Airborne and Ground Data Processing Systems for the RAH-66 Comanche

John R. Cox
Sikorsky Aircraft Corporation
West Palm Beach, FL.

ABSTRACT

The RAH-66 Comanche flight test program requires a state of the art air vehicle and avionics data system consisting of: 1) An airborne, all digital multiplexing and recording system capable of combining digital streams at very high data rates; 2) The ability to record high speed avionics busses from the MEP (Mission Equipment Package) such as MIL-STD-1553B, HSDB (High Speed Data Bus,) PI (Processor Interconnect) Bus, DFN (Data Flow Network,) and TM (Test and Measurement Bus;) 3) A miniaturized, programmable, modular/distributed high speed PCM measurement system for 550 air vehicle measurements recorded on the Comanche Flight Test Aircraft and Propulsion System Test Bed; 4) an airborne digital multiplexing and recording system for recording a composite stream on an Ampex DCRsi tape recorder; 5) A high capacity ground data processing system using parallel processing computers for real time data compression; and 6) distributed analysis system using workstations for data processing with centralized disk storage.

KEY WORDS

Telemetry, Instrumentation, Data Processing,

INTRODUCTION

The First Team, consisting of Sikorsky Aircraft Corporation and Boeing Helicopters, was selected to develop the next generation of attack helicopter, the RAH-66 Comanche for the U.S. Army. Flight testing of the prototype RAH-66 helicopter will be conducted at the Sikorsky Development Flight Center, West Palm Beach, Florida starting in 1995. The First Team will be required to validate the Mission Equipment Package (MEP,) the digital fly-by-wire control system and various other major avionics subsystems in addition to the traditional structural, handling qualities and performance flight testing,

It was determined that a single, integrated flight test program, with the avionics and air vehicle testing at a single site was the most efficient test plan.

The small size of the aircraft, limited space available for instrumentation, the requirement for numerous measurements and the heavy use of digital flight management and control systems with data busses that must be monitored forced the development of a new generation of airborne recording systems that could record PCM and an assortment of high speed data busses on the same medium.

RAH-66 Comanche Flight Test Requirements

The need to acquire and record data simultaneously from Avionics busses and the air vehicle PCM encoders required a system for multiplexing digital data streams at data rates much higher than usual for air vehicle flight testing. Continuous recording was desirable in order to provide for incident recording.

It was required to record each data bus in its entirety wherever practical. The small size and relative inaccessibility of spaces suitable for the PCM encoder made necessary the development of a miniaturized, programmable, modular PCM encoder capable of having components located in small empty areas around the aircraft.

The lack of space on the aircraft for a central patch panel and the potential for schedule improvement required that the system be capable of simultaneously recording a large number of air vehicle measurements. The final air vehicle measurement requirement was 550 parameters.

The large number of digital samples recorded per second required that the ground acquisition system be capable of performing useful compressions on the data in real time. Otherwise, disk storage requirements and processing time would become unmanageable.

The large amount of computation required for Comanche and the expense of purchasing minicomputers rather than workstations meant that the analysis system should be distributed and use workstations rather than mainframes or minicomputers wherever possible.

It was required that recorded data formats for both the Sikorsky and Boeing test vehicles be similar and be suitable for being processed at either team member's site.

Availability of telemetry channels defined the telemetry capability as two megabits per second. The use of a PCM combiner for recording and a selector for telemetry allows great flexibility in the selection of critical measurements for ground monitoring. The use of a PCM combiner and frequency diversity receiving system helps to ensure telemetry signal quality during maneuvers.

An Integrated Bench Test Facility (IBTF) and System Integration Line (SIL) at the West Palm Beach test site is available to expedite avionics development. A separate data processing facility was provided for specialized avionics processing.

Air Vehicle PCM and Avionics / MEP Bus Digital Multiplexing System

The recording requirement consisted of both air vehicle measurements and avionics measurements. The air vehicle recording requirement was up to 8 megabits / seconds per stream and up to 8 PCM streams. The initial recording method considered was 1 inch instrumentation tape recording 8 tracks of PCM with a 60 inch per second tape speed. This limited flight test time to 30 minutes per tape, which was unacceptable and did not provide an acceptable solution for recording the avionics busses.

The avionics recording requirement is to record 3 MIL-STD-1553B data busses, and two HSDB's (High Speed Data Bus - JIAWG 200-86 or JIAWG 200-89) in their entirety for the duration of the flight. Comanche aircraft 2 was also required to have the capability to record PI (Processor Interconnect - JIAWG J89-N1A Version 3.15) bus, TM (Test and Measurement- JIAWG J89-N1B) bus, and DFN (Data Flow Network) if required for troubleshooting. There is also a ground test requirement to record these busses in the laboratory.

The total recording requirement was well beyond the capability of traditional analog instrumentation tape recorders. The size and weight constraints in the Comanche aircraft dictated the use of a digital recorder. Ampex DCRsi recorders were selected based upon their recording capacity of 47 gigabytes per cassette and either 107 or 240 megabits/second maximum bit rate and demonstrated experience in airborne data recording.

Since this device is a single track recorder, a digital multiplexing system was required to combine PCM, MIL-STD-1553B busses and the other Comanche avionics busses. A digital multiplexing system, the MEPDAS (Mission Equipment Package Data Acquisition System) was developed by Boeing Helicopters in cooperation with Calculex, Inc. This unit is a VME-64 based system with one card for each bus type to be monitored. These cards acquire and time tag bus messages and pass them to a DCRsi Interface card which causes the messages to be written to the DCRsi tape. PCM is treated as a bus where each minor frame is a bus message. Each of the bus monitoring cards is programmable to acquire subsets of the bus data rather than the entire bus, if required. The cards also have an interactive mode to support laboratory troubleshooting. A block diagram of this system is shown in Figure 1.

Air Vehicle Digital Data Acquisition System

The air vehicle data acquisition system is entirely PCM. It supports continuous or burst type recording, will support encryption if required, and is capable of sampling rates of up to 2,000 samples / second / channel. The use of the DCRsi cassette tape with its long

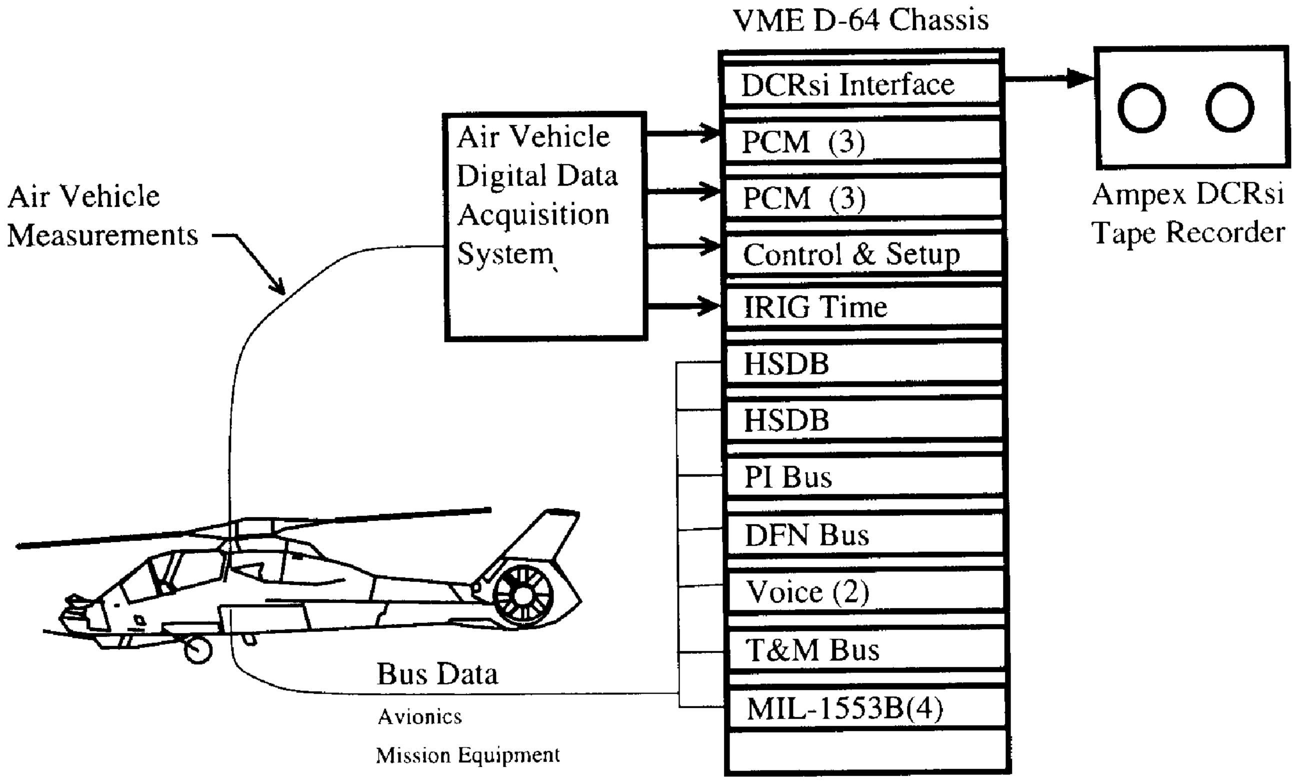

Figure 1: Airborne Recording System Block Diagram

record time allows continuous recording of data during the test. This improves diagnostic ability by allowing any event during a flight to be investigated. A continuously operating instrumentation system also substitutes for an incident recorder. Setup and checkout of the system uses a portable computer which is connected to the data acquisition system.

Airborne system components of the ADAPS (Advanced Data Acquisition and Processing System) airborne system are as follows:

(1) Pilot's Control Unit (PCU) is used to start and stop recording on the airborne tape and mark events of interest. A unique feature in the pilot's control unit is a keyboard where the pilot may enter a maneuver identification number to support post flight maneuver identification.

(2) Data System Control Unit (DSCU) is the device which controls all of the airborne instrumentation.

(3) Remote Multiplexer Units (RMU) are the enclosures for signal conditioning cards. Each RMU is capable of holding up to 16 signal conditioning cards. It will operate with other RMU's in a master/slave configuration. Each master RMU samples all of the channels in its and its slaves' chassis using a single sampling clock. Simultaneous sample and hold is optional.

(4) Data Combiner Unit (DCU) is a device for merging the outputs of several RMU's and producing output PCM streams for telemetry, driving the airborne computer and pilot's display, and producing an output stream for recording on the DCRsi recorder.

(5) Signal conditioning cards that plug into RMU's are the interface between the measurement system and the transducers. Signal conditioning module cards currently in use are the following:

a. Strain gage bridge conditioner.

b. Resistive Thermal Device (RTD) conditioner.

c. Counter/Accumulator used as a fuel flow totalizer.

d. 16 channel analog multiplexer.

e. 36 bit discrete conditioner.

f. Frequency/rate conditioner.

g. Voltage conditioner. These are typically used for thermocouples.

h. Integrating charge amplifier for accelerometers.

i. Rotor azimuth conditioner.

j. MIL-STD-1553B Bus monitor.

k. ARINC 429 Bus monitor.

l. IRIG PCM input module.

A block diagram of the air vehicle data acquisition system is shown in Figure 2.

Airborne Computer and Pilot's Display.

A ruggedized 486 PC computer was selected to provide airborne computation to drive the pilot's display and perform other specialized computations. The pilot's displays are LCD arrays which emulate a standard VGA display. A Berg board level PCM decommutator provides the interface to the data. Apollo Tech software is used to provide real-time pilot displays. This feature proved to be especially important in Comanche because the limited amount of panel space and pilot workload simplification led to the elimination of many gages which are required for the flight test.

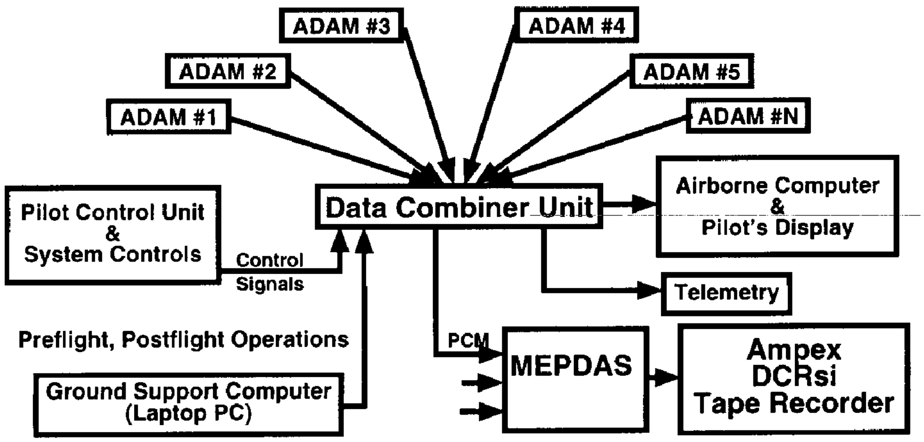

Figure 2: Air Vehicle Data Acquisition System Block Diagram

Set up of the airborne data system is accomplished from a ground support computer (GSC) which is a standard, PC compatible laptop computer system which connects to the airborne system via an RS-422 serial connection. This system is capable of performing a checkout of the airborne system and downloading the system setup to the airborne system through the DSCU. The GSC may also be used for quick setup modifications at the flight line.

An integrated air-ground setup system located in the ADAPS (Advanced Data Acquisition and Processing System) ground station provides the setup file for the airborne system. When used in this manner, a setup change is reflected both in the airborne system configuration and in the ground processing system.

This system was specified by Sikorsky and developed under capital funding. The system ultimately developed is the MDAS system by MicroCom, Inc.

Ground Data Acquisition and Processing System

Data Acquisition System

A significant amount of custom real time processing was clearly required for ADAPS, as was the ability to add and modify algorithms as experience dictates. A Loral Pro 550 data acquisition system was selected because of its large compute capability and its programmability in the "C" language which simplified the development of the custom processing algorithms. A block diagram of this system is shown in Figure 3.

Considerable attention was paid to providing similar processing capabilities for handling PCM as were available for FM. Digital filtering is provided with variable frequency and roll-off characteristics similar to analog filters. The ability to quickly change filter characteristics during a flight was a requirement for output to analog strip charts. All digital processing implies that the sample rate of data entering the computer is much

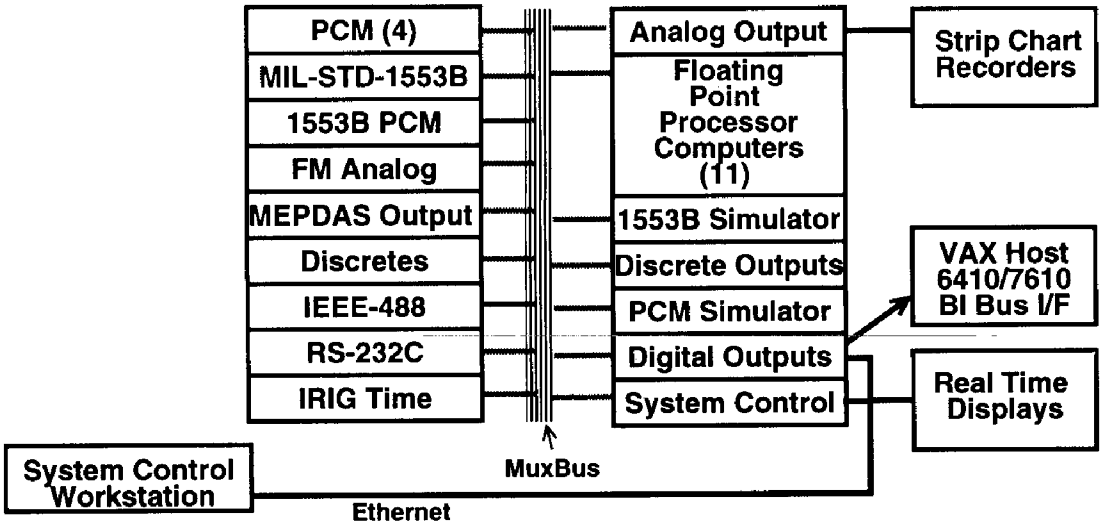

Figure 3: Loral Pro 550 Data Acquisition System Block Diagram

higher than was used with analog processing because of the absence of hardware preprocessing. As a result, similar functions were provided for PCM to reduce the bandwidth expansion, Digital peak stress conversion algorithms, discrete Fourier transforms, field extractions, concatenations, number format conversions, and interpolation of high rate PCM samples to lower, fixed time or rotor based sample rates were provided in real time to reduce the amount of stored data. A significant reduction in post flight processing was obtained by being able to compute statistics for flight test maneuvers, a standard part of the data file structure, in raw units, in real time.

The ADAPS system can simultaneously acquire data from up to 4 PCM streams, 32 FM analog channels, MIL-STD-1553B, IRIG time, IEEE-488, RS-232C and computer generated data placed on the system bus either from Ethernet or the VME bus used for control in the Pro 550. This ability to simultaneously acquire data from multiple sources reduces the time required for post flight processing.

Data recorded on the MEPDAS data acquisition system is read back by a software decommutation program. This program runs in a DEC 3000-700 AXP workstation, reads the DCRsi tape over a VME interface, performs record synchronization, restores the time sequence of data from the different busses, selects data samples from the streams, and transmits data to the Pro 550 system where it uses existing data processing algorithms for analysis and storage. The DCRsi recorder can also be used to record a subset of the Loral Pro 550 system's MUXBUS traffic. This provides a high throughput data recording capability for telemetry. A block diagram of the MEPDAS tape playback is shown in Figure 4.

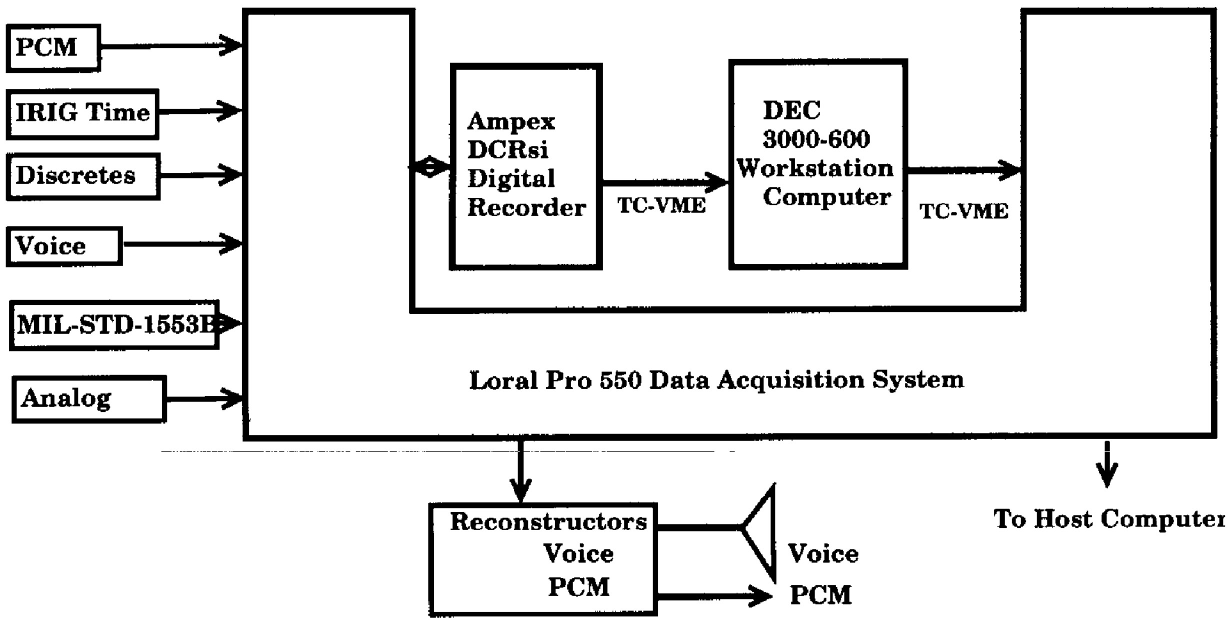

Figure 4: MEPDAS Recording System Playback Block Diagram

Ground Computing Facility

An advisory group was formed early in the development process to elicit inputs from the prospective flight test users early in the system design process. Their inputs formed the basis for key design features of the ADAPS system. A primary requirement was that the same computer processing environment be available in telemetry as at their desktops. This requirement led to the use of VAX workstations in both the telemetry rooms and on the flight test engineers' desks. VAX computers are also used in the host computer system, and result in the ability to run telemetry and post flight analysis tasks on any of the computers in the facility. This gives great computing flexibility and capacity to the system and allows capacity to be expanded by purchasing a workstation rather than a large computer. Disk storage space is centralized using a disk storage facility of approximately 140 gigabytes of on-line data storage. Significant storage is also available on the engineers' workstations and is used for specialized analyses.

A VAX 4000-90 workstation is able to support real time displays with 20-30 measurements and significant computation at a display rate of 50 frames per second, which is adequate for most performance and handling qualities display requirements. The use of a multitasking operating system with memory protection allows the test engineer to run multiple analysis / display tasks simultaneously with little interaction between tasks. Structural processing requires the use of strip charts with a display capability of 2,000 samples per second. A block diagram of the ADAPS computer processing facility is shown in Figure 5.

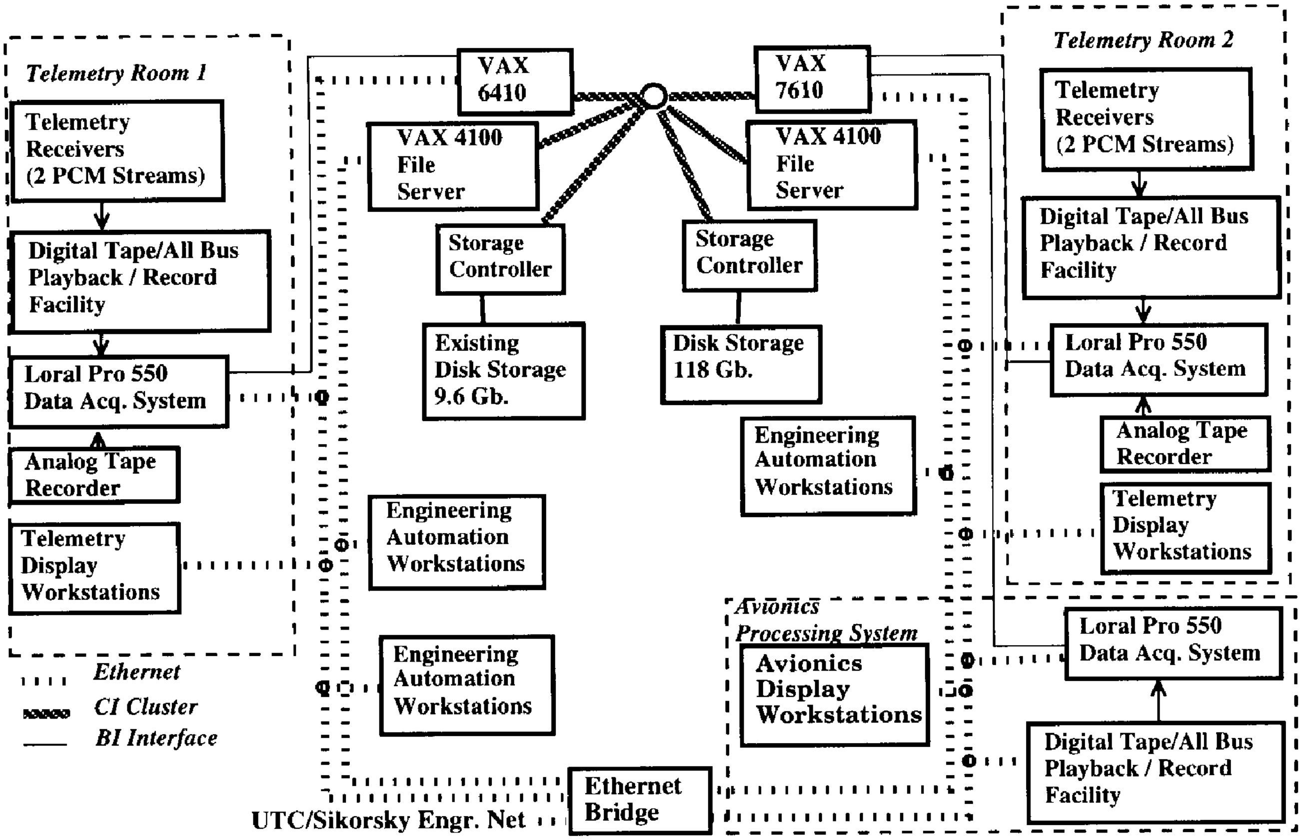

Figure 5: ADAPS Ground Computer Facilities Block Diagram

GROUND PROCESSING SOFTWARE

Post Flight Data Processing Software

It was felt that many benefits would accrue if the system software took advantage of the lessons learned from the many years of software development of the data processing system that was replaced by ADAPS. In particular, the training effort would be simplified, transition to the new system would be simplified and many years of minor but extremely useful improvements would be preserved. It was determined that most of the post flight batch processing software could still be used. Accordingly, the flight test data file format and the programs that load, manipulate, and analyze this test data were converted from the existing Encore system to work with ADAPS. A significant user requirement that surfaced was to be able to store time history data samples and statistics from many (100-200) flights on line. Experience has demonstrated the value of having at least this amount of data available. Disk space available for flight test data storage currently exceeds 140 gigabytes. 8 mm. tape is used for the long term archival medium.

Real Time Telemetry Display Software

Real time telemetry display software was completely rewritten for ADAPS using as a basis, programs developed for analyzing PCM test data on HP-150 PC's. These programs were rewritten in the "C" language using DECWindows (X-Windows) graphics. The additional processing power of the VAX workstations and the multitasking capability of the VMS operating system resulted in major improvements in system performance and flexibility.

Setup and Record Keeping

A significant requirement of the users' group was that setup of the system be automated to eliminate the transcription of measurement setup and processing requirements to the maximum extent possible. Accordingly, an integrated setup system was developed which uses common information stored in the Rdb database to set up both the instrumentation on the test aircraft and the ground processing system. Other software integrates maneuver identification from the maneuver list in the flight test plan through the pilot's flight card to the run log listing used for identifying maneuvers on the test data tape.

An aircraft configuration management and tracking system was developed to help keep track of the often hectic parts installations and removals on all of the test aircraft. The daily report system was also moved on-line to facilitate data entry by all of the required personnel and retrieval as a combined entity. The setup system has been responsible for a significant portion of the productivity improvement in ADAPS, because of the lower error rate due to reduced transcription errors and the automated equipment setup using the database reduces preflight preparation time and wiring errors.

Acquisition Software

Useful compression was a major thrust of data acquisition. As a result, the traditional signal compression methodology was rejected in favor of providing digital processing counterparts to the traditional analog processing. The following compressions were considered useful:

(1) Peak Stress Conversion, in which only the vibratory and steady values are stored within a sampling period, typically 1 to N samples per rotor revolution.

(2) Sample rate reduction; either to a fixed time rate or a fixed number of samples per revolution, usually preceded by low pass filtering.

(3) Discrete Fourier Transform, in which an amplitude and phase of a specific harmonic is reported out rather than the individual values.

(4) Value change algorithm in which the sample number and value are reported out whenever the value of the sample changes.

(5) Turning point reporting, in which the sample number and value are reported out whenever the slope of the samples changes and the change since the last sample exceeds a threshold.

Experience to date suggests that the compressions described reduce the data sample storage requirements by a factor or 10-20.

A significant challenge was to be able to use parallel processing and still maintain control of time correlation of data samples. This is because if data is recirculated on the MUXBUS, the path lengths will not remain constant and the ability to precisely locate a sample in time is compromised. Several solutions to this problem were considered before recirculation of data samples was ruled out. Absolute time correlation can now be maintained for samples processed within the same processing computer in the Loral system. Time correlation among processing computers is accomplished by matching up the time samples associated with the data processed in each computer.

SUMMARY

The Comanche Power System Test Bed will begin operation in mid-1995 with an ADAPS airborne data system and a data van based ground system. The first flight of Comanche aircraft 1 will occur at the end of 1995, so the final word on the suitability of the Comanche instrumentation and processing system has not been written. With the successful flight testing of the VH-3D, and the T64-GE-419 engine integration test program on the MH-53E the validity of the all digital airborne data system has been demonstrated.

The ADAPS ground system has demonstrated its ability to perform traditional FM sampling on S-76 and UH-60 flight test programs with little strain. This has helped to ensure the long term usefulness of this FM equipment

The ADAPS system has demonstrated the following:

o Automated checkout significantly reduces preflight time. This has greatly reduced the number of takeoffs delayed due to instrumentation checkout problems.

o The automated setup and assisted run log generation has reduced setup time enough that same day turnaround on flight test data occurs regularly versus overnight turnaround on the previous system.

o The improvement in turnaround time has been sufficient to allow flights requiring prior data review to be scheduled sooner.

- The use of the ADAPS system has allowed the size of the test team to be reduced by one half on the H-3 PIP test program. This was due to the higher quality of the data and improved methods of validating the data.

- The test data aide group who performed the data entry on the previous system has been eliminated. The remaining data entry effort is being performed by cognizant engineering personnel without transcription.

- The flight test programs that were used to validate system performance were completed with higher flight rates than usual in spite of system immaturity and growing pains. This increases the confidence that the productivity improvements required to support the Comanche test schedule can be achieved with this data system.

- The easy availability of data reports and configuration information has improved communication between flight test and other parts of the engineering organization.

- The integrated air and ground system setup clearly reduces setup and transcription errors and greatly reduces the data validation effort.

- The flight log and run log generation program is now fast enough that the run log can be developed during flight. This has greatly improved our ability to develop a correct tape log very quickly.

- The visibility of test data results during flight increases confidence that maneuvers are being flown correctly and will not have to be repeated.

- The stability of PCM compared to FM has been demonstrated to Sikorsky's satisfaction. The amount of data spikes and other sampling problems have been greatly reduced. It is clear that PCM may be used for all traditional air vehicle flight test data processing.

ACKNOWLEDGMENTS

Mr. Allen Carnicke, a Senior Instrumentation Engineer at Sikorsky Aircraft Corporation in Stratford, Connecticut contributed a great deal of information on the ADAPS airborne system.