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Review of aeronautical fatigue investigations in France during the period May 2009- April 2011

TECHNICAL NOTE N°3-31/ST/2/2011

DGA

DIRECTION GENERALE DE L'ARMEMENT

DGA Techniques aéronautiques

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Abstract :

The present review, prepared for the purpose of the 32th ICAF conference to be held in Montreal (Canada), on 30-31 May 2011, summarises works performed in France in the field of aeronautical fatigue, over the period May 2009-April 2011.

Topics are arranged from basic investigations up to full-scale fatigue tests.

Companies or organizations which contributed to the review are the following :

- Airbus
- ATR
- Dassault Aviation
- DGA Techniques aéronautiques
- EADS Innovation works
- Institut P' Poitiers
- Latécoère

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1. INTRODUCTION AND ACKNOWLEDGMENT

The present review, prepared for the purpose of the 32th ICAF conference to be held in Montreal (Canada), on 30-31 May 2011, summarises works performed in France in the field of aeronautical fatigue, over the period May 2009-April 2011.

Topics are arranged from basic investigations up to full-scale fatigue tests.

References, when available, are mentioned at the end of each topic.

Correspondents who helped to collect the information needed for this review in their own organisations are :

- Bertrand Journet for EADS Innovation Works
- Alain Santgerma for Airbus France
- Dominique Tougard, Frédéric Desbordes, Eric Garrigues for Dassault Aviation
- Gilles Garrigues for Latécoère
- Damien Théret, Mathieu Fressinet, Pierre Madelpech and Pascal Hamel for DGA Techniques aéronautiques.
- Gilbert Hénaff for Institut P’ (Poitiers)
- Maurizio Cajani for ATR.

They will be the right point of contact for any further information on the presented topics.

Many thanks to all of them for their contribution.

2. MATERIAL FATIGUE BEHAVIOUR

2.1. FATIGUE BEHAVIOUR OF A WING PANEL MATERIAL FROM A TEARED DOWN AIRCRAFT (INSTITUT P’)

The fatigue behaviour of an aluminium alloy 2024 T351 cut from an aircraft wing at the end of life has been analysed in order to characterize the effect of aging on the fatigue resistance. High-cycle fatigue tests and fatigue crack propagation tests have been carried out on specimens machined from dismantled panels. The specimen geometries were selected in relation with the machining conditions and the thickness of the panel. Two directions, L-T and T-L, were tested to examine the influence of the orientation. In addition, two areas corresponding with different load histories were considered : an area located at the end of the wing and an area close to the engine.

S-N curves and da/dN - ΔK curves were established and compared with new material references. After testing, the fracture surfaces were observed by SEM in order to analyse cracking mechanisms in relation with aging conditions.

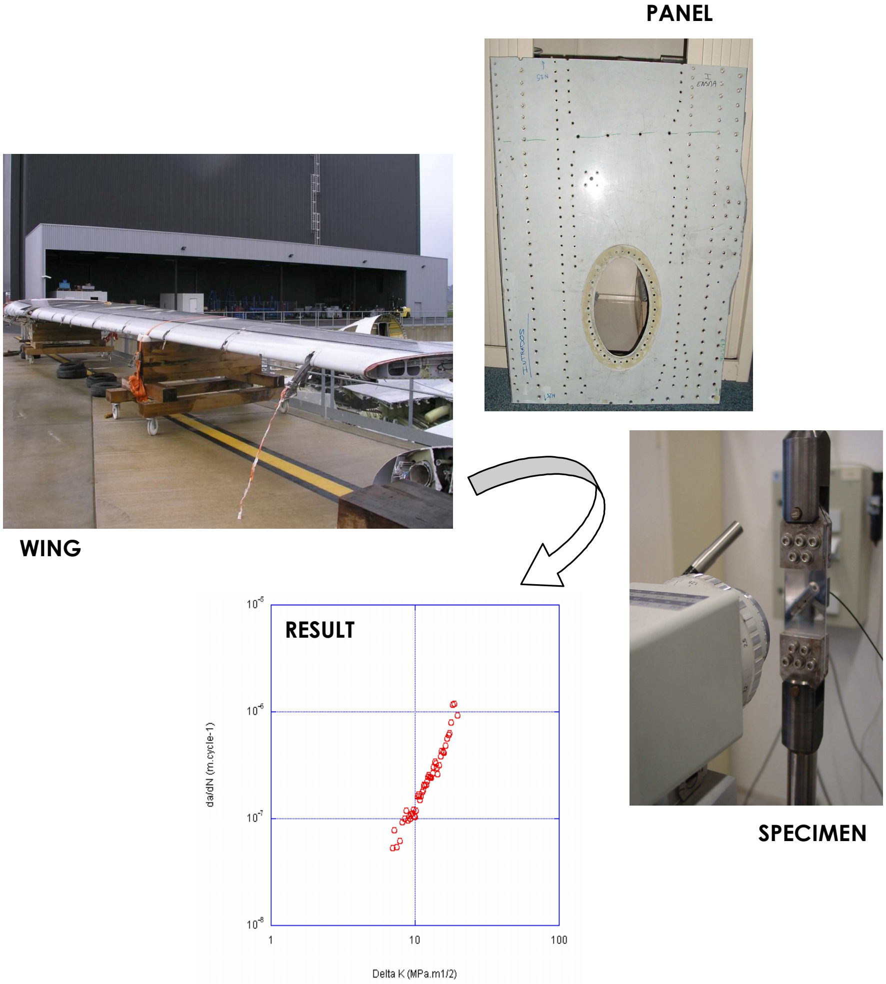


Figure 1 : From dismantling of the wing to crack propagation results

2.2. FATIGUE OF ALUMINIUM ALLOYS AND TITANIUM MATRIX COMPOSITES (EADS IW)

During the last two years, the activities of EADS IW dealing with the fatigue, damage tolerance and integrity of structures have been carried out on several grounds: involvement in EADS business units programmes and involvement in more upstream research activities.

The work reported addresses the more upstream research activities, namely the fatigue and fracture mechanics of metal structures. More effort has been devoted to the space application than to the aeronautical field. Few results have been obtained in this latter area since fewer projects were running and now new projects are starting.

The main lines of running or starting activities related to the aeronautical field are as follows:

• fatigue area: fretting fatigue, corrosion and fatigue

• damage tolerance area: fatigue crack growth under spectrum loading, ageing

This paragraph deals with the first topic mentioning two studies being in an early stage. See §3.2 for the second one.

IW is involved in a European project ECODESIGN. The contribution of IW in one of the work packages is to assess and model the reduction in fatigue in air in the presence of an intergranular corrosion flaw. The work will focus on a 2024 alloy. The work is in a starting phase.

IW is involved in a national project COMETTi to assess and model the fretting fatigue behaviour of some titanium matrix composites. The work is also in a starting phase.

3. FATIGUE LIFE PREDICTION STUDIES AND FRACTURE MECHANICS

3.1. PREDICTION OF FATIGUE CRACK PROPAGATION UNDER VARIABLE AMPLITUDE LOADING IN A MARTENSITIC STAINLESS STEEL (INSTITUT P')

Most of the models that have been developed to account for the fatigue crack growth behaviour under variable amplitude loading are based on the crack closure concept as originally proposed by Elber. These models generally provide reasonable predictions of the growth life in light-weight alloys. However it is not clear whether this still holds in the case of high strength alloys.

With this respect, a preliminary study has been carried out in the lab in order to evaluate retardation effects under repeated overloads in a precipitation hardened martensitic stainless steel. A retarded crack growth behaviour is noticed in the case of an overload (t=1.7) applied every 1000 cycles of a baseline loading at R=0.1 (Figure 2). Furthermore this behaviour cannot be correctly accounted for by conventional models such as FASTRAN., However preliminary calculations of the incremental approach developed by S. Pommier provide promising results. This issue will be investigated into more details within the framework of the ANR “Mat&Pro” PREVISIA starting in 2011. The effect of temperature and aging will be also examined.

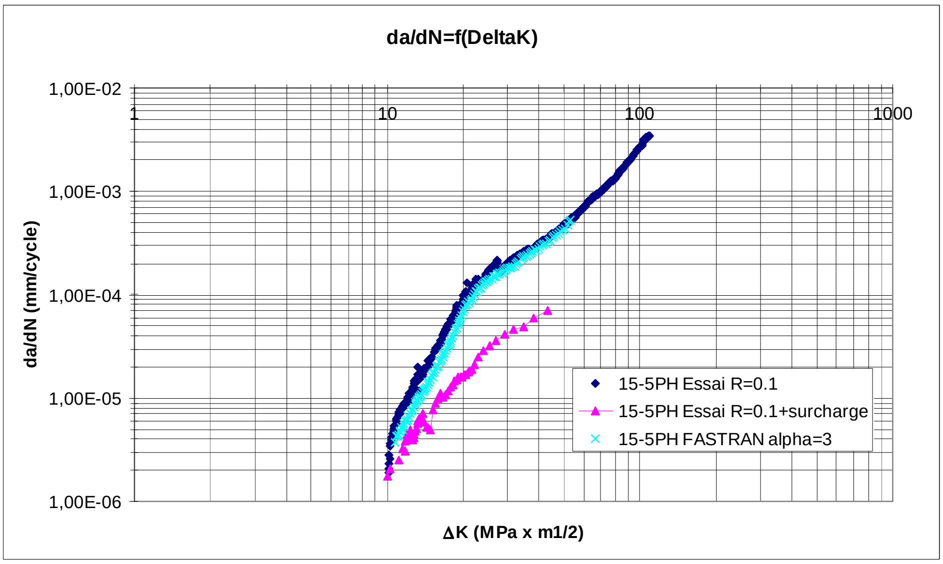


Figure 2 : comparison of experimental data and Fastran predictions provided by AFGROW

3.2. DAMAGE TOLERANCE EVALUATION OF AN INCONEL ALLOY : FATIGUE CRACK GROWTH UNDER SPECTRUM LOADING, AGEING (EADS IW)

IW is involved in a starting national project PREVISIA. The contribution of IW in one of the work packages is to assess and model the fatigue crack growth under spectrum loading of a steel that will operate in an elevated temperature environment. The issues of crack growth retardation effect at temperature and ageing will be addressed.

IW has evaluated PREFFAS model on an inconel alloy under a pylon spectrum loading. The experimental and predicted results obtained on a CCT panel are shown in the figure below (figure 3). There is a 12% difference in the propagation life between the prediction and the test result (ainitial = 6.8mm, afinal=52.4mm). PREFFAS model implements an Elber's type relationship to account for both R load ratio and retardation effects in fatigue crack growth. At each spectrum cycle, the preceding loading history is taken into account to assess the cycle closure level.

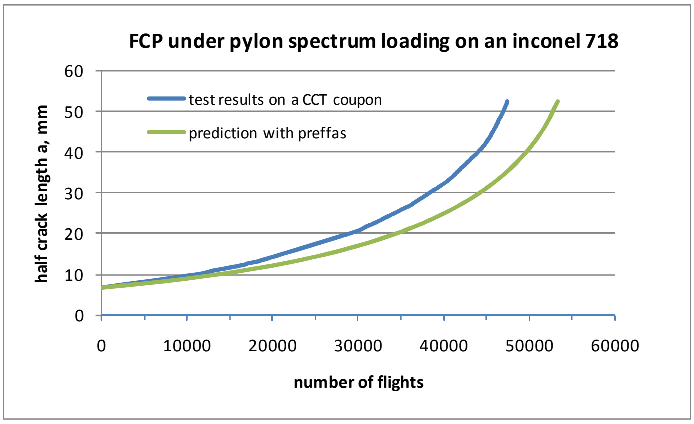


Figure 3 : crack length vs flights number

3.3. F&DT METHODS IMPROVEMENT IN AIRBUS (AIRBUS)

Over the last decade, AIRBUS migrated from 4 national entities to an extended company. Huge efforts were made to harmonise and standardise stress policies, methods and tools.

The material and processes test data banks from the four entities have been compiled into a single one. This included fatigue, crack growth and residual strength data, but also technological parameters such as interference fit, cold expansion, fastener and assembly types, CAA influence, shot peening. Results are available for a wide range of materials, thicknesses, heat treatment and loading conditions. The material data have been standardised into a common format.

The existing fatigue endurance calculation law has been refined. Apart from the material and local stresses in the design feature, it takes into account a number of technological parameters (examples mentioned above). The availability of a comprehensive test databank allowed the law parameters to be refined in order to consolidate the endurance calculation law. It is adjusted on standardised constant amplitude loading and is used to predict fatigue life of any structural feature under complex loading (after rainflow and using a Miner law).

3.4. FATIGUE LIFE ESTIMATION OF STRUCTURES SUBJECTED TO VIBRATORY LOADING (DGA/TA)

Fatigue life is commonly estimated by an analysis of the stress time history through a peak-valley counting method and the damage is calculated thanks to a damage summation method. Unfortunately, vibratory loadings are often random and this kind of calculation would be very time consuming. Such spectrum requires other methods and that’s why especially dedicated models have been developed. Known as spectral methods, they enable to calculate the fatigue damage in the frequency domain where the loading is expressed as a power spectral density function (PSD) of stresses [1]. In the literature a huge number of models can be found, such as the one’s developed by Dirlick [2] or Tovo-Benasciutti [3], which have been developed to estimate fatigue life of structures subjected to wide-band stationary Gaussian loading.

The philosophy of fatigue life calculation in the frequency domain is based on a Miner damage summation method. Nevertheless, the number of occurrences of a rainflow extracted cycle of a certain amplitude is estimated thanks to a probability density function calculated directly from the PSD.

In that context, DGA Techniques aéronautiques has launched its own study on that topic in order to review the main models and to test their robustness and sensitivity to different parameters such as the mean stress correction methods, the RMS value or the slope of the Wöhler curve.

At this stage, the aim was not to confront these models to real vibration tests performed on coupons, but basically to compare their predictions with a “reference” obtained with the classical models in time domain they are based on, that is to say Miner rule with a rain flow counting. The accuracy of the different spectral models has thus been assessed. This comparison has been performed with a wide range of PSD (more than 500) which were chosen to be representative of a real PSD met in helicopter environment and has enabled to identify the more relevant models for this kind of application.

This study also gave the opportunity to assess the influence of different parameters on the committed error. Different mean stress correction methods (such as Goodman, Goodman symmetric, Gerber) and different material's fatigue life parameters and Wöhler representations (Basquin and Haibach) have been considered.

This work has led to a better knowledge of these models for aeronautics applications but has of course to be carried on with an evaluation on real tests.

[1] Predicting fatigue life from frequency domain data: current methods, Part A, F. Sherratt, N. Bishop and T. Dirlik, 2004

[2] Applications of computers in fatigue analysis, T. Dirlik, Ph.D. Thesis, University of Warwick, 1985

[3] Fatigue analysis of random loadings, Benasciutti D., Ph.D thesis, University of Ferra, 2004

4. COMPUTATIONAL TECHNIQUES

4.1. A CONTINUUM DAMAGE MECHANICS MODEL OF FATIGUE CRACK PROPAGATION FROM MODERATE TO HIGH ΔK LEVEL (INSTITUT P')

The aim of this study was to develop a numerical model to predict the behaviour of cracked panels under monotonic as well as under cyclic loading. In particular, the model has to simulate fatigue crack propagation at high ΔK levels for a wide variety of metallic alloys including aluminium alloys, titanium alloys and steels. An advanced fatigue model, developed in the framework of Continuum Damage Mechanics (CDM), has been proposed. The CDM approach, initially proposed by Lemaitre, considers the effects associated to a given damage configuration through the definition of a thermodynamic state variable. This proper thermodynamic framework provides numerical robustness. This study examines the possibility to use such models to simulate fatigue crack propagation. The analysis of fracture modes and of $\frac{da}{dN}$ - ΔK curves at different load ratios suggest that two damage mechanisms are involved in fatigue crack propagation. To improve the damage description of the Lemaitre model, two distinct damage variables are introduced. The evolution of the first one, called "static damage", follows the classical Lemaitre formulation, while the second one, "cyclic damage" is related to cyclic cumulative plastic strain. The model only requires the determination of a single data point on a da/dN curve. Reasonable agreement with experimental data has been observed in many cases.

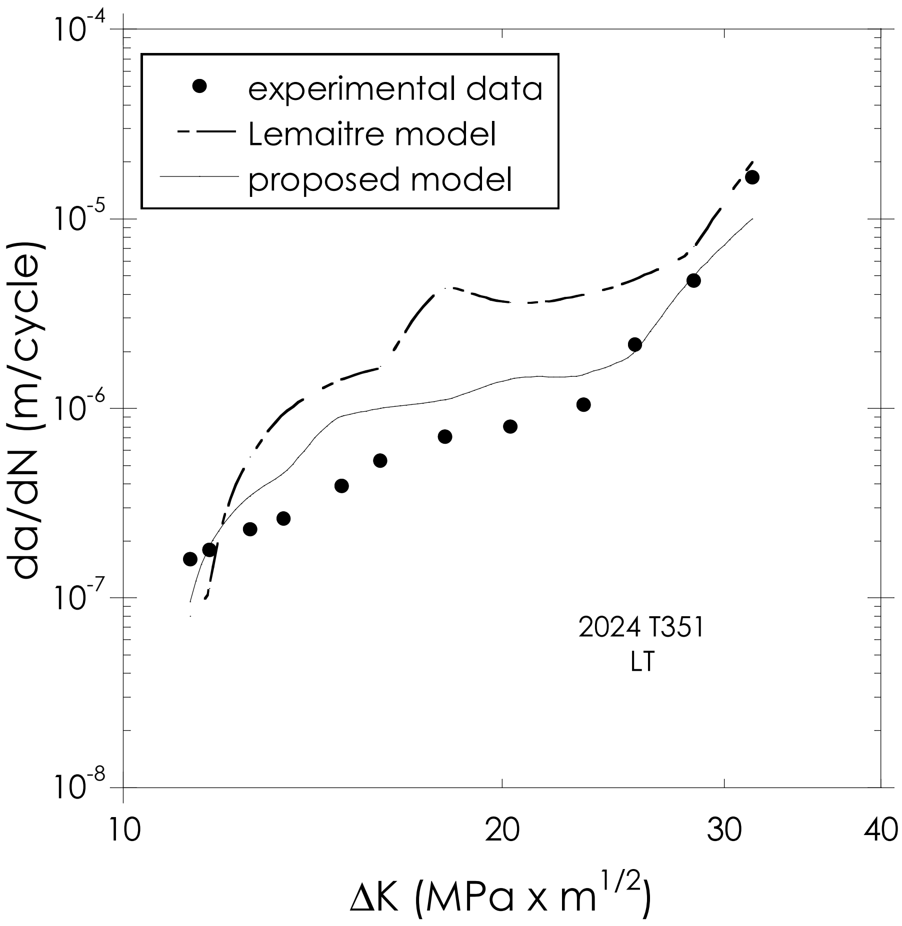


Figure 4 : prediction of fatigue crack growth rates provided by the proposed CDM model as compared to experimental data

[1] F. Hamon, G. Henaff, D. Halm, M. Gueguen, and T. Billaudeau, CDM approach applied to fatigue crack propagation on airframe structural alloys, Procedia Engineering, Fatigue 2010, 2 (2010) 1403.

4.2. A COHESIVE ZONE APPROACH TO ACCOUNT FOR COUPLED EFFECTS DURING FATIGUE CRACK PROPAGATION (INSTITUT P')

Experimental studies indicate a deleterious influence of a hydrogenous environment on the fatigue crack propagation resistance of metallic materials. In order to provide a predictive tool to assess fatigue lifetime of structures subjected to hydrogen, an ABAQUS finite element model has been developed. A cohesive zone model (CZM) with a specific tension-separation law is used in conjunction with an elastic-plastic bulk material to model fatigue crack growth. The tension-separation law has been developed to take into account the influence of cyclic loading on crack propagation. A special attention has been paid to develop the model in the framework of thermodynamics, i.e. to ensure that the dissipation remains positive at any time. In addition, the parameters of the traction-separation law depend on local hydrogen concentration. This tension-separation law was implemented using ABAQUS user element subroutine UEL which is used to predict the influence of hydrogen on fatigue crack growth rates. Given the similarity between heat and mass diffusion equations, the coupling between hydrogen diffusion and the mechanical behaviour of the material has been implemented using ABAQUS coupled temperature-displacement procedure.

[1] C. Moriconi, G. Henaff, D. Halm, Influence of hydrogen coverage on the parameters of a cohesive zone model dedicated to fatigue crack propagation, to be published Procedia Engineering (2011).

5. FATIGUE OF COMPOSITES

5.1. ELECTRO-MECHANICAL FATIGUE OF CFRP MATERIALS FOR AIRCRAFT APPLICATIONS : PRELIMINARY RESULTS (INSTITUT P')

The employment of carbon fibre reinforced polymer (CFRP) composite materials for aircraft fuselage structures is foreseen in the next future. Aircraft fuselages may serve as "mass" and Faraday cages, therefore composite fuselage panels may be subjected to parasite electric currents which may promote temperature changes due to Joule heating; temperature effects may then couple with cyclic mechanical solicitations, contributing to material degradation. A better understanding of the material ageing phenomena under the effect of coupled electro – mechanical solicitations is thus needed for the development of such structures.

The ENSMA Poitiers Pprime DPMM department has studied the thermo-electro-mechanical response of UD and QI CFRP composites samples subjected to DC and AC currents up to 8A and 900Hz. Preliminary thermoelectric tests have been carried out to optimize the electro-mechanical test conditions: electro-mechanical fatigue tests have been then carried out to estimate the impact of currents on the sample numbers of cycles to rupture, Nr. During the test, transient and steady temperature fields have been measured on the sample surfaces by infrared thermography and real time voltage measurements to monitor the sample electrical resistance. Sample dimensions and electrode types have been chosen in order to achieve a homogeneous temperature field along the sample and to minimize the contact resistance; with the imposed electrical solicitations, sample temperatures do not exceed the glass transition temperature of the resin. Electro – mechanical fatigue tests have been performed on "as released" QI samples with a maximum fatigue stress, Smax, close to 70% of the average QI strength (Smax ≈ 600 MPa) and with Smax/Smin = 0.1. The mechanical frequency of the test was 5Hz. Electrified samples have been subjected to the simultaneous action of mechanical fatigue and DC (3A and 6A) and AC (6A, 300Hz and 600Hz) currents: at least three samples were tested for each experimental condition. According to the preliminary thermoelectric tests the average QI sample current induced temperature is around 60°C at 3A and around 160°C at 6A. Figure 5 shows preliminary Smax - Nr curves for all the tested sample conditions. The horizontal line appearing in the curve indicates the scatter of the number of cycles to rupture for each tested sample.

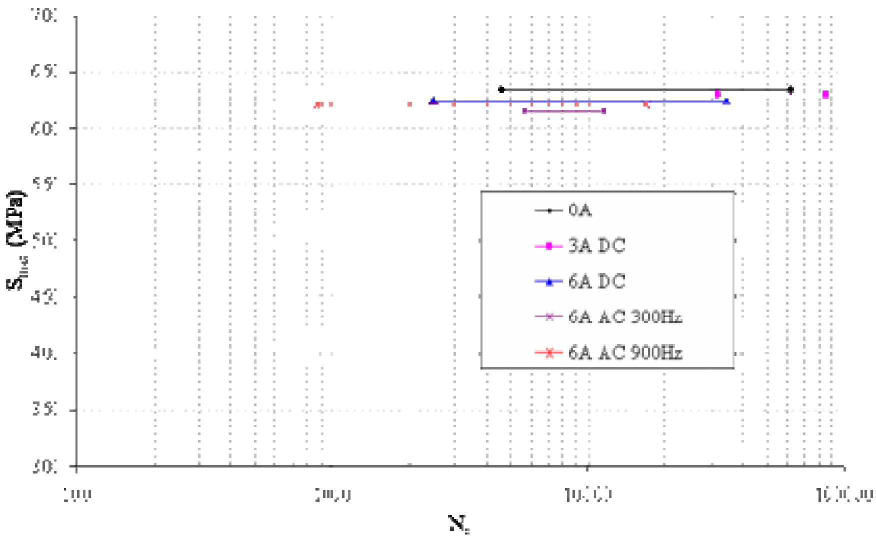


Figure 5: Smax - Nr curves for CFRP samples under electro-mechanical fatigue

Despite the large experimental scatter, Nr seems to be influenced by the electric condition; in particular, the average Nr value is sensibly decreased by a test condition involving 6A 900Hz AC currents.

References

[1] Gigliotti M., Marchand D., Lafarie-Frenot M.C., Grandidier J.C. Sur le Comportement Thermoélectrique de Matériaux Composites pour Applications Aéronautiques. JNC16, Seizièmes Journées Nationales sur les Composites, 10-12 Juin 2009, Toulouse, France.

[2] Gigliotti M., Grandidier J.C., Lafarie-Frenot M.C., Marchand D. Development of Experimental and Modelling Tools for Electro – Mechanical Fatigue Tests in Composite Materials for Aircraft Applications. Proceedings of ECCM14, 14th European Conference on Composite Materials, 7-10 June 2010, Budapest, Hungary.

[3] Gigliotti M., Lafarie-Frenot MC, Grandidier JC, Development of Experimental and Modelling Tools for the Characterisation of the Thermo – Electro - Mechanical Behaviour of Composite Materials for Aircraft Applications. Mécanique & Industries. In press.

5.2. EUROPEEN ALCAS PROJECT: EVALUATION OF THE RISK OF DELAMINATION PROPAGATION IN COMPOSITE STRUCTURES (DASSAULT AVIATION)

Within the European ALCAS Project (Advanced Low Cost Aircraft structure, which aim is the development of new technologies involving composite structures with cost and weight reductions as drivers) some fatigue cycling were performed to evaluate the risk of delamination propagation in composite structures.

The technology developed by Dassault-Aviation is the LRI technology: Liquid Resin Infusion on dry fibers. This technology permits to integrate many parts of the structures during one infusion and permits costs reduction by reducing assembly operations.

To validate this technology a sub-scale wing box was manufactured and mechanical tests were performed on it. This sub-scale wing box is representative of a wing box in terms of loads, height, sizing complexity (kink, stiffener run-out, local effort introduction…).

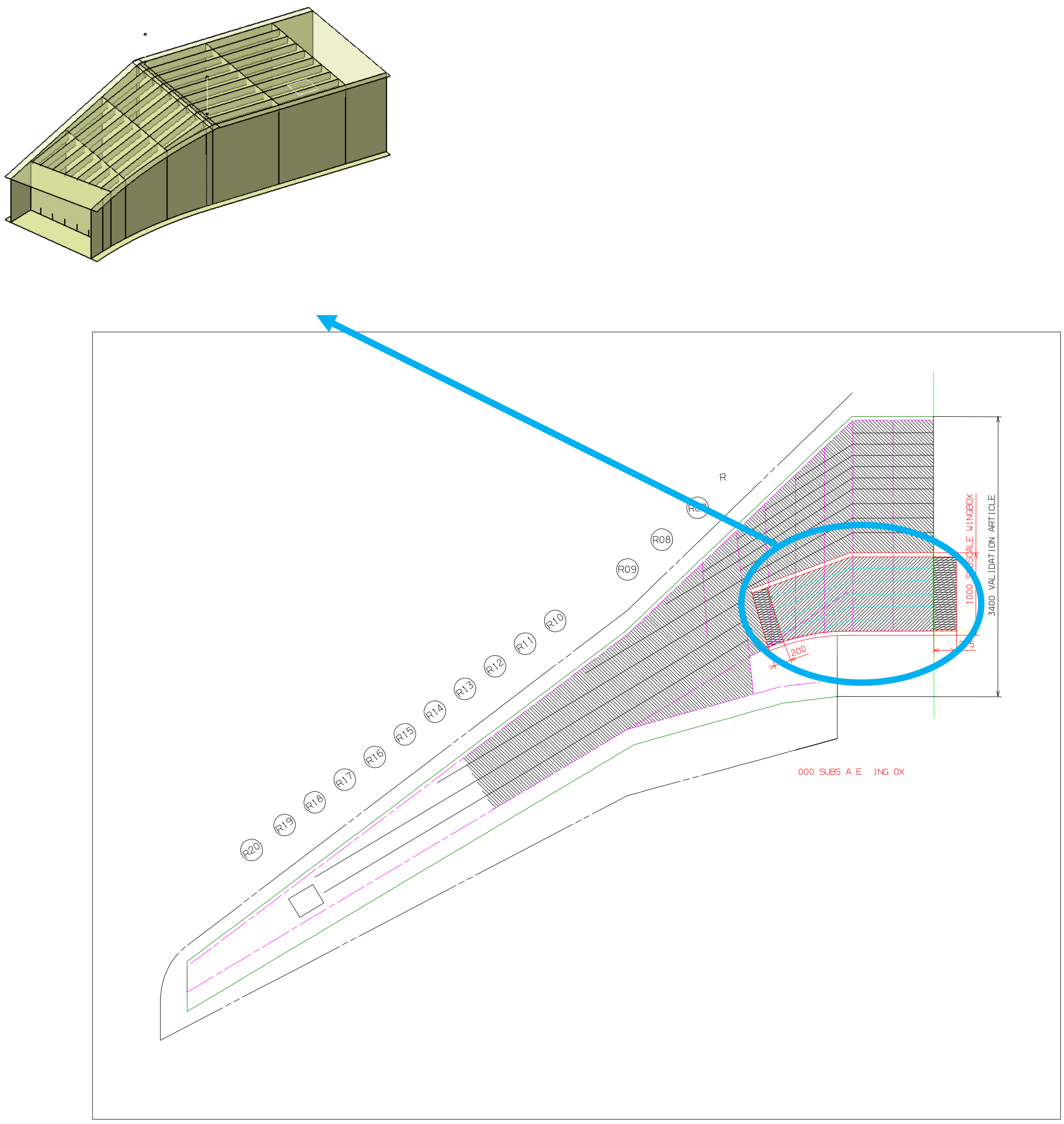


Figure 6 : Localization and picture of the sub-scale wing box

The test sequence imposed on the sub-scale wing box was:

- Limit Loads session

- Impact session

- Fatigue cycling

- Limit Loads session

- Ultimate Loads session

- Failure session.

Description of the impact session:

- The impacts were performed in the most loaded areas

- The certification authorities imposes an energy level of 35 J except if the BVID is reached for energy level lower than 35 J (BVID is an indentation of 1 mm before relaxation).

Fatigue cycling: the purpose of the fatigue session is to demonstrate the ability of an impacted composite structure to avoid delamination propagation obtained either by manufacturing defects or after impacts during the aircraft life cycle.

According to airworthiness requirements, fatigue demonstration for composite structure requires either a coefficient of 13.3 on the number of test cycles or an enhancement coefficient of 1.17 applied on loads. In order to shorten the test duration, the second solution was applied for sub-scale wing box testing (in accordance with composite fatigue requirements, all fatigue cycles of the spectrum below 0.3 x LL were suppressed).

The result is that there was no propagation of the delamination generated by the impacts during the fatigue cycling.

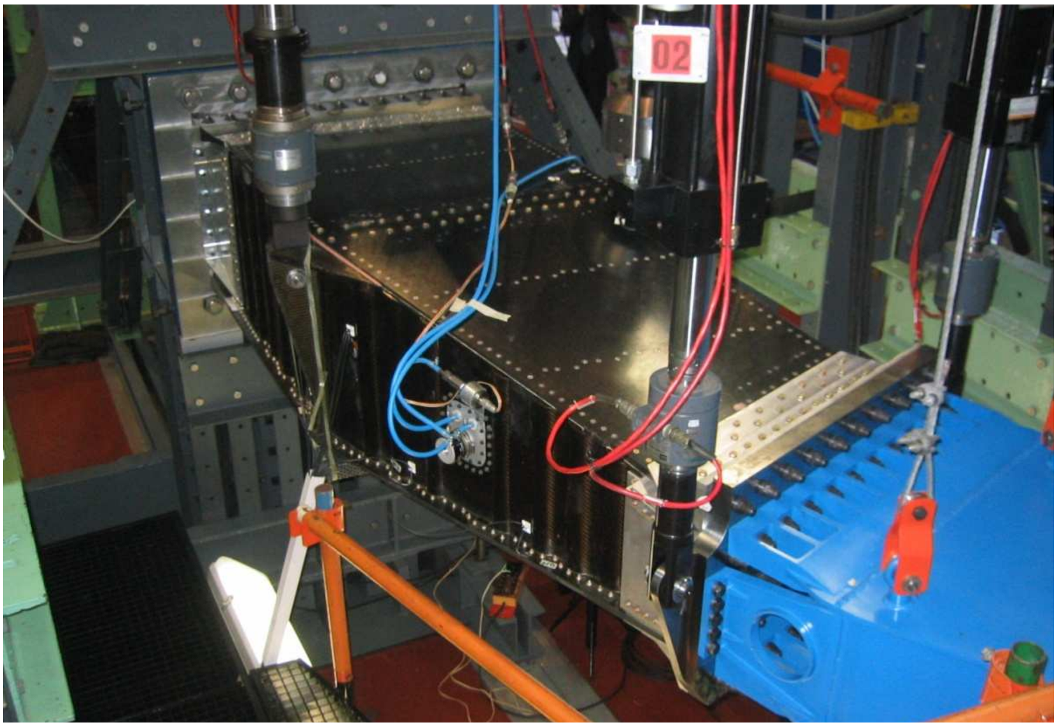


Figure 7 : Picture of the test

5.3. DESIGN, SUBSTANTIATION AND MANUFACTURING OF AN INNOVATIVE AIRCRAFT PASSENGER DOOR STRUCTURE (LATÉCOÈRE)

5.3.1. CONCEPT AND DESIGN

Introduction :

As a world leader in the manufacturing of passenger doors for commercial aircrafts, Latécoère has got a unique and huge experience of door behaviour and constraints. A progressive reflexion on the existing processes of manufacturing and on the door load cases, led to develop new concepts and use new materials to propose a product that can meet airworthiness requirements and in the same time save time, cost and weight.

Indeed, through its reflexion, experience and some product demonstrators, Latécoère found that copying existing concept of “metallic” doors (known as “black metal”) to introduce composite materials does not drive to expected gains.

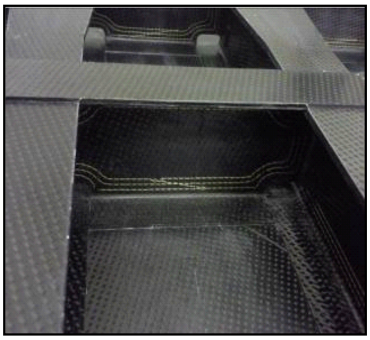
By its intrinsic characteristics, RTM process combined with stitched process was considered and showed to best answer to the above objectives. This process gives the opportunity to integrate the main elements of the door structure driving to a “fasteners free” structure synonymous of weight, assembly and cost savings, and fatigue behaviour increase.

Associated to RTM process, the use of the stitching process for the preform appeared to be the most adapted since it allows, not only to assemble the door components in one preform, but also to transfer and carry loads within the structure. In addition, the capacity for stitching to be automatized meets the final objective searched by OEM and their sub contactors to have a fully automatized manufacturing process.

Aluminum (Metallic structure)

Black metal (Hybride Structure)

One shot (Full composite)



Innovative concepts :

In addition to the integrated structure made by RTM, Latécoère is introducing within Maaximus project, several innovative concepts to design the passenger door :

- A “Fasteners free” structure.

Thanks to stitching technology, no rivets are present on the composite structure after molding. All components of the structure are stitched together allowing to have a monoblock structure. In addition, stitching allows replacing fasteners to transfer high loads from components to others and increase damage tolerance behaviour.

- “Crack stoppers” inside

Generally, the assembly of elementary plies to constitute component preforms implies to hot form or consolidate them. Latécoère chooses to stitch the preforms together not only to make and assemble the preforms but also to act as a “crack stopper”. Indeed, thanks to a suitable choice of the stitching pattern, it is possible to increase the mechanical performances of the structure by limiting “crack propagation”. Usually, this is made by fasteners called “chicken rivets” what drives to make heavier the structure. It is obvious that, again, the use of stitching drives to weight and assembly time savings by avoiding fasteners.

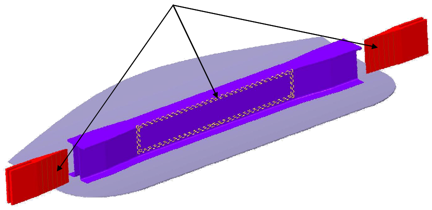


Figure 8: Stitching lines with double function

- The “load pass”

Main loads introduced within door structure come from fuselage stop fittings. This generally drives to design heavy door stop fittings to carry such loads and transfer them to door structure. By taking care of advantages of composite materials as well as stitching and RTM processes, a new concept has been designed and developed. This concept allows introducing main loads directly into the web of the beams by only shear loads. So composite material will no be subject to pull-off loads and fatigue and damage tolerance behaviour will be improved in these areas. This is possible thanks to specific parts called “forks” where optimized and light stop fitting can be inserted and fastened thanks to only 4 fasteners.

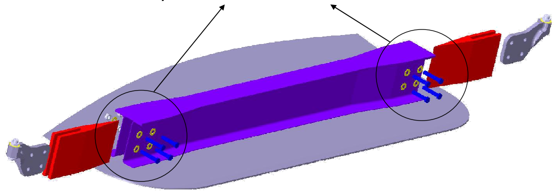


Figure 9: Innovative load pass

5.3.2. STRESS ANALYSIS AND JUSTIFICATION

Substantiation approach

Due to the aircraft internal pressure, each element of the door structure is submitted to a pull off / radius bending loading at its skin side (outer cap) and compression strength on the internal side (inner cap). Moreover, under this pressure, the skin is loaded in tension/bending.

To validate the design choices and demonstrate the ability of the structure to withstand these loads, several coupons and parts have been designed, sized and tested. All are part of the test pyramid used to validate the MAAXIMUS door structure.

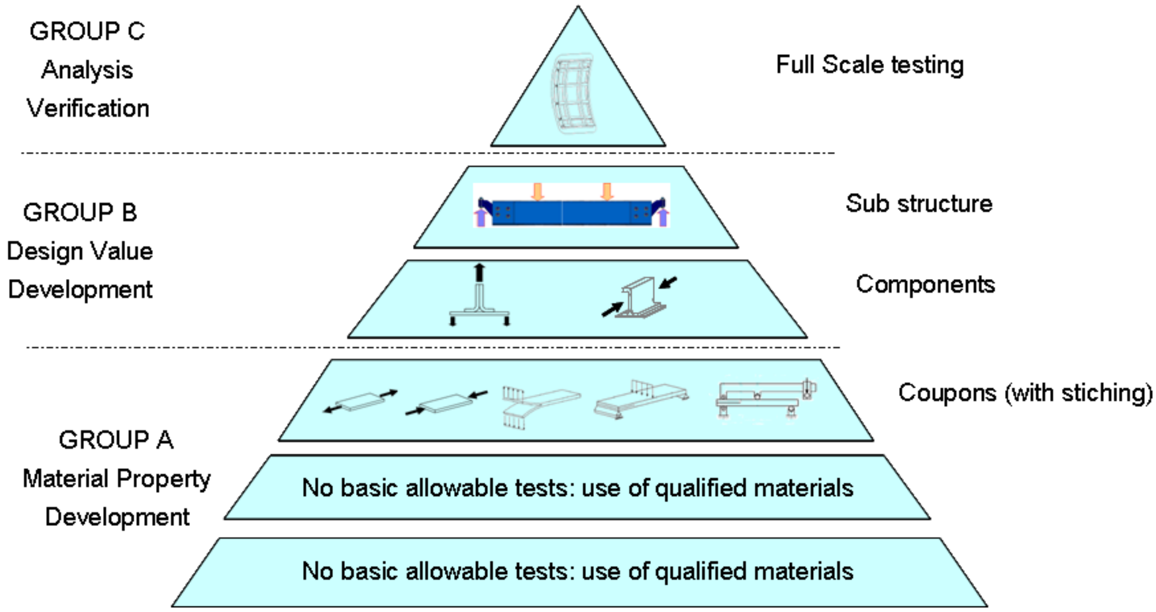


Figure 10: Test pyramid used for MAAXIMUS door substantiation

Test results :

The results of the different tension and compression tests demonstrate a low impact of the stitching "in plane" properties contrary to the results of the DCB and ENF tests whose reveal a high improvement of the stitching "out of plane" properties from 250 to 300%.

Furthermore, all coupons and components (pull-off, compression) tested have achieved fatigue, damage tolerance and static loads requirements and stitching has demonstrated to reach a strength level equivalent to riveting.

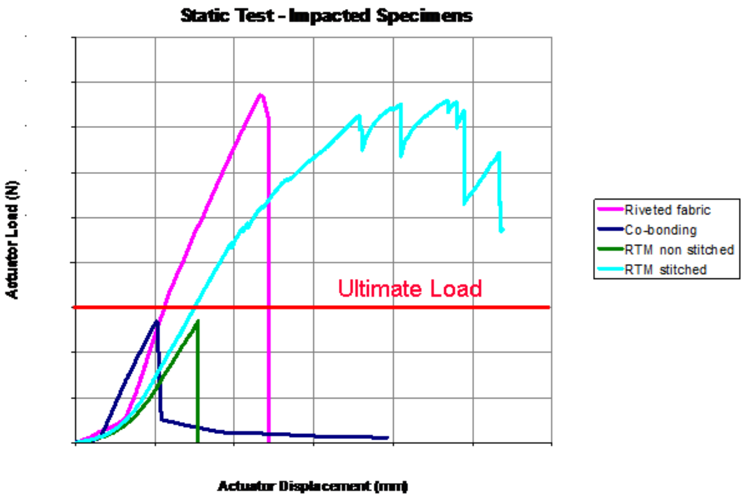


Figure 11 : Pull-off properties comparison

In addition, advanced FEM were implemented in this project based on fracture mechanics theory in order to estimate delaminations propagation and residual strength of stiffeners with skin stitched joint under pressure loading.

VCE analysis (with Samcef) were developed using specific interfaces elements. Results shows good correlation between analysis and testing and enable us to :

- reduce test samples

- assess design changes (material, lay-up, dimensions)

- estimate joint strength

Figure 12: Correlation between testing and analysis (Pull-off)

6. FULL-SCALE FATIGUE TESTS, LIFE EXTENSION, FLEET MONITORING & MANAGEMENT

6.1. AIRBUS FULL-SCALE FATIGUE TESTING (AIRBUS AND DGA/TA)

Because of a dynamic phase in aircraft project development, AIRBUS is currently in a peak of activities for Major Structural Tests. Many of these tests are for Fatigue & Damage tolerance substantiation of both metallic and composite structure.

The preparation phase for A350 major tests is going on. Full-Scale fatigue tests will be performed for metallic structure as well as for composite structure. Forward fuselage fatigue test will be performed in DGA Techniques aéronautiques test facilities.

As part of the life extension of the A320 family, a new Full-Scale Fatigue Test was performed. The 3 tested specimens i.e. forward fuselage (tested at DGA Techniques aéronautiques), centre fuselage & wing, rear fuselage recently reached their test target of 180,000 simulated Flight Cycles. The tested specimens were mostly representative of the latest A/C standards, whereas different modification configurations have been introduced on left and right hand sides. Typical manufacturing defects, accidental damages and repairs have been also introduced in the specimens for testing. A new set of fatigue loads was defined based on the latest information about how the worldwide A320 fleet is operated (e.g. in terms of weights and flight duration). These updated fatigue missions and loads were used to build the loading sequence applied at test. Service experience is taken into account, F&DT calculations are updated, and a refined correlation to the test results will allow our maintenance programmes to be revised and optimised. These new full-scale fatigue tests will also be beneficial for A320 programme improvements such as Sharklet introduction and New Engine Option (NEO).

6.2. MIRAGE 2000 FIGHTER AIRCRAFT LIFE EXTENSION PROGRAM (DASSAULT AVIATION AND DGA/TA)

A full-scale fatigue test has been carried out in DGA Techniques aéronautiques test laboratory on an aged airframe retired from the French Air Force fleet. The loading spectrum simulates the French Fleet Fatigue Index (FI) Consumption Rate expected in the future on all the key elements of the structure, with updated in-flight and ground loads.

After 4 years of fatigue test, the objective to demonstrate a significant extension of the Mirage 2000 fatigue life (in a "Safe Life" approach, with punctual damage tolerance) is achieved. The disclosed fatigue damages are not critical, in terms of static strength or reparability. The very good behaviour of the Airframe is demonstrated.

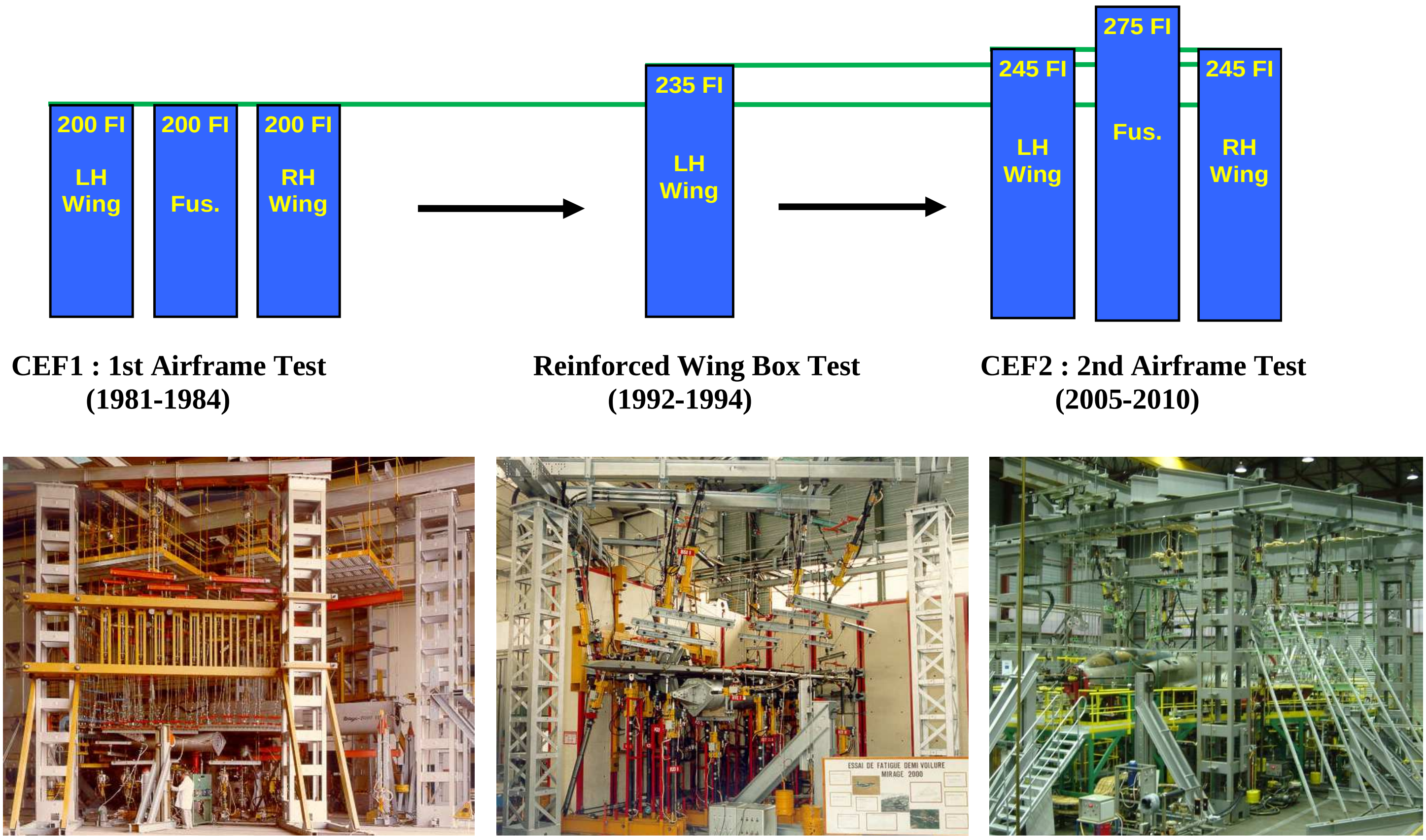


Figure 13 : Safe Life directly validated by the full-scale fatigue tests

Only "light" repairs (that can be applied to in service aircraft as curative or preventive solutions) have been implemented and validated through this fatigue test. M2000 specific Non Destructive Control systems have also been validated.

Figure 14 : Wing Phased Array ultrasonic NDT

Figure15 : Wing Main Spar Reboring

An upgraded inspection and structural maintenance plan of the aircraft with improved cost effectiveness has been issued to the Mirage 2000 operators.

Ultimate load cases and a final margin research are under achievement.

6.3. ALPHA JET TRAINER LIFE EXTENSION PROGRAM (DASSAULT AVIATION AND DGA/TA)

Two fatigue full-scale tests have been carried out in DGA Techniques aéronautiques test laboratory.

Using these test results, in service dedicated additional inspection on a sample of wings (for areas not solicited on the fatigue test cells) and the damage tolerance approach, the FI have been extended up to 325 for fuselage and 245 for wing.

The damage tolerance complete study has included the damages due to fatigue, that have happened during the fatigue tests as well as damages due to corrosion or accidental damages liable to occur in service (assumed to be situated at the most critical area).

To increase the probability to reach this extended life potential, Cold-Working operation are proposed for the most critical bores in the course of the scheduled maintenance operations on the wings.

6.4. ATR LIFE EXTENSION PROJECT (ATR)

Designed in the mid 80’s, ATR 42 and ATR 72 regional turboprops were designed under Damage Tolerance approach for a Design Service Goal (DSG) of 70 000 flights or equivalent 25 years in a mixed utilization (93% short range + 7% long range missions).

Since the oldest aircraft in the ATR fleet are approaching the DSG (see table below), activities under a joined impulse of the ATR Operations and Commercial Directions have been launched in 2005 to provide the ATR operators with an Extended Service Goal (ESG) of 1.5 times the DSG (i.e. 105 000 flights).

	ATR 42	ATR 72	whole fleet
fleet leader, FH	59 717 (MSN 62)	42 169 (MSN 297)	
fleet leader, FC	58 613 (MSN 39)	60 939 (MSN 126)	
total FH	10 336 433	8 294 239	18 630 673
total FC	11 517 263	9 548 314	21 065 577

Feedback from the in service world fleet and the results of major fatigue inspections (36 000 flights) are encouraging. The new ESG would dramatically increase the residual values of ATR aircraft.

The initial Full Scale Fatigue Test (FSFT) does not cover the Life Extension. Since a new FSFT is not envisaged, because of the high associated costs, it has been decided to perform the Life Extension by calculation, analysis and additional testing on some components if necessary. The aim is to limit the impact to the Maintenance Program only, avoiding or minimizing structural modifications. The following activity areas have been identified :

- evaluation of the impact on existing Significant Structural Items (SSI) and on Airworthiness Limitations Section (ALS). New available calculation tools such as Airbus SAFE allow for finer analyses than original ones giving potentially greater safety margins to achieve the ESG;

- analysis of FSFT tear down results and possible late damages;

- analysis of in service life experience;

- evaluation of the possible impact of Widespread Fatigue Damage (WFD) on structures susceptible to Multiple Site Damage (MSD) and Multiple Element Damage (MED). The process would identify ATR primary structures susceptible to WFD, predict if or when it is likely to occur, establish additional maintenance actions (inspections or modifications) to ensure continued safe operation of the aircraft;

- establishment of fleet leaders inspection requirements at or before 70 000 flights;

- additional analysis of composite primary structures to validate the results of the original tests, performed on artificially aged composites. New ageing tests could be performed on naturally aged composite structures to compare mechanical features with certification test values. Moreover, physical and chemical analyses could be implemented to observe the structural changes and to better apprehend the consequences of ageing on composite structures;

- analysis of the actual worldwide fleet utilization compared to the design and certification figures. This is because the fatigue and damage tolerance calculations depend heavily on flight duration and maximum cruise altitude;

- analysis of the impact on Life Limited Components: engine shock mounts, torque tubes, isolators, landing gear assemblies and attachments;

- analysis of the repairs and modifications embodied on each single aircraft, either via published data, like the Structural Repair Manual (SRM) and the Service Bulletins, or by means of unpublished data, like the single specific repairs covered by the ATR Structural Repair Approval Sheet (SRAS), currently validated under the privilege of the DOA (Design Organization Approval). The result of the analysis will consist in updating the above mentioned documentation.

Following the above described method, a first step is the validation of a new Limit of Validity (LOV) of 90 000 flights. Most steps and associated documents are now completed. The final impact should be limited to the Maintenance Program in this case. Actually, analyses show that both the fuselage and the wing are free from WFD at least up to 100 000 flights, while few are the new SSI that have been defined and that will begin to be inspected after the DSG is reached. As for the repairs embodied on aircraft, these will be reviewed at the moment of the working party that will take place at or immediately before the DSG, in order to evaluate the need for issuing or updating the supplemental inspections. By the way, this operation could coincide with the repair survey that the FAA rule for the Aging Aircraft Safety mandates to the American operators (refer to the Part 26 Subpart E too), and that the EASA also recommends.

The main action still in progress is the behaviour of the composite structures, which could require some more efforts, being this the very first time a primary composite structure (i.e. ATR 72 outer wing box) is subject to a life extension program. ATR remains confident that the final consequences will be negligible. The ESG of 105 000 flights still remains the final objective. The aircraft is structurally health, especially on the main load carrying elements, and this is demonstrated by the rare significant findings on the nearly 150 ATR that have undergone the fatigue-related 36 000 cycles visit at today. The economical interest will be most probably confirmed by the few possible structural modifications and/or additional maintenance actions required to get up to this higher ESG.

In conclusion, ATR is close to obtaining the Life Extension. Available data justifies at least an initial ESG of 90 000 flights, which will be most probably reached on a step-by step basis, per steps of 10 000 flights. At each step, suitable inspections are defined and performed in order to confirm the results of the analyses and update the reliability. The suitable importance of these elements will result from the negotiation with the European agency, after the application has been filed in a form of a “Major Change” certification. ATR is very confident that the few actions in progress should not call into question the final approval.

6.5. LIFE EXTENSION: FATIGUE LIFETIME UPDATING OF THE FRENCH XINGU FLEET (DGA/TA)

Embraer 121 Xingu is a reduced wing span version of the EMB110 "Bandeirante" with its own smaller fuselage. French Forces bought 41 of the 105 produced aircraft. It mainly helped for the training of the transport aircraft pilots. Primary designed for passenger transport, the French use was slightly different and less severe due to lighter take-off weight and fewer pressurization cycles. The applied loads in terms of wing bending are therefore far below the ones considered to certify this aircraft. This leads EMBRAER, in 1994, to give a fatigue life extension for the fleet, based on a comparison of load spectrum between the one corresponding to the current use and the one applied on the full scale fatigue test of the EMB110. The study concluded on an extension from 15000 flight hours to 45000.

Today, the mean use has evolved and the number of transport flights has increased. As those flights are pressurized and undergo heavy payloads, the result is a global increase of the load spectrum severity. As a consequence, the potential of 45000 flight hours is no longer applicable to the concerned aircraft. Such a decrease made the available fatigue lifetime insufficient to continue until the operational objective of a retirement in 2020. Therefore, the fleet needs an update of its fatigue potential, in an adaptable way taking into account that a change of the mean use could still be possible. As Embraer did not give a satisfactory answer in terms of costs or delivery time, the study was performed by DGA Techniques aéronautiques.

The used method consists in:

- Dividing the standard use of the aircraft in several missions, each being associated with a typical flight profile, fixing flight time, reached altitude and take-off weight.

- Analyzing each branch of the profile and using the probability of vertical loads factors occurrences, deducing two cumulative load spectra based on manoeuvre, from statistics on military training aircraft, and on vertical gusts, computed from the ESDU data.

- Computing from these loads cumulative spectra, first local stress spectra at each critical point, defined by Embraer, and then the associated fatigue damages deduced from Miner law.

Since the aerodynamical model of the aircraft was not available, a flight test campaign was undertaken measuring strain gauges responses at the vicinity of the critical point and at standard locations such as wing to fuselage junction. Performing calibrated manoeuvres at controlled load factors on a wide range of altitude, speed and mass, the relationship between the parameter and the bending moment and between the moment and the local stress could be obtained with a sufficient degree of confidence.

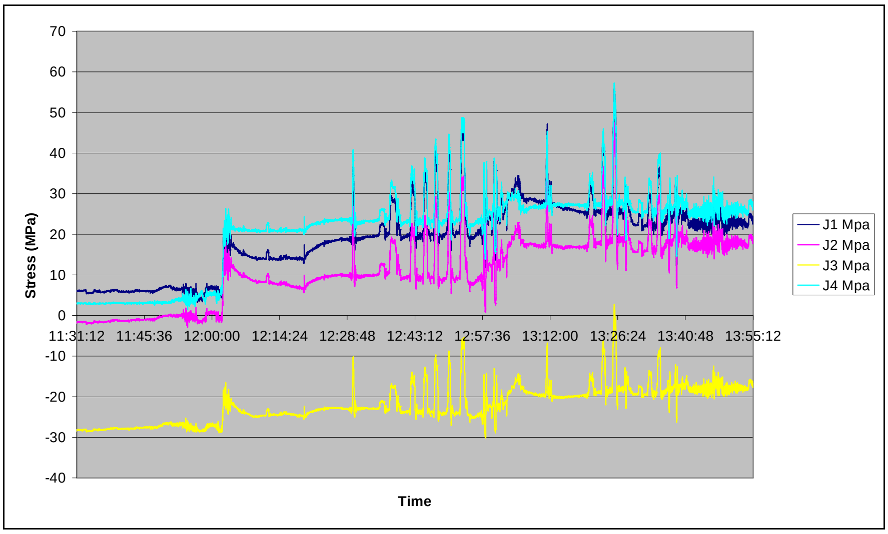


Figure 16: typical flight test results

Then the cumulative stress spectrum associated with the defined missions is easily deduced. Traditional fatigue damaging formulas based on Miner cumulative laws were finally used to compute the fatigue lifetime. A global potential was calculated but also one per mission enabling to easily adapt to future evolutions of the mean use. It is noticeable that some missions were far more critical than others concerning the fatigue of the aircraft.

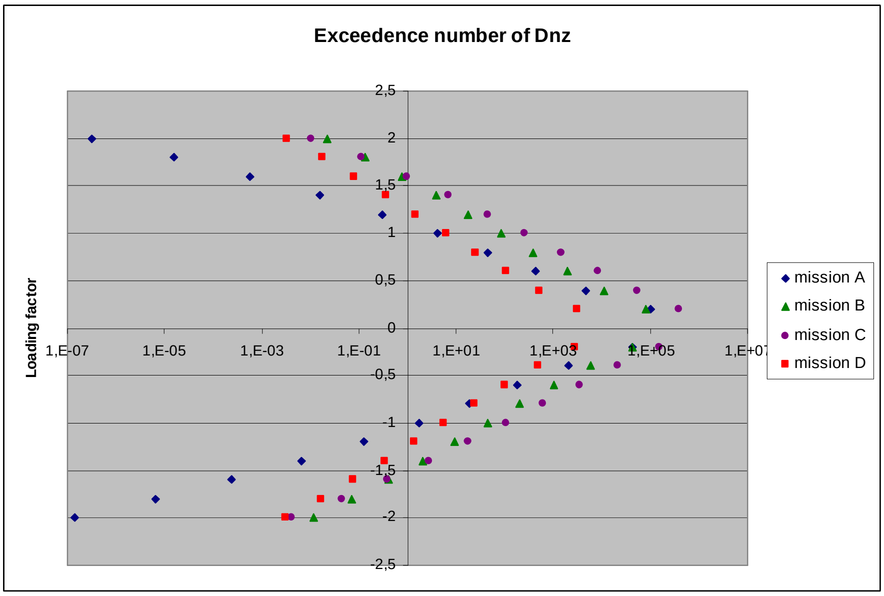


Figure 17: exceedences number of load factors due to gusts in 1000 fh by missions.

The study enables to obtain the necessary flight hours potential to extend lifetime until 2020, initial objective of retirement year. Moreover the flight safety was increased by pointing out the worst missions and the importance of standardization of the aircraft use over the fleet concerning those missions. An action is currently going on to compile the history of the fleet and make forecast on the fatigue lifetime evolution.

6.6. FRENCH CL-415 STRUCTURE INTEGRITY PROGRAM (DGA/TA)

Most European Mediterranean countries own a fleet of water bombing aircraft for fire fighting. The French “Sécurité Civile” uses 12 CL-415, designed and manufactured by Bombardier as an evolution of CL-215 in the late 80’s.

The European use of this ageing fleet is very severe, due to the mission it is devoted to and the environment of flight, and, above all, is quite different from the profile initially defined by the manufacturer: violent winds, strong relief, salty water, large waves, severe manoeuvres…

Additionally French pilots suffer from a lack of confidence in their aircraft due to some recent accidents. This feeling is reinforced by the very numerous damages found out during inspections. These lead not only to high maintenance costs on the fleet but also to this general mistrust from the pilots.

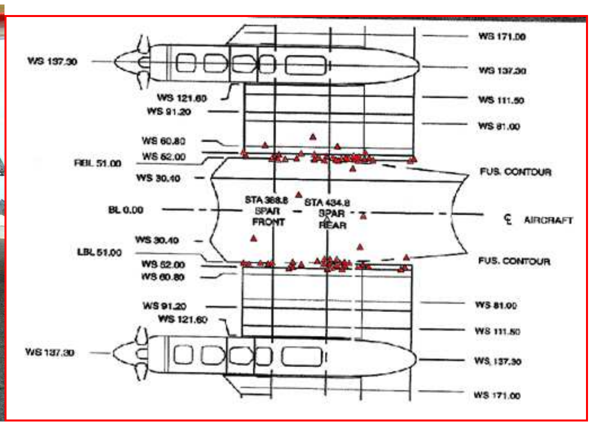
In that context, DGA Techniques aéronautiques was asked to launch a program to improve this situation. Consequently a wide project is currently in progress, aiming at monitoring the whole or a part of the fleet in order to:

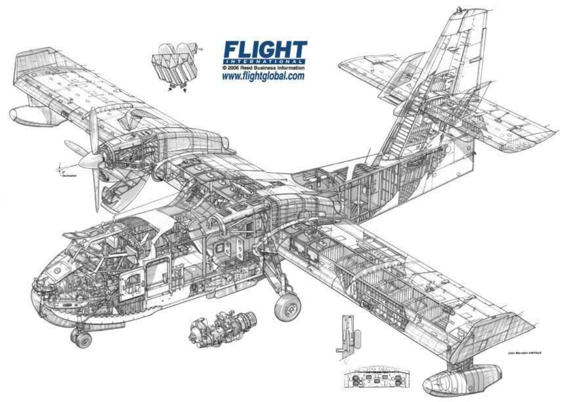
• Regain the trust of the users

• Maximize the availability of the fleet by predicting damage occurrence and adapting maintenance

• Participate to the safety and the structure integrity of the fleet by analysing the real loads

This program has started with the identification of the relevant structural points to monitor. These hot spots have been located taking into account in service findings, the general loading of the airframe and the available justification documents from the manufacturer. Some examples are illustrated below with the lower part of the fuselage, the wing-to-fuselage junction or the base of the fin.





The phase was to determine the load cases and the relevant manoeuvres from each of these hot spots. This study has been based on the general loading, the experience of the pilots and an engineer judgment. But all this has to be validated through a flight test campaign. Consequently, an extensive instrumentation plan has been determined in order to launch this initial flight tests campaign which is about to start. The aim is to finalize the choice of the instrumentation and the collected flight data.

The certification of the instrumentation devices will allow starting a real in-service monitoring on a few aircraft to begin the data collection. The next stages will depend on the results of the exploitation of these flight data.

6.7. FATIGUE DEMONSTRATION OF THE RAFALE PYLONS – FATIGUE SAFETY FACTORS (DGA/TA)

Before the 90's, the French airworthiness requirements for military aircraft pylons were limited to static tests demonstration. With the Rafale program, a fatigue performance test requirement had been added for pylons with a safe-life approach and a safety factor of 2 which only concerns the qualification of the part.

Recently a complete certification context for military aircraft was set up in France with DGA as Airworthiness Authority. The current concerns on certification issues in addition with fatigue damages encountered during a fatigue test on a pylon equipped with new weapons, led DGA to reconsider the safety management of pylons.

A study driven by DGA Techniques aéronautiques was launched to analyse the philosophy to adopt for fatigue issue to grant structural integrity for pylons.

This study took into account the following elements:

- The materials and manufacturing technologies of the pylons are the same as the ones used for the airframe of the aircraft;

- The load spectrum applied on the pylon is linked to the manoeuvres profile of the fighter aircraft. Consequently, from a general point of view, the scattering on this spectrum must be so important as the one on the spectrum of the airframe itself;

- The spectrum applied during the fatigue test is most of the time very severe as compared with the real one observed in service;

- Because of the geometry of such parts, the cracks mainly initiate on high stress zones due to a non application of elementary fatigue design rules as the design is usually limited to static cases;

- The improvement of the design methods and the optimisation of the static design increases the risk of fatigue damages;

- A pylon has generally to be considered, from a safety point of view, as a primary aircraft element, because its failure may be catastrophic for the aircraft;

- Most of the time, a pylon is an unsymmetrical part with an unsymmetrical loading, which prevent from considering a fatigue test as a double specimen test;

- The classical safety factors and their origins, as used in the main countries in the world for military aircraft, were analysed to give a basis in the study.

Based on these points, the safety factor of 2 basically appeared to be too low to cover the scattering of both spectrum and fatigue behaviour of a pylon. Several scenarios were proposed to define a philosophy to pilot the fatigue justification of future pylons. A definitive requirement has now to be chosen.