Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

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Abstract

In the Netherlands a capability to qualify new stores for military aircraft exists. This capability consists of elements contributed by the Royal Netherlands Air Force (RNLAF) and the National Aerospace Laboratory NLR of the Netherlands

The RNLAF operates a fully instrumented F-16 Mid Life Update test aircraft. Currently running and envisaged programs are in the field of external store qualification and future avionics concept demonstration.

Recently, a program to prove the airworthiness of two external store systems has been completed. The qualification procedure developed jointly by the RNLAF and NLR is described in general terms, together with the tailoring of the procedure to the airworthiness qualification program of external stores. Furthermore the analytical tools are described which are available at NLR and support the F-16 airworthiness qualification. Also, a short overview of the instrumented aircraft and its capabilities is given.

The interaction of analytical tools (simulations) and the test aircraft (actual tests) in the program is emphasized. Results of the external store qualification program in the fields of flight handling, flutter/limit cycle oscillation behavior, stores separation, structural strength in general and ventral fin issues in particular are given.

It is concluded that a unique infrastructure, consisting of analytical tools, procedures, test facilities, and last but certainly not least, skilled people, is available to support the RNLAF in their aircraft operations.

Contents

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1 Introduction

The relationship between the Royal Netherlands Air Force (RNLAF) and the National Aerospace Laboratory NLR of the Netherlands in the field of the qualification of fighter configurations goes back to the introduction of the conventional air to surface role for the F-104G in 1968. National qualification of conventional weapons took place with the emphasis on performance, flying qualities, aeroelastics and separation. Instrumentation was packed in Mk-64 bodies.

The NF-5 was introduced in the RNLAF in 1970 with a limited number of qualified stores configurations. All new stores configurations were qualified by a joint RNLAF/ NLR test group. A dedicated aircraft was equipped with a flight test instrumentation package including telemetry, a ground vibration rig was set up, and analytical tools were developed.

Shortly after the introduction in 1979 of the F-16 fighter aircraft in the Royal Netherlands Air Force (RNLAF) it became clear that again an in-country flight test facility was required in order to support operations of the aircraft.

Support was foreseen for mission training where recording of data may improve tactics, for trials to determine or improve the performance of aircraft systems, and for qualification of new (avionics) systems or external stores.
Under contract to the RNLAF and in cooperation with the manufacturer of the aircraft, NLR started the development of analytical tools to predict the behavior of the aircraft in terms of flight handling, performance, flutter, fatigue and external store separation. This development was of course based on the tools and knowledge gained from the NF-5 program.

Also, the RNLAF awarded a contract to NLR to design, provide, and install a data acquisition system in one of the F-16 aircraft (Ref. 1), and to assist the RNLAF with the operation of the system and the analysis of flight test data.

The Flight Test Instrumentation (FTI) system became operational in October 1984 and has fulfilled its task without major problems. The system has been decommissioned on 19 May 2000.

The development of the tools turned out to be an ongoing effort, with changes and additions required each time the aircraft was modified, the latest major modification being the Mid-Life Update (MLU) of the F-16 European Participating Air Forces (Belgium, Denmark, Norway and the Netherlands).

In 1996, with the coming introduction of the MLU program, a requirement was drafted for a new instrumented aircraft, tailored to the (extensive) avionics updates and provided with additional functionality as a result of the experiences with the former system (Ref. 2). The contract was awarded to NLR in December 1997 and a new test aircraft became operational in June 1999 with the start of a program for the airworthiness qualification of external (engine inlet mounted) night vision/ target designation equipment.

This report is positioned around the above mentioned qualification project.
First the qualification procedure developed jointly by the RNLAF and NLR is described in general terms, together with the tailoring of the procedure to the airworthiness qualification program of the external equipment.
Next the analytical tools are described and a short overview of the instrumented aircraft and its capabilities is given. For an extensive description of the instrumented aircraft see Ref. 3.
Finally a case study of the qualification project is carried out. The interaction of analytical tools (simulations) and the test aircraft (actual tests) in the program is emphasized. Results of the program in the fields of flight handling, flutter/limit cycle oscillation behavior, stores separation, structural strength in general and ventral fin issues in particular are given.
It is concluded that the RNLAF and NLR are ready to support F-16 operations well into the 21st century.

2 Qualification of Military Aircraft in the Netherlands

In a joint effort by the RNLAF, the Royal Netherlands Navy, and NLR the procedure for the qualification of military aircraft in the Netherlands was drafted. The qualification process is described in Ref. 4 and is copied in condensed form in the following subsection. In subsection 2.2 the general procedure is tailored to the airworthiness qualification of external stores.

2.1 General procedure

Reference 4 defines Type Qualification as 'The process leading to the recognition that the design of an aircraft, aircraft system or aircraft component complies with the applicable airworthiness and operational requirements'. Qualification includes:

- *airworthiness* qualification to demonstrate compliance with the applicable airworthiness requirements, and
- *operational* qualification to demonstrate compliance with the operator's operational requirements, such as performance, maintenance and logistics requirements.

The qualification process comprises the following phases.

a. Preparation activities. In this phase all preconditions to assure a well organized, efficient, and properly and timely conducted qualification project are established. Preconditions include, but are not limited to the establishment of the applicable operational, functional, and technical requirements, including the intended usage conditions with the expected usage spectrum.
b. Requirements Basis Definition (RBD). This definition comprises the activities to determine, define and formally establish the requirements to which the design has to conform. The requirements basis includes:
   - the applicable airworthiness requirements,
   - the functional requirements derived from the operational requirements,
   - interpretation of the requirements: the documented agreement between the parties involved on the requirements that may be subject to different interpretations, and
   - special conditions: aspects for which no adequate requirements yet exist.

   Non-compliance with requirements may be formally approved.
c. Means of compliance definition. In this phase the required verification methods and activities to demonstrate that a design conforms to the agreed qualification requirements basis are established. The phase leads to:
   - the (sub) system design description,
   - the Airworthiness Compliance Plan (ACP),
   - the Performance Compliance Plan.
d. Compliance demonstration. The compliance demonstration comprises the execution of all verification activities as laid down in the compliance plans, and results in:
   - design documents, drawings and declarations,
   - test result reports,
   - analysis reports,
   - inspection reports, and
   - operational procedures and limitations (to be included in flight manuals and maintenance manuals).

   Non-compliance's are identified and waived, if accepted by the responsible authority.
e. Review of data and issue of certificate. The authorities responsible for airworthiness- and for operational aspects conduct a review in order to verify that the qualification process has been properly executed. The authorities formally declare that the design complies with the requirements for airworthiness qualification, and formally accept the design.

2.2 Airworthiness qualification of external stores for the F-16MLU aircraft

The RNLAF recognizes qualifications of other nations, in particular of other F-16 users. A store that has been qualified on an aircraft, which is similar or partly to the RNLAF F-16MLU or operates under identical conditions, can be qualified or partly qualified on basis of similarity. Aspects, which can not be qualified on basis of similarity, need further attention.

In this subsection the tailoring of the above general procedure to the qualification of external stores to the RNLAF F-16MLU aircraft is described. Moreover, the procedure is limited to airworthiness qualification.
The tailoring may be applicable to other (fighter) aircraft types.

2.2.1 The US Air Force Seek Eagle program

F-16 specifications do not specify which standards or specifications are required for the qualification of external stores. The US Air Force introduced the Seek Eagle program (Ref. 5) to determine the safe carriage, employment and jettison limits, safe escape, and ballistics accuracy (when applicable), for all stores in specified loading configurations. This program includes: compatibility analyses for fit, function, electromagnetic interference, flutter, loads, stability and control, and separation; stores loading procedures; ground and wind tunnel tests, under expected flight and ground conditions. The end product is source data for flight, delivery, and loading manuals, and the weapon ballistics portion of the aircraft Operational Flight Program.

The Seek Eagle program fits naturally in the procedure as described in subsection 2.1 above. For this reason, and 'not to reinvent the wheel', it has been decided to copy as much as possible Seek Eagle segments into our procedure.

The Seek Eagle program refers to MIL-HDBK 244 “Guide to Aircraft Stores Compatibility” (Ref. 10) for basic guidelines for evaluating aircraft-store compatibility, and to MIL-STD-1763A “Aircraft-Stores Certification Procedures” (Ref. 11) for DoD standardized procedures for the certification (safe carriage and separation) of stores on aircraft. Hence these sources are taken as guidance for the airworthiness qualification of external stores.

The Seek Eagle program requests a Certification Data Package and store handling instructions to support the tests and analyses for certification. A cross-check confirmed that all data requirements and certification topics of Seek Eagle program are covered by those in MIL-STD-1763A (Ref. 6) and hence this standard should yield a certification process that is similar to that of Seek Eagle. Because Seek Eagle addresses qualification issues for aircraft and store in combination, another source, e.g. MIL-HDBK-244A (Ref. 7) Section 5.3, shall be used for the qualification of the store on its own, i.e. detached from the aircraft.

2.2.2 The RNLAF airworthiness qualification procedure

Following the general procedure from section 2.1 the phases leading to the airworthiness qualification of external stores are as follows.

a. Preparation

This phase identifies the applicable regulations and requirements, such as:

- MIL-HDBK-244A, section 5.3 “Store Design” and references therein are used for the stores to be qualified.
- MIL-STD-1763A and references therein are used for the combination of the aircraft with the external stores.
- Applicable aircraft. The RNLAF operates both single seat and dual seat F-16s in different build standards ('block numbers'). Not all aircraft undergo the MLU program. Thus, the applicable aircraft versions are defined.
- The aircraft operational limits ('envelope'). These are defined in the aircraft Prime Item Development Specification.
- External stores configurations. Operational requirements determine the external stores configurations (including 'downloads', remaining configurations after store separation). Configurations that have been qualified earlier are marked so.
- Store limits. External stores limits may further restrict the aircraft operational limits.
- Usage spectrum. The annual use of an aircraft version in terms of mission types and external stores configurations shall be estimated.

b. Requirements Basis Definition

The RBD contains all airworthiness requirements for a store in general, and it motivates which of these requirements are NOT applicable to the store to be qualified.
One RBD is drafted for the store, based on MIL-HDBK-244A. This RBD is drafted collectively by the airworthiness authority and the store contractor. Main topics are store structural issues, store electrical issues, store mechanical issues, and store environmental issues.
A second RBD is drafted for the combination aircraft-store. Input of the aircraft manufacturer may be required. Main topics are here: aircraft structural strength, aircraft performance, handling qualities, stores separation, and flutter issues.

c. Airworthiness Compliance Plan

The ACP (one for the store, one for the combination) elaborates the plans to demonstrate compliance with the requirements. The requirements are defined in the RBDs, and are supplemented by requirements identified in alternative approaches such as a system safety analysis, software verification/ validation, service history reports of the F-16 with similar stores, or of the store on similar aircraft, and the contractor's company information. The ACP refers to design drawing numbers, report numbers, etc., which form the basis for qualification.

d. Compliance Demonstration

The store contractor carries out the compliance demonstration of the store, and provides the Certification Data Package (relevant design documents, test plans, test results, etc., see Ref. 5) to the airworthiness authority.

The compliance demonstration of the aircraft with store is usually carried out by the operator of the aircraft: the RNLAF, and in cooperation with the store contractor. Disciplines to be addressed are aircraft structural strength and fatigue, aircraft performance and handling qualities, aircraft flutter and LCO, store separation, and aircraft/ store mechanical- and electromagnetic compatibility.

The demonstration takes the following general steps.

1. Identify in the list of external store configurations (including downloads) those configurations that are already qualified. These configurations form the basis for the demonstration.
2. Add stores to the basis configurations and estimate the impact of the added store for the disciplines mentioned above. This can be done by similarity to an already qualified and sufficiently identical store, by computer/ wind tunnel simulation or analysis, or by ground testing.
3. Identify from step 2 the configurations, which may have unwanted behaviors and check the behaviors on the aircraft on the ground or in flight.

Document the above steps.

e. Verification

In this phase it is verified that all design documents, bench-, ground and flight test results comply with the ACPs. Non-compliance is evaluated by the airworthiness authority, and leads to either a re-design of the store or limitations in the operational use of the store, or is waived with a proper motivation. Once compliance to all requirements is verified, the airworthiness authority approves the operational use of the store.

2.3 The role of NLR

The Director of Material of the RNLAF is responsible for the enforcement of aviation laws and regulations within the air force for aerial vehicles. At the start of a qualification program a qualification board for that program is established. External parties, such as NLR, may be tasked to provide manpower, tools and expertise to the program. An external party is accountable for its work to the qualification board.

3 Tools and procedures

The relation between the RNLAF and NLR goes back to the early days of NLR, about 80 years ago. NLR supports the RNLAF in operational aspects, in maintenance aspects and in acquisitions of new systems. Analytical- and test tools have been acquired, either by procurement or by in-house development.

Since the introduction of the F-16 in the Netherlands in 1979, NLR has procured and developed analytical-, ground-, and flight test tools to predict the behavior of this aircraft in terms of flight handling, performance, flutter, strength and fatigue, and external store separation.

This paper describes the tools used during the 'Compliance Demonstration' phase (see section 2.2.2 above). The demonstration of any new external stores configuration proceeds in general as follows.

1. Check if the new configuration can be qualified on basis of similarity. If not, proceed with the next steps.
2. Identify an already qualified configuration, which differs minimally from the new configuration. This is the basis configuration.
3. Investigate by analysis, possibly trend analysis, the impact of the new configuration with respect to the basis, mark critical conditions and check these conditions with earlier experiences.
4. Verify critical conditions in flight by gradually expanding the conditions to the critical values.
5. Establish safe limitations.

In the following subsections the tools and procedures are described in more detail for each discipline.

3.1 Flying qualities

In the late 70s NLR started the development of the Active Control Technology (ACT) computer program package, to acquire a tool to investigate flying qualities. To tailor the program for the F-16 aircraft of the RNLAF, a model of the aircraft’s flight control system has been incorporated, based on block diagrams from the manufacturer’s publications. Under the terms of a cooperation project the manufacturer (at the time General Dynamics) has provided NLR with the aerodynamic data required.

After a process of refinements, updates and additions, NLR now possesses a reliable simulation tool for the F-16 that has proven its value.

The program has been used to evaluate aircraft modifications and aircraft behavior and as a tool for accident investigations and for the safety analysis of display programs for air shows.
The model is used to investigate the sensitivity of the aircraft to a departure from controlled flight in relation to the loading of external stores.

The procedure followed to investigate the flying qualities of the aircraft in terms of resistance to departure proceeds along the following lines.

1. For a number of predetermined maneuvers, known for their potential to initiate a departure from controlled flight or to reveal detrimental flying qualities, the behavior of the aircraft in response to the appropriate control input is simulated. These maneuvers consist of loaded, unloaded and negative-g aileron rolls at high angles of attack, rudder rolls rudder doublets and the so-called low speed recovery.
2. On the basis of predetermined departure criteria, a departure sensitivity rating is given to the different configurations.
3. The configurations are graded according to this rating and the resulting list is compared with experience and test results of more or less similar configurations. The list will be re-arranged if judged necessary.
4. Critical configurations are chosen for further evaluation in flight.

3.2 Flutter/LCO

In general, sufficient data are available to model the F-16 aircraft in aeroelastics calculations, but no scaled wind tunnel model of the aircraft with external stores is available for additional testing, usually because of the high expenses involved. Therefore, if the stores configuration can not be qualified on similarity, store flutter qualification is carried out by a combination of calculations, ground resonance tests and flight tests.

The qualification proceeds along the following lines.

1. Any external stores configuration is subject to a full flutter calculation. This calculation uses an aeroelastic model of the aircraft, mass and inertia data of the external stores, results of ground resonance tests, and a linear aerodynamic model of the aircraft. Downloads are analyzed by changing mass and inertia parameters only, with the advantage that the laborious calculation of air loads needs to be performed only once for each stores configuration. The calculations are carried out for sea level conditions, the worst-case for flutter, at subsonic- and supersonic speeds. If any flutter is predicted, the flutter frequency is calculated.
2. If flutter is predicted close to the transonic speed regime, calculations are repeated with more advanced, non-linear tools. The flutter is either classified as 'classical' or as amplitude limited (Limit Cycle Oscillation, LCO).

3. The safe limits for classical flutter cases are established in flight in the traditional way, using download telemetry of data to safeguard the aircraft from a ground based control room. LCO cases are also further investigated in flight, non-critical LCO usually without telemetry.

3.3 Store separation and weapon scoring

From the early 70s NLR has been involved in store separation analyses to establish or extend store separation release envelopes. The in-house developed (and continuously being improved) tools are the following.

- Test aircraft instrumentation (see also section 3.5 below):
  - high speed 16-mm film cameras installed in camera racks under pylons, installed in a centerline pylon, in a box below a chaff dispenser position (aft fuselage) and in nose and tail positions of modified missile launchers on wing tips,
  - store release moment,
  - aircraft position and attitude reference.
- Ground-based instrumentation such as impact cameras and a laser tracker.
- A database with aircraft aerodynamics and store ejection-, aerodynamic-, and inertia parameters. This database is continuously being expanded with data from current separation programs.
- A store trajectory (position, attitude) reconstruction program using digitized data from the cameras.
- A store separation prediction program using the database.

When the customer asks for clearance of a new store configuration, the first step is to look for similar, already cleared configurations. If no sufficient similarity can be found the process proceeds as follows.

1. If necessary, the database is expanded.
2. Separation trajectories are simulated under various release conditions (speed, altitude, attitude, and load factor).
3. Critical cases are further investigated in flight, starting with conservative release conditions, update the model using the actual trajectory, proceed with less conservative release conditions, update the model, etc. This process is repeated until either the required release conditions are reached safely, or lower limits have been found.

For weapon scoring the aircraft- and ground based instrumentation, which is GPS-time synchronized, is used. The simulation programs can deliver the data required to update the aircraft operational flight program for the particular store.

3.4 Aircraft structure and fatigue

Since the seventies NLR has been active for the RNLAF in the field of static strength and fatigue life calculation for different weapon systems as Northrop NF-5, Lockheed F-104 and General Dynamics F-16. Know how and computer programs for static strength, (Finite Element Model calculation), and fatigue strength, (fatigue life and crack growth calculation), are available and are kept up to date.

With the introduction of the F-16, the Aircraft Structural Integrity Program (ASIP) became part of the RNLAF maintenance of the F-16 fleet. ASIP has been introduced by the United States Air Force and covers all phases of the life of the aircraft from design trough the operational life to the end of the life. Load monitoring and updating maintenance, for example inspection schedules, are important elements of ASIP.

Within the framework of ASIP, static strength finite element models have been designed for some local aircraft areas such as the outer wings, and the engine covers to which the ventral fins are mounted. A full aircraft model however is not yet available at NLR. NLR therefore contracts the aircraft manufacturer, Lockheed Martin Aeronautics Corporation, if static strength calculations of the aircraft are required.

3.5 Test Aircraft and data pre-processing facilities

In 1984 NLR installed a data acquisition system in an F-16A (Ref. 1), which was transferred to an F-16B a few years later, and which has been in service until May 2000. With the introduction of the F-16MLU NLR was tasked to provide a new data acquisition system for that aircraft. The test aircraft became operational in June 1999 (Ref. 3).

The test aircraft instrumentation is well equipped for stores qualifications programs. The following parameters are recorded:

- aircraft position, attitude and time derivatives,
- air data (including angle of attack/ side slip boom),
- aircraft configuration (landing gear position, door positions, fuel state),
- pilot inputs, control surface responses,
- local structural strain and vibration (wings, center section, ventral fins),
- separation parameters (camera's, release discretes).

Parameter samples rates can be programmed or reprogrammed individually, typically between 1 Hz for configuration parameters to 2500 Hz for strain- and vibration measurements.
All data is recorded from engine start before take-off to engine shut down after landing. A measurement run is marked with a unique recording number. The recording medium is a Hi-8 VCR tape.

A personal computer based facility at the test aircraft home base (Leeuwarden Air Force Base) enables post-flight checks on data consistency and quick look analyses of the test results to be carried out.

For further analysis the tape is transferred to the processing station at NLR Amsterdam. This station is under configuration control and delivers data to the performance level as agreed upon by the customer. The station converts the bit stream on the VCR tape to time histories of parameters in engineering units.

4 Airworthiness qualification of infrared- and designation equipment

In 1997 the RNLAF acquired BAE SYSTEMS 'Falcon Owl' forward looking infra red navigation pods (in short: nav pod) and Lockheed Martin 'Enhanced Targeting Pods' (in short: tgt pod) for the F-16MLU aircraft. At the same time NLR was tasked to assist the RNLAF with the airworthiness qualification program.
Although the pods are derivatives of earlier designs, some additional effort was required to prove their airworthiness.
LANTIRN nav and tgt pods have already been certified for several F-16C/D aircraft versions. However, the F-16A/B differs significantly from the F-16C/D in some aspects. This requires a considerable effort to prove the airworthiness of the aircraft in combination with the pods.
In the following subsections the airworthiness qualification process is dealt with.

4.1 Description of equipment

The nav pod is a 2.46 m long by 0.25 m diameter, 125 kg pod, mounted with a short stub wing to the left-hand inlet station of the F-16, see fig. 1. The pod contains an infra red forward looking line scanner and a laser spot locator. The pod will be used for low-level, low light (night, smoke) navigation, and for identification of targets, designated by an airborne or a ground based laser system. The pod sensor information can be showed on one of the cockpit displays.
The nav pod is based on earlier designs, but quite heavily adapted to the RNLAF requirements.
The tgt pod is a 2.50 m long by 0.38 m diameter, 240 kg pod, mounted with a standard F-16 pylon to the right hand inlet station, see fig. 1. The pod contains a laser designator, a small field of view infrared sensor and a day light TV sensor. The pod shall be used to designate targets; the sensors enable positive identification by the crew of the target. The tgt pod is in fact a LANTIRN targeting pod with the day-light TV sensor added.

Operation with either the nav pod ('buddy lasing') or tgt pod, or with both pods, is foreseen. The pods shall enter operational service with the RNLAF at the end of 2000.

4.2 Pod qualification

4.2.1 Nav pod

Since the nav pod was quite heavily modified with respect to earlier designs, the pod had to be considered as a new design from an airworthiness qualification standpoint. Along the procedure as described in section 2.2.2 above the manufacturer has supplied the certification data package of the pod to the RNLAF. Verification of the data has been carried out by NLR. It has resulted in a release for flight testing of a mass model of the pod in September 1999 and a release for operational use of the fully operational pod in August 2000.

4.2.2 Tgt pod

The LANTIRN targeting pod is qualified for carriage on the F-16C/D versions under operational conditions matching or surpassing those defined for the RNLAF-16MLU. Since the difference between the RNLAF version of the tgt pod and the original LANTIRN pod is minimal, airworthiness qualification is largely based on similarity. The tgt pod will be released for operational use by the end of 2000.

4.3 Qualification of the F16MLU with pods

The LANTIRN navigation- and targeting pods have been qualified for use with several F-16C/D versions. However, at the start of the qualification program in 1997 some concern was raised about the compatibility of the F-16MLU aircraft with the nav- and tgt pods for a number of reasons.

1. The aircraft structure of the F-16MLU (updated F-16A/B) differs from the F-16C/D versions. This may restrict the operational use of the F-16A/B compared to the F-16C/D. In particular the allowable aerodynamic- and inertia loads imposed on the aircraft by the pods may be restricted, the service life of the aircraft (components) may be reduced, and the flutter characteristics may be negatively affected.
2. The F-16MLU is equipped with an analog flight control system, the F-16C/D with a digital system.
3. The nav pod has not been qualified earlier for use on the F-16.

Because of these reasons it was decided to enter an airworthiness qualification program to prove the compatibility of the pods with the aircraft. Highlighted in the following subsections is aircraft structural strength- and fatigue issues, the flutter behavior of the aircraft, the flight handling qualities of the aircraft and some store separation issues.

4.3.1 Flying qualities analysis and flight tests

The flying qualities were analyzed according section 3.1 above. The results of this analysis were:

- No re-arrangement of the list was necessary.
- The impact of the pods on the departure sensitivity was minimal within the defined operational envelope of the aircraft (Cat III store loading).

Seven test flights in 'worst case' external store configurations without- and with pods were dedicated to verify the flying qualities characteristics. The results confirmed the analysis and were in general judged 'satisfactory'.
Configurations with substantial asymmetric loads showed unacceptable flying qualities when rolling maneuvers were initiated at negative g (inverted flight). Normally operation under this condition is, however, already excluded in the aircraft's flight manual.

4.3.2 Flutter and LCO analyses and flight tests

The F-16 is well known for its Limit Cycle Oscillation (LCO) behavior, which is considered to be (nonlinear) flutter with non-diverging amplitude, even at constant speed and altitude.
LCO happens almost always when analyses of aircraft/stores configurations indicate flutter (or close to flutter) at transonic speeds (Ma=0.8 to 1.1). Besides being a nuisance to the crew, LCO may result into an aircraft structure fatigue problem.

Because some concern was raised about a possible negative influence of the chin-mounted stores on flutter/LCO behavior of the aircraft, it has been decided to investigate the dynamical structural characteristics as function of the nav/tgt stores configurations.

A number of 'LCO heavy' store configurations were selected and analyzed along the lines in section 3.2. The analysis indeed predicted LCO for the configurations. Six flights in worst case LCO configurations without and with pods were (partly) dedicated to the verification of the analysis results. The flight tests confirmed the analysis results. In particular the negligible impact of the pods on the LCO behavior of the aircraft is shown in figure 2 for two flights, one with pods and one without, in a further identical configuration. In this figure the vibration level of a transducer in the left wing tip launcher, expressed in the effective value of the LCO frequency (about 4.5Hz for this configuration) is plotted against the Mach number.

4.3.3 Store separation analyses and flight tests

Adding pods at the aircraft inlet positions is considered not to have any influence on separation of stores at the outboard wing positions (stations 1, 2, 3, 7, 8, and 9). The pods may have impact on the separation of stores from the inboard wing positions (stations 4 and 6) and the centerline position.

In the required external stores configurations list, non-jettisonable stores are defined for the centerline position and 370 gallon pylon tanks for the station 4 and 6 positions. So, only the separation of the fuel tanks from stations 4 and 6 needed to be evaluated.

Separation limits for tanks on station 6 (with a LANTIRN targeting pod on the right hand inlet station) have been well established for the F-16C/D versions; these separations limits have been cleared on basis of similarity.

The BAE SYSTEMS nav pod, however, is new to the F-16. Analyses of available tank separation reports for several configurations with and without LANTIRN navigation- and targeting pods revealed that the pods did hardly or not effect station 4 or 6 tank separation behavior. Because of this information only two tanks will be dropped, in order to verify that the conclusions are also valid for the new navigation pod.

4.3.4 Structural strength and fatigue

Discussions with Lockheed Martin Aeronautics Company, the manufacturer of the aircraft, revealed possible overloading of the aircraft center section structure and the tail control surfaces due to inlet mounted stores. Since no sufficiently accurate structural models were available at NLR for these areas, Lockheed Martin was subcontracted to analyze the structural loading of the aircraft in the external stores configurations and under the operational conditions as defined at the start of the program. This analysis showed no overload cases.

The F-16 ventral fins may be damaged or separate from the aircraft as a result of oscillatory loads on the fins due to e.g. upstream mounted bodies such as inlet mounted pods. Earlier flight tests with LANTIRN nav and tgt pods did show increased ventral fin excitation levels due to the pods. Although in the MLU program improved fins have been mounted, it was decided to assess the influence of the nav- and tgt pods on the fins.
In the period from September to October 1999, six flights with the test aircraft in external store configurations with and without pods have been dedicated to the ventral fin issue. During each ventral fin flight, slow accelerations from Mach 0.6 to maximum allowable speed, followed by a sudden deceleration (throttle chop) were carried out at various flight levels. The slow accelerations and throttle chops were chosen because from earlier experience it was known that these maneuvers might excite the ventral fins.
During the flights the ventral fins were instrumented with two vibration transducers and three strain gauges each. Also the skin panels, to which the fins are attached, were equipped with two

strain gauges each. The analog signals from the 14 transducers were low-pass filtered at 640Hz and subsequently sampled at 2500 Hz. The filter- and sample frequencies have been based on results of the ventral fin ground vibration tests.

After the flights the data was converted to engineering units, and power spectral density plots were made of the parameters in comparable speed ranges.

Comparison of a configuration with the nav pod to a configuration without the nav pod but otherwise similar showed no significant difference in excitation levels. The slender shape of the nav pod apparently has a minor influence on the structural dynamical behavior of the ventral fins.

Comparison of a configuration with the tgt pod to a configuration without the tgt pod but otherwise similar showed an increase in excitation on all right hand ventral fin- and skin panel transducers by about a factor of two to five in effective value, but only during the slow accelerations. As a consequence the chance of fatigue damage to the ventral fins will increase. The bluff body shape of the tgt pod causes the higher excitation levels.

5 Conclusion

During the long lasting cooperation between the RNLAF and NLR, a unique infrastructure consisting of analytical tools, procedures, test facilities, and skilled people, has been realized to support the RNLAF in their aircraft operations. Airworthiness qualification of external stores to the F-16 fighter aircraft has been highlighted in this paper. A program to prove the safe carriage of engine inlet mounted navigation- and targeting equipment is nearing successful completion.

The RNLAF and NLR are ready to support F-16 operations well into the 21st century.

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Biography

After finishing a study in experimental physics at Amsterdam University (BSc), Sam Storm van Leeuwen was employed by NLR as a flight test instrumentation engineer. He was project leader for the design and integration of instrumentation systems in various vehicles such as a Leopard tank, a P3C Orion aircraft, an RNLAF F-16A fighter (1984) and the Fokker 100 prototype aircraft (1986).
From 1987 to 1996 Sam headed the development group of the flight test instrumentation department. In this period NLR's instrumentation was updated to support the Fokker 70 and Fokker 60 development programs. A major milestone was the design and introduction of a centimeter accurate position reference system based on differential GPS/ inertial integration.
In 1996 he moved to the operations research department to become a flight test engineer. Since then he has worked on integrated electronics warfare and F-16 flight-test support. He currently leads the F-16MLU nav/ tgt airworthiness qualification program.

Major Tjebbe 'Speedy' Haringa heads the F-16 flight test group (also known as Speedy's Flight Test Center) at Leeuwarden Air Force Base in the Netherlands.
He received his pilot training in Canada in 1977 and accumulated the majority of his 3300 flying hours on the Northrop NF-5 (375) and the F-16A/B (2500). From 1990 to 1994 he was flight commander of the 323 Tactical Training, Evaluation and Standardization Squadron, in charge of F-16 flight training, standardization and flying instructor training.
Maj. Haringa received his test pilot training in 1995 at the Empire Test Pilot School. He leaded the selection of nav/ tgt pods for the F-16 MLU and leaded integration- and qualification tests of various stores and avionics systems. He is currently the RNLAF senior F-16 test pilot, and in charge of the integration and qualification testing of nav/ tgt pods, and the assessment of potential candidates for the replacement of the RNLAF F-16 aircraft.

Figures

Figure 1. The F-16MLU test aircraft ('Orange Jumper')

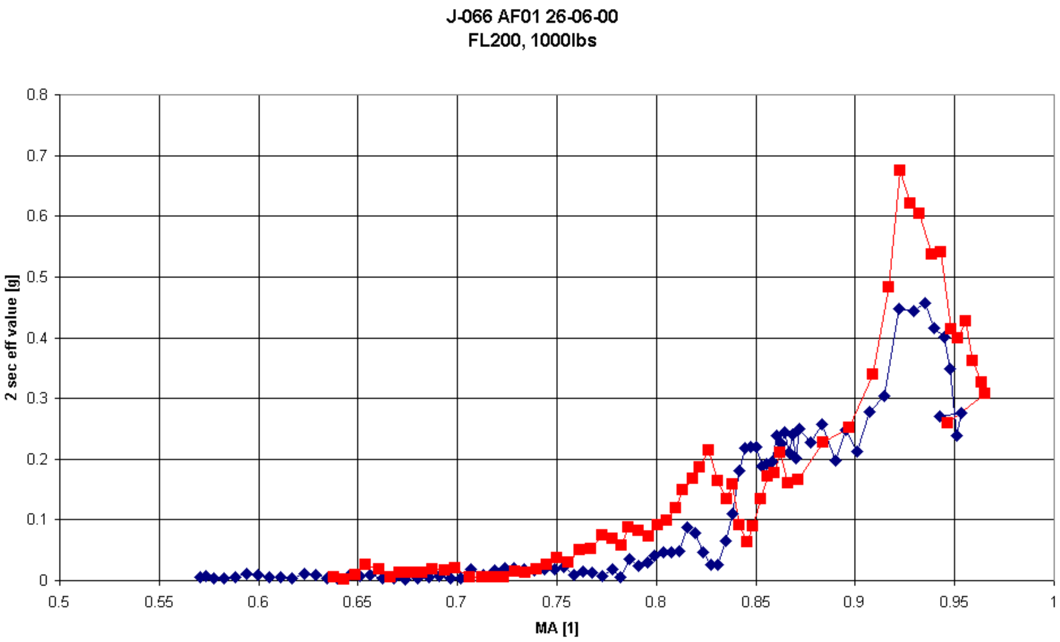
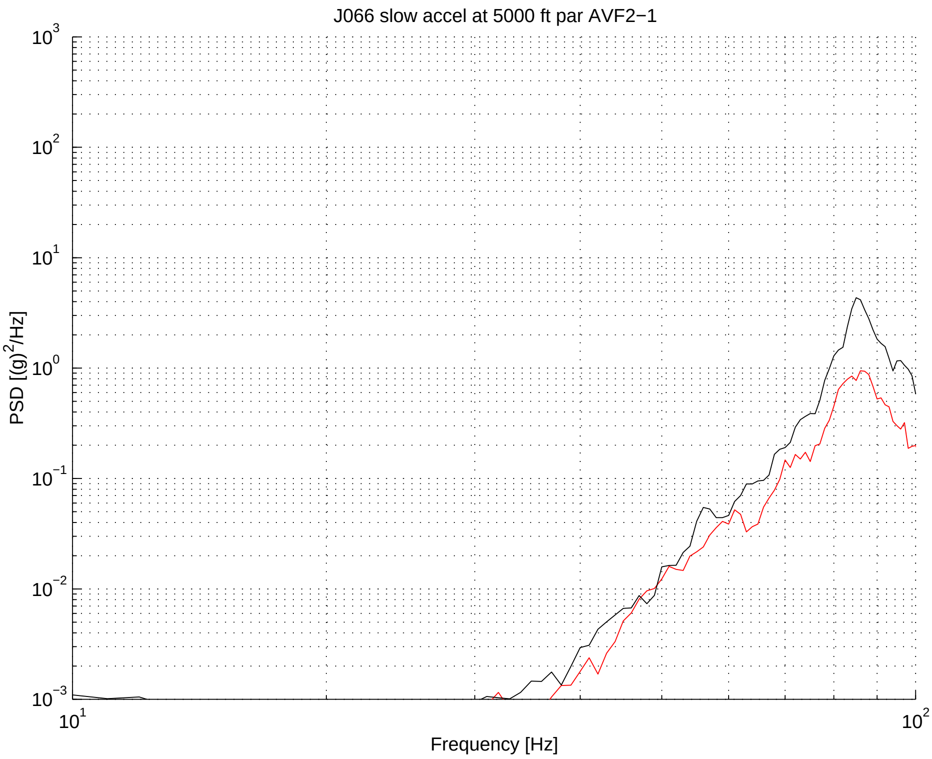


Figure 2. LCO (effective g) level measured at left hand wing tip launcher, with pods (blue) and without pods (red).



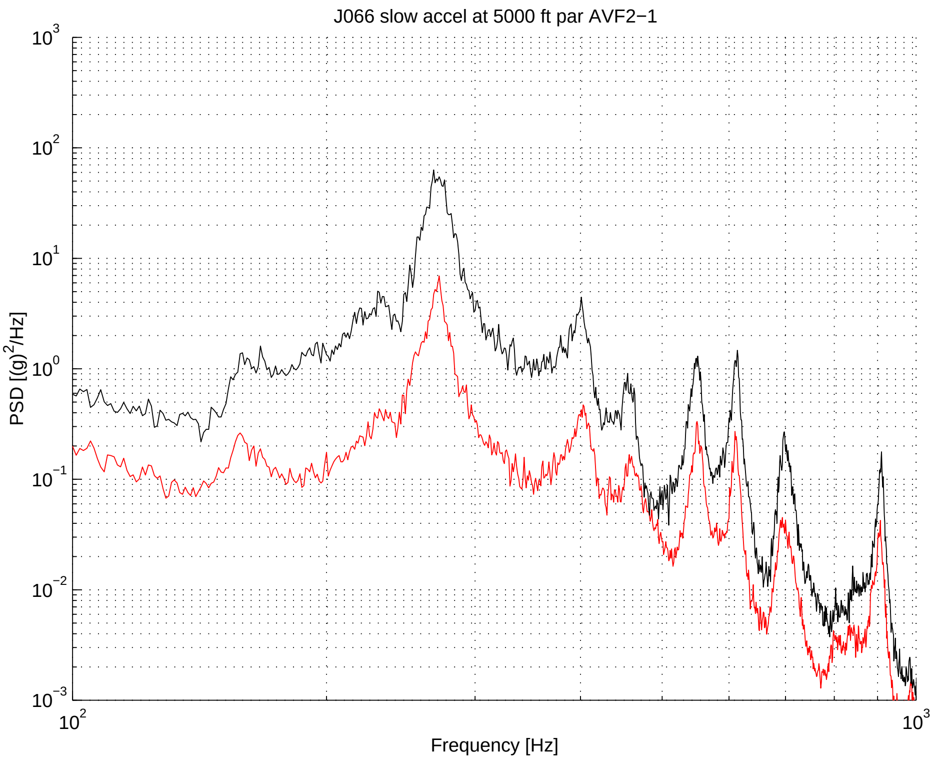


Figure 3. Power Spectral Density plot of right forward ventral fin accelerometer, red: without tgt pod, black: with tgt pod.