

N72-29913

DETECTION OF STRUCTURAL DETERIORATION AND ASSOCIATED
AIRLINE MAINTENANCE PROBLEMS

By H. D. Henniker
British European Airways
United Kingdom

and

R. G. Mitchell
British Overseas Airways Corporation
United Kingdom

STRUCTURE INSPECTION

The requirement to operate a civil transport aircraft on scheduled operations for a period of perhaps 15 to 20 years, with a constant level of safety, creates a need for a system of continuous monitoring of the structure. At the same time it is implicit that no unnecessary work should be done and that the time out of service should be minimal.

It is perhaps necessary first to outline the approach to the maintenance and inspection of the components and systems of the aircraft. It has become apparent that most components, and therefore systems, suffer primarily from random effects. In a relatively few cases a life can also be dictated by a wear-out rate, but random defects predominate and have to be dealt with by inspections and functional checks so that the defect is detected at the earliest opportunity.

By duplication, or triplication, the integrity of the aircraft can be maintained, and the study of reliability levels can set the periods for inspection or checks which limit the period of dormant failure. Since a large number of components are functioned on each flight, the number of additional checks required to reveal a dormant fault is reduced.

It can be seen that for systems and components, the optimum periods for inspection, maintenance, and overhaul can be safely developed in respect of a particular aircraft type and a particular operation by a process of recording and analysing data on failures and strip reports and by general experience gained in service. The aircraft itself determines its own maintenance schedule.

In respect of structures, a different approach has to be adopted. With the advent of fail-safe structures, the duplication of load path which provides failure survivability has been achieved. Unfortunately, no ready indication of failure is available. The purpose of inspection is therefore to detect failures before they become catastrophic,

and to detect such deterioration with time and use which, in itself, will lead to failure. The object of maintenance is to restore the structure to its original condition and to maintain the failure survivability originally built into it.

It is natural that there should be a desire to use the same downtime of the aircraft to deal both with structure and systems. Improved component life and improved reliability lead to longer intervals between major maintenance inputs. There is therefore an inevitable clash of requirements because the structure tends to deteriorate with age and demands increased vigilance.

The structure inspection that emerges is therefore a compromise influenced by opportunity, and it changes with time. In deciding initially on the nature and extent of inspection, the design philosophy and the background of fatigue and fail-safe substantiation tests are of paramount importance. A structure inspection schedule for the lead fleet of a new type of aircraft is arrived at by extracting the structure content from the total schedule. A typical structure schedule is outlined as follows (in this schedule flight-hours and flights are approximately the same):

At each departure and at each 72 hours elapsed time: A general walk-around check which would detect gross damage, due to either serious structural failure or damage inflicted on the ground.

At each 300 hours or flights: A general visual inspection of the complete exterior, supplemented by opportunity inspection of such areas where access is required for maintenance and servicing. This check is also used to monitor any item on special surveillance.

At 2000 hours (12 to 15 months): A more detailed visual inspection of the lower fuselage, externally and internally, including pressure bulkheads, and door-surround structure. This is aimed primarily at detecting corrosion. Ultrasonic checks are also made at this interval on bonded stringers in the lower fuselage, and radiographic inspection is made in those areas of the lower fuselage not accessible for visual inspection.

At 5000 to 6000 hours or flights (2 to $2\frac{1}{2}$ years): The major maintenance check in which all access panels are removed and all structure inspected visually. This represents the most detailed routine visual inspection of the structure possible by normal access, that is, without stripping out interior trim and lagging. At the same intervals – but not necessarily at the same time – radiographic inspections are made of closed structures such as

- Horizontal stabilizer
- Fin
- Primary control surfaces
- Slats, flaps, airbrakes, and so forth

All these inspections are carried out on all aircraft in the fleet. The extensive areas of the internal structure of the upper fuselage (above floor level) are the subject of a sampling procedure. This approach is made because of the extensive downtime involved if all trim, soundproofing, thermal lagging, air ducts, and so forth are removed. Experience has shown that the area below floor level is that most prone to corrosion. This can occur early in the aircraft life and can progress relatively rapidly. Experience also suggests that the upper areas dry out more rapidly, and corrosion is only likely at a later stage and will develop less rapidly.

The sampling programme is therefore started in about the 5th year of operation (10 000 to 12 000 hours). Because of the large work load and downtime involved, radiographic inspection is used extensively but is supported by visual inspection as follows: In each of the 5th, 6th, 7th, and 8th years of operation, one composite aircraft is examined, 25 percent by visual means and 75 percent by radiographic means. The samples involve not less than 60 percent of the fleet, and at the end of this period one complete composite fuselage will have been examined visually; and three, radiographically. It is planned that after the 9th year the sampling will be extended so that by the 20th year all aircraft in the fleet will have been examined completely both visually and radiographically.

The choice of inspection method is basically economic. Where visual inspection is viable, it is preferred. Radiography is an adequate tool to detect the significant cracking of internal structure such as frames, stringers, and cleats. It can also indicate corrosion and paint flaking – but requires considerable skill in interpretation. A 10-percent reduction in material thickness can be reliably detected, provided the corrosion deposits are not retained. The critical corrosion along the heel line of a stringer or lap joint is detected mainly by evidence on the adjoining surface.

In a particular case where this inspection schedule has been applied up to an average aircraft life of 12 000 flights or 6 years, 38 defects have been identified. Of these, 16 involved fatigue cracks, in secondary structure, and two involved corrosion in primary structure. Most of these defects were detected on the major check. In the period concerned, the major check period has been progressively increased from 3000 to 5000 hours, or flights, on the basis that those items which have shown up and are not subject to modification action are retained as specific items on the annual or 300-hour inspection.

For detection of deterioration that could be the cause of fatigue, this increase in the major check period is feasible. If, however, the major check is to form the basis for detection of fatigue cracks concerned with the fail-safe design concept, then the period between inspections must have some finite limit. This should be the interval assumed in the design concept from first detectable crack to the point at which crack propagation reduces the static strength to proof load. Ideally, this should be demonstrated by a full-scale test for all fatigue-critical regions of the structure. For the aircraft concerned

the period is not less than 5000 flights, with proof load applied each 2500 flights. On this basis each aircraft structure must be examined in detail at maximum intervals of 5000 flights. It might well be argued, however, that when the aircraft life is relatively low, so that this interval represents a significant part of the probable scatter between identical failures on aircraft of the same fleet, then staggered inspection over a longer period is perhaps justified on the basis that no cracked aircraft will fly more than 5000 flights before the defect is detected in another of them. It is implicit that all aircraft will be checked within a short period from the discovery of the first defect.

As the aircraft life increases, so that the safe period of crack propagation becomes small in relation to the probable scatter in failure, the inspection would have to be increased to cover each aircraft in 5000 flights. As the aircraft life increases still further so that the probability of failure is high and simultaneous failures become probable, it would be prudent to reduce the inspection interval.

Finally, it would seem logical that whilst the ratio of test life to aircraft life is 5 or more, inspection can be done on a sampling basis only, to assess the general deterioration, such as corrosion. Thus, an ideal structure inspection schedule would result and would be based on aircraft life and test life. (See fig. 1.) The practical problem would then be to integrate this schedule with the remainder of the maintenance requirements and the seasonal demands on aircraft.

If there are several operators involved in making up a significant fleet of "lead" aircraft, there is a case for spreading the initial sampling across all the aircraft to thus reduce the requirement on the individual operator. This involves a reporting system so that the manufacturer can coordinate results. There are possibly limitations to this approach, since each operator tends to operate on a different route structure and in a different environment.

Most aircraft types operated by British European Airways (B.E.A.) have carried some form of in-flight recording equipment, either fleetwise or on selected aircraft. In some cases this has been a condition in the terms of the warranty on the fatigue life of the primary structure. The recording equipment has fallen into two categories:

- (1) Continuous recording of acceleration thresholds or strain-range thresholds on entire fleets
- (2) Continuous recording of acceleration thresholds together with other flight data on a limited number of aircraft

In the first category, counting accelerometers mounted at the center of gravity record threshold counts at increments of 0.2g between 0 and 2g. Total counts in each level are read and recorded at each 300-hour check.

Fatigue-meter data are fed back to the respective manufacturers at intervals, together with operational data from which a typical flight plan, representative of the route network, can be deduced. This is done by taking significant samples of summer and winter operations and includes take-off weight, fuel state at take-off, cruise altitude, and flight duration. Fuel burn-off is computed and thus actual weight and fuel state at each phase of flight are deduced. The aircraft manufacturer then computes fatigue damage rate and compares this with the damage rate used in the fatigue test or calculated fatigue life.

Similar procedures are adopted in the case of strain-range counters, except that these give a more direct indication of damage rate and require less operational data.

In both cases the manufacturers concerned have stated that an increase in service life of up to 30 percent has been possible compared with the service life that would otherwise be imposed. So far, this has all been in respect of those parts of the structure which are on a "safe life" basis.

Both these types of recording instrument are such that they are quite practical for an airline to carry on all aircraft. They need little attention and are reasonably reliable. As long as there are safe-life items in the primary structure, the improvement in life that has been possible would appear to be adequate return.

The more comprehensive type of observer unit is more questionable. Attempts have been made on two types of aircraft to get a simultaneous record of acceleration counts, speed, height, time of flight, and so forth by use of film recorders, switched on at take-off and off on landing by an airspeed switch. They have been installed in perhaps two aircraft of a new fleet with the object of obtaining more complete data for an initial period. The problems with film recorders have been

- (1) Short duration of film leading to either much lost recording time, or very frequent film changes
- (2) Unserviceability revealed only after film development
- (3) Reference still required to flight documents to obtain aircraft weight and other data
- (4) Low order of reliability

The authors have found from experience that only about 10 percent of the total hours flown by the aircraft equipped with the film recorders were satisfactorily recorded. It does not seem practical to use this type of equipment in the environment of day-to-day airline operation.

It has been B.E.A. policy to record manually maximum cabin differential pressures for each flight on all aircraft. The pilot records this in an appropriate box in the techni-

cal log. This information is extracted and the total flights in each band of pressure, in increments of 1/2 psi, are computed. Where there are maximum lives prescribed for modification or replacement of structure, this information is forwarded to the manufacturers and to the airworthiness authorities at six monthly intervals. All unrecorded flights are assumed to be at maximum differential pressure, and a factor of 10 percent is added to the recorded pressures to allow for inaccuracies of recording. At the same time, the equivalent flights at maximum differential pressure are computed and forwarded to the inspection department to allow mandatory life requirements to be monitored.

This policy has yielded significant benefits where safe-life situations have existed. It allows advantage to be taken of all flights where only low pressures are needed, yet retains the advantage of operational flexibility, such as cruise altitude on longer flight sections and occasional high rates of descent. This flexibility is otherwise lost if pressure is permanently reduced. On one type of aircraft it has allowed an extension from 12 500 to 30 000 flights before a major modification, with its accompanying weight penalty, was required and from 17 000 to 50 000 flights before wholesale replacement of fuselage skins.

It is true to say that the advantages so far gained by continuous recording in airline operation have all been associated with safe-life structure situations. It is questionable whether real advantages can accrue in the case of a truly fail-safe structure. One of the advantages, to the manufacturer, of a fail-safe philosophy is that the duration of the full-scale test can be reduced. If the structure is designed for a long fatigue life, it is probable that natural failures will not be produced on test. Provided adequate fail-safe tests are carried out, this may be satisfactory from an airworthiness point of view, but it would seem pointless, in this case, to try and correlate test and actual aircraft usage in order to try and predict the operator's long-term planning requirements.

Only if full-scale testing is extended until fatigue failures occur – and perhaps only if these then indicate the need to impose a finite life when action must be taken – can better data on actual aircraft usage yield some dividends.

MAINTENANCE ASPECTS

It will be appreciated that although the modern public transport aircraft is a highly complex and sophisticated engineering product, it is also the means by which the airlines earn their revenue. The aircraft utilisation rate, which varies during the year and reaches its peak during the summer months, is laid upon a foundation of known work programmes which stipulate that various aircraft will be undergoing maintenance for block periods of time during the year. It will be seen, therefore, that in order to support the commercial plans, an extremely well-devised maintenance programme is required. For

an airline to operate at optimum efficiency, the maintenance programmes are planned to ensure that the work requirement is matched by the necessary spares, materials, tools, equipment, and labour at the commencement of the hangar check.

The unexpected and nonscheduled problem is, therefore, strictly an economic embarrassment. The discovery of a fatigue crack, corrosion, or any of the other mechanical faults which beset airline operators from time to time and which must be repaired on an urgent basis are the ones which really cause the headaches.

Ideally, the airline engineering base should be a facility carrying out planned maintenance and changing or repairing wornout components. This is, of course, an ideal situation which never exists in practice. For instance, a piece of ground-support equipment could be run into the side of an aeroplane and thus cause a delay to the service. Similarly, the work necessary to repair the unexpected crack in a major piece of structure can soon seriously upset the best planned engineering commitment and rapidly lead to nonavailability of aircraft.

It must also be remembered that there will be an internal conflict of interests within the airline. The production and maintenance departments are charged with producing aeroplanes for service to meet the commercial demands, and an engineering requirement which may extend the hangar check times or takes aircraft out of service is resisted, unless vital to continued safe operation. Also, since modern aircraft construction is making ever-increasing use of integrally machined components, which in themselves are much more difficult to repair in terms of time and complexity than the riveted skin-stringer combination, it also follows that the flow of spare parts from the manufacturer in the event of a rash of fatigue problems across the fleet could be inadequate to meet the demand.

All aircraft exhibit cracks in various structural components. Many of these, having relieved a local stress condition, will then remain static in length for a considerable period of time, and the aircraft will continue in service with these known defects. Normally such defects are examined for signs of propagation at each scheduled inspection until the part can be replaced or repaired, ideally at a convenient hangar check. This applies mainly to multi-load-path and secondary structure, but of course all cracks and defects are evaluated and a course of action decided upon which is dependent upon the significance of the defect. In the case of more serious defects the normal procedure is to raise a special check on the remainder of the fleet to determine the extent of the problem fleetwise. The speed at which the fleet examination takes place, of course, depends upon the severity of the initial defect. In this way the extent of the problem is assessed and the final action will take the form of a modification or repair, which can be raised either by the airline or manufacturer, or by replacement on a lifed basis. In many cases the defect is subsequently monitored by the addition of a specific item to the approved

maintenance schedule for inspection at appropriate intervals, or included in the reportable structural inspection programme.

In the case of a repair, the structure is usually returned to the "as new" condition, but when this is impractical or economically not justified, the fatigue life of the repair must at least match the residual life of the aircraft. In many cases when extensive testing or investigation of a fatigue problem is required, it may be necessary to incorporate a temporary repair which satisfies limit loads and thus keeps the aircraft flying. The long-term action which may require a slightly more extensive repair can then be carried out at a later stage, usually at a major overhaul. It has been found from experience that the manufacturer's solution to most light-alloy fatigue failures invariably results in a steel replacement.

Once a defect is found, a repeat inspection of the area is established, which can be extremely frequent in serious cases. The general accessibility and nature of the defect will determine the method of inspection, that is, visual or nondestructive testing techniques. In any event the general aim is to implement modification-campaign action to eliminate the defect and its associated inspection.

When a new defect is found, the airline informs the manufacturer, who then advises all operators of similar equipment to inspect for that particular defect. The manufacturer's notification usually ranges from a newsletter covering general advice, the service bulletin which forms the usual channel of communication, to the service cable for serious problems which require rapid investigation.

Since fatigue failures are generally related to total flying hours or landings, it follows that an airline operating "young" aircraft is less likely to be hit by the nonscheduled problem than an operator with older aircraft of the same type, and has a better chance of carrying out the rectification on a planned basis.

A large number of fatigue problems encountered can be traced to detail design faults, and occasionally the classic "don'ts," such as sharp section changes and stress raisers, still seem to be perpetuated.

It has been found from experience that unnecessary disturbance of an area during maintenance can in fact be detrimental in the long run. For example, abrasion of surfaces can break down sealants, particularly in integral fuel tanks, and minute scratches are then susceptible to corrosion or crack initiation.

The Corporation is an approved design organisation and designs and incorporates a great deal of repair work, particularly to components. For example, the Corporation has a great deal of experience on the repair of honeycomb structures. Any repair work must maintain the aircraft to airworthiness requirements. This, of course, includes correct heat-treatment techniques, particularly with the high-strength steels, and maintenance

of adequate strength reserves after such rework. A copy of the repairs is automatically sent to the manufacturer for his information, but naturally in the event of serious problems the manufacturer is consulted prior to making the repair.

Although the primary airframe structure, critical joints, representative panels, and the like are subjected to extensive fatigue testing at the design and construction stage to prove the integrity of the basic airframe, secondary structure does not receive the same consideration. Experience shows that defects in secondary structure tend to be repetitive and are both costly and time consuming to repair or replace. For example, certain areas of most aircraft floors require frequent replacement because of corrosion under and adjacent to galley and toilet areas and for damage due to cargo loading and repeated walking traffic. It would seem that the original floor is largely designed by static load requirements on the grounds that a stronger and longer lasting floor, because of the weight penalty incurred, is not justifiable on economic grounds. This, of course, is all good theory, but replacement floor costs are extremely high. Because of the absence of reliable fatigue data on floor materials, various sandwich floor-panel materials were investigated on a cost-effective basis which involved static testing and fatigue testing a large number of samples. In fact, representative panels of various materials have been installed for service evaluation. The airline is, of course, ideally suited to perform actual in-service tests, and new ideas are often subjected to field tests in a true operational environment. Although in the manufacturer's initial fatigue test every attempt is made to represent a true operational condition, it sometimes happens that despite the best efforts of the designer, a part will fail prematurely because of the influence of a secondary unknown or neglected loading system. A case in point recently occurred when a fairly substantial shear angle hidden from immediate view was found to have cracks of considerable length along the bend radius. On investigation the fracture face showed that the angle, which had been designed to carry shear loads, was in fact also being subjected to secondary bending loads which tended to open and close the angle. Fortunately, in this case, the cracks were found before a failure occurred.

Another example in which the initial design failed to take complete account of the full loading cycle is the fatigue cracks experienced in top wing skins of some aluminium alloys containing a high percentage of zinc. The alloy is chosen in the first instance because of its mechanical properties and because the normal flight loads give a compressive loading. It has been established, however, that the ground loads, which reverse the wing bending system, cause tensile loads of sufficient magnitude to cause fatigue cracks around stress concentrations, fastener holes, for example, in this material.

One interesting case of structural failure occurred when the designer had assumed a certain airspeed for flaps extended for his fatigue analysis within the flaps-out speed range. The pilots, however, were in fact flying the aircraft right up to the flap limit speed, and premature failures occurred. Another problem which occurred was that in

the original design certain assumptions were made with respect to ground turns based upon airports known at that time. Subsequently the Commercial Department decided that a great deal of revenue was forthcoming from lesser known airports, and ground manoeuvres in excess of the assumptions were made. Airports are very congested places on the ground as well as in the air, and ground turns can be dictated by available ground space.

An aspect of airline usage which is outside the normal operating pattern is crew training. It is quite normal for one aeroplane to spend a considerable time on a training detail, and this operation sometimes results in flying techniques which are not up to normal standards. The number of landings are very considerable over a short period of time and since one of the objects of the exercise is to acquaint flying crews with aircraft-handling characteristics which are seldom met in practice, the airframe is subjected to a great number of loads which are not normally met in passenger service. These facts must be recognized at the design stage. Airframe damage has, in fact, resulted from training details.

Civil aircraft are in service for a considerable period of time, some 15 years or more typically. Airframe lives on the order of 60 000 flying hours are commonplace with the current generation of aircraft, and of course the fatigue problem intensifies as the aircraft get older. The economics of airline operation is such that operators are carrying out life-extension programmes in order to achieve these lives by replacing and/or reworking critical areas at some stage during the service life of the aircraft. It is vital, therefore, that the initial assumptions, analysis, and testing faithfully represent as far as possible the complete loading programme and its environment, and that the effect of new materials is fully examined, particularly where no previous experience is available.

Each new generation of aircraft brings a new challenge both to the operator and manufacturer, and the SST will be no exception. The operator must rely on the manufacturer to provide a trouble-free product, and to this end, practical airline experience of day-to-day operational problems and practices is freely available. Operational experience should be fed back into new designs to ensure long, trouble-free lives, particularly at the detail design stage.

The addition of speed and temperature will bring new complications to the SST. It is to be hoped that the racehorse will not exhibit the temperament of a thoroughbred but will retain the cart-horse stamina for everyday reliability.

SUGGESTED BASIS OF MAJOR STRUCTURE INSPECTION

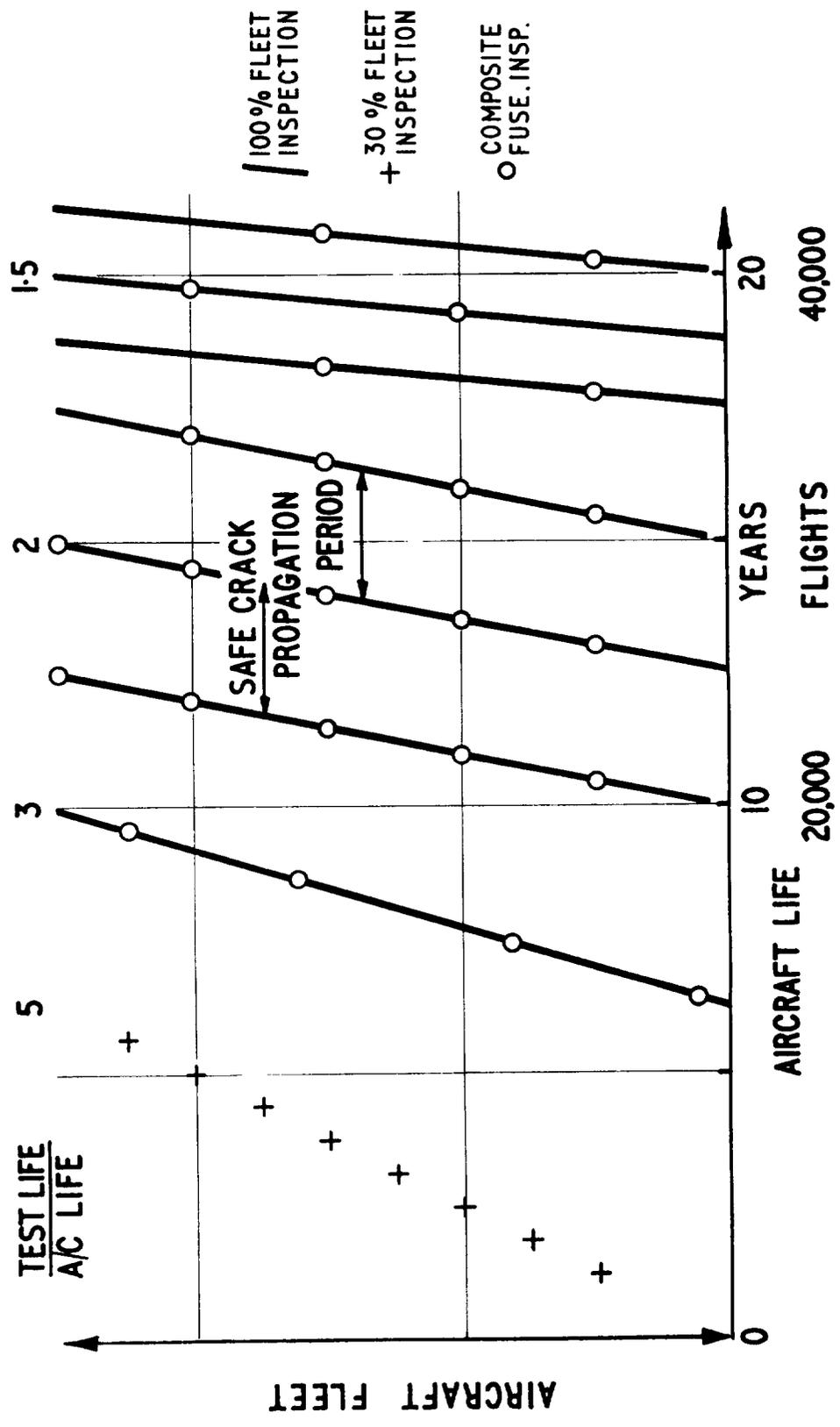


Figure 1.

