Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary

Development of flight test instrumentation: an evolutionary approach

Problem area

The development of flight test instrumentation at NLR is presently concentrated in a long term project called Advanced Flight Test Facilities (AFTF). This project is based on a flexible concept of instrumentation, not only concerning the present system design itself but also with regard to maintainability in the future.

From this concept parts were developed and implemented stepwise, continuously using the feedback from the operational teams. This made the process more evolutionary than in the past.

Important decisions were made regarding purchase of the main components of the system including data acquisition units, airborne solid state recorders and the ground-based data processing system. The interfacing between these components was considered to be very important. For configuration data an interface based on eXtended Mark-up Language XML was developed. For the transfer of measurement data the new standards according IRIG-106 chapter 10 were applied.

Results and conclusions

During the development process parts of AFTF were successfully applied in a wide variety of flight test programmes such as helicopter/ship qualification trials, flight tests with the F-16 test aircraft of the Royal Netherlands Air Force and UAV testing. The components and interfaces of AFTF are also used in the design of a "Generic Instrumentation System".

Applicability

The building blocks of AFTF are generally applicable in present and future projects requiring flight test instrumentation systems.

Report no.
NLR-TP-2006-407

Author(s)
J.M. Klijn

Classification report
Unclassified

Date
July 2006

Knowledge area(s)
Vliegproeven en Instrumentatiesystemen

Descriptor(s)
Flight Test Instrumentation

This report is based on a presentation held at the Society of Flight Test Engineers 17th European Chapter Symposium, Amsterdam, 12-14 June 2006.

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

NLR-TP-2006-407

Development of flight test instrumentation: an evolutionary approach

J.M. Klijn

This report is based on a presentation held at the Society of Flight Test Engineers 17th European Chapter Symposium, Amsterdam, 12-14 June 2006.

Customer	National Aerospace Laboratory NLR
Contract number	---
Owner	National Aerospace Laboratory NLR
Division	Aerospace Sytems & Applications
Distribution	Unlimited
Classification of title	Unclassified
	July 2006

Approved by:

Author	Reviewer	Managing department
24/7-06	24/7-06	24/07/2006

Summary

The development of flight test instrumentation at the National Aerospace Laboratory NLR is presently concentrated in a long term project called Advanced Flight Test Facilities. This project is based on a flexible concept of instrumentation, not only concerning the present system design itself but also with regard to maintainability in the future.

In the past the process of development of flight test instrumentation at NLR was closely related to the introduction of new types of aircraft, which made every new system rather revolutionary. In the new approach the flight test equipment is continuously developed in pace with the fast developments of electronic equipment in other fields of application. Parts of the systems have been introduced at an earlier stage in ongoing projects to be able to use the feedback of the operational teams.

In this paper the new instrumentation concept will be discussed and parts of it and their implementation will be highlighted. Examples of application will demonstrate how the more evolutionary approach of development of flight test instrumentation can contribute to an efficient execution of flight test programs.

Contents

Abbreviations

AFTF	Advanced Flight Test Facilities
AMS	Airborne Measurement System
COTS	Commercial Of-The-Shelf
DMS	Data Management System
GDPS	Ground-based Data Processing System
GIS	Generic Instrumentation System
IRIG	Inter Range Instrumentation Group
MRVS	Measurement, Recording and Processing System (Dutch acronym)
NLR	National Aerospace Laboratory NLR (Dutch acronym)
ODE	Omega Data Environment
PCM	Pulse Code Modulation
RNLAF	Royal Netherlands Air Force
RNLN	Royal Netherlands Navy
SAMS	Stand-Alone Measurement System
SPADES	Small Parafoil Autonomous Delivery System
TMATS	Telemetry Attributes Transfer Standard
UAV	Unmanned Aerial Vehicle
XML	eXtended Mark-up Language

1 Introduction

Since its foundation in 1919 NLR has built up extensive experience in the development and application of flight test instrumentation [Ref. 1]. Before the WWII the instrumentation mainly consisted of single instruments of which the readings were written down on a kneepad or recorded with a built-in recording mechanism like a self-recording altimeter. Shortly after the war the need arose to measure more parameters simultaneously during one flight for which special measurement and recording systems were developed.

These developments were mainly initiated by the introduction of a new aircraft. The specified performance was based on the requirements for the prototype flight tests and for the design the state-of-the-art techniques were used. This resulted in flight test instrumentation systems that came in generations of approximately twelve years. The prototype of the Fokker F 27 Friendship in 1955 was instrumented with a photo panel recorder or so-called automatic observer, consisting of a panel with many dial gauge instruments filmed by a camera. In the prototype of the Fokker F 28 Fellowship in 1967 a new system DR-28 was used, introducing digital recording on a magnetic tape. In the late seventies the increased avionics in the design of the Fokker F 29, later resulting in the Fokker 100 and 50, required a more powerful distributed and modular data acquisition, recording and processing system referred to as MRVS.

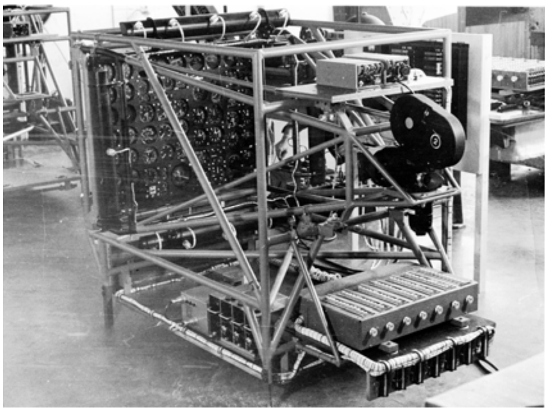

Figure 1: Photo panel recorder or “Automatic Observer” (1955).

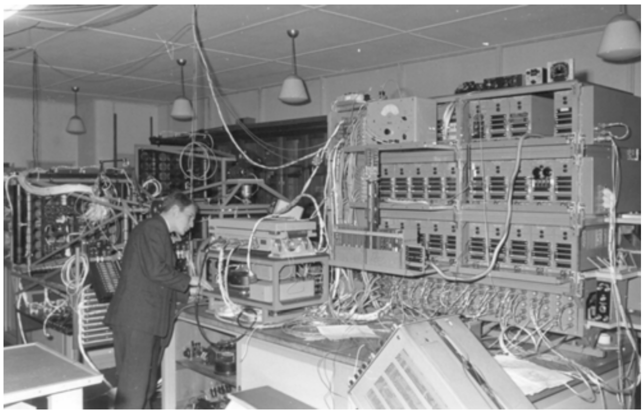

Figure 2: Digital Recorder DR-28 (1967).

Already in the end of the 1980’s it became clear that the development of flight test equipment had to be a more evolutionary process. The changes in electronics and informatics in general were going fast. The application of commercial of-the-shelf equipment in the field of flight test instrumentation became very attractive. In order to keep up with these fast changes monitoring the market had to be a continuous process. Newly available techniques and equipment had to be tested, where necessary adapted and introduced for operational use. This also required a stable financial funding independent of specific flight test programs. Therefore the MRVS-90 project was launched which concentrated on the further development of flight test equipment for Fokker aircraft. However, in 1996 this project was terminated because of the bankruptcy of the Fokker Aircraft Company.

Advanced Flight Test Facilities (AFTF) started in 2001 with the goal to modernise the existing flight test equipment in response to the requirements of upcoming projects. Budget was made available for long term development, although at a more moderate level than for MRVS-90. AFTF had to cover a wide range of applications comprising fighter aircraft, military helicopters, civil aircraft, Unmanned Aerial Vehicles (UAV) and even not aviation related applications like railway systems. In the following chapters the AFTF approach and technical concept will be discussed and some examples of applications will be given.

2 The ATFT approach

The first step was to develop a general concept of a flight test system. This concept is not a strict set of specifications described in extensive documents. It is just a point from which the iterative process between development team and operational teams started. Based on this concept the system was implemented and introduced stepwise, continuously using the feedback of the operational teams. This operational participation was considered to be crucial because without this involvement there will be no application, making modernisation a useless process.

In the new concept several Commercial Of-The-Shelf (COTS) techniques are applied. For on-board data processing a computer and display is designed using PC/104 components, running under an embedded MS-Windows operating system and programmed with National Instruments LabVIEW. The magnetic tape recorders are replaced by solid-state data recorders making use of Flash Memory cards, of which the steady increase in available capacity was mainly driven by consumer electronics like digital cameras. On the ground, data processing facilities are based on Personal Computers programmed with commercially available software packages for data management and analysis.

To deal with the rapid changes in availability of COTS equipment and software much attention is paid to the interfaces between the different parts of the system. By adhering to open standards the system will be less sensitive to changes. Besides, a lot of generally available tools can be used. For creating system set-up files eXtended Mark-up Language (XML) is used. Other elements of the interfaces are based on the newer chapters of the IRIG-106 specification [Ref. 2], especially the packetized data format definition of chapter 10.

3 Technical concept

The AFTF concept describes a framework on which the further development of flight test facilities is based.

The concept depicted in figure 3 consists of four main parts:
- a Data Management System;
- a Ground-based Data Processing System;
- an Airborne Measurement System;
- a Stand-Alone Measurement System.

The Data Management System (DMS) stores multi-disciplinary information about the configuration of the instrumentation into a database. The flight test project manager defines the requirements for the parameters according to which the measurement channels have to be designed. The designer uses this together with the stored information about the available equipment, like serial numbers, calibrations and equipment settings. The operational team compiles the information to be able to configure the data acquisition system. The configuration data from the database are also used to convert the measurement data into engineering units. The results, together with its administrative data, are stored back into a database, from where it is made available for the end users.

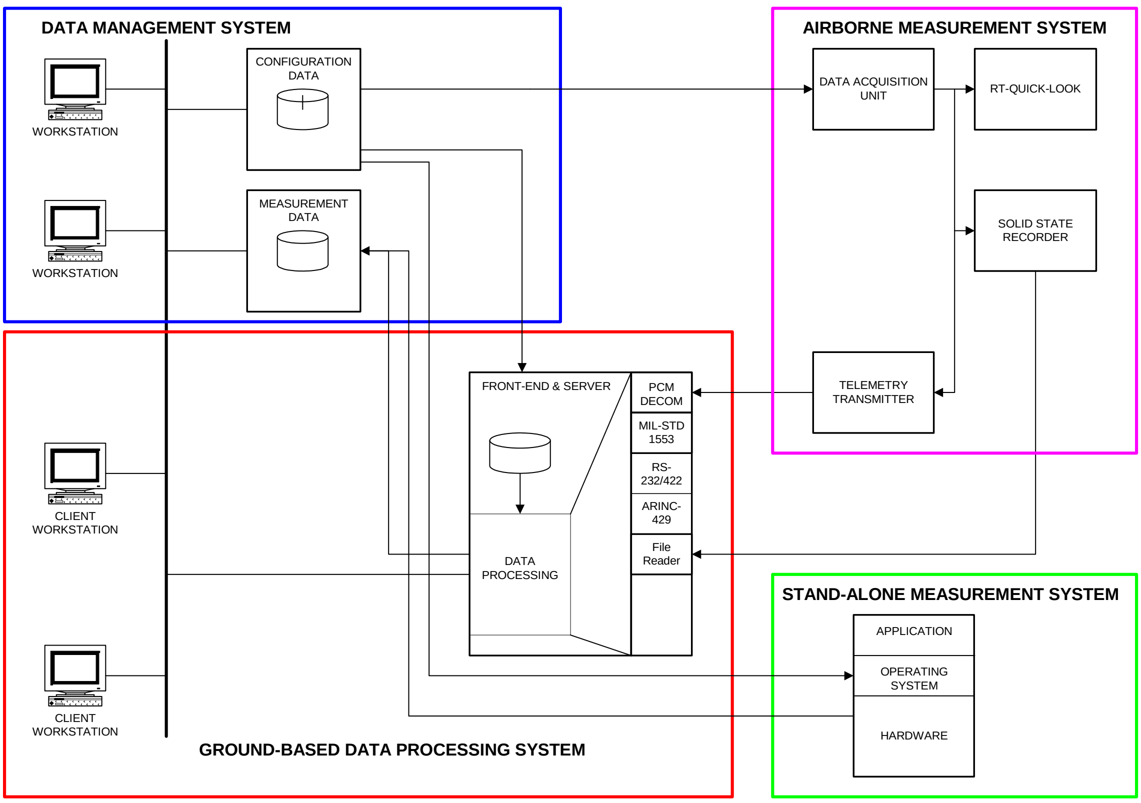

Figure 3: Block diagram of the concept of AFTF.

The Airborne Measurement System (AMS) includes all functions for data acquisition, recording and on-board data processing and presentation. During the test flight the data is recorded on a medium which can be read by the ground-based data processing system, but if required the measurement data can also be transmitted directly via a telemetry link.

To obtain the most optimal solution with regards to performance the AMS uses dedicated equipment for each function. Sometimes however this conflicts with the requirements for weight and volume. For these cases the Stand-Alone Measurement System (SAMS) incorporates in one small and light-weight housing all basic functions of the AMS. The configuration of the SAMS can also be controlled by the database of the DMS.

The front end of the Ground-based Data Processing System (GDPS) has the capability for input of data from several sources. The IRIG-PCM decommutation input is necessary to process data from the AMS telemetry link or from a conventional digital tape recorder to maintain compatibility with the older measurement systems. The solid state recorder requires a new interface to process the file based data from its media. Also other common interfaces like Mil-Std-1553, Arinc-429 and RS-232/422 are foreseen. The processed data can be presented directly on client workstations or stored into the DMS.

4 Implementation of the concept

With the above concept in mind some important equipment choices had to be made based on market investigation and evaluation of demonstration units. Even more important than the equipment choice itself, the interfaces between the system parts had to be selected carefully. The use of open and commonly accepted standards makes the design less sensitive to obsolescence of equipment and avoids single source problems.

4.1 Equipment selection

Data acquisition and recording are considered to be the most critical functions of the flight test instrumentation and therefore the equipment must have a high degree of reliability. The data acquisition equipment sometimes has to be connected directly to aircraft systems making safety also an important issue. During the selection of equipment it was a requirement that the equipment had to be fully airborne qualified. After a thorough evaluation the KAM-500 system of ACRA Control was selected for the data acquisition.

It was obvious that a new airborne recorder had to be a solid state recorder. The lack of moving parts greatly enhances the reliability and reduces the required maintenance in comparison with the conventional magnetic tape recorders. The constraints on weight and volume, especially for application in military aircraft like the F-16, were an important factor. At time of evaluation most airborne solid state recorders were already very powerful with regard to capacity and data throughput rate, but also rather large and heavy. The final choice was made for the S3DR-F recorder of SES Ltd., which records on two standard ATA flash memory modules and can be mounted into standard Arinc avionics instrument panels.

Figure 4: S3DR-F solid state recorder from SES.

Figure 5: Installation of the recorder in the F-16 cockpit

For the GDPS the Omega Series 3000 system from Veridian (now Wyle Labs) was selected because of its high degree of flexibility for data input and output interfaces, the processing performance and strong capabilities for customisation of the real-time presentation. Furthermore the system has a local database for configuration data which already came close to the requirements for the DMS.

For the management of the huge amounts of measurement data special tools have to be made available. At this moment the evaluation of the Omega Data Environment (ODE) from Wyle Labs is in progress.

The SAMS is based on Common-Of-The-Shelf (COTS) computer hardware according the PC/104 standard. Depending on the application the hardware interface of this system can be selected from a wide range of commercially available cards. For time critical applications, e.g. when the measurement data is also used in a flight control system, the SAMS is configured with a VxWorks real-time operating system and dedicated software application programs. For other applications the Microsoft Windows-XP Embedded operating system with applications written in National Instruments LabVIEW are used. This configuration is also used for the development of the real-time quick-look facility of the AMS.

4.2 Interfacing

In general we can distinguish between interfaces for configuration data and interfaces for measurement data. For transfer of the configuration data there was a preference for the Telemetry Attributes Transfer Standard (TMATS) defined in chapter 9 of the IRIG-106 specification. However, the extent of this specification makes that for most equipment it is seldom fully implemented. On the other hand important items are missing and not easy to add in a structural way.

Especially for the set-up of the SAMS an interface was developed using eXtensible Markup Language (XML), which is a text based format for storing data in a highly structured form. One of the advantages of using XML, which is not exclusively dedicated to flight test equipment, is the availability of software tools. It also matches close with the data structures of relational databases which eases the implementation of import and export facilities. In the future the draft XML version of TMATS seems to be promising, but the implementation waits for further definition and issuing by the IRIG organisation. Meanwhile ACRA is also introducing an XML based configuration interface called XidML [Ref. 3], which is pretending to become an open standard. It seems to be in competition with TMATS-XML.

For transfer of the data recorded on the solid state recorder the packetized data format definition from chapter 10 of the IRIG-106 specification was used. Although the S3DR-F records on flash memory in a SES proprietary format, the companion software Reveal transforms the data into chapter 10 compatible files. These files can be read directly by the file reader component of the Omega system. The implementation of this interface, which was limited to PCM data from the data acquisition system, was realised in close cooperation with both suppliers. In the future also other types of data like Mil-Std-1553, Arinc-429 and video will be implemented when the chapter 10 specifications become more mature.

5 Applications

The development of AFTF has always been closely related to direct application in ongoing flight test projects. In the following paragraphs some examples are given.

5.1 F-16 Flight Test Instrumentation

Since 1984 the Royal Netherlands Air Force operates an F-16 test aircraft which was in 1997 equipped by NLR with a newly designed flight test instrumentation system [Ref. 4]. This instrumentation was highly integrated into the aircraft. Even with the instrumentation installed the aircraft maintains it full operational capabilities. Although the system was designed for the total expected lifespan of the aircraft until 2020 benefits of the AFTF design were attractive enough to decide to modify the system implementing AFTF developments. The addition of more systems in later aircraft upgrades reduced the available space for flight test instrumentation to even less than at the time of the initial design. The smaller size of the new AFTF equipment was a great benefit to overcome this problem.

The replacement of the existing magnetic tape recorders by solid state recorders reduced the volume of the flight test equipment considerably and added the benefits of reducing maintenance and improving reliability of recording. Also the existing ground data processing system was replaced by the Omega system to interface with the recording media using the IRIG-106 chapter 10 interface.

Figure 6: Generic Instrumentation System to be installed for Apache helicopter flight test trials.

5.2 Generic Instrumentation System

From a wide field of customers like the Royal Netherlands Air Force (RNLAF) and Navy (RNLN), Fokker Services and NLR’s own research aircraft, there were requirements for a new basic flight test instrumentation system, the “Generic Instrumentation System (GIS)”. The system had to be easy installable in various types of aircraft such as the Apache, Chinook and Cougar type of helicopters. Due to the high vibration levels in rotary wing aircraft the recorder had to be solid-state. The data to be recorded is in most cases available from the avionics data busses, but also recording of additional sensors like strain gauges and vibration pick-ups was required. Optional on-board data processing and presentation was specified and data processing after the flight had to be easy enough to be performed on-site shortly after the test flight.

In the design of the GIS most parts of the AFTF concept have found their application: the data acquisition system is based on the KAM-500 equipment, data is recorded on the S3DR-F solid state recorder, on-board quick-look facilities are realised using PC/104 systems and the Omega system is used as the ground data processing system.

The GIS was used during flight test trials with an Apache helicopter of the RNLAF and the aerodynamic certification of a radar dome for use on the Fokker 100 aircraft. The operational feedback from these projects was used for the further development of GIS and AFTF in general. One of the main items was to improve the facilities and procedures to handle the measurement data on site.

5.3 Helicopter-ship qualification

For recent helicopter-ship qualification trials for the Royal Netherlands Navy [Ref. 5] the Omega system, consisting of a server and two client stations, was used. The server was configured to process, display and store data from four RS-422 inputs for wind sensor and ship information. Via the IRIG-PCM input also data from the helicopter telemetry system was processed. The client stations were used to monitor the progress of the tests and to perform a quick analysis shortly after the measurement runs. For this purpose special displays were developed using the Omega built-in components and customized Active-X components.

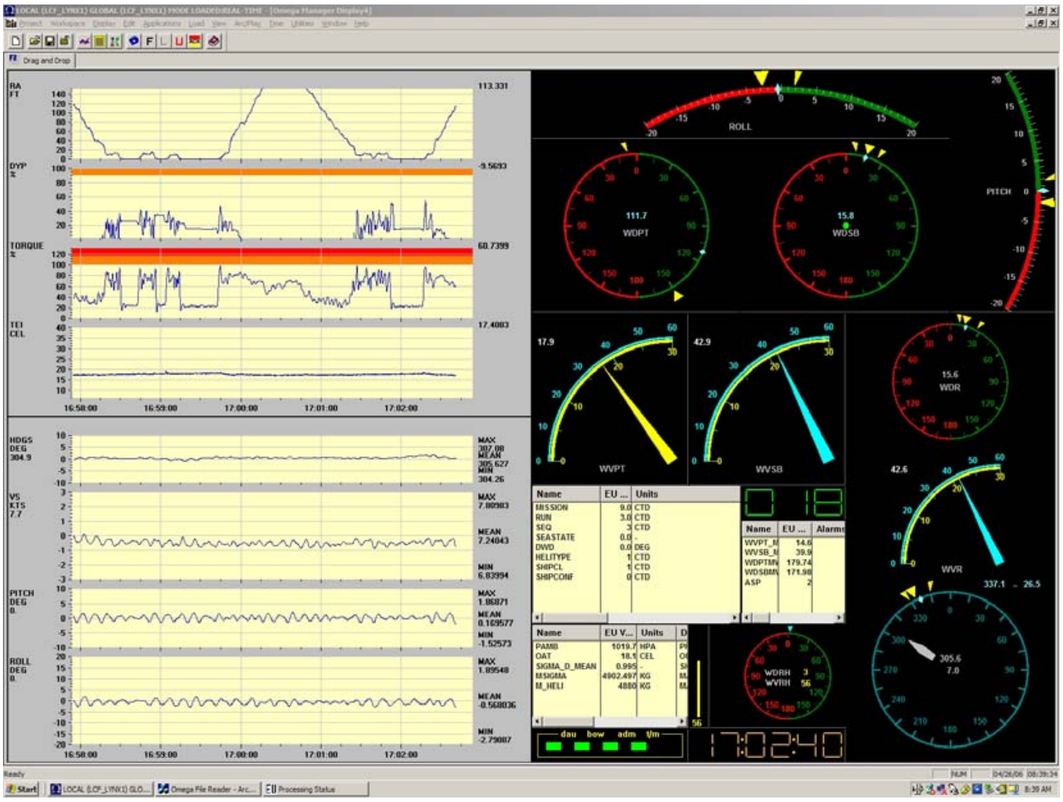

Figure 7: Example of an Omega display used for helicopter-ship qualification trials.

5.4 Small systems

For applications with strong constraints on weight and volume of the instrumentation the rigid approach of the AMS and GIS is not applicable and the integrated approach of the SAMS has to be used. The Small Parafoil Autonomous Delivery System (SPADES) which is developed by Dutch Space in partnership with NLR is capable of delivering payloads in the range of 100 – 200 kg [Ref. 6]. The on-board computer in the prototype of SPADES performs in addition to its flight control tasks also the data acquisition and recording from additional sensors. This on-board computer is based on the PC/104 components from the AFTF concept.

Another example of application is the on-board computer of a rotorcraft Mini-UAV system demonstrator [Ref. 7]. Also in this case the PC/104 based computer performed both the tasks of flight control and data acquisition and recording.

6 Conclusion

It can be concluded that the more evolutionary approach of AFTF has been successfully applied. Although the project started without a full set of detailed requirements for an “AFTF system”, it has been proven that the developed technical concept itself is powerful enough to continue developments closely related to real-life applications and in close cooperation with the operational teams. In this way of development the operational teams benefit from having modern techniques timely available for their projects and the developers can use their feedback for further improvement of the flight test facilities.

Zooming in on the technical content of the concept important progress has been achieved in the field of the application of high capacity, small volume solid state recorders and the implementation of the IRIG-106 chapter 10 standard for the exchange of data from recorders to data processing facilities.

It was shown that the versatility of the developed building blocks allowed the composition of flight test instrumentation systems for many different applications.

7 References

[1] NLR, “75 years of aerospace research in The Netherlands: a sketch of the National Aerospace Laboratory NLR, 1919 – 1994”, ISBN 90-9006909-7, 1994.

[2] Document 106-05 Part 1: Telemetry Standards, Telemetry Group, Range Commanders Council, July 2005.

[3] “XidML 2 Handbook; An open standard for an eXtensible Instrumentation Data exchange Mark-up Language”, 26 January 2006.

[4] J.M. Klijn, P. Koks and G.J. Kobus, “New flight test instrumentation for the RNLAF F-16 MLU aircraft”, NLR-TP-2000-362, SFTE 31st Annual Symposium, Turin (Italy), 19-22 September 2000.

[5] R. Fang, Cdr. (Ret.) H.W. Krijns and R.S. Finch, “Helicopter/ship qualification testing, Dutch/British clearance process”, Appendix A2: Instrumentation in flight trials, NLR-TP-2003-113, March 2003.

[6] H.W. Jentink and J.W. Wegereef, “Autonomously guided parachute delivery systems; Development and test approach”, NLR-TP-2003-315, 14th SFTE European Chapter Symposium, Toulouse (France), 10-12 June 2003.