# DESIGN FOR RELIABILITY

by

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The following thoughts have been provoked by a study of the defects which ground our naval aircraft and of the methods by which those aircraft come into being, considered against a design background from other branches of engineering. It must be emphasized that the views expressed are the personal opinions of the writer. If they stimulate thought in others they will not have failed in their object.

Few engineers from other walks of life can fail to be struck by the difficulty of the problem which faces the aircraft designer and production engineer, and there will also be few who will not be envious of the research effort available and directed towards the achievement of the desired result. The test equipment alone makes the mouth of a marine engineer water.

Yet, it is a hard fact that for every naval aircraft ready to fly or flying, there are, quite apart from the reserve backing, between two and three on the ground being serviced, having defects remedied, awaiting spares, and so on. In fact, in comparison with other forms of weapons or craft, aircraft come pretty low in the reliability scale. To such an extent is this so, that what amounts to lack of reliability is often taken for granted.

Now this state of affairs is somewhat paradoxical, for no one would deny the effort expended to make the British aeroplane supreme. The need for this has long been appreciated, and the scale of the effort is widely known. Only recently the Chief of the Air Staff emphasized that in the air quality in material is vital, and stressed the need for quality before quantity.

Most of us recognize the startling rapidity of the advance in performance of aircraft, and pay tribute to the skill and devotion of far-sighted designers in making this possible. Few would challenge the supremacy of British aircraft in many fields. Nevertheless, this last statement brings with it the thought,—supremacy in what? The answer is surely quite clear—supremacy in performance. And quality—what of this?

**Analysis of Accidents**

Consider the facts. Analysis of accidents to naval aircraft shows that mechanical, structural, or electrical fault has been an important factor in about half of them. Of these, in about two-thirds of the cases, design or manufacture has been at fault, and only about one-quarter of this number has been due to faulty maintenance. Study of modifications reveals a similar high proportion to remedy defects of design or manufacture. Clearly then, our aircraft,—and this is generally true of all aircraft,—are by no means as reliable as we should like, or perhaps, might expect.

Before seeking the reason for this state of affairs, it is as well to consider what are the principal types of defect. They can conveniently be placed in four groups, (i) those due to a lack of realization of operating conditions and requirements, (ii) those due to pressing the aircraft or its components beyond their original design point, (iii) those due to lack of design or manufacturing knowledge or insufficient testing, (iv) those due to lack of attention to detail, or carelessness.

In the first class are such things as insufficient undercarriage strength for deck landing, due to lack of appreciation of the true requirements on the part of those who call the tune. In the second class fall all those defects inherent from trying to squeeze a quart into a pint pot without the magic touch. In the third class come many types of defect, such as shimmy, and failures of components due to inadequate prior testing.

It is in the last class, however, that the writer believes can be put by far the majority of defects which ground aircraft. It is in this class that come all that host of defects which are caused by the unconscious flouting of simple and well-established design principles. The principles are well known : avoidance of stress concentrations ; avoidance of having dissimilar materials in contact where electrolytic action is likely ; avoidance of the use of redundant locating points ; ensurance of alignment by spigots, fitted bolts, or dowels ; in fact, all those simple rules which the beginner learns, or certainly should learn, as the groundwork of his trade. Look at the first few things which you find wrong on the next aeroplane you tackle, and see how many of these simple rules have been neglected.

**Performance and Reliability**

When discussing the reliability of aircraft, many who read this must have been struck by the often voiced opinion that lack of reliability was the price which must be paid for high performance and the rapidity of advance essential to the achievement of supremacy in the air. This opinion is tantamount to a belief that reliability is the enemy of performance.

There are a number of specious arguments which lend colour to this fallacy. It is argued, for instance, that by pressing an engine, greater output can be obtained, but usually at the price of reliability. This is, of course, perfectly true, and no one would deny that it happens. It is equally true that an aircraft which is not reliable under the maximum conditions may be perfectly satisfactory under limited conditions, such as straight and level flight.

Let us, however, examine the question a little more closely. There are two chief methods by which a successful advanced product can be achieved. These can be exaggeratedly described as brilliant design or painstaking development, and it is seldom that the former alone is sufficient. Usually, a combination of both is necessary. Development can be halted when the design target is reached or can be continued beyond it. The second course is very usual, and contains seeds of danger, for in development beyond the design point, every piece will, if original allowances were right, be stressed beyond that originally considered prudent. Herein, then, lies a danger, and one that applies particularly to aircraft.

Now let us consider reliability, and of what is its essence. It is a simple matter to achieve reliability at the price of low stresses and poor specific performance, but how is reliability to be achieved at the same time as high performance ? The higher the stresses, and the nearer the design stress approaches the safety line, the more precise must be the knowledge of the operating conditions, and of the design problems involved and their exact solution. The

more thorough, too, must be the testing. The detail design must obviously be beyond reproach. In fact, it can be said with much truth that reliability is a fruit of good detail design.

How then can reliability be the enemy of performance, since performance can only be enhanced, and not diminished, by good detail design ?

What is so often forgotten, is that as a performance target is raised, and with it the design effort involved, so equally must the design and production effort to achieve reliability be increased in step. Only so will the final product ring the bell with regard to quality ; that is, performance and reliability.

**Maintenance**

One example from another sphere of engineering may illustrate the fallacy of suggesting that to meet maintenance requirements, restrictions on performance must be imposed. Some time before the Second World War, the U.S. Navy decided to increase considerably the performance of its warships. Technically, this meant going into the high temperature and pressure range, with all the difficulties associated with creep,* and they realized that unless they stepped up their design knowledge and technique, they would have a " whale of a lot " of maintenance troubles. The Bureau of Ships, therefore, set up a new organization for handling these designs. At the same time, they took a very great deal of trouble over the details of their design, both in the design office, on the drawing board, and in production. The resultant ships were those with which they fought the war, and in spite of the arduous Pacific conditions, it is a fact that these ships, whose performance was so much superior to their predecessors, had far fewer maintenance troubles than anything the U.S. Navy had built before.

It must be realized that there are a number of special factors which tend to make the goal of reliability especially difficult in the case of aircraft. One is the startling rate of aircraft development which leads to a minimum of time for development, and consequently, for study of the details. The necessary and desirable competition between firms enhances this, but is dangerous to the attainment of reliability so long as there is no real penalty for lack of it. As a result, the evolution of a type is a steady progress towards higher performance —but not always greater reliability—by the painful process of eliminating the bugs ; in other words, very greatly of " suck it and see."

**Design in the Heavier Industries**

This attitude, which does enable rapid advance, is not open to the heavier industries, whose products are too large and costly, and designed for too long a life to permit such a method. The power station plant, designed for a hundred thousand hours life, has to be right first time, and yet in competitive days one quarter of one per cent advantage in specific performance might secure an order. Design here has to be extremely accurate and reliable, but weight, that bugbear of the aircraft designer, is of little importance. In the case of warships, prototypes are seldom built, and that similar conditions apply is illustrated by the following tale. The 72,000 h.p. ships with a displacement of some 3,000 odd tons, designed for a standard speed of 40 knots, were the first essay of this country to cram a high h.p. into a comparatively small hull. The first ship, H.M.S. *Abdiel*, was completed fairly early on in the war, and sailed from her builder's yard to northern waters to carry out her preliminary and other trials. On the way she was diverted by the Admiralty to carry out an operation. In fact, that ship carried out three operations before she ever did her preliminary

* This is one of the jet-engine designers' problems also.

trials. There was no prototype, and there were no trials before what was a brand new departure in design went into active service.

No one would suggest that this is an admirable procedure, or that it would be wise or desirable for aeroplanes, but it does illustrate that the different approach to the warship design problem does usually, at least, secure reliability at the first time of asking. When one thinks of it, how seldom has one known one of H.M. ships fail to get underweigh at the appointed moment, except on account of enemy action, or to reach her destination on time.

If any lessons can be drawn, they are, perhaps, that the maximum effort must first be put into the design to ensure that the prototype will have as few bugs as possible, and secondly, that prototype testing should be sufficient to ensure that all the bugs really are out before production starts. In practice the combined urge on the part of the user to have, and the manufacturer to produce the aircraft, seldom, if ever, allows time for these processes.

It must have been noticeable to many that Service aircraft in this country carry no manufacturer's guarantee covering either performance or reliability. One reason for this is that it has been felt that the giving of a guarantee by the manufacturer would be apt to put a brake on progress. At the same time it is quite evident that where a guarantee is given, avoidable errors have to be reduced to the minimum for financial reasons. There is little doubt that in the past the spotlight in the aircraft world has been on performance, and reliability has correspondingly suffered. The question that is exercising the minds of many at the present time is how to alter the balance without removing the spur towards ever-increased performance. In other words, how to turn a second, and equally powerful, spotlight on reliability.

**Scrutiny of Designs**

Quite apart from the rapidity of the development of aircraft and their equipment, which makes it difficult to devote adequate drawing board time to refining the details, the industry has been faced with enormous expansion, and consequent dilution of drawing office and design staff. This aggravates the situation, but is not the essence of the difficulty, which springs from the fact that weight, space, and shape are such vital factors in aircraft. In every design step, weight is all important. In other industries, where weight is not vital, the indifferent draughtsman can often play safe, and merely use too much metal. In aircraft work this would be fatal. The danger lies in the unskilful man paring down weight. Sooner or later he will fail to avoid an abrupt change of section, shall we say, with its stress magnifying factors, and we shall have a potential and very real source of trouble.

This state of affairs is, naturally, well recognized by the industry and by the Ministry of Supply. In fact, a special study of Design for Reliability is being made. We ourselves, in the Navy, are making our own contribution in the shape of a trial scrutiny of new naval aircraft and their drawings in the design stage by engineer officers, with design experience, resident at the firm. As well as this, every defect reported is scrutinized carefully in an endeavour for the future to eliminate the cause of the trouble.

If we are to be successful in eliminating most of the petty troubles which ground aircraft, even greater co-operation on the part of those handling them is required. Every defect, no matter how trivial, should be studied to determine what is the underlying cause. If this is unsatisfactory design or indifferent workmanship, it must be reported. It is unreasonable to expect designers or manufacturers to be clairvoyant, and unless they receive an accurate flow of factual information on shortcomings, how can we expect them to eliminate similar errors from future products ?

**Classifying Defects**

In considering faults, it is frequently convenient to endeavour to put them in a category which indicates the underlying cause. As an example, defects not due to mishandling, fair wear and tear, or faulty maintenance, might be placed in one of the following groups, which are by no means exhaustive, and some of which have already been mentioned :—

(i) Insufficient attention to detail. Can refer to design, manufacture, installation or inspection.

(ii) Failure to obey well-established design rules, *e.g.*,

- (*a*) Avoid stress concentrations and abrupt change of section.
- (*b*) Avoid the use of dissimilar materials in contact where electrolytic action could take place.
- (*c*) Length/breadth ratio of working parts to be satisfactory.
- (*d*) Avoid the use of redundant locating points.
- (*e*) Ensure alignment by spigots, fitted bolts or dowels.
- (*f*) Design so that incorrect replacement is not possible.
- (*g*) Ensure adequate locking arrangements.
- (*h*) Take care that limits are satisfactory.
- (*i*) Consider inspection and the gauge maker.

(iii) Failure to appreciate requirements or nature of the forces acting.

(iv) Use of wrong techniques.

(v) Acceptance of inferior methods or materials because of expediency.

(vi) Over elaboration.

(vii) Lack of accessibility.

(viii) Lack of pre-testing.

Grouping of defects like this could lead to an increase in the attention given in the field to nailing down the real cause of many of our troubles, and thus, to their elimination from our future aircraft.

No attempt has been made in this short article to suggest how the present situation, with its adverse effect on the availability of aircraft and on the ever difficult spares position, can be remedied.

Opinions would be valuable, and readers are invited to send their views to the Editor, *Maintenance Matters*, A.M.R. Dept., O.P. Sect., Admiralty, Rex House, Lower Regent Street, London, S.W.1.