Modernization of U-2 Dragon Lady Flight Test Instrumentation System and Utilization of Airborne Datalink for CH10 Telemetry

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ABSTRACT

A demand for improvements in infrastructure and increased flight test demonstration cadence has resulted in a boom of flight test activity for the U-2 Dragon Lady, which celebrated its 65th year of flight in 2020. Upgrades in airborne instrumentation hardware and the utilization of a networked data acquisition infrastructure have allowed U-2 Flight Test Instrumentation (FTI) to meet the requirements of modern flight test while minimizing modification impacts. These upgrades resulted in a flexible telemetry system that can be deployed on any U-2 fleetwide.

Keywords
IRIG 106 CH10, CH7, Datalink, Network, Telemetry

HISTORY

Since its first flight in 1955, the U-2 has been in a never-ending state of evolution, constantly improving aircraft performance and adding capabilities to its payloads as technology improves and mission diversity increases. Instrumentation has played a critical role in the U-2 development cycle, providing engineers with the necessary information to close the loop between models and empirical data in test and operational environments.

For decades analog acquisition and recording methods were used to capture flight test data, using basic analog signal conditioning and magnetic tape recording media until the late-1990's. Magnetic tape introduced many inefficiencies, requiring near-real time playback and dubbing in order to process the data, and resulted in a high re-fly rate for instrumented flights due to recorder errors. Near the end of the 20th century the program upgraded to a digital data acquisition system (DAS) and solid-state recorder system that incorporated modern digital acquisition and conditioning tools, and reduced recorder fault re-fly rates to near-zero.

As the use of unmanned vehicles in reconnaissance grew, the U-2 program had the threat of retirement hovering over it throughout the early 2000's, reducing flight test opportunities and the budget to keep up with advances in instrumentation methods and hardware. For much of the flight test performed in the early 2010's, there was no dedicated airframe to use for flight test; fielded aircraft were loaned to flight test as-needed. In 2018 imminent retirement directives were lifted and plans for upgrades to the aircraft and its payloads began, all of which would need flight testing and a resulted in the requirement for a dedicated flight test aircraft.

LEGACY SYSTEM

The status quo "legacy" acquisition system designed in the late 1990's and used throughout the early 2000's was comprised of a centralized Solid State Airborne Data Acquisition System (SS/ADAS) rack located in a pressurized equipment bay that all sensor and bus signals were routed to.

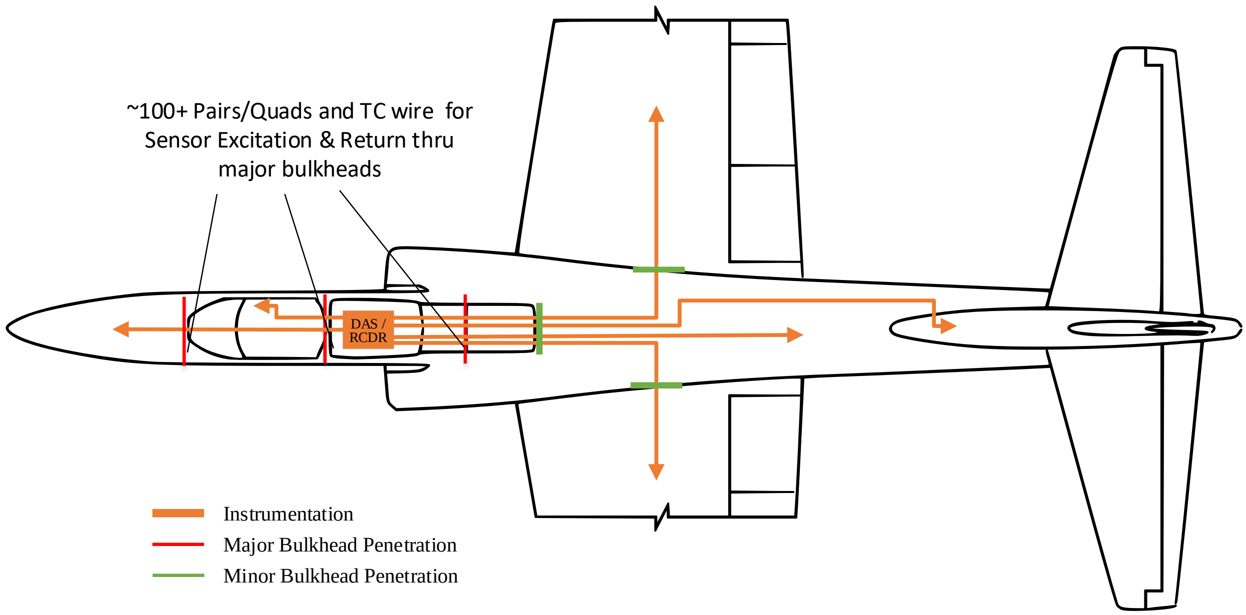

Figure 1: Legacy DAS/Recorder System

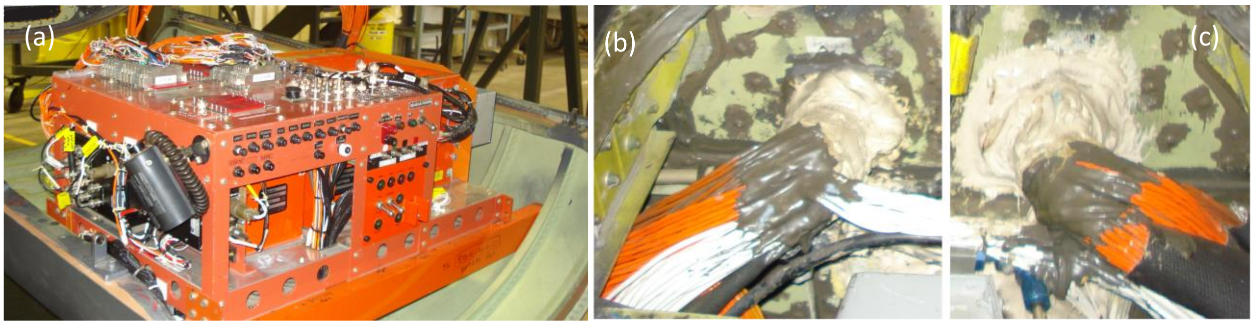

Figure 2: (a) Legacy SS/ADAS rack on equipment bay hatch, (b)(c) wiring bundles routed through aft pressure bulkhead

This configuration resulted in a large amount of orange wire that had to be routed from all extremities of the aircraft through pressure bulkheads, forcing major modification to bulkheads and severely limiting the ability to expand data acquisition as requirements grew. Due to the physical size of the of the SS/ADAS, it could only be mounted in a single compartment on the aircraft. Extensive modification was required if external locations needed to be instrumented on non-orange wire aircraft.

A Quick-Reaction Instrumentation Package (called the "Clip-In"), essentially a smaller version of the SS/ADAS system, was created to be 1553 bus recorder. While smaller than the SS/ADAS, the Clip-In still suffered from still being too large to place in remote areas of the aircraft, limiting its usefulness beyond bus recording or analog acquisition in the mounting bay. As dedicated flight test ended and transitioned to an as-needed basis the SS/ADAS became unused and the Clip-In was exclusively used for drop-in instrumented activity.

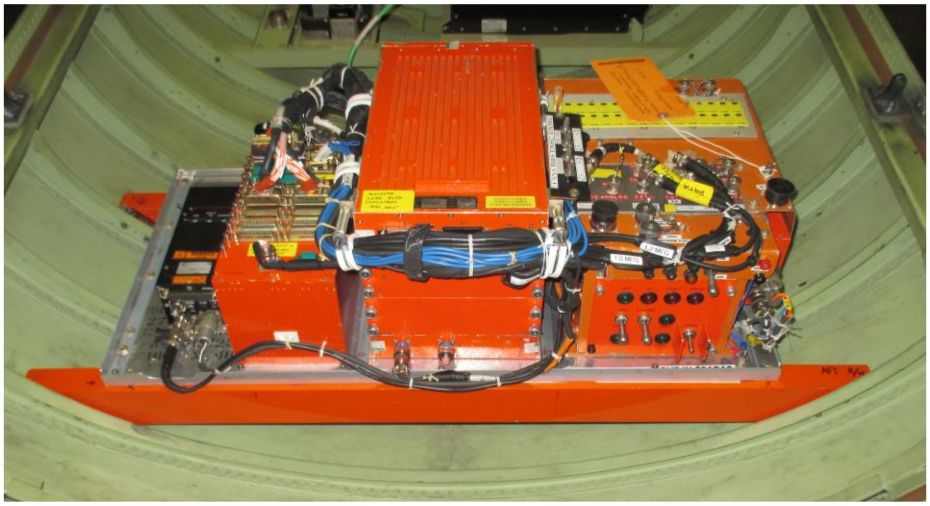

Figure 3: Clip-In Instrumentation Package

For both the SS/ADAS and Clip-In, preflight configuration and postflight data download required that the equipment hatch be lowered for access. To validate data during preflight a tap or secondary output of the PCM stream had to be accessed and a decommutation box was needed to display the data on a shipside computer. Media had to be removed and downloaded to an external workstation, and then formatted and reinserted before the next mission. All this added time (maintenance action), risk (hatch removal, potential equipment damage), and cost (for hardware for output and decom, maintenance crew) to basic operational activities.

SYSTEM REQUIREMENTS

In late 2019 U-2 program management requested that a dedicated flight test aircraft be instrumented in anticipation for the ramp-up in flight test activity. The FTI team was given no requirements other than to develop an "orange-wire" system to support flight test for the foreseeable future and accommodate a one-time major modification window in early 2020. After weighing the capability and limitations of the legacy systems, the FTI team decided to move forward with developing a new data acquisition system. The new system had to be expandable, maintainable, and telemetry capable.

Without being given an explicit list of parameters that had to be acquired, the system needed to have a basic capability that could grow over time as requirements developed. Since the system needed to be installed in an aircraft that could potentially be fielded, the modifications needed to be non-permanent and easily revertible. The system also had to be accessible and serviceable without driving major aircraft maintenance.

Telemetry capability was the final requirement, as upcoming test programs would have a need for data in real time. With no existing provisions for a dedicated airborne transmitter on the aircraft or telemetry receiver on the ground, a system that could integrate with existing aircraft hardware for datalink to a ground station was needed. Since the aircraft can carry multiple different configurations of communication equipment depending on the mission, having a variety of telemetry output types (CH4/CH7 PCM, CH10 UDP data) was a necessity for any new system.

SOLUTION SYSTEM

The solution system, the Distributed INstrumentatiOn Sensor AcqUisition and Recorder (DINOSAUR), is comprised of a central Safran Data Systems MDR Recorder, 5 distributed XMA data acquisition units, cockpit media and control unit, and a Telspan Data ethernet switch. Each DAU collects data from sensors local to its area and packetizes the data for transmission via ethernet back to the recorder. Locally collecting sensor data and transmitting via ethernet means only 2 cables are needed per DAU back to the "Core" system, one for ethernet and one for power. This alone reduced the amount of wiring going through aircraft bulkheads by 95% compared to the legacy SS/ADAS system.

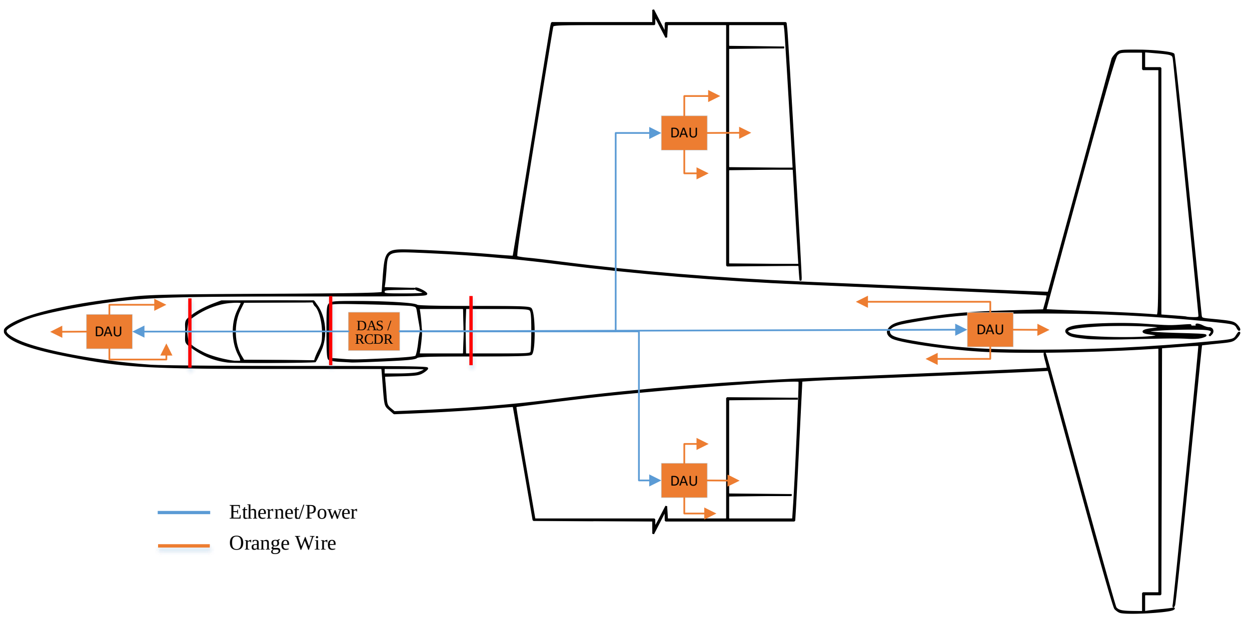

Figure 4: Proposed Networked FTI System

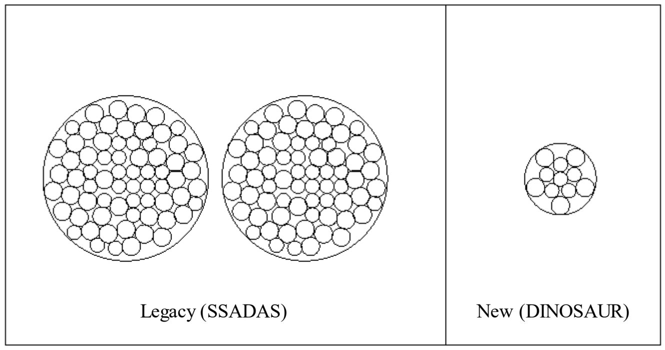

Figure 5: Wire Bundle through Pressure Bulkhead Size Comparison

Configuration and monitoring of the entire system can be accomplished by connecting to the Core system via ethernet through the cockpit control panel, eliminating the need to lower hatches or remove panels to gain access. The MDR recorder and DAUs have built-in health and status reporting, which give the user visibility of unit temperature and channel status.

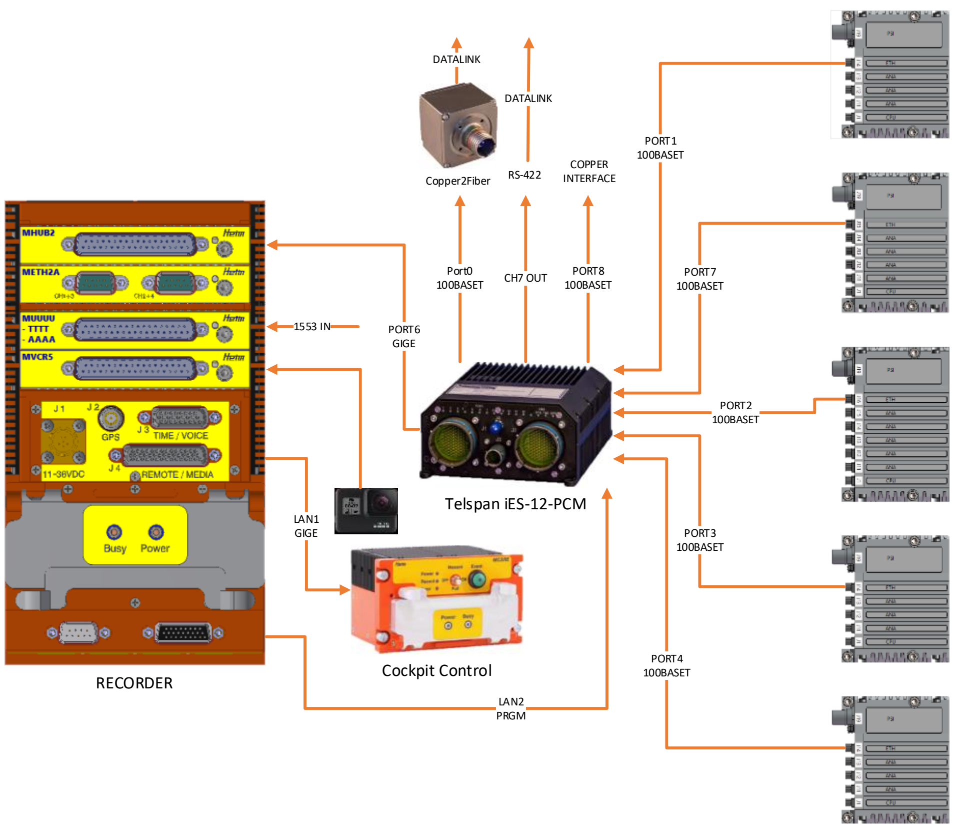

Figure 6: DINOSAUR Data Acquisition System Topology

Data download is accomplished via ethernet or media docking. The ability to download via ethernet has reduced the amount of time to download by nearly 60% making it possible to present data at debrief. One incredibly useful feature of the MDR recorder is that it can be configured to make separate streams for telemetry and for multiple media canisters. For example, if there is a data canister installed in the recorder and one in the cockpit control panel, the MDR can be configured to save full-rate data to the internal media, a filtered subset for presentation at debrief in the cockpit media, and another filtered stream for telemetry.

The DINOSAUR system ultimately fulfilled all requirements of flight test: expandability through DAU modularity and localized sensor wiring, maintainability due to remote configuration and reduced size, and built-in telemetry capability.

TELEMETRY

Telemetry has been relatively underused for the past 20+ years on the U-2 as most programs on the platform do not require real-time data or have their own monitoring via aircraft datalinks. With the revival of flight test, programs are now beginning to require data during missions for real-time validation and safety monitoring. Since the early 90's telemetry was accomplished by sending PCM data to a serial port on the datalink, then routing the data from the datalink ground station to the telemetry ground station OS/ 90 rack and display stations. This method limited the telemetry bandwidth to under 1.5Mbps, a significant bottleneck in the usefulness for real time applications as data demands increased.

Without the ability to make modifications for a dedicated telemetry transmitter on the aircraft or to procure receiver antennas and ground equipment it was decided that the legacy method of using the datalink for telemetry was the most realistic option given the timeframe for implementation.

Recent improvements in datalink hardware on the U-2 have enabled ethernet connectivity with the datalink, which then can be switched its end-user via existing ground networks. By using the MDR recorder's ability to output a filtered CH10 UDP stream from the recorder, connecting to the datalink ethernet port allows the FTI system to operate in a unified, end-to-end CH10 environment from airborne acquisition to ground station display. By integrating into the datalink ethernet architecture, overall FTI available bandwidth increased to 50+ Mbps for dedicated instrumentation flights.

The new CH10 topology also simplified the entire ground network required for real-time information requiring only the recorder, datalink, and a workstation connected to the datalink ground terminal for display and command & control. This new system eliminated all the legacy PCM formatting, receiving, amplification, bit synchronization, and distribution hardware required on the ground.

In case the aircraft configuration needed to revert to the legacy non-ethernet datalink, the FTI system also had to support PCM telemetry. Both the MDR recorder and Telspan ethernet switch can perform gateway functions and convert a defined CH10 stream into a CH7 bit stream. With an additional Telspan gateway on the ground, the CH7 stream can be easily converted back into a published CH10 stream for display in the control room. By using a gateway, the recorder stream can remain CH10 in configuration and prevent the need to build PCM maps by hand.

QUICK-REACTION PACKAGE

While the DINOSAUR significantly reduced the amount of modification required for installation and the Core system and rack was designed to be able to be installed on any aircraft, it still was too large for rapid deployment and installation on fielded aircraft that need instrumentation for troubleshooting. MIL-STD-1553 bus acquisition, integrated recording, and telemetry output capability ultimately were the minimum requirements for a quick-reaction package, with analog sensor acquisition as a peripheral requirement.

Ultimately the Miniature INstrumentatiOn Telemetry AcqUisition Recorder (MINOTAUR) was designed to meet these requirements. The MINOTAUR consists of a single Safran Data Systems XMA stack with internal timecode generation, CH4 or CH7 output from the CPU module, 32GB onboard memory, Ethernet connectivity for DAU configuration and Ch10 UDP output, 2 MIL-STD-1553 buses, 2 channels of 10/100BASET Ethernet bus capture, and 24 channels of generic analog inputs (ICP, Thermocouple, Bridge, etc…) all housed in a 7.5” x 7.5” enclosure.

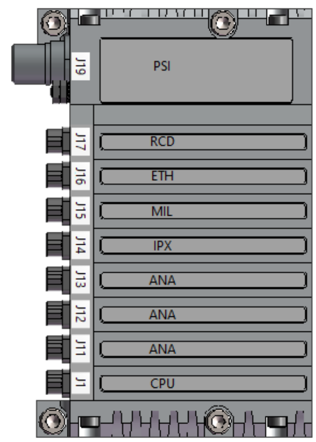

Figure 7: MINOTAUR Quick Reaction/Rapid Installation Prototype

In this configuration the MINOTAUR exceeds all the required capabilities and then some, and significantly outperforms the legacy Clip-In package in size, weight, and built-in capability. The MINOTAUR’s compact size makes it ideal for installation at multiple points on the aircraft if localized analog (accel, strain, thermocouple, etc.) measurements are required for pop-up troubleshooting.

CONCLUSION

Converting to a unified end-to-end networked CH10 topology has eliminated the need for PCM mapping, significantly reduced the hardware required for onboard acquisition, and led to significant size optimization. Adopting modern FTI hardware also made it possible to have a standalone acquisition/telemetry/recorder unit available for fleetwide troubleshooting and flight testing with zero modification. The modernization efforts have resulted in reduced configuration effort, increased data acquisition, recording, and telemetry capability, and enabled flexibility that will enable the FTI system to expand as requirements grow over the life of flight test.