Reliability approach applied on fatigue safety factors for fleet monitoring

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Structure design is often calculated by a determinist approach. For a given load and material resistance, this approach determines the ability of the airframe to sustain this load. Nevertheless, physical randomness is always present in every mechanical environment. Indeed, military aircraft loads (wind gusts, missions, manoeuvres), geometry design and material properties introduce some degree of randomness. These ones are considered into the aviation regulation at different levels like the use of material design values (99% probability with 95% confidence) or scatter factor. For instance, AIR 2004/E norm, which is one of the regulations for French military aircraft, specified the use of a scatter factor for fatigue structure demonstration.

These scatter factors lead to prevent the dispersion of each constitutive part of the system. They usually come from statistical data, with no clear other justification than the positive feedback on former aircraft. These factors emanate from a strict regulatory environment which can be awkward. Especially, if the impact of a modified scatter factor on the occurrence probability of an adverse event cannot be evaluated.

The goal of the reliability approach is to carry out a quantitative study about the structural failure based on random phenomenon. Then the failure probability of the airframe related to a specific scatter factor is obtained by this method. This method is currently implemented at DGA in order to quantify aircraft safety level.

According to AIR 2004/E norm, the scatter factor is equal to 5 for all critical parts which cannot be inspected on a no-monitored aircraft. For instance, the certified lifetime comes from the result of the full-scale fatigue test divided by 5. The norm says that in other cases, the scatter factor can be reduced according to qualified authorities.

Most French military aircraft are equipped with load monitoring systems (flight parameter recorder, and g-counters). These systems give direct or indirect access to the in-service loads. In that case, French military authorities allow reducing the scatter factor from 5 to 3 with a safety level at least preserved. A monitoring leads also to reduce this factor in other countries such as 3.33 in UK. However, this reduced scatter factor is used on calculation for every monitoring system like either flight parameter recorder or simple g-counters (vertical g-level detection). One may wonder to what extent the safety level is modified by the monitoring system.

A preliminary study has been conducted concerning the safety level induced by different monitoring systems. As the fatigue damage computation is different, a comparative analysis was made. More specifically, several z-acceleration spectra coming from a g-level statistical survey were implemented. All the damage values were compared thereafter. The key point was to build a random spectrum using stochastic modeling. The aim was to estimate the difference of safety level between the g-counter method and the temporal one.

Then, the main study will be conducted concerning the safety level of aircraft without monitoring system compared with monitored ones. To carry out this study, a reliability analysis will be completed considering material and load scattering. The first point consists in determining the probability that the real fatigue damage exceeds the calculated damage with or without monitoring system. Indeed, for multiple cases, several fatigue damages are computed from the input data as “triplet”: (spectrum, scatter factor (k), and material Wöhler curve). For instance, fatigue damage is calculated with the following input data:

1- (g-counter spectrum, k=3, deterministic Wöhler curve) for a monitored aircraft,
2- (specification spectrum, k=5, deterministic Wöhler curve) for an aircraft without monitored system,
3- (g-counter spectrum, k= 3, stochastic Wöhler curve) for a ‘real’ fatigue damage.

Military aircraft have a very large amount of different missions, leading to many different load spectra. Thus, these computations have been done for several random load spectra.

The second point of the reliability study is to find the adequate scatter factor to obtain the same safety level. To carry out this point, a parametrical analysis will be done in order to find the scatter factor that leads to the same probability between monitored/no-monitored aircraft.

In the future, investigations will be carried out to extend the conclusions with other methods to obtain random acceleration spectrum with the cumulative number of occurrence vs g-level.