Analysing Missile Telemetry Data with the Generic Telemetry Viewer and the Whiteboard Viewer

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***Keywords**: Telemetry; Data Analysis; Visualisation; Weapons; Charting.*

EXTENDED ABSTRACT

The analysis of missile telemetry data from live or simulated firings has traditionally been a time consuming and complex task. Missile telemetry data can consist of over a thousand channels, and data files can be hundreds of megabytes. Hundreds of runs can be performed in a single day of testing, resulting in an information overload for the analyst. The Generic Telemetry Viewer (GTV) and Whiteboard Viewer have been developed to analyse telemetry and simulation data in an efficient and repeatable manner.

GTV is the primary software tool used by the Defence Science and Technology Organisation's Weapons Systems Division (WSD) for the detailed analysis of missile telemetry data and model and simulation generated telemetry data. GTV is a *Windows*®-based software application, which has been specifically designed to process and display large data files by using efficient data loading and data access routines. Although originally designed to analyse missile telemetry data, GTV accommodates any format of time stamped data by providing a generic importing capability.

GTV has an intuitive Graphical User Interface (GUI), including a built-in search facility to quickly navigate to data of interest. Data is displayed on 2D charts that can be easily manipulated, with the ability to zoom and scroll. Charts can be customised, with extensive properties allowing users to specify axes labels, chart colours, chart styles and more. A plug-in architecture enables users to develop custom modules to manipulate data for specialised purposes. GTV is currently used for the analysis of both hardware and software telemetry data[1] for several different weapon systems. GTV's client base includes WSD, other organisations within the Australian Defence Force (ADF) such as the Royal Australian Navy's Ranges and Assessing Unit (RANRAU) and international organisations such as the Defence Science and Technology Laboratory (Dstl) in the UK.

Unlike GTV, which is designed for detailed data analysis, Whiteboard Viewer provides the user with the 'big picture'. Whiteboard Viewer enables analysts to visualise hardware telemetry, software telemetry or Time Space Position Information (TSPI) using 2D and 3D computer graphics in a trajectory replay mode.

Whiteboard Viewer displays the data with respect to time and allows the replay speed and data rate to be varied. The data is displayed in both graphical views and textual displays with varying detail. The graphical views can be toggled between a 2D plan view (XY-plane) and 2D elevation view (XZ-plane) or a 3D world view that includes the ability to reposition the camera. The textual displays provide a means of communicating text-based information.

Whiteboard Viewer provides a visual representation of the missile 'thought process' and is an invaluable tool used to educate analysts and managers on complex missile functionality that would normally require a long time to grasp.

GTV and Whiteboard Viewer have dramatically reduced the time required to analyse missile telemetry data. In addition, these visualisation tools have allowed analysis to be performed at a deeper level than would otherwise be achievable using currently available commercial software. GTV is fast becoming the standard time dependent data analysis tool in DSTO, and other Australian Defence organisations. Similar success is expected for the Whiteboard Viewer, whose development is still in its infancy.

Note that all data shown in this paper is purely fictional and is not representative of any ADF weapon system.

[1] Hardware telemetry refers to telemetry data generated from hardware eg. Weapons. Software telemetry refers to data generated from simulations

1. INTRODUCTION

Missile telemetry data provides the missile analyst with information on the processing that occurs inside the missile. By analysing missile telemetry data the analyst can visualise the missile acquiring and tracking the target and use this information to evaluate its performance. Telemetry data can be generated from live missile firings, hardware-in-the-loop simulations or software simulations.

The advent of faster processors and cheaper memory has not been lost on the missile community. Modern missiles collect and process several times as much data as their older counterparts. Analysing this data with older generation telemetry analysis tools is a cumbersome task. Older telemetry analysis tools are not capable of processing large amounts of data in a memory efficient and time efficient manner. As of 2001, no telemetry analysis software existed on the market to analyse large amounts of data in the manner required by DSTO missile analysts. This paper describes the development of two software tools that assist with the analysis of telemetry using traditional graphing techniques and computer graphics.

2. THE GENERIC TELEMETRY VIEWER

DSTO's Weapons Systems Division (WSD) performs analysis on telemetry data for a number of different missile systems. For some systems the missile manufacturer's provide specialised software for the analysis of the telemetry data. For other systems WSD has the choice of using commercially available analysis software or developing its own in-house software.

Analysis software provided by missile manufacturers generally only supports the missile system it was designed for. In addition, analysis tools for trials generated telemetry and model generated telemetry are typically different software applications. This means that WSD analysts are unable to easily compare model telemetry and trials telemetry side-by-side within the same application. Also, the analysis capability provided by these tools can differ from tool to tool, meaning that the level of analysis that can be performed varies for different systems.

As of 2001, commercially available telemetry analysis software was not completely suitable for WSD analysts. Some of this software was unsupported with outdated graphing functionality and limited Graphical User Interface (GUI) features. Many of the features available in modern *Windows*®-based applications such as graphical tree views, drag and drop functionality and quality graphics for charts (where users can easily scroll or zoom using the mouse), were unavailable.

Another issue with some of the commercially available software is the cost of licenses. WSD collaborates with other organisations on modelling and simulation activities, where WSD provides analysis tools with in-house developed models that generate telemetry. Expensive licenses for commercial software can limit the potential for these collaborative projects.

Using commercially available analysis tools, the loading of large telemetry data files can take several minutes and consume significant computer memory resources. Consequently, these tools have limitations on the number of data files which the user can have open at the same time (typically limited to one data file) and the number of channels and charts that can be displayed. This was also a concern for WSD missile analysts.

Finally, WSD analysts can often work across several missile systems. Using several specialised software applications for telemetry analysis, requires significant training for analysts to become familiar with these tools. Consequently WSD analysts require a generic tool that can be used for the analysis of telemetry for all or most systems.

The lack of commercially available telemetry analysis tools that could satisfy DSTO's analysis requirements signalled the development of the Generic Telemetry Viewer (GTV), which was developed by WSD. Development of in-house telemetry analysis tools is commonplace worldwide due to the lack of a suitably generic commercially available tool (Crowley and Apodaca 1997, Zimmermann and Nitsch 2003).

2.1. Design features

The key features of GTV are its ability to *efficiently* and *generically* load telemetry data. In addition, GTV was designed through extensive consultation with WSD analysts to ensure that the GUI functionality is intuitive to the user, enabling efficient analysis of data.

GTV is designed as a generic tool, and therefore cannot provide analysis functionality that is specific to a particular weapon or weapon class. To address this, GTV has the ability to extend its analysis capability by interfacing with other analysis tools, which enabled the development of

the Whiteboard Viewer. Further details on GTV's features are detailed below.

2.3.1 Efficient data handling

The fundamental limitation of most telemetry analysis tools is that they directly load the data in the original format. Telemetry formats are optimised to store a large quantity of data while minimizing the amount of space required. This is a consequence of bandwidth limitations for the transmission and recording of data. From an analysis perspective, this data format requires significant processing to extract the actual data values. GTV uses a specially developed intermediate data format, TeleStore, which is designed for efficient data loading and memory performance.

There are a number of key elements to TeleStore's design that allow GTV to efficiently display data. TeleStore is a binary format data file that is structured to enable random access to specific channels. This enables GTV to only load the channels selected by the user. In addition the channel values are stored without compression, which means that minimal processing is required to display the data, enabling GTV to load and display channels to the user with minimal delay. TeleStore also provides a high level interface to read and write TeleStore files. Consequently GTV has no knowledge of the actual binary format of TeleStore files, as the reading and writing of TeleStore files is handled by TeleStore. This means that GTV is decoupled from the actual TeleStore format, such that future enhancements can be made to TeleStore with minimal impact on GTV.

The trade-off for using the TeleStore format is an increase in file size, which is not a significant issue due to disk space being relatively inexpensive. The use of the TeleStore data format enables GTV to open tens of data files simultaneously, each containing thousands of channels, and displaying tens of charts to the user. Files are opened within a couple of seconds, and charts are displayed within a few seconds. To date, no issues have been reported regarding limitations in the quantity of data loaded or performance.

2.3.2 Generic data handling

GTV is required to load any time stamped data format. To achieve this GTV provides a *plug-in architecture,* which is a software design pattern commonly used by modern software applications. A plug-in architecture provides a mechanism to decouple the application logic from specialised functionality. For GTV, its plug-in architecture enables the application logic to be physically separated from plug-in modules that contain logic to read the specific telemetry data formats. These GTV plug-in modules are called *Importers,* and they convert the original telemetry format into the intermediate TeleStore format used by GTV. GTV Importers are implemented as Dynamic Link Libraries (DLLs)[2], enabling physical separation between GTV and the Importers. This means that Importers can be added to GTV at runtime without any changes to the application itself. This feature is particularly useful for ensuring that security-classified data importers can be easily separated from GTV without having to create separate versions for different customers. This is illustrated in Figure 1, where it can be seen that the physical executable file (GTV.exe) is separate from the Importers (Importer A.dll, Importer B.dll and Importer C.dll).

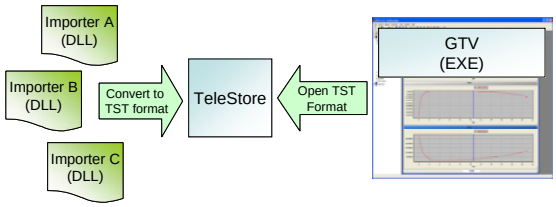

Figure 1. Diagram shows the relationship between GTV, TeleStore and Importers.

2.3.3 GUI and other functionality

GTV provides an intuitive modern *Windows®*-based GUI. A screen capture of GTV with a number of charts and channels displayed can be seen in Figure 2. Data files are displayed in a tree view, similar to *Windows® Explorer,* allowing users to navigate through thousands of channels easily.

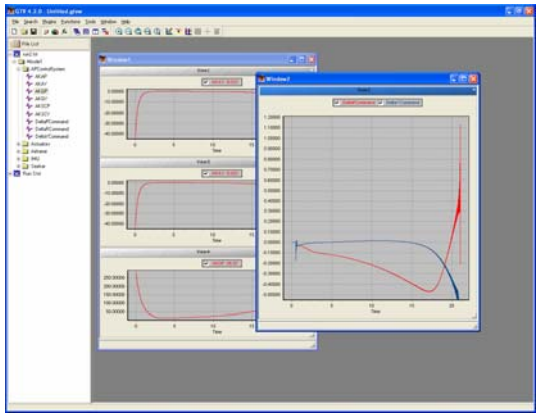

Figure 2. GTV screen capture showing multiple files and multiple charts

[2] A DLL is a piece of software that can be loaded at run-time.

Displaying a channel on a chart is very easy, and is done by double clicking on the channel of interest to create a new chart, or dragging and dropping a channel onto an existing chart. Charts can display multiple channels. Each window can display multiple charts.

All charts within a window are synchronized along the x-axis to enable the user to compare the relative values of a number of channels at the same index value (eg time). A screen capture of GTV showing synchronised charts is shown Figure 3.

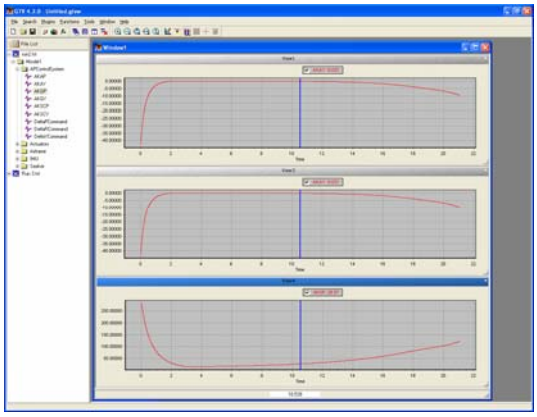

Figure 3. GTV screen capture showing synchronized charts and GTV's Line Tool

Two other key features of GTV are the ability to load and save Workspaces and Profiles. Workspaces enable the user to save the state of GTV, then re-open the application at a later time and restore it to that state. This means that all the files are re-opened and charts re-displayed as specified by the user. This is similar to saving a presentation in *Microsoft PowerPoint*®. Profiles are slightly different, as Profiles reload a different set of data files according to the same display options (which channels are displayed on which charts). This is relevant for the data analysis of multiple runs of the same system. This way the user isn't required to re-select all the channels of interest when investigating a specific aspect of the system, providing a significant time saving for the analyst. Profiles provide a similar capability to that of templates in *Microsoft PowerPoint*®.

2.3.4 Extendable

GTV is a generic analysis tool. A potential limitation of a generic tool can be its inability to accommodate for specialised functionality. To address this, GTV provides a *Function* interface to add customised analysis methods.

GTV accommodates Functions in a similar manner to its Importers, providing a plug-in architecture that allows users to develop custom DLL modules to perform specific data manipulation routines. Examples of this include data filtering and data smoothing operations. The DLL implementation keeps the generic application logic separate from specialised data manipulation routines.

2.2. GTV Summary

GTV has been used by WSD analysts since 2001. GTV is currently used for the analysis of hardware generated telemetry data from several different missile systems. In addition GTV has become an essential tool used by WSD engineers for the analysis of software telemetry generated by various detailed weapons models and simulations. GTV is also used by international organisations that WSD collaborates with on modelling and simulation activities.

GTV is maintained by WSD and is undergoing development to provide more sophisticated features that are useful for the analysis of telemetry data for modern missile systems. This work includes features to assist with the analysis of Infra-Red (IR) imaging missile systems, and features to enable analysis of Monte-Carlo (multiple runs) simulation data.

3. THE WHITEBOARD VIEWER

GTV has been an exceptionally useful tool for missile analysis. Analysts with detailed knowledge of missile functionality are able to process telemetry data in an efficient manner using GTV. However, analysts are not the only people interested in missile functionality. Managers, operators and other staff often need to be briefed on missile performance.

WSD's ability to provide higher level analysis to its customers and present results to a wider audience became more important as analysts were able to efficiently process large amounts of telemetry with GTV. This resulted in the development of the Whiteboard Viewer, which now provides a complementary role to GTV.

The Whiteboard Viewer is a PC *Windows*®-based tool that allows analysts to view Time Space Position Information (TSPI) and telemetry in two or three dimensional computer graphics. It provides a way of visually analysing trajectory data and other features of interest such as missile seeker beamwidth using the *OpenGL*® graphics environment.

3.1. Telemetry Visualisation Requirements

The analysis of missile telemetry data obtained from trials can be greatly enhanced by using an appropriate set of visualisation tools. In the past, analysts studying missile telemetry did not have the ability to visually replay engagements. Most detailed analysis of telemetry data was performed using GTV, which provides an excellent way of easily plotting and storing data. However, the ability to visually replay an engagement or explain characteristics of the data quickly and easily was not possible using GTV alone. Whiteboard Viewer was developed to enable the analysis of large amounts of missile telemetry data more efficiently and effectively. Visualising the graphical components of the data in conjunction with parameter values and messages provides a new capability for missile telemetry data analysis. The analyst is now able to visualise operational characteristics of the weapon system that is not possible when looking at individual channels of data.

A unique feature of the Whiteboard Viewer, as compared to other replay-style viewers, is its ability to display other articulations of interest such as radar illumination direction or radar error boxes. This significantly improves the ability of the user to visualise data of interest that is related to the missile's target acquisition and modes of operation. Examples of this include the missile switching guidance modes or the missile creating track-files[3] on targets of interest. The Whiteboard Viewer also displays messages on the screen notifying the user of these 'missile events', which are more difficult to identify when plotted as channels on a chart in GTV.

3.2. Whiteboard Viewer Design

The Whiteboard Viewer was developed by WSD using the object oriented programming language, C++. The application operates in the *Windows*® operating system environment and uses both the *OpenGL*® Application Program Interface (API)[4] (Segal and Akeley 2004) and DIVA 'in-house' developed API. *OpenGL*® has become one of the most widely used and supported interactive 2D and 3D graphics application that is commonly used in modern PC-based games. DIVA provides a simple interface for imparting and storing geometric spatial data to an unspecified viewer. Typical geometric spatial data used by the Whiteboard Viewer includes missile position, velocity, acceleration and orientation with respect to time. DIVA also provides the facility to send information about shape, collisions and articulations such as radar illumination direction.

Data can be loaded into the Whiteboard Viewer using either a Whiteboard Viewer Importer or a DIVAStore file. A Whiteboard Viewer Importer is a weapon-system-data-specific DLL that reads TeleStore files created by GTV and converts the data to 'DIVAStore format' for use by the Whiteboard Viewer. The importer is where the analyst's knowledge of a specific weapon system is embedded. The Whiteboard Viewer Importer uses the 'raw' TeleStore data channels to create the necessary 'visual data' that can be displayed in the Whiteboard Viewer (e.g. missiles, aircraft and missile seeker beamwidth). (Delatizky, Morrill, Lynch and Haberl 1991 describe feature abstraction of telemetry data to assist with automated diagnosis of torpedoes). This information is passed to DIVA and stored in DIVAStore. Once this is complete, the Whiteboard Viewer is able to read the data from DIVAStore and display the 'visual data' with respect to time using *OpenGL*® graphics. This data can be saved to a 'DIVAStore format' file and loaded directly into the Whiteboard Viewer for viewing at a later date. Figure 4 is a visual representation of the data loading functionality.

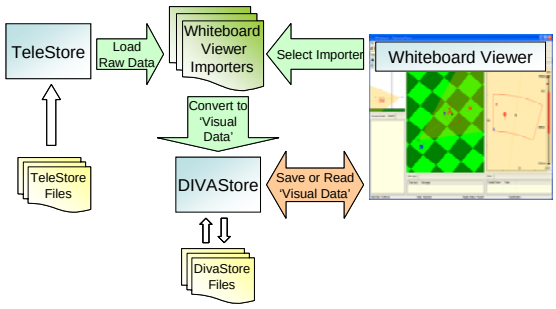

Figure 4. Whiteboard Viewer's Data Loading Functionality.

The Whiteboard Viewer is able to display 'visual data' in multiple views with varying detail. Figure 5 is a screen capture of the Whiteboard Viewer showing three graphical views [(1), (2), (3)] and three textual displays [(4), (5), (6)]. The first graphical view (1) displays the entire scenario and enables the user to keep track of all entities that are present in the current scene. The second graphical view (2), world view, provides a closer look at the scene and the third graphical view (3) is a detailed view that can be customised to display information or other features that are relevant to a particular weapon system. An example of a customised display feature is a 'Doppler bar', located on the

[3] Track-files are created by some missiles to represent the pseudo position of targets detected by the missile seeker.

[4] An API provides a set of routines, protocols and tools for building software applications with a consistent interface.

right side of view (3), which displays the range rate (velocity) of the targets. Each of the graphical views can be toggled between a 2D plan view (XY-plane) and 2D elevation view (XZ-plane). The world view can also display a 3D view of all entities in the scene and includes the ability to follow a selected entity, such as a missile, and look along the seeker line of sight. The textual displays provide a means of communicating text-based information in real-time. Examples of data that can be displayed include a selection of missile telemetered parameters and real-time messages of the missile's current mode of operation.

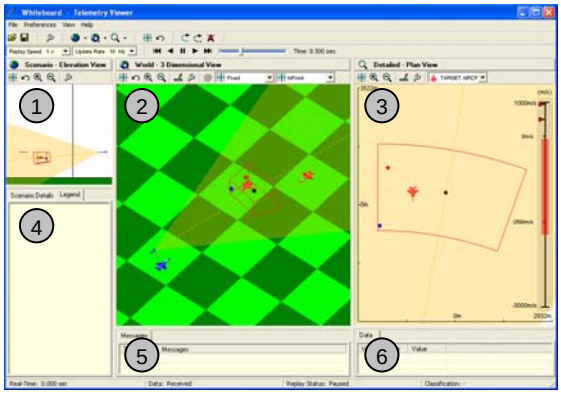

Figure 5. Whiteboard Viewer's 3 Graphical views [(1), (2), (3)] and 3 Textual displays [(4), (5), (6)].

The Whiteboard Viewer displays visual data with respect to time and allows the user to replay the scenario at varying speeds. This assists with visualising and understanding some of the more complex details that can be overlooked whilst viewing in real-time. The user may also replay the scenario at different data rates, enabling the Whiteboard Viewer to display data at any discrete time interval irrespective of the rate that it was updated. This feature was required in order to view missile telemetry data that has varying updates rates.

Other functionality includes zooming and panning the views, a manually selected target centred view and a facility to measures distances between manually selected entities such as track-files and targets. The right screen capture in Figure 6 demonstrates the range tool function displaying the distance between the blue launch aircraft and a red target aircraft using a 2D plan view (XY-plane). The 3D view also allows the selection of the camera location and camera target direction. Positioning the camera on the missile and pointing the camera along the seeker line-of-sight is a frequent use of this functionality, allowing the user to 'ride the missile' and observe the seeker tracking a target. The left screen capture in Figure 6 shows an example of this camera positioning functionality and also demonstrates that the location of the target is within the missile seeker's 3dB (half power) beamwidth.

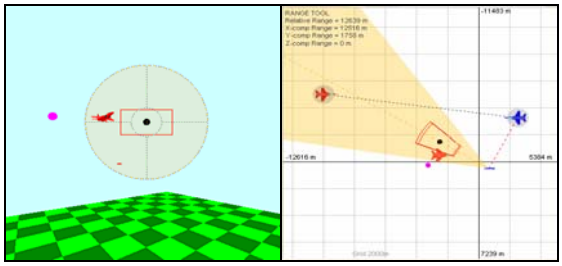

Figure 6. Screen capture of a 3D scene (left) and the range tool function (right).

3.3. Whiteboard Viewer Benefits

3.3.1 Reusable and Customisable

Significant modules of the Whiteboard Viewer can be reused to enable the rapid development of new applications that may be used for visual analysis of other weapon systems. When creating a new application, the structure and functionality of the Whiteboard Viewer is inherited and new features can be easily added to accommodate different weapon systems. Examples of these customised features include missile data-links, radar error boxes and track-files. This software reuse methodology enables a consistent and cost effective approach to software development and maintenance.

3.3.2 Visually Characterise Features

The ability to visualise data has proven to be very effective in uncovering unusual features of missile fly-outs that were missed using plots. This is due to the amount of complex data and inherent knowledge that is required to fully comprehend the missile's behaviour. Visualising the data allows the user to see what the weapon is 'thinking'. This has been especially useful whilst trying to understand the effects of Electronic Attack (EA)[5] on weapon systems. The left screen capture in Figure 7 demonstrates the camera following the missile in a 3D scene, whilst the right screen capture demonstrates a customised antenna view with the Doppler bar shown on the right of screen. The antenna view visually recreates what the weapon is 'seeing and thinking'; displaying the missile seeker beamwidth, target track-files and an error box. This type of view can provide an indication of how successful EA is against the

[5] Electronic Attack involves the use of electromagnetic or directed energy with the intent of degrading the opponent's combat capability.

missile. In the example shown, the EA has the effect of causing the missile seeker to 'look in the wrong direction' and as a result, not acquire the target.

3.3.3 Communicate Complex Information

The Whiteboard Viewer is able to visually display information of a complex nature in a simple manner and can assist in identifying important characteristics of the information. With limited explanation, complex techniques can be more easily demonstrated and understood by a wide audience. This not only makes Whiteboard Viewer an effective and efficient way of analysing data, but also provides an effective way of communicating information easily.

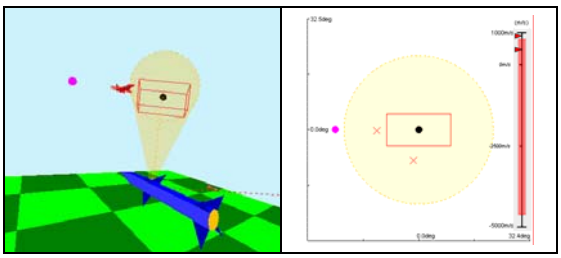

Figure 7. Screen capture of a 3D scene (left) and an antenna view (right).

3.4. The Whiteboard Viewer Summarised

The Whiteboard Viewer has been used within WSD since 2003 and provides a new capability to efficiently and effectively analyse missile telemetry data visually. It has been used in the analysis of missile hardware generated telemetry data as well as software data produced by modelling and simulation tools used by WSD.

The Whiteboard Viewer is also used as a training and development tool for DSTO analysts and ADF personnel, demonstrating missile characteristics such as trajectory shaping, missile-bourne computer processing and the effects of EA on weapon systems. The ability of Whiteboard Viewer to communicate complex missile functionality provides a medium for analysts, managers and defence personnel to 'see the same picture' and operate together more effectively. Whiteboard Viewer provides a capability that should enable the ADF to make better informed decisions with respect to the procurement, operation or upgrade of both current and future weapon systems.

4. CONCLUSIONS

The analysis of missile telemetry data is an increasingly difficult problem with weapon functionality becoming more complex. Consequently, WSD has developed efficient and powerful software tools to process telemetry data and analyse weapon system performance. GTV and Whiteboard Viewer are complementary telemetry analysis tools that provide the analyst with a means to analyse large amounts of data in a short time. The tools also help communicate complex missile functionality to non technical staff, resulting in more knowledgeable managers, operators and other staff. Given the ever increasing reliance of modelling and simulation for defence projects (ADSO 2004), it is expected that GTV and the Whiteboard Viewer will continue to provide valuable insight into missile performance and functionality in the future.

5. REFERENCES

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