DOCUMENT CONTROL SHEET

	ORIGINATOR'S REF.		SECURITY CLASS.
	NLR-TP-2000-362		Unclassified

ORGINATOR
National Aerospace Laboratory NLR, Amsterdam, The Netherlands

TITLE
New flight test instrumentation for the RNLAF F-16 MLU aircraft

PRESENTED AT:
the Society of Flight Test Engineers 31st Annual Symposium, Turin, Italy, 19-22 September 2000

AUTHORS	DATE	pp	ref
J.M. Klijn, P. Koks and G.J. Kobus* * Royal Netherlands Air Force (RNLAF)	November 2000	13	2

ABSTRACT

Since 1984 an F-16 aircraft of the Royal Netherlands Air Force (RNLAF) has been equipped with a data acquisition and recording system, developed and installed by NLR. With the introduction of the Mid-Life Update (MLU) programme for the F-16, which consists mainly of a major upgrade of the avionics, the current instrumentation system was no longer able to fulfil its tasks. In December 1997 the RNLAF awarded NLR a contract to develop and install a new system in an F-16B MLU aircraft.

Besides the required expansion of the system capacity, a number of functional and operational improvements were added. The most significant improvements were the addition of an on-board presentation of measurement data and the introduction of a so-called instrumentation databus, which reduced the amount of flight test cabling. The system meets the requirement of the RNLAF to keep the aircraft, even with the instrumentation installed, fully available for its operational tasks.

In the period of September 1998 until June 1999 the system was installed in an F-16 aircraft at Woensdrecht Air Force Base in close co-operation with the RNLAF. The instrumented aircraft successfully made its first flight on June 4. A few days later it was ferried to Leeuwarden Air Force Base to serve for both the normal operational tasks and test flights conducted by the Flight Test Office of the 323 squadron.

In this paper an overview will be given of the requirements for the new system. A description of the system will highlight the key characteristics. Finally some future developments will be discussed.

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

NLR-TP-2000-362

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J.M. Klijn, P. Koks and G.J. Kobus*

* *Royal Netherlands Air Force (RNLAF)*

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Division: Avionics
Issued: November 2000
Classification of title: unclassified

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(13 pages in total)

NEW FLIGHT TEST INSTRUMENTATION FOR THE RNLAF F-16 MLU AIRCRAFT

J.M. Klijn and P. Koks
National Aerospace Laboratory NLR
Amsterdam, The Netherlands

G.J. Kobus
Royal Netherlands Air Force
The Hague, The Netherlands

Abstract

Since 1984 an F-16 aircraft of the Royal Netherlands Air Force (RNLAF) has been equipped with a data acquisition and recording system, developed and installed by NLR. With the introduction of the Mid-Life Update (MLU) programme for the F-16, which consists mainly of a major upgrade of the avionics, the current instrumentation system was no longer able to fulfil its tasks. In December 1997 the RNLAF awarded NLR a contract to develop and install a new system in an F-16B MLU aircraft.

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In this paper an overview will be given of the requirements for the new system. A description of the system will highlight the key characteristics. Finally some future developments will be discussed.

Figure 1. The F-16B MLU J-066 “Orange Jumper” test aircraft.

Introduction

In 1983 the Royal Netherlands Air Force (RNLAF) awarded a contract to the Netherlands National Aerospace Laboratory (NLR) to design, build and install a flight test instrumentation system in one of their F-16 aircraft. The system had to be used for operational test flights and flight tests with a technical objective. The first type consists mainly of flights for mission training where recording of data may improve tactics or the quality of a system. The second type consists of flights mainly related to a special programme, e.g. certification of new stores or technical evaluation of new or modified aircraft systems.

In 1984 the instrumentation was installed in a single-seat F-16A aircraft. Shortly hereafter a dual-seat F-16B aircraft was modified to allow the installation of the instrumentation package in this aircraft as well. In 1987 the RNLAF decided to bring the F-16A aircraft back to standard and to modify a second F-16B instead.

The F-16 aircraft are planned to be operational until 2020. Therefore several modification programmes have to be executed. One of these is the Mid-Life Update (MLU) programme started in the beginning of 1998 and expected to be completed in 2001. Since the avionics of the F-16 MLU are extended significantly, with four instead of one Mil-Std-1553 avionics data buses, the RNLAF awarded NLR in December 1997 a contract to develop and install a new modern instrumentation package in one of their F-16B MLU aircraft.

Requirements

Functional requirements

The functional requirements for the new system are comparable with the specifications of the older system, described in [Ref. 1], with the following major extensions:

- Input capacity for four dual redundant Mil-Std-1553 multiplexer databuses (further referred to as muxbus). Selections of data to record and display have to be made at time of system set-up.
- Recording of all data communication via these buses in such format that exchange of data with the Lockheed flight test facilities at Edwards AFB will be possible.
- Due to the expected increase of the required number of parameters the maximum data throughput rate of the system has to be at least 5 Mbit/s.
- A real-time data display which must be able to present in-flight selectable sets of plots of at least four parameters.

Recorded parameters

The recorded parameters can be divided into a basic set of parameters, which will be recorded during every test flight and flight test programme related parameters. The basic set of parameters mainly consists of:

- *Configuration*: landing gear up and weight on wheels;
- *Position*: latitude, longitude and altitude;
- *Attitude*: angle of pitch, angle of roll and heading;
- *Control*: control surface deflections, throttle position, stick forces and rudder pedal force;
- *Angular rates and accelerations*: pitch, roll and yaw rates and acceleration in x-, y- and z-direction.

The sample rates of these parameters vary from 16 to 256 samples per second. The signals to be measured stem from either one of the aircraft muxbuses or the transducers of the former Flight Loads Recorder System (FLRS), which is not a part of the MLU aircraft configuration anymore.

Examples of flight test programme related parameters are:

- *Limit cycle oscillation and flutter trials*: accelerations at the wing tips, tail section and pilot's seat;
- *Store separation trials*: store release commands and camera running signals;
- *Structural load measurements*: strain gages and accelerations on parts of the airframe;

- *Flight handling characteristics and in-flight performance*: besides the standard configuration and attitude parameters the angle of attack and angle of side slip.

Most of these are high-dynamic parameters with a sample rate of at least 256 samples per second. The signals to be measured stem from specially installed transducers, e.g. accelerometers and an angle of attack and side slip nose boom.

Figure 2. Angle of attack and side slip nose boom.

Operational requirements
Most of the operational requirements are based on the twelve 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.

The removal of the gun and ammodrum, necessary for installation of the old system, was not allowed anymore. Also the additional cooling requirements for the instrumentation, requiring adaptation of the aircraft environmental control system, had to be avoided. Adaptations to the cockpit layout had to be kept to a minimum.

To increase the efficiency of flight testing an in-flight presentation of parameters had to be added. With this information the flight test engineer is able to decide in an early stage on how to proceed the test.

At the aft crew station the full instrumentation display and control functions have to be present. Mainly due to lack of space only the essential functions for a single pilot flight have to be provided at the forward crew station.

Other requirements
Great emphasis was laid upon configuration control and documentation. All changes to the aircraft had to be documented in separate drawing sets and incorporated in technical manuals.

The installation of all flight test instrumentation had to be performed in accordance with normal aircraft installation practices and specifications of the manufacturer.

The first scheduled flight tests with the F-16 MLU, the certification of a navigation and targeting pod, were foreseen in June 1999. The availability of only one and a half year for design, manufacturing and installation of the system influenced the choices for the realisation of the system. In general long term development had to be avoided and commercially available equipment had to be applied as much as possible.

Project realisation

Involved parties
The system requirements were not only defined by the RNLAF, but also by the Operational Research department of NLR's Flight Division. The Instrumentation Department of the Avionics Division of NLR designed the system.

The RNLAF actively participated in the project, especially in the design and installation of aircraft modifications, additional brackets and wiring.

Most of the equipment was purchased from external suppliers such as the data acquisition equipment from Aydin Vector Division and the recording equipment from Merlin/TEAC. In-house developments were necessary for the cockpit control system and the software for the cockpit display.

Planning
At the time of contract award in December 1997 a well defined pre-design [Ref. 2] was already prepared. This made it possible to design, manufacture and test the system, before installation, in less than one year. The modification of the aircraft started in September 1998 at Woensdrecht AFB, and was followed by the installation of the system in the beginning of 1999. After ground tests of the aircraft with the installed system a first flight with the new instrumentation was made on June 4, 1999. Because no serious problems were encountered no further flights were necessary. The aircraft was ferried a few days later to Leeuwarden AFB where it was put into use for both its operational tasks and test flights.

Figure 3. Check-out of the J-066 “Orange Jumper” test aircraft.

In the second half of 1999 the system was finalised and documentation was completed. In May 2000 the old system was put out of use.

Resources
The project required approximately nine man-years, mostly of engineers and technicians. Equipment was bought for an amount of approximately $ 750,000. Besides the effort of NLR the RNLAF contributed five man-years especially with regard to the modification of the aircraft and the documentation.

Electrical design

System lay-out
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, both requirements could be met.

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. In the latter case the required removal of standard aircraft parts would be conflicting with the requirement to keep the aircraft fully operational.

Figure 4 depicts the top-level block diagram of the system. The signals to be measured are conditioned, sampled and digitised by remote data acquisition units. A Programmable Master Unit (PMU) controls these units via an instrumentation data bus. The PMU also acquires the data from the four muxbuses. The data is formatted into three independently configurable PCM data streams, which are distributed to respectively a Cockpit Display and Control System, a Recording System and optionally a Telemetry System.

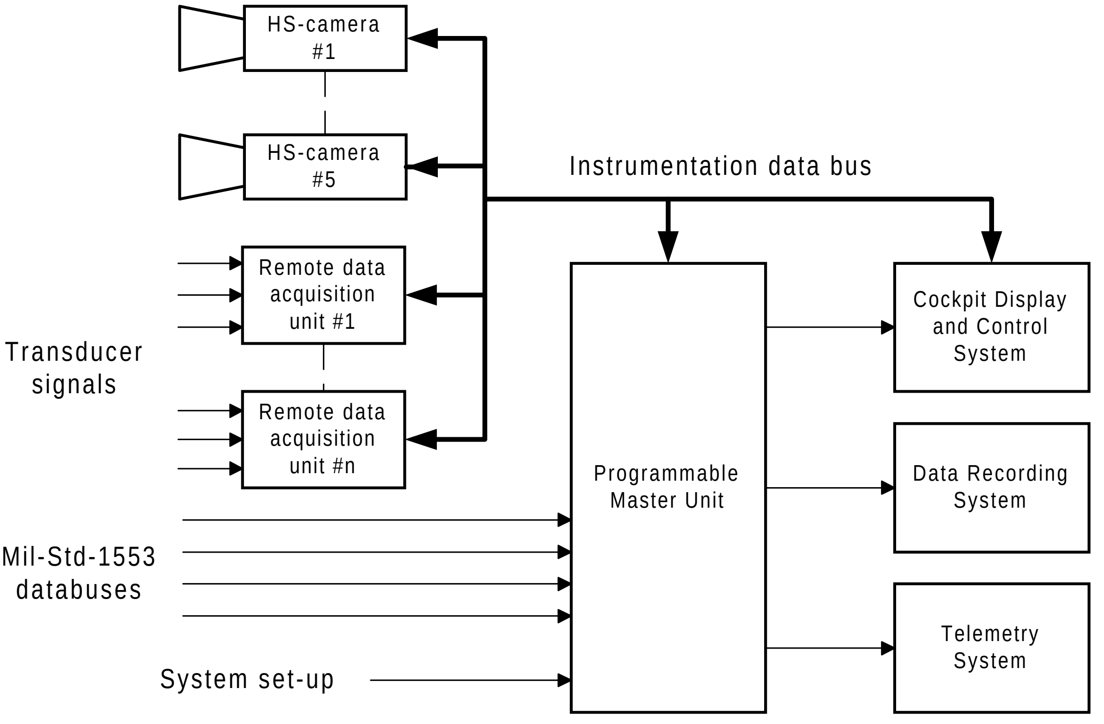

Figure 4. Block diagram of the instrumentation.

High-speed cameras can be mounted to aircraft, e.g. for store separation trials. The cameras are controlled by the Display and Control System via the instrumentation data bus.

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.

Data acquisition system

The components for the data acquisition system consist of:

- Programmable Master Unit PMU-700 series III; this unit controls the system, acquires the data from the remote data acquisition units and muxbuses and formats these into PCM data streams. This unit is capable of performing calculations, e.g. engineering unit conversion, and adding the results to the PCM data stream.
- Programmable Conditioner/Encoder Unit PCU-800 series I; these units are used as remote data acquisition unit at places were enough space is available to mount a relatively large unit.
- Micro Miniature Signal Conditioner MMSC-800; this unit is significantly smaller (and more expensive) than the PCU and is used at places where space is limited.

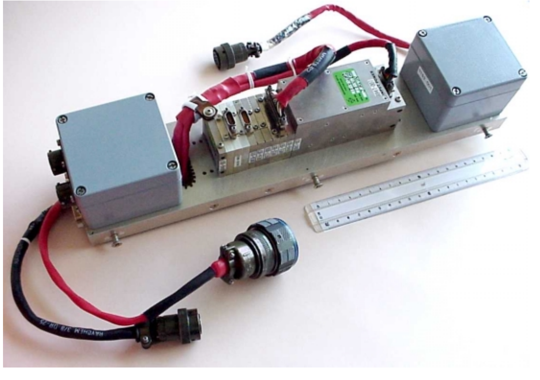

Figure 5. Micro Miniature Signal Conditioner with two camera interfaces mounted on a bracket for installation in the wing tip launcher.

The above units communicate via the Aydin Vector's proprietary command/respond data bus, the so-called 10-Wire Interface (10-WIF). This data bus is extended with five extra wires to control the cameras via an RS-422 connection and three wires for power supply of the remote data acquisition units. The wires are bundled in a specially manufactured cable, which is routed through the aircraft. At specified locations connections to this bus are provided.

The maximum throughput rate of the data acquisition system is 24 Mbit/s. The word size used is 16 bits. The resolution of the analog to digital conversion is 12 bits and the overall system accuracy is better than 0.5% of full scale.

Recording system
The basic configuration of the recording system consists of a Merlin ME-981 data to video encoder and a TEAC V-80 Hi-8 airborne videocassette recorder. Currently the system is capable of recording the PCM data from the PMU up to 2.2 Mbit/s. In addition the cockpit voice signal is recorded on the audio track of the tape.

To meet the requirement of exchanging data with Edwards AFB, the system can be expanded by replacing the V-80 by a triple-deck version, the V-83 and adding two Merlin ME-981 encoders with dual muxbus interfaces. On the extra two decks the four muxbuses are recorded. On the audio track an IRIG-B time code signal from the PMU is recorded.

Real-time display and system control
The data from the PMU can be visualised on an Instrumentation Display Panel (IDP) at the aft crew station of the cockpit. This display is mounted in a modified Aft Seat HUD Monitor (ASHM) console. In this console also the Cockpit Electronics Unit, which processes the data to be displayed, and the Instrumentation Selection Panel, which is the user interface to the system, are mounted.

Four predefined screens with plots of maximum four traces of parameters can be selected. The test pilot in the forward seat can select the image of the IDP on his right-hand Multi-Function Display.

Common control functions like instrumentation power switching, starting the recorder and event markers are available at panels both at the forward and aft crew station.

Figure 6. Aft seat HUD monitor console with instrumentation display.

Camera system
The camera system is used to record the separation trajectory of an external store. For this purpose maximum five high-speed cameras can be selected independently on a camera selection panel in the aft cockpit. If the camera run signal is initiated on the aft instrumentation panel the selected cameras will run with a pre-set speed of 16 to 200 frames per second.

On the edge of the film the store release signals and a time reference are recorded. For synchronisation with the other data the store release signals are also recorded by the data acquisition system.

The cameras can be connected via a special camera interface to any of the connectors of the instrumentation data bus.

Usual locations to mount the cameras are a modified tip launcher (either mounted at the right hand or left hand wing), a modified centreline pylon or in the right hand chaff/flare dispenser at the tail of the aircraft.

Telemetry system
One of the PCM outputs of the PMU is reserved for transmission to a ground station via a telemetry downlink. The cockpit instrumentation control panels provide for switching the power to the telemetry transmitters.

The telemetry transmitters and antennas can be installed whenever required by the flight test program.

Mechanical design and installation

Design procedure
In close co-operation with the Maintenance Engineering Department (DME) of the RNLAF a survey at the aircraft was made for possible locations to install the extra equipment. Based on the conclusions NLR made a preliminary design, which was reviewed with DME. The final design was authorised by the RNLAF. For some modifications to the aircraft structure authorisation from Lockheed was obtained.

System locations
The most challenging task was to meet the requirement to keep the aircraft fully operational. Removal of aircraft equipment to create the necessary space was not allowed. Although in some cases considerable modifications to the aircraft had to be made, installation of the equipment was accomplished fully meeting the requirements. The result is illustrated in figure 7.

The PMU was located in the aft avionics compartment after relocation of an existing aircraft system. In addition some minor alterations of the cable routing were necessary.

A PCU, necessary to measure most of the standard analog signals, is mounted at the right-hand side of the fuselage behind an

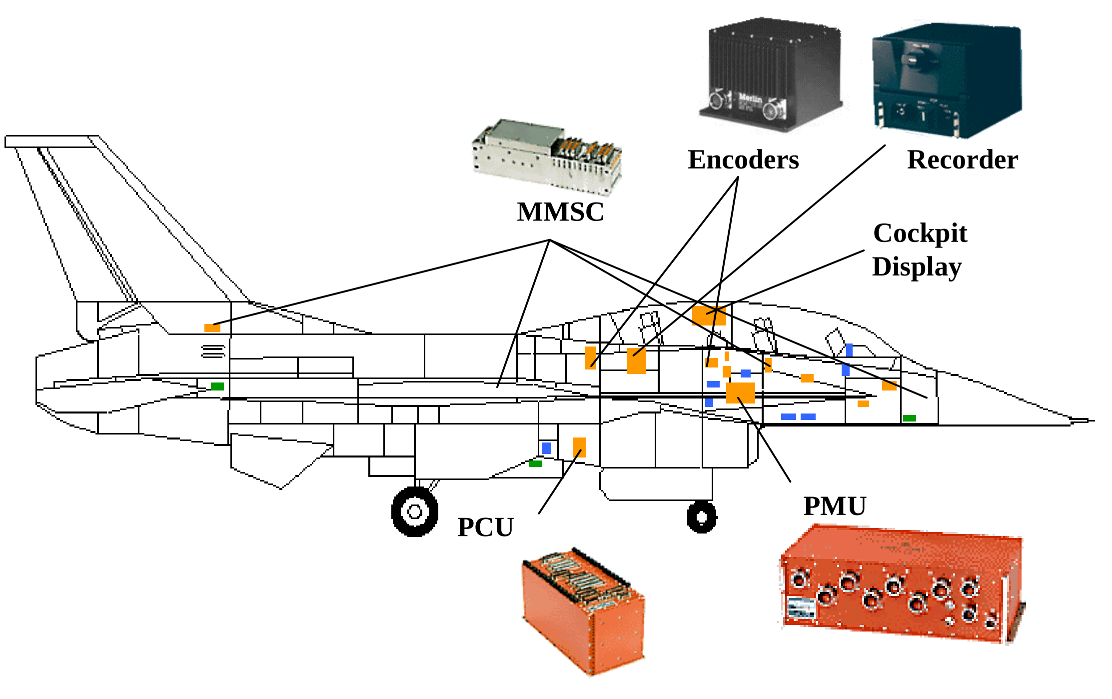

Figure 7. Major locations of installed flight test instrumentation equipment.

access panel. A tailor-made PCU tray replaces an existing empty bracket. During fitting of this bracket modification of the above-located bracket of the gun control unit turned out to be necessary.

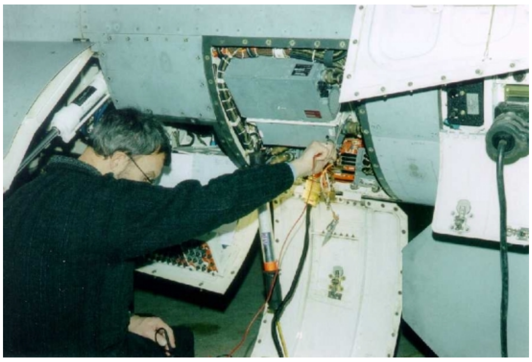

Figure 8. Servicing the PCU.

At different locations MMSCs are installed:

1. *Vertical tail*: a MMSC to measure accelerations in the tail is mounted on the support dorsal fairing at the right-hand side of the vertical tail, accessible via an inspection panel.
2. *Cockpit*: a MMSC to measure the accelerations at the pilot's seat and several discrete control signals is mounted on top of a fairing in the forward crew station.
3. *Forward avionics compartment*: a MMSC to measure the stick forces and angle of attack and side slip is mounted at an unused location on an existing mounting frame, accessible via a panel.
4. *Wing tip*: two AMRAAM tip launchers are equipped with a MMSC to measure the wing tip accelerations.

In order to facilitate the use of either a single or triple deck recorder three Merlin encoders had to be installed in the aircraft. The encoder for the single deck configuration is mounted on the left-hand side of the aft crew station. The two additional encoders for the triple deck configuration are installed in the ammodrum compartment.

The recorder is located in the right-hand console of the aft crew station, easily accessible for the flight test engineer. The existing cockpit panels of this console were rearranged and the lining of the side panel was modified.

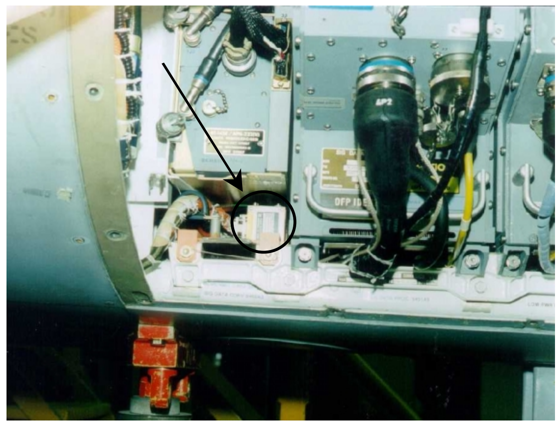

Figure 9. MMSC in the forward avionics compartment.

Instrumentation data bus routing
The instrumentation data bus is routed from the PMU as a star point in five branches through the aircraft. At every branch several connections to the bus are provided.

Two branches are routed symmetrical to the left-hand and right-hand wing. Connectors are provided at the four weapon stations at each wing.
The third branch is routed to the nose section of the aircraft and connects the MMSC in the forward avionics compartment.

The fourth branch is routed via the fuselage stations at the left and right side of the air intake and ends at the MMSC in the cockpit.

The last branch is routed to the tail section and connects the PCU and the MMSC in the tail. Connectors are also provided at the centreline weapon station and the right-hand chaff/flare dispenser position.

Aircraft interfaces and modifications
Installation of flight test instrumentation requires interfacing with existing aircraft systems and in some cases modification of these systems. Major changes will be highlighted below:

- To create enough space for the PMU in the aft avionics compartment a Flight Monitor Unit (FMU) had to be relocated to the ammodrum compartment. Together with the installation of the two Merlin encoders in the same compartment this was one of the most complicated operations.
- For the power supply of the instrumentation system the AC/DC and the DC power panels were modified.
- For one of the four muxbuses a spare stub on a coupler could be used. For the other buses additional couplers were installed.
- In the MLU aircraft the FLRS is obsolete. However the existing FLRS wiring was kept intact and the transducers were re-installed (e.g. the control surface deflection sensors) to be used by the flight test instrumentation.
- For measuring the stick forces an interface with the Flight Control Computer was implemented.
- The cockpit lighting panels were modified to control the lighting of the instrumentation control panels.
- The test aircraft can be equipped with specially prepared ventral fins and engine covers, provided with strain gages and accelerometers for structural load analyses programs.
- The existing rudder pedal assembly is fitted with an extra sensor to measure the pedal force.

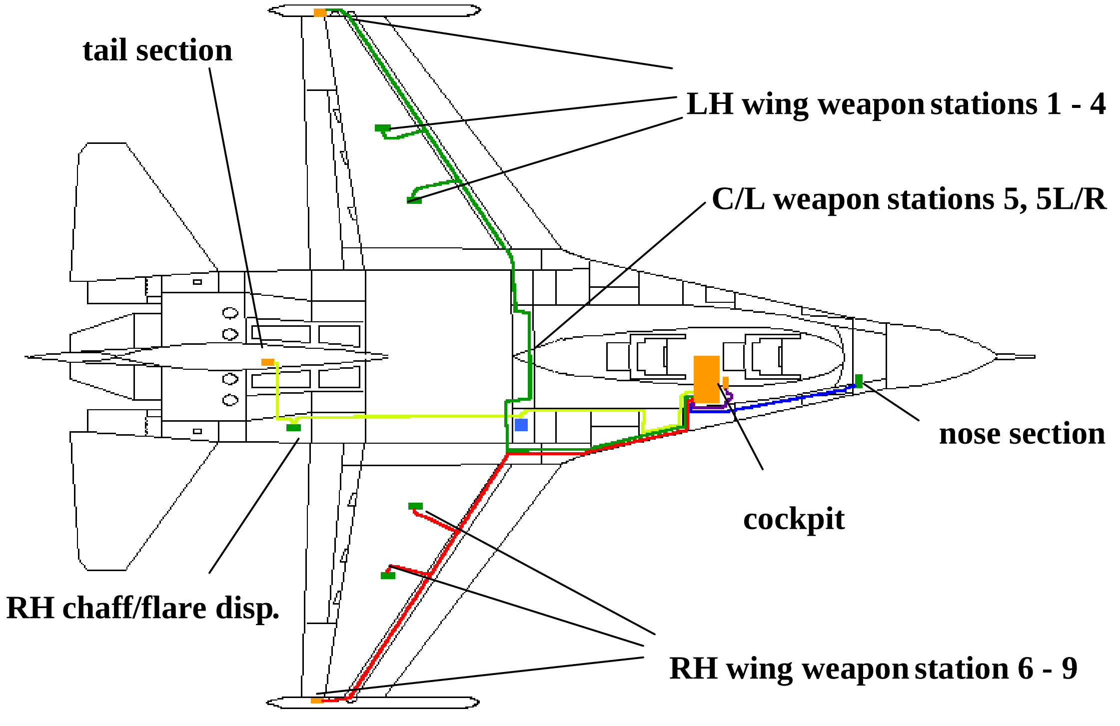

Figure 10. Routing of the instrumentation data bus.

Cockpit layout
Both crew stations of the cockpit are equipped with instrumentation control panels. A Forward Instrumentation Panel (FIP) installed in the left console provides the pilot the essential control functions for a single pilot flight. In the right console a video converter is installed, which adapts the signal of the instrumentation display to be presented on the Multi-Function Display.

At the aft crew station the basic control functions are present on the Aft Instrumentation Panel (AIP) just besides the control stick. In addition the Camera Selection Panel (CSP) in the left auxiliary console and the ASHM console with the instrumentation display on top of the glareshield are installed. Other alterations to the cockpit layout are the installation of a data encoder in the left console and the recorder in the right console.

Figure 11. Aft Instrumentation Panel right to the control stick.

Flight Safety

Mechanical and electrical analyses were performed to prove that the modified aircraft is safe to fly. Therefore strength calculations for the new or modified parts have been made. The electrical safety analyses considers the interfaces with the aircraft systems. The results of environmental tests on separate parts were used to proof the integrity of the instrumentation. To avoid problems with regard to Electro-Magnetic Interference (EMI) the aircraft was subjected to a Safety of Flight Test.

The results from the safety analyses were reviewed in a Safety Review by RNLAF attended by representatives of the flight test department, the airworthiness department, the avionics department and NLR. Based on this review the Director of Materiel of the RNLAF released the aircraft for both operational and test flights.

Future developments

Although the system is designed to be operated throughout the expected operational lifetime of the F-16 MLU until 2020, future demands in combination with availability of new equipment might require system upgrades. The modularity of the system facilitates the implementation of these upgrades.
Possible future upgrades are:
- Extension of the functionality of the cockpit display panel.
- Replacing the magnetic tape recorder by a solid state recorder. The absence of mechanical moving parts has unquestionable advantages. In addition these recorders allow for higher recording speeds and larger capacity within a smaller volume.
- Replacing the conventional wet film cameras by high-speed video cameras.

Conclusion

In a relatively short time a flight test instrumentation system for an F-16B MLU aircraft of the RNLAF was designed, developed and installed in the aircraft. Key functionality includes on-board data processing and display, data recording and telemetry provisions. The system was designed in such a way as to maintain the full operational capabilities of the aircraft. The system already proved its capabilities in a certification programme for a navigation and targeting pod. The system provides the RNLAF with a flight test capability for its F-16 MLU aircraft that is not available elsewhere.

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Authors biography

Johan Klijn holds a BSc degree in Electrical Engineering from the Institute of Technology of Amsterdam where he graduated in 1981. Since that time he works at the National Aerospace Laboratory as a flight test instrumentation engineer at the Instrumentation Department of the Avionics Division. He was involved in the design and installation of flight test instrumentation systems in both military (F-16) and civil (Fokker prototype) aircraft. In his most recent position he was project manager for the design and installation of flight test instrumentation in an F-16 MLU aircraft of the Royal Netherlands Air Force. In the past he presented papers about flight test instrumentation at symposia of the SFTE (1991) and AGARD (1996).

Paul Koks holds a BSc degree in Aeronautical Engineering from the Institute of Technology 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 Instrumentation Department of the Avionics 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.

Gert Jan Kobus holds a BSc degree in Electrical Engineering from the Institute of Technology of Alkmaar where he graduated in 1981. After fulfilling his military services at the Royal Netherlands Army he joined the RNLAF. At the F-16 avionics office he is responsible for several projects concerning the maintenance, modification and configuration control of F-16 electrical systems. In his most recent position he is project leader for the design, installation, configuration control, maintenance and support of the flight test instrumentation in the ‘Orange Jumper’ F-16 MLU aircraft.