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Dennis Normyle

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Naval Air Warfare Center Aircraft Division
22347 Cedar Point Road, Unit #6
Patuxent River, Maryland 20670-1161

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Telemetry and HPC
Potential Applications

Dennis Normyle
Naval Air Warfare Center
Patuxent River, Maryland

NAWCAD
S.P.S.I

As the amount of data generated by flight test increases, new techniques and applications are needed for analyzing and reducing the data. These applications must aid the user in safety of flight monitoring, test point validation and flight clearances. The High Performance Computing (HPC) center located at Naval Air Warfare Center - Aircraft Division (NAWC-AD) Patuxent River, MD, is uniquely collocated with NAWC-AD's Telemetry Data Center. Applications can be developed that will combine the tremendous amounts of data generated by a telemetry mission with the superior computing power of the HPC. This paper will deal with these potential applications

Introduction

"Plan the Flight, Fly the Plan" is a favorite quote of Naval Test Pilots at Patuxent River. In the telemetry world, this quote reflects the single minded nature of our business. The reason we exist is to support of the Test and Evaluation (T&E) community in the real-time testing of Aircraft. To us, the most important services we supply in this support are:

- Safety of Flight Monitoring - Are Aircraft and Pilot safe?
- Flight Test Validation - Did the Pilot hit the test point? Yes or No?
- Data Acquisition for Post Flight Analysis - Did we learn what we set out to learn?

We tend to gravitate towards any system or procedure that aids us in these tasks, and anything that is a hindrance we avoid like the plague. People who work in telemetry like to own the equipment and systems they need to perform their task and they are wary of relying on mission dependent systems that are out of their control.

As telemetry data rates increase, and the sheer amount of data that are generated by flight testing expands, new applications and techniques must be found that will help in the digestion of the data. The High Performance Computing (HPC) center offers a new and unique resource for the generation and use of new applications that will support the T&E community.

The intent of this paper is to familiarize the reader with the telemetry world and to investigate possible applications that the HPC facility will provide for the T&E community. The following is a brief outline of the paper.

- Current NAWC-AD Telemetry Capability - This section describes the current capability of RTPS (i.e. Number of PES rooms, Room Layout, Computers Used, Projects Supported, Number of flights flown etc....).
- Anatomy of a F/A-18E1 Flutter flight - This section will describe the anatomy of a flutter flight, the type of maneuvers performed, the type of data collected, the AMOUNT of data collected, and how the data is processed post flight.
- Telemetry/ACETEF Applications. A brief discussion on how RTPS and Manned Flight Simulator are currently linked and some of the early applications used.
- Possible applications for HPC in Telemetry applications.
- Conclusion

NAWC-AD Telemetry Data Center Current Configuration

The Telemetry Data Center is located at the Naval Air Warfare Center Aircraft Division (NAWC-AD), Patuxent River, Maryland. The Telemetry Data Center provides telemetry reception, processing and display facilities at both the central and remotes sites. The central system is referred to the Real-Time Telemetry Processing System (RTPS) which resides in the Telemetry Division building (#2118) at the Cedar Point Complex. The facility was designed to provide comprehensive and reliable telemetry flight test support to meet the expanding requirements of the Flight Test community well into the 21st century. Support for real-time operations include the acquisition, processing, storage and display of telemetry data from aircraft under test.

The system is comprised of seven telemetry data "streams" each of which is linked to a dedicated Project Engineer Station (PES). Each of the data streams is capable of processing information from up to four PCM and one FM source for a maximum of 2007 Engineering Unit (EU) converted data measurements. The PES can be utilized to monitor real-time flights or for post-flight data processing of test data which include SGI graphic and Challenge workstations, critical measurement displays, 80 pens of strip chart recorders, and video display terminals. Each PES room can be linked to the Atlantic Test Range Command and Control Stations (RCCS II), which allows for the fusion of telemetry and range information. A link also exists between the Cedar Point Complex and Air Combat Environment Test and Evaluation Facility (ACETEF) complex where the Paxtuxent River HPC facility resides.

Sophisticated telemetry decoding equipment provides flexibility in the types and mix of data that may be handled. Each of the seven concurrent test operations are capable of processing four independent 10 megabit pulse code modulation (PCM) sources Each PCM source may contain two independent subframe sets and/or embedded asynchronous wavetrains. MIL-STD 1553 avionics bus data handling is built-in. Sixty-four channels of analog data up to 200,000 samples per second and a variety of Frequency Modulation (FM) types are accommodated. PCM and FM data are converted to EU at up to 250,000 samples a second and are available to the PES rooms in a Current Value Table (CVT) or Time Series Buffer (TSB) format.

Flight test engineers operate the system from any of the seven project engineer stations. Each PES room operates autonomously from the other PES rooms which makes the system both inherently secure and mission independent.

Since the beginning of the 1997 fiscal year RTPS has supported 2491 flight test operations. Some of the active projects to date are:

- F/A-18E/F EMD - Seven Flight test Aircraft which have flown a total of 1836 flights as of 9 May 1998.
- V-22 EMD - Four test Aircraft.
- F-14 Digital Flight Control System (DFCS)
- SLAM-ER testing
- T-45 Buffet testing
- SH-60 & SH-3H Helicopter testing

- F-14 Fatigue Management
- EA-6B HARM testing
- F-18C/D Flutter familiarization flights
- S-3B Upgrade

Example of Typical Telemetry Data Requirements
Flutter Flight Test

While Paxtuxent River has been in the Telemetry business since 1973, the Navy has only had the ability to monitor Flutter flight tests since 1988. Flutter testing is still considered one of the most dangerous types of testing, because the testing truly "stretches" the flight test envelope, and could lead to the destruction of the Airframe. Currently, Patuxent River is the only Navy facility where Flutter is tested. What follows is a brief description of what is Flutter, followed by the anatomy of a Flutter test. Lastly, the amount of data generated by a test is calculated.

Flutter is a self excited, frequently destructive oscillation of any air vehicle or part of an air vehicle. Flutter may be regarded as a condition whereby energy from external Aerodynamic forces prevents a structure's oscillation from diminishing in magnitude.

Anatomy of a Flutter Test Program

- Intensive preflight analysis to estimate the point where Flutter condition will occur. This is based on Wind Tunnel and large scale predictive aeroelastic software packages (i.e. IDEAS, NASTRAN etc...).
- Ground Vibration Testing of actual aircraft to validate preflight analysis.
- Flight Test build up and envelope expansion that approaches the estimated Flutter points.
- At test points, induce Aircraft oscillation using the following methods
    - Pilot Control Stick Raps to excite control surfaces as aircraft approaches test point
    - Sweep of Control Surface through the natural frequencies of the structure at the test point
    - At the test point, dwell the control surfaces at the natural frequencies identified by the Sweep
- Between test points, perform Frequency and Damping extraction from the data. Compare the data with predictive models and make a decision as to whether it is safe to continue to the next point.
- If everything is okay, go onto next test point
- After the Flight test is over, perform intense Modal analysis on all structural data from the flight and compare with predictive models and previous flights.
- Clear the aircraft for the next flight.

Flutter is not the only flight test program that requires extensive preflight and post flight planning and analysis, along with a requirement that real-time safety of flight be monitored. However, Flutter is a good example where large data storage, CPU intensive software algorithms, and historical flight test data storage are all required to complete the program.

Amount of Data Collected by typical F/A-18E1 Flutter Flight

Given all the maneuvers that go into a Flutter testing, and the instrumentation package on the F/A-18E1 test plane, one can easily estimate how much data is required in the collection of all data pertinent to one Flutter flight.

Given the following:

- F/A-18E1 has a 2 Megabit/sec Telemetry signal
- Approximately 1600 Parameters are instrumented on the aircraft
- An additional 512 Parameters are derived from the Telemetry signal on the ground station at RTPS
- Data rates of 200,000 aggregate samples a second of data are typical for E1. Each data sample is a 4 byte word.
- The duration of each maneuver or "Prime data" is based on:
  - 30 seconds per level stick rap acceleration
  - 240 seconds per sweep
  - 200 seconds per set of dwell
- For each "Point in the Sky" test point there are
  - one level stick rap acceleration to the target condition
  - six sweeps both symmetrical and anti-symmetrical on aileron, stabilator, and rudder
  - three sets of dwells aileron, stabilator, and rudder
  - each test point requires around 35 minutes of data acquisition
- Around four test points can be accomplished per flight (40 maneuvers)

This is not a sentence.

Based on the data rate of the instrumentation and the amount of time the aircraft is performing a manuever. The total data storage requirement for one flight is around 7 **Gigabytes.** As of May 1, 1998, E1 has performed at least 200 flight tests dedicated to flutter. That equates to almost 1.5 Terabytes of data aquired for just one portion of the F/A-18E/F EMD program.

It is interesting to note that E1 is only one of seven F/A-18E/F aircraft currently being tested at Patuxent River. Through 9 May 1998 that have been a total of 1,836 flights or 2,749 total flight hours. At the average data rate of 200,000 32 bit samples/sec that equates to **7.4 Terabytes** of data! That is a stack of 9 track tapes over a 1/2 mile high. F/A-18 E/F testing is not yet halfway complete.

Telemetry to ACETEF/HPC
Current Examples

Currently, the link between the Atlantic Test Range facility and ACETEF is a dedicated T-1 line. A small subset of the telemetry signal is linked through a SDLC interface at a RTPS PES room to the Operations Command and Control (OCC) facility at ACETEF. From the OCC facility, the data can be optically "patched" to the various labs inside ACETEF. These labs include the HPC and the Manned Flight Simulator. A rather small data rate of 200 parameters at 10 samples/sec can be handled in a single direction, or 100 parameters at 10 samples/sec in a two way direction.

This restriction severely limits the type of applications that could be realized using the two facilities, but this problem is being addressed with the Aircraft Interoperability Center (AIC)

network. The AIC is a base wide fiber optic link that will open up the preferable data flood gates. As a mater of fact, the first use of the AIC was the transfer of raw telemetry signals over the fiber obtic. This eliminated the need for the current microwave links that exits between the various aircraft hanger and antenna facilities, and which were susceptible to line of sight interference.

The limited capability of the current link between the Atlantic Test Range and ACETEF/HPC is preventing the full potential of the HPC becoming a tool for telemetry. However, there have been some examples of how the two facilities can be used in conjunction to enhance safely of flight and crew training.

Test Team Coordination Training TTCT

The Integrated Product Teams (IPT) that support both the V-22 and F/A-18E/F projects support each of their aircraft with a dedicated group of flight test engineers. These teams can have up to 20-30 personnel. Having these people fully trained not only on the use of the RTPS PES telemetry rooms, but on how a particular flight test will be conducted before first flight was not always properly conducted. Also, any training that was performed did not reflect the real life interaction between the pilot and the flight test team.

The TTCT put a "man in the loop" by having the pilot run the aircraft simulation at MFS and sending the simulated data to the PES room were the test team conducted the flight test. Animation for the simulation had the option to run on the HPC. Communication between the pilot and ground team were the same, and actual flight cards where used in the training. Whole flights could be conducted that would acclimate both pilot and test team to how the flight test would be conducted. Difficult test points could easily be "reset" and tried again, or test points could be refined to optimize the flight card.

F-18 Asymmetric Stores

Asymmetric loading of an F/A-18 could lead to the situation where the aircraft would not maintain enough control in roll to overcome the discrepancy in weight from one side of the aircraft to another. Important information in the Aircraft's Flight Control Computer (FCC) would tell the ground crew how close the aircraft was approaching departure. Unfortunately, this information was not available to the telemetry stream. This information, however, could be replicated at the Manned Flight Simulator if the proper inputs from the aircraft were available.

Telemetry data from RTPS was sent in real-time to ACETEF where it was run through a simulated F/A-18 FCC. Data from the simulated FCC was then sent back in real-time and made available to the PES. Total delay time was 1/5 of a second. A real-time comparison of the telemetry flight controls input and the simulated FCC output was performed in the PES and safely of flight calls were made based on this data.

Telemetry HPC Potential Applications

The current link between the HPC facility at ACETEF and RTPS is the limiting factor in the growth of new applications that could utilize both facilities. While Network improvements are being worked on, other methods are being developed that will aid in flight testing at Patuxent River. One of these developments is the Telemetry Data Server (TDS).

The TDS is a simple method of capturing ALL Engineering Unit converted data from a flight test to formatted direct access hard drives. Disk space size and access has finally reached a point that one can write all the data from a telemetry flight to a large formatted disk. In the case of the F/A18 E/F data rates, one 4.2 Gigabyte hard drive could hold approximately 45 minutes of flight test data. Two 9 Gigabyte hard drives would hold around 3 hours of flight time, which is about the duration of a typical flight test. Utilizing Fast Wide SCSI II interfaces to the disks is more than enough to handle the F/A-18E/F data throughput requirements of 1.6 Megabytes per Second. These hard drives, which are being continually upgraded, are mounted to the SGI Challenge Computers in each PES room. The hard drives are refereed to as "Data Bricks".

Immediately after the flight, the Data Bricks are removed from the PES room and mounted on a SGI Challenge Computer that resides in the post flight data distribution lab. This lab is collocated in the same building as the PES rooms, but it has the advantage of having access to the base wide network. Utilizing the base wide network, or the new AIC optic network, ACETEF/HPC would have immediate access to all the data from the flight test. If the networks were still an issue, the data bricks could be driven over to the HPC facility and mounted directly to its machines (at Patuxent River, RTPS and HPC are separated by roughly 3 miles).

Once the HPC facility has access to ALL of the data from a flight, a myriad of applications could be performed. Also, to "close the loop", HPC terminals could be made available in each PES room, so the engineers could have access to the processed results while conducting the next test flight. The following is a brief synopsis of the potential applications that would benefit the telemetry world.

Flutter Analysis

As stated in the example above, after a Flutter flight, intensive analysis must be performed on the structural data before the Aircraft can be cleared to fly again. This analysis is typically performed utilizing third part software, and involves extensive modal analysis, which is in turn compared with both the predictive models and results from previous flights. Any procedure that speeds this process up can easily justify its existence. The HPC is tailor made for this type of processing.

After analysis is complete and the aircraft has been cleared to fly, there is still a need to review previous data from a flight while the next flight is in progress. A HPC terminal in the PES room would allow for the quick access of previous flight information and would greatly enhance safety of flight. This capability exists in principle with the V-22 testing at Paxtuxent River. Real-Time data is processed at RTPS, while a terminal is available in each PES room can access previous flight data due to a link to Bell Helicopter's Computer Aided Flight Test Analysis system (CAFTA). CAFTA's computers are at the Bell facility in Arlington, Texas, and are linked to Pax River via dedicated T-1 lines.

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Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) is one of the more computationally demanding applications that utilizes HPC. However, the validity of its results are based upon the quality of the model that is being analyzed.

Traditionally, CFD relied upon schematic drawings and wind tunnel data to refine the computer models used in the computations. Access to telemetry data would provide the CFD engineer with accurate atmospheric conditions, control surface positions, wing and tail surface deflections, and store configurations. These, and many other available "real life" inputs, would greatly refine the CFD model and could only lead to better results.

Higher Fidelity Simulations

The current 200 parameter at 10 samples a second transfer rate severely limits the ability to feed simulators "real-life" flight conditions. As the networks improve, the ACETEF/ HPC facility can be provided all of the data during a flight test, which can only lead to more accurate simulations.

Engine Analysis

Testing of the turbine and compressor stages of an aircraft's engine requires the accurate resolution of frequencies out to 50,000 Hertz (Hz). Traditionally, only dedicated frequency Hardware Analyzers could accomplish this task. If an appreciable amount of engine data were to be digitally captured, the computing power of the HPC would be indispensable as a tool in "crunching" the data. Individual compressor and turbine blades could be tested for torsional and shear stresses during both transient and steady state events.

Fatigue Analysis

The average age of fleet aircraft continues to go up, as does the length of time a particular aircraft is in demand for service This trend will certainty continue. Fatigue testing and analysis of airframes is becoming a major requirement in the T&E community.

Fatigue and Stress computations are generally not very intensive. What is intensive is the sheer amount of data that must be stored and warehoused. Insturmented aircraft must be tracked over many flights, if not for the aircraft's whole service career. Users must be able to quickly review the data and identify types of maneuvers the aircraft performed and other environmental conditions it encountered. The HPC would aid in the search for this data.

Conclusion

Nature abhors a vacuum. Likewise, people who work with computers abhors empty disks and unused CPU's. That fact alone will be enough to get the folks in the Telemetry world to investigate the resources made available by the HPC facility.

It is important to note that the HPC facility must be readily accessible and be treated as a mission critical asset before the Telemetry world would consider having the HPC "in the loop" during a flight test. However, as a post flight tool for massive data reduction and analysis the HPC facility should not have much trouble finding a niche in the Test and Evaluation Community.