Transactions on Engineering Sciences vol 40, © 2003 WIT Press, www.witpress.com, ISSN 1743-3533

CF-18 wing full-scale fatigue testing and structural certification

A. Dabayeh, C. Yeung & P. Londei
Bombardier Aerospace, Mirabel, Quebec, Canada

Abstract

The Canadian Forces (CF) ordered 138 F/A-18 from McDonnell aircraft company (McAir)/Northrup for delivery starting 1982. The design was intended to last 6000 hours under severe US Navy usage. This life was determined by the manufacturer after conducting full-scale fatigue tests. These tests were required to certify the safe life of the F/A-18 based on the USN operating conditions. However, the difference between the CF-18 usage and the usage on which the airframe was originally tested, in addition to these tests not considering structural modifications performed on production aircraft after completion of full-scale testing, have created some structural concerns and a need to do additional full-scale fatigue testing. The Canadian Forces and the Royal Australian Airforce (RAAF) are currently collaborating in the International Follow-On Structural Test Program (IFOSTP) to conduct a full-scale fatigue test for the CF-18.

This paper will show a summary on the effort which is currently going on the FT245 full-scale fatigue testing of the CF-18 wing. The wing is being tested by the National Research Council of Canada (NRC) at the Institute of Aerospace Research (IAR) and technically supported by Bombardier Aerospace The fatigue test loads derivation process will be introduced, the test response and loading feedback monitoring through strain gauging of the entire wing and centre fuselage will be discussed, and the test inspection process for detecting/monitoring growing fatigue cracks will be presented. The paper will also present the effort done in preparation for the structural certification of the CF-18 wing.

Transactions on Engineering Sciences vol 40, © 2003 WIT Press, www.witpress.com, ISSN 1743-3533

1 Introduction

The CF concerns about the representativeness of the McAir test with respect to CF operations has initiated the thought of performing a full-scale fatigue test other than what has already been performed by the Original Equipment Manufacturer (OEM). The most important issues in assessing the representativity of the OEM structural fatigue test are the structural configuration and the test spectrum. Having unrepresentative configuration and spectrum increases uncertainty about the relevancy of the test results to operational usage. The CF usage data and studies have shown that the OEM test spectrum is not representative. Besides, the OEM test failures have resulted in fleet retrofits and in production line changes which did not make it back to the test article for testing. These uncertainties provided a ground for the need to the IFOSTP testing which would be performed for the following requirements [1]:

1. Ensure continued airworthiness of critical aircraft structure.
2. Determine the safe life of critical aircraft structure.
3. Determine the economic life of the aircraft structure.
4. Develop engineering data on aircraft structure whenever possible.

The IFOSTP test is divided to three parts; the RAAF are responsible for the aft fuselage and empennage, and the CF are responsible for the centre fuselage and the wing. The centre fuselage testing was contracted to Bombardier Aerospace and have been completed with 16,636 SFH. The Institute for Aerospace Research (IAR) at the National Research Council of Canada (NRC) was tasked to carry out the wing test with technical support from Bombardier Aerospace. Testing is currently going on with 11,922 SFH of testing accumulated to-date and is expected to end by the year 2006. The aft fuselage testing was conducted by the RAAF and has been recently completed with 23,090 SFH. The aft fuselage test have also been followed by RST testing and have passed it successfully.

The CF-18 airframe was designed based on the safe-life approach. Consequently, the aircraft should be retired after full life as determined by the full-scale fatigue test. However, due to the severe usage of the CF to the airframe some major structural parts are expected to fail before the end of the service life. The centre fuselage test (FT55) determined that the major 3 bulk heads will not meet the full life target and the CF is considering major structural modifications to the centre fuselage or implementing a Central Barrel Replacement (CBR) to part of the CF-18 fleet. The wing test (FT245), which is currently going on at NRC, will determine and certify the possibility of taking the CF-18 to the full service life. The wing and aft fuselage vertical stabiliser are multi-spar structures and consequently are considered load redundant. One of the approaches which could be applied to the wing and vertical stabiliser for structural certification, and would lead to economical outcomes, is the damage tolerance approach, or safety by inspection. The aircraft safety for certain components would then be managed using fracture mechanics to ensure that cracks will not grow to final fracture before being detected through periodic inspections. Simpson *et al* [2] presented a summary of the benefits from the collaborative IFOSTP work giving some background about the aircraft test set-up, usage spectrum selection, test systems and more. In this paper a summary on the effort which is currently going on the FT245 full-scale fatigue testing of the CF-18 wing will be introduced, and the test inspection process to ensure test safety and collect durability and damage tolerance data will be presented. The paper will also explain the effort done in preparation for the structural certification of the CF-18 wing. This effort included fatigue stress spectra comparison, in terms of fatigue damage, between previous tests performed by the manufacturer, the wing test (FT245), and the CF-18 fleet usage. The purpose of this comparison was to project the required testing time for certification and consequently determine the full-scale fatigue test end strategy. The paper will show how the fatigue test is also used for certification of the preventative modifications which are to be applied on the fleet aircraft. Preventative modifications are applied to locations which are expected to fail before a complete service life of the aircraft.

2 FT245 full-scale test

The FT245 full-scale fatigue test is planned/expected to go through the following phases [1]:

a) Definition phase - During this phase, all the test requirements and criteria are clearly defined, including load spectra development and test rig design. This phase has been completed successfully.

b) Test phase - During this phase, the actual full-scale test activities shall be performed to the specifications defined in the previous definition phase. This phase is currently in progress; and

c) Post Test Phase - This phase encompasses the post testing activities of residual strength demonstration and tear down. This phase is expected to be done by 2006.

2.1 Load spectra development

It was agreed upon between CF and RAAF, involved in the IFOSTP program, that wing loads are considered represented by accurately defining the interface load components at 12 locations. A list of these interface loads is given in Table 1, while their corresponding location is given in Figure 1 [3]. Table 1 is listed in approximate order of importance. In this section a quick overview of the load set development is given. The usage spectrum for the FT245 test is called IARPO3a. This spectrum was obtained from the Maintenance Signal Data Recording System (MSDRS) of the CF-18 and consists of data from 236 unique flights. The data was arranged to form a sequence of 279 flights corresponding to 326 Spectrum Flight Hours (SFH). IARPO3a is a compromise spectrum for CF and RAAF usage. The manoeuvre sequence in the IARPO3a spectrum was generated

Transactions on Engineering Sciences vol 40, © 2003 WIT Press, www.witpress.com, ISSN 1743-3533

at 10Hz and contains about 10 million lines. The full sequence was very huge, much more than 10 million lines, mainly due to dynamic loads, and consequently a 1% rise/fall truncation was applied to obtain a baseline sequence. This sequence was named "99LD" and contained about 25 million lines. The 99LD is considered an accurate representation for the CF fleet operation.

Table 1: Wing interface loads.

Interface Load	Abbreviation
Right Wing Root Bending Moment	RWRBM
Right Wing Fold Bending Moment	RWFBM
Right Inboard Leading Edge Flap Hinge Moment	RILEFHM
Right Outboard Leading Edge Flap Hinge Moment	ROLEFHM
Right Trailing Edge Flap Hinge Moment	RTEFHM
Right Aileron Hinge Moment	RAILHM
Right Trailing Edge Flap Outboard Vertical Lug Load	RTEFOLZ
Right Aileron Outboard Vertical Lug Load	RAILOLZ
Right Wing Tip Torsion	RWTTOR
Right Inboard Pylon Rolling Moment	RIBPMX
Right Wing Root Torsion	RWRTOR
Right Wing Fold Torsion	RWFTOR

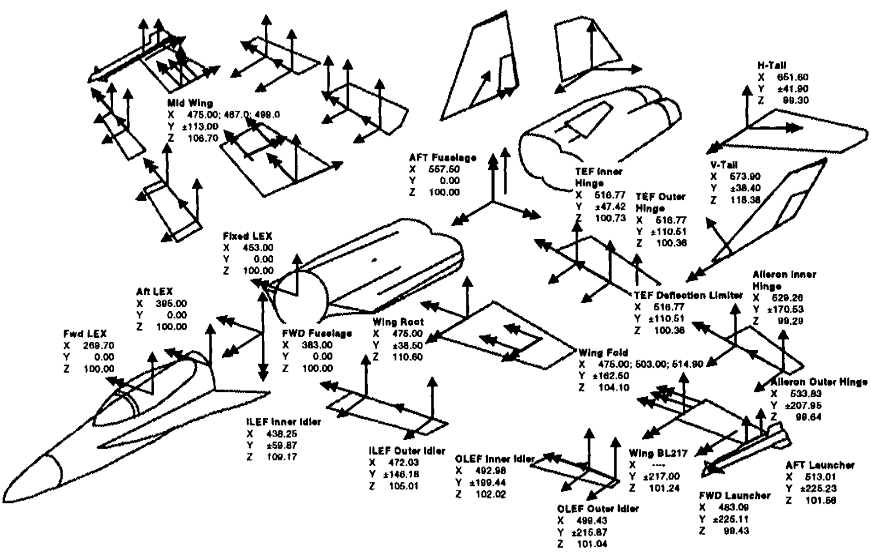

Figure 1: Wing interface loads locations [3].

The 99LD was subjected to several consecutive truncations and filtering to achieve a representative/reasonable sequence, in terms of number of lines, for fatigue testing purposes. The following are the processes applied:

1. A Rise/fall truncation for each of the 12 primary interface load components of the 99LD at various ratios. The 99LD lines were reduced to 174,598 lines and the new sequence was named "99LD-Residual".
2. The 99LD-Residual loads were distributed and balanced by Bombardier and delivered as "90LD". The 90LD load set included new derived interface load components, such as the shear, with a total of 43 components per wing from which only 20 were used. A list of the additional 8 derived interface load components used is given in Table 2. The 90LD sequence contained the same number of lines as the 99LD-Residual, 174,598 lines.
3. The 90LD, which contained 134,921 unique load lines, was binned, by grouping similar loads into bins, to reduce the spectrum to less than 50,000 unique lines for testing purposes/limitations. The binning process resulted in 49,889 unique load lines. When these loads were inserted back to the sequence some load lines were redundant, as they were between a peak and a valley, and were removed/filtered out. This filtering process resulted in a spectrum with 154,463 lines which was named "FT245 Target".
4. A Jack load optimisation process lead to substitution and removal of unrepresentative load cases. This process resulted in a spectrum which was named "FT245 Jack loads".
5. Applied loads on the FT245 test were fed back during a block of testing and the measured spectrum was named "FT245 applied".

Table 2: Derived wing interface loads.

Derived Interface Load	Abbreviation
Right Wing Root Shear	RWRSH
Right Wing Fold Shear	RWFSH
Right Inboard Leading Edge Flap Shear	RILEFSH
Right Outboard Leading Edge Flap Shear	ROLEFSH
Right Trailing Edge Flap Shear	RTEFSH
Right Aileron Shear	RAILSH
Right Wing Tip Shear	RWTSH
Right Wing Tip Bending Moment	RWTBM

2.2 Test inspection

Inspections are the fundamentals of structural fatigue test programs. They play a vital role in completing the test without long delays due to failures and collecting valuable durability and damage tolerance data. Thus the aim of test inspection can be summarized in the following [4]:

Transactions on Engineering Sciences vol 40, © 2003 WIT Press, www.witpress.com, ISSN 1743-3533

1. To support management of fleet aircraft by detecting and monitoring fatigue induced damage in order to obtain crack growth information, validate/certify modifications and repairs, and obtain engineering data.
2. To evaluate standard NDI methods that can be used for in-service aircraft.
3. To validate load/spectrum severity.

The FT245 first passed through a pre-test inspection activity to perform a baseline inspection of all test article to be used throughout the test as a comparison tool of structural discontinuities found during testing and to ensure the structural integrity of the aircraft components prior to test start. To build the FT245 inspection card deck the areas of inspection were first identified, based on failures reported on previous tests, and the suitable inspection method was then selected, and then the cards were created. The baseline inspection card deck for the wing test consisted of 175 cards. Few additional cards were added during the early course of the test due to inspection cards review and rationalization. Different NDT methods are used for inspection which includes visual inspection, ultrasonic, eddy current, radiography, magnetic particle, and liquid penetrant techniques. A description of each technique is provided in table 2.

Table 3: FT245 test NDT techniques.

Technique	**Description**
General Visual Inspection (GVI)	A straight visual wide area inspection looking for gross deformation, large cracks or broken fasteners
Close Visual Inspection (CVI)	Inspection of limited area using aided visual inspection equipment such as lights, magnifying glasses and digital endoscopes with a magnification of 100X.
Special Visual Inspection (SVI)	Inspection of a specific location using video endoscopes, boroscopes, video boroscopes, and remote video cameras
Eddy Current (ET)	A passive method for detecting surface and sub surface flaws in conductive materials
Radiography (RT)	Used in cases of limited inspection access to the wing structural components
Ultrasonic (UT)	A passive method (with couplant) that can be used on any material. It is the primary method of inspection for composite skins
Magnetic Particle (MT)	A good real time method for finding surface and sub surface flaws in ferromagnetic materials.
Liquid Penetrant (PT)	Was used as a means of confirming damage found through other NDT methods

Inspection periods can be classified into two types; inspection threshold and inspection interval. Inspection threshold is the first inspection to be performed while inspection interval is the repeated inspection after the threshold inspection.

Transactions on Engineering Sciences vol 40, © 2003 WIT Press, www.witpress.com, ISSN 1743-3533

Inspection periods are used to allow the detection of growing cracks before reaching unstable growth and fast fracture.

Inspection thresholds and intervals can dictate the speed of testing. Too many inspections will require prolonged downtime periods while little inspections can risk the test safety with fractures and long downtime for repair in addition to overloading adjacent structures and loosing test data information. The baseline FT245 inspection card deck was passed through a detailed analysis for the critical cards only. The detailed analysis was aimed to minimising inspection downtime while ensuring test article and transition structure safety, as well as the adequacy of the gathered information. The effort done through the detailed analysis of critical cards has shown a substantial relief of the FT245 test inspection burden with a total LOE decrease, for the critical cards reviewed, of 47% [5]. The FT245 card deck was passed also through an optimization process to minimize downtimes by grouping inspection cards and performing the inspection for those within a certain area/group at the same time.

As the CF-18 aircraft is designed to withstand fatigue failure using the safe life approach, and as it is approaching its demonstrated safe life, structural management using the safety by inspection approach (Damage Tolerance) could be implemented for certain regions of the aircraft. The approach could be considered in many circumstances, and could lead to avoiding costly repairs and/or component replacements. As such the requirement to use DTA in managing the wing and Aft fuselage has increased recently, especially for those with redundant structures. The crack growth data obtained from monitoring cracks through inspection intervals on the test and/or fractographic analysis of the fractured surface after tear-down inspection would be a key to aircraft management using safety by inspection.

2.3 Test data types

The FT245 test consists of a series of repeated blocks with 326 SFH each. The test is monitored through strain gauges attached at different locations, mainly on the wing with others at the center fuselage. Several types of data are generated and recorded during the test. Each type of data provides useful information about the test article. These data types consist of the following:

1. Strain Gauges
    a. 512 channels on MDAC (low speed recording)
    b. 60 channels on IDAC (high speed recording).

    Strain gauge data is used for trend monitoring and transfer function calculations. Data health checks are performed every block of testing which helps in identifying any structural loading changes through the test course.
2. 12 Displacement Transducers
3. 6 Reaction Loads

4. 63 Command and Feedback Jack Loads. Figure 2 [6] shows the different locations of the 63 load jacks. Load is distributed on the wing through a whiffle tree ending with pads attached to the wing upper and lower skins. Figure 3 shows a picture of the whiffle tree arrangement of the FT245 test.
5. 20 Targeted and Applied Jack Interface Loads

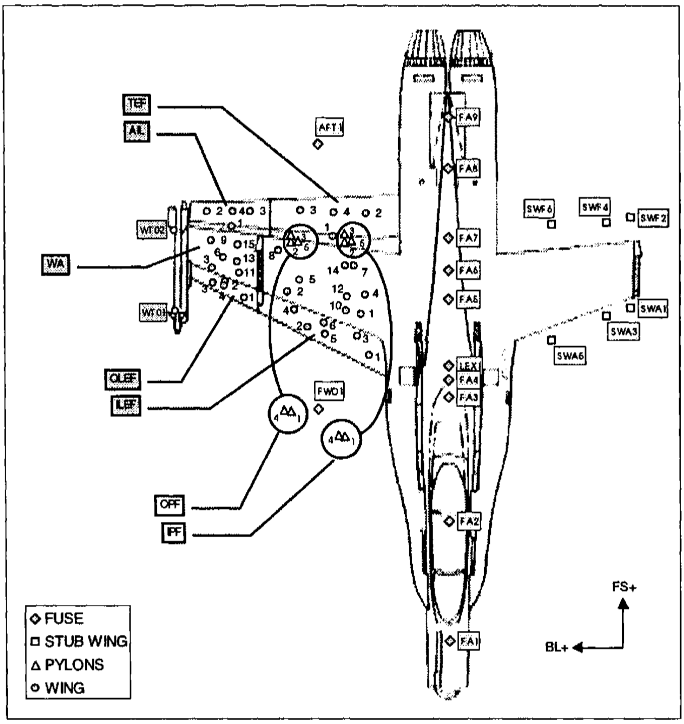

Figure 2: FT245 Test 63 Jack Load Actuators [6].

Strain gauges on the FT245 test are very useful in support of fleet aircraft and test management. They are useful in many applications such as test trend monitoring checks. If measured strains, through the test course, are not within the predicted limits (based on values recorded in previous blocks), the test operator is notified. The trend monitoring can serve as a protection for the test from sudden failures, and as a warning for component cracking and/or drift in strain gauge data. Strain gauges are also useful in strain surveys and influence lines or unit jack load surveys. The data obtained is very useful in the calculation/determination of transfer functions which is greatly supporting the Aircraft Structural Integrity Program (ASIP).

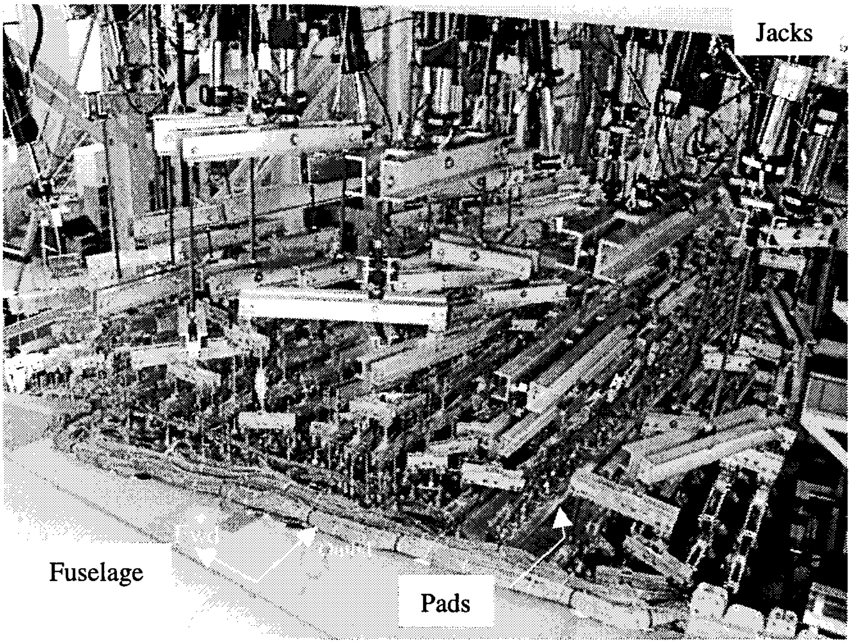

Figure 3: Whiffle tree arrangement on the FT245 wing test.

3 Structural certification and test end

The CF18 is structurally identical to the USN F/A-18 A and B models, and therefore the original basis of certification by the OEM are valid. However due to the severe and different operational usage of the Canadian aircraft, and due to the structural modifications of the aircraft, the additional testing of the IFOSTP program is considered essential in ensuring the structural certification of the CF18. As the CF18 is primarily managed using the safe-life approach, then one life time of fleet service can be structurally certified if:

1. Aircraft components have demonstrated no failures after being tested for not less than one lifetime of usage amplified by the test factor. Test factors considers uncertainties in manufacturing, material properties, fatigue damage monitoring and corrections for test loading inconsistencies.
2. Aircraft components have demonstrated sufficient residual strength following the test end.

Due to the different truncations, filtering and balancing processes applied to the usage representative spectrum "99LD" to size it down to a reasonable size for testing, the test applied spectrum had to be interpreted to evaluate its severity and project the required test end for structural certification. The interpretation process included examining all structural components which have cracked as well as which have not cracked in previous full-scale tests. The idea was to obtain a basis of certification for the CF18 wing structure components which are expected not to fail by test end, and thus agree on the test end strategy. For the components which are expected to fail earlier, i.e. before demonstration of full service life through testing, and would require preventative structural modifications, the idea was to use the test spectrum interpretation in calculating the post modification certification test time and the latest incorporation test time. The interpretation process consisted of the following:

1. Examination of health checks on all strain gauges to identify gauges with reliable data for the test block considered.
2. Transfer function calculation using wing main interface loads (Table 1).
3. Test factor calculations which include scatter factors, tracking factors, and dynamics factors.
4. Crack Initiation (CI) life calculation using strain life approach and SWT mean stress parameter [7].
5. Fleet CI spectrum factors with respect to FT245 and previous OEM tests.
6. FT245 test end target for certification calculated as:

$$\frac{6000 * (\mathit{Test\ Factor})}{\mathit{Spectrum\ factors}} \tag{1}$$

7. Percentage of certification with other OEM testing.
8. Test time required for certification of preventative modification, which will completely remove all pre-mod accumulated damage, calculated as:

$$\frac{(6000 - \mathit{fleet\ incorporation\ time}) * (\mathit{Test\ Factor})}{\mathit{Spectrum\ Factors}} \tag{2}$$

Results obtained from this certification effort had defined the test end strategy for structural certification of most wing areas. It had also defined the need to do extra component/coupon test program for the certification of specific areas which can not be certified by reasonable test extension of the full-scale test.

4 Summary

This paper has presented a quick summary of some aspects regarding the CF18 wing test (FT245) currently being tested by the National Research Council of Canada (NRC) at the Institute of Aerospace Research (IAR) and technically supported by Bombardier Aerospace. The paper showed the FT245 test load development steps, inspection program, test data types and data collection, and test monitoring. The structural certification effort for the wing, currently in progress, and the test end strategy have been highlighted.

References

[1] Zavitz, D., *IFO 0051: CF-18 IFOSTP Statement of Work – FT-245 Wing Test Project*, Revision A, Bombardier Aerospace, Mirabel, 2001.

[2] Simpson, D., Landry, N., Roussel, J., Molent, L., Graham, A. & Schmidit, N., *The Canadian and Australian F/A-18 International Follow-On Structural Test Project*, ICAS 2002 congress, Toronto, Canada, 2002.

[3] Black, C. & Hotte, M., *IFO 0079: FT245 Standard Reference Data*, Bombardier Aerospace, Mirabel, 1998.

[4] Sullivan, A.B. & Brothers, M., *LTR-SMPL-2000-0180: CF-18, F/A-18 IFOSTP, FT245 Inspection Plan,* NRC Canada, IAR, 2000.

[5] Dabayeh, A., *IFO 0116: FT245 Test Inspection Cards Rationalization And Deviation Reports*, Bombardier Aerospace, Mirabel, 2002.

[6] Girard, E., *IFO 0113: CF-18 IFOSTP – FT245 Health Check Summary Report, Full Block 01 – Trend Monitoring Block 01-13,* Bombardier Aerospace, Mirabel, 2002.

[7] Smith, K.N., Watson, P. & Topper, T.H., A stress-strain function for the fatigue of metals. *J. Mater.*, **5**, pp. 767–778, 1970.