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AGING EVALUATION PROGRAMS FOR JET TRANSPORT AIRCRAFT STRUCTURAL INTEGRITY

ABSTRACT

The paper deals with criteria and procedures in evaluation of timely preventive maintenance recommendations that will support continued safe operation of aging jet transports until their retirement from service. The active service life of commercial aircraft has increased in recent years as a result of low fuel cost, and increasing costs and delivery times for fleet replacements. Air transport industry consensus is that older jet transports will continue in service despite anticipated substantial increases in required maintenance. Design concepts, supported by testing, have worked well due to the system that is used to ensure flying safety. Continuing structural integrity by inspection and overhaul recommendation above the level contained in maintenance and service bulletins is additional requirement, in such cases. Airplane structural safety depends on the performance of all participants in the system and the responsibility for safety cannot be delegated to a single participant. This system has three major participants: the manufacturers who design, build and support airplanes in service, the airlines who operate, inspect and mantain airplanes and the airworthiness authorities who establish rules and regulations, approve the design and promote airline maintenance performance.

KEY WORDS

old-age transport aircraft, maintenance, exploitation, experiment

1. INTRODUCTION

The active service lifetime of the commercial aircraft has increased over the recent years as a result of lower fuel prices, increased purchase costs of new aircraft and the prolonged delivery times of aircraft for the replacement of the existing fleet. The manufacturers expect the older aircraft to remain in exploitation in spite of increased costs due to greater requirements of maintenance. This paper points out the current initiatives to ensure safety of exploitation of old-age aircraft, as well as the Boeing manufacturer's standards which support the continuity of the aircraft structure integrity, by carrying out checks and recommending replacements. These initiatives are jointly supported by manufacturers, authorities and air carriers. They are directed more towards the obligatory modifications, rather than continuous checks defined by service bulletins for aircraft that have completed their structurally planned service life; development and improvement of the obligatory programs for corrosion control; replacement of the basic maintenance programs and additional programs for structure testing; development of instructions for determining feasible structure repairs in relation to the defined tolerances of damage for long-term exploitation.

2. AIRCRAFT STRUCTURE RELIABILITY

The criteria and procedures used in designing commercial aircraft over the last three decades have resulted in long-term exploitation structure, tolerant to damages with extremely good results in the safety of operation.

This has been achieved by careful designing of construction details. Application of such systemic design concept, supported by testing, results in the commercial aircraft fleet which flies safely during its structur-

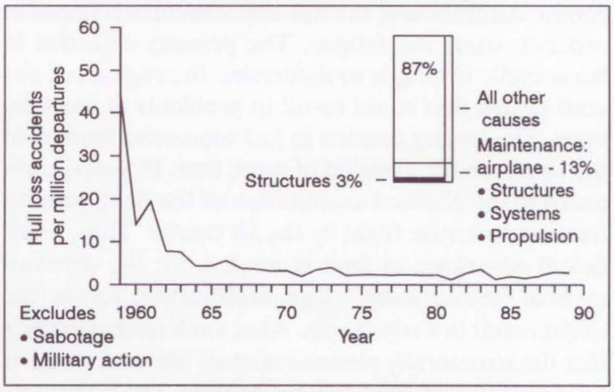

Figure 1 - Results of commercial aviation exploitation safety

ally planned lifetime. In such a system of exploitation, the responsibility cannot lie with one participant only, but it includes also the manufacturer, air carrier, and the authorities issuing the airworthiness certificate and approval of the maintenance program. All the Boeing jet transport aircraft have been designed on the principle of tolerating damage, which evolved from the previous "fail-safe" principle[1]. In the practice of using the "fail-safe" structure elements, damages caused by fatigue or other reasons have been detected and repaired in thousands of cases. The aircraft manufacturer experts discuss whether technology of "fail-safe" elements used during the 1950s and 1960s is satisfactory, since these aircraft exceed their planned service life now. Boeing aircraft have been designed for a minimal lifetime of economic service of 20 years. It is pointed out that there is no limit for aircraft designed on the principle of structure tolerant to damages, provided necessary checks are carried out with time limited repairs and / or replacements of the damaged structure or preventive modifications on aircraft that have completed their objective, structurally planned lifetime. The basis for a productive aircraft service life implies the operative efficiency of the aircraft, since the older aircraft are subjected to costs and more frequent repairs.

3. VERIFICATION OF PREDICTIONS BY TESTING

It is practically impossible to perform verification by testing for all the critical aircraft parts and all the exploitation conditions. Therefore, a verification program by testing is being developed in the laboratory for smaller samples, big hull plates, and major wing components, the whole tail cone of the aircraft fuselage, aircraft fuselage design and the whole full-size aircraft.

Static full-size testing of the new aircraft model is carried out in order to verify the design capabilities to support loads and meet the requirements of homologation. Additionally, the full-size structure is tested in order to study the fatigue. The primary objective in these cyclic testing is to determine the regions of aircraft design that could result in problems or early fatigue. The testing consists in fast successive loading of the structure for a period of more than 10 years, compared to the planned exploitation of the fleet, prior to the first operative flight by the air carrier. Thus, a sufficient advantage in time is created, for the development of the necessary design modification details that might result in early cracks. Also, such testing verifies that the structurally planned aircraft lifetime, which is economically justified, will be fulfilled. The additional objectives of full-size structure testing to fatigue are the development and verification of the planned checks in the maintenance program.

The aim of such testing is not to demonstrate the safe service time of the structure and to licence the tolerance to damage, nor is it an alternative to the required checks in the maintenance program for continuing safe exploitation of the old aircraft. Testing of the new aircraft structure does not include damages caused by corrosion i.e. accidental damages, that might propagate cracks and accelerate fatigue. Therefore, parallel to the testing of new aircraft structure before exploitation, similar testing is done on the old aircraft, in order to determine the possible problems in the structure of really highly used aircraft with repairs and defects caused in exploitation.

The Boeing factory co-operates in this respect with quite a number of air carriers all over the world, so that various methods of exploitation, different climatic conditions, and various quality of regular maintenance operations would be represented in the studies. A certain number of factory experts are present when major regular overhaul of the aircraft structure is performed, using the NDT[2] methods of control and keeping minute records for every case separately. The results are confidential in the interest of the air carrier. The Boeing factory buys back some aircraft, and uses such isolated specimens, after 18-20 years of exploitation for expanded testing and simulation of exploitation of up to 40 years of service life. In some cases, where no cracks occur, artificial cracks are made at hot spots, and the crack propagation is monitored over the next 15-20,000 cyclic loadings. Then the whole structure is disassembled and all the elements checked, especially those that are inaccessible and where hidden cracks or damages might occur.

4. ADDITIONAL PROGRAMS FOR CHECKING THE CONTINUOUS INTEGRITY OF AIRCRAFT DESIGN

Standards for determining the continuity of airworthiness of the old transport aircraft is the basic topic of the factory experts and aircraft authorities who determine the rules and regulations and control the maintenance. The attention is focused on the feasibility of the program for structure testing, and for determining the deadlines for timely detection of damages, as support to "fail-safe" design principles over the last three decades.

The CAA[3] instruction 89 and FAA[4] advisory circular 91-56 allow re-establishing of the aircraft design integrity, including the recommendations for any necessary additional structure testing, as alternative to the defined lifetime, operative limitations or testing time limits. The additional structure testing programs along with the existing operator's maintenance programs have given very effective results for the Boeing structure design principles, tolerant to damages. The mentioned documents for single aircraft models allow the option for the selected structurally significant items (SSI)[5] which ensures timely detection of damage by fatigue in older aircraft. This is achieved, when needed, by the use of more refined checking techniques within the existing air carrier maintenance program or as additional checking programs. If a crack is detected, the whole fleet is checked. This activity consists in determining new checking intervals, utmost allowed limits and methods of analysing. Thus the whole fleet is controlled and the reliability and aircraft structural integrity for airworthiness and safe flying continuously monitored.

5. PROGRAM ANALYSING THE FLEET CONDITION

Boeing continuously reads the reports and studies direct air carrier information in order to promote safe and economic aircraft exploitation in the whole world. The actual average age of aircraft in exploitation is increasing, e.g. from 8 years in 1986 to 12 years in 1989, and the trend is expected to continue further.

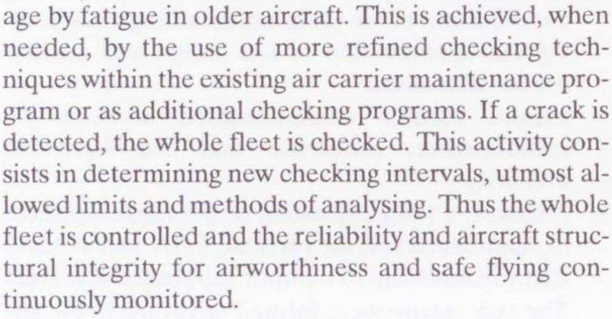

Figure 2 - The world age of the jet aircraft fleet

With the aim of increasing the knowledge about the old aircraft and the factors that influence the possibility of maintaining the structure and system of the aircraft, Boeing introduced in 1986, a two-year Program of Assessing the fleet aging. Specific objectives of the Program were:

1. to create an engineering basis for the assessment of the condition of the older aircraft with the emphasis on the structure and systems;
2. to evaluate the efficiency of the Boeing anticorrosive technology and of other actions against corrosion carried out by the air carriers;
3. to create an additional database to improve the recommendations regarding aircraft maintenance and to promote improved design of new aircraft.

Because of its great success, the program has been continued and expanded to include all the manufactured models. The research includes 56 operators in 30 countries in the world, i.e. about 15% aircraft that have passed 75% of their planned lifetime. The research is done by the experts of the Boeing factory, who monitor about 350 structure items and about 150 system items per each aircraft model. The research also records the air carrier's practice related to exploitation, as the maintenance program and the reliability and regularity of lines. The results, as already mentioned, were confidential (because of the air carriers - research participants), and served as the basis for determining the necessary measures.

6. RESULTS OF THE FLEET CONDITION ANALYSIS

The operators have supported the program and participated and co-operated well. The research focused on the condition of the significant structural parts, partition walls and thin-wall fuselage structure, primary systems such as e.g. the undercarriage, control systems, avionics, etc. In most of the cases the results were good, but in some cases below the expected, as e.g.:

- In certain aircraft relatively bad condition was found especially regarding the amount of corrosion, which was not expected in well maintained aircraft. It is obvious that the repair activities were not undertaken on time. Corrosion prevention and checking measures need to be strictly stipulated in order to reduce the necessary excessive maintenance and promote the continuity of airworthiness.
- The majority of the found cracks have already been known earlier and the prevention measures were defined in the form of servicing bulletins. The newly found cracks did not require immediate action for safety reasons.
- The application and realisation of servicing bulletins varies from one air carrier to another, and ranges from only 20% all the way to 80%. It was noted that many air carriers prefer the option of successive checks than repair, when this option is provided in the bulletin.
- Repairs on the structure have been found in the worrying related field. Each repair for itself is adequate to the repair standards, but cumulatively greater number of repairs on a smaller area deviates from the accepted standard technical procedure. In the majority of such repairs an inadequate application of anticorrosive technology has been noted, so that the corroded area concentrates and new cracks occur. There are also inadequately performed repairs (with countersunk rivets on the thin-wall

structure, hollow rivets or of improper dimensions). This is the result of inadequate repair quality control in authorised workshops.

- In a part of aircraft that have changed owners or operators in shorter intervals, the aircraft have not been maintained properly, and there is discontinuity in the maintenance program. It has been noted that little attention is paid to maintenance, especially in rented aircraft, or the maintenance program is inadequate compared to the operative exploitation method.
- A certain number of aircraft was found that do not fulfil the airworthiness requirements, i.e. have unrealised airworthiness directives, e.g. the steel bolts that had to be replaced both according to the servicing bulletin and according to the aircraft technical directive, were not replaced, and a certain amount is found in warehouses and has not been eliminated from usage yet. The need for replacement has been re-emphasised.
- The problem of inaccessibility to certain structure parts has been noticed, with the aim of checking and maintaining, i.e. the required check technologically foresees disassembling and increase in costs. The recorded problems have been used emphasising the necessary changes in the future new structures.

The findings were used for the service letter communication, maintenance recommendations, changes in the production line, change of the maintenance manuals, etc. with the aim to provide adequacy of aircraft and the whole fleet according to single models.

7. THE STARTED ACTIVITIES IN MAINTAINING THE OBSOLETE FLEET OF JET TRANSPORT AIRCRAFT

The findings of the program studying the fleet condition, have resulted in joint initiatives of the manufacturers, air carriers and authorities. In order to maintain safe flying and reliability of usage of the obsolete fleet in air traffic, recommendations of the Conference 1988 held in Washington, D.C. were accepted:

1. The existing maintenance and checking system needs to be continued more conscientiously and with integrity. Investigate the causes for failure of a certain aircraft, and adapt the system to other aircraft as the need arises.
2. Initiate the analysis for finding a better way of aircraft structure condition monitoring and problem detection.
3. Continue with the practice of detailed disassembling of the older aircraft, determine the structure condition, and perform the testing to fatigue in older aircraft.
4. Create a body or an institution with the knowledge of using NDT analyses and its applicability in Testing the aircraft.
5. Establish a fund for investigating and developing NDT methods and feasible technologies, for special aircraft requirements.
6. Study all the aspects of human factor influencing the efficiency of the program, including the schooling and qualification of the design and maintenance controllers.
7. Ensure feasible communication between the manufacturer, air-carrier and the legislative authority.
8. Establish a body consisting of the representatives of manufacturers, air carriers, FAA and NASA[6] that will continue to monitor the started research.

The task groups were formed according to the aircraft models, and they have determined the consistent approach to the testing of the obsolete fleet, with the priority recommendations:

- to select the servicing bulletins for modification of the older aircraft, based on the potential problems for the flying safety, the probability of formation and the possibility of checks;
- to develop a direct preventive program for studying corrosion, based on the data of the whole fleet;
- to check the applicability of SSI programs in determining the possible exclusion or inclusion of certain vital elements of the structure or aircraft system;
- to develop full maintenance recommendations for the old-age aircraft in the fleet;
- to determine the quality standard of the structure repair regarding long-term exploitation.

Based on the defined recommendations and according to the set priority, every aircraft manufacturer develops with special and constant care their proper program of testing and maintenance of the fleet. The servicing bulletins are selected specially for the old-age aircraft, depending on the impact on the flight safety, probability of occurrence and possibility of checking; programs of preventive activities against corrosion are developed and the requirements and standards of checks are determined; the additional program of checking the aircraft structure according to the selected significant aircraft elements is continuously studied, maintenance programs for old-age aircraft per cycles and calendar intervals are developed, and the required quality of old-age aircraft repairs defined. This provides the basis for the continuous monitoring of the condition of the structure in old-age aircraft that are close to the end of the structurally planned economic justified lifetime, or have already exceeded it. As the "Condition Monitoring" system has been introduced for certain vital parts of the aircraft, i.e. system of monitoring the condition instead of a fixed resource, so this system also, continuously monitors the condition of the structure tolerant to damages and allows safe exploitation even after the fix determined service lifetime of economic exploitation has been exceeded.

8. CONCLUSION

Boeing, as the biggest world manufacturer of commercial jet transport aircraft has devoted itself to designing and manufacture of a safe aircraft. The responsibility and consistency of policy which gives top priority to safety, has resulted over the last 30 years in the leading position in the world. This work stresses the fact that ensuring the aircraft structure integrity is a very serious and disciplined process. High standards need to be kept in order to ensure the safety of flying old-age aircraft, if their economic characteristic dictates exclusion from the operative exploitation. The Boeing standards and practice in monitoring the continuous integrity of the commercial fleet structure include:

1. Programs for the maintenance of aircraft structure, which recommend checks and required replacements;
2. Continuous communication between the representatives in the field and organisations for product support;
3. Informing air carriers about the recommended activities in the form of servicing letters, advice on certain structural elements and servicing bulletins.

As additional help in identifying the potential problems regarding the old-age fleet, Boeing performs additional activities:

1. develops additional programs for checking the structure requiring the air carrier to regularly check the significant structural elements, at selected older aircraft and to inform Boeing because of the current action regarding the whole fleet.
2. disassembles old re-purchased aircraft in order to define (as additional help) and identify corrosion and other structural defects caused by exploitation.
3. tests fatigue in old-age aircraft in order to determine the behaviour of the structure under the influence of the induced special problems caused by the exploitation method, such as corrosion, repairs, loose or unwound joints.
4. using engineering approach and with the aim of improving the product, develops databases according to selected specimens of the old aircraft, in order to define the efficiency of the preventive anticorrosion technology, and collects data which can serve for better recommendations to air carriers in maintaining the aircraft.

Care taken of the old-age fleet is the result of joint actions of the manufacturers and aircraft authorities with the intention of timely preventive recommended maintenance of the aircraft in order to prolong the operative life of the aircraft exploitation. This allows continuous and safe exploitation of the obsolete jet aircraft until their final elimination from air traffic.

Due to the high purchase costs of the new aircraft, long delivery times and economic factors, the reality in the aircraft industry is that the old-age aircraft continue to be used in spite of significantly higher requirements in maintenance. The economic reasons stipulate using aircraft even longer than planned, and this is realised without reduction in flight safety, with additional maintenance programs for the old aircraft and continuous condition monitoring.

Similar situation is present also in other categories of aircraft (e.g. general aviation), i.e. they stay in exploitation up to and after their planned lifetime has expired. These aircraft are used mostly for individual purposes, but quite a number is involved in commercial trading. Some manufacturers of such small aircraft, using as example and motivated by the success achieved with jet transport fleet, develop and introduce standards and recommendations to operators. The manufacturer of Cessna, has a developed program of the activities that need to be undertaken with older aircraft in order to check the aircraft structure integrity, and determine the airworthiness. Unfortunately, the application is not sufficiently present, and varies from one country to another. This obviously causes new costs in exploitation, but the flight safety, as the rightly set top priority objective justifies the costs and increased efforts, whereas the responsibility for realisation lies with all the participants and users of the aircraft.

SAŽETAK

PROGRAM PROCJENE INTEGRITETA STRUKTURE ZA ZASTARJELE MLAZNE TRANSPORTNE ZRAKOPLOVE

U radu se razrađuju kriteriji i procedure za procjenu periodičnog preporučenog održavanja koje će podržati kontinuirano sigurnu eksploataciju zastarjelih mlaznih zrakoplova do njihovog povlačenja. Aktivno uporabno razdoblje komercijalnih zrakoplova u novije je vrijeme povećano uslijed konkurentnih cijena goriva te povećanih rokova i troškova isporuka za zamjenu flote. Tendencija je operatera da se stariji zrakoplovi nastavljaju koristiti usprkos većim zahtjevima u održavanju. Konstrukcijske koncepcije, podržane eksperimentalnim ispitivanjima, daju zavidne rezultate u uporabi novog sustava održavanja, koji jamči sigurnost letenja, osiguranjem kontinuma strukturalnog integriteta ispitivanjima i preporukama iznad razine zahtjeva sadržanih u priručnicima za održavanje i servisnim biltenima. Sigurnost zrakoplovne strukture ovisi o udjelu svih sudionika u sustavu zračnog prometa: proizvođača

koji konstruira zrakoplove; avioprijevoznika koji koriste i održavaju zrakoplove; te zrakoplovne vlasti koja utvrđuje pravila i propise, ovjerava konstrukciju i nadzire izvršno održavanje zrakoplova.

REFERENCES

1 fail-safe: safe to failure (element designed usually so that it consist of two parts, where if one part breaks, the other one takes over the load)
2 NDT - non-destructive testing (ultrasound, X-rays, etc.)
3 CAA - Civil Aviation Authority
4 FAA - Federal Aviation Authority
5 SSI - Structurally Significant Items
6 NASA - National Aeronautics and Space Administration

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