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THE APPLICATION OF DYNAMIC LOADS TO A FULL SCALE F/A-18 FATIGUE TEST ARTICLE

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ABSTRACT

A unique full scale fatigue test system has been developed by AMRL which combines buffet induced dynamic loading with manoeuvre loading to reproduce the flight loading conditions experienced by an F/A-18 aircraft aft fuselage and empennage under normal flight operations. The system uses a newly developed pneumatic loading system rather than the more conventional hydraulic loading system to apply the distributed aerodynamic and inertial loads induced by aircraft manoeuvres. The severe buffet dynamic loading experienced in flight is defined using a multi-channel vibration control system and applied by high powered, high displacement electromagnetic shakers. This paper describes the AMRL test methodology, the flight loads environment, the derivation of the dynamic loads sequence and their method of application and control.

1.0 Introduction

Although significant full scale testing of the F/A-18 structure was conducted by the manufacturers to meet United States Navy (USN) design requirements, Australia and Canada have embarked upon a collaborative full scale structural testing program, the F/A-18 International Follow On Structural Testing Project (IFOSTP). IFOSTP aims to determine the economic and safe life of the F/A-18 structure under test loading more representative of Royal Australian Air Force (RAAF) and Canadian Forces (CF) operating conditions. Testing is being shared between the two countries. Canada is testing the centre fuselage and wings and Australia is testing the aft fuselage and empennage. The Australian portion of the test is being conducted at the Defence Science and Technology Organisation's Aeronautical and Maritime Research Laboratory (AMRL) in Melbourne, Australia.

A unique full scale fatigue test system has been developed by AMRL which combines buffet induced dynamic loading with manoeuvre loading to simulate the flight conditions experienced by an F/A-18 aircraft under typical operations. The system uses a pneumatic loading system rather than the more conventional hydraulic loading system to apply the distributed aerodynamic and inertial loads induced by aircraft manoeuvres. The severe buffet dynamic loading experienced in flight is defined using a multi-channel vibration control system and applied by high powered, high displacement electromagnetic shakers. This paper describes the AMRL test methodology, the flight loads environment, the derivation of the dynamic loads sequence and their method of application and control.

2.0 F/A-18 Operational Environment

The F/A-18 is an extremely manoeuvrable, versatile, high performance fighter/attack aircraft. The inner wing leading edge extension (LEX) provides fuselage lift enabling it to achieve angles of attack (AOA) in excess of 60 degrees. The twin vertical tails canted slightly outward exploit the high energy vortices generated by each LEX to provide good directional stability at these high AOA conditions. Unfortunately, these vortices break down at high AOA, buffeting the structure and energising the resonant frequencies of the empennage, producing high acceleration levels at the tips of each vertical tail and horizontal stabilator. The empennage response excites engine and other aft fuselage resonant dynamic response causing high stress levels in various structural components.

3.0 IFOSTP Aft Fuselage Test Methodology

The methodologies adopted for the AMRL test were dictated by the requirement to apply realistic buffet loads to the test article while simultaneously applying manoeuvre loading. This was desired as dynamic loading is responsible for a large percentage of the fatigue damage caused in the F/A-18 aft fuselage structure and thus, realistic simulation of these critical loads should yield more representative fatigue test results. The simultaneous application of dynamic and manoeuvre loads was necessary as significant manoeuvre loading does occur while the structure is subjected to high buffet dynamic loading.

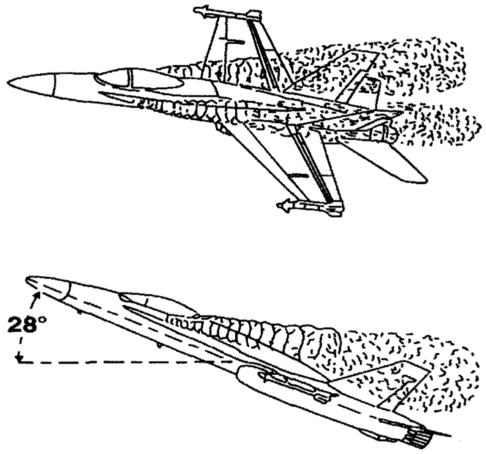
The primary objective of the loading development process was to ensure that the test article was loaded in such a manner that its dynamic response matched as closely as possible that of an aircraft in flight. To accomplish this, a manoeuvre loading system was required that would not significantly affect the dynamic characteristics of the structure. Typical fatigue test loading systems use hydraulic actuators, loading beams and pads, and cables to load the structure. This system was unacceptable for the given test approach as the loading system would effectively add stiffness and mass to the structure and thus, alter its dynamic characteristics.

Consequently, AMRL devised a loading system which would allow the critical structural modes of the empennage and aft fuselage to be excited as they would be in flight, while still allowing the application of manoeuvre loads. This had the added benefit that the high number of dynamic load cycles could be applied more quickly than they have been in previous tests using conventional loading systems. Previous tests either applied dynamic loads as equivalent static loads or did not apply them at all. The system developed to meet these IFOSTP requirements consists primarily of dual pneumatic soft springs to apply manoeuvre loads and electromagnetic shaker systems to impart the dynamic loads.

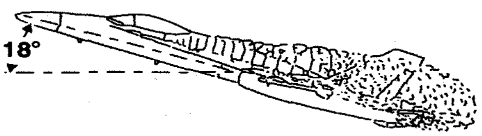
4.0 Characterisation of the F/A-18 Buffet Environment

Previous flight trials and wind tunnel tests have shown that the frequency characteristics and intensity of the buffet excitation vary primarily as a function of AOA and dynamic pressure (Q). Typical air combat manoeuvre flight situations involve rapid variations in AOA-Q conditions with peak levels of empennage and aft fuselage response occurring in different AOA-Q ranges, as shown in Figure 1. The AOA-Q conditions at which peak response levels occur for the most damaging empennage modes are given in Table 1 along with the typical accelerations experienced. Figure 2 provides sketches of these empennage modes.

The vertical tail primary bending mode has a significant impact on the fatigue life of the lower aft root region, particularly the fuselage to vertical tail attachment stubs. The vertical tail first torsion mode predominantly affects the life of the upper fin region. Stabilator first bending and second bending/first torsion modes primarily affect the stabilator spindle and stabilator actuator support structure. The excitation of empennage surfaces cause engine modes to be excited which in turn induce further dynamic loading into the engine mounts, mount backup structure and aft fuselage structure.



VERTICAL TAIL EXCITED
IN 16°- 42° AOA RANGE, PEAK AT 28°



STABILATOR EXCITED
IN 10°- 26° AOA RANGE, PEAK AT 18°- 22°

FIGURE 1 Empennage Buffet at High AOA

TABLE 1 Empennage Peak Modal Response Characteristics and Mode Shapes

Dynamic Mode	AOA (deg) for Peak Levels	Q (psf) Range for Peak Levels	Approx Freq. (Hz)	Approx Aft Tip Peak Accel.
VT 1st Bending	32-36	175-225	16	± 170 g
VT 1st Torsion	24-28	400-500	45	± 500 g
Stab. 1st Bending	36-39	225-300	12	± 100 g
Stab. 2nd Bending & 1st Torsion[1]	16-20	350-400	38/46	± 350 g

Note: 1. Modes are closely coupled and thus the peak response represents the superposition of both.

To reduce the accumulation of fatigue damage caused by the buffeting of the empennage and aft fuselage, McDonnell Douglas Aerospace (MDA) implemented both structural and aerodynamic modifications. Vertical tail structural modifications included strengthening the inboard side of the three aft most attachment stubs as well as other fatigue critical locations through a fleet retrofit program. In addition to structural modifications, MDA proposed the fitting of an aerodynamic modification called a LEX fence. The streamwise LEX fence, shown in Figure 3, interacts with the flow above the LEX to

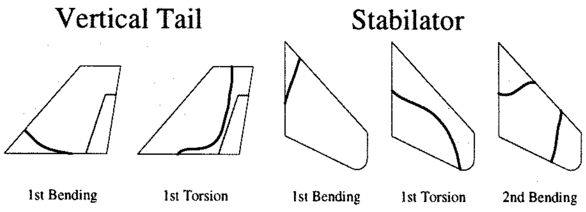


FIGURE 2 Approximate Nodal Lines for Fatigue Critical Empennage Modes

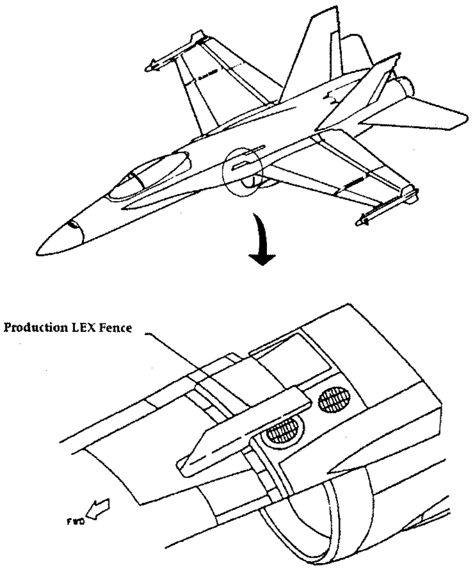


FIGURE 3 F/A-18 LEX Fence

effectively alter the characteristics of the vortex breakdown before it impinges on the aft fuselage and empennage.

The LEX fence has been shown, through extensive flight testing, to reduce the buffet response of some F/A-18 empennage structure and has been installed on all aircraft. However, many RAAF and CF aircraft flew for considerable periods without this modification, resulting in a significant accumulation of fatigue damage to the aircraft. To correctly represent Australian and Canadian F/A-18 fleet usage, both pre and post LEX fence dynamic loading will be applied during the test. However, this paper focuses on loading derived for the more severe pre LEX fence testing phase.

5.0 Dynamic Loading Test Approach

The objective of the IFOSTP F/A-18 aft fuselage dynamic test approach is to apply representative dynamic loading to the test article. The dynamic excitation required to excite the structure to prescribed response levels is applied by electromagnetic shakers. Testing is accomplished using narrowband random excitation (with a constant level across the band) and a form of input force control. This method allows for shifting structural resonances during testing. Excitation is simultaneously applied in the 10-20 and 34-52 Hz bandwidths. Energy is needed at these frequencies to excite resonant response shown to be critical to empennage and aft fuselage structural fatigue. The modes to be included in the AMRL IFOSTP fatigue test are listed in Table 2.

TABLE 2 F/A-18 Modes Included In Test

Mode Description	Approximate Frequency (Hz)
Vertical Tail 1st Bending	16
Vertical Tail 1st Torsion	45
Stabilator 1st Bending	12
Stabilator 2nd Bending	38
Stabilator 1st Torsion	46
Engine Yaw	13
Engine Pitch	14
Engine Roll	38
Engine 1st Lateral Bending	44
Engine 1st Vertical Bending	49

The level to which each mode must be excited is defined based on response measurements obtained during F/A-18 flight testing. This response is characterised as a function of AOA and Q as discussed in Section 4. The dynamic response of the structure is derived at key locations referred to as control accelerometers or control locations. These locations, shown in Figure 4, correspond to accelerometer locations used during F/A-18 flight testing where high dynamic response for a given surface or structure has been measured. The premise is that exciting the primary structural modes to match the flight response levels measured at these locations will result in the correct internal dynamic loading of the structure.

The force required to excite the structure to target response levels is defined by a testing process referred to as characterisation. Once the required dynamic input forces have been defined, they are reapplied in all subsequent test blocks as they are deemed to characterise the in-flight buffeting force of the LEX vortices. Test article response is allowed to vary throughout testing as it presumably would through the life of the aircraft. In this sense, it is an input controlled test, although there is actually no feedback control on force. Rather, periodic tests are performed to ensure that the correct dynamic inputs are applied throughout testing.

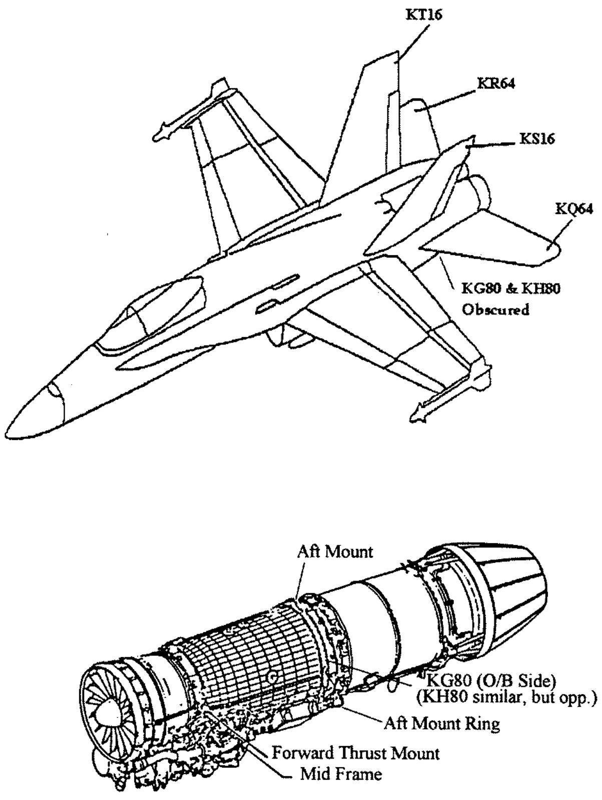


FIGURE 4 F/A-18 IFOSTP Control Accelerometer Locations

6.0 IFOSTP Test Article, Test Rig & Loading Systems

6.1 Test Article and Test Rig

The IFOSTP F/A-18 test article, designated FT46, consists of centre and aft fuselage sections with a dummy forward fuselage spliced onto it. The nose of the forward fuselage is supported on a tripod and the test article is suspended from a heavy portal frame via hydraulic actuators connected at the wing attachment points of the centre fuselage. A spherical bearing at the fuselage nose allows the test article to rotate and bend but not translate. Scrap F/A-18 engines, dynamically similar to fleet engines, are installed in the test article to ensure that the correct dynamic and manoeuvre loads are imparted into the engine mounts and support structure.

During the application of high manoeuvre loads, the test article deflects significantly. To minimise displacement at the rear of the aft fuselage, a feedback control loop has been installed between aft fuselage displacement transducers and the test article suspension actuators. This system is referred to as the active reaction system (ARS). Through the use of feed forward control technology, the actuators of the ARS apply load in the appropriate direction to cancel any displacement caused by manoeuvre loading. This ensures the test article load application points do not move appreciably. A lateral hydraulic actuator at the wing attachment point is used to minimise lateral displacement during asymmetric loading of the test article.

A large cathedral style reaction frame has been built for the fin and stabilator manoeuvre loading actuators. A separate portal frame has been built to support the vertical fin dynamic shaker system. All frames are attached to the laboratory strong floor. Because the test article is inaccessible for inspection when it has been installed in the rig, a test article removal/installation rail system has been designed to allow the test article to be rolled out of the rig for inspection. The actuators used to apply engine loading and fuselage loading are also installed on a removable trolley as they have to be removed before the test article is removed.

To minimise test complexity, the stabilators are fixed in a 12 degree leading edge down position for all loading conditions as it was deemed to be an average stabilator angle during buffet. A dummy speed brake has been installed and speed brake deployment and lock-down loads are applied during the test. The stabilators are held in position by dummy actuators, as are the vertical tail rudders. These actuators have been designed to have the correct dynamic characteristics to ensure that the correct control surface dynamic modes can be achieved.

Because of the complexity of this loading system and its associated control system, AMRL developed the test rig system and loading techniques using a scrapped development F/A-18 test article on loan from the USN, designated ST01. This approach ensured that the new test article was not put at risk during rig system development and commissioning.

6.2 Loading System Overview

There are 67 load actuators used in the test article loading system. These are shown in Figure 5 and are summarised in Table 3.

6.3 Manoeuvre Loading System

To minimise the effect on the dynamic characteristics of the FT46 test article, AMRL has implemented the use of pneumatic actuators, or air bags, to apply manoeuvre loading as these contribute less mass, stiffness and damping to the structure than a conventional hydraulic loading system. There are three types of air bags in use in the test. The first type developed consist of commercial air springs arranged as opposing pairs on either side of

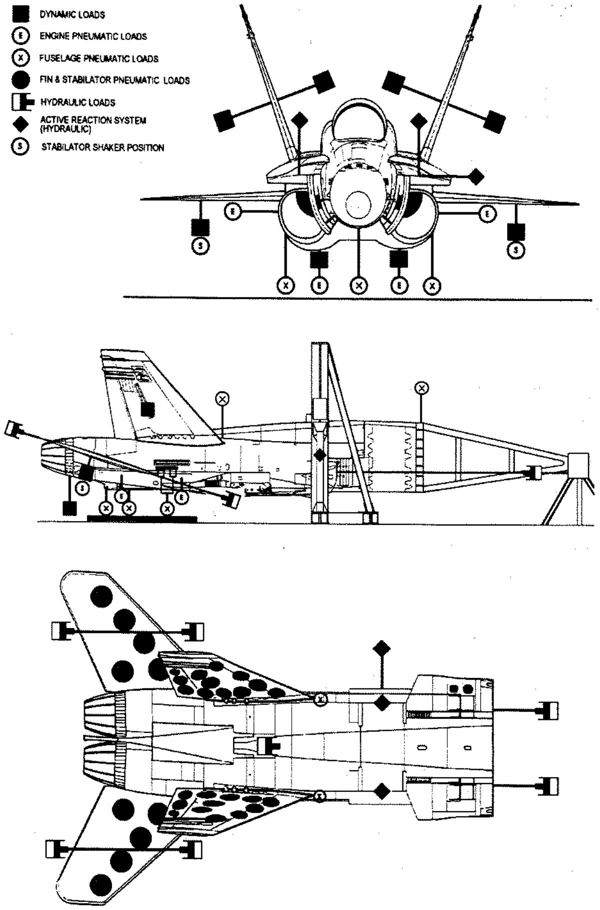


FIGURE 5 IFOSTP FT46 Actuator Configuration

TABLE 3 IFOSTP FT46 Actuator Summary

Structure	Actuator Type	Total Number
Fuselage	Pneumatic	7
Vertical Tails	Pneumatic	24 (12 per tail)
	Electromagnetic Shaker	4 (2 per tail)
Horizontal Stabilator	Pneumatic	10 (5 per stab)
	Electromagnetic Shaker	2 (1 per stab)
	Hydraulic	2 (1 per stab)
Engines	Pneumatic	8 (4 per engine)
	Electromagnetic Shaker	2 (1 per engine)
	Hydraulic	2 (1 per engine)
Speedbrake	Hydraulic	1
Stabilator Shaker Positioning	Pneumatic	2 (1 per shaker)
Active Reaction System	Hydraulic	3

the structure. These are primarily used near the roots of the vertical tails and stabilators as they are capable of applying the high loads required and contribute minimal stiffness to that already present in the structure in these regions. These actuator pairs are controlled by a single servo-valve that is designed to control differential pressure (i.e. applied load) only. Thus, the mean pressure of the bag can be approximately half of the supply pressure during rapid manoeuvre load application. As a result, the minimum stiffness of the air bag pair was governed to some degree by the supply pressure.

It was found that the commercial bags applied too much stiffness near the tips of the empennage surfaces and thus, altered the resonant frequencies and modes unacceptably. The commercial bags also had difficulty following the higher displacements near the tips of these surfaces. To address this problem, special low stiffness rolling sleeve actuators were developed by AMRL for the outer tip regions of the test article. These are made of a rubber coated polyester reinforced vinyl material, and are attached to large volume reservoirs. The servo-valve control system was modified to control the mean pressure, as well as the differential pressure, helping reduce the bag stiffness to about one third the stiffness of the commercial air springs.

A third type of pneumatic actuator was developed to enable the application of tension/compression loads to simulate engine and fuselage inertial loads. These use two opposing commercial air springs contained in a self-reacting frame but separated by an aluminium disk. This disk is connected to the test article via a central push-rod. By reversing the pressure differential between the bags, bi-directional loading can be applied.

In addition to the air bags, hydraulic actuators were required in some instances. Hydraulic actuators are used to apply engine thrust loads, speedbrake loads and in-plane stabilator loads required to obtain correct stabilator root manoeuvre loading for the fixed 12 degree leading edge down stabilator position. Hydraulics are also used by the ARS.

6.4 Dynamic Loading System

The electromagnetic shakers used to dynamically excite the test article have a four inch peak to peak stroke, a maximum force capacity of 5000 lbs and each is driven by a 65 kW amplifier. The shakers were built specifically for the test by LING Corp. USA. Shaker locations were selected that would allow excitation of all modes of interest in the 5-100 Hz frequency range. Load bridges are installed on each shaker attachment sting so the force being applied can be monitored. Up to eight shakers, or six shaker systems, may be used during testing.

Two shakers are attached to each vertical tail in a push-pull configuration. Their location optimises the dynamic excitation of the fin modes. One shaker is attached to the lower surface of each horizontal stabilator. During manoeuvre loading, significant stabilator deflections occur at the shaker location. To ensure the shaker does not run out of stroke during high manoeuvre loading, the shaker body position relative to the stabilator is controlled by a pneumatic actuator.

An additional shaker has been installed beneath each engine at the aft ring of the afterburner. These shakers are aligned vertically to supplement excitation of the critical engine mount vertical dynamic loads. These shakers will only be used if excitation from the vertical tails and stabilators alone is inadequate to induce the correct dynamic loading in the engine mounts and backup structure. It was not possible to fully assess this in development testing and thus, the need for the engine shakers will be determined based on response measurements obtained during the first test block. Thus, initially only six shakers are being used; two on each vertical tail and one on each stabilator. Approximate shaker locations are shown in Figure 5.

7.0 Test Control and Data Acquisition

7.1 Test Controller

Test control is being carried out by a system designed and developed at AMRL. It is based on state-of-the-art digital loop controllers using transputer technology with parallel processing. Each manoeuvre load actuator is controlled by a loop controller located close to it and connected to the test controller in a binary tree configuration. This allows actuator configuration changes to be made relatively easily and minimises cabling. A hardware broadcast link provides real time synchronisation and network communications efficiency for the multi-channel control system. Each loop controller provides all load waveform generation, control law implementation, fault sensing and diagnostic capabilities for the actuator. The test controller is an IBM PC with an additional interface card installed to provide the user interface and external interface to the system.

The IFOSTP FT46 master control system is used to apply all manoeuvre loading, define all load limits, control all safety systems and perform all other control functions. The control system applies manoeuvre loading as quickly as the loading system will permit during non-buffet testing but synchronously applies manoeuvre loads in real time with dynamic loads. The system also controls the integrated data acquisition of three separate systems and is used to command another control system which generates and controls the dynamic loading applied during testing. These systems are discussed in the following sections.

7.2 Data Acquisition

The test article has been instrumented with over 1350 strain gauges and load bridges and 22 accelerometers. Response measurements from these channels as well as command and control channels are recorded on three data acquisition systems. These are the Buffet Data Acquisition System (BDAS), used to record 112 channels at a sample rate of 606.06 Hz, the Manoeuvre Data Acquisition System (MDAS), used to record 490 channels at each applied load line, and the Control Data Acquisition System (CDAS), used to record various control parameters. The data collected by these systems is synchronised and handled by AMRL developed data acquisition and post processing software. BDAS measurements are the primary data source for use in FT46 dynamic loading assessments.

7.3 Dynamic Control System

In order to simulate the complex dynamic loading environment experienced by the F/A-18, AMRL purchased the Multi-Exciter Vibration Control System, or MEVCS. This multi-channel control and data acquisition system was developed by Synergistic Technology, Inc. (STI) based in California, USA. The system has a number of capabilities required not only for the application of buffet loading, but also for the preliminary testing and analyses required to develop the dynamic loads. The MEVCS could also be controlled remotely by the IFOSTP test controller for synchronisation with manoeuvre loading.

Up to eight interacting excitation and feedback channels can be controlled by the MEVCS at one time, with eight channels available to output signals to drive the Ling shakers/amplifiers, and up to 20 channels available to record or monitor feedback and other response signals. A signal processing subsystem (SPS) performs all run-time array processing operations, and communicates with the user interface, a VAX Station 4000, via Ethernet. A Test Article Protector (TAP) system, an independent system monitoring and comparing drive and feedback signals against allowable instantaneous peaks, independently performs a soft test shutdown if an error is detected or a limit is exceeded.

The modes of operation of the AMRL MEVCS system include Data Acquisition and Signal Generation (DASG), Random Mode operation and Replication Mode operation. Each of these is used for different purposes for IFOSTP dynamic testing and will be discussed in the following paragraphs.

The DASG function is used primarily for dynamic similarity testing (see Section 8) and is not used during routine fatigue cycling. In this mode, the MEVCS can operate purely as a data acquisition system or acquire data while sending out pre-defined drive signals to a number of channels. However, there is no feedback control loop in this mode or compensation for structural cross-coupling, and only the TAP system protects the test article from accidental overtest.

The multi-channel Random and Replication control modes of operation are the most useful for IFOSTP testing. These take into account the interaction between sting forces through cross-coupling of the structure, and hence can more accurately reproduce the required random or transient waveform loading or response at multiple control locations. In order to anticipate the structural response to a given drive signal input to one of the shaker amplifiers, a sine sweep or chirp test is performed. This determines an estimate of the voltage required at a given frequency to obtain a unit force on each sting and is stored as a complex spectral matrix. The MEVCS Random and Replication Mode software uses this information to determine the drive signals necessary at each control channel in order to obtain the desired response. The matrix is typically called the Impedance Matrix, or Test Article Frequency Response Function but it is actually the inverse of the excitation/feedback frequency response function matrix.

In the Random Mode of operation, the user specifies power spectral density (PSD) levels required at the control locations. These may be in units of force, acceleration or strain, depending on the feedback transducer being used. For IFOSTP testing, the levels are generally specified in terms of force for such tests as ground vibration testing (Section 8.2), dynamic strain surveys (Section 8.3), and dynamic input force characterisation (Section 9.3). In order to obtain the desired levels at each control location, the MEVCS first determines random drive voltages with the desired frequency content but at a fraction of the desired level. It then operates in closed-loop mode, modifying its output until the correct response spectral shapes are obtained. While still using feedback, the excitation is incrementally increased until the desired levels are reached and held for the requested duration. As well as recording feedback transducers, auxiliary response history measurements are typically made at the full test level.

MEVCS Replication Mode, or Waveform Mode, requires a response waveform to be specified for each of the control channels. This may be an analytical function, random signal, or transient waveform of a specific duration. Prior to running such a test, the MEVCS software generates a drive signal using the impedance matrix to estimate the drive voltage required at each shaker amplifier to simultaneously obtain the desired waveforms at each feedback transducer. This pre-recorded drive waveform is then applied to the test article in open-loop mode. This test approach is used for IFOSTP routine cycling.

8.0 FT46 Dynamic Characteristics

8.1 FT46 Dynamic Similarity

For the test approach described in Section 5, FT46 had to be dynamically similar to a fleet F/A-18 aircraft to ensure that the correct internal dynamic loads were applied for the structural modes to be tested. Dynamic similarity was assessed prior to fatigue cycling in two ways. Ground vibration testing was conducted to identify and map aft fuselage and empennage modes of vibration and a dynamic strain survey of FT46 was conducted to determine if the correct internal loading would be induced if these modes were excited to response levels measured in flight.

In addition, analysis of data obtained in ST01 development tests have shown that the modal damping present with the air bags applying load is comparable to that derived from flight response measurements. The amount of modal damping present is critical to reproducing accurate internal dynamic loading. Assessments of the FT46 test results will be used to further evaluate this parameter.

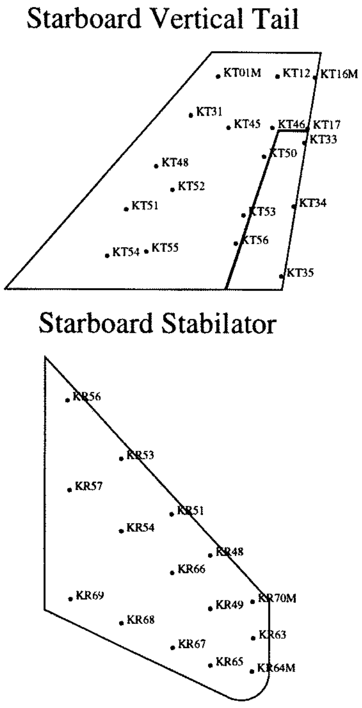
8.2 FT46 Ground Vibration Testing

Ground vibration testing (GVT) was conducted to identify and map the FT46 structural modes of vibration. Testing was conducted both with manoeuvre loading applied, referred to as "loaded GVT", and without manoeuvre loading applied, referred to as "bare structure GVT". The manoeuvre loaded testing was needed to determine the manoeuvre loading system's effect on the structural modes during routine cycling. The objectives of the GVT were:

- to excite and map FT46 empennage, engine and aft fuselage bare structure modes using the existing shaker configuration
- to compare bare structure results to existing F/A-18 aircraft modal results to determine dynamically similar modes
- to excite and map modes with FT46 under manoeuvre loading
- to assess the effect of manoeuvre loading on FT46 dynamic characteristics
- to take measures to maintain dynamic similarity of fatigue critical modes when under manoeuvre loading

8.2.1 GVT Approach

The FT46 test article was instrumented with PCB 330A accelerometers for the purpose of modal identification and mapping. The locations of the accelerometers were selected to provide adequate coverage for modal mapping purposes given constraints imposed by pneumatic actuator locations. Empennage modal accelerometer locations are shown in Figure 6 and were used to measure accelerations normal to the surface.


Starboard Vertical Tail

Starboard Stabilator

FIGURE 6 FT46 Empennage Modal Accelerometer Locations (starboard shown, port similar)

An extensive set of vertical and lateral accelerometers was installed on the fuselage and engines. In addition to the modal mapping accelerometers, others were used as required to assist in tuning the structural modes. Force measurements were taken from load bridges installed on each shaker sting. The MEVCS was used to drive the shakers during random excitation and also as a data acquisition system during both sine and random testing. A signal generator with transfer function analysis capabilities was used to excite and tune modes during sine testing.

Broadband (5-110 Hz) random testing was used to obtain data for transfer function analyses, modal curve fitting and to provide modal damping estimates. Sine excitation was used to tune and map the structural modes of interest using any combination of the available FT46 test shaker systems necessary to tune a mode. These modes included all vertical tail and horizontal stabilator modes in the 5-100 Hz frequency range, engine rigid body and first lateral and vertical bending modes and fuselage fundamental bending and torsion modes, as well as higher order modes if possible. The dynamic similarity comparisons of FT46 with an F/A-18 fleet aircraft are based on the normal modes obtained using sine tuning and thus, sine results will be the focus of the following discussions.

8.2.2 Bare Structure Testing and Results

Testing was first conducted without manoeuvre loading applied to FT46 to determine the baseline FT46 modal characteristics. Preloads of 150 lbs and 50 lbs were applied to the horizontal stabilator and rudder, respectively, to allow the excitation of the rotational modes of these surfaces. Comparison of the bare structure sine tuned GVT results to available F/A-18 aircraft or dynamic finite element model (FEM) modal results were the basis for the dynamic similarity assessment.

While comparisons were made for modes up to 100 Hz, only those modes to be included in the test are discussed here. Empennage modes were compared based on frequency and mode shape correlation as data were available for such a comparison. However, engine and fuselage modes were compared on the basis of frequency and to some degree, visual comparison to available mode shape plots. Fuselage modes were not expected to be similar and are omitted from subsequent discussions as they should not be significantly excited during testing. Table 4 presents fatigue critical modal frequencies and where available, correlations for the bare structure test results.

In summary, the comparisons showed that the fatigue critical modes of the FT46 test article are dynamically similar to a fleet F/A-18. The engine modes were deemed acceptable based on frequency and a visual assessment of the mode shapes. Some engine modes were not found as they were difficult to excite. Lateral and yaw modes were especially difficult to tune as there were no engine shakers in the lateral direction and also because of the lower force levels allowed during non fatigue cycling testing periods such as the GVT. However, these modes were deemed acceptable as pitch and bending modes found were comparable to fleet results and because pitch and yaw inertias are similar due to engine symmetry. Thus, lateral modes should be comparable also. It is expected that these lateral modes will be adequately excited during testing when vertical tail and stabilator modes are excited to higher levels than were permitted during the GVT.

TABLE 4 FT46 GVT Results

Main Structure Involved in Mode	Mode Description	Loaded FT46 Freq. (Hz)	Bare FT46 Freq. (Hz)	Modal Correlation (Loaded /Source)	Modal Correlation (Bare/ Source)	Source Freq. (Hz)	Source
Vertical Tails	S 1st Bending	16	16	0.998	0.999	16	FEM
	A 1st Bending	15	15	0.967	0.992	16	FEM
	S 1st Torsion	45	46	0.816	0.948	45	FLT/FEM*
	A 1st Torsion	46	45	0.815	0.797	45	FLT/FEM*
Horizontal Stabilators	S 1st Bending	14	14	0.992	0.992	12	GVT
	A 1st Bending	14	14	0.994	0.980	12	GVT
	S 2nd Bending	42	41	0.926	0.816	38	GVT
	A 2nd Bending	43	41	0.949	0.936	38	GVT
	S 1st Torsion	45	47	0.994	0.939	46	GVT
	A 1st Torsion	46	47	0.986	0.948	46	GVT
Engines	S Yaw at Fwd Mount	N/A	N/A	-	-	13	GVT
	A Yaw at Fwd Mount	12	11	-	-	13	GVT
	A Yaw at Aft Mount	N/A	N/A	-	-	19	GVT
	S Pitch at Fwd Mount	N/A	N/A	-	-	16	GVT
	A Pitch at Fwd Mount	14	14	-	-	14	GVT
	S Pitch at Aft Mount	22	22	-	-	22	GVT
	S Roll	41	35	-	-	38	GVT
	A Roll	46	42	-	-	43	GVT
	S 1st Lateral Bending	46	N/A	-	-	44	GVT
	A 1st Lateral Bending	49	48	-	-	47	GVT
	S 1st Vertical Bending	54	50	-	-	49	GVT
	A 1st Vertical Bending	40	41	-	-	41	GVT

Notes:

- S refers to symmetric modes
- A refers to antisymmetric modes
- GVT refers to data from an F/A-18 aircraft ground vibration test
- FEM refers to results from a NASTRAN finite element model of the bare structure
- N/A indicates that this mode was not tuned on FT46
- Data were not available for correlation analysis of engine modes

* Loaded structure correlation with in-flight (FLT) response shape and bare structure correlation with FEM

8.2.3 Manoeuvre Loaded Testing

ST01 development testing has shown that the manoeuvre loading system's effect on the structural modes depends on the manoeuvre loading applied and specifically, on the actuator loading distributions. Manoeuvre load conditions applied to FT46 are designed to represent all significant load cycles and loading distributions measured in flight as derived from the representative flight usage data (see Section 9.1) and wind tunnel testing and thus, the effect on the structural modes will vary as a function of the load applied. Dynamic FEMs, which include models of the pneumatic actuators, have been developed for the vertical tail and stabilator to assist in assessing these effects. While these FEMs have proven useful in assessing general trends, they have not reliably predicted the mode shape and resonant frequency changes caused by manoeuvre loading.

Therefore, modal testing on FT46 while under manoeuvre loading was conducted. One loading condition was developed to represent the average stiffness effects present at each actuator during flight conditions most important to dynamic response of the "structure" of interest (i.e. vertical tail, stabilator, engine and fuselage). The flight conditions chosen were associated with regions of high dynamic response for the given structure and are provided in Table 5. The average load magnitudes for each actuator for the 250 flight loading spectrum (see Section 9.1) were calculated for the applicable AOA-Q flight region. The worst case average loads for comparable actuators on opposite sides of the aircraft were selected and a symmetric condition was defined.

As the combined loading condition was not representative of F/A-18 flight loading, equal and opposite pneumatic actuator loads were defined that represented stiffness

TABLE 5 AOA-Q Regions Used for GVT Average Load Condition Development

Actuator Type	AOA (deg)	Q (psf)	Reason Chosen
Vertical Tail	20-39	75-400	High vertical tail 1st bending & torsion response
Stabilator	12-28	125-500	High stabilator 32-52 Hz response
Fuselage & Engine	12-24	225-500	High engine response

values equivalent to that imparted if such loads were applied. These loads were maintained during testing and in this way, with the exception of stabilator air bag loads applied for preload purposes and the average hydraulic actuator loads, no net load was applied to FT46. Thus, the effect that the manoeuvre loading system had on the primary modes of interest for critical AOA-Q response regions could be assessed. The criteria for acceptance of the empennage modes were that the mode shapes were comparable and modal frequencies were within 5% of the bare structure results. Due to the difficulties inherent in tuning installed engine modes, the goal was to keep engine resonant frequencies within 10% of target F/A-18 values.

8.2.4 Mass Additions to Maintain Dynamic Similarity

Testing with the manoeuvre loading described above resulted in shifts in resonant frequencies as expected from the dynamic FEM analyses. In general, resonant frequencies for empennage modes less than 52 Hz increased due to a stiffness effect while modal frequencies over 52 Hz tended to decrease due to a mass effect. Engine resonant frequencies tended to increase with loading applied.

To maintain dynamic similarity with an F/A-18, mass additions were investigated to lower the resonant frequencies of the vertical tail and stabilator fatigue critical modes. The effect on higher order modes was of secondary concern as these modes were excluded from the test. Initial investigations to determine empennage mass additions and locations were performed using dynamic FEMs. Based on these results, FT46 testing was conducted with various mass modifications until optimum results were obtained.

Results indicated a total of 10 lbs were needed at the stabilator tip air bag location and a total of 20 lbs were required for the vertical tail, consisting of 10 lbs at the tip air bag and 10 lbs at the aft most bag of the second row of actuators from the tip. This mass, made from lead sheets and attached with hook and loop tape, compensated for the resonant frequency shifts seen under manoeuvre loading without significantly affecting the mode shapes. While these mass additions maintain dynamic similarity and allow correct fuselage-empennage interface dynamic loading, they will cause local loading of the structure not normally present due to additional inertial loading imparted by the mass. This was deemed acceptable as representative interface loading was more important. Any structural failures detected in the vicinity of the mass will be studied to assess their relevance.

8.2.5 Manoeuvre Loaded Testing Results

When under the previously described load condition, and with the required mass additions in place, all FT46 fatigue critical modes needed for IFOSTP fatigue testing were shown to be dynamically similar to the F/A-18 aircraft. The results for modes being tested are provided in Table 4 and are compared to target values. While it is expected that the modes mapped will vary as manoeuvre and dynamic loading change throughout fatigue cycling, they have been tuned for an average loading condition. It should be noted that similar changes in modal properties occur during flight due to changes in aerodynamic and buffet loading. Some modes above approximately 52 Hz were adversely affected by the manoeuvre loading and the mass required to tune the more critical lower order modes. However, these modes are not included in the test as they are not fatigue critical.

8.3 FT46 Dynamic Strain Survey

A preliminary assessment of FT46 strain gauge responsiveness to manoeuvre loading was completed during a pre-test Static Strain Survey (SSS). The SSS consisted of applying manoeuvre loads, developed from IFOSTP F/A-18 flight test programs and a previous MDA fatigue test (FT25), to assess strain gauge response to steady-state manoeuvre loading. To further assess FT46 instrumentation and investigate test article response to dynamic excitation, a Dynamic Strain Survey (DSS) was conducted. The major objective of the DSS was to assess dynamic strains at critical gauge locations to further demonstrate dynamic similarity. Another objective was to obtain dynamic response measurements for all FT46 strain channels for use in transfer function analyses. These transfer functions enable the generation of analytical dynamic strain response for a gauge not included in the measurement set recorded on the BDAS during testing. This will prove extremely useful when assessing fatigue failures.

The DSS testing consisted primarily of applying random dynamic excitation but also included some sine excitation applied using the vertical tail and stabilator shakers.

During the random testing, FT46 was subjected to low level broadband and narrowband random dynamic excitation with and without representative manoeuvre loads simultaneously applied. Testing was also conducted with and without the modal tuning masses installed. These tests allow the local loading effects and any changes to the dynamic loading distributions caused by the manoeuvre loading or masses to be assessed. Transfer functions were generated with strain gauge response referenced to the four control accelerometers. Single and multi-reference transfer functions were generated and compared to flight test results. For the empennage strains studied in the initial analysis, the results are reasonable in the frequency range of interest. However, engine loading requires further investigation based on data acquired after full response levels are applied. A typical transfer function for the vertical tail to fuselage aft stub gauge, LS33, to vertical tail aft tip acceleration, KS16, is provided in Figure 7.

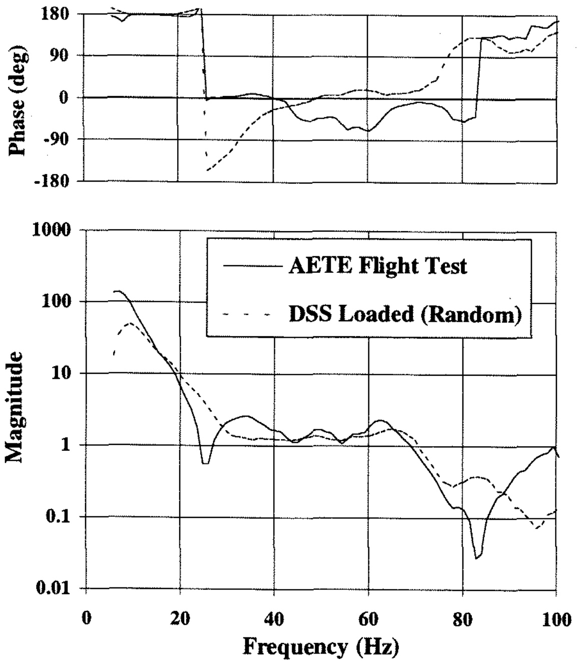
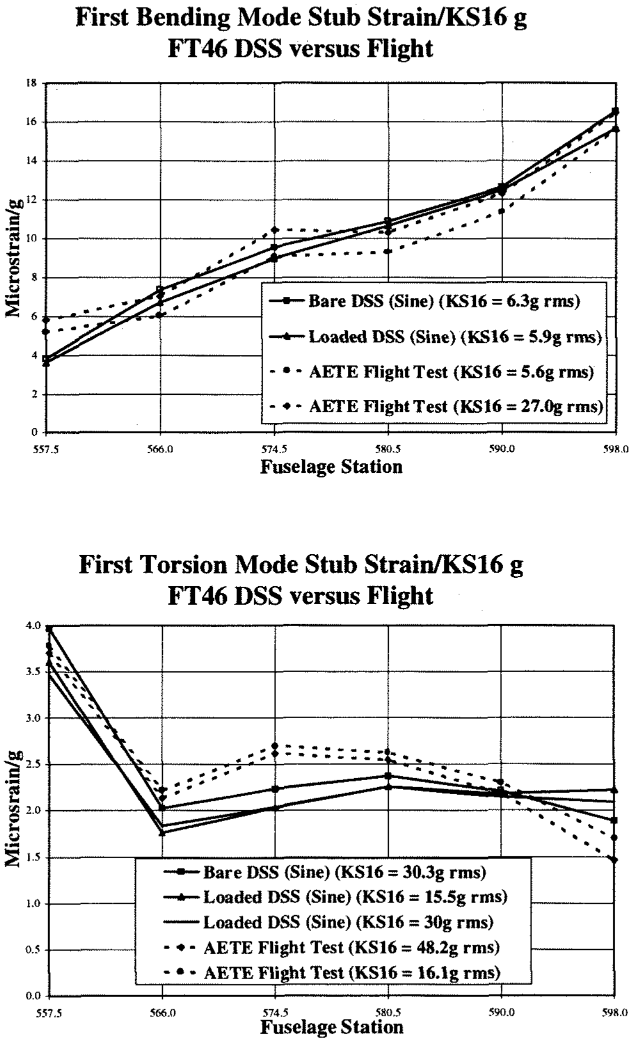


FIGURE 7 LS33/KS16 - FT46 vs Flight

Broadband testing results enabled more specific dynamic loading conditions to be defined for narrowband testing. Narrowband random excitation in the 10-20 and 32-52 Hz test frequency bandwidths allowed the investigation of dynamic strains for higher fatigue critical modal response levels than was possible under flat spectra broadband excitation. Empennage control point root-mean-square (RMS) acceleration levels measured during this testing were of the order of 5.0 g rms in the 10-20 Hz band. Response levels of 20 and 25 g rms were measured in the 32-52 Hz band for the vertical tails and stabilators, respectively. Strains and accelerations measured in these tests were used to assess the similarity of the FT46 dynamic loading versus flight results, usually on a strain per g basis. Results for the channels assessed have shown that in general, the FT46 dynamic loading is similar to flight loading. As an example, Figure 8 provides FT46 vertical tail to fuselage interface dynamic strain distributions (normalised to the control point acceleration) for vertical tail first bending and first torsion modes of vibration.


First Bending Mode Stub Strain/KS16 g
FT46 DSS versus Flight

First Torsion Mode Stub Strain/KS16 g
FT46 DSS versus Flight

FIGURE 8 Vertical Tail Stub Loading Distributions

DSS data resulting from both broadband and narrowband random excitation were also used to investigate other test article characteristics and associated instrumentation. Several DSS tests were also completed using identical test configurations, but at different excitation levels to check response linearity. In addition, inspection of the raw digital data acquired during testing gave an indication of both strain gauge health and the performance of the data acquisition system.

9.0 Dynamic Loading Spectrum Development

9.1 Usage Data Analysis

In order to simulate the loading of a typical RAAF/CF F/A-18 aircraft, a suitable set of flight data had to be obtained that could be used to determine flight loads. This database was required to cover a wide variety of operating conditions. This set of data is referred to as a usage spectrum or usage data. A different usage spectrum will be used for the pre and post LEX fence buffet environments to reflect the different flying carried out in each. This paper focuses on the pre LEX fence flying and usage data.

For the IFOSTP usage spectrum development, in-flight measurements were obtained from the Maintenance Signal Data Recording System (MSDRS) of a RAAF fleet aircraft. The MSDRS data provided such details as strain turning points at critical structural locations, flight parameters (AOA, Q, Mach number, altitude, etc), control surface positions and times for each flight flown. Using these data, flights covering a mix of typical RAAF mission types were analysed with a subset of flights selected to assemble a representative 250 flight set that defined the pre LEX fence usage spectrum (designated SPEC6GE). The flight parameters and strain turning points available for these flights are used along with F/A-18 wind tunnel and inertia data and other analytical techniques to derive the manoeuvre loading spectrum for pre LEX fence flying.

This same 250 flight set of SPEC6GE data was used to derive "dynamic" or "buffet" usage. This is defined as any time the aircraft is flown above 10 degrees AOA. Since buffet response can be characterised by AOA and Q, narrow bands of AOA and Q were defined to assist in the analysis of dynamic response. The resulting AOA-Q regions were used for both usage and response analyses. Table 6 provides the AOA-Q regions used for the RAAF pre LEX fence spectrum development.

As part of the manoeuvre loads development, AOA and Q were provided at least once per second for AOA greater than 10 degrees for each flight in SPEC6GE. Linear interpolation of these AOA and Q traces was used to define the times at which the aircraft crossed an AOA-Q region boundary, and thus, defined the time spent in different AOA-Q regions. By also knowing aircraft response as a function of AOA and Q, the accumulated time essentially defines the number and magnitude of dynamic cycles for the selected usage spectrum.

9.2 Flight Testing & Dynamic Response Database Development

To define the dynamic response levels to be achieved during routine cycling, it was necessary to establish a database of fleet aircraft aft fuselage and empennage dynamic strains and accelerations. During 1989, F/A-18 flight trials were conducted at the CF Aerospace Engineering Test Establishment (AETE) in Canada under AETE Project Directive (PD) 88/12. The primary objective of the AETE flight trials was to measure typical vibration response data for the aft fuselage and empennage for use in developing a dynamic loading spectrum for FT46. Strain and acceleration data were acquired for a range of typical flight manoeuvres with and without the LEX fence installed. Further IFOSTP flight

TABLE 6 AOA-Q Regions Used in RAAF Pre LEX Fence Spectrum Development

	Q (psf)										
AOA (deg)	0-40	40-75	75-125	125-175	175-225	225-300	300-350	350-400	400-500	500-700	700-1000
10-12	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
12-16	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
16-20	▨	▨	▨	▨	▨	▨	▨	▨	▨		
20-24	▨	▨	▨	▨	▨	▨	▨	▨	▨		
24-28	▨	▨	▨	▨	▨	▨	▨	▨	▨		
28-32	▨	▨	▨	▨	▨	▨	▨	▨	▨		
32-36	▨	▨	▨	▨	▨	▨	▨				
36-39	▨	▨	▨	▨	▨	▨					
39+	▨	▨	▨	▨	▨	▨					

Note: Shading represents AOA-Q regions covered during RAAF pre LEX fence flying.

test programs, flown to supplement the AETE PD 88/12 flight trials data, were undertaken at AETE (PD 93/03) and at the RAAF Aircraft Research and Development Unit (ARDU Task 0021 Phase 2) in Australia. Pre LEX fence aft fuselage and empennage response data from the USN F/A-18 aircraft A358 flight test program were also obtained from MDA.

All data were processed using both spectral and time history data analyses. Power spectral densities were generated and frequency response function analyses were conducted as required. Time domain data analyses involved digitally filtering the data to capture the response of the fatigue critical modes to be included in the test. The applicable filter bands used were 10-20 and 32-52 Hz. Statistical and exceedence analyses were then conducted using the band pass filtered data. The data were analysed for each of the AOA and Q regions used in defining the usage data.

From the four pre LEX fence flight test programs, the RMS acceleration values at the six test article dynamic response control points were time weighted to obtain a combined control point response database for each filter band of interest for each AOA-Q region. For a given frequency band, the maximum acceleration RMS measured on either the right or left side for a given surface was chosen. This approach accounted for variations in response magnitudes across the aircraft and was adopted to yield a more conservative and symmetric dynamic loading spectrum. The result was a table of target pre LEX fence RMS response levels for each AOA-Q region, for each control accelerometer. The maximum target pre LEX fence acceleration response for empennage control accelerometers is provided in Table 7.

TABLE 7 Maximum FT46 Pre LEX Fence Target Control Accelerometer Response

Empennage Surface	Frequency Bandwidth (Hz)	Max Control Accel g RMS
Vertical Tail	10-20	37.1
	32-52	128.7
Horizontal Stabilator	10-20	22.6
	32-52	56.9

In addition to the control accelerometers, other accelerometer and strain channels, for which flight test data were available, were chosen for monitoring during routine cycling of FT46. The channels were selected to cover a range of critical structural locations for the purpose of validating the dynamic loads applied. These channels are referred to as the dynamic load validation channels (DLVCs) and are provided in Table 8. Response measured at these locations will be used to determine if the FT46 dynamic loading compares acceptably with flight measurements.

TABLE 8 FT46 Dynamic Load Validation Channels

Channel Designation	Location
20009 (LS42)	Port VT 557 stub
20010 (LT46)	Stbd. VT 557 stub
19013 (LS27)	Port VT 566 stub
18013 (LS37)	Port VT 574 stub
17013 (LS38)	Port VT 580 stub
16013 (LS34)	Port VT 590 stub
15015 (LS33)	Port VT 598 stub
15016 (LT26)	Stbd. VT 598 stub
28011	Port stab boot strap fitting
28012	Stbd. stab boot strap fitting
28013 (LS50)	Port stab spindle
28014 (LS51)	Stbd. stab spindle
23001 (LS11)	Port 557 upper O/B longeron
15057 (LS13)	Port 598 frame
15059 (LS14)	Port 598 frame
15061 (LS15)	Port 598 frame
23067 (LG07)	Port aft engine hanger
23068 (LG46)	Stbd. aft engine hanger
KS16	Port VT aft tip
KS01	Port VT fwd tip
KT16	Stbd. VT aft tip
KT01	Stbd. VT fwd tip
KQ64	Port Stab aft tip
KQ70	Port Stab fwd tip
KR64	Stbd. Stab aft tip
KR70	Stbd. Stab fwd tip
KG33	Fwd engine mount OB long
KG34/KH34	Fwd engine mount OB lateral
KG35/KH35	Fwd engine mount OB vert
KG37	Fwd engine mount IB vert
KG61/KH61	Aft engine mount IB lateral
KG80/KH80	Aft engine mount OB vert

Note: 1. (xxxx) designates flight test channel name
2. Kxxx designate accelerometers. Others are strain gauges.

Not all of the DLVCs were monitored during all four flight test programs used to define the target FT46 pre LEX fence control accelerometer response. Thus, the same time weighting process could not be used to define the target dynamic response expected at these locations. For these cases, multi-reference transfer function analyses were performed on available flight test data to define frequency response relationships between these locations and the four empennage control accelerometer locations; KS16, KT16, KQ64 and KR64. These relationships were then applied to flight spectra that were scaled to yield the target control channel RMS levels per band. The result was predicted response PSDs for all DLVCs per AOA-Q region. A schematic of this process is shown Figure 9. In general, the response for all DLVCs could be predicted based on the four control channels used, with high coherence present in the frequency ranges of interest. However, limitations of this process, especially as related to engine response, will be considered when comparing FT46 and target response.

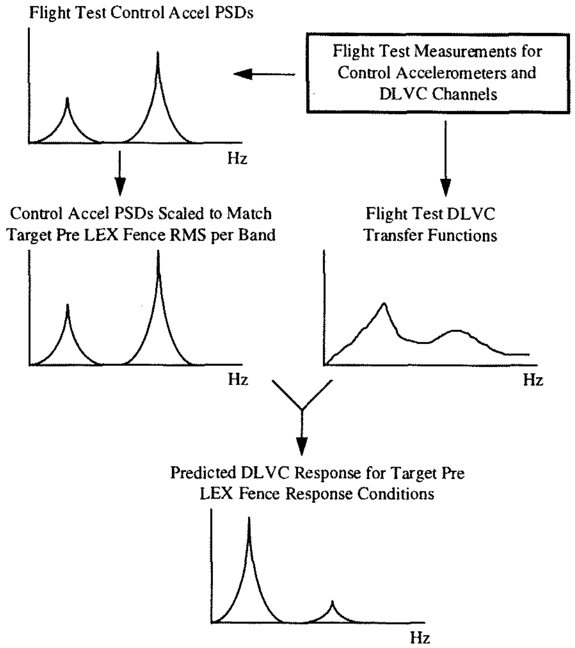


FIGURE 9 DLVC Response Prediction for Target Control Accelerometer Response Conditions

Bandpassed (10-20 and 32-52 Hz) flight test time histories for all DLVCs were scaled to match the predicted DLVC RMS response values per frequency band that resulted from the process shown in Figure 9. This was done for each AOA-Q region and yielded time histories with the target RMS but with response distributions as measured in flight. Exceedence analyses were carried out and when combined with the pre LEX fence usage data, yielded target exceedence curves to which FT46 dynamic response will be compared. These curves and the RMS per AOA-Q response tables constitute the IFOSTP Pre LEX Fence Dynamic Response Database. A similar process will be undertaken using post LEX fence flight trials data for use during the post LEX fence phase of FT46 testing.

9.3 FT46 Input Force Characterisation

Having defined the target control accelerometer RMS response levels for the vertical tails and stabilators, a test was conducted to determine the electromagnetic shaker force requirements to excite the empennage to different response levels at the FT46 empennage control accelerometers. This process is defined as FT46 input force characterisation. Once determined, these relationships were used to define the shaker forces required to produce the target response for each AOA-Q region. The requirement for the use of the engine shakers will be assessed using data acquired during the first block of testing.

Testing was designed to excite vertical tail and stabilator fatigue critical modes in the 10-20 and 32-52 Hz bands to 30% of the maximum target response to be achieved during the test as discussed in Section 9.2. The reduced level was necessary to minimise FT46 pre test fatigue cycling. Separate groups of tests were conducted in which each mode was treated individually as the primary mode under test. For each of these groups, separate tests were conducted to 20, 40, 60, 80 and 100% of the maximum allowable response for the primary mode being tested. This allowed a force to response relationship to be defined. The relationships between the target response levels of each mode were based on in-flight relationships present in AOA-Q regions.

Previous test results were used to define the initial 10-20 and 32-52 Hz narrowband random forces required to achieve the target responses for each test described. Testing was conducted with FT46 under the average manoeuvre load condition of Section 8.2.3 and under realistic load conditions present during buffet response. These load conditions were extracted from the SPEC6GE manoeuvre loading spectrum.

Control accelerometer and shaker force response data acquired during testing were analysed to generate PSDs for each test. RMS values for each test frequency band were determined and plots of shaker RMS force versus control RMS acceleration were created for each empennage surface for each frequency band. A linear force to accelerometer response relationship was defined using a least squares fit of the data over the test response range. The resulting relationships are provided in Table 9. These relationships were extrapolated and used to define the force required to excite the structure to the target levels. This process assumed there was no cross-coupling in the structure and that all response for a given surface was due to input force on that surface. While this is not actually the case, cross-coupling terms are reasonably small and will be addressed by the system impedance matrix discussed in other sections.

TABLE 9 FT46 Characterisation Results

Shaker System	Frequency Band (Hz)	$\frac{\text{RMS Force}}{\text{RMS Accel.}_{\text{control}}}$
Vertical Tail	10-20	43.42
	34-52	10.99
Stabilator	10-20	17.86
	34-52	9.67

9.4 Buffet Waveform Generation

With the RMS force to RMS response relationships defined, it was possible to define the RMS force for each empennage shaker (or shaker pair for each vertical tail) required to yield the control point RMS accelerations for each AOA-Q region. These characterisation results were used to define a 4×4 shaker force spectral matrix (with zero cross-spectra) for each AOA-Q region. The spectra required flat force over the 10-20 and 34-52 Hz frequency bands. The second bandwidth was narrowed slightly from previous testing to prevent unnecessary driving force being applied to the test article. This was accounted for in the characterisation results as well and will have negligible effect on FT46 versus flight response comparisons as the frequencies omitted are far enough from resonance.

The MEVCS was then used in Random mode to generate shaker force time histories for each AOA-Q region. This was achieved by connecting the MEVCS drive outputs directly to the feedback inputs in a configuration designated "wire-to-wire". In this way, the MEVCS acts as a signal generator and recorder, producing input force time histories with the desired spectral characteristics for each AOA-Q region. A four sigma clipping of the signal, which is within typical flight test peak/RMS results, was used when running the test in an attempt to minimise the peak force obtained in the time history. Once the target force spectra were achieved, the MEVCS recorded a significant amount of shaker input force time history or for each shaker. The amount of time recorded was at least enough to cover the SPEC6GE usage time in the given AOA-Q region plus the time needed for splicing time histories when generating buffet sequences (see Section 9.5). These force waveforms will be used when developing the buffet loading sequences to be applied to the test article. A schematic of the waveform generation process is shown in Figure 10.

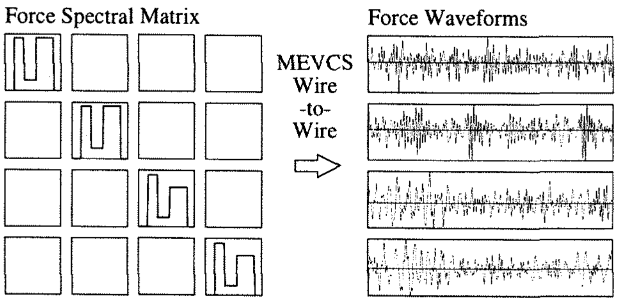


FIGURE 10 FT46 Characterisation Process

9.5 Buffet Sequence Development

For the purposes of IFOSTP, a buffet sequence was defined as a period of flying during which the F/A-18 maintains an AOA above 10 degrees and during which dynamic excitation is applied to FT46. It was further broken down into time spent in each AOA-Q region using the same interpolation technique implemented in usage data analysis. As a result, a listing of flight parameters and time durations was constructed to describe each buffet sequence for the entire 250 flight usage spectrum. Sequences not separated by more than 10 seconds in flight time were spliced together to minimise the number of test stop/starts. Essentially zero excitation is applied during these splice times. A total of 896 buffet sequences were defined for the SPEC6GE 250 flight pre LEX fence usage spectrum.

According to the sequence definition, portions of force waveforms of the required duration were selected from time histories (described in Section 9.4) for the appropriate AOA-Q condition, with 10% extra time allowed for overlapping. The data were windowed with a cosine window (or sine pulse window) on either end, and overlapped to produce a smooth but rapid transition from one condition to another. This window and overlap method was found to provide the best preservation of signal RMS and spectral content for similar random signals. Hence, a continuous sequence of transient data was formed to simulate buffet response for each buffet sequence for four simultaneous channels which represent the desired shaker force inputs. A schematic of this process is shown in Figure 11.

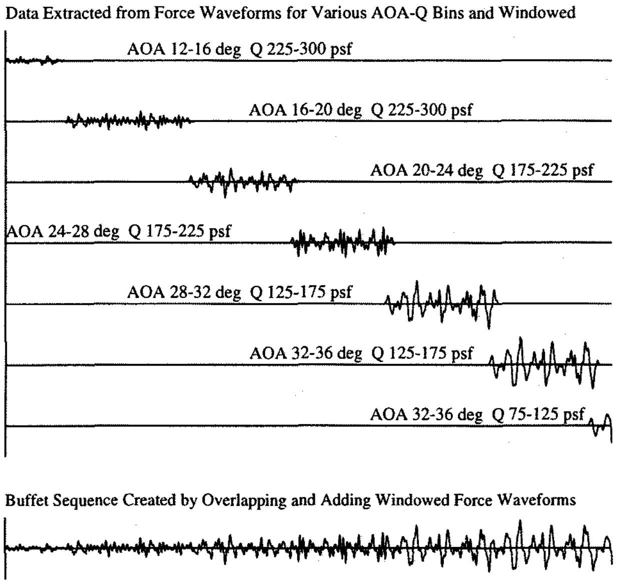


FIGURE 11 FT46 Buffet Sequence Development Process

The final waveforms for each sequence were stored in the form of desired waveforms for MEVCS Replication Mode tests in units of pounds force. Simultaneously, a Test Set file is also produced for each sequence to define test parameters required by MEVCS. A listing of all buffet sequences is also produced for the IFOSTP master test controller, defining points at which the dynamic load sequences are to be applied within the manoeuvre load sequence.

9.6 Shaker Drive Signal Generation

To produce drive signals which will result in the most accurate driving force for each of the interacting shakers, the MEVCS requires an impedance matrix to be generated for the test article/load bridge/amplifier/shaker system. As described in Section 7.3, this is usually accomplished via a sine chirp test which involves excitation of the system in a series of increasing and decreasing frequency sweeps on each drive channel. This test was done with FT46 under the average manoeuvre loading condition developed for the GVT (Section 8.2.3). From the shaker load bridge recordings during this test, the inverse of the load/voltage spectral transfer function matrix is computed. This is referred to as the impedance matrix for the system.

The resulting matrix is then convolved with the buffet force waveforms (defined in Section 9.5), using STI developed software, to produce voltage drive signals for the interacting excitation channels. These buffet sequence shaker drive signals are stored until the Test Controller requires them to be downloaded to the SPS for use during routine testing. These signals represent the drive signals necessary to impart the shaker dynamic loading into FT46 that is required to excite the structure to match the target responses derived from flight measurements. This ensures the resonant modes reach response levels as measured in flight for the entire SPEC6GE pre LEX fence usage spectrum. This in turn, imparts the correct internal dynamic loading to the test article.

Because the test article/load bridge/amplifier/shaker impedance can change as testing progresses, regular impedance matrices will be calculated from FT46 test measurements obtained during full level testing. These matrices will be used to update the drive signals as required to maintain the desired force input into the structure.

10.0 Combined FT46 Dynamic and Manoeuvre Loading

Once the buffet sequence drive signals are available for the entire 250 flight usage spectrum, the dynamic loads can be applied to the test article. The IFOSTP master test controller is used to apply manoeuvre loading as quickly as possible for AOA less than 10 degrees. During buffet conditions, the controller applies manoeuvre loads in real time and synchronises the application of the manoeuvre and dynamic loading by operating the MEVCS remotely to apply the shaker drive signals for the required buffet sequences.

11.0 Dynamic Loading Validation and Modification

While considerable development testing and analyses were conducted, the IFOSTP dynamic load development techniques and approach can not be fully validated until full level fatigue testing is conducted and results evaluated. To minimise risk to the FT46 test article during testing, extensive checks and safety systems have been developed and implemented. In addition, a stop is scheduled after 10 flights of testing to ensure that the dynamic loading approach is working properly. This assessment is designed to catch any gross problems.

Another stop is scheduled after 70 flights of testing when enough dynamic response data will have been acquired to enable FT46 dynamic response to be statistically compared to flight test results. This assessment is designed to validate the dynamic loading of the test article and the approach taken. FT46 dynamic response data will be compared to the target response of the dynamic load validation channels based on exceedence curves, which is the most important comparison, and on RMS response per AOA-Q per frequency band. Spectral analyses will be performed as necessary. Similar studies will be done with shaker force measurements. Should any changes to the input shaker forces be required to more accurately match the target response levels, modifications will be made.

12.0 Conclusions

AMRL has developed a complete test system which can simulate the operational flight conditions experienced by an F/A-18 aft fuselage/empennage structure. One of the most unique aspects of the test is the simultaneous application of realistic dynamic loads and manoeuvre loads representative of those measured in flight. At the time of the writing of this paper, fatigue testing had just begun and no test data has yet been analysed. The true measure of the success of the dynamic loading process described herein will depend on the results obtained during FT46 fatigue cycling.

13.0 Acknowledgments

The authors wish to thank their colleagues at AMRL who have contributed to the large team effort required for a test of this magnitude and complexity.