An Integrated Real-Time Turbine Engine Flight Test System

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Abstract

New developments and modifications to existing gas turbine engines require qualification through extensive ground testing followed by flight testing. An increasing work load necessitates productivity improvements in the test platform utilization and the telemetry ground station.

This paper addresses the application of a compatible family of commercial off-the-shelf telemetry systems for quick-look to ensure data integrity on board the Boeing 720 test platform, and a distributed architecture ground station to serve multiple engineering disciplines through the use of an acquisition subsystem serving data to independent color graphics workstations via an Ethernet local area network.

Introduction/History

Garrett began flight test in 1963 to support turboprop engine development and demonstration on a modified A-26C. In 1977, a Falcon 20 was added to the flight department to provide a turbofan test platform. The original A-26 was replaced by a B-26K (an updated version of the same aircraft) in 1980 to accommodate turboprop engine growth. In 1987, a replacement vehicle for the B-26 was needed to allow testing of a greater variety of engines. This prompted the purchase of the existing Boeing 720 now operating as a testbed for the “pusher” turboprop. The generic pylon adapter and the easily configurable data acquisition system allows testing of many types of engines on the Boeing 720.

Previous System

Data acquisition, prior to the implementation of PCM at Garrett, was performed by ruggedized analog recording equipment and computer-controlled data logging equipment. The analog equipment was used to record data on-board the aircraft and to display only basic safety of flight and data confidence parameters. The need for precise measurement was filled by a data logger patterned after the test cell computer systems.

The basic structure of the data logging system was a computer-controlled multiplexer with a precise A/D converter. Once digitized, the data was fed back into the controlling computer and routed to a digital tape recorder.

After the flight or ground test was completed, the digital data tape was removed from the aircraft and carried to a central data acquisition computer network. The data was then corrected, reformatted, and sent to the Cyber computer used in Garrett's engineering department for data manipulation and engine modeling analysis.

In 1977, an FM telemetry link consisting of 21 VCO channels was installed to allow real-time monitoring of analog engine data. This system has provided a reliable data link for many programs and continues to be a valuable asset.

Ground Station Goals

The ground station has traditionally provided only twenty real-time analog parameters to strip charts and a "slave" computer CRT to repeat the data of the on-board data logger. This slave CRT was fed by downlinking the RS-232 signal from the on-board system through a special VCO in the FM telemetry link.

The primary goal of the new ground station data displays (Figure 1) is to allow real-time digital and analog display of ALL parameters in the on-board acquisition system. IRIG standard equipment was selected so Garrett Flight Test could conform to the flight test industry standards rather than the company standard for data acquisition.

A second goal of the ground station is to provide expeditious transfer of flight test data to Garrett's engineering department.

New System Requirements and Objectives

The new ground station equipment has two primary tasks. First, the system is required to offer real-time display of all data parameters in engineering units. This requirement includes the display of parameters calculated from multiple raw data measurements and the analog output of any parameter in scaled engineering units to strip charts.

The system's second requirement is to provide data to the Cyber engineering computer system. The data has to be in a format identical to that coming from both the test cell computer and the previous flight test data logger. The data transferred from flight test has to be identical in form, fit, and function to eliminate new software development on the existing engineering computer programs.

On-Board Data Acquisition System

Sensor Description

The parameter list for turbine engine flight test consists primarily of pressure and temperature measurements. In 1984, the flight test department established a goal to condition and convert all possible parameters to high-level, single-ended (0 to 5 VDC) form as close to the sensor as possible. This practice has changed the discrete sensor inventory to newer technology and has provided the base for simplified on-board systems. Full bridge pressure transducers requiring external signal conditioning are being replaced by amplified devices that offer high-level, single-ended output. These new transducers no longer require regulated excitation voltage, and the ripple effect through the sensor inventories has eliminated the need for complex signal conditioning and amplifiers.

Encoding System

The aircraft-mounted data gathering hardware (Figure 2) is divided into two major areas. A cabin-mounted encoding system and an engine mounted encoder are tied together through a digital interface that allows the engine-mounted hardware to appear as an extension of the main encoder. The entire system is under program control and is configurable on a test-by-test basis so the input range of each parameter can be optimized.

The cabin multiplexing system consists of a 12-bit Aydin-Vector PMU-700 encoder with internal analog, bi-level, counter-timer, and ARINC-429 signal conditioning. This master encoder has an internal time code generator that provides embedded time in the data stream and is externally tied to a Datum time code generator for synchronization of recording systems. The master encoder has a satellite temperature multiplexer providing PAM data into the analog inputs at the system minor frame rate. A pressure scanning system, which is tied to the master encoder word rate, provides digital corrected pressure data in engineering units in some of the bi-level input lines. Engine control and operating data from the test engine fuel control computer is fed into one of the four input channels on the ARINC-429 module.

The engine mounted multiplexer, acting as an extension chassis, is a 10-bit Aydin-Vector MMP-900 encoder tied by way of a 10-wire interface to the master encoder. When the 10-bit data is fed through the interface module in the master encoder, the two missing bits are added to each data word, simplifying data decommutation. The engine-mounted encoder has internal analog, bi-level, counter-timer, and thermocouple signal conditioning. For measurements requiring greater resolution or accuracy, a patch network of both thermocouple wire and instrumentation wire is provided to allow engine parameters access to the cabin-mounted equipment.

New System Architecture

Both the on-board “quick look” and ground station telemetry data acquisition and processing systems employ the same architecture. Common function modules are interchangeable between both systems to reduce the requirement for spares. The “quick-look” system is based on Loral Instrumentation’s ADS 100. The ADS 100 is a complete system in a box, providing bit synchronization, frame synchronization, decommutation, data distribution, IRIG time data, and analog outputs. The ground station system is based around a System 500, which extends the ADS 100 architecture to enhance and distribute data display and control. The data display and control functions are made available to multiple color graphic workstations through a local Ethernet network.

On-Board Quick Look System

The ADS 100[1] includes an integral display for viewing tabular data, bar charts, and graphs, and for setting up the system. The user interface is friendly and easy to use. Flight test engineers set up the system via a menu-driven, selfprompting series of commands and page displays. Data entry is made easier by an anticipation mechanism that attempts to complete the command with a minimum of key strokes. Page definition is simplified by cursor keys and the “next” key, which allows the operator to see quickly the complete library of allowable entries for many fields. Programmable function keys are also available to automate command sequences and data entry operations. All data base and module setup information can be saved for later use with the integral 3 1/2-inch floppy disk drives.

Modules, in the ADS 100 (Figure 3), provide real-time processing, data compression, equation processing, and analog outputs (for driving on-board discrete displays). A complete PCM simulator in the ADS provides essential system setup and troubleshooting capabilities. Additional modules are available to provide MIL-STD-1553B bus monitoring, analog input, computer interface, disk and tape storage and control, multiple stream handling, etc. This expandability of the ADS 100 allows easy configuration for any future on-board needs without major system changes.

In hardware and software, the ADS 100 has a multiple bus architecture. This architecture facilitates expansion at the module and chassis levels. The system is organized around two independent buses: the Microprocessor bus, and the MUXbus.

The Microprocessor bus provides the setup and control interface for all modules in the system. It also allows the system microprocessor to access resources for user interface functions and for various background tasks. In addition, several modules have on-board processors, which apply distributed processing techniques to specific real-time tasks.

The MUXbus is a high-speed, 4 million word-per-second, real-time data bus. It is fully arbitrated in hardware and implements a data flow architecture for all modules that acquire or process real-time data. The MUXbus consists of 16 data bits, 12 tag bits, three stream bits, and one alarm bit. The 12-bit tags are data identifiers and are used to control data distribution. The alarm bit is used by the ADS 100 integrated alarm handling system. Each incoming data word is checked against upper and lower limits. Limit violations are flagged via the alarm bit on the MUXbus. The alarm bit can signal other modules to take action based on the alarm (data display, audio alarm, function key execution, etc.).

The MUXbus priority scheme is based on a rotating priority. A module places data onto the MUXbus and the arbitration circuitry latches the request and checks the priority of the module. If no higher priority requests are pending, the arbitration circuit allows the requesting module to place the tag and data onto the bus. Data on the MUXbus is available to all modules on the bus, allowing multiple modules to receive the same data during one bus cycle. Tag assignment and recognition are defined during setup from the system data base. Thus, data distribution becomes a simple hardware function with no overhead required during real-time operation.

The software consists of system software and module software. System software performs initialization, setup, memory management, task management, command processing, and other overhead functions. Each module contains the additional code required to implement the routines unique to that module. System and module software communicate via a software bus across the Microprocessor bus. This arrangement eases system expansion and module addition by eliminating lengthy and complicated “sysgen" sequences when the system is changed.

Ground Station

The ground station system utilizes the Loral Instrumentation System 500[2], a product that has extended the ADS 100 architecture. An Ethernet Processor within the System 500 architecture (Figure 4) distributes information for the man-machine interface to multiple color graphics workstations. The availability of lower cost workstations that adhere to computing industry standards (UNIX for the operating system, Ethernet for the network, TCP/IP for reliable data transfer, UDP for efficient data transfer, NFS for remote file access, SQL for data base access, and the X Window System for graphics) allows rapid system development and eases operation and maintenance.

PCM data is brought through Loral’s DBS 530 Bit Synchronizer[3] into the System 500, which applies algorithms to the data, converts it to engineering units for display on the workstations, and scales it for display on the strip chart recorders. FM telemetry data is converted back to analog through the 21 discriminators and is fed into the quantizer inputs of the System 500 for digitizing. The System 500 then corrects the data, applies algorithms, and converts the data to engineering units for display on the workstations and chart recorders. The simultaneous throughput of both PCM and quantized data allows the ground station to reconstruct both the slower PCM and wideband FM data to the original relationship for display on the workstations and chart recorders.

Workstation displays (Figure 5) provide a consistent interface to users. A “soft” annunciator panel makes up the top 20% of the screen for real-time monitoring of critical parameters, data streams, the network, system errors, and data alarms. The remaining screen area is available for viewing data in independent windows defined through pull-down menus and list picks. Operators quickly define each window with the Display Builder (Figure 6) and its catalog of display objects. The catalog contains a variety of strip charts, bar charts, and annunciator panels. In addition, users may import bit maps of unique characters or photographs, or draw diagrams and objects connected to form a process. Along with defined parameters, these window formats may be stored, and then retrieved modified in real time. In addition to depicting data (e.g., graph or text) (Figure 7), the display object has a background color that indicates adherence to predefined limits (e.g., green - within limits, yellow - caution). The data value can determine which bit map is presented, enabling process diagrams to depict switch or valve status, aircraft systems operation, or antenna direction.

On demand, operators may capture data to a workstation file (Figure 6). They can dynamically switch between real-time and data file playback, or play back a data file even while recording is in progress. Optionally, the user can select a start and end IRIG time for viewing portions of the data file. After the data file is selected, a scroll bar appears. The user manipulates the mouse to move the slider on the scroll bar which in turn moves through the data file and display points on the screen. The data can be played back in both forward and reverse directions. Users can play back data a single point at a time in forward or reverse direction by simply clicking the mouse button on the right and left direction arrows on the scroll bar. Note that single-stepping maintains the exact order the data had in real time. A user can have two identical quick-look displays on the same screen, with one display showing real-time data and the other display showing recorded data.

The real-time, quick-look displays also support a history buffer for reviewing the most recent (n) real-time samples that have been displayed. The value of (n) is user-configurable. The user activates playback of the history buffer by pressing the playback button on the display. Once playback is activated, a scroll bar appears. The scrolling works in the same manner as the data file scroll bar. A data loss indicator provides confidence of the integrity of data versus a static value measured earlier in time.

Because of the limited capabilities of the network and workstations, the System 500 maintains a complex CVT (Current Value Table) in the front end's programmable processors (FPP). Only those parameters required for processing or display on a workstation are gathered and transmitted. A library of "data gather" algorithms[4] pass all or compressed data to the workstation. For example, the STATGAT data gather sends the minimum, maximum, average, current value, and number of samples read for the specified parameters and the specified time interval. The GATALL data gather sends all samples of the specified parameters. Unique gather algorithms may be created in "C" for display use or workstation applications. A digital data tape is prepared using the gather programs for engineering analysis. Though not presently used at Garrett, the system can transfer data in real-time to the front end for control and simulation applications.

In addition to maintaining the CVT, the FPP provides real-time preprocessing and data compression. Algorithms may be chosen from a library of traditional flight test routines (e.g., bit manipulation, data conversion, EU conversion); unique ones can be created in "C". Algorithms are created and tested on the workstation and are then downloaded to the FPP[5]. A rich debugging environment is provided for testing under real-time conditions. The front end's parallel data flow architecture allows multiple FPPs to maintain the desired throughput. Garrett is using two FPPs in the current system.

Present Data Display and Transfer Methods

The Western Graphtec chart recorders in the ground station (Figure 1) are interactively controlled by the 386 computer. These devices offer engineering unit scaling, on-page annotation of test configuration and parameter identification, overlaid traces, and many other features.

Through the years, a real-time analyzer, providing spectral density display of vibration and strain parameters, has been attached to the discriminator outputs of the FM link. This tool has become valuable for recognizing flight safety issues and analyzing engine vibration.

The data gather program that allows post-test data to be sent to the 9-track digital tape for transfer is now being developed to send a similar packet to one of the workstations for on-line processing. This feature differs from real-time display because of delays of transfer (1-3 seconds) and application to imported computer programs (10-30 seconds). In addition, the gathered data must be fit into the complex engine modeling programs from the engineering computer system. Because of this process, the display of vital engine performance information is now reduced from two days to less than a minute.

Data Transfer Tomorrow

The ground station will soon be connected to the engineering computer system by the large area Ethernet that links all the company computing systems. Data will be ported across a separate Ethernet node in the larger workstation and will be sent directly to the Cyber system. The realization of this process will open nearly unlimited access to post test, on-line, and eventually, real-time flight test data.

Conclusion

The flight test analog data systems at Garrett have ranged from humble beginnings in the early 1960s with simple analog meters and oscillograph recorders in an A-26 to today's state-of-the-art computer-generated analog displays in a telemetry ground station. The digital data acquisition systems have come from low-speed data logging equipment on-board a Falcon 20 to a distributed PCM acquisition system with nearly unlimited growth potential. Three years ago, the units of time describing data transfer for engineering analysis were in days. The present units of time for the same operations are in hours, with simpler analysis in seconds and some even in real time.

The hardest question to answer when speaking about flight test data acquisition at Garrett is, "What are the limitations of the new data system?"

References

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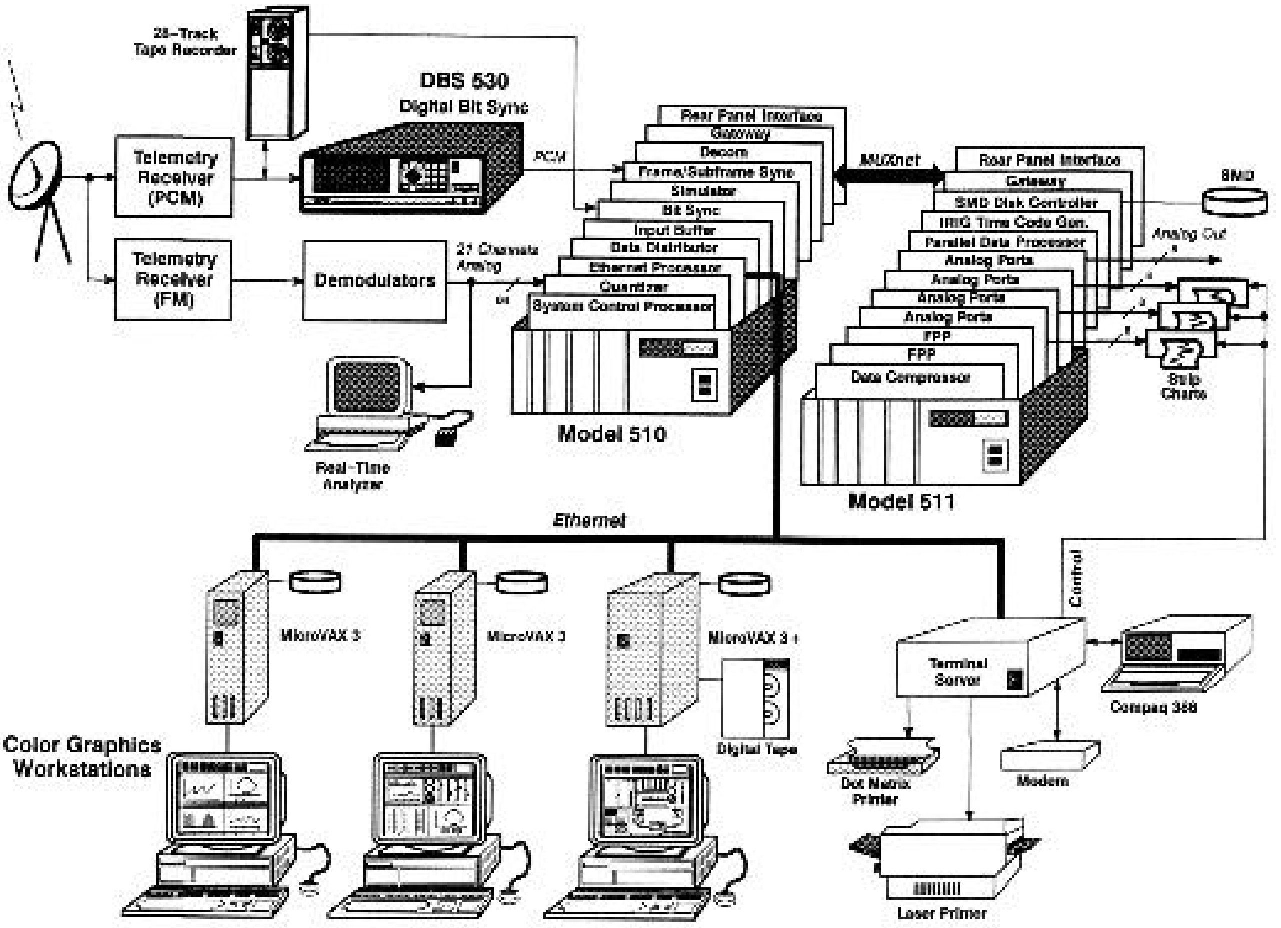


Figure 1. Garrett Engine Ground Station

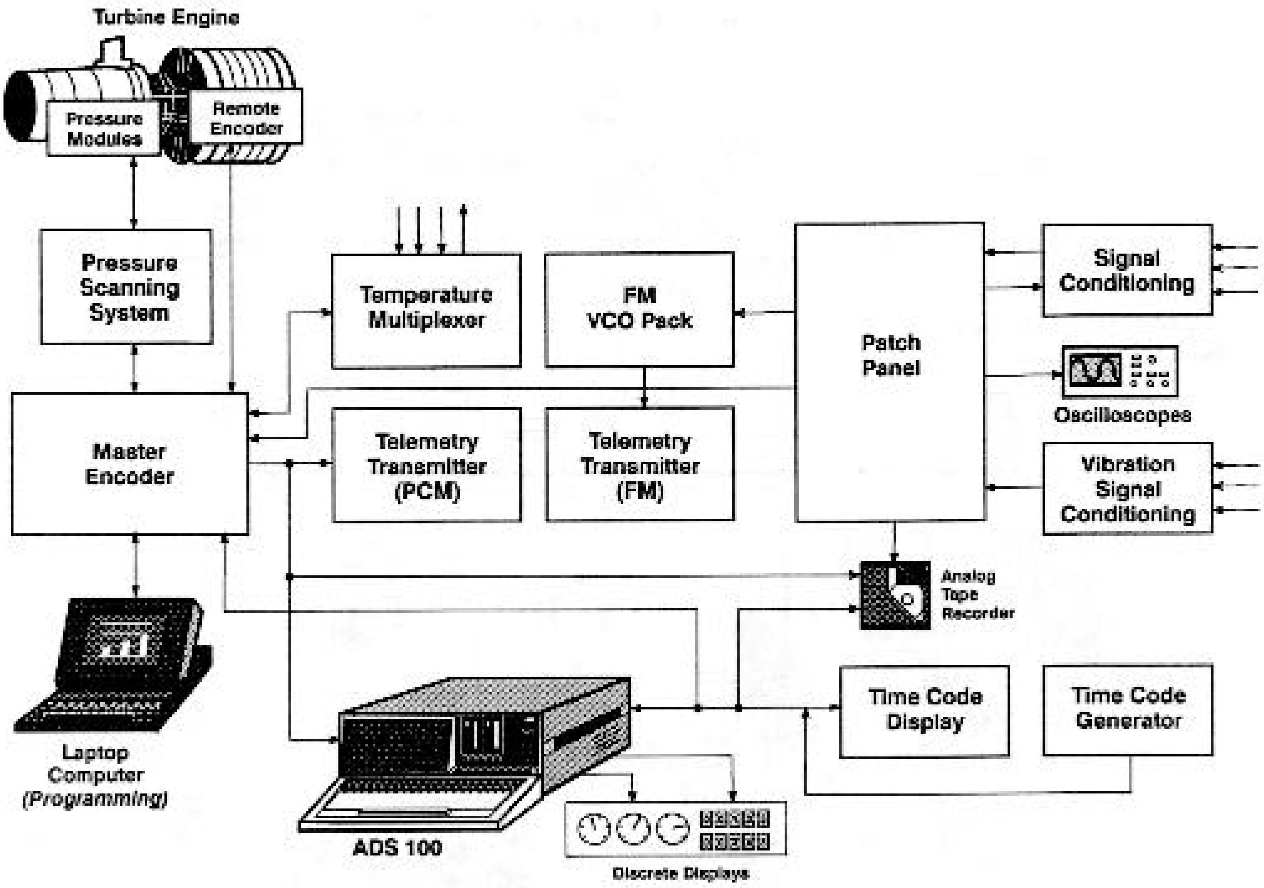


Figure 2. Airborne Data Acquisition System

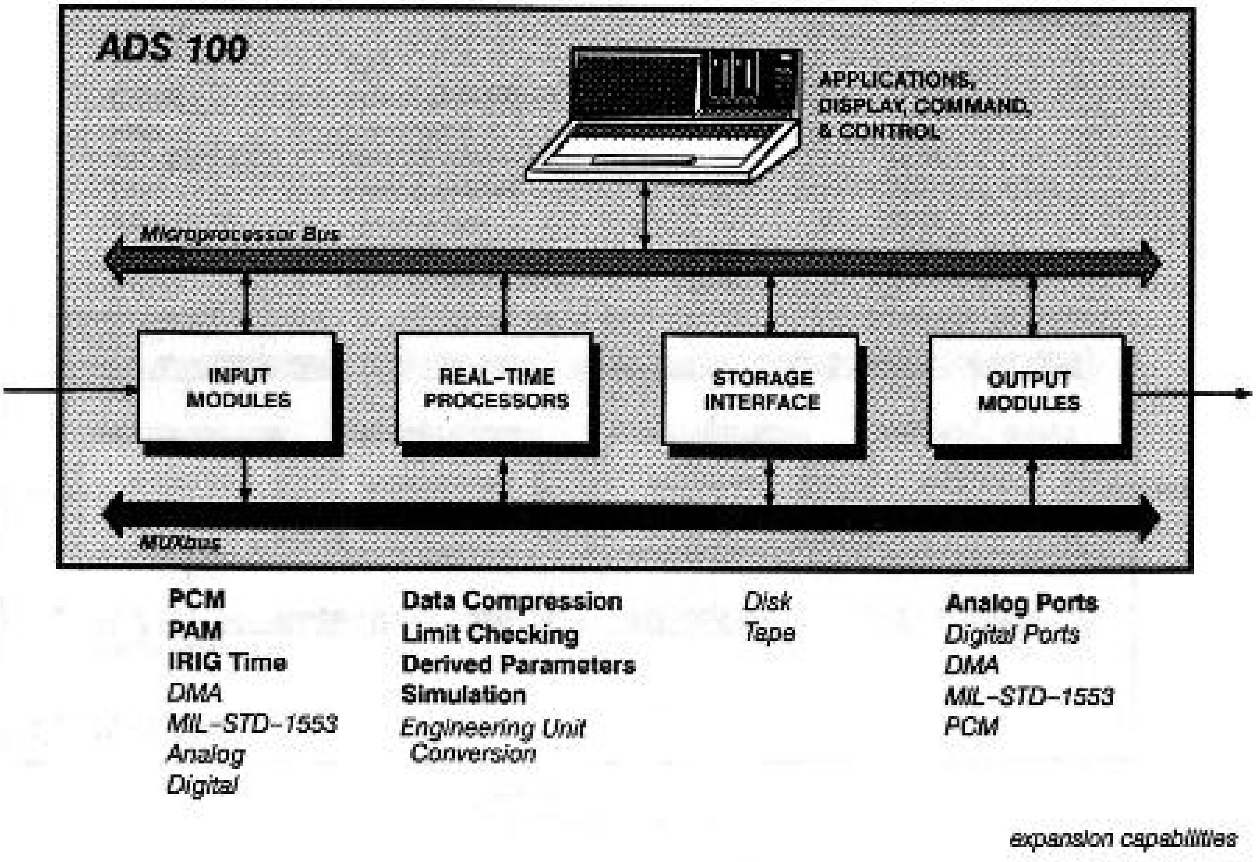


Figure 3. ADS 100 Data Flow Bus Architecture with Separate Control and Display Bus

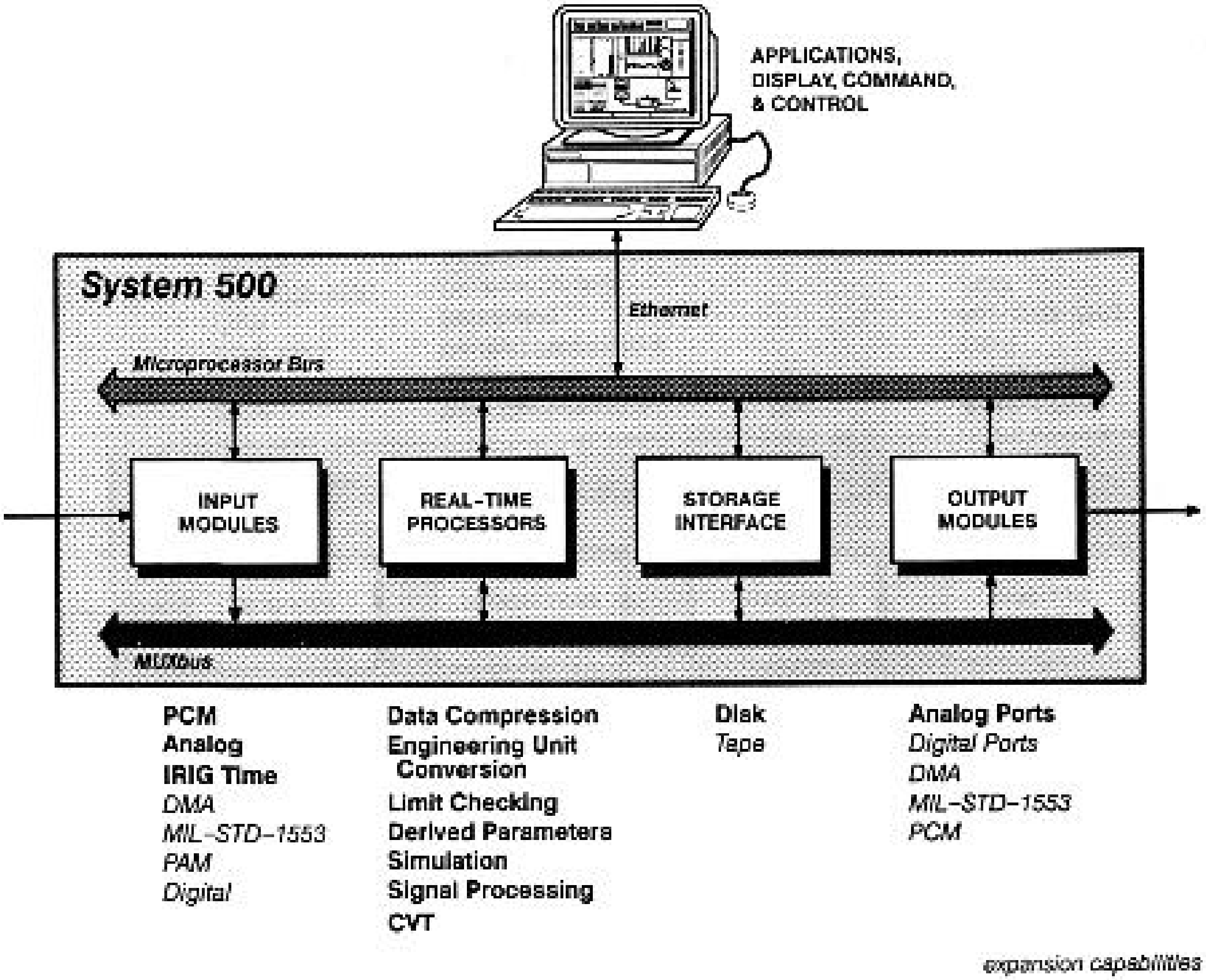


Figure 4. System 500 Data Flow Bus Architecture with Separate Control and Display Bus

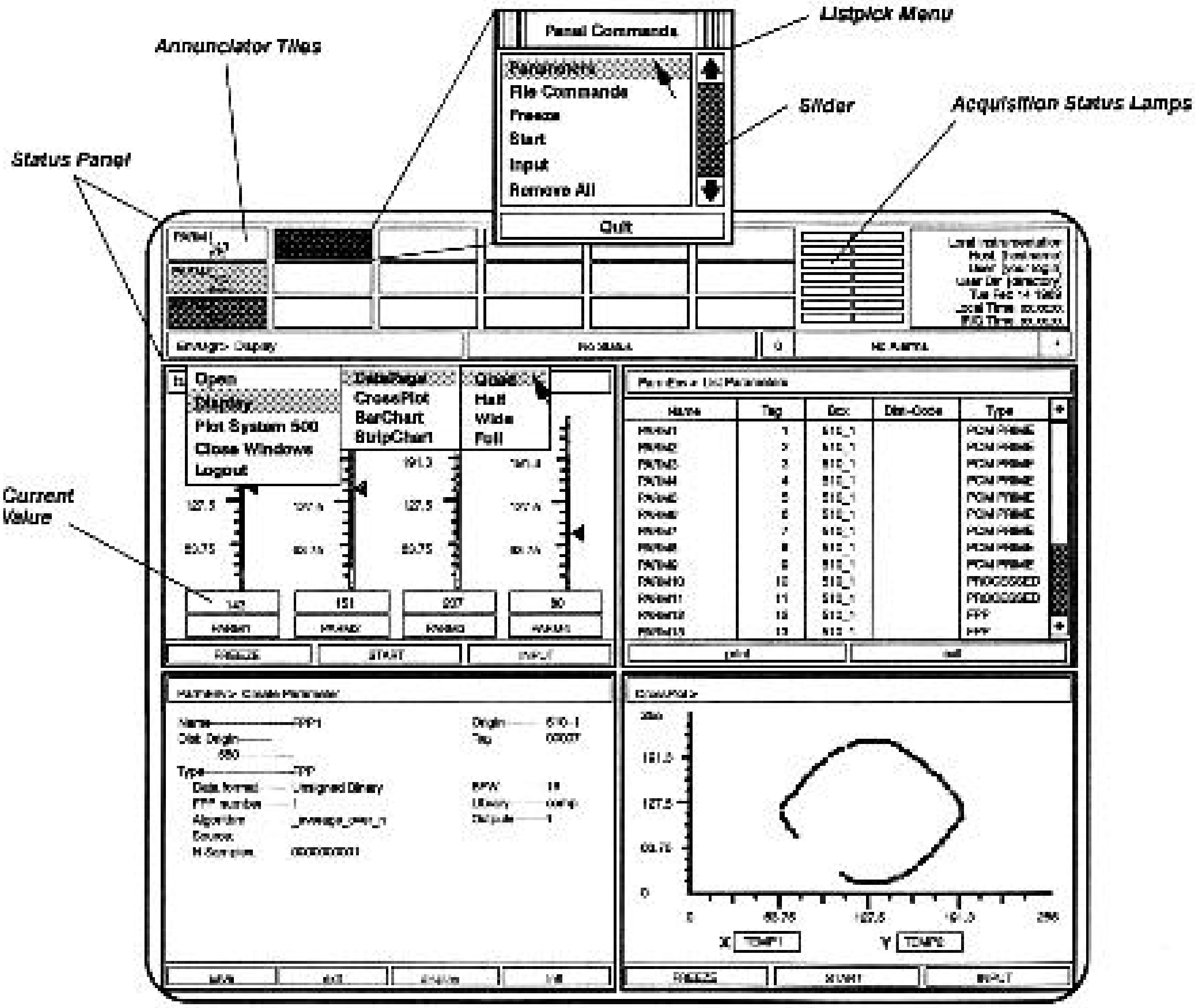
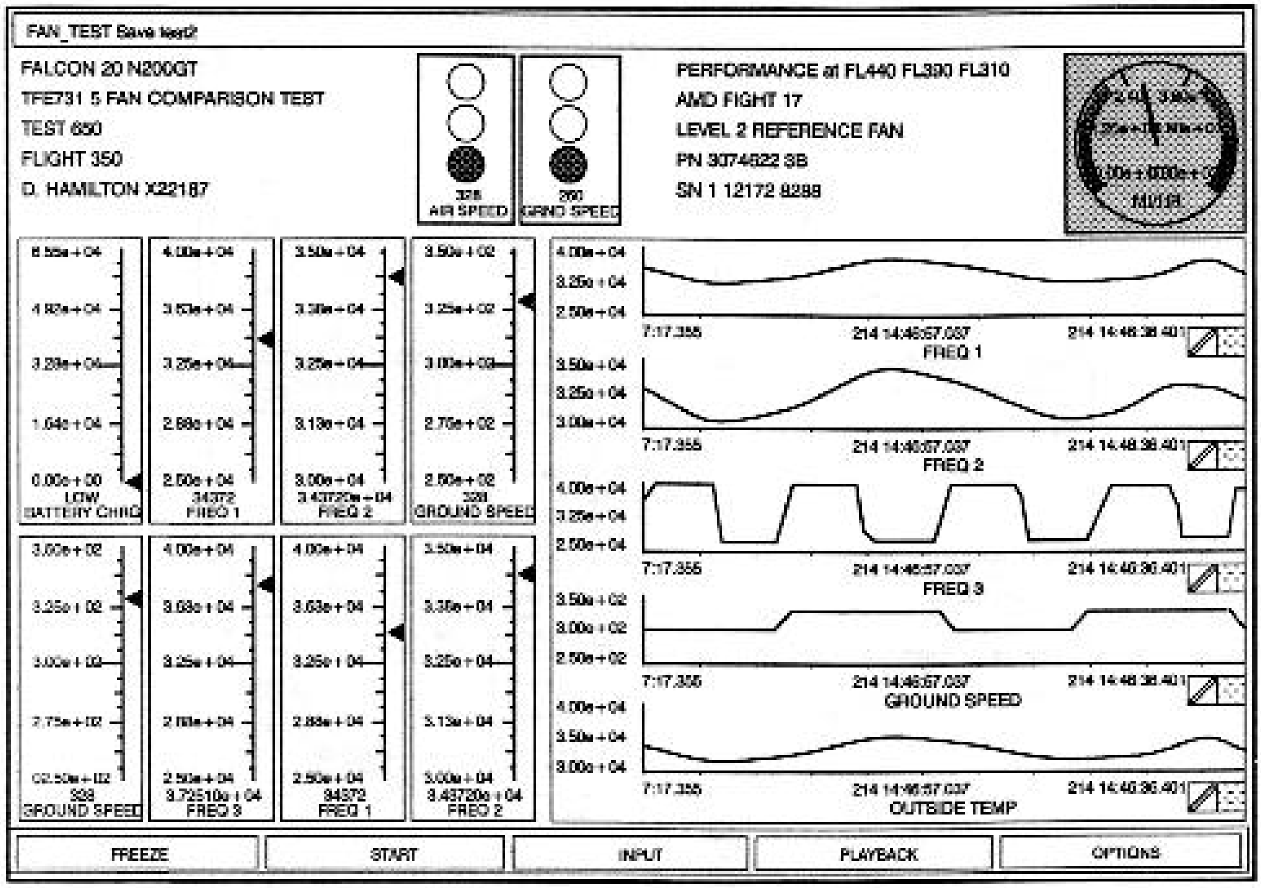


Figure 5. Components of the Color Graphics Display



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TFE731 5 FAN COMPARISON TEST
TEST 650
FLIGHT 350
D. HAMILTON X22187

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AMD FIGHT 17
LEVEL 2 REFERENCE FAN
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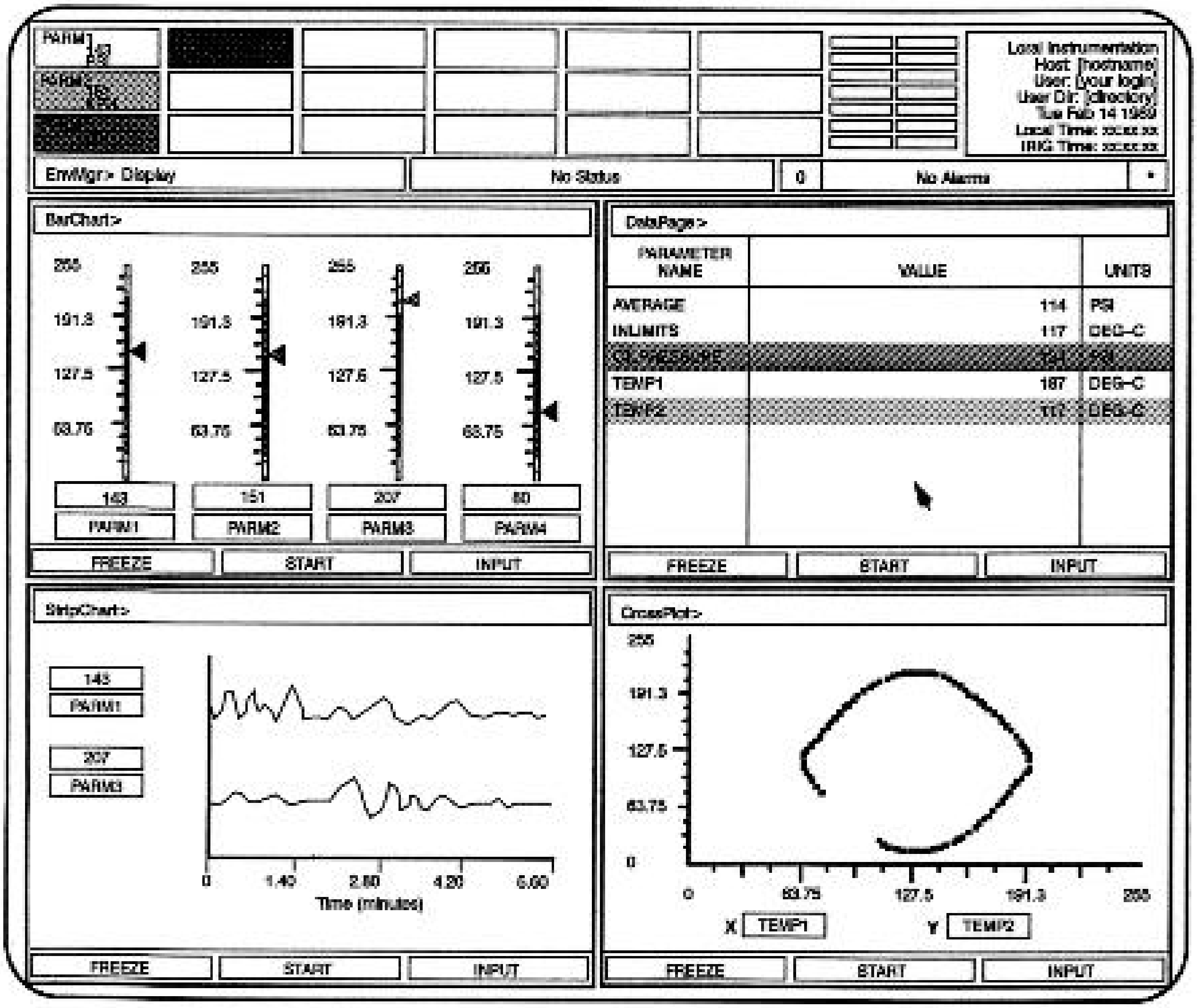
Figure 6. Example of a Display Created with the Display Builder Feature



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Tue Feb 14 1989
Local Time: xx:xx:xx
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TEMP2	112	DEG–C

Figure 7. Example of Four Typical Display Windows