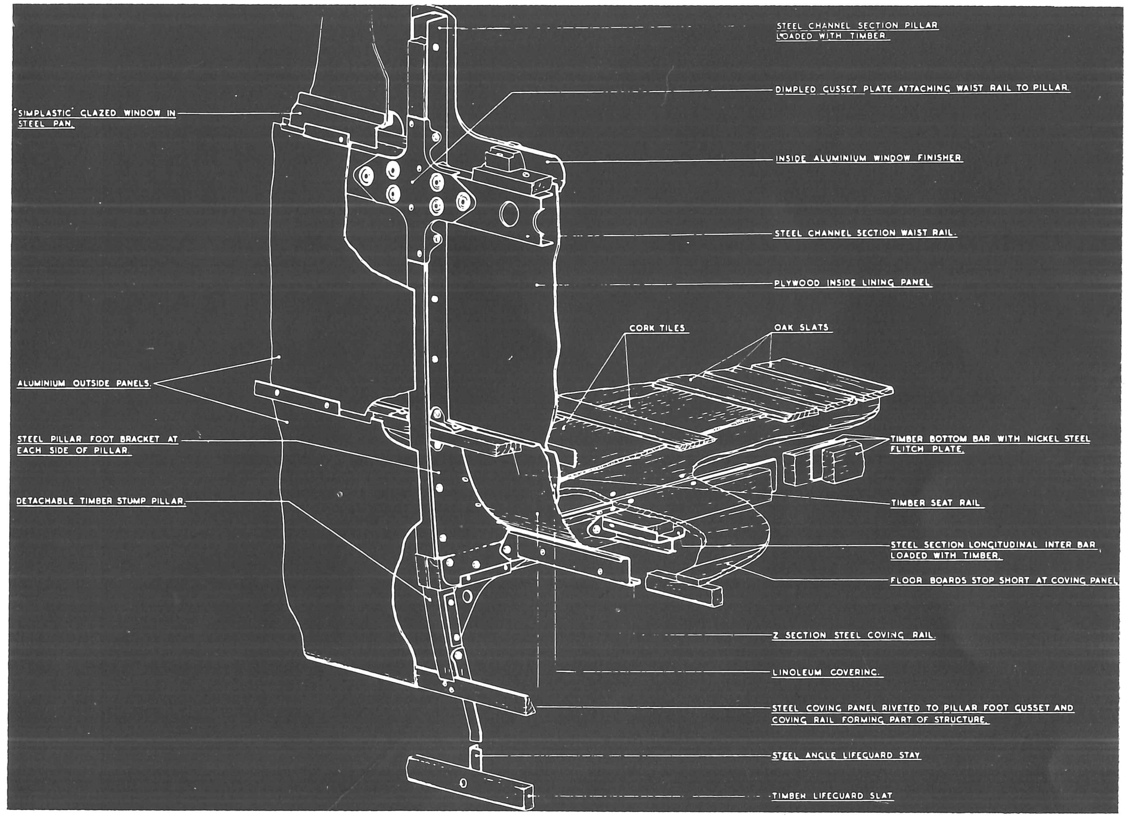
16 The structural frame of the RT3 body without its cladding and fittings—Bus and Coach copyright.

Control of accuracy in production and assembly

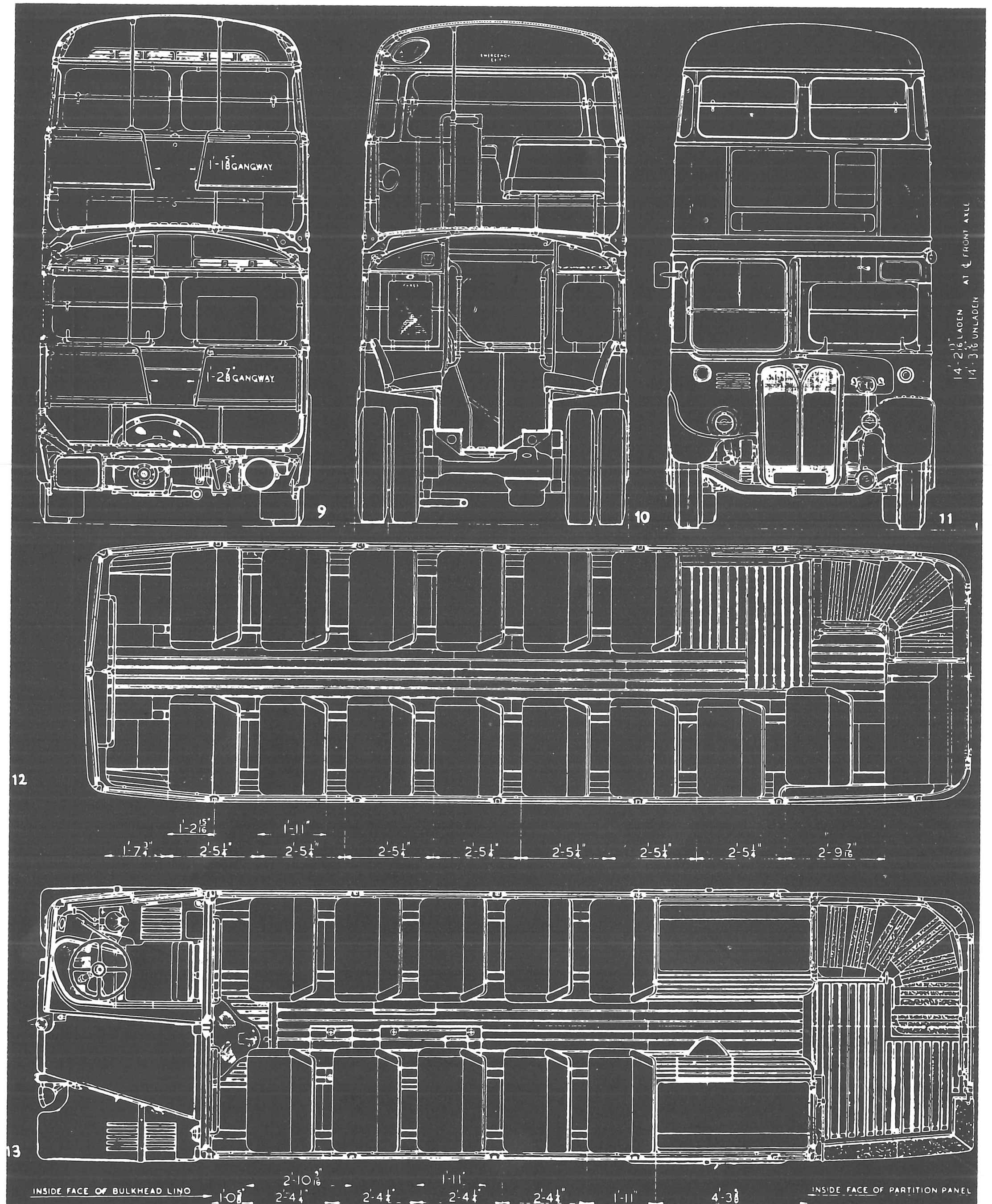
Tolerances: The basic ideas of interchangeability and standardisation which run through the whole design demand a high degree of accuracy. But in machine production the higher the accuracy the greater the expense. It is, therefore, necessary to control the degree of accuracy of each part, so that it is no more than it need be. During the design specific degrees of accuracy were calculated for every part according to its function and assembly, from ± 0.002 in. to ± 0.001 in. for machined parts, and $\pm 1/32$ in. for sheet metal parts, to $\pm 1/16$ in. laterally and $\pm 5/16$ in. longitudinally between the complete body and the chassis.


EXPANDED RUBBER
OUTER SKIN ALUMINIUM ROOF
INNER SKIN 1/16 PLYWOOD
ALUMINIUM LIGHTING PANEL
TIMBER CANT RAIL
32 OZ TOUGHENED GLASS
STEEL CHANNEL SECTION PILLAR LOADED WITH TIMBER
'SIMPLASTIC' GLAZED WINDOW IN STEEL PAN
INSIDE ALUMINIUM WINDOW FINISHER
STEEL CHANNEL SECTION WAIST RAIL
PLYWOOD INSIDE LINING PANEL
STEEL FLAT JOINT STRIP SECURED WITH RAISED HEAD SCREWS
CORK TILES
OAK SLATS
SINGLE SKIN TONGUED AND GROOVED FLOOR BOARDS STOPPED SHORT AT COVING RAIL
ALUMINIUM COVING PANEL FORMING PART OF UPPER SALOON STRUCTURE
LINOLEUM COVERING
UPPER SALOON PILLAR FOOT BRACKET
CHANNEL HOOPSTICK LOADED WITH TIMBER
ALUMINIUM OUTSIDE PANELS
24 SWG ALUMINIUM SHEET UNDER FLOOR BOARDS
PLYWOOD INSIDE ROOF PANEL
STEEL SECTION INTER ROOF CRIB RAIL
STEEL GUSSET BRACKET ON EACH SIDE OF HOOPSTICK
ALUMINIUM LIGHTING PANEL
32 OZ TOUGHENED GLASS

17a


STEEL CHANNEL SECTION PILLAR LOADED WITH TIMBER
DIMPLED GUSSET PLATE ATTACHING WAIST RAIL TO PILLAR
'SIMPLASTIC' GLAZED WINDOW IN STEEL PAN
INSIDE ALUMINIUM WINDOW FINISHER
STEEL CHANNEL SECTION WAIST RAIL
PLYWOOD INSIDE LINING PANEL
CORK TILES
OAK SLATS
ALUMINIUM OUTSIDE PANELS
STEEL PILLAR FOOT BRACKET AT EACH SIDE OF PILLAR
TIMBER BOTTOM BAR WITH NICKEL STEEL FLITCH PLATE
DETACHABLE TIMBER STUMP PILLAR
TIMBER SEAT RAIL
STEEL SECTION LONGITUDINAL INTER BAR LOADED WITH TIMBER
FLOOR BOARDS STOP SHORT AT COVING PANEL
Z SECTION STEEL COVING RAIL
LINOLEUM COVERING
STEEL COVING PANEL RIVETED TO PILLAR FOOT GUSSET AND COVING RAIL FORMING PART OF STRUCTURE
STEEL ANGLE LIFEGUARD STAY
TIMBER LIFEGUARD SLAT

17b



General arrangement drawings of the complete bus

9 Mid-section looking forward—*the typical cross-section.* Internal headroom—lower saloon, 5 ft. 11 1/16 in., upper saloon, 5 ft. 8 3/8 in.

10 Section at rear axle looking aft.

11 Front elevation.

12 Upper saloon plan.

13 Lower saloon plan.

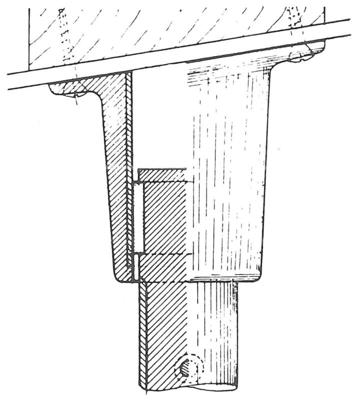
Roof: The long middle section is a prefabricated sandwich structure, built up of an inner skin of 1/16 in. plywood and an outer skin of 22 gauge aluminium, resin-bonded to a core of expanded rubber: this provides thermal and acoustic insulation and imparts both longitudinal and lateral rigidity to the body structure, **17a:** the front and rear domes are of pressed aluminium.
Front end support: The front section of the upper saloon, the cab structure, the bonnet and wings are all cantilevered from the upper deck framework, which at the front has triangulated side frames for this purpose, **16.**
Rear end support: The rear section of the upper saloon, and that proportion of the rear platform load which is not taken by the bottom deck frame, is cantilevered through the loading platform handrail stanchion, from the upper deck side frames, which are provided at the rear with stressed panels to take the bending moments of this cantilever, **16.**

PANELLING, FLOOR COVERING, AND FINISHES

Body panelling: 19a, b, 21, 22. Double skin for insulation: external panels aluminium: internal panels aluminium or plywood covered with leather cloth: pressed aluminium shrouds and finishers used to smooth over joints and window reveals for easy cleaning: these are covered with leather cloth so as to be warm to the touch: windows are made of 32 oz. toughened glass with continuous strip glazing: the windows have round corners so that the glass can be inserted from outside in one operation using a single length of rubber strip, **18a, b, c.**
Floors: Upper deck: Tongued and grooved boarding on aluminium sheets to prevent the penetration of water to the lower saloon. Lower deck: **23.** Half lap boarding for easy removal, since this floor is particularly exposed to mud and water brought in from the street and is thus liable to rot.
Circulation space: Oak slats to keep dirt from under foot and to give a safe and pleasant walking surface.
Sitting Space: Cork tiles to save weight, provide easy cleaning and keep the feet warm. At the junction of the floor and the sides, a steel curb is formed to cover the supporting brackets for the side frames and to provide a gutter for washing out the interior.
Loading platform: The surface at the edge has a special frictional finish for safety: research is continually being made into new materials for this purpose.
Paintwork: There are twenty-eight different paint finishes used in the design. Typical examples of these are the external red which consists of one coat of air drying primer, one undercoat of flesh colour, two coats of mail red, and two coats of synthetic varnish; and the internal ceiling of one undercoat of white primer, one undercoat and enamel mixture, and one coat of broken white enamel. The designers specify brush application but allow concessions where the contractor prefers to use a spray.

EQUIPMENT, FITTINGS AND SERVICES

Seats: Simple tubular steel and aluminium alloy structure fixed to the body at three points: the latex rubber seat squabs are immediately removable: the colour and pattern of the upholstery have been designed to be bright without showing grease and dirt too quickly: the shape of the seats was determined by testing mock-ups on batches of people: these mock-ups were adjusted within the available space limits, until dimensions were arrived at which gave the greatest comfort to the greatest number of people.
Handrails: The material mainly used is magnesium aluminum alloy which resists corrosion by sweat, but steel is used in highly stressed positions: the vertical grab rails inside both the saloons are provided with a sliding joint at the top, **22:** where safety is particularly important the handrails are covered with a white wound-on plastic strip which provides a good grip, shows up at night and is quickly replaceable, **21:** the position and contour of the handrails were determined by means of motion studies.
Stairs: Prefabricated in plywood and independent of the structural frame: this makes for easy repair.
Ventilation: Fresh air inlets above the bottom and top front windows.
Lighting: Natural and artificial daylight factors were checked experimentally and found adequate: for wiring see **Positioning on chassis,** page **16.**



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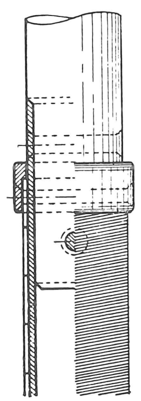

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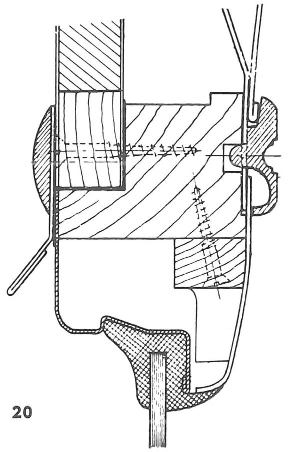
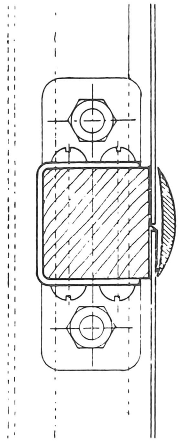


20

Typical details, half full-size



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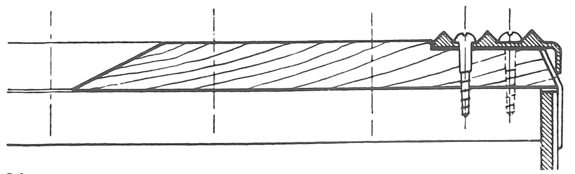

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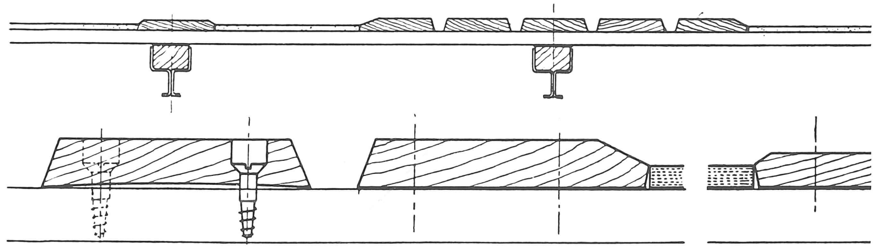


23

18 Half full-size details of an opening window; a, head; b, transom with opening gear; c, sill. Rubber strip glazing and draught excluders; opening window frame of aluminium; fixed window frame of pressed steel fixed to the wooden fixing rails; junction between window frames and external panels waterproofed with 24 gauge copper flashing and covered with strips of steel at the head and aluminium at the sill; junction between window frame and internal panels made with pressed aluminium finishers. The opening gear works a rack and pinion at each side of the window, the opening section of which closes against a grooved rubber strip screwed to a fibre block in the window head.

19 Vertical section through a horizontal structural rail of U section steel loaded with timber. The external aluminium panels are joined on the rail and the joint is weathered with a 24 gauge copper flashing with an extruded aluminium cover strip screwed on.

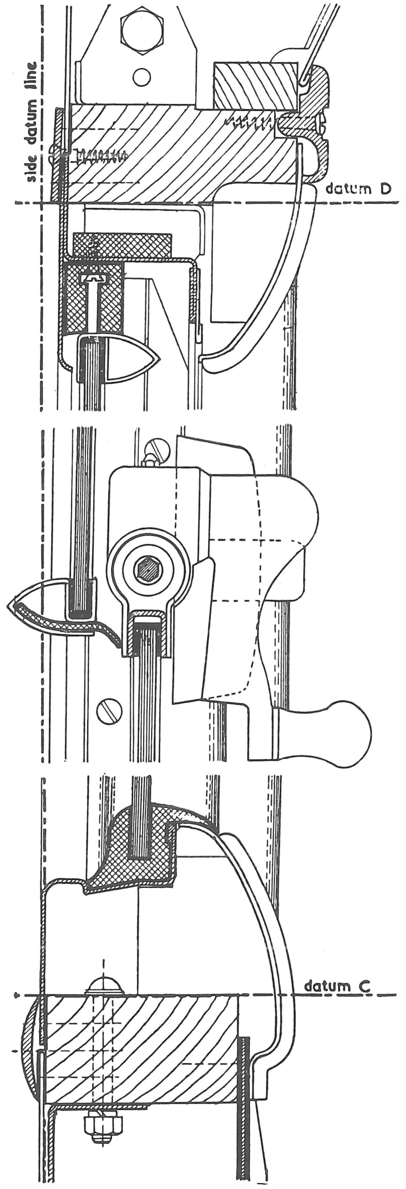
20 Eaves detail at a window head. The prefabricated sandwich roof is screwed to the top wooden structural rail, with copper flashing and an aluminium cover strip and drip at the joint. Internally the joint between the aluminium lighting panel and the pressed aluminium finishers round the window is made with an extruded aluminium section.

21 Fixing detail of the plastic handrail grip. A sliding sleeve fits over the end of the plastic strip and is held by a through-rivet.

22 Detail of the sliding joint at the top of the upper and lower deck vertical grab-rails. These grab-rails are fixed to the top of the seat frames rather than to the floor so as to avoid restricting foot-space in the gangways. The sliding joints are therefore necessary to prevent the inter-roof and roof deflections (which may amount to 1/2 in.) from being transmitted through the grab rails to the seat structure which would thus be over-stressed. In order to make this joint the tubular grab rail is finished with a solid spigot which holds a friction strip of brake-lining fabric. This strip slides on a steel liner which is let into a cast aluminium alloy socket screwed to the roof or inter-roof.

23 Lower deck floor construction. The upper drawing shows a vertical section through the floor with the half-lap boarding supported on the main longitudinal frame members. The lower drawing shows the oak slats and battens in the gangway joining on to the cork tiles under the seating space. The heads of the fixing screws for the slats are recessed to allow for wear.

24 Detail of the iron tread-plate on the nosing of the riser between the loading platform and the lower saloon. The face of the riser is of aluminium sheet on a steel backing plate.



18.

The Routemaster

The latest design, "The Routemaster" is a result of the continuation of the same work carried on by the "Design Group", of the London Transport office with the combined help of A.E.C. LTD. and Park Royal Vehicles. It is a double decker design based on an integral structure so much lighter than the current 56 seater (RT3) that, when carrying its greater compliment of 64 passengers, the new bus weighs no more than the other fully laden. Put another way, earning capacity has been greatly enlarged without increase in running cost.

Within the dimensional limits imposed by regulations and because of the need to increase rather than reduce seating capacity, there was no opportunity to alter the general overall form of the double-decker, and the rear loading platform and the half cab are retained. Neither was a change in the forward location of the engine considered to offer any advantage. What has been done, however, in order to economize in the space available was to remove the radiator and the fan from in front to a position behind the engine and beneath the floor, and to move the power unit forward in their place. The inches so gained, plus an increase in overall length from 26 ft. to 27 ft. without any reduction in the length of the loading platform, has made it possible to increase the lower saloon seating from 26 to 28 and the upper from 30 to 36 without departing from the current seating plan.

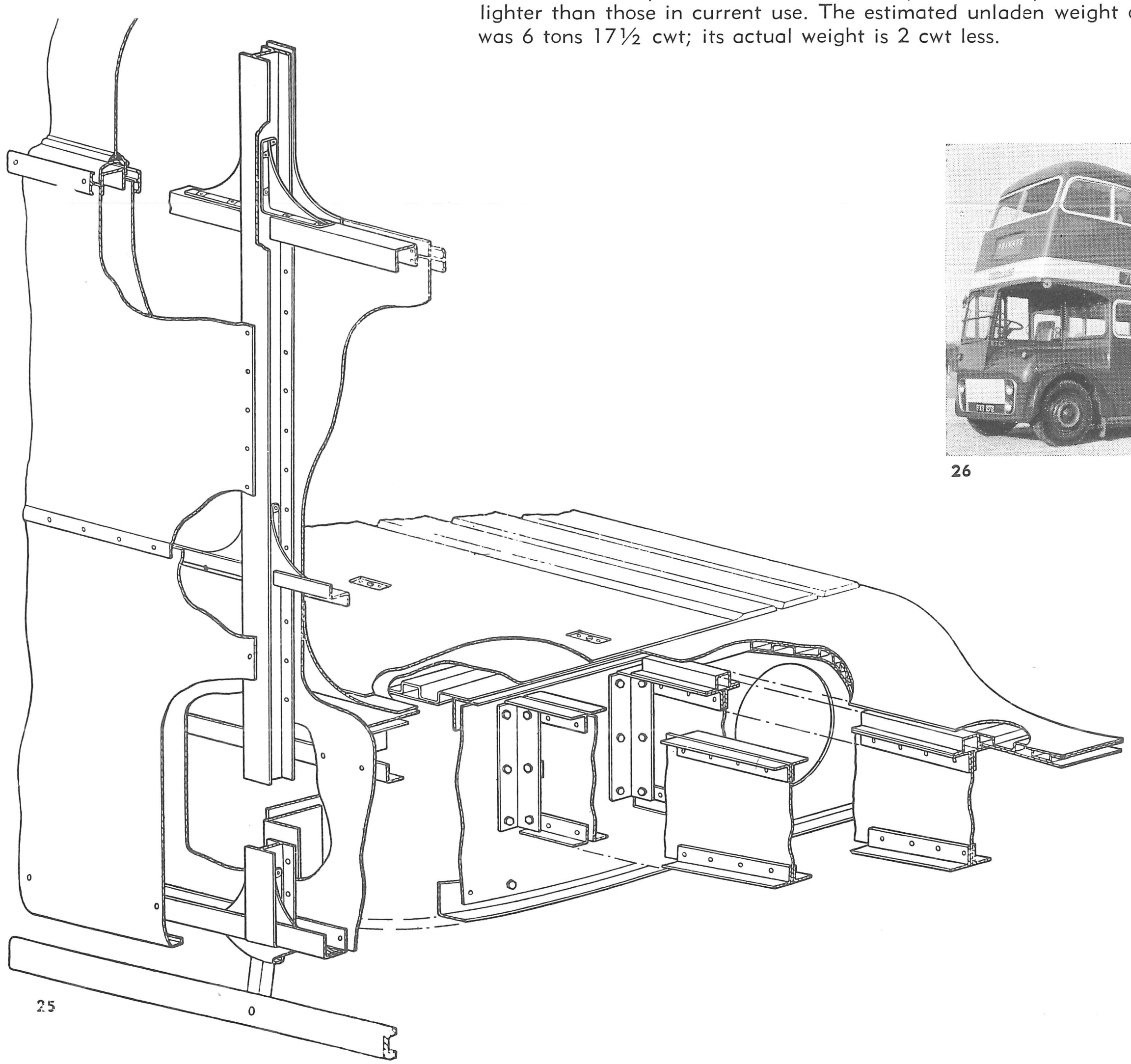
From the outset, weightsaving was regarded as of paramount importance and this led inevitably to the adoption of an integral or chassisless construction of high duty aluminum alloys to serve as the main load carrying unit. In this way, the heavy conventional chassis has been eliminated and is replaced by much lighter subframes in which to mount the mechanical units front and rear and which are readily removable for overhaul. The main structure consists of an extremely rigid four bay box formed by the floor, the sides, the roof, and the front and rear bulkheads. Some measure of additional stiffness is imparted to the box by the intermediate floor and its supports. On the front bulkhead is carried the driver's cab and an assembly of the nearside front wing, the bonnet and front cowling. The rear platform structure and the staircase are suspended from the upper deck.

A number of deep cross-bearers **25**, positioned to correspond with the pillar stations, form the main members of the underframe and serve to transfer the load to the body sides, thus dispensing with the need for the traditional type of frame longitudinals These cross-bearers are fabricated from high-duty alloy in the form of an I-beam of great strength and extruded H-section pillars are bolted to their extremities, the junctions being made with angle brackets. The lower saloon body side is completed by interior stress panels extending from the skirt to the waist, solid riveted to the pillar flanges and sandwiched between the cross-bearer and pillar joints. Waist-rails and cant-rails are simple channels riveted to the pillars in bay lengths to provide anchorages for the panelling and window pans, the exterior panels being butt-jointed and blind-riveted to the framing without the addition of vertical cover strips.

Bearers for the intermediate floor are also fabricated I-beams. They taper towards the centre, bridging the body sides and forming supports for the upper saloon pillars which are again of extruded H-section, but of lighter material. Not being so exposed to accidental damage, the upper saloon stress panels are riveted externally and are also butt-jointed without cover strips; interior panels are secured by solid rivets. Square section alloy tube is employed for the roof framing, to which overlapping external panels in bay lengths are riveted.

Both saloon floors are unusual in being made of corrugated alloy material covered above and below with flat sheet and overlaid with a hard-wearing rubber-cork composition matting which is slatted along the gangway. This type of floor is immensely strong yet at the same time light in weight. Floor cove panels of chequered aluminum plate are fitted on both decks and the ceiling panels of sheet aluminum extend from cant-rail in bay lengths. Adjacent to both bulkheads are jacking points for the lifting of the main structure during the removal of running units. At the front these lifting points are incorporated in a recessed step to the cab and a similar step on the body skirt to support the structure on jacks. Similar pegs and recesses are provided at the rear.

In the interest of weight saving some use is made of resin-bonded fiberglass. It is employed for the bonnet top and for the wing valances and, more unusually, for the squab backs of the seat frames. Seat cushion and squab fillings, moreover, are of a resilient foamed plastic material. In consequence each pair of seats is some 7½ lb. lighter than those in current use. The estimated unladen weight of the complete bus was 6 tons 17½ cwt; its actual weight is 2 cwt less.



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RT3

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EPILOGUE

Research is conducted both on long term problems where speed is not a governing factor, as well as on more immediate problems concerned with the development of prototypes.

The buses we have described are for many of us an intimate part of our daily lives. In the morning we enjoy its bright colour, gay posters, and elegant form. In the evening we are refreshed by its quiet efficiency and unassuming comfort. It has a greater impact on our lives than many, more pretentious, buildings. Public criticism is therefore of first importance. The design is largely determined by the conditions of London's roads—within these limits the solution seems to be as good as technique and economy permit. It is an interesting argument whether the concealment of the frame internally and externally by means of rather coarsely shaped shrouds around the windows is not a loss compared with the structural clarity of earlier designs, **1, 2, 3.** This is not an argument for structural honesty—there is no need to take a moral view—but there is room in this design for the development of a greater unity between structure and cladding without sacrificing ease of cleaning. Internally the use of colour is uninteresting, but the external red is the happiest possible choice, particularly with the white strip at inter-roof level, although the increasing use of cream for this purpose is to be regretted. Structurally the design is magnificient—a tour de force in the solution of the problems of designing for machine production. The whole bus has that quality of datelessness which has become the design tradition of London Transport. There are signs—in poster design for instance—that this tradition is now failing, and the prototype for the new long-distance bus, **26,** reveals a tendency, particularly at the front end, to yield to the fashion of arbitrary 'styling' which is ruining present-day car design. We understand that an industrial design consultant was called in to advise in this case, and without drawing any unwarrantable conclusions, we would like to make the plea that the LTE should not be too ready to inflict on their capable design team cliches current in the fashion market. When we consider the architectural lessons of RT3 certain main points emerge. Firstly, the development of a group of designers, working closely together, as the best solution to the problem of designing a product of complex requirements for machine production. Secondly, the conception of the design task as the consideration, not of the product alone, but equally of the process by which it is made. This means that the design group is only complete when it includes the production team, and that dimensional tolerances must be accurately calculated for each component from the beginning. Thirdly, we can learn much from the technical confidence of the engineer who is undiverted from his task as a constructor by the myth of taste. The experimental approach to the design of structure, detail, and equipment has produced in this case a highly-stressed construction of astonishing lightness, and has led to the courageous use of new forms and materials uninhibited by an academic sense of tradition. But perhaps the most important lesson is to be found in the way the LTE have tackled the whole problem of increasing bus production under difficult economic conditions. They have had the vision to find the solution in the problem itself—to see in machine production the means, not only of satisfying an urgent human need, but also of greatly improving the product.

EXCERPT FROM A LETTER WRITTEN BY CHARLES EAMES TO IAN MCCALLUM, EDITOR OF **ARCHITECTURAL REVIEW,** GIVING BACKGROUND FOR OUR FILM, "A COMMUNICATIONS PRIMER", WHICH HAS JUST RECENTLY BEEN RELEASED.

One of the reasons for our interest in the subject is our strong suspicion that the development and application of these related theories* will be the greatest tool ever to have fallen into the hands of the architects or planners. One of the reasons for writing this to you is that I also suspect that the use of such a tool will reinforce those qualities which you have so richly presented in "Townscapes."

If ever an art was based on the handling and relating of an impossible number of factors, this art is architecture. One of the things that makes an architect is the ability to include in a concept the effect of an affect on many simultaneous factors—and a precious tool has been his ability to fall back on his own experiences which have somehow turned into intuitive associations. It is one reason why an architect seldom is, nor can afford to be, bored with anything.

The ability to make keen intuitive associations does not, of course, relieve the architect of the responsibility of calculating and predicting all factors of a problem that can be calculated and predicted. It is perhaps safe to say that in any architectural problem very few of the factors involved have been calculable—the relationships of factors are almost impossible to calculate—and most of the factors remain unknown.

If, however, a tool should be developed which could make possible the inclusion of **more** factors—and could make calculable the possible results of relationships between combinations of factors—then it would become the **responsibility** of the architect and planner to use such a tool. The talent for associations would be far from negated—it would be put to a much keener use. The level of creativity would be immediately raised and so would the responsibility. We may have the possibility of such a tool in the "Theory of Games."

You are no doubt familiar with the main aspects of the "Theory of Games or Strategy" (Now some 35 years old, it was of great importance during the war, and in complex organizational and industrial problems today, linear programming is a development of games theory). While the big concept is great and simple, the working vocabulary gets so super-mathematical as to be unintelligible and the working mechanics would have been impossible had it not been for the simultaneous development of the present day electronic calculator.

Like **linear programming,** game theory is a pure mathematical system that can be used in relation to very human problems. By it a number of variables can be considered simultaneously and a solution calculated that has the highest probability of filling the desired requirements under the given circumstances.

How human and confidence giving it is to learn that such answers are **not** given in terms of "a sure thing" but in terms of "high probability."

About 10 years ago John von Neuman, mathematician (and author of the theory of games) and Oskar Morganstern, economist, co-authored a book "Theory of Games and Economic Behavior." Many of its pages are so filled with mathematical symbolism that they look like (and are for many of us) pages of a foreign language. But very real was the method and concept of treating human actions and needs in such a way that they can be discussed mathematically. In most any economic situation, some of these actions and needs are emotional or psychological. To discuss these aspects of a problem mathematically seems difficult but not unreasonable, when we hear that mathematics did not exist in physics before the 16th century or in chemistry and biology until the 18th century.

Here is a supersimple and interesting example of thinking taken from a footnote in the von Neumann-Morganstern book:

"Assume that an individual prefers the consumption of a glass of tea to that of a cup of coffee, and the cup of coffee to a glass of milk. If we now want to know whether the last preference—i.e., difference in utilities—exceeds the former, it suffices to place him in a situation where he must decide this: Does he prefer a cup of coffee to a glass the contents of which will be determined by a 50%-50% chance device as tea or milk."

As the authors go step by step through the process of evaluating economic situations in mathematical terms—the very nature of the situations make it apparent that one can substitute "planning" or "design" for "economics" and since the direction is toward high probabilities and not sure things, the factors are all open to re-evaluation on a highly creative or personal level—including nothing out.

It is unfortunate that in this time much of the really creative thinking in organizing and programming and evaluation should be so shrouded with the panic of secrecy. Here is a useful working tool that comes to us at a time when numbers and complications seem about to obliterate the human scale. What makes this tool so handy is that it would seem to actually use large numbers and unlimited relationships to help us return to the human scale and the richness of the Townscape in the terms of our time.

Of course, there will be the hidden fears of loss of individuality and creativity which tend to swamp any concept which gives greater responsibility to the individual and the creator—but of one thing we can be quite sure—the buildings and communities of the near future **will** be planned with the aid of some development of these theories. Whether or not they are planned by architects may pretty well depend on the way architects today prepare to use such tools.

GAMING AS A TECHNIQUE OF ANALYSIS

A. M. Mood and R. D. Specht

Rand Corp., Paper 579

This is the age of the high-speed computer or, more popularly, the giant brain. Whether or not we can really breed intelligence into our high-speed digital computers, however, is not a question that will concern us here. We are interested, in fact, not in the digital but rather in analog computers and, in fact, in one element of the many that go to make up an analog device. Our analog element is not a differentiator or intergrator or multiplying circuit, but a human, homo sapiens we hope. That is, our concern here is not with computing machines that think, but rather with the thinker as part of a computing machine.

Now there is nothing new in solving a problem by asking an expert in the subject—or even an operations researcher—to think about the problem. This process goes back at least to the first caveman who asked his neighbor's opinion concerning the optimum tactics for tracking tigers. What does have a certain air of novelty, however, is the growing practice of imbedding a sapient human in a machine and acquiring thereby a new and different sort of machine—one whose capabilities and limitations are today understood somewhat less than perfectly.

In speaking of a "machine" we may take the word literally and understand by it a device begotten of vacuum tubes, potentiometers, and associated hardware. On the other hand, our machine may be a logical structure represented only by symbols on a piece of paper. The machines in which we are interested, however protean in form, have all of them similar functions—each is used to help solve problems connected with some decision process.

To change the terminology, our machine is a model in the sense in which that word is used in scientific theory—a model of that part of the real world with which our decision problem must deal. It is a black box into which we crank inputs and out of which are ground outputs. From these outputs we seek guidance in our decision problem.

The traditional relation of man to model is threefold. In the first place man designs the machine. That is, he decides what factors are relevant to the problem and what the interactions between these factors are to be in the machine. In particular, he decides what variables are to be inputs, what are to be outputs of the black box. In the second place, the user of the model, who may not be identical with the onlie begetter of the black box, decides the numerical values of the input variables fed into the machine. And, finally, man inspects, analyzes, interprets the results, the outputs of the model.

The human qualities of judgment and intuition are essential to all three of the activities just mentioned: The design of the model, the choice of input values, the analysis of outputs. But within the black box no meditation goes on. The machine may contain random elements—dice cup and roulette wheel may be among its components—or, on the other hand, it may be completely deterministic. But in either case the operation of the model, the passage from inputs to outputs, does not involve the attributes of judgment and intuition that we found necessary for the invention of the model.

Now we change radically the nature of the machine by imbedding a man (or several men) within it. We can, for example, insert our man into the black box by giving him a potentiometer to twist and dials from which to read the values of variables in the machine, thus setting up a feedback loop.

In a symposium organized to discuss the use and value of war game methods, it is fitting that we take a war game as an example of a model. In order that our example set no foot on terrain labeled secure, we choose it from the military activities of an earlier century. Putting behind us the temptation to discuss the war games conducted by Uncle Toby and Corporal Trim, together with the reconnaissance campaign of the Widow Wadman, we consider instead the American Kriegsspiel as played by the Volunteer Militia of Rhode Island in the years following the Civil War.

In the conventional war game of that period, the Red and Blue teams play through a military campaign in detail over a map of the theater. One or both players may follow a scenario, or each may be free to plan his tactics and attempt to carry them out under the impact of his opponent's actions. The results of the players' moves are adjudicated (after a certain amount of debate) by the umpire. For example, the umpire decides whether Red succeeded or failed in establishing a bridgehead, whether Blue was able to hold his strongpoint or was forced to withdraw. So far we appear to have only thinkers, not a machine or quantitative model. But let us turn to the American Kriegsspiel and the Volunteer Militia.

The American Kriegsspiel was developed from its Prussian counterpart, the latter having been introduced into this country about 1865. The interactions of the elements, from the effect of musketry fire to the velocity effects of a cavalry charge, were spelled out quantitatively, the rules were formalized, and the umpire's functions could be limited to the determination of random numbers for those cases in which the rules prescribed probability distributions.

Major Livermore, author of "The American Kriegsspiel,"[1] described the game as follows. "The Kriegsspiel is played upon a topographical plan, with small blocks representing the troops, which are proportional to the scale of the map. . . . When the position of the blocks indicates that the hostile troops are within sight and range of each other, they may be supposed to open fire, if the players desire it, and in this case it becomes the umpire's duty to decide the result upon the basis of experience. The rules of the game explain to him how to estimate the loss from this fire; for example, it may have been found that in similar circumstances, the number of killed and wounded has varied from ten to twenty; by throwing a common die he decides whether to assign a greater or less result to the case in view."

From this quotation it is evident that the American Kriegsspiel came closer to resembling a parlor game than did those war games in which the experienced military judgment of the umpire provided the link between the tactics chosen by Red and Blue and the results of the engagement as measured by movement and attrition of forces. In the language we used earlier, the Kriegsspiel constitutes a model, a black box in which the Red and Blue players are integral parts together with the mechanical elements as constituted by the formal rules of the game and the random number generators. The judgment and intuition of the players are used at each stage of the game to make decisions as to allocation, deployment, and operation of forces. These decisions are made under the constraints imposed by the rules, and the interactions of the various elements of the game are determined by the rules together with the random numbers generated.

[1] W. R. Livermore, "The American Kriegsspiel. A Game for Practicing the Art of War Upon a Topographical Map," W. B. Clarke Co., Boston, rev. ed., 1898.

This resemblance to a parlor game is essential if gaming is to be used as a technique of analysis. The game representing the problem must be easily playable and must be played numerous times by the same players so that they can develop a knowledge of the structure of the game and a feel for good strategies. A game that is to be replayed many times needs a fixed set of rules so that experience gained in one play is valid in other plays.

Our example, the American Kriegsspiel, has illustrated the more or less traditional use of the human computer as employed in a war game. This use of gaming can be extended to those non-military situations that involve elements of conflict too important to be ignored. That is, gaming may be used to study situations in which there are elements having a significant effect but which are in the control of a competitor or opponent. Such elements can be neglected only when the opponent's strategy is clearly fixed and known—a condition which sometimes obtains in the case of those simple problems which can be factored out of their context and treated as component problems, but rarely in the case of the more complex systems problems with which we are here concerned.

Having thus dropped the word "war" from war gaming, we can continue and abandon the gaming as well. That is, our man-machine computer may very well find employment in the study of problems in which no element of conflict occurs. The computation of the transportation capacity of a complex rail network may be a case in point. Other examples of a different character arise in which the responses and interactions of the humans in our man-machine model are themselves the principal object of study. The Systems Research Laboratory[2] at RAND has studied man-machine problems involving "the interactions between a group of . . . people, associated machines and communications network working against a system criterion."

But if the characteristic of war gaming which is important for operations research has neither to do with war nor with gaming but rather with the man-machine computer, then the name "war gaming" may be something of a misnomer. Morse has used variously the labels "simplified gaming," "the gaming technique," and "simulated operational experiment" to refer to the use of the human as part of the model. As Morse says,[3] "Simplified gaming furnishes another means of operational experiment. Sometimes it is not sufficient to provide the random processes and then just compute the consequences; human judgment or human competition may also enter. In this case we may simplify the operation down

[2] J. L. Kennedy, "The Uses and Limitations of Mathematical Models, Game Theory and Systems Analysis in Planning and Problem Solution," RAND Corp. Paper P-266, 11 February 1952.

[3] P. M. Morse, "Trends in Operations Research," Journal of the Operations Research Society of America, Vol. 1, No. 4, August 1953, pp. 159-165.

to a specialized game (two-person or solitaire as the case may be) with the random events and other rules devised to provide a close analogue with the actual operation. By observing a reasonably intelligent person learn to play such a game we can often learn a great deal about an actual operation that is far too complicated to be analyzed by theoretical means." Morse goes on to describe the solution of antisubmarine air-search problem by this gaming technique and says, "Within these few weeks we learned more about the more complicated problems of submarine search than 6 months of analytic work had taught us. Search theory could work out the simple cases well enough; the complex cases, when there were not enough planes, or when delays occurred in starting the search, had to be worked out by gaming."

What about the difficulties that attend the use of gaming. There is no need to dwell here upon those stumbling blocks that are ever with us regardless of the technique of solution. The central problem—that of the wise selection of criterion or payoff—is just as important and no easier of solution, whether gaming is used or no. The related questions of adequate measures of cost and effectiveness, of loss and profit, are still essential, and these measures are not always easy to arrive at. As in any operations research project, we must decide how much context is to be provided as a necessary background for our problem, how extensive a slice of the real world is to be modeled. If the Volunteer Militia uses the American Kriegsspiel to study new tactics proposed for the horse artillery, then it may be that little additional context is needed. A game may be designed with few elements other than those directly and obviously concerned with the horse artillery. If, on the other hand, the game is called upon for assistance in deciding proper budget for the horse artillery, then far more context is required. This is a system problem rather than a component problem; it is a problem that can not be detached from its natural context, that can not be factored out and treated separately from all the other military and economic factors that are entangled with it.

Another vexing problem, but again one not unique to gaming, is that of the proper amount of fine structure to be included in the model. In our attempt to be realistic, how much detail must be preserved, how much can be sloughed off or aggregated. The player of American Kriegsspiel can even dispatch a cavalry charge and take into account the aversion of the horses to tread upon prone infantrymen.

These problems of suitable criterion, adequate measures of cost, proper amount of context, necessary level of detail are important problems; they deserve all the study and need all the help the Operations Research Society of America can give. But they are not unique to gaming; on the contrary, the analyst must contend with them however he may choose to make his analysis. On the other hand, gaming does aggravate some of these knotty points and may even introduce a few of its own. Consider the matter of evaluating the sensitivity of the results of an analysis to parameter values, to model structure, to payoff. In the simplest of models it may be possible to make sensitivity tests analytically. More complex models may demand extensive numerical computation, particularly if random elements are present. The sensitivity problem becomes even harder to handle if human decision links are used in the model, that is, if the analysis employs gaming. A partial solution lies in the direction of making the game easily playable and hence repeatable.

A second apparent drawback to gaming is that it discards the possibility of analytical optimization. The theory of games has developed a considerable body of clarifying ideas and a technique which can analyze simple economic and tactical questions. In particular, the theory of games may furnish solutions to some factorable component problems and these suboptimizations may be built into our machine. However, the theoretical techniques now available are not even remotely capable of dealing with complex systems problems.

The last difficulty attendant upon gaming to be mentioned here is that playing a game may be too easy and too attractive. That is, the temptation is great to devote too much effort to play, to little effort to good design of play and of the game itself to the end that desired results may be achieved. An allied point is that of achieving good play, or insuring, for example, that a player's decision is made in accordance with the specified criterion or payoff of the game and not dictated merely by the quirks and crotchets of the individual human player, bedeviled as he is by the accumulated prejudices of a life time. However, this is less of a stumbling block for gaming than might first be supposed. The human decision link in our machine is not free but is rather bound by all the constraints of the machine, constraints that express the structure of the model and that have been arrived at by combining the knowledge and experience of many experts. So, while irrational play may be present in either the gaming solution of a problem or in a solution arrived at by a round-table discussion among experts, the gaming technique does have some built-in safeguards.

We have characterized gaming as the use of a model containing a human decision link. Now this man inside the machine is not a hypothetical Maxwell's demon with that character's attribute or infallibility. On the contrary, we have a real and therefore fallible human. What can we possibly gain by adding to our machine an element whose unreliability and unpredictableness exceed that of our electronic gear. In orther words, why game?

The construction of a game involves judgment at every turn: in the scope of the game, the level of detail, the content of the rules, the adequacy of its representation of reality, the opinions of players as to what are good strategies. Why not just answer the questions the game is supposed to analyze by referring to an expert in the area of the given problem? What does the game do that an expert cannot do?

The expert, of course, is not the only alternative to the use of the man-machine computer in studying complex problems. Instead of dispensing with the machine we can dispense instead with the man. The former choice corresponds to the use of the expert—or a committee of experts. The latter course is the usual scientific model-building of the operations researcher. This modeling of the real world by a machine has been a potent tool in the study of component problems. For the more complex systems problems that cannot be factored out of their context, however, analysis by a model, by a pure machine, is usually feasible only if the real world is ruthlessly simplified with the accompanying sacrifice of elements that may be essential.

A game pools the knowledge of numerou expects. The more complex a problem is, the less the likelihood that a person can be found who is expert in all its facets. And even if such a person could be found, he would himself have to integrate in his mind all this special knowledge into one coherent structure and analyze that structure.

Having just disposed of the catholic expert, we must now admit that we have been too glib—that we can not really dispense with him completely, although we can make his job a finite and feasible one. For recall that the man within the machine is not the only human involved in the game. As we saw earlier in talking of scientific model building and using, man designs the model, chooses input values, and analyzes the results. The designing of a model, the writing of a set of rules for a game is a major project. Decisions must be made as to the amount of context to be included. Those aspects which are retained in the game must be simplified and combined into easily manipulable factors in the interest of having a playable and understandable game Planning factors must be compiled, the interactions of various factors spelled out, and side studies made to fill in areas where rules are necessary but knowledge lacking.

In the language of our computer analogy, the great advantage of the man operating within the machine is that he is not free. He is bound by the constraints of the model, constraints that have been built into the machine to represent the results of component studies on various pieces of the problem, and the pooling of experience and judgment concerning portions of the problem.

Gaming, like all model building, has another paramount advantage over unbuttoned judgment—it forces the explicit recognition and statement of assumptions. Intuition and instinct are indispensable to the operations researcher; abandon them and he abandons the power of creative thought. But however important are suggestion and supposition, speculation, and surmise, it is equally important that these things be clearly recognized and labeled.

A virtue of gaming that is sometimes overlooked by those seeking grander goals—the solution of allocation problems or the study of the military worth concept, for example—is its unparalleled advantages in training and educational programs. A game can easily be made fascinating enough to put over the dullest facts. To sit down and play through a game is to be convinced as by no argument, however persuasively presented.

But to return to our discussion of the use of man-machine as opposed to machine alone or man alone. For a very complex problem it certainly is necessary to combine the knowledge and experience of many experts. It is a plausible assumption that a carefully organized combination of their knowledge into a single self-consistent whole would provide a much firmer basis for decisions than, say, a round-table discussion among experts. Of course, it is a great deal more trouble too, but we face many problems that justify the effort.

A game is an endeavor to put down in writing a basic structure which must necessarily be a part of any intelligent consideration of any nonfactorable problem. People can then see it and study it and debate it, and over a period of time arrive at some sort of general agreement about it. Even when that has been accomplished, gaming is admittedly an inexact analytical tool beside the methods that chemists and physicists use, for example. But it is a wide step beyond armchair judgment in the sense that it provides an operational and roughly verifiable (repeatable by other persons) technique for dealing with problems not otherwise amenable to quantitative analysis.

WHAT ABSTRACT ART MEANS TO ME . . .

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Willem de Kooning

The first man who began to speak, whoever he was, must have intended it. For surely it is talking that has put "Art" into painting. Nothing is positive about art except that it is a word. Right from there to here all art became literary. We are not yet living in a world where everything is self-evident. It is very interesting to notice that a lot of people who want to take the talking out of painting, for instance, do nothing else but talk about it. That is no contradiction, however. The art in it is the forever mute part you can talk about forever.

For me, only one point comes into my field of vision. This narrow, biased point gets very clear sometimes. I didn't invent it. It was already here. Everything that passes me I can see only a little of, but I am always looking. And I see an awful lot sometimes.

The word "abstract" comes from the light-tower of the philosophers, and it seems to be one of their spotlights that they have particularly focussed on "Arts." So the artist is always lighted up by it. As soon as it—I mean the "abstract"—comes into painting, it ceases to be what it is as it is written. It changes into a feeling which could be explained by some other words, probably. But one day, some painter used "Abstraction" as a title for one of his paintings. It was a still life. And it was a very tricky title. And it wasn't really a very good one. From then on the idea of abstraction became something extra. Immediately it gave some people the idea that they could free art from itself. Until then, Art meant everything that was in it—not what you could take out of it. There was only one thing you could take out of it sometime when you were in the right mood—that abstract and indefinable sensation, the esthetic part—and still leave it where it was. For the painter to come to the "abstract" or the "nothing," he needed many things. Those things were always things in life—a horse, a flower, a milkmaid, the light in a room through a window made of diamond shapes maybe, tables, chairs, and so forth. The painter, it is true, was not always completely free. The things were not always of his own choice, but because of that he often got some new ideas. Some painters liked to paint things already chosen by others, and after being abstract about them, were called Classicists. Others wanted to select the things themselves and, after being abstract about them, were called Romanticists. Of course, they got mixed up with one another a lot too. Anyhow, at that time, they were not abstract about something which was already abstract. They freed the shapes, the light, the color, the space, by putting them into concrete things in a given situation. They did think about the possibility that the things—the horse, the chair, the man—were abstractions, but they let that go, because if they kept thinking about it, they would have been led to give up painting altogether, and would probably have ended up in the philosopher's tower. When they got those strange, deep ideas, they got rid of them by painting a particular smile on one of the faces in the picture they were working on.

The esthetics of painting were always in a state of development parallel to the development of painting itself. They influenced each other and vice versa. But all of a sudden, in that famous turn of the century, a few people thought they could take the bull by the horns and invent an esthetic beforehand. After immediately disagreeing with each other, they began to form all kinds of groups, each with the idea of freeing art, and each demanding that you should obey them. Most of these theories have finally dwindled away into politics or strange forms of spiritualism. The question, as they saw it, was not so much what you could paint but rather what you could not paint. You could not paint a horse or a tree or a mountain. It was then that subject matter came into existence as something you ought not to have.

In the old days, when artists were very much wanted, if they got to thinking about their usefulness in the world, it could only lead them to believe that painting was too worldly an occupation and some of them went to church instead or stood in front of it and begged. So what was considered too worldly from a spiritual point of view then, became later—for those who were inventing the new esthetics—a spiritual smoke-screen and not worldly enough. These latter-day artists were bothered by their apparent uselessness. Nobody really seemed to pay any attention to them. And they did not trust that freedom of indifference. They knew that they were relatively freer than ever before because of that indifference, but in spite of all their talking about freeing art, they really didn't mean it that way. Freedom to them meant to be useful in society. And that is really a wonderful idea. To achieve that, they didn't need things like tables and chairs or a horse. They needed ideas instead, social ideas, to make their objects with, their constructions—the "pure plastic phenomena"—which were used to illustrate their convictions. Their point was that until they came along with their theories. Man's own form in space—his body—was a private prison; and that it was because of this imprisoning misery—because he was hungry and overworked and went to a horrid place called home late at night in the rain, and his bones ached and his head was heavy—because of this very consciousness of his own body, this sense of pathos, they suggest, he was overcome by the drama of a crucifixion in a painting or the lyricism of a group of people sitting quietly around a table drinking wine. In other words, these estheticians proposed that people had up to now understood painting in terms of their own private misery. Their own sentiment of form instead was one of comfort. The beauty of comfort. The great curve of a bridge was beautiful because people could go across the river in comfort. To compose with curves like that, and angles, and make works of art with them could only make people happy, they maintained, for the only association was one of comfort. That millions of people have died in war since then, because of that idea of comfort, is something else.

This pure form of comfort became the comfort of "pure form." The "nothing" part in a painting until then—the part that was not painted but that was there because of the things in the picture which were painted—had a lot of descriptive labels attached to it like

"beauty," "lyric," "form," "profound," "space," "expression," "classic," "feeling," "epic," "romantic," "pure," "balance," etc. Anyhow that "nothing" which was always recognized as a particular something—and as something particular—they generalized, with their bookkeeping minds, into circles and squares. They had the innocent idea that the "something" existed "in spite of" and not "because of" and that this something was the only thing that truly mattered. They had hold of it, they thought, once and for all. But this idea made them so backward in spite of the fact that they wanted to go forward. That "something" which was not measurable, they lost by trying to make it measurable; and thus all the old words which, according to their ideas, ought to be done away with got into art again: pure, supreme, balance, sensitivity, etc.

Kandinsky understood "Form" as a form, like an object in the real world; and an object, he said, was a narrative—and so, of course, he disapproved of it. He wanted his "music without words." He wanted to be "simple as a child." He intended, with his "inner-self," to rid himself of "philosophical barricades" (he sat down and wrote something about all this). But in turn his own writing has become a philosophical barricade, even if it is a barricade full of holes. It offers a kind of Middle-European idea of Buddhism or, anyhow, something too theosophic for me.

The sentiment of the Futurists was simpler. No space. Everything ought to keep on going! That's probably the reason they went themselves. Either a man was a machine or else a sacrifice to make machines with.

The moral attitude of Neo-Plasticism is very much like that of Constructivism, except that the Constructivists wanted to bring things out in the open and the Neo-Plasticists didn't want anything left over.

I have learned a lot from all of them and they have confused me plenty too. One thing is certain, they didn't give me my natural aptitude for drawing. I am completely weary of their ideas now.

The only way I still think of these ideas is in terms of the individual artists who came from them or invented them. I still think that Boccioni was a great artist and a passionate man. I like Lissitzky, Rodchenko, Tatlin and Gabo; and I admire some of Kandinsky's painting very much. But Mondrian, that great merciless artist, is the only one who had nothing left over.

The point they all had they all had in common was to be both inside and outside at the same time. A new kind of likeness! The likeness of the group instinct. All that it has produced is more glass and an hysteria and for new materials which you can look through. A sympton of love-sickness, I guess. For me, to be inside and outside it to be in an unheated studio with broken windows in the winter, or taking a nap on somebody's porch in the summer.

Spiritually I am wherever my spirit allows me to be, and that is not necessarily in the future. I have no nostalgia, however. If I am confronted with one of those small Mesopotamian figures, I have no nostalgia for it but, instead, I may get into a state of anxiety. Art never seems to make me peaceful or pure. I always seem to be wrapped in the melodrama of vulgarity. I do not think of inside or outside—or of art in general—as a situation of comfort. I know there is a terrific idea there somewhere, but whenever I want to get into it, I get a feeling of apathy and want to lie down and go to sleep. Some painters, including myself, do not care what chair they are sitting on. It does not even have to be a comfortable one. They are too nervous to find out where they ought to sit. They do not want to "sit in style." Rather, they have found that painting—any kind of painting, any style of painting— to be painting at all, in fact—is a way of living today, a style of living, so to speak. That is where the form of it lies. It is exactly in its uselessness that it is free. Those artists do not want to conform. They only want to be inspired.

The group instinct could be a good idea, but there is always some little dictator who wants to make his instinct the group instinct. There is no style of painting now. There are as many naturalists among the abstract painters as there are abstract painters in the so-called subject-matter school.

The argument often used that science is really abstract, and that painting could be like music and, for this reason, that you cannot paint a man leaning against a lamp-post, is utterly ridiculous. That space of science—the space of the physicists—I am truly bored with by now. Their lenses are so thick that seen through them, the space gets more and more melancholy. There seems to be no end to the misery of the scientists' space. All that it contains is billions and billions of hunks of matter, hot or cold, floating around in darkness according to a great design of aimlessness. The stars I think about, if I could fly, I could reach in a few old-fashioned days. But physicists' stars I use as buttons, buttoning up curtains of emptiness. If I stretch my arms next to the rest of myself and wonder where my fingers are—that is all the space I need as a painter.

Today, some people think that the light of the atom bomb will change the concept of painting once and for all. The eyes that actually saw the light melted out of sheer ecstasy. For one instant, everybody was the same color. It made angels out of everybody. A truly Christian light, painful but forgiving.

Personally, I do not need a movement. What was given to me, I take for granted. Of all movements, I like Cubism most. It had that wonderful unsure atmosphere of reflection —a poetic frame where something could be possible, where an artist could practice his intuition. It didn't want to get rid of what went before. Instead it added something to it. The parts that I can appreciate in other movements came out of Cubism. Cubism became a movement, it didn't set out to be one. It has force in it, but it was no "force-movement." And then there is that one-man movement, Marcel Duchamp—for me a truly modern movement because it implies that each artist can do what he thinks he ought to—a movement for each person and open for everybody.

If I do paint abstract art, that's what abstract art means to me. I frankly do not understand the question. About twenty-four years ago, I knew a man in Hoboken, a German who used to visit us in the Dutch Seamen's Home. As far as he could remember, he was always hungry in Europe. He found a place in Hoboken where bread was sold a few days old—all kinds of bread: French bread, German bread, Italian bread and particularly Russian black bread. He bought big stacks of it for very little money, and let it get good and hard and then he crumpled it and spread it on the floor in his flat and walked on it as on a soft carpet. I lost sight of him, but found out many years later that one of the other fellows met him again around 86th street. He had become some kind of a Jugend Bund leader and took boys and girls to Bear Mountain on Sundays. He is still alive but quite old and is now a Communist. I could never figure him out, but now when I think of him, all that I can remember is that he had a very abstract look on his face.

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