A HIGH-DEMAND TELEMETRY SYSTEM THAT MAXIMISES FUTURE EXPANSION AT MINIMUM LIFE-CYCLE COST

Viv Crouch
Aircraft Research and Development Unit (ARDU)
RAAF Base
Edinburgh, SA 5111
Australia

Anna Goldstein
Loral Test & Information Systems
P.O. Box 3041
Sarasota, FL 34230

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ABSTRACT

The Aircraft Research and Development Unit (ARDU) of the Royal Australian Air Force (RAAF) is the only agency in Australia that performs the full spectrum of military flight testing and is the new custodian of the instrumented weapons range at Woomera. Receiving early attention will be the upgrade and integration of ARDU's telemetry systems with the meteorological and tracking data acquisition capabilities at Woomera to minimize overhead and data turnaround time.

To achieve these goals, maximum modularity, extensibility, and product interoperability is being sought in the proposed architecture of all the systems that will need to cooperate on the forecast test programmes. These goals are also driven by the need to be responsive to a wide variety of tasks which presently include structural flight testing of fighter and training aircraft, weapons systems performance evaluation on a variety of combatant aircraft, and a host of other tasks associated with all fixed and rotary wing aircraft in the Army and Air Force inventory.

Of all these tasks however, ARDU sees that responsiveness to future testing of F-111Cs fitted with unique Digital Flight Control Systems along with USAF standard F-111Gs may place the most significant demands on data handling — particularly in regard to providing an avionics bus diagnostic capability when performing Operational Flight Programme (OFP) changes to the mission computers.

With the timely assistance and advice of Loral Test & Information Systems, who has long-term experience in supporting USAF F-111 test programmes, ARDU is confident of making wise design decisions that will provide the desired flexibility and, at the same time, minimize life-cycle costs by ensuring compliance with the appropriate telemetry and open systems standards. As well, via cooperative agreements with the USAF, the potential exists to acquire proven software products without needing to fund the development costs already absorbed by the USAF.

This paper presents ARDU's perception of future needs, a view by LTIS of how best to meet those needs, and, based on ARDU data, a view of how LTIS' proposal will satisfy the requirement to provide maximum extensibility with minimum life-cycle costs.

INTRODUCTION

The Aircraft Research and Development Unit (ARDU) of the Royal Australian Air Force (RAAF) is the only agency in Australia that performs the full spectrum of military flight testing. Recent consolidation with other organizational elements of both the RAAF and the Defense Science and Technology Organization (DSTO) has also added responsibilities for Electronic Warfare, Aircraft Stores Compatibility Engineering, and management of the Woomera weapons range to ARDU's duties. Critical to achieving self-reliance in monitoring the effectiveness, suitability, and performance of foreign and locally-acquired or adapted products will be the successful integration of these and future flight test systems to meet the forecast need.

FLIGHT TEST SYSTEMS — NOW

Essential to the conduct of any test programme is accurate and timely meteorological data (test conditions), Time-Space-Position-Information or TSPI data (where is the System-Under-Test and at what time?) and telemetry/recorded data (what's the behaviour of the System-Under-Test?). Prior to the recent consolidation, these data sources were provided by different agencies and upgrades could only be considered in a piece-meal fashion owing to the different budgeting arrangements and the constraints they imposed. Creating a single time-stamped data file that contained all three sources of information could therefore only be achieved by tedious, error-prone, and time-consuming means. This problem is not unique to ARDU. As reported by staff at the Naval Air Warfare Center (NAWC — China Lake), handling the telemetry/TSPI data assimilation and post-processing effort has required a software effort that boasts 700,000 lines of executable code [1]. And I'm willing to guess that like us, this effort was never planned, estimated, budgeted, and staffed "up front." Where has the philosophy gone that used to demand that the tools used for testing be already evaluated prior to commitment for use? NAWC, you have our sympathy and respect for the low suicide rate among your staff. In my own opinion, the last thing you need in any Test & Evaluation programme is unproven tools — otherwise you are measuring things with a yardstick of unknown precision. Unfortunately however, realistic up-front estimates frighten the generals and the accountants and we all end up captive to ongoing tasks. This is a bit like trying to build an automobile while you're driving it.

THE FUTURE

In view of the isolation of the present data sources in Australia, it's useful to look into the future and forecast the likely demand, mostly driven these days by software maintenance activities rather than developmental activities for inventory aircraft. In Australia, the future brings modifications to F/A-18s along with USAF-supplied F-111Gs and RAAF F-111Cs with modernized avionics.

As a result, the data complexity and volume demands on future test programmes is expected to increase tenfold over anything within ARDU's previous experience and capacity.

As a first guess, using the existing methods of preparing the flight test systems and assimilating (post-test) the meteorological, TSPI, and behavioural data will cause unacceptable data turnaround times, inadequate data quality monitoring, and high costs. Real-time (or near-real-time) assimilation, compression, formatting, and quality monitoring of the data from the three sources concurrently is therefore needed to improve the data turnaround time and to detect problems as early as possible in the data processing and analysis path. Cognizance of the appropriate telemetry and open standards is also essential to ensure interoperability, improve extensibility, and reduce the life-cycle costs associated with maintenance and enhancement.

SOME FACTS AND FIGURES

Preceded by the days of ultraviolet trace recorders and the armies of itinerant workers needed to manually translate the traces into "real numbers," ARDU's first venture into the digital data acquisition era began in 1977. Data demands then were quite modest

(120 parameters with user-selectable sample rates from 1 to 120 samples/second). Constructing a suitable telemetry data format (known as a Data Cycle Map at ARDU) was also readily achievable. Why? The"information content" of a data word was the same bit length as the telemetry data word, and they were all the same length anyway (12 bits). Things have changed since then. We're now talking IRIG-106 PCM Class I streams (with many Class II attributes) telemetered at up to 1.6 Mbps where there is NO LONGER a direct match between the telemetry word length and the "information content." For example, a single measurand or flight parameter (such as roll angle) might occupy portions of multiple words in a telemetry frame, or conversely, a single telemetry word might be comprised of multiple parameters. A way of viewing this is shown in Figure 1, where a serial stream of telemetry has been shown as a stacked pile of digital words (of length n) having different characteristics within each subframe. You simply can't construct these things "in your head" any more.

Hence, the synthesis of a suitable Data Cycle Map for each phase of a test programme becomes a real "cranium-cracker." This problem is not unique to ARDU. As reported by BBN, who pioneers much of the post-telemetry assimilation analysis software, "put two telemetry engineers in a room to decide on a format and they will come out with three specifications — or they won't come out at all" [2]. Alongside this problem, we are now talking about the concurrent assimilation of the meteorological and TSPI data with in-built quality monitoring and near-real-time correction and smoothing destined for storage to disk in a format that is:

a. directly digestible by the analyst's favorite number-crunching and display software (such as BBN Probe), or

b. able to be easily formatted onto a medium suitable for immediate delivery and playback by the agencies responsible for enhancing or bug-fixing the mission computer and avionics software.

SOME CONCERNS

Traditionally, life-cycle costing has never played the role it deserves in the product procurement process, since if we play according to the antiquated business rules, an upgrade cannot be justified in the absence of a task that needs it. Once the task is active of course, the focus is on instantly satisfying the task authority — at the expense of the future.

My comments here are not an isolated observation. "While life-cycle cost is not a totally new concept to the Australian Defense Forces (ADF), it has been rarely practiced" [3].

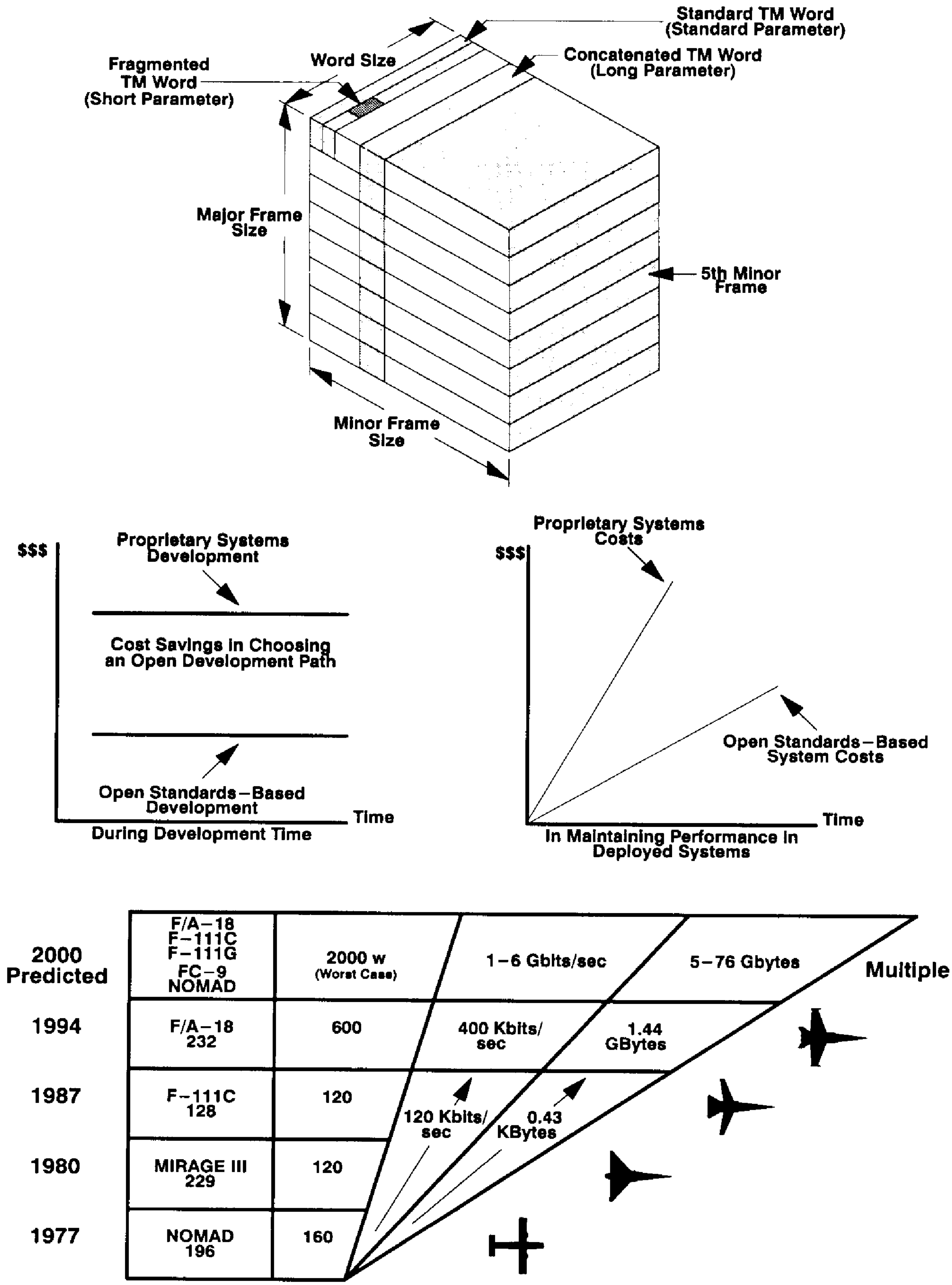
Standard TM Word
(Standard Parameter)
Word Size
Concatenated TM Word
(Long Parameter)
Fragmented
TM Word
(Short Parameter)
Major Frame
Size
5th Minor
Frame
Minor Frame
Size
$$$
Proprietary Systems
Development
Cost Savings in Choosing
an Open Development Path
Open Standards–Based
Development
Time
During Development Time
Proprietary Systems
Costs
$$$
Open Standards–Based
System Costs
Time
In Maintaining Performance in
Deployed Systems
2000
Predicted
F/A–18
F–111C
F–111G
FC–9
NOMAD
2000 w
(Worst Case)
1–6 Gbits/sec
5–76 Gbytes
Multiple
1994
F/A–18
232
600
400 Kbits/
sec
1.44
GBytes
1987
F–111C
128
120
120 Kbits/
sec
0.43
KBytes
1980
MIRAGE III
229
120
1977
NOMAD
196
160

Figure 1

LESSONS LEARNED

Lessons learned from recent ARDU sorties at the Woomera weapons range significantly highlight the application of telemetry as a productivity improvement tool. Problems that could easily have caused total failure of the test programme were detected early enough to enable the programme to proceed with minimum waste of flight hours and data processing time.

In the case of the last test programme at Woomera, the Real-Time Monitoring Facility (RTMF) detected three major problems with the airborne system on the first flight. It took approximately three days to fix two of these problems and four days to fix the other one. In the absence of this early feedback from the RTMF, these problems would not have been detected until the detailed analysis phase of the programme — approximately two months after the campaign had finished. Only at that time would it have been discovered that the test programme had failed to yield the critical operational data it was supposed to provide.

Other problems were detected which, although not critical to the specific test missions being flown, spurred the planning needed to rectify those problems in preparation for future missions. Consider some simple sums based on:

> Test Programme Cost
> Aircraft flight time costs = $55,000 per hour x 40 flights = $2.2M
> Airborne/ground instrumentation preparation & activation = $150,000 per Sortie x 40 flights = $6M
> Post-processing effort = 4 staff x 8 weeks x $200/day = $32,000
> Woomera deployment cost = $60,000
>
> Partial Cost = $9.12M (Additional costs such as chase aircraft and consumables such as weapons/stores have not been estimated).

The up-front cost of about $5M for the telemetry system has therefore already been justified from the perspective of "detecting problems early while they're cheap to fix." Apart from any safety-of-flight conditions that might be monitored during a test programme, the application of telemetry to future test efforts offers potential for further dramatic cost savings. Telemetry is a low-cost investment and an "early warning system" to remedy problems before they become expensive to fix or simply not affordable to fix.

Given that productivity may be defined as "the ratio of valuable output to input" [4], these assertions are of particular value since a key measure of productivity is given by "the cost of recovering deficiencies if they had remained undetected" divided by "the cost of the test programme." The sums given sound nice. In reality however, the customer would probably find that "repeating" the test programme was not affordable and months would be spent by the analysts trying to salvage anything useful out of the data provided — at their own expense. These efforts never seem to be costed.

With a view to the future, and the application of telemetry to Software V&V flight testing, the potential to do it once and do it right is within our grasp. In this instance, the transmittal of undetected data faults to a "fleet" of aircraft and the costs of recovering them would be embarrassing and quite likely unaffordable to remedy in a hurry. The introduction of operational deficiencies could also adversely affect operational readiness.

THE LORAL TEST & INFORMATION SYSTEMS SOLUTION

Loral Test & Information Systems (LTIS) has, through its prior involvement with a number of Telemetry Systems supplied to ARDU, developed a unique understanding of the RAAF methodology, task management, and the attendant problems surrounding upgrade programmes applied to in-service equipment.

In view of the uncertainty associated with concurrent processing of meteorological data, TSPI data, and telemetry data, LTIS is able to offer a nucleus system to meet future F-111 needs that complies with open system standards and can be readily adapted to meet the needs once defined.

In the evolution of the proposed system, available alternatives were carefully evaluated to determine cost of procurement, cost/performance relationships, and life-cycle costs. The proposed system is based on the Loral O/S90 (Open System for the 90's). This system will provide a POSIX-compliant Open System that will support both the F/A-18 and F-111C programmes. The O/S90 is readily adaptable to support the F-111G and is capable of meeting the RAAF's needs well into the twenty-first century. The proposed system is fully complaint with telemetry standards and is extensible to handle IRIG as well as packet-switched data formats. The open system environment protects the investment because the software is completely portable.

With the O/S90, a separate dedicated host computer is no longer required. System setup, real-time data distribution, and data archiving functions are now performed by dedicated modules within Loral's 8715 chassis. The DEC workstations will be replaced with Sun IPX workstations with 19-inch color monitors. This ensures maximum supportability hardware selected for hosts, and workstations that are compatible to new, current-generation items that are commonly used in Australia. The workstations will be responsible for receiving real-time data from an Ethernet Output Module (EOM) and creating real-time or post-flight displays in an X Windows environment. One of the workstations will be configured with additional memory and disk space to act as a server on the system. X Windows provides the power and freedom to access other software applications without leaving the O/S90 environment. X Windows provides a tremendously powerful desktop. Multiple windows can be opened simultaneously, where users can "do it all" from one workstation.

An OSF Motif graphical user interface ensures that all menus operate consistently. Motif-based menus are easy to read, making system tasks intuitive.

The proposed O/S90 system consists of SQL Database Interface software which is designed to provide database configuration options for processing multiple data streams of different formats. The ARDU keeps Flight Test Mission tapes for several years and requires compatibility between mission setups. The SQL databases are not compatible with ARDU's currently existing database mission setups. To save time in reentering old mission parameters into the SQL database, Loral developed the Database File Import and Export Utility. The export portion of this utility generates an ASCII text file from the database that can be ported to another platform. The import utility reads an ASCII file and loads the database. SQL interfaces will also enable ease of interfacing with Telemetry Attributes Transfer System (TMATS) when implemented.

Rather than outputting the data through Parallel Output Modules (POMs) to a separate and dedicated host computer responsible for archiving the data to a mass storage device and distributing the data to the workstations via Ethernet, the O/S90 version of the 8715 chassis includes two dedicated modules for achieving these functions. The Disk Output Module (DOM) includes a Sun SPARC processor running the Sun O/S operating system and is responsible for recording data to mass storage via its SCSI port. This data is then available for post-flight analysis via any of the nodes on the network. The data distribution functions will be performed by the EOM. This EOM, based on the Sun SPARC processor with Sun O/S, outputs data to Ethernet which is then available at the workstations for additional processing and display.

BBN Probe software can read O/S90 files using the Probe Flexible File Server. However, the Flexible File Server takes a very long time to reformat data from the recorded data file to that required by BBN Probe. To eliminate this lengthy reformatting process, Loral proposed the Flexible Data Formatter (FDF) within the 8715 chassis which is interfaced to the server workstation via FDDI. This FDF is a two-card set that is capable of outputting data in various data formats which can then be input directly to real-time processing applications, or recorded onto mass storage devices for post-flight analysis. ARDU's requirement is to use RS 1 and BBN Probe on the recovered data. In addition to supporting BBN Probe's format, the FDF can simultaneously produce files in the RS1 and Ball Fast (BFAST) formats. The FDF can even build multiple files in different formats on several workstations simultaneously, thus saving time and resources in replaying the same analog tape multiple times. By using the FDF, ARDU can use BBN Probe on real-time data and reduce data turnaround time. FDF is fast, BFAST-compatible, and additional formats can be easily added. To support future data rates, up to 8 FDFs can be supported.

In order to handle the increase in data and processing requirements imposed by F-111C data formats, the existing data processing unit (DPU) modules will be replaced with recently-developed DPU-2 modules. All of the special F111-C processing algorithms will execute within the new DPUs. Each DPU-2 will provide approximately three times the processing power as contained in the existing Primary Analysis Processor 3 Upgrade (PAP3-U). These DPU-2s will contain all of the same algorithms currently available under the PAP3-U. In addition to providing more processing power, the algorithm development environment for the DPU-2 allows the user to develop algorithms using the "C" high-level language in addition to the 100-plus already available algorithms. A menu-driven, easy-to-use editor, assists in the creation of new algorithms.

One of the most important aspects of the proposed system is data quality. With the software for alarms and events, limits and exceedances can be flagged early, saving both time and money. The Alarm/Event Logger software organizes and categorizes event messages and distributes them to user-selected output and storage media. Events include data in- or out-of-limits, data match or mismatch, data in- or out-of-alarm conditions, and special user-defined conditions.

With a single pass system, all data merging will be performed in real time. A utility is provided that will merge data files in time sequence. Using a single pass system configuration and based on a two-hour test flight, the system will process the data and clear the system in less than 8 hours.

AN ARDU PERSPECTIVE ON THE LTIS PROPOSAL

Scheming for the future, ARDU views are consistent with those expressed by the NUWC Division Newport [5] that an open standards-based system will provide:

- o Economic benefits by allowing different vendors to compete with open standard hardware/software offerings.

- o Productivity benefits by having established consistency and predictability in the supply of services regardless of the host platform.
- o Reduced life-cycle costs by minimizing the duplication of skills and configuration overhead on dissimilar host platforms.
- o Improved extensibility by enabling modular insertion and stable vendor target paths.

Looking at a simple life-cycle costing chart, the expectation is that a system offered within the open system framework and compliant with the appropriate telemetry standards will have half the life-cycle cost of a proprietary solution. Without even extrapolating to future upgrades, this equates to a cost savings of $500,000 per annum to the RAAF in field service and maintenance. And with respect to lessons learned, life without telemetry would make the remedial actions associated with deficiencies discovered on future test programmes unaffordable. This directly affects war-time readiness and is unacceptable.

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