# ADVANCED RANGE TELEMETRY DYNAMIC MEASUREMENT LISTS

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## ABSTRACT

A typical telemetry system for aircraft flight-testing transmits one or several data streams to the ground for real-time display and analysis, and also records the same stream on-board for later playback. During test operations, only a fraction of the available data is used at any given time for real-time display or analysis. More efficient use of the RF channel could be realized if only the data needed for the current test point is transmitted, rather than the entirety of the data. Intelligent selection of a subset of the data stream can provide large reductions in the required telemetry downlink bandwidth.

As one of the Advanced Range Telemetry (ARTM) On-Board Data Management (OBDM) initiatives, a prototype on-board data selection subsystem is being developed and demonstrated. The demonstration utilizes COTS telemetry workstations to the maximum extent possible and includes “plug-in” data requestor, selection, and server components to implement the added DML functionality. A significant objective of the OBDM/DML project will be to validate RF channel models to help minimize the amount of flight-testing necessary to validate the DML concept.

This paper will discuss the OBDM/DML architecture, integration of several custom components with the COTS portions of the ARTM “test bench”, and the current status of the OBDM/DML development and test program.

## KEY WORDS

Advanced Range Telemetry, On-board Processing, Dynamic Measurement Lists, Packetized Telemetry

## INTRODUCTION

Telemetry is utilized for the transmission of data and video necessary for the safe and efficient conduct of test and training missions. Many programs require telemetry during high-risk phases of air vehicle testing (Aerodynamic Flutter Analysis, Performance and Flying Qualities, Engine Integration, etc.) for the safe conduct of the mission to prevent aircraft damage or loss. Testers also use real-time telemetry data to decrease the mission turnaround time by minimizing and/or optimizing post-flight analysis.

The system throughput capacities of modern data systems (like the Common Airborne Instrumentation System) exceed the bit rate capacity of current range telemetry capabilities. Coupling this with the shrinking spectrum allocated for telemetry results in a serious problem for test, training, and space telemetry users. We can foresee that the telemetry (TM) links will become the bottleneck in the end-to-end real-time data stream. Telemetry providers are being required to provide more data with less spectrum.

To address this problem, the Advanced Range Telemetry (ARTM) program was created and funded by the Central Test and Evaluation Investment Program (CTEIP) under the Office of the Secretary of Defense, Undersecretary for Acquisition and Technology. The ARTM project is intended to assure that test and training programs over the next several decades can meet their data quantity and quality objectives in the face of these challenges. ARTM expects to improve the efficiency of spectrum usage by changing historical methods of acquiring telemetry data and transmitting it from systems under test to range customers. The ARTM program is initiating advances in coding, compression, data channel assignment, and modulation. On-Board Data Management (OBDM) and processing is just one of the initiative areas being pursued by ARTM. Dynamic Measurement Lists (DML) is one task of several which are attempting to better utilize whatever TM bandwidth is available.

## THESIS / RATIONALE

Over the years we have observed that, of the data available on board an aircraft under test, flight test engineers in a control room on the ground are actually using a relatively small percentage at any given time. A significant pre-flight effort is required to identify those measurands/instruments which will be necessary and sufficient to support the objectives of a given test flight. The subset identified for any given flight is typically constrained most strongly by the availability of TM bandwidth and frequently represents less than 10% of the data available on board (all of which is recorded on a tape recorder for later post-flight analysis). The subset is also constrained by the time and effort required to reprogram typical multiplexer-encoders, which tends to cause test and instrumentation engineers to enlarge the subset to minimize the number of times reprogramming is required.

We have also observed that, of the data available in the TM link, again only a portion (perhaps 10% again) is actually in use at any given instant, due to the dynamic selection of data for observation by test engineers. This selection typically takes the form, in recently developed control rooms (such as IADS at Edwards AFB), of individual display "pages" on computer workstations, potentially resulting in as little as 1% of the data available on board being utilized on the ground..

The Dynamic Measurement List initiative proposes that TM data requests can be formulated in real-time, based on the display pages test engineers have actually "pulled up" on their workstations. As these data requests are modified, they can be uplinked to the aircraft under test to support dynamic formatting of the TM downlink, such that, at any given instant the TM downlink contains only the data actually desired and in use by ground-based test engineers.

## ARCHITECTURE

The typical, classical TM system comprises an on-board data encoder/formatter that is programmed to select the desired subset of instrumentation. A ground station captures the resulting TM stream and makes the data available to test engineers for display and analysis, typically via a "Current Value Table" (CVT). Various mechanisms have been used to forward the appropriate data to individual computer workstations. One model broadcasts messages containing all available data to all workstations, leaving them to extract the data they require. Alternatively, a data selector in the ground station responds to *a priori* or dynamic data requests and sends customized messages to each workstation.

Conceptually, the proposed DML approach maintains the classical overall data system architecture while simply moving the data selection mechanism from the ground station up to the aircraft. This concept requires a command uplink to achieve its full potential, but alternative implementations could utilize predefined data selection programs, perhaps driven by on-board events, to achieve significant link bandwidth reductions. The key requirement/concept of the DML initiative is that of an on-board dynamic data selector.

The problem is to determine dynamically, in real-time, the required data subset and to define a bandwidth efficient method to select and to transmit that subset to the ground station while minimizing latency, preserving time correlation, minimizing data drop outs, and maintaining transparency to the system's users.

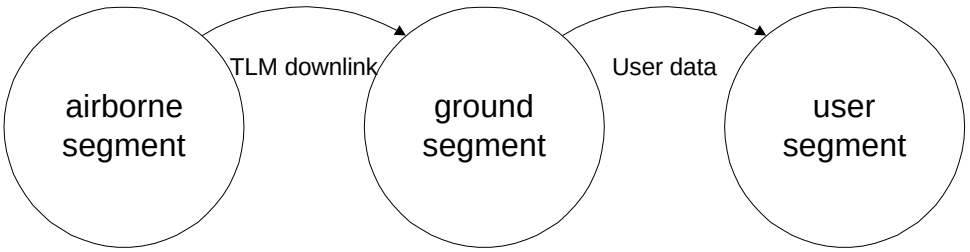


**Figure 1 – Typical Test Instrumentation System**

A typical flight test instrumentation system (Figure 1) consists of an airborne (or space) segment, a ground (station) segment, and a user (display and analysis) segment. The airborne segment consists of the instrumentation required to collect data, format it for transmission, and telemetry transmitters and antennae. In some situations, a command and control ($C^2$) transceiver is included. The ground segment typically consists of appropriate antennae, receivers (and $C^2$ transceiver), telemetry synchronization and formatting equipment and software, and communications facilities to send appropriate data to the user segment. The user segment typically consists of multiple engineering workstation computers, potentially widely scattered geographically.

Current airborne telemetry data acquisition systems (PCM and avionics bus) do not have dynamic reconfiguration capabilities. A "Dynamic Measurement List" (DML) capability is to be implemented in a typical flight test instrumentation system through appropriate insertions of software, to allow a wide range of DML experimentation.

Objectives for the DML demonstration include:

- Be "bulletproof" – if it's not absolutely reliable, don't bother.

- Minimize the telemetry downlink bandwidth required to support real-time analysis of flight tests by selecting and transmitting only those measurements that are actively being monitored/analyzed by ground-based personnel and/or automated systems.

- Select measurements to be down linked in accordance with a prioritization strategy to insure that predefined critical measurements are always transmitted and that currently requested measurements are transmitted if bandwidth is available.

- Maximize the utilization of the downlink by filling unused bandwidth with useful or anticipated measurements, perhaps by analysis of flight card information.

## DESIGN CONCEPT

In general terms, functionality will be added to the ground-based portions of a telemetry data acquisition and analysis system to identify only *active* measurements and to issue instructions to the airborne portion of the system to transmit *only* those measurements. All information necessary for operation of the telemetry system will be stored in a relational database. In addition to setup information, *a priori* requests for data to be recorded, to be transmitted, analyzed and displayed in real-time, as well as flight card information, may be stored. Any data prioritization information, perhaps based on mission and test point, from test engineers and managers may be entered into the database prior to the mission. Critical (high priority) measurements should be identified so that they will always be sent to the ground station in case of test vehicle loss. Indicator measurements could be monitored (possibly in the on-board portion of the system) so that exceeding a critical threshold could trigger a change in the content of the downlink to more relevant data. Test engineers will be able to dynamically modify the content of the downlink based on their current real-time data needs, presumably as indicated by data display pages they select and/or analytical software they choose to run. The Test Director/Manager will define a list of low priority measurements to be used as "fill" if the active data requests don't utilize the available downlink bandwidth. A really "smart" system might even be able to anticipate the upcoming needs of test engineers and use these measurements as "fill". Finally, "never transmit" measurements will be defined to eliminate any "dead" measurements which are of no use during a given mission.

Three major subsystems will be developed and added to the three segments defined in the Background section (see Figure 2). A DML Requestor will be integrated with the user segment; a DML Server with the ground station segment, and a DML Selector with the airborne segment. The Requestor will communicate with the Server via the network connecting the analysis and ground station segments. The Server will pass downlink format requests to the Selector via a command uplink implemented using telemetry modems. Downlink data will be "intercepted" by the DML Server near the ground station segment output and the DML Server will forward the data requested by each analysis workstation to those workstations.

The DML Requestor will provide the user segment with appropriate information to allow the user to identify the data currently available to him, potentially from several concurrent test activities. The user will be able to select the data of interest to him, typically by selecting predefined (graphical) display pages, by manually selecting individual measurements to be displayed using generic tools, or indirectly via analysis software. The potential will also exist for automatically sequencing displays/pages based on various selection strategies, e.g. test step on a flight (test) card, selection from various predefined anomalous situations, etc. Each user workstation's DML Requestor will forward its workstation's current request to the (appropriate) DML Server. A single

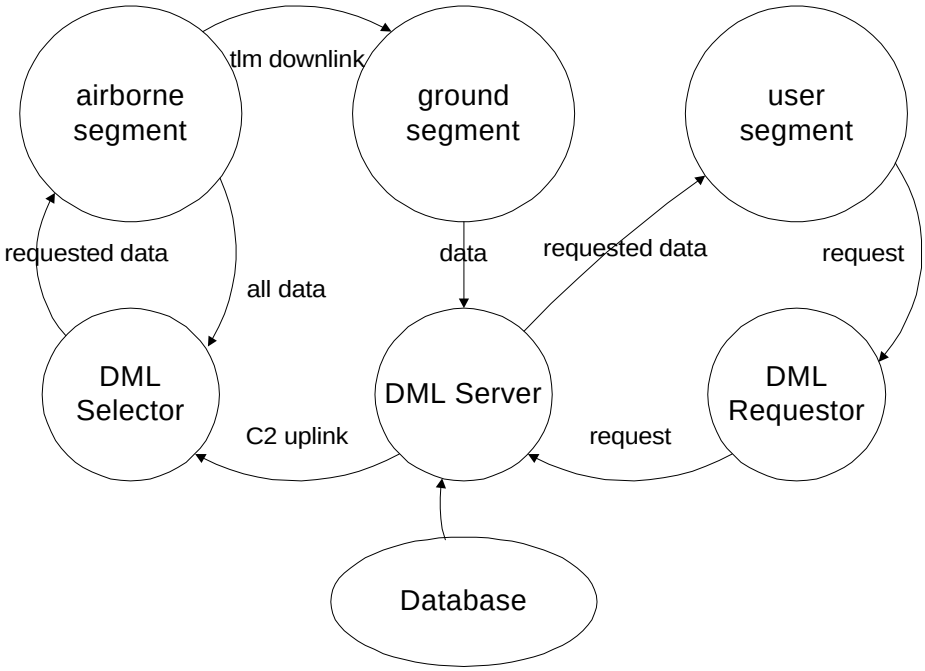


**Figure 2 – DML Modified Instrumentation System**

specific workstation will be designated as the Test Director's workstation, giving it management authority over certain operational aspects of the DML Server and overall DML system.

Multiple DML Servers will eventually be supported, to allow multiple concurrent flight tests. Each Server will provide appropriate information to any DML Requestor to facilitate measurement selection by engineering users. This information will be extracted from a relational database established and loaded prior to any flight test activity. The DML Server will respond to each data request by combining (forming the union of) all user data requests, a (high priority) critical data request, and a (low priority) background "fill" data request. The test director (who will be the highest priority user) may prioritize individual users, insuring that high priority users have their data requests filled, potentially at the expense of low priority users. The DML Server will then forward, via the $C^2$ uplink, the combined data request to the DML Selector in the airborne/space segment.

The DML Server will maintain sufficient prior, current, and proposed data request information to enable it to inform the user segment when the format of data packets is about to change. Updated format description information will be forwarded to the user segment when the DML Server detects a downlink format change. The DML Selector will insert a minimum of overhead data in the downlink to enable the DML Server to detect the format change.

The DML Server will attempt to minimize its utilization of the $C^2$ link through several strategies. Several (nearly) simultaneous user requests could be aggregated if some small delay in forwarding the combined request is acceptable. Only changes (adds and deletes) to the currently active request need be forwarded to the airborne DML Selector, providing a mechanism for guaranteeing synchrony between the DML Server's and the DML Selector's version of the request is incorporated.

When the DML Selector receives the ground station segment's combined data request, it will update its replica of the current data request and begin transmitting the newly selected measurements via the downlink. It is not yet clear which of two basic transmission strategies will be optimal: fixed length PCM frames containing a fixed number of measurements, or variable length "packets" carried over fixed length "transport frames", *a la* CCSDS. The latter strategy has the advantage of more easily supporting a generalized networking model, potentially allowing implementation of a full-blown internetworking capability between the air vehicle and ground systems. Both strategies will be explored during development and evaluation of the initial system. In any event, an identifying sequence number will be inserted into the downlink data frame/packet to allow the DML Server to determine when the content of received data packets has changed.

Upon detection of a downlink format change, the DML Server will inform the user workstations that a change has occurred. Two general possibilities exist for the distribution of data to the workstations: point-to-point (logical) links can be created between the Server and each workstation, or a multicast arrangement can be utilized. If the point-to-point strategy is implemented, the Server will be responsible for sending a format description message to each workstation, followed by a stream of data messages containing the measurements requested by each workstation. If the multicast strategy is implemented, the Server will insert a (multicast) format message into the data message stream, which would consist essentially of the data frames/packets transported over the telemetry downlink. As each workstation receives the format message, it will use its own copy of its data request to determine the location of the measurements it requested, then extract those measurements from each subsequent data message. In either case, each workstation receives the data it requested a short while earlier. It is anticipated that the request latency will be less than a second in typical aircraft test situations.

## IMPLEMENTATION

The ARTM program has established both a ground-based test laboratory and an Airborne Telemetry Demonstration System (ATDS). AvTec Systems' PTP-NT telemetry workstations provide support for onboard processing and data management experiments. One of the workstations is installed on a T-39 (SaberLiner) and provides instrumentation simulation capabilities along with capacity for on-board processing experiments. The

second workstation is installed in the ARTM ground station. A third Windows NT workstation is also installed in/near the ground station to emulate a typical test engineer workstation/console.

The AvTec PTP-NT telemetry software is being used to provide a basic TM system emulation. The airborne workstation emulates an instrumentation system by allowing the playback of an IRIG-106 Chapter 4 (PCM) multiplexed telemetry link recording. The PTP hardware/software can be configured to format and transmit either PCM or CCSDS (packetized telemetry) link formats. The ground-based workstation is configured to provide basic ground station functionality including separation of the data payload from either TM transmission mechanism. In a simple classical TM system emulation, the data payload (typically a Chapter 4 minor frame) is simply passed to the user's NT workstation for display.

In one configuration (Figure 3), we were experimenting with multiplexing multiple asynchronous data streams into a CCSDS "carrier". The highlighted DML Data Requestor temporarily combines the minimal functionality of a user display station and the ground station data server. A test engineer interacts with the Data Requestor to create a message that is passed over the Digital Communication Network System (DCNS) to the highlighted Data Selector. The Data Selector extracts the requested data from the Chapter 4 frames and constructs variable length payloads that are multiplexed into the CCSDS downlink. Upon reception by the ground segment, the payloads are extracted and passed to the Data Requestor for display to the test engineer. Both highlighted custom DML components were simple Visual Basic programs that communicate with the rest of the system using User Datagram Protocol (UDP) network sockets ("fat" arrows in Figure 3). The DML components are implemented in such a way that they can "talk" to each other without the other portions of the system simply by running them on one computer.

## STATUS / ISSUES

Quite recently, all the disparate components of the ATDS "test bed" have finally been collected and assembled. Presently, we are adding functionality to the basic Data Requestor and Data Selector and defining the communications protocols necessary to achieve a robust dynamic telemetry system. Ground testing of the prototype system (as described by Figure 3) has just been accomplished; flight-testing is expected to begin this summer (FY99).

The next major step will be the design and implementation of the prioritization scheme discussed above in the Design Concept section. The optimal means for implementing this "Quality of Service" mechanism is not at all clear at the present time. It is clear, however, that something resembling packetized telemetry mechanisms will be required, and that the data payloads will be of varying length from one packet to the next.

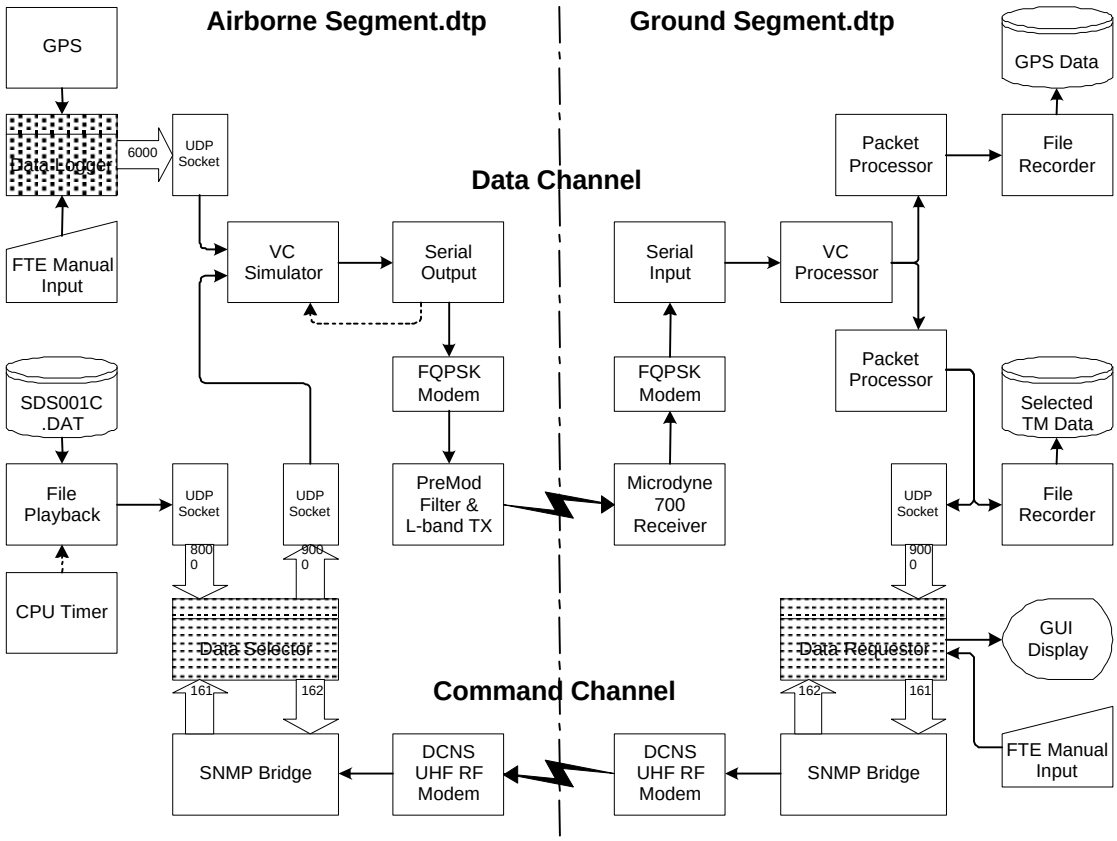


**Figure 3 – DML Experimental Instrumentation System**

An interesting question has arisen in the preliminary analysis of the DML concept. On occasion, an on-board event will occur that causes the Test Engineer to want to "back up" and look at some data that was not on his screen during the event. Some telemetry systems maintain a buffer containing the most recent several minutes of all the down linked data to support these needs. A DML ground system could maintain such a "look-back" buffer, but it is unlikely that it would contain the desired data. However, with the advent of on-board data recorders with a real-time "playback" capability, the downlink could be reconfigured to accommodate a playback request. But then the normal real-time data must be impacted either by reducing the number and/or the rate of the measurements being sent, leading to some interesting "holes" in the real-time data that might be available in a ground-based playback buffer. Requirements derived from this sort of desire for a playback capability will have to be addressed in more detail as the development of the DML concept proceeds.

Some concern has also been raised about the partial failure characteristics of the DML concept, particularly the situation where the command uplink is lost, either temporarily or permanently. Possible solutions include the definition of fallback link formats and content. We anticipate that many more issues will arise as we make further progress over the next few months.