EXTENSION IN CALENDAR LIFE LIMIT FOR AIRCRAFT STRUCTURE

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Abstract

This paper describes factors which affect the structural life limits of the aircraft and analyses the criteria which have been proposed by different manufacturers in order to extend the life of their machines. The paper proposes a methodology for safe extension of structural life limits.

It is always considered safer to follow the manufacturer's laid down limits for overhaul or retirement of aircraft components and structure from the operation. However due to variation in the operating conditions of different user agencies, these limits cannot be applied strictly. The operating conditions lead to ageing of aircraft structure in which main contributory factors are pilotability, maintenance standards, accident/occurrence record of the aircraft, climatic conditions, parking conditions and corrosion level in the area of operation. These factors are not constant and cannot be applied uniformly to all the aircraft thus requiring detailed inspection of each component before extending the life limits. This paper highlights the importance of each contributory factor and discusses in detail how it affects the aircraft/helicopter life. A mathematical model is also proposed which can help in extending the life limits of the aircraft.

Introduction

All the manufacturers of aircraft/helicopters have laid down the limits on their products for their retirement/overhaul. Due to variation in operating conditions of different user agencies, these limits may not be applicable to all cases uniformly. In this paper it has been endeavoured to analyse the subject in-depth and recommend means to develop a safe calendar life extension criterion.

In third world countries, aircraft are considered to be one of their most precious assets. It is thus quite painful to ground an aircraft just because it has completed its stipulated Time Between Overhaul (TBO) or calendar life when it is apparently in a good flying condition. In contrast there are cases where the aircraft or its components have to be discarded before reaching T.B.O limits because their operation is considered unsafe due to their apparently unsafe condition. These plain facts have singled out physical condition of structure of each aircraft as the most reliable means to decide about respecting, extending or reducing T.B.O and retirement limits. If this approach is accepted then it would help to conclude that T.B.Os laid down by the aircraft manufacturers are only to serve as guidelines and each operator must evolve its criteria to decide the change in the T.B.Os/service life limits (S.L.L.) based on actual physical state of its equipment as a consequence to operation in its peculiar conditions. An operator can lay down its limits only if sufficient experience/data base is available else the manufacturer's recommendation must be followed [1]. The limits laid down by the operator may be even lower than those of the manufacturer in some of the cases.

The paper starts with review of the major factors which effect the aircraft structure life. The section discusses the effects related to environment, operating conditions, material and manufacturing processes. The structure limits as laid down by three manufacturers of different helicopters are also discussed.

The most important part of the paper is about the development of a mathematical model for extension in the aircraft calendar life. The mathematical model is followed by important tips for the consideration of any extension in the aircraft structure life. Recommendations and the conclusion are presented in the end.

Factors Affecting Structure Life

There are a large number of factors which affect the physical condition of aircraft/helicopters and limit their calendar life [2]. Broadly these can be grouped under environments in which the aircraft flies, the types of operations and its design elements including material and manufacturing processes. These factors are discussed in the following.

a. **Environment** The aircraft especially its structure is directly exposed to various environmental factors like temperature, humidity and corrosion due to proximity to sea, waste industrial gasses, sand/dust and gusty winds. The effect of each is presented below:

(1).**Temperature** The temperature effects the aircraft structure in many ways. The ambient temperature always varies in certain ranges from place to place. The aircraft manufacturers accordingly lay down the allowable temperature ranges. Whether in air or on ground each aircraft is exposed to the temperature variation. Minor variations in temperature which are within maximum and minimum limits generally improve the endurance limit of the materials however large variations in temperature which occur for short duration reduce the endurance limit due to effect of the cyclic strain. The effect is severe when the structures are frequently exposed to such variations. The operation of aircraft in a hot temperature mobilises dislocations, reduces fatigue resistance/strength thereby causing overall reduction in the endurance limit. During flight envelope of the aircraft, the variations in temperature and their effect are more complicated. The temperature being lower at higher altitudes causes chill factor over the aircraft skin. At the same time there is rise on the aircraft surface temperature due to skin friction drag. Hence the aircraft skin is affected by multidimensional cyclic variations in temperature. Apart from these, different areas of aircraft structures are subjected to different temperature variations such as engine cowlings and exhaust pipes etc. Such areas become critical and require careful inspection before taking any decision regarding their life extension.

(2). **Corrosion** Aircraft operating in corrosive atmosphere will have a lowered fatigue resistance. It is due to roughening/pitting of the surface by corrosive material. Effects of corrosion on the aircraft structure cannot be determined easily because corrosion and stresses occur simultaneously. Following aspects needs to be considered while evaluating effect of corrosion:-

(a). **Frequency of Cyclic Stress** The cyclic stress becomes important when an aircraft is operating in corrosive environment. The rule of thumb is, slower the frequency and higher the temperature, the higher the crack propagation and shorter the life at a stress level.

(b). **Humidity and Salt Laden Atmosphere** High humidity and presence of salts in the atmosphere enhances corrosion. This increases the chances of aircraft to get corroded which are operating in the coastal areas. To avoid corrosion, the aircraft are depainted, inspected and repainted frequently. Extra care is needed during the depainting process to avoid any scratches which are the ideal locations for initiation of corrosion process.

(c). **Fretting Corrosion** It is essentially due to microscopic motions of tightly fitted parts/structures. The process is visible through discoloration and pitting. The aircraft hard landings or near hard landings over long periods contribute to setting in fretting corrosion. This essentially demands critical review of aircraft history, accident record and inspection of critical areas for fretting corrosion at the time of calendar life extension.

(d). **Industrial Waste Gas Emissions** These emissions damage the environment due to presence of sulphides and nitrides. These toxic compounds combine with water and form acids. Prolonged aircraft operation in such areas causes corrosion in aircraft structures. The process of corrosion is further accelerated if the industrial waste gasses are emitted in a salt laden atmosphere. This is a typical environment of a big industrial cum port city. Aircraft stationed at such places are likely to have more corrosion causing structure life to reduce. Hence the extension in calendar life may not be safe for such aircraft.

(3). **Dust and sand** Prolonged operation of aircraft in dusty/sandy conditions results in faster deterioration/wear of aircraft exterior. It adds to fretting corrosion because sand/dust particles get into crevices and in between the mating surfaces of structural members. The effect becomes more pronounced with cyclic expansion/contraction due to large variation of temperature between day and night. These condition prevail in the desert. Hence aircraft operating in desert areas are more likely to develop fretting corrosion with obvious reduction in life of its structure.

b. **Operating Conditions** These conditions include pilotability, history of aircraft down time and quality of aircraft maintenance. All of these factors have a direct impact on structural fatigue of the aircraft and is discussed in the following paragraphs:-

(1). **Pilotability** This factor has direct effect on the structural fatigue of an aircraft. No two pilots can have identical skill. Although minimum acceptable pilot proficiency level is always ensured but there are other associated factors which significantly affect the structural life are listed below:-

(a). Judgement of the pilot to feel a hard landing or near hard landings and integrity to report the incident.

(b). Flying in adverse weather conditions with high level of turbulence.

(c). Accurate reporting of vibration levels and accepting the aircraft for operational flying only after bringing the vibrations within acceptable limits.

(d). Bird hits and brushing of main/tail rotor blades of rotory wing and wing tips of fixed wing aircraft with trees. All these aspects are counted towards pilotability to evolve a suitable pilotability factor for determining its effect on the structure life of the aircraft.

(2). **Quality of Aircraft Maintenance** This factor is highly significant because good quality maintenance can relieve the cumulative fatigue on the aircraft during its life cycle. Following are some of the ways to help reduce structure deterioration:-

(a). Quick follow up action after a hard landing can help avoiding fretting corrosion due to timely repair of loose rivets in two adjacent structural members.

(b). Reduce the effect of corrosion by carrying out painting of chipped off places and scratches etc.

(c). Maintaining vibration levels within acceptable limits can certainly reduce the overall structural fatigue.

(d) Maintenance of accurate records of aircraft occurrences, follow-up actions, record of vibration levels, record of periodic inspection including removal of defects found in these inspections can help in safe extension in calendar life.

(e). A good quality maintenance is directly visible as good apparent structure condition with no loose rivets, signs of corrosion, scratches on paint and unrepaired cracks.

(3). **Aircraft Down Time And Parking Conditions** Although the aircraft structure is considerably fatigued while in flying however ageing process of structure is accelerated in prolonged periods of inactivity. Poor parking conditions help accelerate ageing process. Aircraft parked in the pens or hangars would not be affected much even under inactive and reduced maintenance. However aircraft parked in open are affected adversely by the environment and require more maintenance and would have reduced structure life.

c. **Modification Status of Aircraft Vis-a-Vis Material Manufacturing Processes and Design** This factor broadly includes the following:-

(1). Chemical composition of materials with a view to get the desired strength.
(2). Design of the machine which includes its size and shape.
(3). Processes of Manufacturing.
(4). Heat treatment processes in order to relieve undesirable stresses and achieve required strength.
(5). Surface finish.

The factor of material and manufacturing processes is considered to be the most crucial in extending the T.B.O and service life limit. In case of aircraft this factor is however adequately covered by laying down stringent airworthiness standards and regularly issuing modifications to remove weaknesses in materials, methods of manufacture and designs. The research and development activity of the manufacturer is also thus important. This aspect is looked after adequately by all the reputed aircraft manufacturers. This also highlights difference between two manufacturers. One can be more liberal in grant of extension to aircraft produced by reputed manufacturers than those produced under licence or by less known/new manufacturers. In all cases timely implementation of manufacturer's instructions and modifications if done would help in safe extensions in the aircraft life limits provided all other aspects have been carefully looked into.

Structure Life Limits Laid By Different Manufacturers

The aircraft manufacturer's laid down calendar life limits are in the form of service life limit (S.L.L) and Time Between Overhaul (TBO). It is not possible to list down each aircraft manufacturer's limits however to highlight the large variations in these limits only the few cases are discussed here. These include SA-330 Puma, Bell 412 and MI-8 helicopters.

a. **Puma Helicopter** It is manufactured by Eurocopter of France. The manufacturer has laid down its calendar life of 10 years or 6000 operating hours which ever is earlier [3]. In case its calendar life limit is reached earlier than operating hours limit, then calendar life can be extended to 15 years provided yearly ageing inspection results are satisfactory. There is no service life limit laid down. The helicopter can be kept in service till its condition permits subject to its overhauls at laid down intervals.

b. **Bell 412 Helicopter**. It is manufactured by Bell Helicopter Textron of USA. The manufacturer of this helicopter do not impose any limits on their structures for overhaul or retirement [4].

c. **MI-8 Helicopter** It is a Russian origin helicopter. The manufacturer of this helicopter has mentioned varying calendar life of the machine and its system for different environmental conditions. The laid down life of aircraft structure for first overhaul is 8 years if it is operated in the temperate climate and 7 years in the tropical environmental conditions. These life limits are reduced by one year when TBO for these helicopters is worked out [5]. The Russian manufacturers have recommended total service life limit of 25 years operation in temperate climate and 20 years in a tropic climate.

The approach of Americans show their confidence in their machines and adequacy of laid down inspections to ensure that their aircraft and helicopters would be phased out only after becoming obsolete or insupportable and not as a result of hypothetical limits laid down by the manufacturer. There have been cases where an American helicopter operating in coastal area was declared beyond economic repair after 11 years of service while another with calendar life of over 20 years is being operated with no evidence of structural deterioration. This shows that even if such limits are not laid down, the physical condition of the machine would force the operator either to retire it or overhaul it and operate it only if considered airworthy. In this case however routine maintenance inspections need to be elaborate and encompassing all factors so that the aircraft's airworthiness is not compromised.

Development of a Mathematical Model For Determining Extension in Aircraft Life Limits

There are two parameters which are used to determine the remaining service life of the aircraft. Firstly, with the help of aircraft operating hours and secondly, based on its calendar life. The problem however arises when one of these reaches its limits but the physical conditions support the continuation of the machine in operation. Here it is needed that the decision about keeping the aircraft in service should be rational and based upon a scientifically acceptable criteria. This can be evolved by introducing two new terms namely "Effective Operating Hours" and "Effective Calendar Life". The "Effective Operating Hours" can be evolved by rationalising the actual operating hours by taking into account different operating conditions. Similarly the calendar life can also be rationalised into the "Effective Calendar Life"" by taking into account the effects of environment, inactivity and storage period, and parking conditions such as inside or outside the hangars.

a. **Effective Operating Hours** In case of aircraft one hour of flying is basic unit. This operating hour also represents a cycle of stress. it is this cycle of stress which is different for different terrain, flying patterns and skill of pilot flying the machine. To start each of the above parameters can be assigned a mathematical symbol as given below"-

(1). Operating hours in different terrain and flying modes:-

(a). n_1 to include normal flying hours in plain areas in good weather.

(b). n_2 = Aircraft operating hours in mountain flying.

(c). n_3 = Aircraft operating hours over sea/coastal areas.

(d). n_4 = Aircraft operating hours in areas with gusty winds and turbulent weather.

(e). n_5 = Aircraft operating hours in desert and sandy environment.

(f). n_6 = Aircraft operating hours as Instructional flying.

(g). n_7 = Aircraft operating hours as aerobatics flying.

(2). **Pilotability Factor**. Proper handling of the aircraft by pilot is very important. Inexperienced/less skilful pilot is likely to stress the aircraft more. There is variation between pilots of different aircraft operators and also variation in skill/experience level with in a group. Following pilotability factors can be laid down:-

(a) For average skilful pilot the pilotability factors (Pi) can be assigned the value of 1.

(b) For a student pilot, the pilotability factor(Pi) can be assigned value between 1 and 2 depending upon his ability and skill.

(c). As it would not be practicable to assign a suitable value of Pi for each hours of flying. Hence we may assign average pilotability factors for flying in each of above mentioned terrain/condition depending upon the accident record, occurrences and proficiency level of the pilots. This has to be assessed physically by each operator by himself or by some other agency capable of making such assessment for his pilots.

(3). **Stress Intensity Factors**. The concept of stress intensity factor is based on the fact that one hour of straight and level flight is not the same as one hour of flight performing aerobatics as for as stresses on an aircraft are concerned. Similarly flying hour in mountains or in desert with gusty wind has a different stress intensity factor. As a sequel to the above, following stress intensity factors are suggested:-

(a). K_1-Stress intensity factor for normal flying from place A to B can be taken as I.

(b). K_2-Stress intensity factor for flying in mountains with turbulence and heavy load can be taken in between 1 to 1.5 depending upon actual operating conditions.

(c). K_3-Stress intensity factor for aircraft operating over sea/coastal areas with gusty winds can be taken in between 1 to 1.5.

(d). K_4-Stress intensity factor for aircraft operating in desert with winds can be taken in between 1 to 1.5 depending upon intensity of winds etc.

(e). K_5-Stress intensity factor for instructional flying can be taken as 1.5.

(f). K_6-Stress intensity factor for aerobatics flying can be taken in between 2-3 depending on type of manoeuvres being performed. These are some of the factors. each operator can delete some of these and add more. These values are only suggested as a guide line. In fact these have to be assessed for each operator after in-depth study.

(4). Combining all the above mentioned factors following relationship can be obtained for the effective operating life "n".

$$n = n_1 k_1 p_1 + n_2 k_2 p_2 + n_3 k_3 p_3 + n_4 k_4 p_4 + n_5 k_5 p_5 + n_6 k_6 p_6 = \Sigma n_i k_i p_i$$

b. **Effective Calendar Life**. To evaluate the effective calendar life of an aircraft some of the significant factors which can effect the aircraft calendar life are given mathematical symbols and listed below:-

(1). h_1 - Time for which aircraft is in flying trim, parked properly and serviced timely. The associated multiplication factor is c_1 which is taken as unity because this is a normal condition.

(2). h_2- Time for which the aircraft is grounded for prolonged period. The associated multiplication factor is c_2 whose value is less than 1.

(3). h_3 - Time for which the aircraft is exposed to the corrosive atmosphere such as in coastal areas, offshore locations or in industrial waste gases and salt laden atmosphere. The associated multiplication factor is c_3 whose value is significantly more than 1.

(4). h_4 - Time for which the aircraft is exposed to the extreme temperatures. The associated multiplication factor is c_4 whose value is also more than 1.

(5). h_5 - Time for which the aircraft is operating in the desert with high day and night temperature differences and the environment is gusty as well. The associated multiplication factor is c_5 whose value is more than 1. All the above factors and their assigned values are only suggested as guide lines. Each operator may add or subtract to or from these factors depending upon his peculiar environment/operating conditions. However after combining the above mentioned factors following mathematical relationship can be built up to determine effective calendar life. "h".

$$h = h_1 c_1 + h_2 c_2 + h_3 c_3 + h_4 c_4 + h_5 c_5 = \Sigma h_i c_i.$$

c. **Potential for Extension in Calendar/ Operating Hours Life.** The extension is to be considered only for such cases where calendar life limit is reached but operating hours is not. Mathematical model for such condition is presented here. The potential is actually the difference in actual operating hour of aircraft and its maximum operating hours limit. However to be realistic and safe, this maximum potential needs to rationalised keeping in view the effect of all the factors listed in the paper earlier. **Hence we introduce ratios of actual operating hours "N" to effective operating hours "n" and actual calendar life "H" to effective calendar life "h".** The suggested formula for working out potential for extension in aircraft operating hours is given below:-

Potential for extension in operating hours Np

$$= (N/n)\,(H/h)\,(N_{max} - n) \quad (3)$$

Where N_{max} is maximum operating hours life of aircraft. Once the potential of aircraft is known in terms of number of hours it can still fly. **Keeping in view average flying hour per year the operator can transform this potential of flying hours in potential for extension in calendar life.** This however may be quite high if aircraft usage is low. In this case an upper limit for extension in calendar life can be laid down by each operator in consultation with the manufacturer or based on his own expertise/data base.

Important Considerations for Life Extension

The important considerations to ensure safe life extension are as below:-

a. The extension should be granted in steps of 12 to 18 months and be combined with major periodic inspection.

b. The values to be assigned to different multiplying factors are critical and should be laid down on the basis of data base and with the consultation of aircraft manufacturers.

c. Modification status of the aircraft must be considered. A fully modified aircraft with modifications done on due dates be granted extension more liberally if other condition given above are met.

d. The extension period in time between overhaul (TBO) should normally not exceed 50% of TBO time interval laid down by the manufacturer.

e. The limit of 50% laid down life limit would not apply to service life limit which should be extended if physical condition of structure appears air worthy.

f. Life extension inspection criterion would have to be developed for each aircraft by its respective operator. It is considered advisable to involve aircraft manufacturers in developing safe life extension criterion and laying down an upper limit beyond which extension may not be safe.

Recommendation/Suggestion for Extension of Calendar Life

As a sequel to the aforesaid, following recommendations are made:

a. Time between overhaul and service life limits laid down by the aircraft manufacturer be followed generally. However in case of aircraft operating hours are less than the maximum operating hours limit when aircraft calendar life limit is reached, then each operator should assess potential for extension for each of its aircraft in the light of mathematical model developed above and extend the calendar life wherever possible.

b. Following measures if adopted would help in realistic assessment of cumulative fatigue of each aircraft and ensure a safe extension:

(1). Every aircraft should be installed with a "g" meter. It should be installed with a designed threshold value above which stress value should be calculated after each mission. The record of "g" would help in determining the stresses to which the aircraft has been subjected during its service life.

(2). Stress coated panels should be installed in the critical areas by the aircraft manufacturer. Post flight inspections of these panels would help to identify if the aircraft was subjected to excessive stresses during the flight envelope.

(3). Vibra log for windows coupled with Helmut Chadwick vibration measurement and fault isolation system gives an effective way of recording vibration level in a helicopter. It can be used by one of the two ways. Firstly, by laying a threshold value for vibration level in different modes and recording only those values which exceed the threshold. This will help to evolve a multiplying factor for fatigue stress estimation of the aircraft structure. Secondly, vibra log can be maintained on computer diskette as a record of vibration level and this can be viewed to determine stresses due to vibrations on each aircraft. Its direct use however would not give us a tangible criterion for life extension but a reference aircraft in the fleet can be used to get the bottom line and vibration log of other aircraft be compared with it to estimate the value of multiplying factor.

c. The manufacturers should lay down TBOs and Service Life Limits for different world zones according to the environments as is done by Russians.

d. For estimation of effective life of an aircraft, prolonged period of inactivity beyond six months be counted as 50% of actual time for calculating the calendar life. For example if period of inactivity has been for 50% or more of the total calendar life of the aircraft then its calendar life can be extended by 25% if it has a clean history.

e. Extension in TBO or Service Life Limit is advantageous to user in terms of lower life cycle cost and fleet availability for longer time. It is also beneficial to the manufacturers as they can claim enhanced structure life limits and sell spares to support their customers for longer duration.

f. History of individual aircraft has emerged as very crucial factor. Accurate and upto date record of operating hours, inspections, occurrences, and especially hard landings be hence kept. Flying crew must be vigilant and truthful in making all such entries and consequent inspections should be done deliberately.

g. Identification of critical areas for each operator is important because there may be a variation in critical areas for different users due to combination of man, machine and environmental factors. The help of manufacturer should be sought for realistic assessment.

Conclusion

Life extension for aircraft is a critical issue. Any lapse on the part of decision making agency can lead to disaster. The factors listed in this paper help in giving correct and accurate decision. A number of factors which directly affect the aircraft structures have been listed. A mathematical model which encompasses all the relevant factors has been proposed. The mathematical model is simple which can be applied very easily and help determine the aircraft extensions realistically. Some important recommendations have also been made for the users and the manufacturers to optimally utilise the aircraft life.

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