Instrumentation and Data Processing Efficiencies Employed on the P-8A Poseidon System Development and Demonstration Program

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1. ABSTRACT

The P-8A Poseidon is a long-range anti-submarine warfare, anti-surface warfare, intelligence, surveillance, and reconnaissance aircraft. The Test & Evaluation data requirements for the System Development and Demonstration (SDD) phase far exceed any Boeing military program to date. The data requirements include MIL-STD-1553, Gigabit Ethernet, 10/100 Ethernet, NTSC, Video/Audio, ARINC 429, RS232, CAN and PCM data in addition to being CAIS and RTPS compatible.

The strategy for the design of the instrumentation and data processing architecture was to create a common system that could be used for data acquisition and processing for all seven test articles and used for both flight and ground testing. The common approach enables efficiencies and benefits to be shared in all testing and reduces the overall cost to the program.

2. ACRONYMS

AC	Aircraft
ARINC	Aeronautical Radio Inc.
BCA	Boeing Commercial Aircraft
CAIS	Common Airborne Instrumentation System
CAN	Controller Area Network
CDS	Caching Data Server
CIM	Chassis Interface Modules
COTS	Commercial Off-the-shelf
DAS	Data Acquisition System
DP&TRA	Data Processing and Test Requirements and Analysis
DPS	Data Processing System
EMD	Engineering Manufacturing and Development
FDP	Final Data Processor
HSI	Hardware/Software Integration
I&DP	Instrumentation and Data Processing
IBIM	IntelliBus™ Interface Modules
ICCP	Integrated Cockpit Control Panel
INIC	IntelliBus™ Network Interface Controller
IOE	Instrumentation Operations Engineer
IPT	Integrated Product Team
IRIG	Inter-Range Instrumentation Group
ISE	Instrumentation Suitability Evaluation
ITT	Integrated Test Team
MAPS	Multipurpose Acquisition & Processing Station
NDS	Network Data System
NTSC	National Television Standards Committee
PCM	Pulse Code Modulation
PVT	Product Verification Test
RAID	Redundant Array of Independent Disk
RTDS	Real-Time Display Stations
RTPS	Real-Time Processing Station
SDD	System Development and Demonstration
SIL	System Integration Laboratory
SSR	Solid State Recorder
STE	Special Test Equipment
TCP/IP	Transport Control Protocol/Internet Protocol
TM	Telemetry
TRA	Test Requirements and Analysis Engineer
UDP	User Datagram Protocol

3. INTRODUCTION

The P-8A Poseidon is a long-range anti-submarine warfare, anti-surface warfare, intelligence, surveillance, and reconnaissance aircraft being developed by Boeing for the United States Navy as a replacement for the aging P-3 Orion. It is a military derivative of the Boeing Commercial Aircraft (BCA) 737-800 Next Generation Aircraft. The (SDD) program began in June of 2004 with program award and will conclude with initial operational capability in 2013 after an extensive flight and ground test program. The test program will consist of three flight test articles, a static test article, a fatigue test article and two System Integration Laboratories (SILs). The sophisticated mission and stores management systems of the P-8A provide many data acquisition and processing challenges.

The data requirements for the Poseidon program far exceed any Boeing military program to date. The P-8A data requirements include the ability to record, telemeter, monitor on board and process MIL-STD-1553, Gigabit Ethernet, 10/100 Ethernet, NTSC Video/Audio, ARINC 429, RS232, CAN and PCM data. The number of analog parameters on the three flight test articles alone far exceeds the number of analog parameters measured on the seven F/A-18E/F test aircraft during its Engineering Manufacturing and Development (EMD) program. Currently there are close to 11,000 parameters defined for all seven P-8A test articles. Along with all of these parameters comes the additional challenge of data storage. It is estimated that the test flights for test articles T1, T2 and T3 will range in length from 2-8 hours depending on the mission. The average test time being used for planning is 4 hours and it is estimated that one terabyte of raw data will be recorded during an average test flight, with an additional two terabytes for computed data and two terabytes for mission systems data, resulting in more than two pedabytes of data for the entire program. Challenges related to providing fast download capability to a server for test team access, processing, transmitting and storing the data are only a few of those facing the Data Processing Team on the P-8A program.

4. COMMON ARCHITECTURE

In order to meet the data challenges of the P-8A program, a trade study was performed to seek out lessons learned from previous Boeing programs with the hopes of combining the best of Boeing into the next generation data acquisition and data processing system. The primary goal was to develop a common system that could be used for all three test arenas; ground, flight and laboratory. This approach provides the ability to reduce cost and improve information fidelity by ensuring common processes, procedures and tools are used. Another challenge faced by the Instrumentation and Data Processing (I&DP) team is that the P-8A aircraft is being instrumented during production, and therefore, the I&DP equipment must be easy to install in order to support a commercial production schedule.

Figure 1 shows the common architecture design for the P-8A data acquisition and data processing system. The architecture of the I&DP system was designed as a “system of systems" containing five basic systems: Data Acquisition, Recording, Control, Processing and Displays. Hardware, software and systems interfaces were designed to be common across test articles. Some non airworthy equipment was selected for use in laboratory environments and Commercial Off-the-Shelf (COTS) equipment was used as much as possible. The various systems will be discussed in the following sections.

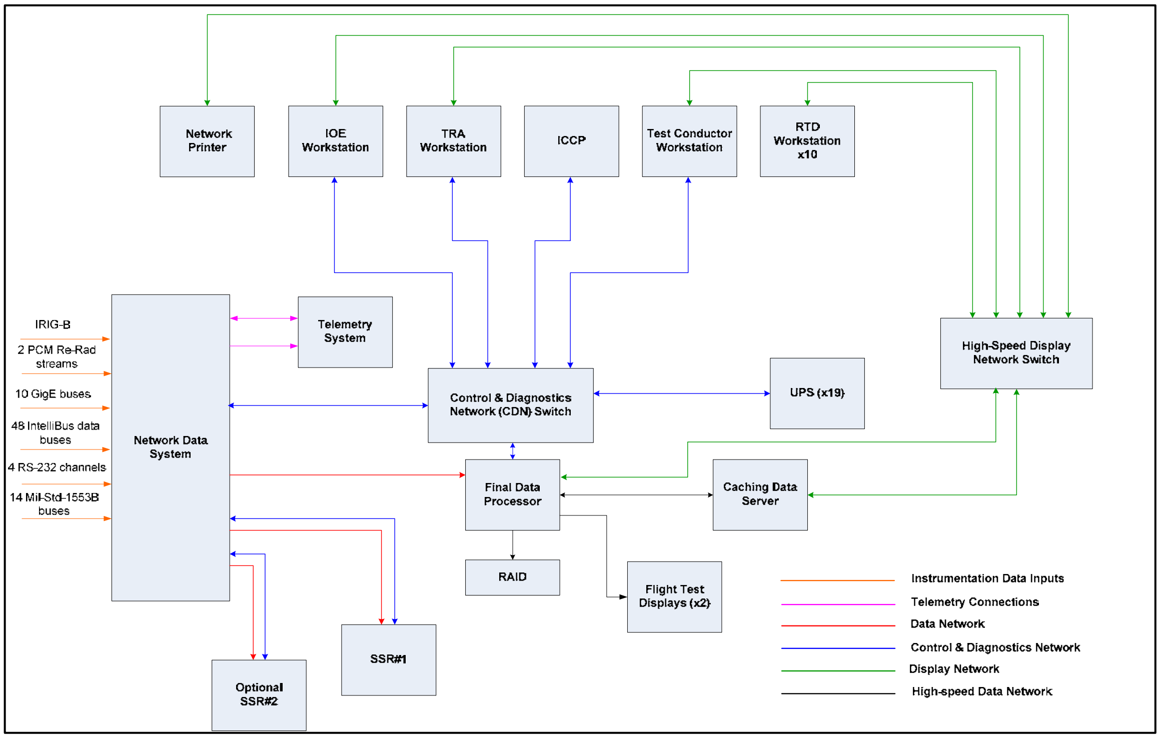

Figure 1: P-8A Data Acquisition and Data Processing Common Architecture Diagram

4.1 Data Acquisition System (DAS)

The principal components of the Data Acquisition System are the NetAcquire™ Network Data System (NDS), IntelliBus™, and a Telemetry (TM) System.

The NDS acts as a gateway between analog, digital and serial data, and the networked systems. It is a system of multiple chassis that collectively gathers test data from multiple sources and integrates them into a single data stream within the NDS. This single stream of data is simultaneously available for multiple outputs for recording, data processing and telemetry transmission. The throughput rate of the NDS is scalable to 400 Mbps, 800 Mbps, and 1200 Mbps. Time tagging is accomplished via an externally provided IRIG-B signal.

The inputs to the NDS include: up to 48 IntelliBus™ buses (including ARINC 429 and analog measurements), MIL-STD-1553, Gigabit Ethernet, 10/100 Ethernet, RS-232, and PCM data streams. There are five outputs of the NDS: one to the solid state recorder

(SSR), two telemetry streams, one to the final data processor (FDP), and a 100BASE-T fast Ethernet interface to control the SSR.

The connection to the solid state recorder is IRIG 106 Chapter 10 compliant. One hundred percent of the real-time raw data stream is sent to the SSR via a Gigabit Ethernet connection using the TCP/IP protocol. An additional output port is available on the NDS to connect a second SSR should the NDS throughput rate grow to exceed the input limit for a single SSR.

The NDS takes selected parameters from all of the input sources and creates two telemetry streams. These two streams consist of selected parameters from: the IRIG 106 Chapter 4 stream (5 to 10 Mbps) which consists of IntelliBus™ or PCM data, and the IRIG 106 Chapter 8 stream which consists of parameters from the 1553 buses. The NDS accommodates and stores up to four IRIG Chapter 4/8 TM formats which can be selected and changed during a test allowing multiple types of maneuvers and tests to be performed during one flight.

The output to the final data processor is via a Gigabit Ethernet connection using the UDP broadcast protocol. One hundred percent of the real-time raw data stream is sent to the FDP. An additional Gigabit Ethernet port is available should the volume of the raw data exceed the capacity of a single Gigabit Ethernet conductor.

The NDS can be controlled by the Instrumentation Operations Engineer (IOE) work station or the Instrumentation Cockpit Control Panel (ICCP). The IOE work station controls all NDS functions and configures the NDS for recording characteristics. The Instrumentation Cockpit Control Panel has a limited set of NDS functionality but it does allow the I&DP system to be controlled from the cockpit when test crews are not onboard during flight testing.

4.2 Recording System

The I&DP system on the P-8A program uses two recording systems. On flight test aircraft a solid state recorder is used to collect raw data from the Data Acquisition System and a RAID recorder with removable memory is used to collect computed data from the Data Processing System. Ground and laboratory test articles, not requiring ruggedized hardware, use some COTs and non airworthy equipment including the RAID recorder.

4.3 Control System

The control system is made up of the ICCP, the Test Requirements and Analysis Engineer (TRA) and the IOE stations. This system contains all of the components through which the operational commands for the I&DP system are entered. The ICCP enables the flight crew to control the operation of the I&DP system. With the press of a single button the entire acquisition and processing system can be powered up and ready to acquire and display data. The ICCP was designed for operational control with minimal crew on board and enables the system to be powered up and acquiring data very rapidly.

Most of the I&DP hardware is installed in 19 inch racks commonly known as MAPS Racks, (Multipurpose Acquisition & Processing Stations). There are four basic configurations of MAPS Racks: Instrumentation Operations Engineer (IOE) Station, Test Requirements & Analysis (TRA) Station, Utility Rack, and Real Time Display Stations (RTDS).

The core I&DP system is installed in the IOE and the TRA MAPS Stations. Sensors, data acquisition signal conditioning and the telemetry system are not. The MAPS Racks that are used for flight were designed to meet the environmental requirements of the P-8A program. The laboratory MAPS Racks are COTS. The installation of the MAPS Rack is considered to be a single item, orange box, thus an entire subsystem of I&DP hardware has one part number and one installation. This is a significant reduction in the effort for installation engineering and installation planning. Multiple configurations of the MAPS Racks were designed to meet the operational needs of the individual test article but the electrical interfaces and disconnect panels have been standardized across all I&DP systems.

The TRA and IOE MAPS stations each provide full system control at either workstation. These workstations control the loading of all configuration and setup files for the I&DP system which include configuration files for the instrumentation system, NDS, FDP, CDS and display stations. The dozens of system load files are created from the central data processing database and can be loaded in one operation. Once loaded and during a test, these stations are used to control which parameters are recorded on the SSR, passed to the FDP for computations, displayed on the monitoring stations and transmitted in the TM stream.

4.4 Data Processing System (DPS)

The Data Processing System (DPS) is responsible for converting the raw data from the NDS into scaled engineering parameters for both real-time and post test analysis and is comprised solely of the Final Data Processor (FDP). The FDP does more than just scale data. It accounts for instrumentation sample delays, initializes parameters to zero or a reference value, properly time aligns parameters from multiple data streams, merges additional data sources, and performs complex computation tasks. Behind the scenes of the FDP is a historical database that contains the parameter information necessary to perform the derived computations to render data for analysis. This database is completely historical and information pertaining to the methodology, equations and coefficients used in computations is available for every computed parameter, and all changes are tracked by test number effectivity. This historical database preserves computation and calibration history and ensures computation consistency across test articles in addition to traceability. Since the data processing occurs during the test, usually on board an aircraft detached from the central database, database synchronicity and configuration management of all load files required to operate the system is essential. The database tool efficiently tracks all of this information and enables the data processing system to be used both in real-time monitoring and post test analysis for both flight and ground testing.

During real-time, the FDP feeds computed data to the real-time display system for monitoring by Integrated Test Team (ITT) members, and the RAID recorder for storage. It receives all of the data from the NDS through Gigabit Ethernet lines and has the capability to scale all data types handled by the NDS. It can selectively send scaled and computed data to either the RAID recorder, the Caching Data Server (CDS) or both simultaneously. Originally it was thought that two different devices would be needed to scale and compute data, however, the FDP design can handle all of the data fed to it by the NDS, and so the second device is not needed. The computed data set is loaded into a data server after the test allowing immediate access to all test team members for analysis.

During post test, the FDP is used for any re-computing of test data in addition to specialized processing such as spectral analysis. The concept of operation for the flight test program is to transmit the raw data from the remote sites back to a central computing facility and recompute the data prior to storage. This is due to the large quantity of data and the efficiency and speed of the FDP computations. It is faster to transmit the raw data and recompute the data for the entire test rather than to transmit both the raw and computed data sets. The central storage repository for all of the test data ensures all analysts have access to the most recent, accurate version of the data. The data is stored in a standard data format used by a majority of the existing analysis tools and translator tools have been developed for those that are not compatible. This has alleviated the need to store the large quantities of data in more than one file format.

4.5 Display System

The display system consists of the caching data server and the various real-time display stations (RTDS) used by the test conductor, TRA, IOE and aircrew. The onboard I&DP test crew will occupy the seats in front of the IOE and TRA stations and system technologists will be seated at the RTDS stations. IADS®, purchased from Symvionics, is being used for real time display and analysis of flight test, ground test and laboratory data. This common software allows for consistency and enables engineers to use tools in flight that they have become comfortable with in the lab. The IADS® software, combined with the caching data server, allow users to pause, rewind and playback data during tests while still gathering data in the background. This has allowed for the removal of paper strip charts and enabled the capability for data to be reviewed in debriefs immediately following tests.

The display system capabilities include the ability to create a set of standard displays that can be used by all test participants, including the flight crew, and the ability for those monitoring the test to modify and create their own displays. Changes or additions made during tests can be stored for future tests. Displays created for one test article can also be shared with other articles ensuring a consistent look that allows for a simplified transition of the test team from one test to another and adds an element of safety as well.

The ability to monitor a test on board the aircraft will have great benefits for the P-8A program. The capacity of the 737 allows the test team to be on board for monitoring along with the data processing system. Having the data processing system on board enables the real time displays to include the complex analysis computations and for first pass data to be available at the completion of the test. This has enabled the P-8A flight test program to plan an aggressive flight schedule. Previous flight test operations relied on limited real time data via telemetry or post test processing to clear test points. Flying the test crew at the IOE, TRA and RTDS station with real time raw and processed data available for review will allow test points to be cleared in a more expeditious manner than in the past.

5. INTELLIBUS™

The Boeing developed IntelliBus™ data acquisition system, a subsystem of the DAS, is responsible for the collection of analog signals and ARINC 429 bus data. IntelliBus™ consists of a bus controller called an IntelliBus™ Network Interface Controller (INIC), a 2 wire data bus and multi channel signal conditioners called IntelliBus™ Interface Modules (IBIMs). The system is easily expandable by adding prefabricated cables and IBIMs and it is also ready to accept smart sensors as they become available. An IntelliBus™ bus has a maximum length of 300 feet and can accommodate up to 64 IBIMs or nodes. The IntelliBus™ bandwidth is 15 Mbps with a 5 Mbps payload.

Traditional data acquisition systems install one or more chassis full of signal conditioners in remote locations of the aircraft. Signal and excitation wiring is run from the remote chassis to the sensors. Using IntelliBus™, IBIMs are located in close proximity to the sensors or signal pickup points thus reducing the amount of wiring associated with traditional data acquisition systems. IntelliBus™ is a less complex system because it does not use overhead modules associated with remote chassis, there is a limited common set of connectors and no disconnect panels are needed. The P-8A program has avoided an estimated $3M in fabrication and material charges for connectors, cables, and installation chassis by using IntelliBus™. Weight savings due to reduced wire count and connectors are still being calculated.

INICs are installed in the NDS chassis. Each INIC controls (4) IntelliBus™ buses and has an Ethernet output which connects to a switch in the NDS. Up to 12 INICs can be installed in the NDS which allows the implementation of up to (48) IntelliBus™ buses for the I&DP system.

An IBIM consists of the signal conditioner package, bus wiring with connectors and a signal wiring pigtail. The IBIM package is smaller than traditional signal conditioners and its design allows it to be bonded to aircraft surfaces instead of using fasteners.

Some areas on the test articles have a high concentration of sensors requiring more IBIM installations than desired so a chassis solution was designed. This chassis was designed to accept plug-in IBIMs, IntelliBus™ bus connections, and (1) D38999 connector for signal interface. The plug-in IBIMs are called Chassis Interface Modules (CIM Modules) and the chassis is called a CIM Chassis. Up to eight (8) three (3) channel CIM Modules can be plugged into a CIM Chassis providing (24) data channels with this single installation. The CIM Chassis is a single node on the IntelliBus™ and is reconfigurable in the field.

6. HOW DO WE KNOW IT WORKS?

All parts ordered for the I&DP team are received by a single contractor. Upon receipt, they are logged into the receiving system, kitted and delivered directly to the P-8A Instrumentation & Integration Lab in less than 24 hours.

The I&DP system is tested and verified in accordance with St. Louis Boeing Flight Test Instrumentation Procedures. Individual component or subsystem performance is validated through calibrations or an Instrumentation Suitability Evaluation (ISE). Upon completion, each I&DP system is incrementally built and tested in the Hardware/Software Integration (HSI) phase. Test inputs are provided with a Bus Simulator STE (NetAcquire™) and a hot bench mock up of the aircraft data acquisition system. All I&DP cable designs will be validated on the Hot Bench during HSI before manufacturing the final set that goes in the MAPS Rack. The final test in HSI is conducted with the complete I&DP system outside of the MAPS Racks. This will provide a baseline to support troubleshooting, if required, in the Product Verification Testing (PVT) phase. When HSI integration testing is complete, PVT begins. PVT is conducted with fully populated MAPS Racks, interconnecting cables, a hot bench to simulate aircraft signals and the Bus Simulator STE. The PVT testing provides an end to end test of the entire I&DP system before it is shipped for installation. This is an important step as it provides another baseline of the system and will help reduce the amount of start up time after installation into the aircraft or test lab. The MAPS Racks are shipped and installed fully populated with I&DP hardware and software.

7. CONCLUSIONS

Below is a list of the Data Acquisition and Data Processing System efficiencies.

- Common software for flight, ground and laboratory testing
- Common interfaces between systems
- Common interface between I&DP MAPS Racks
- Same data acquisition system used for ground and flight test
- Common data stream for recording and data processing
- All raw data recorded on solid state recorder and available for real-time monitoring
- First pass final data available immediately upon test completion
- Onboard test monitoring expedites clearing of test points

- Cockpit control of I&DP system for high risk flights
- All data available for selection real-time for IRIG 106 chapter 4 or 8 telemetry transmission
- St. Louis MAPS Station for training, upgrade verification and field test support
- MAPS Rack cabling designs verified in HSI testing before production of cables begins
- Incremental Hardware Software Integration performed prior to PVT to reduce risk
- End to End Product Verification Testing before installation of I&DP system
- Reduced installations for data acquisition system
- Reduced fabrication and material cost for data acquisition due to IntelliBus™
- Reduced installation engineering and planning effort for core I&DP system
- Systems designed for growth and expansion
- Data acquisition system accommodates smart sensors

8. ACKNOWLEDGEMENTS

The development of the P-8A data acquisition and data processing system is a result of the hard work and dedication of the entire P-8A Instrumentation and Data Processing (I&DP) Team. This paper is a compilation and summary of two years of requirements gathering, design, coordination with vendors and testing. We thank each I&DP team member for their contributions to the development of this system and this paper.