Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary

Royal Netherlands Air Force (RNLAF) flight testing

Determination of a vibration spectrum for countermeasure expendables in a fighter aircraft

Problem area

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Report no.
NLR-TP-2011-335

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Report classification
UNCLASSIFIED

Date
August 2011

Knowledge area(s)
Vliegproeven en Instrumentatiesystemen
Operations Research van luchtwapensystemen

Descriptor(s)
countermeasure
expendables
vibration
spectrum
flight testing

This report is based on a presentation held at the Society of Flight Test Engineers 22nd European Chapter Symposium, Toulouse, France, 14-16 June 2011.

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Determination of a vibration spectrum for countermeasure expendables in a fighter aircraft

Description of work

The Department of Operational Research and Evaluation (AORE) requested the F-16 Flight Test Office (FTO) to perform a flight test programme designed to measure the operationally representative vibration environment of the F-16 ACMDS.

The flight test programme was performed in close cooperation with the Dutch Military Aviation Authority (MAA).

The NLR contributed to the flight test instrumentation, and translated the measured vibration data into an equivalent vibration spectral model representative for the operational flight regime as experienced by the expendables.

Results and conclusions

All test flights were completed successfully in December 2010. Currently the data analysis is in a final stage and an initial, more favourable, equivalent vibration laboratory spectrum has been determined.

Applicability

This paper describes the F-16 ACMDS vibration measurement flight tests from test definition to its goal; a realistic vibration spectral model, to be used for determining and hopefully extending the expendable lifetime.

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Determination of a vibration spectrum for countermeasure expendables in a fighter aircraft

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Customer	National Aerospace Laboratory NLR
Contract number	----
Owner	NLR + partner(s)
Division NLR	Aerospace Systems and Applications
Distribution	Unlimited
Classification of title	Unclassified
	August 2011

Approved by:

Author	Reviewer	Managing department
3-8-2011	3-8-2011	3/8/2011

Summary

Aircraft self protection systems may contain flare and/or chaff expendables which can be ejected from the Aircraft Counter Measure Dispenser System (ACMDS). These expendables have a finite lifetime. An important factor determining the lifetime is the expendable design and the vibration environment to which the expendable is subjected during flight. The lifetime estimate of expendables – certified for use on the F-16 – is currently based on a conservative, theoretical, vibration model, which resulted in an undesired, short lifetime estimate for a new type of expendable. This triggered the need to measure the actual ACMDS vibration environment by executing an F-16 flight test programme. Expendable lifetime improvement is to be expected when measured vibration characteristics are used instead of a conservative theoretical model.

The Department of Operational Research and Evaluation (AORE) requested the F-16 Flight Test Office (FTO) to perform a flight test programme designed to measure the operationally representative vibration environment of the F-16 ACMDS. The flight test programme was performed in close cooperation with the Dutch Military Aviation Authority (MAA).

The NLR contributed to the flight test instrumentation, and translated the measured vibration data into an equivalent vibration spectral model representative for the operational flight regime as experienced by the expendables. This updated model is subsequently used to refine the expected expendable lifetime. The Defence Materiel Organization (DMO) remained responsible for the configuration and airworthiness of the instrumented test aircraft.

Due to the solid structural integration of the ACMDS in the F-16 it was a challenge to instrument the chaff/flare magazines. After laboratory qualification testing the NLR selected the Cranfield Air Countermeasure Data Logger (ACDL), being the first customer outside of the UK.

The ACDLs have been used on various aircraft types. However, ACDLs were not validated for use in a supersonic, high-G, flight regimes, like the one of the F-16.

The FTO determined the required aircraft configurations and set up a flight profile, which included low, medium and high vibration regimes. The ACDLs were used in both the aft fuselage and Pylon Integrated Dispenser System (PIDS) ACMDS. The test aircraft native instrumentation suite was used to verify ACDL generated data.

All test flights were completed successfully in December 2010. Currently the data analysis is in a final stage and an initial, more favourable, equivalent vibration laboratory spectrum has been determined. This paper describes the F-16 ACMDS vibration measurement flight tests from test definition to its goal; a realistic vibration spectral model, to be used for determining and hopefully extending the expendable lifetime.

Contents

Abbreviations

AA	Air-to-Air
AOA	Angle Of Attack
AOS	Angle Of Sideslip
ACDL	Air Countermeasure Data Logger
ACMDS	Aircraft Counter Measure Dispenser System
AECTP	Allied Environmental Conditions and Test Procedures
AORE	Department of Operational Research and Evaluation
AS	Air-to-Surface
CAS	Close Air Support
DDP	Declaration of Design and Performance
DMO	Defence Materiel Organization
DOF	Direction Of Flight
FT	Feet
FTE	Flight Test Engineer
FTI	Flight Test Instrumentation
FTO	Flight Test Office
G	G acceleration unit
GBU	Guided Bomb Unit
GPS	Global Positioning System
KCAS	Knots Calibrated Air Speed
KIAS	Knots Indicated Air Speed
LBS	U.S. pounds
M	Mach number
MAA	Military Aviation Authority
MAR	Military Aviation Regulations
MLU	Mid-Life Update
MTCHOE	Military Type Certificate Holder Organization Exposition
MOD	Ministry Of Defence
NLR	National Aerospace Laboratory NLR
NTO	No Technical Objection
PIDS	Pylon Integrated Dispenser System
PSD	Power Spectral Density
RMS	Root Mean Square
RNLAF	Royal Netherlands Air Force
RTB	Return To Base

S&L	Straight and Level
SME	Subject Matter Expert
SOW	Statement Of Work
STA	Wing store station
THA	Test Hazard Analysis
TGP	Targeting Pod
UK	United Kingdom
VST	Vibration and Shock Test Facility

1 Introduction

A small but ambitious Air Force. That is the most striking way to describe the Royal Netherlands Air Force (RNLAF) which operates several weapon-systems under the slogan “One Team, One Task”. The RNLAF introduced a new type of aircraft countermeasure expendable for integration on the F-16 using a smart-buyer/smart-user concept. Airborne lifetime of an expendable is mostly determined by its design and the vibration environment. This new expendable was designed to incorporate new countermeasure characteristics which led to a more complex design and resulted in a relatively short lifetime. Extension of this lifetime can be achieved by proving that the actual expendable vibration environment is less severe than the standardized test spectrum defined in Def Stan 00-35. This standardized test spectrum is often used in lifetime determination laboratory tests.

In order to provide this proof the RNLAF contacted the Department of Operational Research and Evaluation (AORE) to seek possibilities for determining the actual F-16 ACMDS vibration spectrum. AORE has an F-16 Flight Test Office (FTO) at her disposal, operating an instrumented F-16BM aircraft. The F-16 FTO flight test engineer (FTE) and the Defence Materiel Organization (DMO) worked together to propose measurement options and prerequisites.

2 Project team

For each flight test assignment a team is set up in which each team member has their own specialties, responsibilities and tasks. Being a small Air Force and usually having a small budget, the team is required to be very efficient. The composition of the team and thus possible addition of Subject Matter Experts (SMEs), depends on the test assignment. The following main parties were involved in this flight test programme:

2.1 Military Aviation Authority

The Dutch Military Aviation Authority (MAA) is responsible for the formal acceptance of the aircraft configuration to be tested through a certification process. The foundation for which was laid down in Military Aviation Regulations (MAR) that may be based on civil as well as military equivalents. The MAA has a supervising roll and acts as final authority for so-called major modifications, configuration deviations and high risk test flights.

2.2 Department of Operational Research and Evaluation

The Department of Operational Research and Evaluation (AORE), based in The Hague, coordinates and issues all flight test orders for the RNLAF. AORE also reviews, approves and archives all RNLAF issued flight test assignments, plans and reports.

2.3 F-16 Flight Test Office

The F-16 Flight Test Office (FTO) is based on Leeuwarden Air Base. The F-16 FTO prepares the assignment (flight) test plans and executes the test after test plan approval. After analysis the FTO writes the (flight) test reports. The F-16 FTO operates a specially modified, instrumented F-16BM. Even with the full instrumentation suite the aircraft remains 100% mission capable. It has tail number J-066 and is affectionately called “Orange Jumper”.

Figure 1: Schematic representation of the modular flight test instrumentation suite of the J-066

2.4 Defence Materiel Organization

The Defence Materiel Organization sustains all materiel for the Ministry of Defence. The Department of Fighter and Trainer Aircraft sustains the F-16 and PC-7. DMO is responsible for the configuration management and continued airworthiness of the aircraft. During flight testing, DMO delivers support to the RNLAF by ensuring the airworthiness of the test aircraft and instrumentation.

2.5 National Aerospace Laboratory NLR

The National Aerospace Laboratory NLR is the research institute in the Netherlands conducting applied research in the field of aviation and space technology. NLR identifies, develops and applies high-tech knowledge for both civil and military aerospace.

2.6 Teamwork

During all flight test programmes the whole team works according to a Do-Check-Approve methodology. The F-16 FTO is the executing organization, DMO checks for airworthiness and helps to assess risks. The MAA has issued a clearance mandating AORE to approve low and medium risks flight test programmes. All major modifications and/or high risk flight test programmes require MAA approval. Initial risk assessment is performed by the F-16 FTO and follows a similar approval methodology.

The Fighter and Trainer Aircraft division of the DMO works according to the Military Type Certificate Holder Organization Exposition (MTCHOE). This exposition processes the Military Aviation Regulations (MAR) into procedures, enabling DMO to ensure flight safety and airworthiness during flight testing.

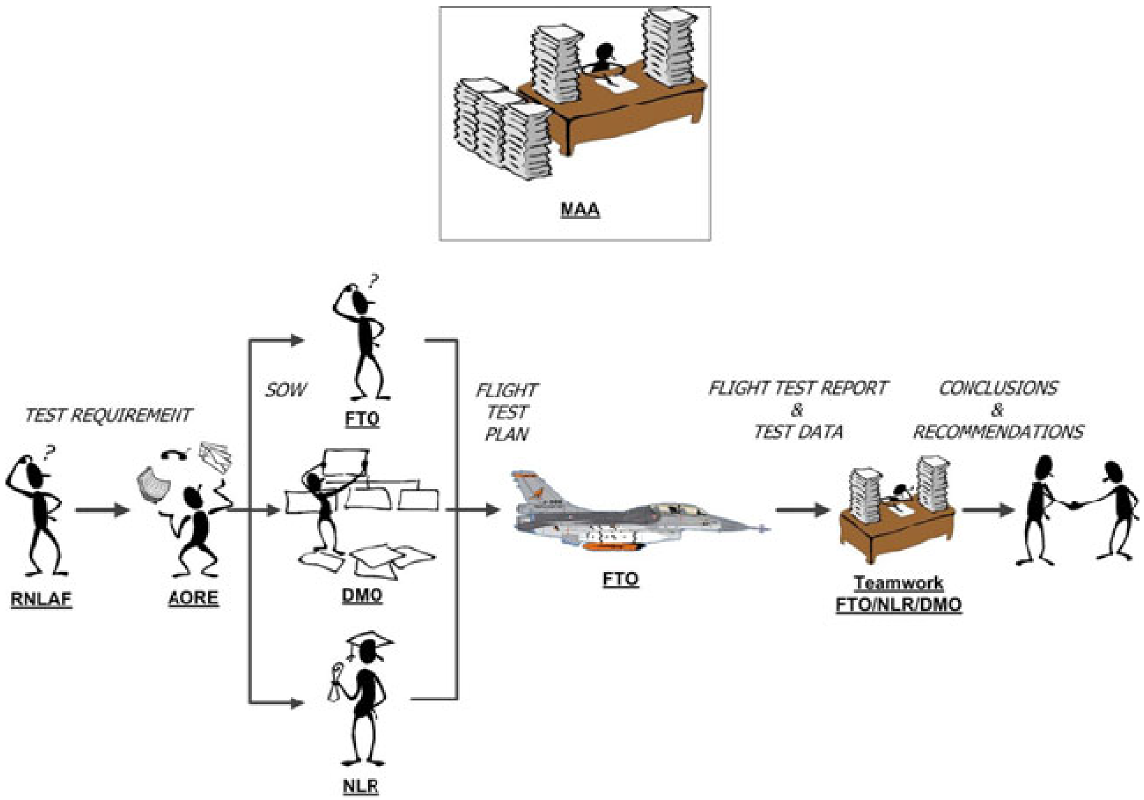

Figure 2: Schematic overview of the relations between all team members

2.7 Statement of work

To be able to achieve the test objectives a clear Statement of Work (SoW) had to be defined and specific tasks allocated to team members. The SoW acted as input for the overall flight test assignment which was required to be further defined by AORE.

The FTO was tasked to define all required aircraft measurement locations and test profiles in relation to the relevant part of the F-16 flight envelope combined with operationally relevant aircraft wing store configurations. This information would be summarised in a formal flight test plan written by the FTO.

2.8 Flight test instrumentation requirements

Possible lifetime extension of expendables based on actual ACMDS vibration spectra was not limited to the F-16 only. Being able to measure these spectra on multiple aircraft types would be an advantage, so the NLR was tasked by DMO to define additional flight test instrumentation (FTI) based on required measurement locations defined by the FTO. Any additional instrumentation was required to capture data time synchronised with the fixed, calibrated instrumentation suite already available in the J-066 F-16BM. Additionally, the NLR was tasked to validate if additional instrumentation components were able to capture vibration data compliant with Lockheed specification 16PS011E titled “Environmental criteria for the F-16A/B and C/D”.

After the flight test and additional instrumentation requirements were identified, AORE was able to finalise the flight test order in October 2010. This flight test enabled the F-16 FTO to commit resources and flying hours to further prepare and execute the required tests. All flight test orders contain test restrictions as well as precautionary measures tailored for the specific tests to be performed. In this case the test order restricted the use of additional instrumentation until verification of safe carriage and F-16 operation was obtained. The ACDL manufacturer provided an airworthiness certificate for use on all aircraft types, however did not specify any restriction for airspeed. Weight equivalent dummy expendables, accelerometers and their connection to the ACDL (independent data recorder) were integrated by NLR. The test order further specified the safety requirements that these test flights could only be executed by an experimental test pilot and that prior to the test a Test Hazard Analysis (THA) was required to be approved by the head of AORE. The THA is an integral part of any flight test plan using risk identification, consequence and probability analysis as well as a mitigation measure analysis.

3 Flight test preparation

With the team in place and the Statement of Work defined, preparations could start for the flight testing.

3.1 No Technical Objection

The design and integration of the ACDL as additional instrumentation was approved via a No Technical Objection (NTO). A NTO is a formal declaration composed and issued by the DMO. The NTO procedure represents a flight safety and airworthiness assessment to validate that all necessary steps were taken to mitigate flight safety risks to acceptable levels.

3.2 Flight Test Instrumentation

The stand alone Cranfield Aerospace Air Countermeasure Data Logger (ACDL) solution was selected as the primary ACDMS carried accelerometer data logger. The main advantage of using the ACDL was that it can be used as an autonomous FTI suite. This solution yielded possible use in all non-instrumented aircraft capable of carrying 1x1 inch and 2x1 inch expendable ACMDS systems. It also eliminated the requirement for a one time, expensive modification to the existing F-16 instrumentation suite.

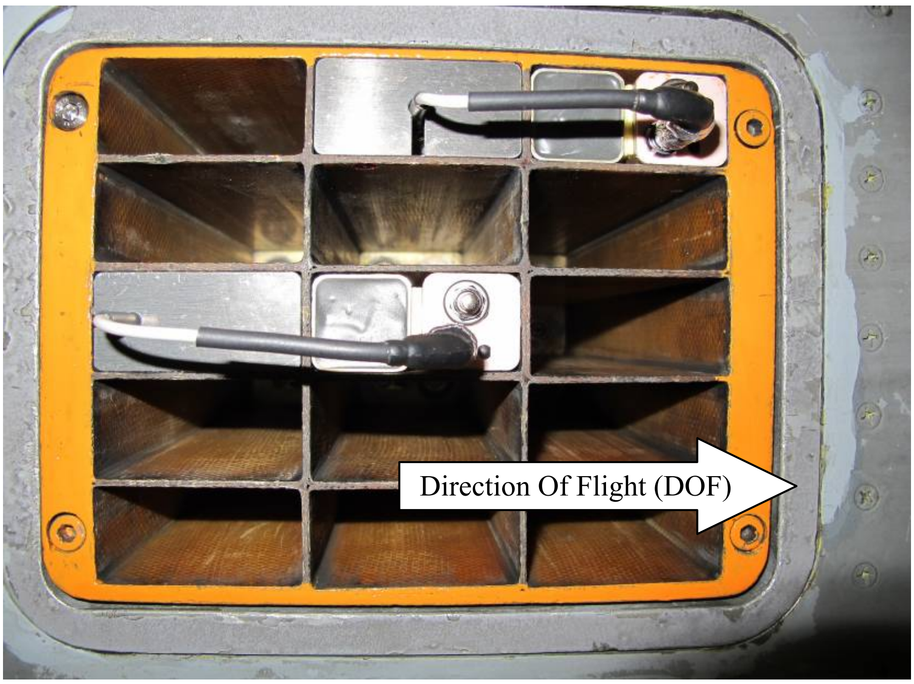

Figure 3: Accelerometer and Air Countermeasure Data Logger integrated in the F-16 Aircraft Countermeasure Dispenser System

The ACDL cartridges were certified by the United Kingdom (UK) Ministry of Defence (MoD) and are compliant with EASA part 21J.145. The ACDL was delivered with a Declaration of Design and Performance (DDP, number CA/DD/DDP013). ACDL key properties are listed in table 1.

Table 1: Key properties for the Air Countermeasure Data Logger

Key property	Limits
Ambient Temperature (Operational)	-45°C to +45°C
Altitude rating	50,000 ft (or equivalent)
Vibration	Suitable for airborne installation in all classes of aircraft (100 G pk)
Frequency range per channel	DC - 2000 Hz (low pass filters)
Sample rate	6000 samples/s
Tri-axial accelerometer	Endevco model 65 (125 G pk)
Recording time	Up to 2 hours continuous

Since the ACDL was only capable of sampling accelerometer generated vibration data at a maximum sample rate of 6000 samples/s, the team added an "ACDL recorded data validation" to the test requirements. For this purpose the J-066 F-16BM was equipped with an instrumented PIDS pylon used during earlier test flights. The instrumented PIDS pylon provided the ability to measure PIDS based ACMDS vibrations using both an ACDL and the Orange Jumper native instrumentation suite. Two identical, tri-axial accelerometers were placed as close together as possible on the same PIDS structural forged element. This ensured that both accelerometers would generate identical output, assuming the structural forged element as infinitely stiff. One accelerometer was connected to an ACDL and one accelerometer was sampled by the native Orange Jumper instrumentation suite. This approach yielded both an ACDL data validation as well as additional vibration data valid for the PIDS ACMDS.

3.3 ACDL installation

The ACDL is a form and fit replaceable unit to replace a 1x1 inch cartridge in an ACDMS magazine. For the 1x1 magazines the installation was relatively simple. The ACDL and the accelerometer were installed in adjacent cells. Special care was taken in completing the finish, alignment and installation of the wiring since the wire routing between the accelerometer and the ACDL is directly subjected to the free airstream as indicated in Figure 4. To minimize influences from sonic effects on the vibration behaviour of individual cells a lid was engineered to close the cell carrying the accelerometer.

Figure 4: Accelerometers and Air Countermeasure Data Loggers integrated in the Pylon Integrated Dispenser System

For the 2x1 magazine an adapter was introduced to install the ACDL (Figure 3). Again, the cell carrying the accelerometer was closed using a specially engineered lid. All engineering and production was performed in accordance with recommended F-16 practices and procedures acceptable for DMO. This enabled the DMO to issue a NTO for the installation of the ACDL FTI suite in the Orange Jumper.

3.4 Accelerometers

For the placement of the tri-axial accelerometers within the magazines, several locations were investigated by laboratory vibration tests using NLR's Vibration and Shock Test (VST) facility. A total of two positions per magazine were selected. The first was the worst-case magazine location with respect to vibrations, determined using the VST data. The other location was selected to be identical to the location used by expendable manufacturers during vibration laboratory testing. Since one ACDL was capable of recording data from one accelerometer two ACDLs per magazine were used. Including one installed PIDS four magazines were instrumented using ACDLs. A total of eight ACDLs were thus used each flight. To capture the expected vibration amplitudes, accelerometers with a 500 G peak-to-peak range were scaled down to a 250 G peak-to-peak measurement range.

3.5 Dispenser loadings

To simulate different load cases, mass and centre of gravity, the magazines needed to be (partially) loaded with expendables. For safety reasons, equivalent dummy expendables were designed to replace the 1x1 inch and 2x1 inch cartridges. Similar to the magazine modifications, engineering and production of the dummy cartridges was performed in accordance with recommended F-16 practices and procedures using empty expendable cases. Based on the VST results a release for flight test use for the dummy cartridges was incorporated in the NTO. The VST test resulted in the load cases used for the flight test as listed in table 2.

Table 2: ACMDS Magazine load cases

	PIDS Middle dispenser	PIDS Aft dispenser	Fuselage sta 9A	Fuselage sta 9B
Test flight 1	100 %	100 %	EMPTY	EMPTY
Test flight 2	25 %	25 %	100 %	100 %
Test flight 3	EMPTY	EMPTY	25 %	25 %

3.6 Time synchronisation

Since the data sets of the Orange Jumper instrumentation system and the stand alone ACDL units were required to be correlated, some kind of time synchronization was necessary. Using a single time generating source was not an option. Therefore a procedure was developed to synchronize time for the different FTI systems. The Orange Jumper FTI system was synchronized with GPS prior to every test flight. ACDLs were also synchronized with GPS prior to each test flight while programming them with a standard desktop PC. Laboratory tests were performed to verify the time synchronisation error and clock speed difference. The worst case error was found to be less then one second for a measurement period of 2 hours. This result was considered acceptable for the purpose of this flight test and was within data analysis methodology limits.

3.7 Data conversion and reduction

The amount of data gathered during a typical test flight ranges between 3 and 4 GB of data. All the captured data is archived for reference purposes. Both raw Orange Jumper and ACDL data were converted into engineering units. Data reduction was achieved by selecting only those parameters from the Orange Jumper data set that were relevant for the analysis. This yielded the final data set used for further analysis by NLR SMEs.

3.8 Flight test plan definition

In close cooperation with DMO and NLR the final flight test plan was defined in November 2010 considering the following limitations:

- During all test flights certified wing store configuration limits were to be adhered to.
- All test flights were performed over sea using the default RNLAF training airspace.
- No live expendables were allowed to be carried when ACDLs are carried. Instead weight equivalent dummies were used in the magazines. Magazine loading layout was determined prior to each test flight.
- Maximum ACDL recording time was 2 hours.
- ACDLs were synchronized to J-066 instrumentation time (GPS) and remain accurately synched (free running) to ±1 second for the remainder of the flight.
- J-066 instrumented PIDS pylon was utilised. All store configurations were required to include this pylon during all flights.

3.9 Wing store configuration

The F-16 is able to carry a large number of different stores on its eight wing store stations and three fuselage store stations. All of these possible configurations were summarised in two main groups, Air-to-Air (AA) and Air-to-Surface (AS) configurations. Only operational configurations were considered.

AA: Characterized by configurations with only AA missiles and optional external fuel tanks. Most of the configurations can utilise the full F-16 flight envelope.

AS: Characterized by configurations with AA missiles, AS stores (500 – 2000 lbs), external fuel tanks and air intake mounted targeting pods. Most the configurations are limited in airspeed and G.

The new type of expendable will only be used in operational environments. Estimation of its lifetime was therefore required to be based on the most realistic operational vibration spectrum possible. Based on operational experience from e.g. Afghanistan, it was decided to focus on Close-Air-Support (CAS) type missions. CAS mission were always executed using an AS type F-16 store configuration.

To avoid overly optimistic results worst-case vibration conditions from the complete F-16 flight envelope were required to be measured. Based on historical flight test data and experience worst-case vibration environments were found to occur at low altitudes, high airspeeds and high G-loads.

This resulted in the following flight test objectives:

- Measure low, medium and high ACMDS vibration levels in the F-16 aft fuselage and PIDS dispensers while flying in operational- and worst-case vibration store configurations and using multiple magazine loading levels.
- Validate ACDL recording capability in an aircraft vibration environment.

Selection of the CAS type mission reduced the number of store configurations dramatically. The total number of configurations was reduced to two configurations, one configuration with AS stores and one identical configuration without the AS stores, e.g. the revert-to configuration. The revert-to configuration represented the configuration where the F-16 would have employed the two AS stores from the wing, being an operational relevant configuration. The AS stores were chosen to be one GBU-12 laser guided 500 lbs bomb and one GBU-38 GPS guided 500 lbs bomb.

Figure 5: Instrumented Pylon Integrated Dispenser System with Guided Bomb Unit-12 Air to Surface store

Historical flight test data showed that gun employment contributed significantly to overall vibrations in the avionics compartment located in the front fuselage. No data was available on its contribution to overall vibrations in the aft fuselage, the location of two dispensers. Based on these considerations gun employment test points were included in the flight test plan.

CAS type missions may include a targeting pod store mounted on the right hand side of the air intake. During the Mid-Life-Update (MLU) modifications the ventral fins of the RNLAF F-16 (Block 15) were replaced by stiffer Block 40 ventral fins. The reason for this replacement was an advisory of Lockheed Martin which stated that the wake vortices behind these types of intake mounted pods could be strong enough to damage the less stiff Block 15 ventral fins. One of the aft fuselage dispensers is located behind the targeting pod. In order to be able to assess if vibrations in that dispenser were influenced by the targeting pod wake one mission was planned without the targeting pod present. Its removal and inclusion of the revert-to configuration in the test matrix also provided the possibility to measure worst-case vibration characteristics during high-G manoeuvres up to 9 G.

When carrying AS stores with weights ≥ 500 lbs the F-16 is limited to 5.5 G and carriage of the targeting pod yields a varying G-limit between 5.5 – 6.5 G. All these considerations resulted in several F-16 wing store configurations used in this flight test programme. These can be found in Appendix A.

3.10 Vibration environment definition

Three vibration levels were defined that characterised different flight conditions. These three vibration definitions were defined based on historical F-16 vibration characteristics measured during other test programmes and subsequently used in flight profile definition. They represented the full vibration characteristics of the F-16. Each of the selected store configurations was used during one test flight. During each of the three test flights all vibration environments possible within the store configuration flight envelope limits were required to be measured. This approach ensured all possible vibrations would be captured in the recorded data, making vibration spectrum creation possible. The three vibration level definitions can be found in Appendix B.

3.11 Test flight profiles

The flight profiles used during test flight execution were based on the selected three wing store configurations combined with the vibration characteristics defined above. The flight profiles covered all requirements and were planned in such a way that measurements for each configuration could be completed within one test flight. An airspeed build-up test approach was selected due to the absence of ACDL airspeed limits defined by the manufacturer and to verify the integrity of the accelerometer connection to the ACDL. Configuration (#1) would be tested first as this configuration posed the most restrictive flight envelope limits, followed by configuration #2 and finally configuration #3. The flight test profiles can be found in Appendix C.

For time synchronisation verification and backup purposes an accelerometer step input using a soft hammer was applied prior to each test flight. This was repeated just after landing where it was combined with a visual inspection of ACDL FTI installation integrity.

4 Flight test execution

During the first week of December the team gathered at Leeuwarden Air Base. After the FTO avionics/instrumentation specialists instrumented the ACMDS together with NLR, the flight crew led a pre-flight test briefing. After team agreement on the pre-flight briefing the FTO executed the first test flight. The data recorded by the Orange Jumper FTI and ACDLs was made available for Quick Look analysis immediately after each flight for NLR SMEs to validate the data integrity.

Figure 6: The J-066 taxiing out to execute a test flight

Unfortunately, during the first flight, three out of eight ACDLs did not record any data. No apparent cause was found during the test execution period. The issue did not re-occur in subsequent flights.[1]

Due to the December weather (-20˚C and windy) the airfield was closed on the second day. Fortunately, with help from Leeuwarden Air Base personnel and the flexibility of the FTO, the remaining two test flights were executed later that week. All planned test points from the flight test plan were successfully executed.

5 Data analysis

The vibration levels recorded during the test flights had to be converted into Power Spectral Densities (PSD) representing vibration environments experienced during representative operational missions. The conversion method was based on leaflet 2410 of NATO publication AECTP-200 “Environmental Conditions” and is elaborated in the following paragraphs. The presented data analysis results illustrate one relevant test location and magazine loading for the newly acquired expendable type.

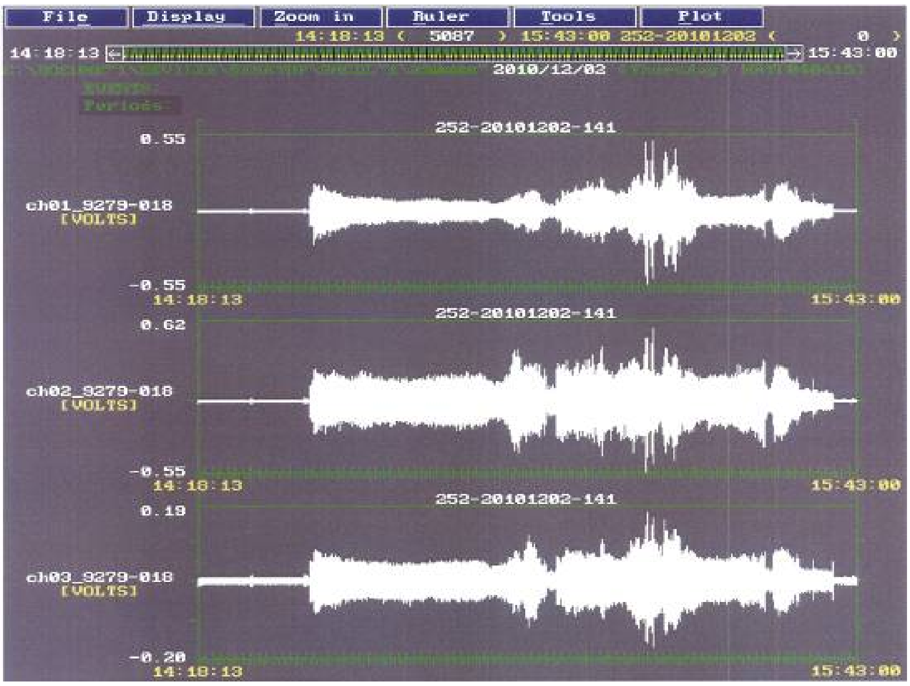

Figure 7: x, y and z accelerometer time history data example

5.1 Data verification

The data collected during the test flights was first reviewed for completeness and integrity. The data sets showed data that corresponded to the flight time duration and clearly varied in amplitude within the calibrated measuring range. Comparing the time histories of similar channels at similar accelerometer locations also showed comparable shapes and magnitudes. Figure 7 shows an example of the time histories of the x, y and z axes of one test point in the aft fuselage.

5.2 Spectral analysis

The spectral analysis aimed at identifying the relevant flight parameters affecting the aircraft vibration levels, the 'governing parameters', so that a representative PSD for CAS type missions could be determined. To achieve this, the measured vibration data was converted into PSDs per one second[2] time intervals and related to the flight parameters recorded by the Orange Jumper FTI.

Dynamic pressure proved to have a significant effect on vibration levels. Therefore, the one second PSDs and their derived root-mean-square (rms) values were related to the one second (average) dynamic pressure determined from J-066 flight parameters. This showed that the dynamic pressure was the sole governing parameter with respect to vibration levels. Even the variation in rms values determined during gun employment, high G turns and high speed throttle chops could be related to the variation in dynamic pressure.

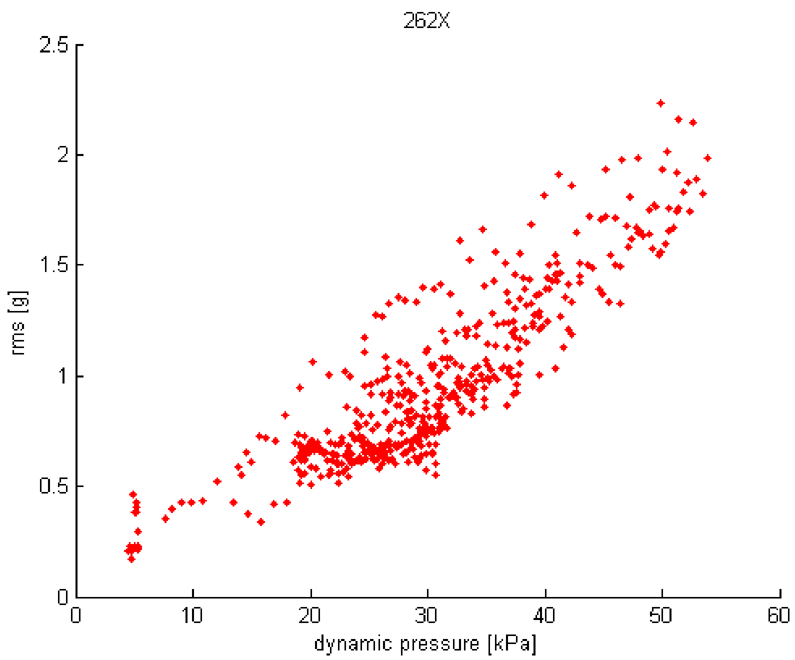

Figure 8: rms of vibration levels vs. dynamic pressure measured in the aft fuselage dispenser

Figure 8 shows an example of the relationship between the rms-value and dynamic pressure for all events combined for one test point in the aft fuselage.

5.3 Representative PSD

With the determination of the dynamic pressure being the sole governing parameter, the whole set of vibration data (per test point) was grouped into smaller sets, so-called pressure bins. Within these pressure bins, the (linear) average PSD and standard deviation were determined.

The complete set of measured vibration data divided in pressure bins, comprising a large part of the F-16 flight envelope, had to be converted to represent the focussed operational representative mission type, CAS. This was achieved by factoring all pressure bins based on their occurrence in CAS missions. The factoring was only possible using a RNLAF operator's usage database that allowed the determination of 'occurrences' of the dynamic pressure bin values during earlier executed missions. These factored data sets were processed to yield one average 'weighed' or 'representative' PSD. For test points located at similar positions (i.e. left and right hand side of the fuselage) the representative PSDs were grouped together to form an 'envelope' PSD.

Expendable lifetimes are determined in a laboratory environment where the required test time can be reduced by scaling the PSD on which the laboratory tests are based. Omitting the scaling implies that the required laboratory test time is identical to the lifetime. The scaling was realized by applying the Miner-Palgren Hypothesis or Miner's rule. According to this rule, the 'representative (envelope) PSD' was scaled by a factor based on the desired test time.

5.4 Comparison to international standards

The derived vibration spectrum of the aft fuselage location was compared to information from the aircraft manufacturer (could not be published due to releasability restrictions) and to the "Test M1 – General Purpose Vibration Test" from Def Stan 00-35. Figure 9 shows the derived envelope vibration spectra of two relevant test points in three aircraft axes.

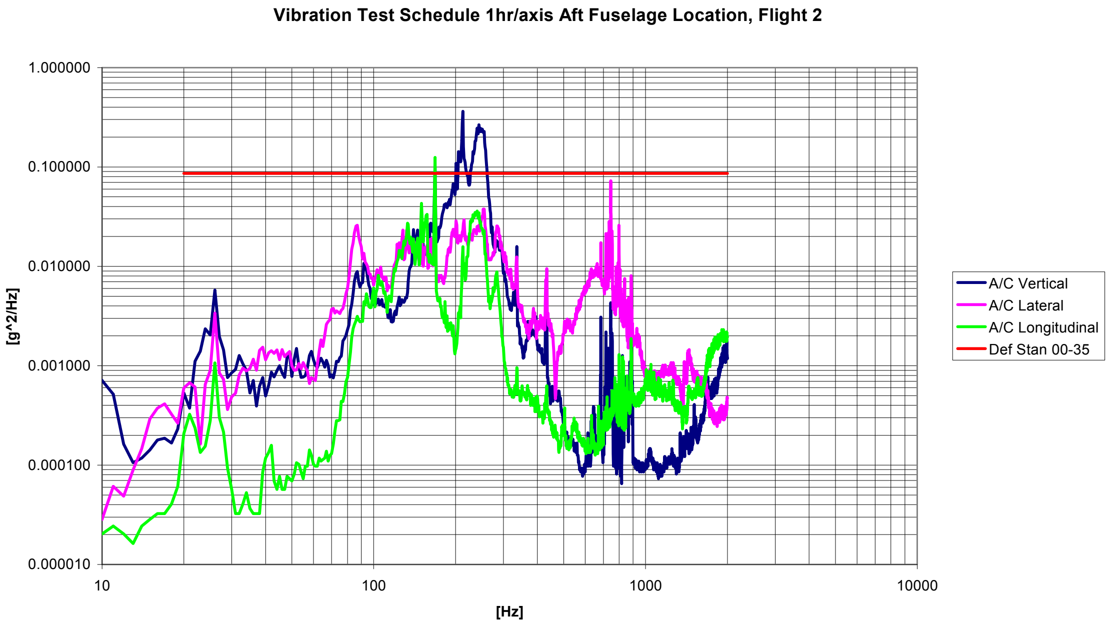

Figure 9: Derived vibration spectrum combined with Def Stan 00-35

6 Conclusions and recommendations

The ACDL based FTI solution was successfully subjected to G-loads up to 8.5 G and airspeeds up to Mach 1.6. Data comparison between Orange Jumper FTI data and ACDL recorded data showed that the ACDL is adequate as stand alone FTI for recording vibration data up to 2 kHz in and around aircraft ACMDS systems provided that the ACDL temperature remains above -46°C.

Utilising multiple ACDLs simultaneously combined with the broad flight profiles used during this flight test programme yielded sufficient data to produce representative ACMDS vibration spectra for the complete F-16 flight envelope and all available magazines. The loss of data from three ACDLs during test flight 1 did not have negative impact on the final analysis result.

Final data analysis showed that the representative vibration spectra are generally more favourable when compared to the international Def Stan 00-35. Vibration amplitude rms values were found to depend solely on governing dynamic pressure. The expendable manufacturer has not yet determined the new expendable airborne lifetime based on these measurements, but based on their favourable appearance compared to Def Stan 00-35 lifetime extension is expected.

The flight test team recommends using the stand alone ACDL FTI solution on other RNLAF aircraft for determining the representative ACMDS vibration spectra.

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Footnotes

Page 21: [1] At a later stage the extreme low temperatures, outside the ACDL operating envelope, were determined to be the cause of the ACDL failure.

Page 22: [2] From experience a one second interval is considered to be sufficient stable (in view of changing parameters) for fighter aircraft.

Acknowledgement

The photograph on the title page was used by courtesy of Mr. Frank Crébas. (http://www.bluelifeaviation.nl).

Appendix A Wing Store Configurations

Wing Store configuration. Station 5R is right hand										
#	**1**	**2**	**3**	**4**	**5**	**5R**	**6**	**7**	**8**	**9**
1	AIM-9	CLEAN	PIDS GBU-12	TK370	CLEAN	TGP	TK370	PYLON GBU-38	CLEAN	AIM-9
2	AIM-9	CLEAN	PIDS	TK370	CLEAN	TGP	TK370	PYLON	CLEAN	AIM-9
2	AIM-9	CLEAN	PIDS	TK370	CLEAN	CLEAN	TK370	PYLON	CLEAN	AIM-9

-) AIM-9: Infrared guided AA missile

-) PIDS: instrumented Pylon Integrated Dispenser System

-) TK370: External fuel tank with a 370 USG capacity

-) TGP: Litening AT targeting pod

-) PYLON: Standard F-16 wing weapon pylon

Appendix B Low/medium/high vibration environments

Low level vibration environment	• High altitude (ALT > 25,000 ft) straight and level (S&L) flight with limited manoeuvring (G < 3). • Slow climb- and descent profiles (pitch angle < 20°). • Supersonic flight (Mach > 1.2).
Medium level vibration environment	• Medium altitude (7,500 ft < ALT < 20,000 ft) flight with moderate manoeuvring (G < 5.5). • Transonic flight (0.90 < Mach < 1.2). • MIL power take-offs. • Medium altitude, low speed, high Angle of Attack (AoA) and Angle of Sideslip (AoS) manoeuvring. • Close Air Support (CAS) type manoeuvring at medium altitude: • Prolonged right turns (1 < G < 5.5). • Air-to-Ground attack profiles.
High level vibration environment	• Low altitude (ALT < 7,500 ft), high speed (KCAS > 430) flight with moderate to severe manoeuvring (G > 5.5). • High speed descents (pitch angle < -30°). • Low-altitude speed brake actions combined with throttle chop • Afterburner take-offs. • M61A gun employment.

Appendix C Flight test profile definitions

	Flight test profile definition
Test flight # 1 **Configuration #1**	• Afterburner take-off. • Default departure profile heading towards assigned airspace. • Climb to altitude > 30,000 ft. • Some Straight and Level (S&L) flying to capture low vibration environments. • Perform a Mach run to approximately M=1.2 (store configuration maximum). • Rapid descend to approximately 10,000 ft. • Perform slow speed; high AOA/AOS manoeuvres (generates substantial flow around the ventral fins). • CAS manoeuvres, prolonged right turns. • Perform at least two simulated bomb runs (or AS strafe) with a safe escape manoeuvre. • Descend to low altitude (<2000 ft, desired 250 ft). • Perform at least 2 level accelerations from min. store configuration speed to approximately 600 KIAS (M = 0.9 – 0.95). At maximum speed perform throttle chop and simultaneously open speed brakes to generate max vibrations. • Perform at least two right and at least two left turns at 5.5 G (maximum configuration G) to capture high G vibrations at low altitude. • Left & right required due to asymmetric configuration (TGP). • RTB Leeuwarden, default approach profile landing drag chute, full stop.
Test flight # 2 **Configuration #2**	• MIL power take-off. • Default departure profile heading towards assigned airspace. • Climb to altitude > 30,000 ft. • Some Straight and Level (S&L) flying to capture low vibration environments. • Perform a Mach run to approximately M=1.6 (store configuration maximum). • Rapid descend to approximately 10,000 ft. • Perform slow speed; high AOA/AOS manoeuvre (generates substantial flow around the ventral fins).

	• Perform at least two simulated bomb runs (or AS strafe) with a safe escape manoeuvre. • Descend to low altitude (<2000 ft, desired 250 ft). • Perform at least 2 level accelerations from min. store configuration speed to approximately 600 KIAS (M = 0.9 – 0.95). At maximum speed perform throttle chop and simultaneously open speed brakes to generate max vibrations. • Perform at least two right and at least two left turns at 6.5 G (maximum configuration G, no fuel in TK370) to capture high G vibrations at low altitude. • Left & right required due to asymmetric configuration (TGP). • RTB Leeuwarden, default approach profile landing, full stop.
Test flight #3 **Configuration #3**	• Afterburner take-off. • Default departure profile heading towards assigned airspace. • Climb to approximately 15,000 ft. • Perform slow speed; high AOA/AOS manoeuvre (generates substantial flow around the ventral fins). • Perform two AA gun attacks with live gun employment. • Descend to low altitude (<2000 ft, desired 250 ft). • Perform at least 2 level accelerations from min. store configuration speed to approximately 600 KIAS (M = 0.9 – 0.95). At maximum speed perform throttle chop and simultaneously open speed brakes to generate max vibrations. • Perform at least two turns at >7G to capture high G vibrations at low altitude. • Perform two AS strafe attacks with live gun employment. • RTB Leeuwarden, default approach profile landing, full stop.

Appendix D Author's Biographies

Meta de Hoon holds a MSc degree in Aerospace Engineering from Delft University of Technology. She did her internship at the F-16 operational base Volkel in 2007 and completed her master-thesis in 2008 in the field of Astrodynamics and Satellite Systems. She joined the Defence Materiel Organization as Junior Type Manager of the F-16 & PC-7 and is responsible for the sustainment of the F-16 frame and components.

Since 2010 she is the Project Leader "Orange Jumper" for the DMO and is responsible for the airworthiness and configuration management of the J-066 and is an SFTE member since 2010.

Hans Devilee holds a BSc degree in Aeronautical Engineering from the Technical University of Amsterdam. After his graduation in 1992, he joined the Flight Operations Department of KLM Flight Division where he worked on numerous projects in the field of Aircraft Performance, Aircraft Operations and Weights. In 2002 he moved to Toulouse to join Airbus at the Weights Engineering Department and later on at the Flight Operations Department. In 2007 he returned to the Netherlands to join NLR, where he participated in military certification projects which led to his current specialization in vibration data analysis.

Paul Koks holds a BSc degree in Aeronautical Engineering from the Technical University of Haarlem where he graduated in 1985. After fulfilling his military service in the Royal Netherlands Army Engineers Corps he joined NLR in 1986 as a flight test instrumentation engineer at the Aircraft Systems – Flight Testing Department of the Aerospace Systems Division. He participated in the NLR's operational flight test instrumentation team for the certification of the Fokker 50 and Fokker 100 aircraft and was instrumentation team leader during the Fokker 70 certification.

During the modification and transformation of the F-16 MLU aircraft J-066 into an instrumented test aircraft he was responsible for the mechanical design and installation of the F-16 MLU flight test instrumentation. In his current position he is NLR project leader for the follow-on support of the J-066 'Orange Jumper' and is involved in both military and civil airworthiness projects.

In the past he presented papers about F-16 flight test instrumentation and F-16 military flight testing at symposia of the SFTE in 2000, 2006 and 2010.

René de Dooij holds a MSc degree in Aeronautical Engineering from the Delft University of Technology where he completed his thesis in the field of aircraft performance and trajectory optimization in 2003. He was awarded the prof. dr. ir. Kooy prize 2004 for best defence related MSc thesis by the Royal Institute of Engineers. In 2004 he joined NLR as junior R&D engineer at the Aircraft Systems - Military Operations Research Department of the Aerospace Systems Division. He specialized in electronic warfare and countermeasure analysis combined with military aircraft operations.

From 2008 up to and including 2010 he was placed at the F-16 Flight Test Office located on Leeuwarden Air Base as Flight Test Engineer. In this role he was responsible for many F-16 flight test programmes in test planning, data analysis and flight test reporting. Together with F-16 experimental test pilots he was a crewmember of the J-066 Orange Jumper F-16BM and responsible for operating the flight test instrumentation system and real-time monitoring of the test flight. He has been a member of the SFTE since 2008.