Study on the method of establishing the maintenance tasks of the significant structural items

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Abstract: Based on the fact that maintenance tasks of significant structural items(SSIs) are too many and the condition of bearing the effect of AD/ED/FD at the same time on flight, this paper puts forward an method of establishing the maintenance tasks as following: (1) To establish the inspection tasks of SSIs for AD/ED/FD separately. (2) To integrate the individual maintenance tasks of SSIs according to the crack occurrence and growth, this way can not only decrease the number of maintenance tasks and the maintenance costs, and also is propitious to safeguard the reliability and safety during a flight.

Key words: significant structural items, maintenance, maintenance tasks, civil aircraft, integration

A significant structural item (SSI) is any detail, element or assembly, which contributes significantly to carrying flight, ground, pressure or control loads, and whose failure could affect the structural integrity necessary for the safety of the aircraft [1]. Therefore, according to the requirement of lastest advisory, the scheduled maintenance tasks must be developed according to the lastest MSG-3 theory. In fact, the scheduled maintenance tasks are generally developed by following steps: (1) analyze fatigue damage, environmental deterioration and accidental damage of SSIs separately. (2) Integrate and optimize the analysis results according to the task types, access ways and maintenance task intervals [2-6]. It is obviously inconsistent to the conservative principle which is ruled in MSG-3 theory. In fact, the aircraft structural items are simultaneity endured the damages of these three aspects, and is not separately endured fatigue damage, environmental deterioration damage and accidental damage. Obviously, the final scheduled maintenance tasks and their intervals must be developed according to the final analyzing results which integrated above three damages. This paper studies and discusses the method of developing the maintenance tasks as an example of metallic significant structural item.

1. Develop the maintenance tasks of SSI for fatigue damage (FD)

The method of developing maintenance tasks of SSI has given for detecting fatigue damage, but it cannot be directly used to develop maintenance tasks because there is only logic decision flow chart in the MSG-3 theory [1]. So the method of developing maintenance tasks of SSI for detecting fatigue damage is often ruled by the scheduled maintenance requirements development policy and procedures handbook (PPH) of the mainstream models of airplanes at present and the requirement of lowest maintenance cost during the total lifetime cycle and the whole airplane while it is met the requirements of safety and availability in the maintenance theory, and the detail procedure of developing the inspection tasks is as following fig.1:

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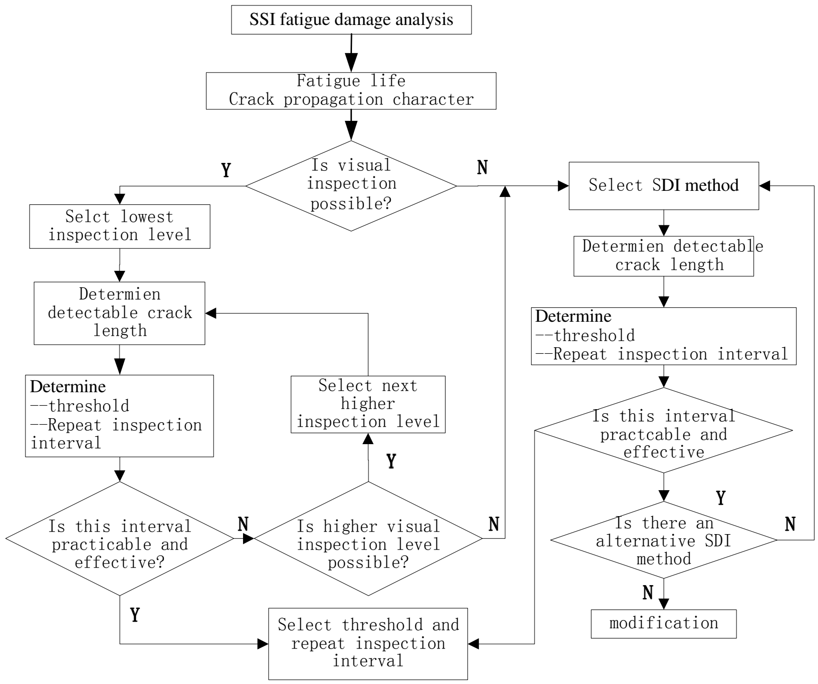

Fig.1 Metal SSI fatigue damage analysis logic diagram

At present, the inspection intervals of metal SSI are usually established by loading spectrum analysis, crack propagation analysis [7-8], growth loading spectrum analysis, and the fatigue life is predicted by evaluating the fatigue damage degree according the varied range of magnetization capability of iron magnetism component [9], of course, the residual life of fatigue structure component can be studied and determined by the finite element structural analysis [10]. In general, the method of loading spectrum analysis is very accurate, but the analysis process is very complex, which needs to be supported by plentiful test datum. The finite element structural analysis method needs to take much time and energy，it is obvious difficult to be adopted in the actual engineering. The iron magnetism method can also be difficult to be used due to the using condition. In the end, the method of crack growth analysis is adopted to determine the inspection interval, i.e. the process of SSI fatigue damage is divided into two stages----- the crack forming stage and

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FC_g——GVI threshold;crack growth stage, as

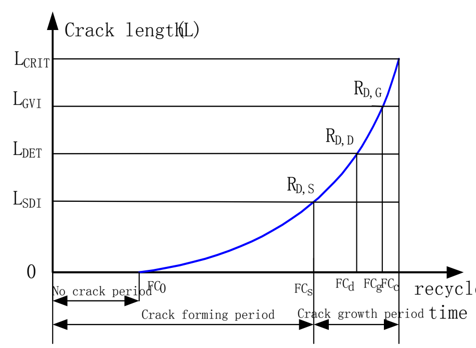

Fig. 2 Fatigue crack growth

following Fig.2

Where:

L_{CRIT}—— Critical crack length;

L_{GVI}——Detectable crack length by general visual inspection;

L_{DET}——Detectable crack length by detailed inspection;

L_{SDI}——Detectable crack length by special detailed inspection;

FC_0——No crack life;

FC_s——SDI threshold;

FC_d——DET threshold;

FC_c——Fatigue damage critical life.

It must be noted that the crack forming period is the time from no crack to the detectable crack in engineering, which includes no crack period and crack occur period, it is obvious that the crack forming period will be effected by detectable crack length in the engineering, and the detectable length is determined by the inspection way. At present, the inspection ways to aircraft structure include three types: general visual inspection (GVI), detailed inspection (DET) and special detailed inspection (SDI). The GVI detectable crack length is longest among three ways due to its lowest resolution, just as L_{GVI} in figure 2; the SDI is the nondestructive crack detection which must be aided by special equipment, so its detectable crack length is shortest, as L_{SDI} shown in above figure 2. The crack propagation period is the time from detectable crack period in engineering to the critical crack period, which can be defined as macroscopic crack growth period. In fact, no matter which inspection way is adopted, the critical crack length is the same long, just as L_{CRIT} shown in figure 2. For GVI work, the repeat inspection interval is relative shorter and the inspection frequency is high, which is because the detectable crack length is comparative longer, and the period between detectable crack to critical crack is comparative shorter, in the end, the inspection interval sometimes is so short that it cannot be operated in engineering. For SDI work, the repeat inspection interval can be enough long because its initial detectable crack length is shorter, and it can leave much more time for the repeat inspection, which is favor to keep aircraft structural integrality and safety. Of course, some cost must be paid while the inspection work is operated, the GVI cost is lowest and the SDI cost is much more. So the final inspection way can be selected by comparing the maintenance costs among various inspection works, which must base on guaranteeing the structural integrality and reliability, just as seen in figure 1.

After the inspection way, detectable crack length and critical crack length have been determined, the inspection threshold can be established by the detectable crack length corresponding to the inspection way, and the repeat inspection interval can be developed by the crack growth period, crack propagating rate, of course, the human errors must be considered, namely:

$$T_t = T_{sdg} / K_t$$

$$T_i = R_c / K_i$$

Where:

T_t—— Initial inspection interval;

T_{sdg}—— Period of the detectable crack associated with the selected inspection way;

T_i—— Repeat inspection interval;

R_c—— Crack propagation time from detectable crack to critical crack;

K_t, K_i——Dispersion coefficient associated with safety.

2. The maintenance task of environmental deterioration damage(ED)

Environmental deterioration damage is the structure deterioration caused by the aircraft structure exposure to adverse environments. In order to develop appropriate inspection work, the corrosion type and location must be known at first while the

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airplane subject to the adverse environment. According to the aircraft structure maintenance manuals and other scholar findings[12-14], the corrosion types of aircraft structure include stress corrosion and other corrosions, and other corrosions include electrochemical corrosion、microorganism corrosion、abrasion corrosion、heterogeneity corrosion、point corrosion and intergranular corrosion, etc. In this paper, the inspection works are selected as following corresponding to the corrosion type according to the PPH of present mainstream model aircraft and related experience.

- Stress corrosion: DET
- Microorganism corrosion: GVI
- Electrochemical corrosion: DET
- Abrasion corrosion: DET
- Intergranular corrosion: DET/GVI
- Point corrosion: DET
- Fiber corrosion: GVI
- Heterogeneity corrosion: GVI

After the maintenance tasks have been determined, their effective inspection interval must be established. At present, some scholars have studied this question, and the inspection intervals can be established by analyzing the aircraft structure life according to the stress corrosion[15-16], or analyzing the operating regularity in different environment[17-20], finite element quantitative analysis method to analyze the structural corrosion and using life[21], or structural deterioration degree and environment deterioration degree and other degrees to develop the structural inspection interval. And in this paper, the structural inspection interval was developed by evaluating the degree of SSI visibility, sensitivity to environmental deterioration, environmental protection and exposure to adverse effect of environment to develop the structural inspection interval, and the detail method can refer the related document [22].

3. Identification of the accidental damage inspection task

According to the requirement of developing maintenance program direction document, the aircraft structure may be subject to damage caused by the contact or impact with foreign objects, or caused by inadequate operation or maintenance practices, and sources of such damage include ground and cargo handling equipment, foreign objects, erosion from rain, hail, lightning, runway debris, spillage, freezing, thawing, etc., and those resulting from human error during aircraft manufacture, operation or maintenance that are not included in other damage sources. And the large size accidental damage, such as that caused by engine disintegration, bird strike or major collision with ground equipment, will be readily detectable and no maintenance task assessment is required. So the loading and crack change are shown as figure 3 after accident damage occurred.

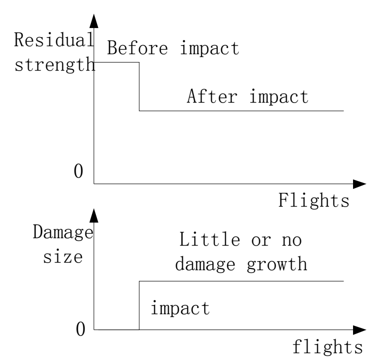

Fig. 3 Change rule of strength and crack after accidental damage occurs

It can be seen that structural strength and crack length will be changed in jumping way when the accidental damage occurred in aircraft structure. In fact, the tiny cracks of structural items are only considered during operation and maintenance as above, and such cracks can hardly bring the serious results, as a result, the maintenance task will not be lonely implemented according to the MSG theory and regulatory of PPH of mainstream

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aircraft model. Even now, some serious damage may be happened when accident damage joins with other damage such as fatigue damage, environmental damage. For this aim, the residual intensity must be determined after the accidental damage occurs by assessment of the susceptibility of the SSI to the various forms of accidental damage, estimation of the expected damage type, location and size, consideration of environmental impact-damage to be considered in environmental deterioration analysis and consideration of fatigue impact-damage to be considered in fatigue damage analysis

4. Maintenance tasks integration of structural items

The failures and/or faults of SSIs are generally brought by integrated actions of AD\ED\FD, As a result, the structural maintenance tasks must determined by the integration actions of above damages, not the simple heaped tasks which are determined by separate damage such as AD,ED and FD, the whole analysis procedure is as Fig.4. After having analyzed AD/ED/FD of the significant structural items, the assessment of damage type and size of AD sources must be developed. And then the effect of AD source to FD/ED is analyzed, the analyzing results of ED/FD can be integrated to be the final maintenance tasks if the AD sources have no effect to the FD/ED, otherwise, some modifications must separately be done to the maintenance tasks of SSIs by assessment result of AD damage sources to the FD/ED. And last, the assessment must be done to the FD with ED, and the integration of maintenance tasks of ED/FD must be re-done so that the final inspection tasks can be done if the analyzing result of FD may be affected by the ED damage. In order to illustrate this process, the integration of analyzing results between AD and FD is given as figure 5 for

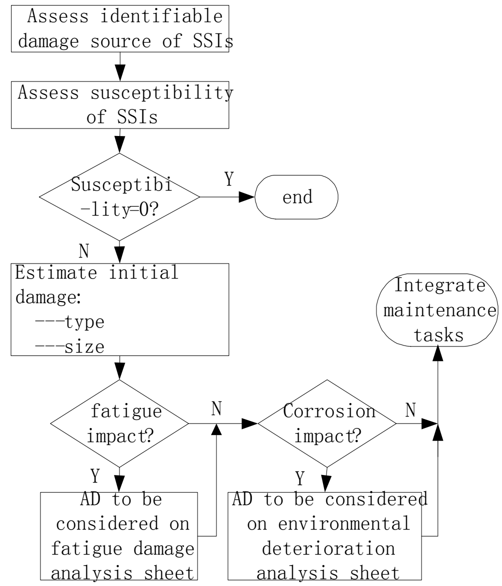

Fig. 4 Maintenance tasks integration of SSIs

example. And in this figure,

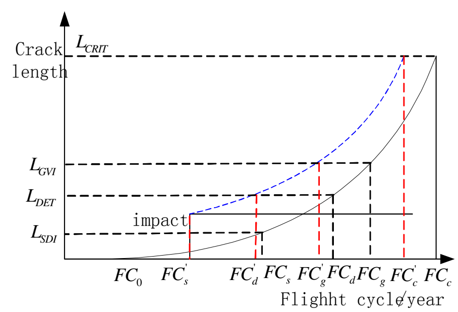

Fig.5 Crack growth regularity while AD impacts

FC_s、FC_d FC_g is the time of initial detectable cracks for SDI, DET and GVI while the AD cannot occur. If the AD may happen and affect the FD, it is obvious that the detectable cracks will be detected earlier, just as FC_s'、FC_d' FC_g' in figure 5. Of course, the critical inspection must be earlier just as FC_c' instead of FC_c. At last, the inspection threshold and repeat inspection interval can be re-determined by above method.

Because the failure mechanism of structure is similar that the structural strength less than loading, or the crack length is longer

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than critical crack length, so the inspection intervals can be determined as above method for the effect of AD to FD, and the detail process will not be repeated here.

5. Example

In order to validate the feasibility of this approach, the process of determining inspection tasks and their corresponding intervals is given as an example for SD847 to SD950 suspension outside SD847 to SD950 of one aircraft model which SSI number is 545001, this section includes fore-edge back segment and all outer structure of center loading segment which is main bear loading structure of suspension.

The detail process is as following: first, the FD/ED/AD analysis is separately made, and the results are following:

FD: inspection work is DET, its inspection threshold is 8000FC, and its corresponding repeat inspection interval is 6000FC.

ED: inspection work is GVI, its inspection threshold is 48 months, and its corresponding repeat inspection interval is 48 months.

AD: the inspection work is GVI, its inspection threshold is 8000FC, and its corresponding repeat inspection interval is 8000FC.

Because the speed of ED and FD will be accelerated once the AD occurs in this structure, and the GVI can be covered by DET, so these three inspection tasks and their corresponding intervals must be integrated, and the detail process is omitted. The final result is: inspection work is DET, Its inspection threshold is 8000FC,its repeat inspection interval is 4000FC. In order to illustrate its economy, the inspection arrangement is given as figure 6 for 40000FC.

It is obvious that there are 6 times DET inspection for fatigue damage, 6 times GVI inspection for ED, and 5 times GVI inspection for AD on the past method to determine the maintenance tasks, and once the inspection

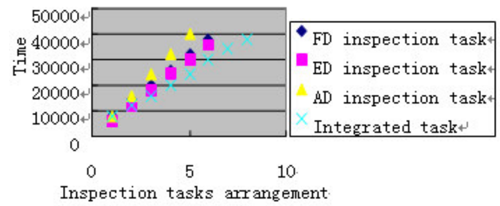

Fig.6 Arrangement for different inspection tasks

works are integrated by this way, only 8 times DET inspection is needed, which is much less than the past inspection way, as a result, its maintenance cost is reduced. For structural safety, the maintenance tasks are more conservative and their intervals are more suitable because the interacting effects of various kinds of damage are fully thought.

6. Conclusion

Some conclusions can be made as following by above analysis and example:

(1) Inherit the past method for analyzing fatigue damage, environmental deterioration damage and accidental damage separately, this method may simplify the process of developing the maintenance tasks, and can ensure the method to be successfully implemented.

(2) The maintenance tasks and intervals which are developed by the crack growth can ensure more safety and reliability, because not only each individual factor of AD\ED\FD is considered, and the integrated damage is also considered while the maintenance tasks and intervals are developed. In addition, the final maintenance tasks are integrated, which can effectively reduce the maintenance times, improve aircraft availability, and reduce maintenance costs.

ACKNOWLEDGMENT

This research reported in this paper has been partially supported by the “863” organization in China under grant 2006AA04Z427 .

Thank Mr. Zuo Hongfu for his direction while I was studying in Nanjing university of Aeronautics and Asttronautics.

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