THE WELL-TEMPERED AIRCRAFT

39th Wilbur Wright Memorial Lecture: A Notable Address

OF the few thousand men in the world who have real technical ability and experience and, therefore, can be reckoned to have something to say to their fellow workers, no more than a few hundred have the ability to put their ideas into clearly arranged words. Of these few hundreds, a few score have the refined ability so to arrange their words as to give a strikingly lucid exposition of their ideas. But rare indeed is the man who not only draws a lucid picture but manages to make it entertaining as well. Such a man, however, presented the Wright Memorial Lecture this year. Mr. Arthur E. Raymond, Vice-President, Engineering, Douglas Aircraft Co., gave a brilliant review of what an aircraft should be—and many of the difficulties in the way—when, last Monday, September 10th, he read his paper, *The Well-Tempered Aircraft*, before the Royal Aeronautical Society assembled at the Royal Institution in London.

Mr. Raymond observed that the Wrights built and flew their aeroplane successfully because, among other things, they saw the problem as a whole, saw its elements in proper relation to each other, gave to each the attention it deserved, and overlooked nothing. Today, although the problem had become enormously more complex, the greatest success came from the same approach. It did not pay to be too theoretical or mathematical, it did not pay to stick too closely to the drawing board, nor could individual judgment alone be relied upon. A proper combination of these and many other elements was necessary.

The task today was to produce a large number of good aircraft with the least expenditure of cost and time. The resources of Great Britain and the United States were limited and had to be used as effectively as possible. By good aircraft was meant aircraft that contributed more to society than they cost. The lecturer then listed eight fundamental elements which, although not necessarily all-inclusive, appeared to be essential to the production of operationally-useful aircraft. These were: (i) proper environment; (ii) good initial choice; (iii) excellence of detail design; (iv) thorough development; (v) follow-through; (vi) thorough exploitation; (vii) correct succession; (viii) adaptiveness. These fundamental elements were then considered in turn.

Proper Environment.—The first item Mr. Raymond dealt with under this head was confidence, and he said that confidence had to be transmitted to others, and among the first who needed to be convinced were those who put money into the project. An aircraft could never be proved a success until its development period was behind it, but on the other hand, until its success had been reasonably established, it was difficult to get people to buy it. Unfortunately, the greatest need for funds tended to come at a time when troubles were most likely, i.e. the early production period (Fig. 1). Many a successful aircraft was built under great physical handicaps, and it certainly could not be proved that good working conditions were imperative. The human spirit often triumphed over obstacles, but that fact was not necessarily a good excuse for having them.

The supply of properly trained and experienced personnel was not enough to meet the demand; the work of every man had to be made to count to the maximum degree. In the design organization, two types of co-ordination had to be provided for, co-ordination by speciality, and co-ordination by project (Fig. 2). Which of these systems was the better was a subject for argument, but it made little difference which was used; they would both work. The important thing was that one or other had to be given preference when it came to administrative authority, and everyone should understand where the preference lay.

Concurrently with the great elaboration of aircraft design had come a narrowing of the designer's horizon, and this narrowing took away much of the feeling of identity between a man and his work—the day of the specialist was here, perhaps even more in the United States than in Great Britain. Everything possible should be done to ensure that the engineer and designer on the one hand, and those who would manufacture and use the aircraft on the other, understood and considered each other's viewpoint.

Good Initial Choice.—Mr. Raymond gave an explanation of how some aircraft had come into being. Someone had become convinced that there was need for a machine of such and such a type; he marshalled a few arguments, convinced someone else and the ball was rolling. As it gathered momentum, arguments in favour were high-lighted, arguments against were stepped on, personal pride became involved, people became committed, and sober analysis of pros and cons became impossible. The project went ahead, the aircraft was designed, built and flown—usually rather successfully—and then what happened? Nothing. Because nobody really wanted it or because those who might have wanted it wanted something else besides. Obviously a project would be doomed from the start if it did not fill a real need.

There were two sides to the question of deciding what to build: one was *what was needed*, the other was *what was possible*—what *should* be built versus what *could* be built. These had to be considered separately and in relation to each other if the choice was to be a good one. The establishment of a sound realistic set of military requirements, for example, was a high art demanding the pooling of experience, analytical skill and judgment of people with widely varying background. The kind of fighter needed five years from now depended not only upon the materials, engines, radar and armament that would be available by that time, but also upon the characteristics of enemy bombers and fighters then, and the tactics they would employ. It depended, moreover, on the amount of money which could be spent on fighters in relation to what was spent on other things. It depended on how good other methods of defence, such as missiles, would be by that time. In other words, it depended not only upon the fighter itself, but upon the whole defence system of which the fighter was a part. The same could be said of any other military aircraft.

That part of the problem of initial choice which had to do with determining what was technically feasible was often called "limitations analysis." One of its end points was a curve on which was plotted against gross weight and wing area a series of curves of various constant performance characteristics. There resulted a shaded area which defined the combinations of gross weight and wing area for a given aircraft configuration that had performances better than certain prescribed values (Fig. 3). Such curves could be prepared for several configurations, and thus could assist in choosing between them. Limitations analysis was really a partial definition of what was commonly called "the state of the art," the level reached by the constantly rising progress curve. An aircraft designed in such a way as not to take reasonable advantage of the state of the art was handicapped competitively; one designed too far in advance of it with too much optimistic anticipation ran into the dangers inherent in all pioneering efforts.

This did not necessarily mean that design should not be in advance of the state of the art, but it did indicate the importance

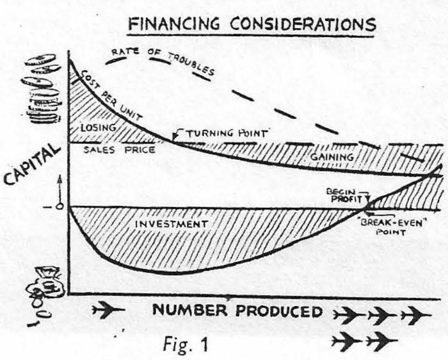

Fig. 1

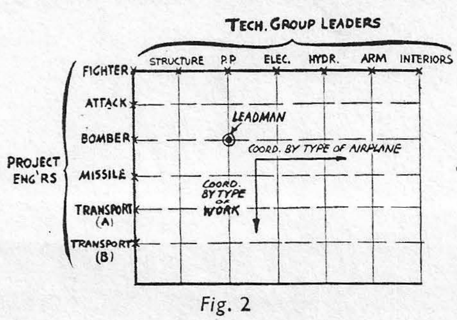

Fig. 2

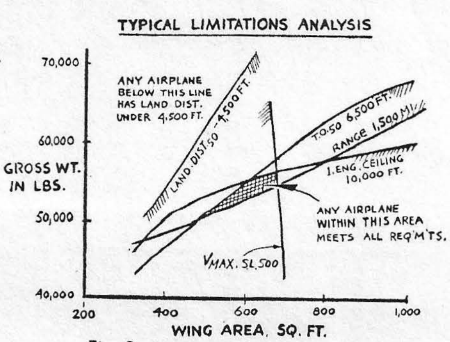

Fig. 3

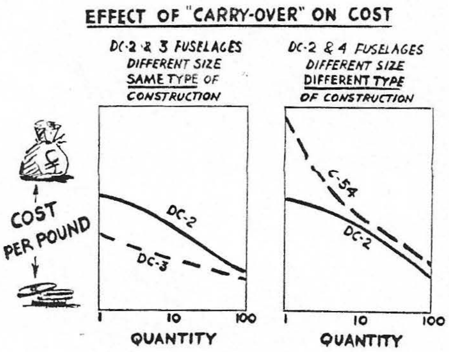

Fig. 4

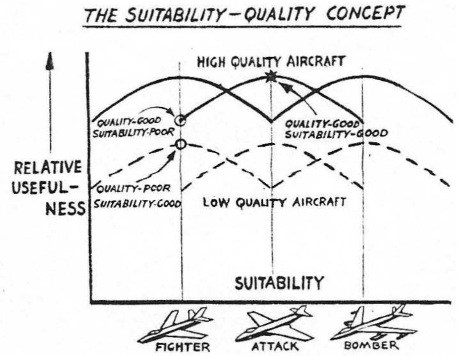

Fig. 5

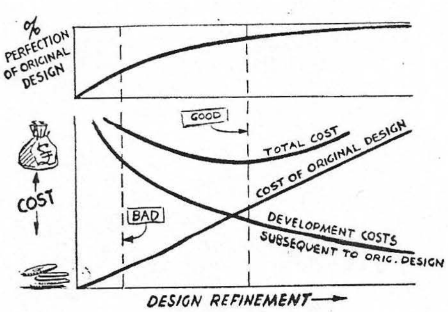

Fig. 6

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of keeping one's eyes open to the resulting dangers. If, instead of aiming too high, a conservative approach was adopted, a number of advantages became immediately apparent. Experience of past designs could be carried over into the new one with little or no change. The assurance of having a design which would require little development often made it possible to start production before the prototype had been tested, thus shortening the elapsed time before the aircraft came into the market. With a civil transport aircraft, near conventionality made passenger acceptance more sure, and made operators more willing to order while the aircraft was in the blueprint stage—and the manufacturer more willing to accept such orders. All of these things made it appear more attractive to do what had been done before, but in a slightly different way, rather than to branch out into something new. On the other hand, such an attitude if carried to extremes stifled progress and, since there were many adventurous spirits in aviation, and always would be, it led to being over-run.

On the whole, "carry-over" had such a great effect on aircraft cost that it would have to be retained as a nucleus around which a few pioneering electrons revolved (Fig. 4). Doubling the number of aircraft produced cut their unit cost by about 20 per cent. Since versatility extended the market, there was a continual temptation to combine two or more requirements into one multi-purpose design. If the requirements were sufficiently similar, this could be done satisfactorily; if they were too far apart, the result was a product which really satisfied no one. It was particularly true of civil transports that, unless the market was extensive, the unit cost would be too high to be borne. Too great a degree of specialization could not be supported.

Excellence of Detail Design.—Two aircraft designed to the same specification might differ widely in size, cost and weight, simply because of the relative quality of detail design (Fig. 5). In fact, thought Mr. Raymond, much of the progress being made in the art consisted in learning how to design a small, efficient aircraft to do the job previously done by a large complicated one. Not only did this hold true of the aircraft as a whole; it was also true of its components down to the smallest parts. It was not always appreciated that a pound saving in weight empty might be compounded into ten or more pounds saving in gross weight on modern designs.

Carry-over of learning from previous designs was a major aid in reducing troubles in service. A design developed from a previous design, if the basic principles were still correct in the new application, was usually better than a completely new one. It took engineers a few hard knocks to make them realize this; some never did. An engineer liked to take pride in a new and original design; he got more satisfaction from this than from improving an existing one. It was a problem in psychology to get designers to take pride in the reliability and trouble-free operation of their production, rather than in the originality of their concept. On the other hand, using an old design in new conditions to which it was basically unsuited could be equally as bad.

When refinement of design was carried on with the idea of making it more nearly perfect, making it meet requirements more exactly, it often resulted in more complication, higher cost and, in general, a poorer overall design. This was the disease referred to as "perfectionism." Complication was sometimes the path of least resistance for the designer. It was either the result of lack of knowledge or lack of adequate thought. The simple way of doing something was not usually one that sprang first to mind. Designing to a fixed budget rather than for a certain level of excellence could result in a spotty combination of good and bad elements. Designing to a fixed budget might be good if the budget was properly set. If, however, it was too low, the result was illusory, for whilst the cost of the original design was kept down, costs of the subsequent development necessary to reach an acceptable level of perfection were higher (Fig. 6).

Another quality which carried through all the way from the general arrangement of an aircraft to the detail design of its components was ability to absorb future technological improvement. A long view was required to sacrifice immediate advantage for the benefit of longevity. A good aircraft might be in service for ten years or more, and it was wise to keep its growth possibilities well in mind from the beginning. The aeronautical profession, thought Mr. Raymond, was beset by stylists and faddists. Proper functioning was more important than style or appearance, and the designer who attempted to force his brainchild into a form which satisfied his æsthetic sense at the expense of its performance or flight characteristics, had not done a good job. Premature enthusiasms and *a priori* conceptions had to be rigidly put to one side if a well-tempered aircraft was to be achieved.

Aircraft production at best was not high-volume production, and the type of tooling required was not high-production tooling. This lesson had been learnt the hard way by the motor industry during the recent war. Considerable progress had been made since aircraft were made by hand with little or no tooling, and the correct middle course was to provide comparatively simple tools which could be augmented or duplicated if production was stepped-up, and which could be thrown away if the design was changed. This type of tooling often dictated the design. The true producibility of a design, as that term should be used, was the degree of its adaptability to the use of this type of simple tooling (Fig. 7).

Development.—It was the lecturer's opinion that there should really be more than one prototype, not only because of the vulnerability of putting all the eggs in one basket, but also in order to shorten development time by running tests in parallel. Experience had shown that, normally, it took at least as long to perfect a design after first flight as the time that had gone into it before the first flight. Flight test time was expensive, particularly on modern aircraft, but it could be shortened by suitable preliminary research and ground or laboratory testing, including wind tunnel testing.

One of the difficulties of model testing was the time required to build models and to test them. The high forces imposed on models in high-speed tunnels demanded model construction so

Fig. 7

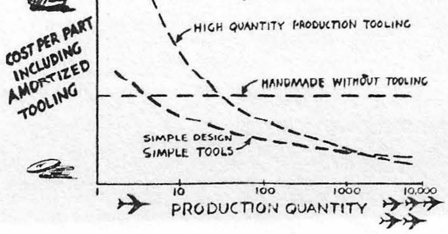


Fig. 8

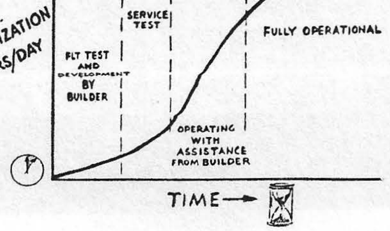
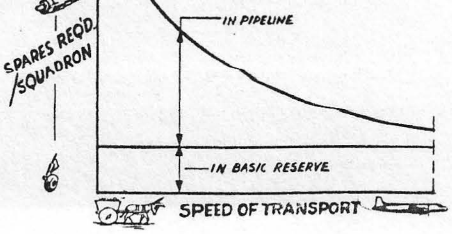


Fig. 9



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intricate and test programmes so long that it was difficult to get tunnel results early enough in the design of the aircraft to allow design modifications to be made while the drawings were fluid. In these circumstances, the wind tunnel tended to become a checking device rather than one for the collection of design information.

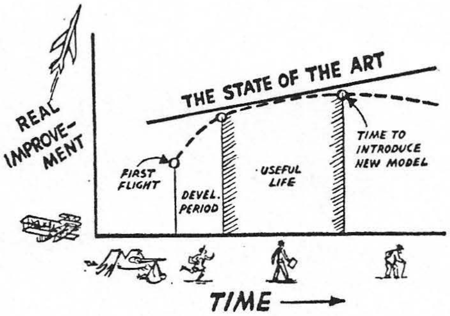

Fig. 10

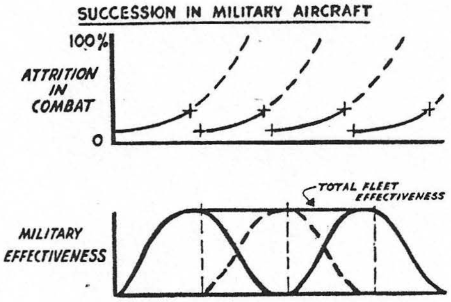

Fig. 11

Aircraft design was not a complete science and never would be, so flight tests and service experience were necessary in order to check what had been done on the drawing board and in the laboratory. The aircraft was, first of all, a flying machine, and there was no substitute for good flying qualities. A good flying aeroplane had to be obtained first of all; the rest could be added later. In a sense, however, the development never ended, for so long as the aircraft lasted, improvements would be made in it. What was aimed at in the development period was to get the aircraft into such shape that it could go into service and do its job month in, month out, and average not less than, say, five and perhaps as many as ten or more hours of flying time per day. If it could do that, it was a well-tempered aircraft and justified its existence.

Follow-Through.—At completion of the development phase, the aircraft passed from builder to operator. This transition could be made easier if key-men from the operating side were brought into the factory some time before delivery, to become familiar with the aircraft and to share in its test programme. There was a tendency to criticize a new aircraft, if it was not fully understood. It might be much better than previous types but, just because it was different, it would at first seem strange and uncomfortable. An easy affection came only after long familiarity and the period of becoming acquainted with something new could be very awkward f a well-thought-out and organized programme was not put into effect to bridge it over (Fig. 8).

On the subject of spares, Mr. Raymond said that nobody knew ahead of time exactly what would be needed, but the spares situation for the civil operator was a good deal better than in the military case. Spares for military aircraft were often badly handled; large surpluses and acute shortages went hand in hand. The nature of military operations made the problem of spares particularly difficult, but the supply problem could be simplified by the use of air transport (Fig. 9).

Thorough Exploitation.—Mr. Raymond expressed the opinion that a well-conceived well-executed and well-developed aircraft could usually be adapted to a wide variety of uses over a period of years, so extending its market and lengthening its life-span. It had been estimated that successful military aircraft underwent, on the average during their useful life, modifications totalling at least one-half of their original cost. The record for successful civil aircraft was much the same, for these found their way to many different customers, each of whom required variations to meet special preferences or conditions of operation.

There was little use bewailing this tendency toward non-standardization. Modifications undoubtedly added to the cost, but without them the number of aircraft produced would be many less which, in itself, would probably raise the unit cost even more.

Correct Succession.—Regardless of how good an aircraft might be, there came a time (and it might come imperceptibly) when it became uneconomical to continue production. Any further modifications would cost more than their benefit (Fig. 10). This was the time when a new model should be through its development phase and ready for operation. The new model must, therefore, have been started several years before. It was not enough to acknowledge the point of obsolescence when it occurred; it had to be foreseen considerably in advance.

The problem of succession when applied to military aircraft had some special elements which were worth noting. The losses that a given air force would sustain in battle against the enemy depended on its quality. If aircraft were not replaced from time to time with newer models, their attrition rate would be higher in the event of war. Replacements in wartime would then have to be more numerous (leaving aside the difficulty of getting them in time) and their total cost would be higher. This added cost would tend to offset the added cost that would have been incurred had more modern aircraft been secured in the first place. Mr. Raymond then made the trenchant observation that the penalty of allowing an air force to slip behind the state of the art through failure to renew was so great that a drastic policy of scrapping existing military aircraft and replacing with new ones as soon as they could be made available would pay in the long run. In other words, as soon as today's bomber or fighter had been placed in production, tomorrow's should be started on the drawing board (Fig. 11).

Adaptiveness.—There had always been a great many people in the aircraft business whose attitude was optimistic and who expected the best. Many projects would never have been started had this not been so. A surprisingly large proportion of these had been successful, when a careful and thorough preliminary analysis would have shown their chances to have been much less than even. If no one drilled an oil well unless he were absolutely sure he would strike oil, petroleum production would be much less than it was. Certainly, there were times when it was justified to take-chances.

The qualities of mind referred to, flexibility, optimism, and lack of caution, were youthful qualities. Aviation would undoubtedly always be a field which attracted young men, and one which was benefited by their presence. Those who had been in it a good many years might be able to supply the tempering judgment which only experience could bring, but they could not allow themselves to think that they had all the answers.

To illustrate the importance of the unplanned-for element, Mr. Raymond concluded his lecture by quoting the case history of the Dakota. What it amounted to was that the DC-3 had been lucky enough in its early years so completely to capture the market (and this had not been the result of particularly good planning) that competition was thrown off balance. It therefore had had the benefit of a rather unique position, but the fact remained that stern realism undiluted by a certain light-hearted assumption of risk might well have damped the project in its early stages.

AN AIRLINE'S QUARTER-CENTURY

"High Horizons," by Frank J. Taylor. McGraw-Hill Book Co., Inc., 330, *West 42nd Street, New York. Price* $4.00.

LATEST addition to the fast-growing library of company histories is this story of United Airlines, who celebrated their 25th birthday this year.* The sub-title "Daredevil Flying Postmen to Modern Magic Carpet" gives a clue to Mr Taylor's picturesque, American style of writing, which may cause the more conservative reader to squirm occasionally, but, on the whole, is highly entertaining and descriptive Take, for example, this story of one of the "Daredevil Postmen" in his war-weary D.H.9 mailplane in 1921: "Pilot J. Dean Hill, when he left Bellefonte, invariably lighted a long cigar and puffed leisurely as he flew. When the stogie burned down to two inches in length, he figured it was time to come down over the Jersey meadows. Hill always claimed that his stogie was the first instrument to aid commercial fliers."

Whether or not that conforms with the reader's idea of great English prose, *High Horizons* is worth a place on every aviation bookshelf. Beginning with the individual stories of Varney Airlines, Pacific Air Transport, Boeing Air Transport and National Air Transport—the four companies which combined to form United Airlines in 1929—it shows how they survived years of big business, political manoeuvring and financial crises to become the great free-enterprise Main Line system of today, carrying 2½ million passengers a year on 13,000 miles of routes.

We read how United pioneered a brand-new profession by taking on the first air hostesses in 1930, and then began the modern mania for red carpets, free meals, orchids and champagne by serving the first in-flight meals to their passengers. Some bright ideas misfired: for instance, after introducing a scheme by which wives could accompany their husbands free of charge on certain flights, United's sales staff wrote to ask the ladies if they had enjoyed the trip. Unfortunately, it transpired that at least one husband had neglected to tell his wife that he had taken her along!

It is a fascinating book, because many of the "great names" in American aviation had a hand in building United Airlines. But more than 94 per cent of United's present top management people came up the hard way in the company's offices and "off the ramp," and Mr. Taylor pays well-merited tribute to them also.

* *See "United is Twenty-five", "Flight", March 9th.*