Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary

F-16 fighter aircraft flight testing in the Netherlands

Problem area
Flight test programmes within the Royal Netherlands Air Force (RNLAF) are primarily intended to support the RNLAF main objective to provide safe and cost effective Air Power. This paper presents an overview of F-16 fighter aircraft flight testing by the RNLAF, supported by the National Aerospace Laboratory NLR. A description of the different processes will highlight the key elements, from 'flight test demand' to analysing processed flight test data.

Description of work
F-16 fighter aircraft test flights are conducted by the Department 'Operational Research and Evaluation' which is located at the RNLAF head quarters. Test flights are executed by the Flight Test Office that is an integral part of 323 Squadron and operates from Leeuwarden Air Force Base. Test flights are prepared and performed in close cooperation with NLR.

The RNLAF flight test capabilities include store configuration testing, separation testing, flutter testing, system integration testing and it was recently used as technology demonstrator for the next generation fighter aircraft.

Since 1999 the RNLAF operates an instrumented F-16B MLU aircraft, called "Orange Jumper".

Results and conclusions
During the past 35 years an infrastructure has been realized consisting of analytical tools, test facilities including a test aircraft, and skilled and dedicated people.

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

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Author(s)
P. Koks
J.B. Buijs

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F-16 fighter aircraft flight testing in the Netherlands

Nationaal Lucht- en Ruimtevaartlaboratorium, National Aerospace Laboratory NLR

Anthony Fokkerweg 2, 1059 CM Amsterdam,
P.O. Box 90502, 1006 BM Amsterdam, The Netherlands
Telephone +31 20 511 31 13, Fax +31 20 511 32 10, Web site: www.nlr.nl

Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

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F-16 fighter aircraft flight testing in the Netherlands

P. Koks and J.B. Buijs[1]

[1] Royal Netherlands Air Force RNLAF

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Summary

Flight test programmes within the Royal Netherlands Air Force (RNLAF) are primarily intended to support the RNLAF main objective to provide safe and cost effective Air Power. F-16 fighter aircraft test flights are conducted by the Department ‘Operational Research and Evaluation’, which is located at the RNLAF head quarters. Test flights are executed by the Flight Test Office that is an integral part of 323 Squadron and operates from Leeuwarden Air Force Base (AFB). Test flights are prepared and performed in close cooperation with the National Aerospace Laboratory NLR. The RNLAF flight test capabilities include store configuration testing, separation testing, flutter testing, system integration testing and it was recently used as technology demonstrator for the next generation fighter aircraft.

Since 1999 the RNLAF operates the instrumented two seated F-16B Mid Life Update (MLU) aircraft from Leeuwarden AFB. The F-16 is equipped with a data acquisition and recording system, developed, installed and supported by NLR. Besides instrumentation system performance requirements the system also meets the demand of the RNLAF to keep the aircraft, even with the instrumentation system installed, fully mission capable.

In the period of January 2005 until November 2005 the aircraft was modified under the authority of the Defence Materiel Organization (DMO) to M3 standard at Woensdrecht AFB. In this period some major improvements of the instrumentation system were implemented to be prepared for the next decade of flight testing.

Flight test data is presented on the On-board Display at the aft crew station. Using the On-board Display the Flight Test Engineer (FTE) is able to monitor the progress of the test flight. Data recorded during test flights is processed on a ground based system for Quick Look (Q/L) purposes immediately after the flight. Data to be used for further analyses is processed at NLR in Amsterdam. Several specialist disciplines (e.g. Flight Physics, Airworthiness Qualification, Store separations, Structural analyses, etc.) within the NLR organization support the RNLAF in its F-16 operations.

An example of a recent programme was the re-certification of the GBU-10 store for the European Participating Air Forces (EPAF) countries. This paper will present some information about this programme.

To conclude this paper some aspects of F-16 fighter aircraft flight testing in the future will be discussed.

Contents

Abbreviations

AFB	Air Force Base
AFSEO	Air Force Seek Eagle Office
ASHM	Aft Seat HUD Monitor
COTS	Commercial-Off-The-Shelf
DMO	Defence Materiel Organization
DT&E	Development Test & Evaluation
EPAF	European Participating Air Forces
FTE	Flight Test Engineer
GD-AIS	General Dynamics Advanced Information Systems
IRIG	Inter Range Instrumentation Group
KTV	Kantoor Test Vliegen (Dutch abbr.)
LVA	LuchtVaart Afdeling (Dutch abbr.)
MAA	Military Airworthiness Authority
MIDS	Multi-functional Information Distribution System
ML	Wapen der Militaire Luchtvaart (Dutch abbr.)
MLU	Mid Life Update
NLR	National Aerospace Laboratory
OCU	Operational Capability Upgrade
OT&E	Operational Test & Evaluation
PCM	Pulse Code Modulation
PCMCIA	Personal Computer Memory Card International Association
PCU	Programmable Conditioning Unit
PIDS	Pylon Integrated Dispenser System
PMU	Programmable Master Unit
Q/L	Quick Look
RH	Right Hand
RNLAF	Royal Netherlands Air Force
RSP	Recorder Select Panel
SP	Stork SP Aerospace
SPO	System Program Office
STA	Station
TACTESS	Tactical Training and Standardisation Squadron
TMC	Titanium Matrix Composite
T/M	Telemetry

1 Introduction

It is probably not commonly known, but fighter aircraft flight testing in the Netherlands dates back as early as the 1930's. During that period the "Militaire Luchtvaart Afdeling (LVA)", part of the armed forces, was involved in flight testing aircraft such as the Fokker D-21 and Fokker G-1. The LVA later on transformed into the "Wapen der Militaire Luchtvaart (ML)" which is the predecessor of the Royal Netherlands Air Force (RNLAF). From that moment on the RNLAF actively participates in flight testing fighter aircraft in the Netherlands.

Nowadays the RNLAF supports and operates an instrumented F-16B with tail number J-066 from Leeuwarden Air Force Base being a part of 323 Squadron. Flight test programmes are prepared and executed by "Kantoor Test Vliegen" (KTV), the flight test office of the RNLAF. Development, installation and support of the instrumentation system are provided for by the National Aerospace Laboratory NLR.

Figure 1 J-066 "Orange Jumper" ready for flight

Figure 2 Badge of J-066

This paper describes in chapter 2 how the organization involved in flight testing is shaped, how test programmes are managed and indicates how the needs of the RNLAF are met. In chapter 3 some in-depth information is presented about the F-16 test aircraft operated by the RNLAF. Some recent example programmes are highlighted in chapter 4. Finally some future aspects are discussed in chapter 5 and a conclusion is given in chapter 6.

2 F-16 flight testing

F-16 fighter aircraft test flights are conducted by the Department Operational Research and Evaluation which is located at the RNLAF head quarters. Test flights are executed by the Flight Test Office that is an integral part of 323 Tactical Training and Standardisation Squadron

(TACTESS) operating from Leeuwarden Air Force Base (AFB). Test flights are prepared and performed in close cooperation with NLR. The RNLAF flight test capabilities include store configuration testing, store separation testing, flutter testing, system integration testing and it was recently used as technology demonstrator for the next generation fighter aircraft. The RNLAF has one instrumented F-16B MLU aircraft specially equipped for flight testing. It is called “Orange Jumper”. The Orange Jumper is fully mission capable and when not involved in test programmes it is used for normal operations.

2.1 Mission

Flight test programmes within the Royal Netherlands Air Force (RNLAF) are primarily intended to support the RNLAF main objective: safe and cost effective Air Power. The RNLAF is a small Air Force operating 108 F-16’s. Nevertheless the ambition level is high. Operating its own test aircraft is an essential tool in fulfilling that ambition. Operating a test aircraft enables the RNLAF to act independently of the availability of US test capability. This is especially the case for systems and/or configurations not in use by the USAF. This will otherwise lead to unacceptable delays in the implementation and extra high costs. Our flight test capability makes it possible to:

- Clear Dutch specific configurations;
- Test according to Dutch specific requirements;
- Have independent system evaluation and selection;
- Verify COTS systems;
- Execute our own DT&E and OT&E programmes;
- Handle time critical projects when required;
- Support our national research and industry;
- Have test capability available for shared programmes within the European Participating Air Forces (EPAF).

2.2 Organization

F-16 Configuration Management is the responsibility of the weapon system manager within the Defence Materiel Organization Air Systems (DMO Air Systems). The weapon system manager configures the F-16 according to the operational requirements of the Tactical Fighter Branch and has to demonstrate compliance with the applicable airworthiness requirements to the Military Airworthiness Authority (MAA).

Test flights can be initiated by the weapon system manager, the head of the Tactical Fighter Branch and/or by the Military Airworthiness Authority. Those requests are addressed to the head of the Tactical Air Force flight test department. The flight test department is responsible for the management of the flight test programmes on staff level. The flight test department tasks the flight test office to execute the test programme. The F-16 flight test office is located at Leeuwarden AFB.

2.3 Military Airworthiness Authority (MAA)

The MAA is responsible for the enforcement of aviation laws and applicable regulations. Test flights of major modifications and high risk test programmes require MAA approval. For minor modifications and medium and low risk test programmes the responsibility of approval is delegated to the head of the flight test department. When a request for test is received by the flight test department a test directive will be written authorising the required test flight. The directive will be issued after approval of the test plan by the MAA or the head of the flight test department. The test plan will be written by the flight test office. The test plan is based on the compliance plan and contains among other things the risk analyses.

2.4 System qualification

Some programmes, like system qualification, require special expertise and the use of specific tools and simulation facilities. NLR provides knowledge and facilities to support RNLAF during, for instance, system qualification programmes. This kind of support is constantly available and actualized. To be able to handle such large programmes and obtain the support needed, the RNLAF has been working closely together with NLR for the last 35 years. NLR supports the RNLAF in the field of:

- Flying qualities;
- Store separation and weapon scoring;
- Aero elastics;
- Structures and fatigue;
- Avionics.

For large programmes NLR supports the preparation process, writing the requirement definition and airworthiness plan. And in some cases, NLR contributes to the verification phase of the programme. The head of the flight test department has been mandated by the MAA to authorize the execution of test flights with medium of low risk. High risk test flights require authorization by the MAA.

3 F-16 test aircraft

The RNLAF operates an instrumented F-16 test aircraft since 1984. Operations started with an instrumented F-16A, but after only a year it was decided to change aircraft and move the instrumentation to an F-16B. This aircraft with tail number J-653 entered service in 1986 and carried a centralized instrumentation system installed in the ammodrum compartment. Upgrading the F-16 fleet to MLU standard in the 1990’s meant that the service of the, dedicated and non operational, OCU F-16B J-653 test aircraft would end.

Figure 3 J-066 ready for a separation test flight to the “Vliehors” test range

In 1996 the RNLAF decided to replace the OCU test aircraft by an MLU F-16B test aircraft. Upgrading not only the aircraft but also implementing a new state of the art instrumentation system as well. After the modification programme was completed the MLU F-16B test aircraft with tail number J-066 entered service on June 1999 operating from Leeuwarden AFB.

Since 1999 the test aircraft has been updated and modified several times, the last modification being the M3 programme, keeping in touch with the latest developments thus being prepared for the future.

3.1 Flight test instrumentation requirements

The requirements for the new flight test system were derived from the specification of the instrumentation system used in the OCU test aircraft extended to the MLU configuration of the aircraft and using a new state of the art instrumentation system [Ref. 1].

3.1.1 Operational requirements

Most of the operational requirements are based on the years of experience with the former system. The most demanding requirement was that the aircraft, even with the basic instrumentation equipment installed, had to preserve its original operational capabilities.

This requirement meant that the additional equipment and cabling had to be kept to a minimum and that an approach of distributed installation was adopted. This led to creative engineering solutions in order to be able to install the instrumentation components in the aircraft as illustrated in figure 4.

Figure 4 PCU i/f & transformer behind panel 2304

Also the additional cooling requirements for the instrumentation, requiring adaptation of the aircraft environmental control system, had to be avoided. Alterations to the cockpit layout had to be kept to a minimum.

To increase the efficiency of flight testing an on board real time display system for parameters had to be added. With the aid of this information the Flight Test Engineer is able to decide, in an early stage, on how to proceed with the test flight. Therefore the full instrumentation display and control functions had to be present at the aft crew station.

Figure 5 FTE behind the Aft Seat HUD Monitor (ASHM)

For a single pilot flight only the essential controls functions for the instrumentation system have to be provided for at the forward crew station.

Great emphasis was laid upon configuration control and documentation. All changes to the aircraft had to be documented and incorporated in an “Instrumentation manual” and appropriate technical aircraft manuals. And last but not least, the installation of all flight test instrumentation had to be performed in accordance with normal aircraft installation practices and specifications of the manufacturer.

3.1.2 Instrumentation requirements

After the M3 modification programme was completed in 2005, the instrumentation system should be able to meet improved requirements. The most important instrumentation requirements for the system can be summarized to:

a. Input capacity for six dual redundant Mil-Std-1553 multiplexer data busses (further referred to as muxbus). Selections of data to record and display have to be made at time of system set-up.
b. Recording of 1553 muxbus data in such format that exchange of data with the Lockheed flight test facilities at Edwards AFB will be possible.
c. A real-time data display system which must be able to present in-flight sets of data, by means of selectable table pages, user pages, caution pages and plots (two time traces with a maximum of four parameters).
d. Due to the expected increase of the required number of parameters in the future the maximum data throughput rate of the system has to be at least 5 Mbit/s.
e. The system has to be easy to reconfigure and expansion of the system by adding additional remote units (e.g. installed in Alternate Mission Equipment) should be incorporated in the design.
f. Recorded parameters: the recorded parameters can be divided into a basic set of parameters, which will be recorded during every test flight and specific project related parameters.
g. Expanded provisions for the telemetry system installed.

3.2 Instrumentation system architecture

Based on the requirements in the previous paragraphs a top level block diagram of the basic instrumentation system is presented in figure 6 showing the single recorder PCM/audio configuration.

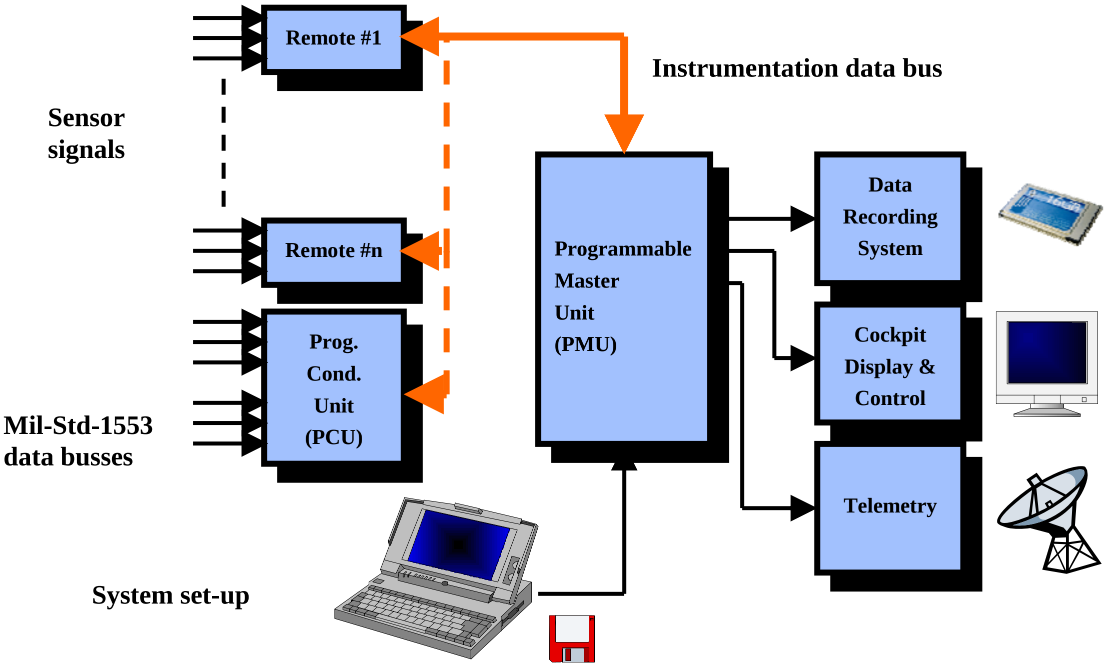

Figure 6 Schematic overview of the Instrumentation System (single recorder PCM/Audio configuration)

The requirement for easy reconfiguration and expansion of the system seemed to be in contradiction with the requirement to keep the additional equipment and cabling to a minimum. However, by choosing a modular distributed system concept, based on an instrumentation data bus combining a daisy-chain/star configuration, both requirements could be met. In addition this concept allows the installation of equipment in small locally available spaces rather than having to make one large space available for a centrally installed system. Two examples of installed equipment are shown in figures 7 and 8.

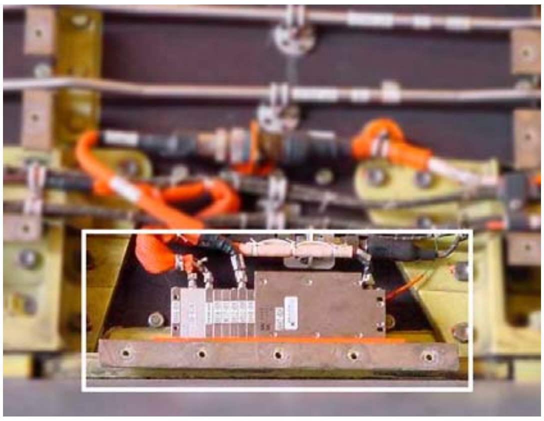

Figure 7 Remote unit at RH side of vertical tail

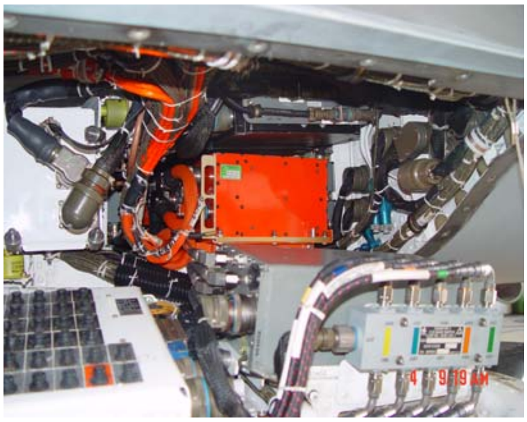

Figure 8 PMU in Aft avionics compartment

The signals to be measured are conditioned, sampled and digitised by remote data acquisition units. One special remote unit ‘the Programmable Conditioning Unit (PCU)’ also acquires data from three selected 1553 muxbusses. A Programmable Master Unit (PMU) controls these units via an instrumentation data bus. The data is formatted into three independently configurable PCM data streams, which are distributed to respectively a Cockpit Display & Control System, a Recording System and optionally a Telemetry System. The system is programmed by means of special set-up software, which runs on a standard (laptop) PC, connected via a serial port to the PMU.

Besides the basic instrumentation the system can be expanded with several sub-systems such as high speed cameras and a video system. High-speed cameras can be mounted, e.g. for store separation trials. As shown in figure 3. The cameras are controlled by the Display & Control System via a separate communication data bus.

3.3 Data processing

To be able to process solid state data efficiently the outdated Vusoft quick look data processing system to be used on location (e.g. AFB Leeuwarden) is replaced with a new system based on Omega series 3000 equipment from GD-AIS/ Wyle labs. This system is selected to be the general data processing system for the next future at NLR and will replace all current data processing systems.

To be ready for the future it has been decided to adopt the IRIG-106 chapter 10 format for recording and processing PCM data as well as 1553 data.

3.4 M3 modification

The test aircraft entered the M3 modification programme in January 2005. This programme was completed late 2005 when the aircraft was returned to 323 Squadron. Besides improvement of the aircraft also improvements of the instrumentation system were implemented. The major improvements are highlighted.

Figure 9 J-066 returned to Leeuwarden AFB at the end of 2005

1) Instead of having to change between the single deck V80 (PCM) and the triple deck V83 (PCM + Muxbus data) tape recorder configuration, depending on the test flight requirements, the flight test instrumentation system is permanently equipped with four solid state data recorders located in the RH console of the aft crew station. Data will be recorded on 4 Gb PCMCIA memory cartridges. Each recorder can carry two PCMCIA cards.

The first recorder records the instrumentation PCM data and intercom signal. In the PCM data stream a selection of Amux, CLmux and Dmux data is standard incorporated. The three dual redundant 1553 data recorders are used for respectively Amux & Bmux, CLmux & CRmux and Dmux & Fmux bus signals and have an IRIG-B interface to synchronize the recorded data. A Recorder Select Panel (RSP) is added to be able to switch between PCM only and PCM & 1553 data recording configuration.

An important benefit of using solid state recorders is that it will permit us to allow higher bit rates when designing data formats for the PMU then the 2Mbit/s limit for the V80/Merlin tape recorder system. The solid state data recorder can be used up to 8Mbit/s.

2) Telemetry (T/M) provisions.
We expand the provisions for using telemetry as far as the aircraft system is concerned. This means that additional antenna cables (for lower and upper T/M antenna) and additional PCM data wiring is installed. A station 5 centre line adapter will be modified to accommodate the T/M transmitters.

3.5 Project related instrumentation requirements

Instrumentation requirements are an integral part of the project description. When adaptation of the system is necessary to accommodate the project requirements, NLR is responsible to deliver the engineering package for the modification. This engineering package will be assesses and authorized by the RNLAF. Approval is needed before manufacturing can start.
Installation of the adaptation to the system in the aircraft will be performed by the RNLAF. Re-programming and system integration tests will be performed by NLR and RNLAF.

If needed, an instrumentation check-out flight will be part of the system integration tests.

3.6 Instrumentation system expansion and innovations

Some adaptations of the instrumentation system are foreseen in the near future of which the most important are listed below:

- The system will be equipped with an additional Multi-functional Information Distribution System (MIDS) flight recorder located in the aft crew station;
- The on-board data display software functionality will be expanded;
- The telemetry system will be made operational;
- Under investigation is the use of digital high speed video technology for store separation trials.

4 Recent programmes

This chapter describes two recent programmes to demonstrate some of the capabilities available within the RNLAF and NLR. The first example programme describes the re-certification of a weapon and the second example describes a technology demonstration programme.

4.1 Re-certification GBU-10/ PIDS

The GBU 10 mounted on a PIDS pylon has been certified by Air Force Seek Eagle Office (AFSEO), until several incidents were reported on cracks in the tail section of the GBU 10.

Together with AFSEO and NLR, a program was initiated to evaluate this problem. AFSEO was responsible for test plan, data analyses and final certification. NLR designed and provided the required additional instrumentation, consisting of accelerometers on the upper fins of the GBU tail section and a Programmable Conditioning Unit (PCU) installed in the PIDS pylon. The additional PCU was integrated with the existing instrumentation system of the Orange Jumper.

Figure 10 Instrumented GBU10 mounted under PIDS at STA3&7

The RNLAF approved the AFSEO test plan and executed the test accordingly. After each flight quick look analyses were performed to identify the correlation between high vibration levels in the tail and transonic Mach numbers. After being exposed to those vibration levels for a certain time, cracks were observed. The configurations could be re-certified with the limitation to minimise operation in the transonic region and inform the manufacturer of these findings in order to improve the design of the GBU-10 tail assembly.

4.2 Technology demonstration: Titanium Matrix Composite Drag Brace

One of the products manufactured by Stork SP Aerospace (SP) is the landing gear of the F-16. Striving for better solutions SP developed in close cooperation with NLR the technology of metal matrix composites. The technology for manufacturing primary structural parts of metal matrix composite had reached the level of maturity that it could be demonstrated in flight.

SP requested the RNLAF to participate in a technology demonstrator programme to verify a Titanium Matrix Composite (TMC) lower drag brace. The RNLAF agreed to participate being interested in the data on the dynamic behaviour of the gear. To reach the flight clearance an extensive test program was executed at SP’s test facility near Eindhoven, to test dynamic behaviour, strength, fatigue and failure modes of the component. After the tests were successfully completed, RNLAF verified the SP qualification procedure and provided the flight test clearance.

NLR was contracted to design and realise the additional required instrumentation. Both sides of the main landing gear were instrumented with strain gauges and accelerometers, including the down link toggle, to compare dynamic behaviour between normal and TMC drag brace. A Programmable Conditioning Unit (PCU) was installed in a special manufactured nose section for a centre line adapter.

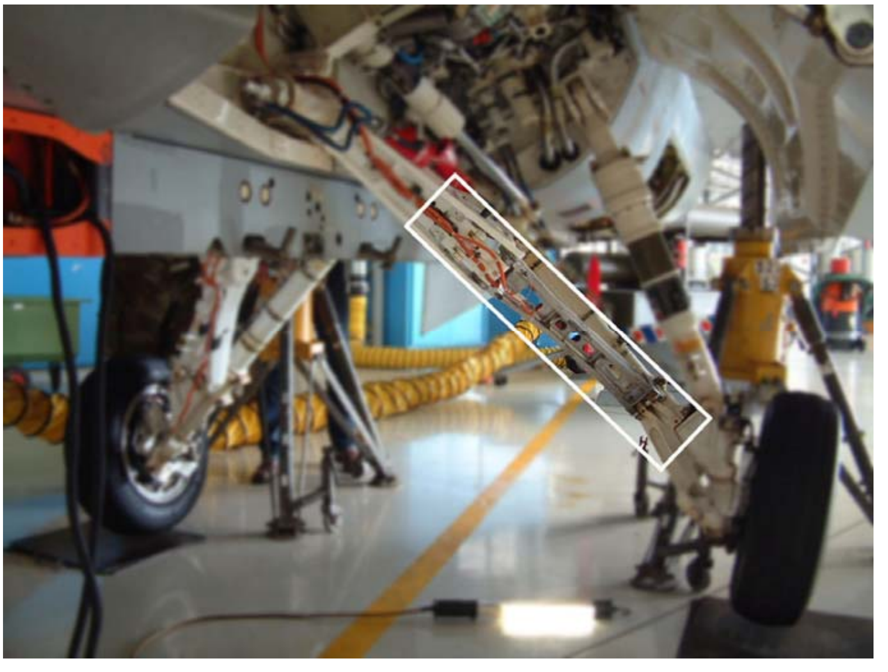

Figure 11 Instrumented landing gear, left lower drag brace is TMC (in the box)

Abort criteria were established in close cooperation between SP engineers and the Flight Test Engineer. The actual flight test started with several taxi tests, gradually increasing taxi speed and brake application. Data analysis showed no unusual dynamic effects and loads.
During the test flight the same build up approach was used, gradually increasing vertical landing speed (and thereby loads). In total six landings were made, ranging from very soft to very hard. In all cases both the loads and dynamic behaviour of the drag brace was as expected giving SP the world's first flight of a primary structural landing gear component manufactured in Titanium Matrix Composite.

5 F-16 flight testing in the future

F-16 operations have to be supported until a successor aircraft has entered service with the RNLAF. Operational demands and technical developments will require the continuing support of the F-16 flight test capability until the end of service. The number of test programmes is expected to maintain at the current level and maybe an increase in programmes might be realistic. With the telemetry system operational new areas of testing will be explored in the very near future.

6 Conclusion

During the past 35 years an infrastructure has been realized consisting of analytical tools, test facilities including a test aircraft, and skilled and dedicated people. RNLAF and NLR are ready to support F-16 operations well into the 21st century.

7 References

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Acknowledgement:
The photograph in figure 11 is used by courtesy of Stork SP Aerospace.

Appendix A Authors biography

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 he joined NLR in 1986 as a flight test instrumentation engineer at the Flight Test Systems & Applications Department of the Aerospace Systems & Applications 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 team leader during the Fokker 70 certification. In his most recent position he was responsible for the mechanical design and installation of the F-16 MLU flight test instrumentation for the RNLAF and is project manager for the follow-on support. In the past he presented papers about flight test instrumentation at symposia of the SFTE (2001).

Bernard (Bernie) Buijs holds an MSc in Aeronautical Engineering from Delft University of Technology. After graduation in 1996, Bernie joined the RNLAF as a ground school instructor at the Initial Pilot training squadron. Bernie used this period to extend his operational knowledge on aviation and concluded this with a Commercial Pilot Licence. After two years the opportunity came to join the flight test department were he was mainly working on transport helicopters. In 2002 Bernie was given the opportunity to attend the FTE fixed wing course at Empire Test Pilot School (ETPS) in Boscombe Down. After graduation Bernie was, and still is, stationed at the F-16 flight test office at Leeuwarden AFB in the position of Flight Test Engineer.