

Immersive Virtual Prototyping Collaboration
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Abstract

The following paper describes an integrated immersive virtual environment developed to increase the proficiency of design engineers in their need to convey and share their engineering knowledge throughout a product development and enhancement process. This developed environment is also an engineering tool used to integrate various modeling and simulation capabilities such as thermal, vehicle mobility, or suspension simulation together into one virtual environment. This collaboration environment can also be used as a presentation tool to present the most up-to-date product design information to customers in a totally immersive virtual environment.

To develop this virtual collaboration capability, various technologies are used which include Modeling and Simulation (M&S), network communication, virtual reality/3D Computer Graphics, and vehicle CAD modeling. By fusing these disciplines together in an immersive environment of virtual prototyping, and real-time collaboration, a company can increase product development efficiency, create company-wide synergy, and enhance communication to customers.

1 Introduction

BAE Systems is a global defense and aerospace company delivering a full range of products and services for air, land and naval forces, as well as advanced electronics, information technology solutions and customer support services.

BAE Systems Inc. is the US subsidiary of BAE Systems PLC. Within BAE Systems' L&A operating group, the Ground Systems (GS) business unit develops and manufactures major ground combat systems for the U.S. Army and Marine Corps, as well as allied nations. Armament Systems (AS) also supports weapon technology and platform developments. Both GS and AS engineering efforts are spread throughout the

United States with major development occurring in Santa Clara, California, York, Pennsylvania, and Minneapolis Minnesota. Additionally, non-engineering development sites have been opened in close proximity to customers and are located in Sterling Heights, Michigan and Arlington, Virginia while a great deal of the manufacturing takes place in Anniston, Alabama. The following diagram outlines the function of each L&A site.



Fig. 1

Because the development of ground-based combat vehicles is a complex process, it requires the coordinated effort of multiple engineering disciplines which include design, modeling and simulation, as well as system engineering, through iterative and lengthy development cycles. Much of the complexity arises from the difficulty in analyzing the performance of a vehicle design before committing to costly hardware prototyping and the difficulty in conveying product design, functionality, performance, and operation to customers.

As a result of these inherent difficulties in designing and developing a combat vehicle, the need exists to:

- Reduce the cost & schedule risk for hardware prototyping
- Increase collaboration between multiple engineering disciplines to share knowledge throughout the organization
- Predict, convey, and market product design, functionality, performance, and operation to customers

To mitigate these difficulties and increase efficiency for product development, GS has developed an integrated prototyping capability by combining an immersive 3D virtual environment with M&S and vehicle Computer Aided Design (CAD) models. This integration of multiple engineering disciplines facilitates collaborative design, development, and prototyping of ground vehicle products in a virtual environment.

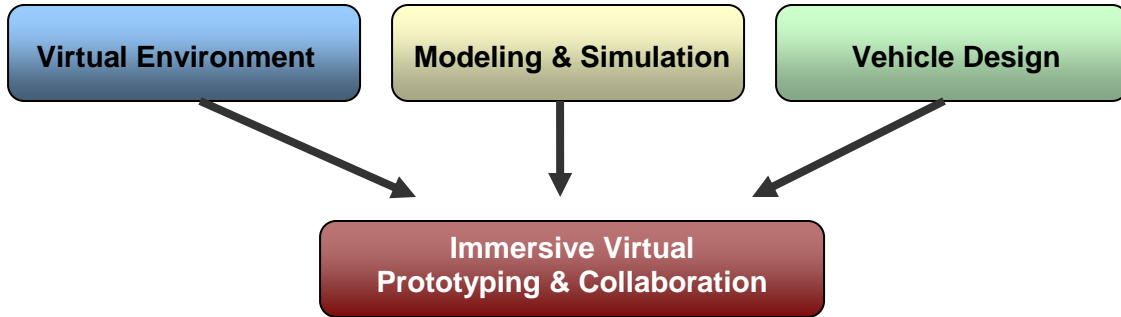


Fig. 2

2 The Immersive Virtual Environment

The Immersive Virtual Environment, also known as the “3D Dome”, was developed at Ground Systems (GS) and has been used as an engineering tool to effectively design and communicate BAE’s new product concepts in a 360 degree immersive graphical environment (see Fig. 3). Even before any prototypes are produced, it is used to demonstrate products and capabilities in a virtual environment to its customers, visitors, and partners.

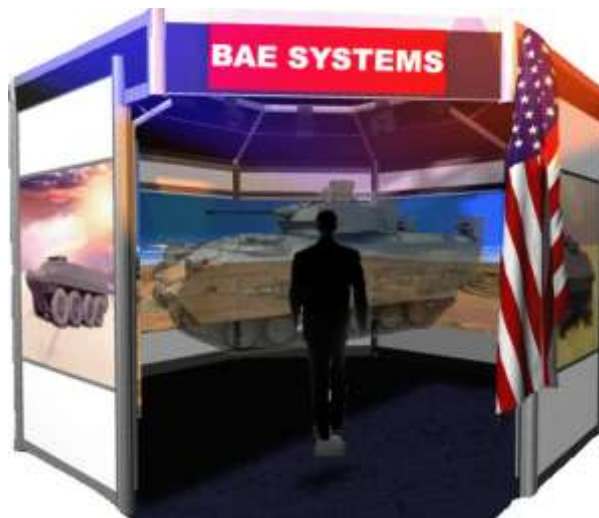


Fig. 3

In order to support flexible engineering design processes and to reduce hardware maintenance and upgrade costs, the 3D Dome was designed with the following objectives:

- **Portability** – to be able to easily dismantle or erect the dome structure within a short timeframe, and transport it by land or air to anywhere in the world in order to bring virtual vehicle prototypes and designs to any customer.

- **Minimal Footprint** – to maximize space efficiency through the use of front projection equipment mounted within the 3D Dome.
- **Modularity** – to be able to inexpensively replace or upgrade individual hardware components such as PCs or projectors, without a complete system overhaul.
- **Compatibility** – to be able to clone this immersive environment system at multiple BAE locations and not only make the domes compatible with each other, but also to make them compatible with other visualization facilities within the BAE organization.
- **Virtual Environment Control** – to allow the 3D Dome user to virtually control the environment using a graphical user interface (GUI) or to dynamically be able to virtually move throughout the dome using a tracker system.

Figure 3 shows a system diagram of the Immersive Virtual Environment. It consists of six major components. The inputs (3D models, simulation data, and user control) feed data into the rendering system that consequently outputs to the visual and audio output.

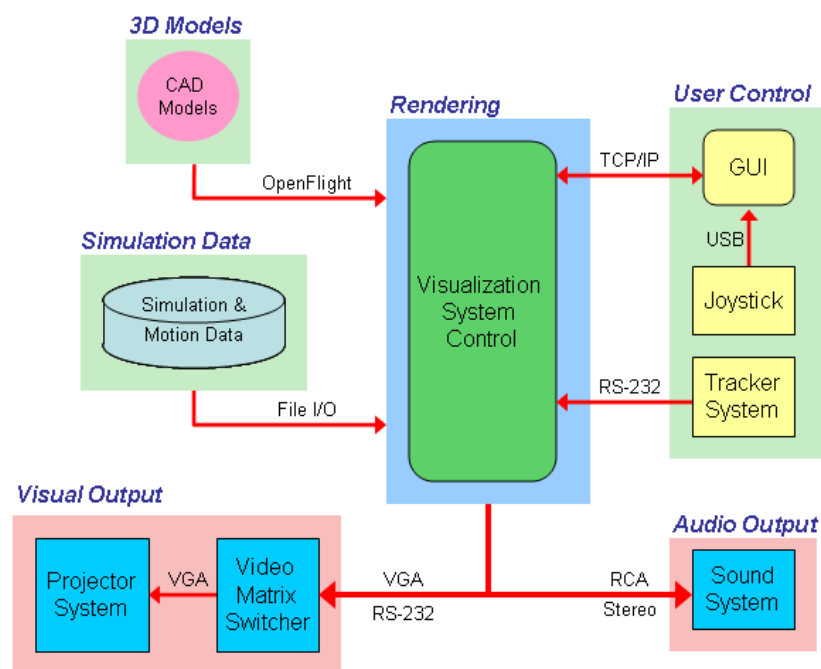


Fig. 4

- **3D Models** – The 3D models represent detailed vehicle and terrain geometry which are input into the rendering system in order to output realistic looking 3D graphics. The models are derived directly from vehicle designs which originate from a CAD format.
- **Simulation Data** – Simulation data consists of physics-based models that drive the underlying characteristics of the 3D models. An example includes a rigid

body simulation which feeds position and orientation data to a 3D model in order to visualize a particular driving scenario.

- **User Control** - User control consists of a graphical user interface to manipulate 3D models within the virtual environment, as well as an ultrasonic motion tracker system which tracks a user's position and orientation within the dome to allow he or she to move throughout the virtual environment as well. Other types of inceptor devices such as steering wheels, yokes, and joysticks can be integrated in order to provide additional man-machine interfaces.
- **Rendering System** – This visualization system is an OpenGL based software platform that loads and updates the 3D imagery based on the input simulation data and user controls, resulting in the generated 3D graphics for the virtual environment [Vega].
- **Audio Output** – The visualization system also triggers audio events such as special effect explosions or engine noise that are output through speakers mounted within the 3D Dome and are used to enhance the realism of simulations.
- **Visual Output** – All 3D graphics generated from the rendering system are output to a video matrix switcher which routes video channels to projectors or LCD displays located within the 3D Dome.

3 Stereo Visualization

In order to increase the realism of the virtual environment, 3D stereo visualization has been implemented to make the graphical models and terrain appear more immersive to the user within the dome. To generate the stereo image, the rendering system generates two images for each of the eight dome screens: one for the user's right eye and one for the user's left eye.

Each set of projectors for each screen has separate polarized filters to produce individual "left" and "right" eye graphics. When a user wears linearly polarized stereo glasses, he or she sees the graphics in 3-dimension, providing enhanced depth perception in order to contribute to the immersive environment.

- **Stereo Viewing Challenges**

A typical problem associated with simulating depth perception when projecting 3D objects onto 2-dimensional screen is the vertical parallax effect. This effect is caused by projecting objects originally at various spatial depths, onto a viewing screen at a fixed-distance from the viewer. This effect becomes most prominent when viewing objects at close distance, especially when near objects cross the boundaries of the enclosing screens. In addition to discomfort to the viewer, it causes distraction from the task at hand (see Fig. 5).

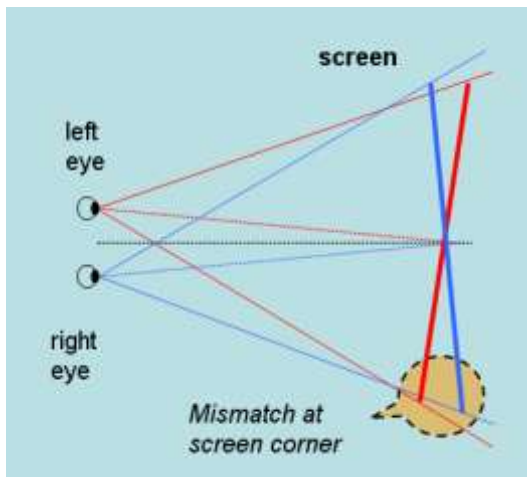


Fig. 5

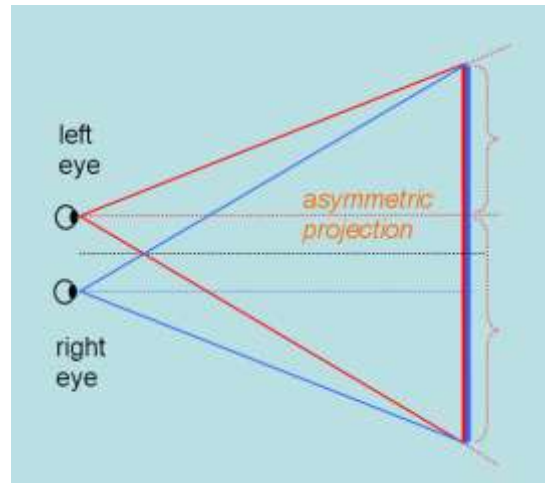


Fig. 6

▪ Stereo Viewing Solutions

To eliminate the vertical parallax effect, the 3D Immersive Environment employs the standard Off-Axis Correction algorithm [Daubert] when viewing objects at close distance. By applying asymmetric projection from each eye, the system renders stereo images that match at screen boundaries, creating smooth transitions spanning across multiple viewing screens. As it turns out, this algorithm is also particularly important when a tracking system is used to track eye movement. As the eye point moves, the algorithm dynamically calculates and applies the adjusted projection ratios across all screens, producing a seamless stereoscopic virtual environment and a comfortable view for the user (see Fig. 6).

This asymmetric projection, however, introduces distortions that cause distant 3D objects to be displayed incorrectly. Because of this, the algorithm is best applied for viewing near objects that are positioned within the virtual perimeter of the 3D Dome. The user control GUI allows the operator to selectively toggle this correction algorithm on and off for viewing objects at a near distance.

4 Tracker System

The 3D Dome also employs a motion-tracking system, which tracks the user's position relative to the center of the 3D Dome, and updates the stereo rendering in real-time. The tracking system allows the user to virtually move within the graphical environment, providing additional capabilities such as evaluating spatial arrangement of a design, assessing visibility limitations from multiple viewpoints, and enhancing the visual realism when presenting a vehicle design and its functionality in a surrounding environment.

To manipulate the graphics display, the following transformations are implemented: The first transformation organizes the 3D object's position and orientation in world coordinate. The second transformation brings the world scenery into the local dome position and tracker viewpoint. The third and final transformation maps the viewpoint into stereoscopic projections onto the surrounding screens.

Transformation Order:

[Objects to World] [World to Tracker Viewpoint] [Viewpoint to Stereo Screen]

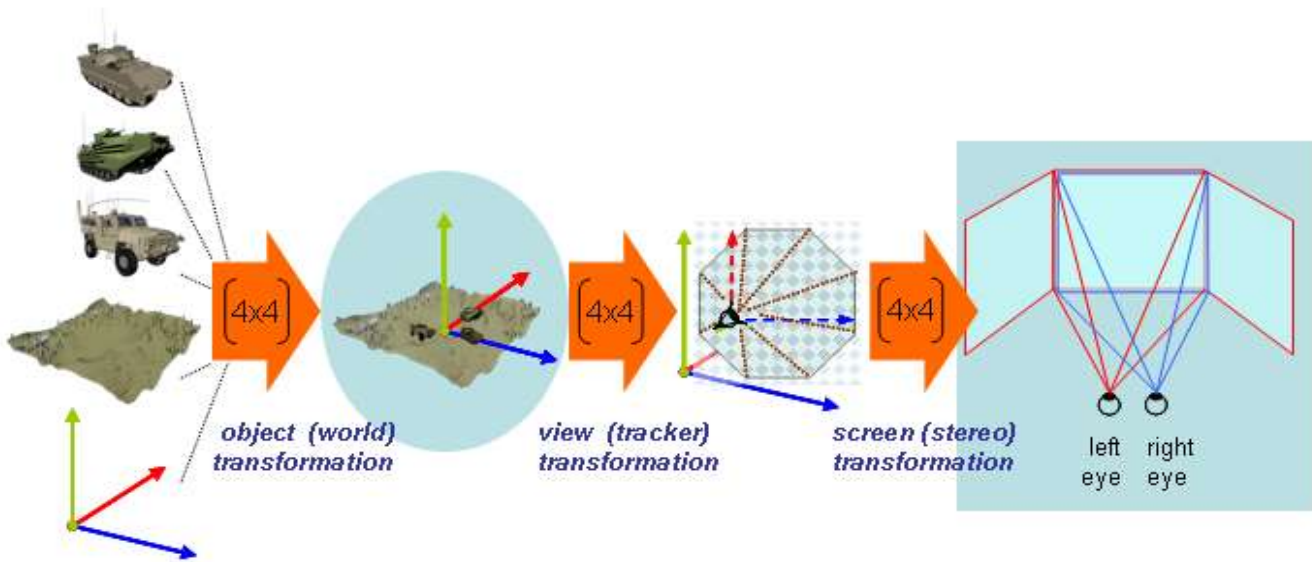


Fig. 7

Operational experience concludes that the tracker is most effective when used to track lateral/horizontal movements. Furthermore, because the 3D Dome is surrounded by 8 screens giving a 360 degree viewing angle, there is no need to track yaw movement.

5 3D Virtual Prototyping

By integrating the 3D immersive environment with modeling and simulation and product design capabilities, Ground Systems has developed 3D virtual prototyping technology to mitigate cost and schedule risk during product design. This 3D virtual prototyping has been applied to a variety of uses which include virtual vehicle design, operational scenario simulation, and vehicle performance simulation.

5.1 *Virtual Vehicle Design*

Prior to the manufacturing of any mockups or hardware prototypes which can be costly and time consuming, engineers and customers can virtually walk through and view life-size designs soon after their conception.

Using a graphical user interface or joystick-like controls, an operator can manipulate the 3D vehicle models within the dome environment and conduct vehicle design reviews. He or she has the ability to modify the position or orientation of the entire model, articulate moving parts, such as rotating a vehicle's turret, raising a gun, or even performing complex movements such as manipulating an engineering crane arm. In addition, they have the ability to switch on and off transparent assemblies, which allows viewers to see through armor or view electronics components or storage compartment which would not be easily viewable or accessible on an actual vehicle. And finally, the 3D Dome enables viewers to virtually walk through the interior of a vehicle [OpenFlight].

This virtual vehicle design capability enables engineers to collaboratively review space utilization and enables the business development organization to display conceptual designs to prospective customers. Below (Fig. 8), is an example of a 3D wheeled vehicle model being manipulated in the 3D immersive environment



Fig. 8

This immersive CAD model visualization is accomplished by importing and converting CAD vehicle designs into a polygonal format that can be displayed in the 3D Dome environment. While a model conversion and simplification process must take place, the end result is a full-scale virtual prototype that is identical to the original CAD design [Pro-E].

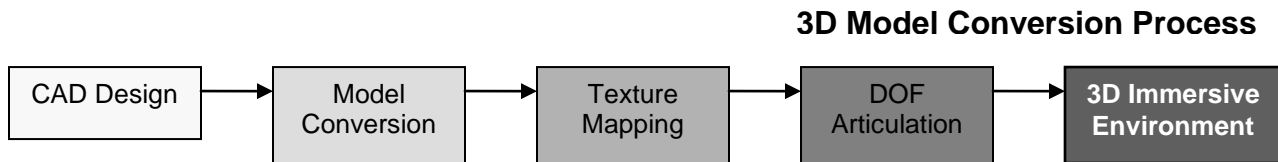


Fig. 9

5.2 Operational Scenario Simulation

In addition to vehicle design, operational scenario simulations can be accomplished within the 3D virtual environment, consisting of realistic battlefield situations in which a vehicle's potential operational capabilities are demonstrated.

Following the subsystem-level CAD analysis and the system and platform-level physics-based analysis, the virtual vehicles can be simulated within a system of systems

environment in order to demonstrate how this future product or enhancement will be used in a realistic mission scenario. For example, operational scenarios may demonstrate how a robotic vehicle would autonomously secure a village in coordination with a military unit or could highlight how future enhancements will be integrated and operate in conjunction with existing vehicle capabilities. An example is illustrated in the images below which depict a stealth view (Fig. 10) and commander's display view (Fig.11) below for a robotic vehicle operational scenario simulation.



Fig. 10



Fig. 11

Within the virtual environment, scenarios can be either automated or driven by user interaction. The battlefield environment and vehicle models are created by importing a variety of 3D database models. Vehicles are given operating characteristics through real-time physics modeling and the user interaction with a given vehicle or scenario is accomplished through a graphical interface or inceptor device. A viewer becomes immersed within the 3D graphical environment, standing with a birds-eye view of the entire virtual battlefield.

5.3 Vehicle Performance Simulation

M&S is a valuable engineering capability able to predict vehicle performance in advance of any hardware prototypes being constructed. Mobility and dynamics simulations demonstrate vehicle driving or other performance characteristics, thermal analysis dynamically displays heat and air flow, and Electromagnetic (EM) simulations depict possible component-damaging electrical forces.

The 3D Immersive Environment has integrated this beneficial M&S capability with high fidelity CAD models to provide better engineering collaboration during the combat vehicle development process. The benefits contribute to enhance the sharing of product design knowledge and enhance the communication of vehicle performance to customers.

Product Design Collaboration:

The integration of M&S with a 3D immersive graphical environment benefits product design in many aspects. The first is the ability to validate performance by simulating

a vehicle in a realistic mission scenario. Doing so will not only validate that the vehicle meets performance specifications, but engineers can also iteratively modify designs to further maximize performance.

A final product design benefit is available by combining M&S with the 3D Immersive Environment to help validate the actual physics-based models that are used to predict vehicle performance. By visually displaying simulation results, M&S engineers can collaboratively work together to decide if large discrepancies exist between expected performance and simulated performance.

Communication of Vehicle Performance to Customers:

In addition to product design, integrating Modeling and Simulation capabilities with the immersive dome environment also enhances the communication of vehicle performance and operation to customers. For example, an integrated physics-based model that consists of mobility, suspension, thermal, or power management modules can drive a 3D graphics model of a vehicle. Figure 12 shows the combined results of high fidelity vehicle CAD model with Electromagnetic simulation. This combined capability allows the company to demonstrate vehicle performance in an operational scenario simulation to a customer.

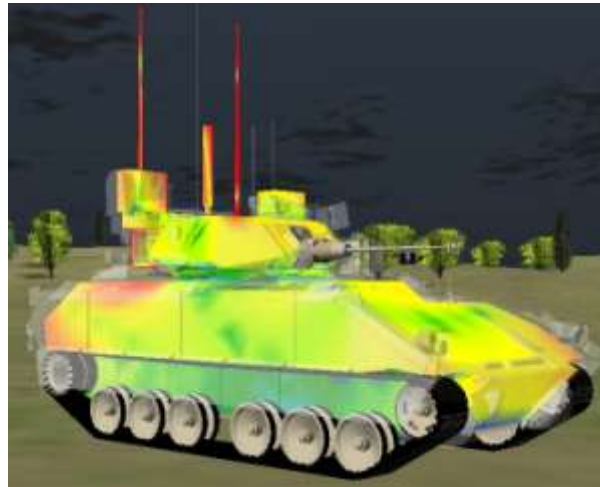


Fig. 12

In the earliest phases of vehicle development, this capability allows L&A to exhibit a vehicle interacting with current forces to allow the customer to better conceptualize a future vehicle. While in the later phases of development, it allows the company to demonstrate and convey predicted vehicle performance so as to contribute to the winning of bids and for showing the customer that a vehicle will meet required specifications.

In order to combine Modeling and Simulation capabilities with the 3D Immersive Environment, the following processes were developed to integrate rigid body and gradient mesh engineering data.

- **Rigid Body Data**

Describing a rigid body motion requires position and orientation information which can be expressed in different forms. To facilitate the integration, a plug-in module was developed to standardize the data format for rigid body simulation information from various applications, including mobility/dynamics, human factor, and manufacturing simulations.

Though each particular M&S model exports unique formats, they tend to generate individual data files for each articulating rigid body part in columns that specify:

- The current incremented simulation time
- The corresponding (x,y,z) position of the part in global space
- The corresponding orientation about the (x,y,z) axis in global space

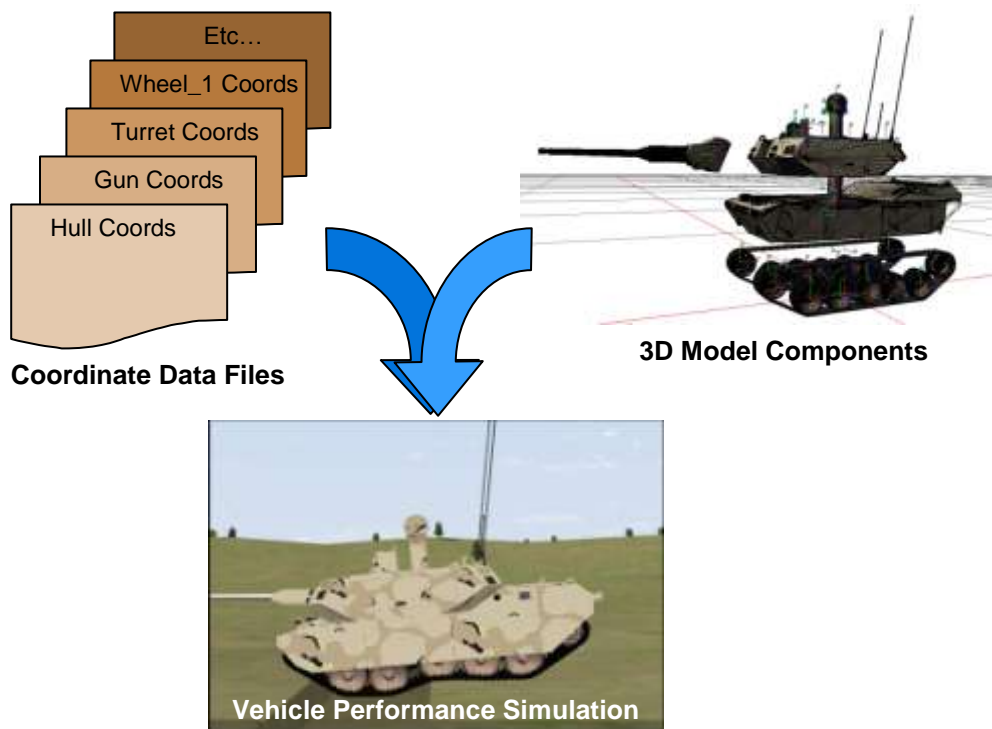


Fig. 13

When the 3D Immersive Environment takes the 3D graphics model and incrementally updates each articulating part's position and orientation based on these data files, the result is a seamless and fluid animation that can be displayed within the 3D immersive environment. For example, the following snapshot of a

data file describes the current position and rotation of a wheel as the vehicle ascends a step.

Time	x	y	z	a1	a2	a3
0.050e+000	-1.003e+000	-2.264e-001	5.305e-001	-4.417e+001	-1.799e+002	1.799e+002

- **Gradient Mesh Data**

The simulation models that output gradient mesh data files include Thermal and Electromagnetic simulations. Similar to rigid body data files, these gradient mesh data files are uniquely based on the particular engineering discipline, however, they each output relatively the same type of information. This includes:

- Node coordinates
- Node mapping to create elements
- Time incremented solution values for each node, representing data

Using a conversion method that maps solution values to a particular color generating the gradient mesh, Red, Green, and Blue color indices are then calculated from the solution data. This RGB color value is used to color each node which depicts a single time step for an entire animation. Below is diagram of a sample gradient mesh that includes nodes and elements.

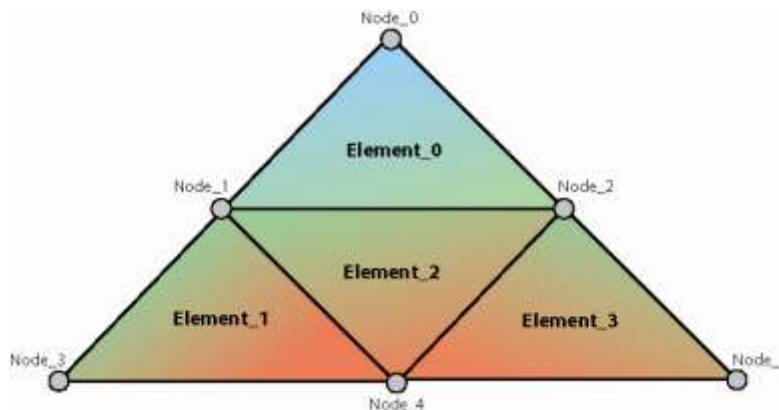


Fig. 14

6 Summary

Immersive Virtual Prototyping benefits the entire BAE Systems organization in several aspects which include product development efficiency, cross-functional synergy, and the ability to create more customer-centric products.

- **Product Development Efficiency**

Because Immersive Virtual Prototyping converges multiple engineering

disciplines to work in a common environment, it allows products to be developed more quickly with greater efficiency. Concepts can be evaluated and assessed by customers and partners early in the development process long before expensive hardware is produced, and cycle times are reduced greatly during concept development which enhances the ability for products to reach the market more quickly.

- ***Cross-Functional Synergy***

Virtual Prototyping also facilitates the cross-functional synergy of multiple engineering disciplines to collaboratively design, develop, and prototype combat system products in harmony. It brings systems, mechanical, design, and simulation engineers together using a common virtual environment as their workspace allowing them to easily share and access information. In addition, it promotes and facilitates site-to-site communication and sharing of engineering knowledge among multiple business units and operating groups.

- ***Customer-Centric Products***

Because of the ability for customers to better track the development progress and receive more precise information on the current design of their product, they are able to provide more detailed feedback in return, thus receiving a more customer-centric product which has been enhanced through this collaborative process. In addition, because several BAE business units and operating groups share a common external customer, the customer can leverage the benefits of virtual prototyping at one or multiple sites. In turn, these external customers receive a superior product that more closely meets the customer's needs.

In addition to the end-user customer, the military has its own customers who are the legislators and political leaders in office. Immersive Virtual Prototyping provides an environment for end-users such as the military to better communicate to these decision makers as to the potential benefits or current status of a new program. BAE has presented its vehicle design capability using the 3D Immersive Environment at various tradeshows and conferences, including, the "Best of Industry" Conference in Washington DC and AUSA (Fig. 15).



Fig. 15

This virtual prototyping capability with immersive technology also has the potential to be applied to a variety of industries including industrial design, architecture, the automobile industry, manufacturing equipment design, or real estate development.

7 References

[Daubert] Catherine Daubert. “Projecting Anaglyph Stereo onto a Dome”. 2002.

[Pro-E] Pro-Engineer is a registered trademark of PTC Inc.

[OpenFlight] OpenFlight is a registered trademark of Presagis Inc.

[Vega] Presagis Inc. “Vega Prime User’s Manual.”