REPORT 58

NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AERONAUTICAL RESEARCH AND DEVELOPMENT

PHILOSOPHY OF AIRWORTHINESS

by

W. Tye

This Report was presented at the Fourth Meeting of the Structures and Materials Panel, held from 27th to 31st August 1956, in Brussels, Belgium.

SUMMARY

This Paper discusses in broad outline some of the considerations which underlie modern approaches to airworthiness.

The matching of airworthiness of the aircraft with the external operational conditions is discussed. The difficulty of establishing what level of airworthiness is acceptable to the community is pointed out, and a possible way of attacking the problem is suggested. Preliminary examination indicates that there is an optimum level of airworthiness.

A distinction is drawn between the 'accident rate' and 'accident probability' approaches to airworthiness, and the moral and technical implications of these are discussed.

The present state of certain important structural requirements is examined in the light of the preceding general considerations. The main weaknesses in the current requirements are underlined. Brief reference is made to the problem of airframe fatigue.

SOMMAIRE

Exposition à grands traits de certains des facteurs à base des théories modernes concernant la navigabilité.

Examen de la question de faire correspondre la navigabilité aux conditions de service. L'auteur souligne la difficulté d'établir le niveau de navigabilité acceptable au public et suggère une méthode pour la résolution de ce problème. Un examen préliminaire indique un niveau optimum de navigabilité.

On distingue les théories basées sur 'le taux des accidents survenus' et les théories basées sur 'les probabilités des accidents' et traite des considérations morales et techniques nées de ces théories.

Certaines conditions importantes relatives aux structures d'avions sont examinées à la lumière des facteurs exposés, les points faibles des conditions actuelles étant signalés. Allusion sommaire au problème de la fatigue de la cellule.

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PHILOSOPHY OF AIRWORTHINESS

Walter Tye*

1. INTRODUCTION

The title of this talk is not of my own choosing. It has a slightly pretentious ring which belies my more modest intention of presenting to you some purely personal reflections on airworthiness. These remarks are made against a background of civil aviation, although the underlying considerations of military and civil airworthiness have much in common. I will first speak of airworthiness generally and then refer to some structural aspects.

2. WHAT AIRWORTHINESS IS

I know of no satisfactory agreed definition of the word 'airworthiness'. I will not attempt to supply a succint definition, but it may be useful to indicate the meanings usually placed upon the word. Broadly, 'airworthiness' is that quality by which an aircraft makes its contribution to safety of flight. It is thus dependent on a number of other qualities such as controllability, stability, performance, structural strength and stiffness, reliability of moving parts, adequacy and accuracy of instruments, and so on. I myself would include in airworthiness the ability of the aircraft to offer protection to the occupants in a crash.

Airworthiness is clearly aimed at keeping safe those who travel in aircraft - both passengers and crew. Whether prevention of damage to the aircraft, in contrast to its occupants, is an airworthiness consideration is not such a clear cut issue. Of course, in most instances, adequate protection of the occupants automatically means that the aircraft itself will be sound. If this were not the case, I think we should more deliberately embrace the idea of prevention of damage to the aeroplane as an airworthiness function.

This leads to a closely related matter of serviceability. Theoretically we could design an aeroplane which suffered from a proof failure on every flight, but would nevertheless remain safe from ultimate failure. This might be narrowly described as an airworthy aeroplane, but it would be an extremely useless one. Although an airworthiness authority might disclaim responsibility for providing serviceability on the score that it was a matter for the operator to determine, I think that provision of serviceability might reasonably be considered as an aspect of airworthiness in the broadest sense.

There are others whose interests are to be considered - the persons on the ground and their property, and the other users of the air. Undoubtedly airworthiness considerations should take into account their protection and, with rare exceptions, the protection necessary for the sake of occupants of the aircraft amply suffices for the safety of the third parties.

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3. AIRWORTHINESS IN RELATION TO EXTERNAL CIRCUMSTANCES

Airworthiness cannot be considered in isolation. The various factors affecting safety are closely inter-related. The airworthiness provisions to achieve a desired level of airworthiness depend on:

(a) the particular conditions in which it is proposed the aircraft should fly;

(b) the general conditions prevailing in aviation at the time.

As regards (a) it becomes more and more necessary to match the characteristics of an aeroplane to its conditions of use. The operational role has, for the last 30 years, had a marked bearing on the structural strength needed. More recently the geographical zone - and its related temperature and humidity ranges - have become important considerations in aeroplane performance. Take-off and landing distance and rate-of-climb are nowadays closely matched with the available runway lengths and the obstacles which surround the airfields. To do otherwise would lead to prohibitive economic penalty at one extreme or to intolerable lack of safety at the other. In the structural field it is a growing custom in England to vary the safe life of components, which are liable to fatigue failure, according to the severity of the loading conditions experienced on particular routes.

This matching of airworthiness with operational use occurs on two levels. There is the coarse matching, as for instance the relating of strength to certain roles. But there is the fine matching by which the weight of the aeroplane, dictated by consideration of performance, is assessed for a particular flight having regard not only to the 'geometric' characteristics of the route, but also to the temperature of the day.

The growing refinement of approach is, at root, a correct and necessary trend. It permits the maximum advantage to be gained from the vehicle without intrusion into safety. But it has its practical difficulties and limitations. It places a heavier load on the crew and others responsible for operational organisation. One cannot carry precision and refinement of operation to such extent as to invite risks due to difficulty of adhering to complicated procedures.

Turning to (b) we have always, perhaps partly subconsciously, paid regard to the general circumstances of aviation when deciding on airworthiness provisions. For instance the skill and training of the pilot is assumed to be of a certain level. A large complex transport aeroplane could not be considered airworthy if the only pilots available to fly it were recruits under training.

But it is becoming more and more necessary to ask the question: 'Is it reasonable, having regard to the limits of human skill, to expect such and such an aeroplane characteristic to be satisfactory?' Airworthiness is becoming another branch of what is now called 'Human Engineering'. Most of us, who are ordinary engineers, have difficulty with the language and the lessons which the psychologist and physiologist have to teach us, but I am wholly convinced that if the aeroplane's airworthiness is to be properly adjusted to the abilities of man, such understanding is essential. The problem is made more difficult, because in deciding airworthiness provisions, we are usually considering extreme conditions rather than normal circumstances. The rarer accidents are, the more unfamiliar will the crew be with the circumstances occurring at the time, and the more difficult it becomes to assess how the human being will behave.

The occurrence of an accident provides the opportunity to study how, in fact, people behave in emergencies. I always feel it is a great pity if accident investigation ceases with the allocation of blame. Wherever possible an attempt should be made to find why a person behaved in the way he did.

4. RELATIVE NATURE OF AIRWORTHINESS

To describe an aeroplane as airworthy has no unique meaning such as is contained in the phrase 'the bottle is full' or 'the temperature is 200°C'. The former of these phrases describes an absolute condition; the latter a condition accurately measured on a universally accepted yardstick. To be airworthy simply means that a condition is met which, in the opinion of someone, is satisfactory.

There would be little to say if it were practicable to achieve absolute airworthiness, i.e. a condition of zero risk of accident from causes associated with the aeroplane. This is however unlikely to be attained in any future which I can foresee. Indeed, it is questionable whether 100% safety is the proper aim.

Even the matter of giving a quantitative measure of airworthiness is difficult. The nearest we can get is to measure the result, or perhaps I should say the inverse result, that is the frequency of occurrence of accidents attributable to inadequate airworthiness. Various yardsticks are used such as passenger fatalities per 10^8 passenger miles, accidents per 10^6 miles, and so on, each having a particular use according to the aspect we have in mind.

5. LEVEL OF SAFETY

There is no wholly satisfactory approach to the rational determination of what level of airworthiness is acceptable. The problem is a part of the even wider issue of what level of safety is acceptable. To illustrate this problem in general terms one may consider Figure 1. This begins with the notion of the total effort which we are prepared to put in. For instance, this might be the total man hours that a particular nation is prepared to make available to providing air transport. This effort can be distributed in various ways. It can be put into the construction of the aircraft, into the provision and training of crews, or into any one of many ground services, such as radio aids, meteorological services, operational organisation, etc. The distribution headings shown in Figure 1 are, of course, an arbitrary choice from among many possible ones. The object is to arrange the distribution so as to produce the best overall results.

Finally there is the achievement. There are the benefits, such as the ton-miles carried. However, an accurate statement of beneficial achievement must take account of other factors, such as speed -or time saved - possibly of comfort, possibly of the sheer ability to do a job which would not otherwise be done. But there is also the negative achievement, the 'detriments' which are a function of the accidents which occur, loss of life, and damage to aircraft.

If it were possible to express the benefits and the detriments in the same units, we could subtract the latter from the former to obtain a net achievement. It is this net achievement which really matters. For a given effort, we can generally improve the efficiency of the vehicle (e.g. in the respects of load carrying or speed) at the expense of an increase of number of accidents. Dependent on the relationship between the benefits and the detriments there may be a maximum net achievement with corresponding optimum rate of accidents.

This is illustrated in Figure 2 in which D the detrimental effect of accidents is plotted against B, the benefits of a useful vehicle. This Figure is a re-plotting of a later picture (Figure 3) the derivation of which I will soon explain. Meanwhile Figure 2 shows that if, for a given total effort, usefulness is bought at the expense of safety, there comes a point where the adverse effects of accidents begin to sweep up to large proportions. Hence, when we consider the net achievement A equal to B minus D there is an optimum, corresponding to a particular safety level.

I cannot carry this argument very far as it requires data which are not available and agreement on the importance to attach to such qualities as speed, comfort, etc., on the one hand and accidents on the other. There is, however, a simple numerical approach which is suggestive. In fairly typical scheduled air transport, of the total indirect operating costs, insurance premiums account for about 4 units out of 100 units. These 4 units are a measure of the cost of accidents, the 96 units being the cost of providing the air line service. These figures correspond to the present accident rate of about 1 accident in 10^7 miles.

Now consider a ten-fold increase in accident rate. The insurance cost would rise to 40 units. There would be no overall economic gain unless the more dangerous service could be operated for less than 60 units against the present 96 units. I think it extremely improbable that a purposeful relaxation of safety of this kind would produce a reduction of cost of this order. I have made an exceedingly rough calculation in which I have taken an extreme case of an aeroplane which would crash on, say, every other flight. Such an aeroplane could have a much reduced structure weight, much lighter engines, and the crew and maintenance engineers could be poorly paid personnel. Making some broad guesses, I think that the previous 96 units could not possibly fall below 30 units. In other words, to provide the air line service at all, no matter how dangerous, would still cost a fair amount (see Figure 3). This to me makes it reasonably certain that reduction in safety would not lead to overall reduction in operating cost.

We may also consider a ten-fold reduction in accidents. In this case the cost of insurance virtually vanishes. If this could be achieved without the cost of providing the service rising by more than 4 units, an overall gain would accrue. It seems unlikely that employing present knowledge and techniques that one could, in fact, improve safety ten-fold for such a small cost. This suggests that we are working near the optimum.

There is a detailed qualification to make. At present the liability of the air carrier in respect of loss of life of passengers is limited by international convention to a small figure. If passengers were insured by the air carrier to cover a figure more commensurate to the monetary value of a deceased person to his dependants, then the 4 units of insurance cost would increase, but not greatly and not sufficiently to alter the general conclusions reached above.

The preceding argument that we are at present near the optimum, does not necessarily mean that no further improvement in safety will ever be desirable. It rather means that at the present state of the art, improvements in safety would in general be bought at too high a cost. However, in the long run, we may reasonably expect to develop better methods of design or operation, which will permit improved safety without serious penalty. Inexpensive gain in safety is more likely to result from research and development rather than from any arbitrary decision concerning safety levels.

Even though we lack the means for fully rational analysis to determine optimum level of airworthiness, I am not altogether discouraged. In problems as intricate as this, mankind has a curious ability to reach right conclusions without knowing how he has done so. This is of course more true of self-supporting organisations, where the price of the ticket is in direct relation to the cost of the service. In such cases the passenger decides for himself whether he is satisfied with the net achievement. It is more difficult in civil aviation, which receives direct or indirect subsidies, to use passenger reaction as a criterion. This places special responsibilities on Government and other organisations who control airworthiness, as to some extent such agencies are obliged to decide what the public wants rather than to ask them. With such encouragement for bureaucratic control it is all the more important to try to understand the public's needs. It is all too easy for airworthiness agencies to try to avoid immediate criticism by aiming at '100% safety', when in the long run this may cost more than the world at large is prepared to pay.

6. ACCIDENT RATE - ACCIDENT PROBABILITY

I have referred to level of airworthiness in terms of the associated accident rate. I now want to distinguish clearly between the expected average accident rate and the probability of occurrence of an accident. The intending passenger is concerned with the probability of occurrence of accident on the particular flight and not with the expected long term average accident frequency. At first sight this may sound a minor quibble, but there is an important distinction to be made.

If we adopt long term average accident rate as the sole criterion, then we may accept a framework of airworthiness requirements which allows flights at a higher than average risk provided that they are balanced by a sufficient number of flights with a lower than average risk. On the other hand a policy of maximum probability of accident offers the same potential chances of arrival on each and every flight.

The underlying moral principle is simple. If person A is responsible for the safety of person B, and if A knowingly allows B to be exposed to risks materially greater than the normally encountered on the particular undertaking and if A fails to draw this fact to B's attention, then A is blameworthy.

The most illustrative example of this in recent times concerns the allowance made for the effects of temperature on aircraft performance. It has long been known that the higher the temperature, the lower the performance. Until aeroplanes operated the world over, and more particularly until the advent of the turbine engine, the influence of temperature variation on performance was not so marked as to cause serious concern. Nowadays, however, if on a given route an aeroplane is operated at the same weight regardless of the temperature prevailing, the difference in performance between the hot day and the cold day is sufficient to cause a material difference in risk.

We could, of course, pitch the performance so high that even on the hottest day the risk was negligibly small, and then to fly on all other colder days at this reduced weight. This would be prohibitively uneconomic. If we fix the performance to be adequate at a medium temperature, and take no further account, then on cold days the aeroplane would have a surplus of performance, and on hot days deficient performance. Now it would not follow that an accident would necessarily occur on every occasion the weather was hot, but the probability would certainly be higher. In fact, over a period of time there would tend to be an accumulation of accidents in above average temperature days. Although the average yearly accident rate might be acceptable, the probability of accident on the hot days might be totally unacceptable.

In recent years, civil airworthiness authorities have been grappling with this matter and have been finding practical procedures for taking direct account of temperature by varying weight accordingly. By this process, at least so far as this factor is concerned, the concept of maximum acceptable probability of accident, in contrast with acceptable average risk, is being implemented.

I have dealt at some length with this matter as it pervades the whole of one's attitude to airworthiness. Over the years airworthiness experts have engaged on what is usually called rationalisation. Really this means a process of developing requirements so that they more directly and precisely take into account those factors which influence risk.

7. 'RATIONALISATION' OF REQUIREMENTS

Much of this work of rationalisation has had as its motive the removal of unnecessary margins in order to achieve better economy of weight. I recall the early change in the landing gear strength requirements. The requirements were first expressed as X times the take-off weight of the aeroplane, and X was a fixed number. This was replaced by a requirement for strength at landing weight in terms of the loads corresponding to a velocity of descent. This change permitted credit to be taken for improved design of shock absorber legs. Later arbitrary drag loads were replaced by loads corresponding to those which occurred during spinning-up of the wheels on impact. The rationalising step was necessary to account for the large difference between one aircraft and another in respect of touch-down speed and wheel inertia.

Broadly therefore all the processes of rationalisation which we have observed have resulted in the achievement of a more uniform minimum level of airworthiness from type to type and, in some instances, from flight to flight. The corollary is that the economic penalties associated with the provision of airworthiness are more justly spread, since with uniform airworthiness level the aeroplane neither carries unnecessary weight nor does the risk become unacceptably high.

8. AIRWORTHINESS IN RELATION TO KINDS OF USE

It is not unusual for the level of airworthiness required to depend on the kind of use to which the aeroplane is put. By 'use' I mean, for example, carriage of passengers, or of goods, or private flying, or agricultural work. According to the kind of use, we may put varying degrees of importance on the accident in relation to the importance attached to providing the particular service.

Some countries distinguish between the level of airworthiness for public transport in contrast with private flying. Some distinguish between passengers and goods. Others distinguish between scheduled and non-scheduled services. In some cases it is difficult to see why such distinctions have been made. However, there appears to be no fundamental point here. It is not unexpected that the varying circumstances of the nations of the world should result in varying conclusions as to the importance of one kind of use compared with another.

9. STRUCTURAL AIRWORTHINESS

Against the general background of the earlier part of this Paper, a few remarks will next be made about structural strength matters. The structural side of airworthiness developed more quickly and comprehensively than other aspects. Perhaps this was due to the fact that with early aeroplanes almost every kind of failure could occur without catastrophe, other than structural failure in flight. Perhaps it was also the deceptive ease with which one could 'prove' on paper that the strength was sufficient, which encouraged such an early blossoming of structural requirements. Whatever the reasons, the structural aspects have until recently tended to be better comprehended as a airworthiness problem than have other design matters. In the last few years, however, aeroplane performance has tended to go into the lead. The trends I have described earlier are to be seen in the development of recent British performance requirements.

On the structural side there is now some lee-way to be made up. The next five or ten years should see very considerable advances for at least four reasons:

1) the wealth of evidence of loads in flight which has been accumulated and continues to grow; the requirements do not yet adequately reflect all that this data can tell us;

2) the big changes of aeroplane design;

3) the continued pressure to remove any margins unnecessary for safety;

4) the growing importance of fatigue in relation to static loading conditions.

10. LEVEL OF STRUCTURAL AIRWORTHINESS

Let us briefly examine the question of whether the present level of structural airworthiness is of the right general order. Making various assumptions, which are described in Appendix I, a rough estimate of overall cost is made corresponding to various levels of wing strength (see Figure 4). With increasing wing strength, the structure weight increases and the payload falls, causing increased cost of providing the service. But accidents due to failure of the wing structure also decrease, thus reducing insurance cost. The calculation suggests an optimum strength a little less than is presently provided.

I would not use this as an argument for reduction of strength. Accidents due to structural failure appear to upset public confidence more than accidents from, say, pilot error. Therefore, since the cost curve is a flat one, it seems reasonable enough to work a little on the side of greater safety. Substantial increase beyond that at present provided does not however seem practicable.

In considering whether any reduction of static strength is desirable or justifiable, it is also necessary to have regard to the fatigue problem. As regards the tension surface of the wing, if this is designed right down to static strength requirements for transport aircraft, and if modern high static strength light alloys are used, a large volume of test results suggest that the average fatigue life will typically be about 30,000 hours. The 'safe' life would be some smaller figure dependent on one's fears of the consequence of fatigue cracks. Now, a reduction of static strength of 10% would lead, other things being equal, to a reduction of average life to about 20,000 hours. Much the same argument applies to the pressure cabin which, if designed down to the conventional static factor, has a very short life. Hence, it seems that the need to provide reasonably long fatigue lives will tend to increase rather than decrease static strength.

11. COMMENT ON FATIGUE

Time permits only one other comment on fatigue, and this concerns so-called 'fail safe' design. By fail safe I mean a design such that if cracks occur, they will be of such a kind, in such positions, and will grow sufficiently slowly, that there will be no material loss of static strength in the period prior to finding the crack on inspection.

Provision of fail safe characteristics is analogous to the duplication and triplication of items which goes on elsewhere in the aeroplane. We have long since ceased to rely on a single engine for flights where an engine failure would be catastrophic. Most items of essential equipment are multiplied. This is done because it has proved impracticable with mechanisms to achieve the extremely high degree of reliability which would be necessary were catastrophe to result from a single failure. In other words, it is more feasible to use two moderately reliable parts, the coincident failure of both being extremely improbable than to strive after a single part of impeccable reliability. Something of this thinking may well apply to the structure, more particularly under fatigue conditions where it is so difficult to be absolutely certain that one has reduced the risk of fatigue failure to a small enough figure.

If the structure embodies members (such as single spars) which do not possess fail safe characteristics, it is necessary to replace such parts at a small fraction of their expected average fatigue life. Due to the difficulties of reliable estimation, and to the large natural scatter of fatigue lives, it is British practice to divide the expected average life of a part by a factor of about 5 to obtain the 'safe life' at which replacement is required. On the other hand, if the occurrence of cracks was non-catastrophic, the aeroplane would continue to fly until such time as the incidence of cracks at inconvenient times became too high for the operator to accept. Suppose that the operator allowed the aeroplane to fly to about half their expected average life before initiating replacement, then perhaps in a fleet of 40 aeroplanes only 1 would have suffered a crack prior to the replacement stage. But on this basis the operator would have benefited by using the parts for 2½ times the life allowed on the previous so-called 'safe' life scheme. In other words, if cracking is no more than an inconvenience, and not a catastrophe, we can so reduce fatigue life margins as to make a very large increase in the useful life of a particular part.

12. RELATION OF STRUCTURAL AIRWORTHINESS TO EXTERNAL CONDITIONS

I referred earlier to the general trends towards close matching of the airworthiness qualities with the duties of the aeroplane. Let us see how far this process has gone in the structural field. For this purpose consider the principal loading actions:

(a) those due to gusts normal to the aeroplane flight path;

(b) those due to pitching manoeuvres.

In Tables I to III the left-hand column shows some of the principal factors which have an influence on strength. The right-hand columns indicate the extent to which current civil airworthiness procedure takes account of these influencing factors. It will be seen that only the most obvious are taken into account.

Looking first at Table I the very extensive collection of V-g records over past years has enabled us to form a fairly close idea of the magnitude and frequency of gust loads at low and medium heights. More recent results from other kinds of recorders enable some allowance to be made for altitude, but the evidence is not yet really adequate. No allowance is made for the part of the world in which the aeroplane flies. My guess is that this may be important for fatigue considerations, but not very important for static strength.

Future problems are the possible reduction of strength when radar detectors are fitted to warn the pilot of severe turbulence. The question is whether the pilot, given this extension to his knowledge of the surroundings, could in practice avoid severe turbulence to such a marked degree that reduction of strength would be justified. Partly related to this is the commonly made assumption that the pilot reduces speed from his cruising speed to a lower 'rough air speed' when encountering turbulence. If the aeroplane is very fast it may be unable to shed speed before entering turbulence unless better warning is given to the pilot than he receives at present. I suspect that for very high speed aeroplanes considerable economies in structure weight may become possible when radar detection is fitted.

We still do not know a great deal about the shape of a gust, i.e. its velocity-space characteristics. We make various rather arbitrary assumptions about gust gradient distance which enables us to analyse statistics of loading into a form which can then be used for future design purposes. However, if the characteristics of the aeroplane change markedly, e.g. the large more flexible wing, or the delta plan form, then it becomes much more important to know the true 'shape' of gusts.

In Table II pilot initiated pitching manoeuvres are shown. For larger transport aeroplanes gust loading is overriding, so no serious problem arises from lack of refinement of the pitching manoeuvre requirement. Perhaps the only matter to mention is the advent of power operated controls which make it possible for the pilot's hand load and movements to be very different from those which are customarily found in manual controls. This could lead to risks of over-stressing. While there may be a problem here, I think it should be tackled by making the controls suit the strength, rather than vice versa.

Table III illustrates a big area of uncertainty, namely the speed margin to provide between the cruising speed and the diving speed. For the light aerobatic aeroplane, this is determined by the manoeuvre it is intended to perform, and past practice forms a fair basis. For large transport aeroplanes very high speed is usually inadvertent and stems from some form of upset, for example turbulence, or auto-pilot runway. Now, in the medium altitude aeroplane V-g records show surprising large speed increments above cruising speed. On the other hand, the high altitude jet has sufficient power to cruise at speeds very close to the diving speeds at which Mach Number influences are felt. Thus, to apply the margins, indicated as necessary by low altitude aeroplanes, to high altitude aeroplanes, would impose a very severe problem. Possibly the reduced turbulence at high altitude will result in less severe upsets and less onerous speed margins. Current opinion is swinging towards relatively close margins being all that is necessary, but an answer based on more positive evidence is highly desirable.

A further speed margin problem occurs in the high altitude aeroplane. In the past it has been customary to specify that the aeroplane should have strength to cope with a high velocity up gust, at a forward speed sufficiently high that the aeroplane is not stalled by the gust. This requirement in effect determined the rough air speed as the best compromise between risk of stalling and risk of structural failure. As altitude increases, and with it Mach Number, the maximum lift coefficient falls and the increment of lift coefficient due to a given gust increases. Hence this concept of rough air speed rapidly increases, approaching the cruising speed at medium altitude, and exceeding it at high altitude. Thus a stage is reached when the aeroplane cannot fly at a speed sufficient to avoid being stalled by a gust. The question here is whether this matters. Does the transient stall due to a gust really cause an upset of any significance?

13. CONCLUDING REMARKS

In a Paper such as this there seems little point in trying to summarise the conclusions. I have tried to suggest some viewpoints from which the questions of airworthiness can be examined, and in particular I have suggested those structural airworthiness matters most in need of consideration. I must assume personal responsibility for any opinions expressed, but I am indebted to my employers for permission to deliver this lecture.

TABLE I

Gust Loads

Influencing Factors	*Examples*	*Extent to which Allowance is made*
Atmospheric condition	Geographical region Altitude	No Yes
Operational control	Avoidance of severe turbulence (use of detectors) Reduction of speed in severe turbulence	No Yes
Aeroplane characteristics	Speed, wing loading, etc. Stability Flexibility of structure	Yes Not usually Not precisely

TABLE II

Normal Accelerations

(Intentional Manoeuvres)

Influencing Factors	*Examples*	*Extent to which Allowance is made*
Operational role	Normal transport or Aerobatic	Yes
Skill of pilot	Pilot under training or Fully qualified pilot	No
Handling qualities of aeroplane	Longitudinal stability Stick force and movement characteristics	No No

TABLE III

Speed Margins

(Between Cruising and Diving)

Influencing Factors	*Examples*	*Extent to which Allowance is made*
Operational role	Normal transport or Aerobatic	Yes
Aeroplane characteristics Gustiness of air	Those factors which influence inadvertent speed increase - passenger movement; autopilot runaway, turbulence	No

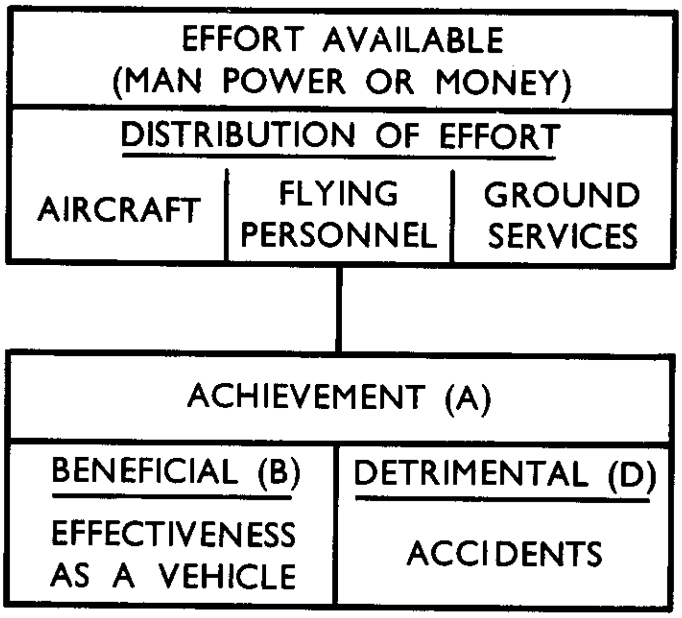

Fig.1 ' Input - Output Diagram

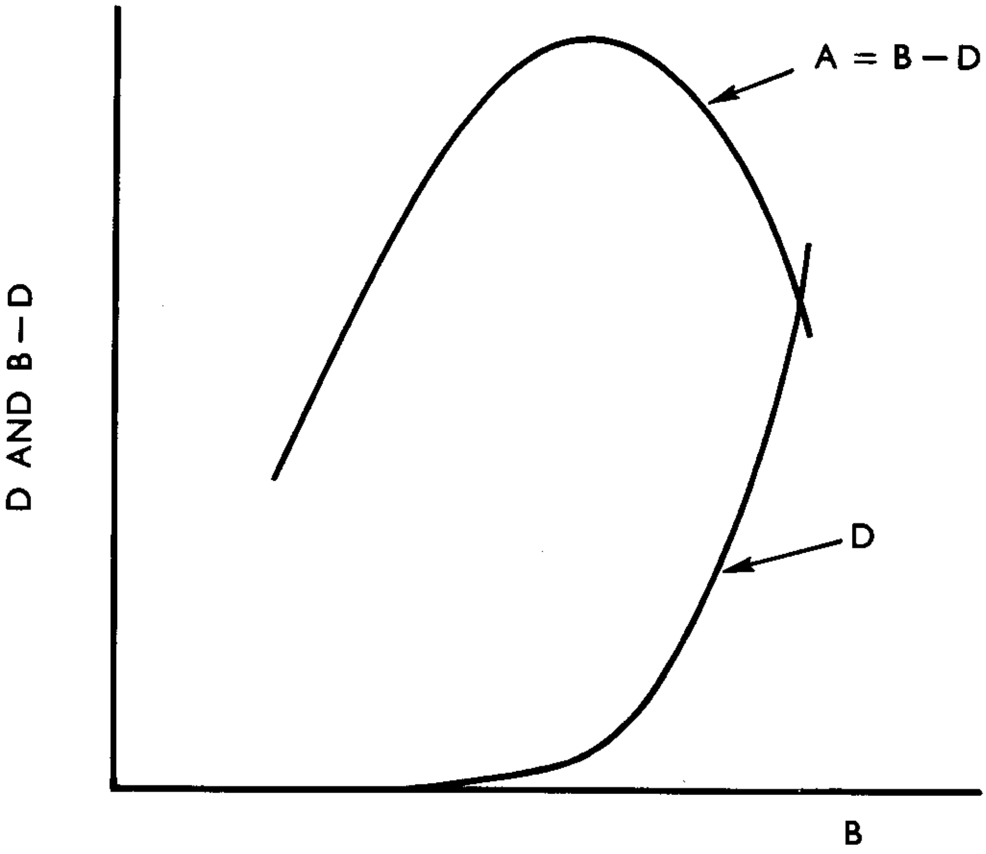

Fig.2 Maximisation of Achievement

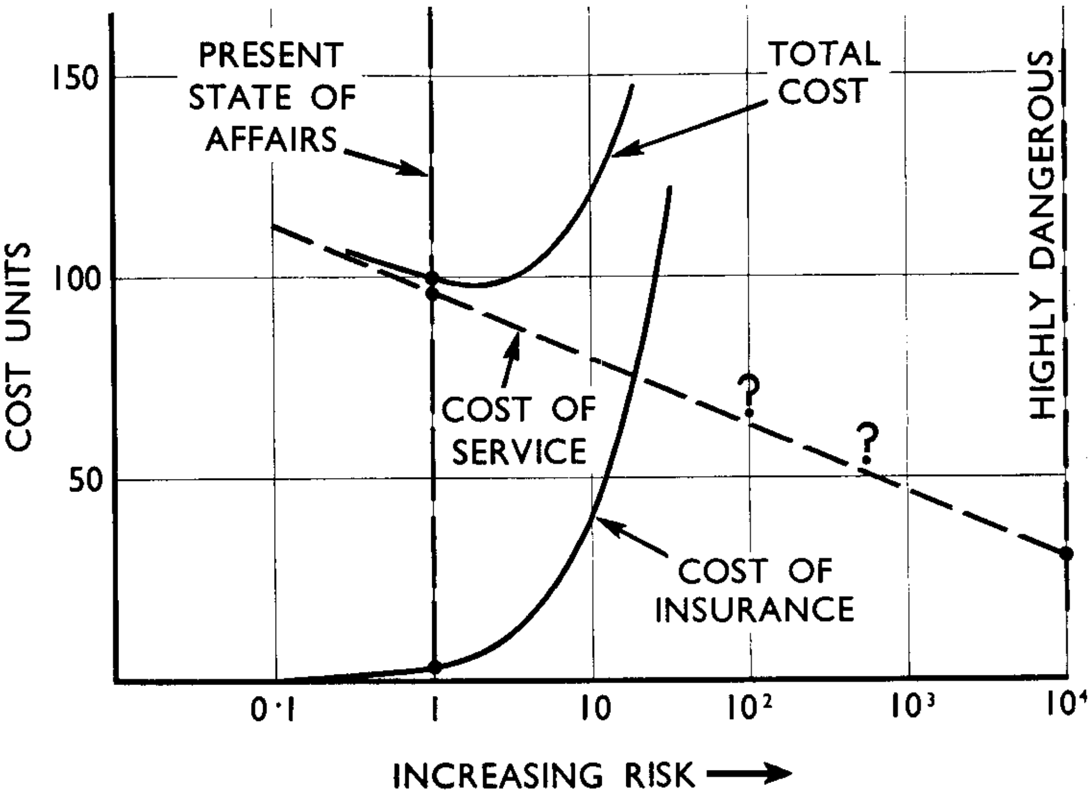

Fig. 3 Optimum Risk Diagram

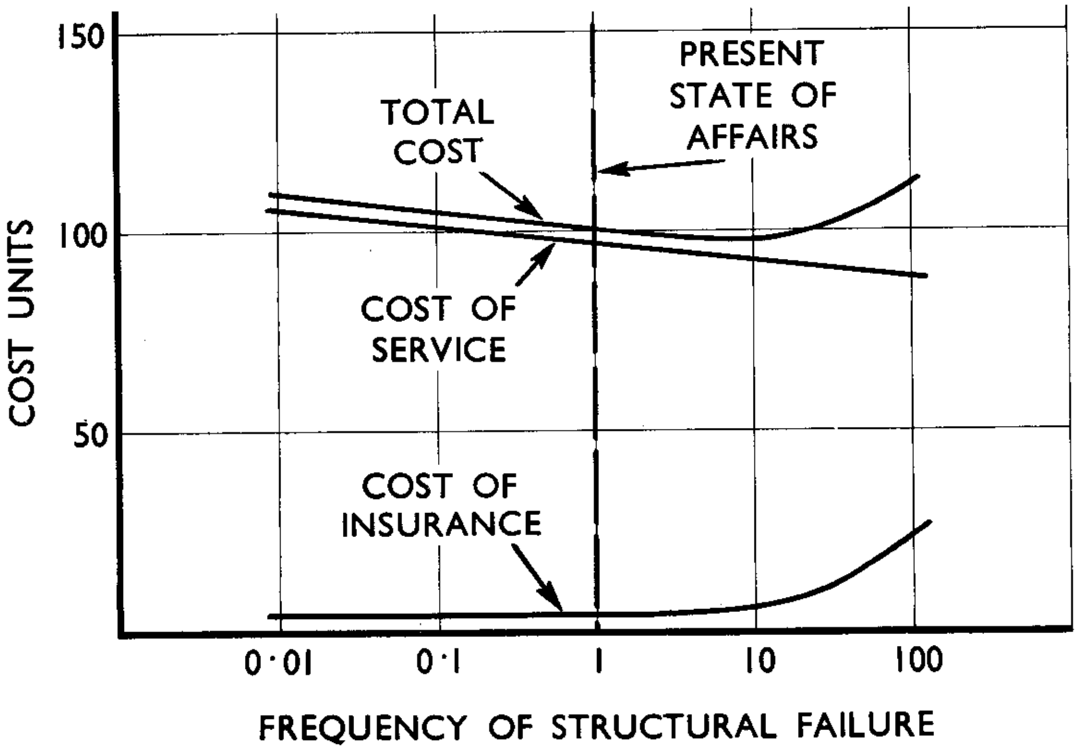

Fig. 4 Optimum Strength Diagram

APPENDIX

OPTIMUM STRUCTURAL STRENGTH

APPENDIX

Optimum Structural Strength

Basis of calculation:

Structural weight which is directly proportional to severity of gust design load	8% of gross weight
Payload typically	12% of gross weight
Accidents associated with structural failure in gusty conditions	5% of total

Ten-fold change of frequency corresponding to change of gust magnitude of 7 ft/sec

Frequency of structural failure	100 F	10 F	F (Normal)	0.1 F	0.01 F
Increment of gust magnitude	-14	-7	0	+7	+14
Approximate change of strength level	-14%	-7%	0	7%	14%
Payload	13.1%	12.6%	12%	11.4%	10.9%
Frequency of all accidents	5.95 X	1.45 X	X	0.95 X	0.95 X
Cost of services	88	91.5	96	101	106
Cost of insurance	24	6	4	4	4
Total cost	112	97.5	100	105	110

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