ENGINEERING PROBLEMS OF FUTURE AIRCRAFT

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A DISCUSSION arranged by the Royal Aeronautical Society was held in London on November 14, dealing with some of the engineering problems presented by future aircraft. The subject was divided into four main sections, each introduced by a paper, which covered the problems that are now appearing on the horizon in the world of aircraft design. They were, broadly speaking: engineering problems of large aircraft, tailless aircraft design, flying-boats with particular reference to their peculiar constructional problems, and power plant installations.

Engineering Problems of Large Aircraft

The most outstanding feature from this point of view is the fact that the increase in size brings with it complication and elaboration of detail that is the work of specialists, many of whom may not have had any interest in the smaller aircraft of the previous decade. It will need the co-operation of a team, not necessarily all aeronautical, who will develop their own products to suit the particular requirements of the aircraft. An obvious example of this is the movements of the control surfaces. The effort necessary for these will certainly demand some kind of power driving, coupled with an extremely delicate control of it, which may be done either by gyroscopic instruments or graded down so that the pilot can operate it by 'feel'. At present pneumatic, hydraulic, and electrical systems are available, and it will have to be determined which can be best developed to the larger sizes with the least added weight and bulk, and retain the most delicate yet reliable control of its workings. There is a good deal to be said in favour of electrical systems, as electric power has to be generated for lighting and radio purposes. Alternating current at a pressure of about 200 volts between phases seems to be the most promising, and its development for both reliability and safety may well be one of the problems in the next few years.

Size of aircraft is very dependent upon the route to be operated. The London–New York route appears to be the most difficult one envisaged for the immediate future. The great circle distance is 3,450 statute miles, but allowing for head winds and other eventualities a fuel load sufficient for 5,500 miles must be carried. Present-day knowledge, based on a 300,000 lb. aircraft, suggests that only about 8 per cent of this figure is available for paying load, increasing to 11 per cent with one intermediate stop or 13 per cent with two stops, using the type of passenger accommodation most suited to aerodynamic and structural requirements. A further complication arises in that it may be convenient to make the longer non-stop run at night, so that sleeping berths will have to be provided. The extra space for these governs the size and weight of the body, and through this the design of the whole machine. Aircraft on the shorter runs with intermediate stops may possibly not operate in this way; and, if travelling during day-time hours, will tend to develop into a machine of a different type.

The proportion of paying load on this type of large machine being so small, it is obviously important to achieve the greatest possible efficiency in structural design in order to keep the weight of this part down to a minimum. This postulates an accurate knowledge of the externally applied aerodynamic forces and the resulting internal loads in the structure. The most critical parts of such loads are those due to dynamic effects arising from vibrations. This necessitates a study of the natural frequencies of the proposed structure, and the effect of gusts upon it. Undercarriage action also induces vibrations with a similar effect. The mathematics of these problems is long and laborious, and needs checking by actual tests. Existing equipment is too small for full-scale tests on such large machines, both from the point of view of size and the magnitude of the test loads to be applied. The design and construction of large test apparatus will constitute a research in itself, or alternatively the relationship between model and full-scale behaviour will have to be developed to a state of certainty in prediction, from both the mathematical and the physical outlook.

The correct use of materials gives another field of extremely interesting development. An aircraft designed to-day for production has to conform to the specifications of materials that are available in sufficient quantities, both as to physical properties and sizes. The designer of the large machine, regarded as a researcher into future design problems, may well consider it advisable to choose materials that give him the most efficient structure, thus in effect creating his own materials specifications, and giving a lead to the materials manufacturer. For example, in the case of a stressed metal skin, the joints between individual sheets give an appreciable additional weight, and another problem is to attain a good smooth outer surface. If sheets of double the present-day maximum dimensions were available, the area of the joints on an average aircraft skin would be reduced by about 40 per cent. Smaller tolerances in workshop production would allow much finer limits in stressing at the design stage and consequent saving of weight. This may call for changes in the materials manufacturer's workshop technique, or possibly the development of new alloys that are capable of more accurate finish in their manufacture.

Tailless Aircraft Design

There are aerodynamic reasons, outside the scope of this discussion, that dictate that the supersonic speed aircraft flying in the stratosphere will need to have wings with a pronounced 'sweep back', of at least the order of 25°. The tail surfaces that are necessary for control purposes may conceivably be carried on these wing tips, now far enough back for the purpose. This will give a useful saving in both drag and structure weight, as the long cantilever body, which serves little useful purpose other than to carry the tail, will not be necessary. This is really only a secondary effect, the principal problem of the future being that of the swept-back wing rather than the tailless aircraft. This problem resolves itself into three main sections: the aerodynamics of the question at lower speeds necessary for take-off and landing; compressibility effects; and 'aeroelastic' problems of dynamic loading as already discussed in the previous paper.

The outstanding problem to be investigated is the early stall, initiated at the wing tips. Their position relative to the line of flight alters the aerodynamics of the problem, and a combination of increase of local lift, reduced negative camber, outward drift of the boundary layer of air, and interference by a forced outward flow of the air from beneath the wings, causes premature stalling and lack of efficiency of the original tail surfaces now placed there. Investigations so far carried out suggest that an entirely separate design of the wing tips will need to be undertaken. The present knowledge of the behaviour of such devices as slots, flaps, etc., used as lift assisters, may need to be extensively modified when fitted in this area. Taper plan form for a wing, efficient in many respects for normal wings, may be definitely bad with swept-back wings owing to their disruptive effect upon the boundary layer behaviour. The control of the boundary layer by suction and ejection of air flowing over the plane, and even the design of completely different aerofoil shapes, are possible avenues of research into this problem.

Compressibility effects at high speeds need perhaps the greatest research in the future. This lack of precise knowledge of the behaviour of the aircraft is not confined to swept-back wings, but the problem is a degree more complicated in these cases. The variation of aerodynamic characteristics, the precise effect of sweep-back, and the problem of the stall, all need re-attacking under these conditions. A mass of theoretical and experimental data is beginning to become available, and assimilation of it and co-ordination of effort is a necessity.

The problems of aero-elasticity are an extension of similar questions on more conventional aircraft, considerably complicated by the fact that the wings are swept back. Spar bending under external loads produces a change of incidence, whereas it does not have this effect in a straight wing. This sets critical limits to most of the manœuvres, the investigation of which is naturally complicated by the introduction of a second variable. The possible effects of aileron reversal upon lateral control and stability, and the chance of its inducing wing flutter all need investigation, both mathematically, experimentally, and in full-scale flight.

Flying-Boat Problems Related to Production and Pressurization

This discussion, although primarily on the large flying-boat, raised general problems of the relationship between design and production that apply equally well to all large aircraft. Up to the present, design has generally been the first consideration, as indeed it must be with anything in the experimental development stage. Light and efficient structures have often been achieved at the cost of complication, with its attendant cost and slow production. Designers have been loth to increase structural weight, with its attendant reduction in useful load carried, in order to assist production. If the production engineer is willing to regard aircraft production as a separate problem, needing its own technique, co-operation with the designer should produce aircraft that will reflect the advance in aeronautical knowledge without necessarily being a bad production proposition. A reduction of the total man-hours needed for the complete building of an aircraft is the same thing, whether it results in cheapness for commerce or quick production for war.

Planning for production is obviously dependent upon the question of possible modifications found necessary during normal use. The present-day practice of building a few prototypes is not good from this point of view, and now that the tempo of development can be somewhat slower, it is possible that an extremely active development department using a larger number of pre-production machines could ensure that the final tooling for production would not be subject to many further alterations. Another criterion from this point of view is that of keeping the number and variety of parts down to a minimum in the design stage. The Republican Aviation Corporation in the United States re-designed the Sea Bee, as its cost of production was more than twice what the manufacturers had envisaged. A radical alteration to the structure involved them in considerable design trouble, as many of the re-designed features were not amenable to accepted strength computation methods, but the manufacturing costs were finally reduced to the required figure. Changes in detail design methods that are in danger of becoming stereotyped are foreshadowed here.

Another problem that has arisen in the production of large flying-boats which will certainly be common to all large aircraft is that of the minimum degree of accuracy needed. Laminar flow in the boundary layer demands exceptional finish of surfaces, and interchangeability of parts sets a limit on working tolerances. Unnecessarily small limits in either of these are wasteful, and much more precise information on these is needed.

Pressurization of cabins for high-altitude flying now appears to be essential with the adoption of the gas turbine. This creates a fresh outlook on the body structure, which now has to be a pressure-tight shell, in addition to being of the required strength. Although a circular cross-section is the stiffest shape, it is uneconomical for passenger accommodation, especially when large enough to accommodate more than one deck. A cottage loaf or figure of eight cross-section appears to be promising. Another question to be investigated is whether the whole body, or only the cabins, need be pressure tight. This is not only a question of human life in the cabins. The pressure differential between the outside and inside will affect the structural strength needed, and although pressure may not matter, the effect of temperature and humidity may affect certain kinds of cargo.

Power Plant Installations

The most outstanding feature of the future under this heading will be the possible change in general outline of aircraft due to the introduction of the gas turbine. This will be caused not only by the different requirements of the power plant itself, but also by changes in aerodynamic layout due to higher speeds and high-altitude operation. Military aircraft may also be extended to rocket-propelled, pilotless projectiles, although the more conventional aircraft will still be required for transport, observation, and possibly interception and destruction of enemy aircraft. Civil aircraft will tend to develop into types governed by range. The high fuel consumption of jet propulsion means that propeller drive will continue for these, although possibly driven by gas turbines. Medium-range, say up to 1,000 miles, and shorter-range aircraft may possibly use the highest possible speeds with jet propulsion, as the relatively short journeys will allow a more intensive use of the machine on the turn-about principle. Freight aircraft may well develop into two types, the faster catering for the transport of perishable goods, when the extra costs of high speed may be justified. The piston engine–propeller combination will probably remain at the lower end of this scale, with the turbine-jet at the other end.

The future development of power plants is obvious in its direction. The piston engine with propeller is efficient mechanically, at least up to speeds where compressibility effects are serious. It has reached a high state of development and does not appear to be likely to undergo any radical change that will enlarge its present application. The gas turbine with propeller gives an engine that is relatively new and capable of development, although its most obvious progress, namely, increase of power, will be limited by the propeller's ability to turn it into thrust, which cannot go much further. Reduction in vibration, noise, fire risks, and such secondary matters are more promising lines of improvement. The gas-turbine-jet combination is capable of unlimited development, so far as the aircraft is able to use its extra power, and the human element can stand the high accelerations inseparable from high speeds, assuming that research succeeds in improving the efficiency of jet propulsion and reducing the high fuel consumption, which up to the present limits the possible range.

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THE MAGNITUDE OF MICROBIAL REACTIONS INVOLVING VITAMIN-LIKE COMPOUNDS

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CHANGES brought about by one or a few units of catalyst in each cell of a living organism are postulated in biochemical interpretations of genetics. The nature of the changes is unknown; but a favoured suggestion is that they may consist of participation in the formation of enzymes, or their 'shaping' from otherwise synthesized protein molecules[1]. This is a theoretical conception, and no reactions defined in terms of substrates or products, and studied by biochemical techniques, have previously been recognized as due to one or a few molecules of enzyme per cell. Reasons are given below for thinking that a certain class of reactions with vitamin-like substances in bacteria may be due to such enzymes.

Formation of Vitamin-like Substances by Bacteria

Authors have previously pointed out the relatively small quantities of known vitamins which are associated with individual cells. When expressed as molecules per cell, numbers of the order of 10^3 to 10^5 are found in the case of many bacteria[2,3] (*b*, Table 1). Consider now their rates of formation in growing bacteria. Cultures of the organisms of Table 1 for which data are available[2] doubled in population each hour. Thus, for example, some 5,000 molecules of aneurin were produced in an hour by (initially) one cell. Allowing for its growth by the factor $\log_e 2$, the rate of production becomes 3,500 molecules/cell of 10^{-13} gm. dry wt./hr., or about 1 molecule/cell/second. These rates (*c*, Table 1), are likely to give low estimates of the synthetic ability of bacteria, for the following reasons. (1) The vitamins are found also in the fluids in which the bacteria have grown. The values *d* of Table 1 take this into consideration. They are likely to be high if vitamin production has continued in the absence of growth, as can sometimes occur[4]. (2) The bacterial generation time of 1 hour, which was employed in calculation, is three times that typical of good conditions of growth. Rates treble those of column *d* (Table 1) give a range of values of 0·24 to 33 molecules/cell/sec., with exceptional upper values for pantothenic and nicotinic acids of 120 and 540 molecules/cell/sec., respectively. (3) The extent to which these rates represent metabolic reactions which are at all well defined needs independent demonstration. They may be the outcome of a balance between vitamin production and breakdown Evidence in specific instances is considered later.

Rates of Enzyme Reactions

The velocities of several reactions catalysed by enzymes can be expressed in terms of the numbers of molecules of substrate which one molecule of enzyme causes to react per second. Such values—the turnover numbers of the enzymes—are usually determined under optimal or physiological conditions of temperature and *p*H, and with excess substrate. Values are given in Table 2. In general, they are seen to be greater than the numbers of molecules of

TABLE 1. QUANTITIES OF VITAMIN-LIKE SUBSTANCES FORMED BY BACTERIA[2], AND THEIR COMPUTED RATES OF PRODUCTION

Compound	Organism	Quantity associated with cells[3]		(*c*) Rate of production of vitamin of cell in culture doubling in size each hour (molecules/cell/sec.)	(*d*) Value corresponding to (*c*) but including vitamin of culture fluid. (molecules/cell/sec.)
		(*a*) μmol./gm. dry wt.	(*b*) Molecules/cell of dry wt. 10^{-13} gm.		
Aneurin					
	Aerobacter aerogenes, aerobically	0·037	2200	0·4	0·8
	Aerobacter aerogenes, anaerobically	0·050	3000	0·6	1·0
	Serratia marcescens	0·090	5400	1·0	1·7
	Pseudomonas fluorescens	0·086	5200	1·0	2·8
	Proteus vulgaris	0·070	4200	0·8	0·8
	Clostridium butylicum	0·031	1900	0·4	1·5
Riboflavine	(above five bacteria)	0·12–0·18	7200–11,000	1·4–2	2·4–11
Nicotinic acid	,, ,, ,,	1·6–2	96,000–120,000	18–23	31–180
Pantothenic acid	,, ,, ,,	0·4–1·6	24,000–96,000	4·6–18	5·2–41
Pyridoxine	,, ,, ,,	0·035–0·11	2100–6600	0·4–1·3	1·1–5·1
Biotin	,, ,, ,,	0·007–0·029	420–1800	0·08–0·34	0·08–3·2
Folic acid	,, ,, ,,	0·003–0·02	180–1200	0·03–0·25	0·25–1·2
p-Aminobenzoic acid[5]					
	Aerobacter aerogenes	0·120	7700	1·50	4·0
	Serratia marescens	0·048	3100	0·60	1·2
	Pseudomonas aerugenosa	0·073	4700	0·92	5·5
	Streptococcus hæmolyticus	0·060	3800	0·74	1·1
	Escherichia coli	0·270	17,000	3·32	3·9