# CHALLENGES TO FUTURE ON-BOARD FTI – SYSTEMS FOR FIGHTER TYPE AIRCRAFT

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## ABSTRACT

The system architecture of an onboard FTI-System is specifically designed to fulfil highly demanding flight test requirements. Since these flight test requirements are steadily increasing with the growing complexity of test aircraft and mission systems, a corresponding improvement in the performance of the FTI-Systems is mandatory to satisfy those flight test demands. In addition, the individual test flights have to provide the maximum of flight test data obtainable in order to improve test efficiency and to cut project costs. Increased performance, miniaturisation, more reduced design and installation costs are the challenges for future system architectures. The developments of commercial and consumer electronics have an increasing influence on the layout of FTI-Systems.

## KEYWORDS

On-board wireless data transmission, wiring reductions, future demands on FTI-Systems

## 1. Introduction

Modern Fighter Aircraft are equipped for their roles with a high number of systems. For example, the EurofighterWeapon System includes 96 subsystems. During the development phase, all these systems have to be qualified and certified by means of flight trials. New scenarios like Network Centric Warfare and its complex communication mechanism are add-ons for future flight tests demands. For flight test (assigned by the programme demands), sophisticated and very capable flight test instrumentation systems are mandatory in order to deliver the necessary data sets to the flight test engineers for their evaluation of the performance characteristics of these complex systems. The degree of complexity increases with every generation of fighter aircraft. The systems are becoming more “intelligent” and at the same time the performance of subsystems and hence of the total weapon system are growing with every upgrade. The data exchange between subsystems within an aircraft will be done with more and more intensity. High speed data buses will be used to cover this data exchange.
All these aspects, the complex data exchange, and the complex structures of the aircraft systems need to be tested for development, verification and certification using flight trials. For this purpose, a high volume of data from an instrumented aircraft have to be recorded and

transmitted for online analysis. This results in a requirement for more data with increased precision, increased speed and time accuracy.
To handle and observe this abundance of parameters online, they are displayed in complex visual representations associated by functionalities. This is the only way to show, analyse and control the status of several systems. To reduce the amount of test flights, on the one hand an onboard FTI – System has to deliver data for detailed system investigations, on the other hand there are many parameters necessary to assess/monitor the overall communication between the subsystems. But there is another essential factor. As mentioned, to save costs, the number of test flights has to be limited. Therefore, the instrumentation has to cover a variety of trials and the conceptual formulation has to be adapted to these tasks. This presentation will show present and future technologies developed to solve these new requirements.

## 2. Increasing Flight Test Requirements

The Flight Test Requirements issued by the flight test engineers are the basis for the architecture and layout of FTI – Systems. There are some main objectives and systems to be evaluated by Flight Test requiring proper data acquisition with the present fighter aircraft:

- Flight Control Systems and control laws
- Parameter identification for aerodynamic data set
- Aircraft performance: aircraft drag analysis, lift polars, take off/landing performance, general aircraft performance
- Handling Qualities
- Engine instrumentation
- Engine-Air Intake Compatibility
- Utility Control System
- Landing Gear System including Brake System
- Fuel System
- Secondary Power System
- Structure, vibration, acoustic noise
- Flutter
- Environmental Control System
- Electric system
- Avionic system
- Attack system
- Auto Pilot system
- Armament Control System including Air to Air and Air to Surface missiles and gun
- Stores as external fuel tanks
- Communication systems like VHF/UHF, MIDS
- Air Data systems
- Instrumentation and safety devices for departures, engine flame outs, etc.
- Radar system, FlIR System and other active or passive sensors
- Defensive Aids Systems

In addition to flight trials which investigate the performance of a fighter aircraft system alone, scenarios with other weapon systems have to be tested. Modern fighter aircraft are fully adapted to the latest scenario of a battle field. They are embedded in complex communication networks to improve the task performance. Methods of the latest IT techniques adapted to the specific requirements are used to communicate in battle field scenarios. These new combat scenarios have to be tested and evaluated. An example is NCW (Network-Centric Warfare). It is an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers and shooters to achieve shared awareness, increased speed of command and higher tempo of operations. NCW translates information superiority into combat power.

## 3. Basic requirements for future FTI equipment and FTI – Systems

There are a lot of wishes of the FTI user for future FTI developments. In the past, every generation of FTI –Systems showed an increase in performance. Modern IT techniques and much more powerful electronic components will have an influence on future FTI – Systems. However there are a few basic requirements for FTI – Systems:

- small in size
- easy to install
- low power consumption
- low maintenance, easy to handle
- adaptable, plug and play
- MTBF very high
- self checking, self testing, checkable
- intelligent systems, to record only useful data but not everything
- growth potential
- long lasting calibration or no calibration necessary
- total costs for installation very low
- reduced wiring
- various interfaces possible, growth potential
- modularity, standards
- to use A/C functionalities, but be independent from A/C
- optimized data acquisition and data recording
- to acquire only useful data, this means to record with respect for resources and bandwidth (recording time, recording capacity, telemetry bandwidth, data storage on ground station)
- multifunction of input modules, to be programmable by software and therefore adaptable to various applications
- delta recording
- up/down link, predefined decisions (mode switches)
- predefined process in failure conditions
- high environmental acceptability of FTI – equipment (temperature, vibration, humidity ….)

## 4. System architecture of an existing state of the art FTI – System, installed in a Fighter Type Aircraft

Example: “Instrumented Production Aircraft 3” (IPA3) from the Eurofighter programme.
The IPA3 performed its first Flight on 8$^{th}$ April 2002. It is one of five Instrumented Production Aircraft. The FTI system for IPA 3 is state of the art and is designed for Instrumented Production Aircraft and is similar to the other FTI systems installed in IPA´s.
<u>IPA3 Main Flight Test Tasks:</u>

- Weapon System Performance inclusive AMRAAM, AIM9L and IRIS-T
- RADAR trials

- Semi – prepared Runway Trials: Heavy instrumented landing gear including brake system instrumentation
- Landing Gear Trials and Brake Performance (Anti Skid Capability, Brake Tuning)

<u>FTI system IPA3:</u>

Aircraft data is acquired from

- Data bus traffic
- hardwired parameters, individual sensors and system tappings
- aircraft video signals
- video cameras

The data is collected and distributed into 11 different data streams. One PCM data stream and one Video data stream are transmitted during flight to the Ground Station for online analysis purposes. Other data streams are recorded only.

<u>Short description of the system architecture</u>

The FTI system includes the following subsystems:

- Data Acquisition System (ACRA)
- Data Recording System (Heim Systems)
- Video System
- Cockpit Control System
- Telemetry System (Frequency Diversity Combining for PCM and Video telemetry, data encrypted)
- Cine Camera System
- Time Code System (GPS-based)
- FTI Power Distribution System

<u>Performance of the FTI system installed in IPA3:</u>

The data acquisition system acquires data from approx.130,000 aircraft parameters. Most of them are selected from aircraft buses.

<u>Data is acquired from the following sources</u>

- selective data from eight Stanag 3838 buses, with provision for100% recording
- selective data from two Stanag 3910 ( EFA bus), with provision for 100% recording
- selective data from the Flight Control System (2 lanes)
- hardwired parameters, approx. 250 (growth potential up to approx. 450) including crew speech

<u>FTI output data streams</u>

- PCM data stream for telemetry purposes, Quick Look (1.3 Mbit/sec)
- Video data stream for telemetry purpose, Quick Look (4 Mbit/sec, multiplexed video signal from cockpit displays or video camera signals)
- General PCM data stream for recording purpose (2.6 Mbit/sec)
- High Speed PCM to record parameters up to 5 KHz bandwidth, at a sampling rate of 20KHz
- 100 % bus recordings

<u>Time Code Generation system</u>

- GPS-based, accuracy of approx. +/- 15 usec

<u>Video System</u>

- multiplexed video signal (four displays), video cameras, high speed video available

<u>Cine Camera System</u>

- wet film camera system up to 500 f/sec

<u>Telemetry System</u>

- PCM Telemetry, Frequency Diversity Combining, data encryption

- Video Telemetry, Frequency Diversity Combining, data encryption

Recording System

- currently installed: D20 recorder, AIT1 tape drive, max. 20 Mbit/sec, 25 Gbyte capacity
- will be updated to: D200 recorder, max. 200 Mbit/sec (Hard Disk Drive, 180 Gbyte capacity/ AIT2 tape drive, 50 Mbit/sec, 50 Gbyte capacity/ Solid State Memory, 120 Mbit/sec, 76 Gbyte capacity)
- recording time: better than 2.4 h at max. recording rate

## 5. Developments in the FTI equipment market

Frequency Ranges for telemetry purposes

Telemetry spectrum availability is a critical item for flight tests. Increasing mission data rates need more bandwidth, but this bandwidth is limited or is decreasing. The frequency ranges have been shifted from the L – Band to the S – Band. Telemetry data for PCM and video transmission at the same time and in the required quality for online purposes are essential items for cost effective test accomplishment. Latest modulation technologies cannot compensate for the lack of telemetry frequency spectrum. The ICTS (International Consortium for Telemetry Spectrum) was chartered in response to the need for global coalition of telemetry users who share a common goal of ensuring availability of the electromagnetic spectrum for telemetering. The allocation of an additional spectrum for wideband aeronautical telemetry in the 3 to 30 GHz band is currently under discussion.

Telemetry Systems

Spectrally efficient modulation technologies have been developed like FQPSK (Feher quadrature phase shift keying) and SOQPSK (shaped offset quadrature phase shift keying). Transmitters with these techniques are available. Another modulation method is under discussion and is used by Airbus France in civil flight testing. It is COFDM (Coded Orthogonal Frequency Division Multiplexing). This technique performs the best multi-path characteristic and is also used for video telemetry.

Data Acquisition systems

Data Acquisition Systems have become smaller, faster and in addition more powerful to acquire all kinds of data including that from high speed aircraft buses. New developments are comprising data multiplexing/demultiplexing systems to collect all necessary, but very different kinds of data e. g. PCM, video, voice, time, analogue data, digital data, Ethernet, RS232, data from buses to one serial data stream for recording, transmitting and finally demultiplexing.

It should be noted, that supplier of Data Acquisition Systems are offering more and more recording capabilities and supplier of Recording Systems are offering optional data acquisition facilities.

Recording Systems

There are several recording techniques available, which have the necessary performance for future recording systems. In the past, tapes were the most commonly used medium. But if we look at the future performance of tape drive (www. aittape.com/ait-tape-roadmap.html) we see a very fast increasing performance of cassette drives up to the year 2008. The AIT website describes a drive called AIT6 * which has a capacity of 800 GByte and a maximum recording bit rate of up to 628 Mbit/sec.

At present, sealed hard disk drives and solid state memories are the top performers. Both need to be milked (to transfer the recorded data to another medium) after tests. Both are driven by the commercial and consumer markets. The medium of solid state memory (flash based solid state storage) has better environmental characteristics. The sealed hard disk drives with hermetically isolated housing are ahead in terms of storage capacity and maximum bit rate.

* AIT means Advanced Intelligent Tape. The AIT forum is an industrial consortium dedicated to advancing the art of data storage and protection through AIT technology application.

Video Systems

Standard video systems from the consumer market will be adapted to withstand the environmental conditions of flight testing. This includes consumer video systems as well as high speed video systems. Video data will be recorded on the standard data recorder.

High Speed Video systems use their integrated recording facilities.

Timing Systems

In the past, timing systems (Time Code Generator systems) were stand-alone systems with their own time code generator and distribution equipment. This has been changed. Now the time code generation is, or will be, a part of the data acquisition or data recording system. A GPS-related 1pps pulse synchronises the time to an accuracy of approx. 100nsec. This method allows time tagging of parameters to within an accuracy of 10 or 1 µsec.

Hardwired Parameters

Reducing both mechanical and electrical installation and maintenance costs are goals for future transducer developments. Small transducers reduce the mechanical impact for instrumentation purposes. “Plug and play” are keywords for modern and intelligent systems.

New transducer generations according to the Sensor Interface Standardization IEEE 1451 are available or are in development.

| | |
|---|---|
| IEEE 1451.1 | Network Capable Application Processor (NCAP), information model for smart transducer |
| IEEE 1451.2 | Transducer to Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) |
| IEEE 1451.3 | Digital Communication and Transducer Electronic Data Sheet (TEDS) Formats for Distributed Multidrop Systems |
| IEEE 1451.4 | Mixed-mode Communication Protocols and Transducer Data Sheet (TEDS) Formats |
| IEEE 1451.5 | Wireless Sensing (Draft) |

The time scale for perfect wireless sensing is open. The standard 1451.5 for wireless sensing is in development and it will be some time before this new standard can be incorporated into transducers and data acquisition units. The reduction of total costs of transducer measurements together with improved flexibility and reliability will also become an objective of industrial users. Therefore, let us hope for a future generation of transducers which fulfils all our wishes.

## 6. Developments in the consumer and commercial markets and their influence upon FTI – Systems

The instrumentation market is a small market. The volumes are limited, therefore developments and production are much more expensive. Developments for the consumer market and for the commercial markets, so called COTS (commercial of the shelf ) products, are also used for FTI purposes. New developments from the automobile industry or others are sometimes adaptable for FTI uses. Miniaturisation and increased performance of electronic integrated circuits and functional modules had, and will continue to have, an influence in the near future.

IT techniques, Ethernet, WPAN, WLAN, WMAN, WAN, Bluetooth, Zig Bee and other communication standards, new modulation methods and the immense market behind these new techniques are the driving forces.

Wireless Network Standards

There are a lot of RF communication standards released and in use, others are in development. Standards like Bluetooth, Zig Bee and some other WLAN standards have been released. New Ultra Wide Band techniques are under investigation and I think their potential will be shown later. The patented method Multi Dimensional Multiple Access (MDMA), which use the so called Chirp Spread Spectrum (CSS), is very promising.
The next chart shows some IEEE standards and their frequency ranges. A standard for wireless sensing is under investigation as standard IEEE 1451.5.

| **Standard** | **Abbreviation** | **max. Bit rate approx.** | **Frequency Range** | **Remarks** |
|---|---|---|---|---|
| **IEEE 802.11** | **WLAN** | **2 MBits/s** | **2.4 GHz** | |
| **IEEE 802.11a** | **WLAN** | **54 MBits/s** | **5 GHz** | |
| **IEEE 802.11b** | **WLAN** | **22 MBit/s** | **2.4 GHz** | |
| **IEEE 802.11b+** | **WLAN** | **54 MBit/s** | **2.4 GHz** | |
| **IEEE 802.11h** | **WLAN** | **54 MBit/s** | **5 GHz** | |
| **IEEE 802.11n** | **WLAN** | **>100 MBit/s** | | |
| **IEEE 802.15** | **WPAN** | **>100 MBit/s** | **3.1 to 10.6 GHz** | **15.1 Bluetooth**<br>**15.4 ZigBee** |
| **IEEE 802.16** | **WMAN** | **- 155 MBit/s** | **10 – 60 GHz** | |
| **IEEE 802.16a** | **WMAN** | **- 155 MBit/s** | **2 – 11 GHz** | |
| **IEEE 802.20** | **WAN** | | | **proposed** |

Legend:

| | |
|---|---|
| IEEE | for Institute of Electrical and Electronic Engineers |
| WLAN | for Wireless Local Area Network |
| WMAN | for Wireless Metropolitan Area Network |
| WPAN | for Wireless Personal Area Network |
| WAN | for Wide Area Network |
| WiMAX | for Worldwide Interoperability for Microwave Access Forum |
| UWB | for Ultra Wide Band |
| MDMA | for Multi Dimensional Multiple Access |

Recording techniques from the consumer market have always influenced the recording of FTI data. A newer example is hard disk recording. With sealed hard disk drives, data recording up to altitudes of 80000 ft and more, is possible. At the moment there is a competition between solid state memory and hard disk drive. Developments in the consumer market could decide future FTI recording methods.

Video Standards are changing for analogue based standards to digital standards. Video signals from cameras or system tappings can be recorded just as well by a video recorder as by a FTI data recorder.
Digital High Speed Video has replaced high speed wet film systems. The total performance including the instantaneous availability of recorded pictures are arguments to use this kind of system for flight tests.
New modulation techniques developed for the consumer market have been released for Television and Audio Broadcast. DVB (Digital Video Broadcast) and DAB (Digital Audio Broadcast) use the OFDM modulation technique (Orthogonal Frequency Division Multiplexing). The multi-path performance of this technique is superior to other modulation methods.

## 7. Future prospects

Telemetry
The basic requirement is a stable HF transmission in both directions (uplink and downlink) which is able to cope with the speed and manoeuvres of the aircraft. Frequency efficiency and robust multi-path performance in conjunction with higher data rates will be required for future flight tests. For example, COFDM combined with other techniques could be the prefered modulation technique. Other modulation techniques such as Ultra Wideband are under investigation, but the driving force of the consumer and commercial market with very complicated telemetry applications will show us the way ahead. It is assumed, that both the consumer and commercial applications will also use more and more frequency ranges in the S – Band. As a consequence, at least a part of the flight test telemetry will be shifted into the frequency band above 3 GHz.
Recording
Two years ago, we assumed, that solid state memories would rapidly become very popular for FTI recording, but hard disks, with lower costs and very good performance data are available, and are offered by several suppliers. We still assume however, that solid state memory will be the medium for the future. One disadvantage is the milking action after tests to transfer the recorded data onto another medium. A data storage medium, which could be the low cost primary data storage (like the cassette tape in the past) with performance data like the hard disk would be our favourite. However the storage medium is only one component of a recording system. The system must be adaptable to all the various input data structures and must report the status of all relevant functions in order to support the user during tests. The user needs to know, whether the recorded data is correct or not.
But there is another option for future recording systems. The abundance of recorded data has to be limited. Only the flight test relevant data should be recorded for use post-flight and finally stored in the ground station. Therefore, the recording configuration has to be dynamically reprogrammed during tests in a way, that only useful data is recorded.
This means, that the recording configuration has to be triggered by parameters or combinations of them. This trigger algorithm can be created by measurement parameters. Let us create the name “intelligent recording”. This onboard filtering of data reduces the burden on the ground station for data storage. On the other hand the recording capacity (as well the storage capacity as the maximum bitrate) of a digital recording facility will be used in an optimised way. Example: recording of vibration parameter and acoustic noise parameter with bandwidth requirements up to 10 KHz and more should only be measured during the actual test and not before and afterwards. Interfaces for input and output have to be adapted in conjunction to the data acquisition systems and wireless conditions.

Data Acquisition Systems

Data Acquisition Systems are the heart of FTI-Systems. But they have to be adapted with other subsystems to be able to communicate data. Very high speed bus data acquisition from GHz buses as well low speed data have to be collected. Network transducers have the electrical circuits like signal conditioning, anti aliasing filters and A to D conversions included. The data acquisition serves the transducer bus or wireless meshed transducer systems. This kind of system architecture shows a more distributed data acquisition system. Ethernet based systems, data multiplexing and incorporation of new IT technologies and standards are used for data collection and communication. As discussed, the recording systems and data acquisition systems are merging together.

Wiring

Wiring reduction including connectors and brackets and other wiring accessories are goals for the near future. Bus systems also for transducers and wireless data acquisition will be established in the near future. Other techniques are power line communication with special modulation techniques. However for some wireless data transmissions, we have to look at additional encryption techniques. Wireless data acquisition by sensors asks for low power consumption of the transducers and their integrated communication transmitters. Transducers without power wiring and no data wiring are the dream for the future. The timing of the raw data and the conjunction of the hand shaking methods of most communication standards has to be solved for time relevant measurements.

Sensors, Hardwired Parameters

So called hardwired parameters are measurement chains with transducers or system tappings. In the past, every single parameter was wired to data acquisition modules and their individual signal conditioning, before the data changed from an analogue structure to a digital structure. Developments followed whereby so called smart transducers and network sensor systems reduced the wiring. At the transducer side, the analogue signal has to be conditioned, digitised and adapted to the bus structure. New developments are enabling all these features on one chip to be integrated in the transducer or as an additional module near by the transducer.

Groups of transducers or system tappings will communicate wireless with the data acquisition. To improve the wireless transmission in fully packed compartments another characteristic of these wireless transducers is helpful. They need the additional capability of being a transceiver for data of other transducers. With this method a wireless mesh of transducers can be built around the aircraft. Much transducer data is time critical. The accuracy of the correlated time information to the data has to be taken into account. If we think of vibration measurement with a bandwidth of 2KHz and acoustic noise measurement with a bandwidth of at least 5 KHz a very strong timing performance of the total system is necessary. Another advantage is the availability of transducer stored data like calibration data, transfer function coefficients, service histories etc. shown in the IEEE P1451 standard (TEDS). But we are thinking of further wiring reductions. Groups of transducers or every transducer have to communicate by wireless transmission with a data acquisition unit. Future transducers will have low power consumption and the power will be delivered by batteries, piezo generators or by an extra electromagnetic field, by light transmission or by thermo generators, which generates energy from temperature differences. Low power methods in the design of the new transducer generations have to be applied.

Timing

It is mandatory to have a time correlation for every parameter or message. This time correlation is necessary for transmitted and recorded data. Time critical measurement requires determined accuracies of the time-of-day information. It is state of the art to synchronise the FTI Time Code System with GPS. When four GPS satellites are received, the GPS time is available with an accuracy of 100 nsec. This is the accuracy of the 1 pps pulse out of the

GPS receiver. This pulse synchronises the Time Code Generation system outputs an IRIG – Code or other time code information for FTI purposes. In case of a distorted GPS reception, an internal clock with an accuracy of $10^{-8}$ buffers the time synchronisation.
The overall time accuracy with time tagged data is approx. +/- 10 µsec as well for acquired as for recorded data. But an accuracy of 1 µsec or better would be possible. The status of the time information has to be recorded. An extra “time figure of merit” would be helpful. For a fighter aircraft with a maximum speed of approx. 750m/s (Mach 2,26, 1458 Kts), it means a distance of 7.5 mm in 10 µsec. What will be the requirement for the next generation of FTI – Systems? Is it necessary to have an accuracy of 1 µsec or better?

Self Tests

FTI – Systems are becoming more and more complex. To check the functionality before and during tests, a self-test facility is necessary. The status of the whole system has to be checked and should be shown to the user. In case of a fault of an item of FTI equipment during tests, the status information has to show the user whether data is true or not true. This status is very important for the decision to continue the test or not. Faulty devices have to be identified accordingly to support decisions concerning the current test plan, and if necessary, to plan repair measures. Therefore, requirements for IBIT (Initial built in test) and CBIT (continuous built in test) should be mandatory.

## 8. Conclusion

This presentation shows many realistic future aspects. But a new revolution of concepts and equipment standards will be established by wireless communication. New fighter aircraft and others will use wireless communication inside. Data will be passed between aircraft systems by wireless transmission via wireless mesh. Optical and RF wireless data transmissions will be used in mixed configurations (although some wiring or fibre optics could still be used as a back up in safety critical systems). Wireless mesh systems improve the redundancy and therefore the MTBF of the total aircraft system. Like the internet and other peer – to – peer router based networks it offers intrinsic multiple redundant communication path through the network. If one link fails, the network automatically routes messages through alternate paths. Wireless mesh systems will replace the traditional bus systems. It will reduce the aircraft weight (5 to 20%) and the volume of wiring including connectors, mounting facilities and so on, as well as the necessary maintenance. These techniques will also reduce production costs and time, improve the MTBF and reduce the vulnerability. All these factors together result in a dramatic increase in the overall performance of a fighter aircraft. It is a challenge to create robust communication standards and to develop new architectures for aircraft electronics and for FTI – Systems. Very robust modulation methods like UWB will be used to withstand EMC requirements. We do not know exactly the time scale for these developments and we do not know whether the next generation or the generation after that of fighter type aircraft will use these new communication techniques. But we should be prepared to adapt new systems to this future technology.

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