Overview of an Integrated Instrumentation Data System Used by the F-35 Lightning II Flight Test Program

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ABSTRACT

The Joint Strike Fighter program is the largest DOD contract ever awarded. There are three F-35 Lightning II variations, each intended to meet the specific needs of the Air Force, Navy, Marine Corps, and U.S. Allies. The Data System required for this flight test program challenged the conventional ways used in instrumenting test aircraft. Typical data systems available today don't provide the level of hardware and software integration required for today’s complex applications. For example, cockpit control panels, recording systems, TM transmitters, data acquisition systems and avionic bus interface units are all independent systems. Additionally, avionic bus catalogs, ground-based systems, and flight setup software have historically been independent components.

This paper will describe the hardware and software components used by the F-35 flight test program to provide an integrated system. A special emphasis will be given to the methods used to accommodate rapid changes to the IEEE-1394B avionic bus catalog including the acquisition of that data, and the use of an IRIG-106 Chapter 10 distributed multiplexer / recorder system, which is being used simultaneously as a data acquisition system.

KEY WORDS

Data Acquisition, Recorder, IRIG-106 Chapter 10, Integrated System, IEEE-1394

INTRODUCTION

The F-35 program is currently in various stages of development and flight test. Fifteen instrumented flight test aircrafts are currently planned, of which nine will be used for airframe test and six for avionics test. The airframe and avionics test will be done on the three F-35 aircraft variations. These variations include the Conventional Takeoff and Landing (CTOL), the Short Takeoff / Vertical Landing (STOVL) and the Carrier Variant (CV). Currently there are seven aircraft in various phases of instrumentation and one aircraft in actual flight test. The complexity of the flight test program dictates that the instrumentation system and the preflight and post flight software must be highly integrated to minimize human errors, to reduce time and cost and to provide maximum flexibility in updating bus catalogs with minimum impact to the test program.

The instrumentation system discussed in this paper will demonstrate the high level of integration and communications between all components of the system, will describe a single software tool used to configure and verify proper setup of the system, and will discuss the extensive use of XML files, which are electronically imported and exported between the Flight Test Data Center Data Base (FTDCDB) and the aircraft setup software called TTCWare.

INSTRUMENTATION SYSTEM

The current phase of the F-35 flight test program concentrates primarily on airframe test. It includes a large amount of sensor data acquisition, and some avionics bus data acquisition. Future phases are scheduled to commence in 2008 and will have avionics test systems, video acquisition systems, and radar acquisition and recording systems. This paper will not discuss the future test phases, but will concentrate on the current airframe instrumentation system and preflight software setup and integration.

The airborne instrumentation system (shown in Figure 1) can be divided into several subsystems categorized by data bandwidth or specific functional tasks. All subsystems are connected via a centralized unit called the Airborne Instrumentation Controller (AIC). The AIC provides single point programming and data sampling synchronization. The subsystems are:

- Wideband Data Acquisition subsystem
- Narrowband Data Acquisition subsystem
- Distributed IRIG-106 Chapter 10 Multiplexer / Recorder subsystem
- Airborne Instrumentation Controller and Cockpit Units

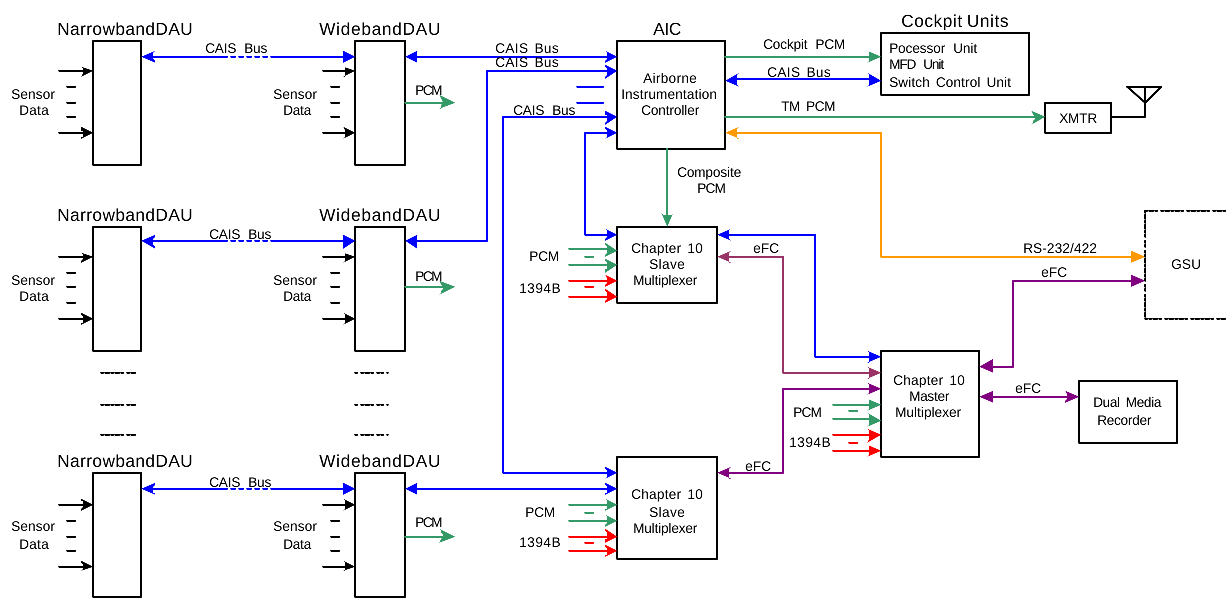

Figure 1. Airborne Instrumentation System

Wideband Data Acquisition Subsystem

The wideband data acquisition subsystem uses eight MWDAU-2000 units (Miniature Wideband DAU), which operate simultaneously as standalone units and as CAIS (Common Airborne Instrumentation System) Bus remote units to the AIC. Each wideband unit includes 10 to 30 data acquisition modules, each providing 2 to 4 acquisition channels for acoustic and high bandwidth sensor data. Each channel has a built-in ADC, which is used for raw data acquisition as well as to develop an RMS data representation of channel data. Each unit operates with its own data format at up to 20Mbps and 16 bits of data resolution. The PCM output from each wideband unit is routed to the on board IRIG-106 Chapter 10 multiplexers for 100% data recording. The Airborne Instrumentation Controller extracts selected RMS data from all wideband units via the CAIS bus under format control for safety of flight transmission.

The wideband subsystem has 300 channels with raw data sampling of 10 KSPS per channel and RMS data sampling of 200 SPS per channel. The combined data rate of all wideband units is 50 Mbps (300 x 10KSPS x 16 Bits per Sample + Overhead) for recording with the capability of achieving a combined data rate of up to 160 Mbps. The combined RMS data rate retrieved by the AIC is about 1 Mbps (300 x 200 SPS x 16 Bit per Sample).

TTCWare software configures the channels and the format of each wideband unit. The same software is used for configuration of the AIC to extract RMS data samples from the wideband units. Since the same software is used for IRIG-106 chapter 10 multiplexer configuration, the software also configures the frame correlator of each PCM input channel of the multiplexer with the frame structure of each wideband unit without reentering the frame structure. This simplifies the user task and minimizes any human errors.

Narrowband Data Acquisition Subsystem

The narrowband acquisition subsystem has twenty MCDAU-2000 (Miniature CAIS DAU) units operating as remote acquisition units to the AIC via the CAIS Bus. Each unit includes an average of 25 conditioning modules for the acquisition of:

- High level analog signals
- Wideband analog
- RS-232 buses including TSPI information
- Bi-level signals (discrete and relay signals)
- Temperature data (RTD and Thermo-couple)
- Strain Gauge
- Synchro/Resolver and L/RVDT sensors
- Accelerometers (including Motion pack)
- Frequency and period measurements
- GPS and Time
- Charge amplifiers

- Pressure
- Many others

The channel density of each acquisition module depends on the type of module and the programmability features of the channels. Many signal-conditioning modules include built-in DSP for programmable anti-aliasing filter using FIR or IIR filters. The filter cutoff frequencies are user-configurable based on format data sampling and over sampling factors. This capability provides significant flexibility in applications where a large number of sensors requiring different data sampling rates and wide variety of cutoff anti-aliasing frequencies need to be instrumented.
The narrowband unit allows for data sampling of up to 417 KSPS with 12-bit resolution or up to 312 KSPS with 16-bit data resolution. All data acquired from narrowband units is collected by the AIC for recording while data subsets are steered to the cockpit display and to the TM.

The narrowband subsystem has about 1400 channels with aggregate data samples of over 1 MSPS total. The contribution of the narrowband data to the AIC bit rate is about 16 Mbps.

Distributed IRIG-106 Chapter 10 Multiplexer / Recorder System

The primary function of the multiplexer recorder subsystem is to acquire all wideband PCM channels and avionics bus data for recording. On the surface this seems a simple task that can be achieved by any off-the-shelf IRIG-106 chapter 10 recording system, but the requirements imposed on such a system required a significant departure from the conventional recording system while maintaining the Chapter 10 standard recording format.
The key requirements include:

- Acquisition of data channels must be as near as possible to the data sources. This is particularly important when acquiring IEEE-1394B buses with maximum length of 20 ft.
- Multiplexer / Recorder system must operate as a data acquisition system for retrieving selected avionics parameters and recorder status information.
- The system must be capable of sustained data record rates of up to 100 MBps. This capability is required to record future avionics Fibre Channel data.
- The entire instrumentation and recording system must use single point programming and must utilize common configuration software to take advantage of frequent bus catalog updates via XML import / export capabilities.

The multiplexer / recorder subsystem used for the F-35 program meets all of the requirements by utilizing three distributed multiplexers and a cockpit mounted dual media recording unit. The three multiplexer units include a master multiplexer called Airborne Instrumentation Multiplexer (AIM) that interfaces with the slave multiplexers and the recording media via a 1 Gbps Fibre Channel bus. Each multiplexer has:

- An IRIG-B time code input
- A CAIS bus to communicate with the AIC for setup and data acquisition
- A modified 64-bit 66 MHz compact PCI bus (cPCI) with four I/O slots

The AIC configures the multiplexers via the CAIS bus for setup and entry of the avionics bus acquisition list. The types of data the AIC retrieves under format control from the multiplexers includes:

- Avionics bus parameters
- Media(s) percentage memory remaining
- Health status on each card and port
- Running count of frames / packets received per port
- Running count of megabytes received per port

The system acquires eight PCM streams from the wideband and AIC units, and up to 12 IEEE-1394B buses. It has several spare slots for the future acquisition of Fibre Channel buses. The cockpit mount dual media receptacle utilizes two 300 GB sealed hard drives or two 98 GB solid-state drives. Both media types are wired using a Fibre Channel arbitrated loop within the receptacle, and interface with the master multiplexer via a single Fibre Channel bus. The user can define which data source should be recorded on which media. Duplication of data on both media is allowed. The current overall PCM aggregate rate is 70 Mbps, and the bus data is 80 Mbps. These rates vary based on the flight test of the day.

The multiplexer / recorder subsystem places the required IRIG-106 chapter 10 TMATS file on the media at the beginning of every recording session. This TMATS file represents only the multiplexer / recorder setup. This was of no use to Lockheed Martin since it did not include any metadata or configuration of the entire system. Lockheed made extensive use of the system configurations and metadata exported by TTCWare using XML files to the FTDCDB.

Airborne Instrumentation Controller (AIC) and Cockpit Units

The AIC is used as the central instrumentation control unit. Every unit in the instrumentation system is connected to the AIC by way of the CAIS bus for setup, system audit, system synchronization and data acquisition. The unit provides up to eight CAIS buses with an average of four to five data acquisition units (Wideband, narrowband, Chapter 10 multiplexer, or Cockpit unit) per bus. Most wideband data is routed directly from the wideband units to the multiplexer / recorder, and bypasses the AIC. The AIC acquires all the narrowband data, wideband RMS data and selected avionics / recorder status from the multiplexers.

The AIC provides composite PCM of 20 Mbps to the multiplexer for recording, and outputs up to four-user programmable PCM streams. Two of the outputs are not used, one is used for TM at 5 Mbps for transmission of safety of flight, and one stream is steered to the cockpit control and display unit.

The TM data includes wideband RMS data, selected IEEE-1394B bus data from the multiplexers, selected recorder status information, selected sensor data from the narrowband units and cockpit unit data including cockpit switch(s) activation information.

The cockpit unit includes the processing unit, the display unit and the switch panel control unit. The cockpit unit has a built-in frame correlator function to acquire and process PCM data from the AIC. Using the TTCWare software configuring tool, the user selects PCM parameters for processing to display data graphically using widgets (LCDs, strip charts, LEDs, labels, dials, status bars, etc), and configures engineering unit conversions. Some of the cockpit-processed data is acquired back by the AIC using the cockpit unit CAIS bus for TM. The processing functions used for the F-35 program include:

• Unprocessed Data (Raw data counts)
• Polynomials (up to 10th order)
• Interpolations / Lookup tables (up to 32 input-output pairs)
• IRIG Time Processing
• Average, Minimum, Maximum
• Derived calculations using a calculator-style interface

The cockpit unit is also used for controlling several instrumentation subsystems under pilot control. This includes instrumentation power, TM On/Off, Upper and Lower antenna control, Recorder(s) control, Event marker, and others.

SOFTWARE

The airborne instrumentation system with over forty separate units was shown to be a highly integrated system capable of interfacing with low bandwidth sensors, high bandwidth sensors and high data rate buses. The interface between the units, subsystems and the software are designed to minimize duplication of work, human errors, automatic update of the latest catalog data, and reduces time from test requirements to test readiness. The discussion here will only concentrate on the preflight software integration system shown in figure 2. Post flight data retrieval and analysis is beyond the scope of this paper. The key interface points of the integrated system are:

- Airborne units
- Ground instrumentation configuration software called TTCWare
- Flight Test Data Center Data Base (FTDCDB)

Airborne Units

The airborne instrumentation system is wired through CAIS buses to the Airborne Instrumentation Controller for programming, system audit, synchronization, and data acquisition. The system provides a single point programming from the ground support equipment using TTCWare instrumentation configuration software. The configuration of each unit type includes:

- **Narrowband units**: card / channel configurations
- **Wideband units**: card / channel configurations, and wideband PCM format
- **Multiplexers**: card / and port configurations, System rules, selected bus data list, and recorder TMATS per IRIG-106 chapter 10

- **Cockpit unit**: Frame correlator setup, EU conversions, MFD pages
- **Airborne Instrumentation Controller**: PCM formats, Programmable secondary PCM outputs.

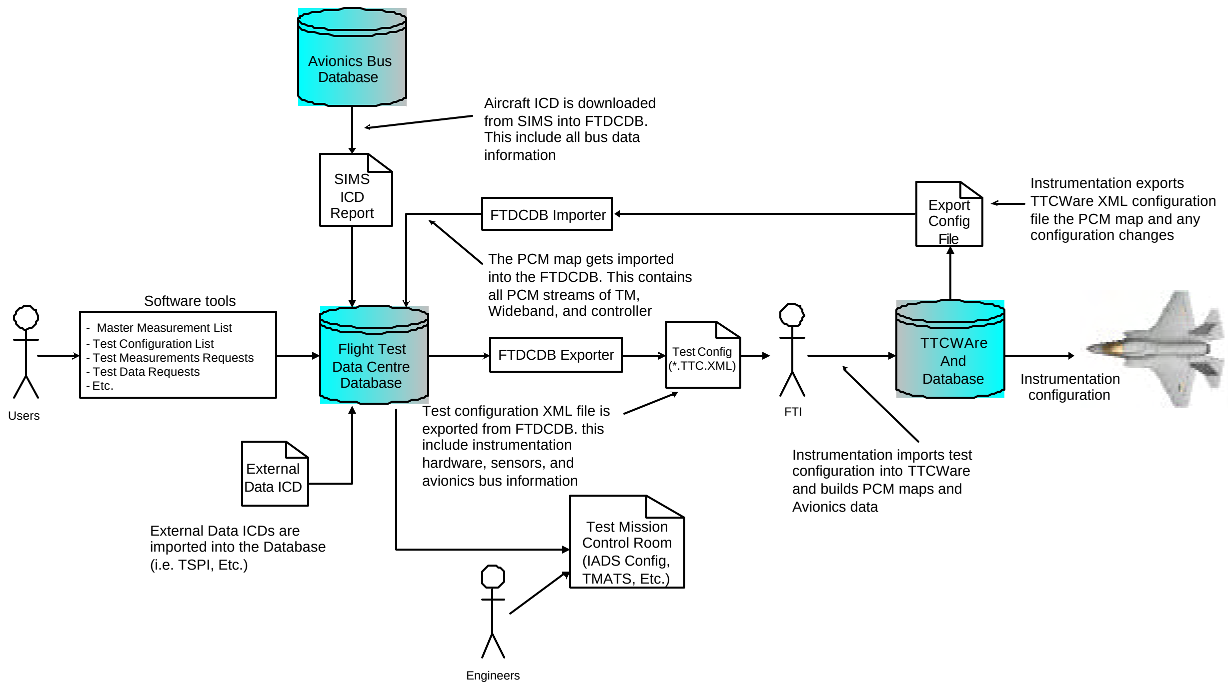

Figure 2. Preflight software configuration

Ground Instrumentation Configuration Software (TTCWare)

TTCWare is the software tool used for configuring the airborne instrumentation system. It allows the user to define the airborne system controller configuration, including the number of CAIS buses, the number of remote DAUs on each bus and the card type / slot on each DAU. The definition of the system can also be done outside TTCWare by using other tools that export the configuration to TTCWare by way of XML files. In the case of the F-35 program the airborne system definition, channel setup, and bus catalog are all defined as part of Lockheed's FTDCDB. This capability was developed jointly between Teletronics (TTC) and Lockheed through an "XML Data Exchange Document" to allow data exchange between TTCWare and FTDCDB. This capability allowed Lockheed and TTC to use their own dissimilar databases and exchange data through XML. The Document defines the vocabulary, Hardware, Parameters, setting ranges and others.

FTDCDB exports the XML file of the system and parameter configurations to TTCWare. TTCWare compiles the imported XML file to generate the airborne system configuration files. The compiler is highly optimized to the specific hardware being used, and therefore only TTCWare is capable of generating the programming files. After programming the airborne system, the user performs ground preflight checkout and tweaks the system by modifying parameter settings though TTCWare. TTCWare exports the latest settings and format structures using XML files to update the FTDCDB with the latest modifications.

Flight Test Data Center Data Base (FTDCDB)

The FTDCDB interfaces with the Avionics Bus Database by using the latest bus catalog through an ICD report. It also uses other ICD reports of other airborne components of the instrumentation system such as instrumentation TSPI unit and others. Users interface with the FTDCDB via Lockheed proprietary software tools to generate the Master Measurement List (MML), Test Configuration List (TCL), Test Measurement Request (TMR), Test Data Request (TDR), and others. The FTDCDB exports test configuration XML file(s) to TTCWare, and imports from TTCWare XML files with the PCM maps, PCM streams, and any configuration changes. FTDCDB exports various files to the Test Mission Control Room with the TM configuration data to include IADS configuration, TMATS, etc.

CONCLUSIONS

It was shown that a good system design of an integrated airborne instrumentation, ground instrumentation configuration software and flight test data center can provide great benefits by reducing the time from test requirements to system readiness, minimize human errors, reduce cost and increase system flexibility.

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