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VIRTUAL PROTOTYPING WITH LOW-END 3D GRAPHICS PROGRAMS

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ABSTRACT

Virtual prototyping and photo-realistic rendered drawings convey images of expensive high-end CAD work stations and drawing programs. These are out of financial reach for most small businesses that want to enter this market, and the products are expensive for small-budget customers. This paper provides examples of the quality and value that can be obtained from low-end 3D drawing programs on minimum configuration Macintosh computers. Levels of detail for a hierarchy of virtual prototype model requirements are suggested, and some insight is provided on the role of low-end virtual prototypes in the various stages of the acquisition cycle starting with the Battle Labs concept development.

1 INTRODUCTION

Virtual prototypes are correctly dimensioned, high fidelity scale models of equipment created with a three dimensional (3D) program in a computer. The creation "exists" as a 3D object in the computer, and can be manipulated, modified and even "entered" for study and analysis. The model has the same usefulness as a scale wood or plastic model, but has an infinite capacity to be quickly modified with slight variations or totally new concepts. From an illustrator's viewpoint, the model has to be constructed only once to produce an infinite variety of art viewed from any angle.

Virtual prototypes should not be confused with virtual reality. Virtual prototypes can be used in a virtual reality "world", but they are equally useful viewed and studied on a two dimensional (2D) screen or printed to paper.

Figure 1 shows a moderately detailed virtual prototype of a theater missile defense system concept mounted on a 5 ton medium tactical vehicle (MTV) truck chassis. During the construction of this concept, a Patriot-like missile launcher model was created and mounted on an existing MTV chassis model in the computer. The MTV models were created earlier from the manufacturer's drawings and are maintained on file in several of the MTV model number configurations. In the computer, the launcher can be changed from its march-order configuration to a launch configuration.

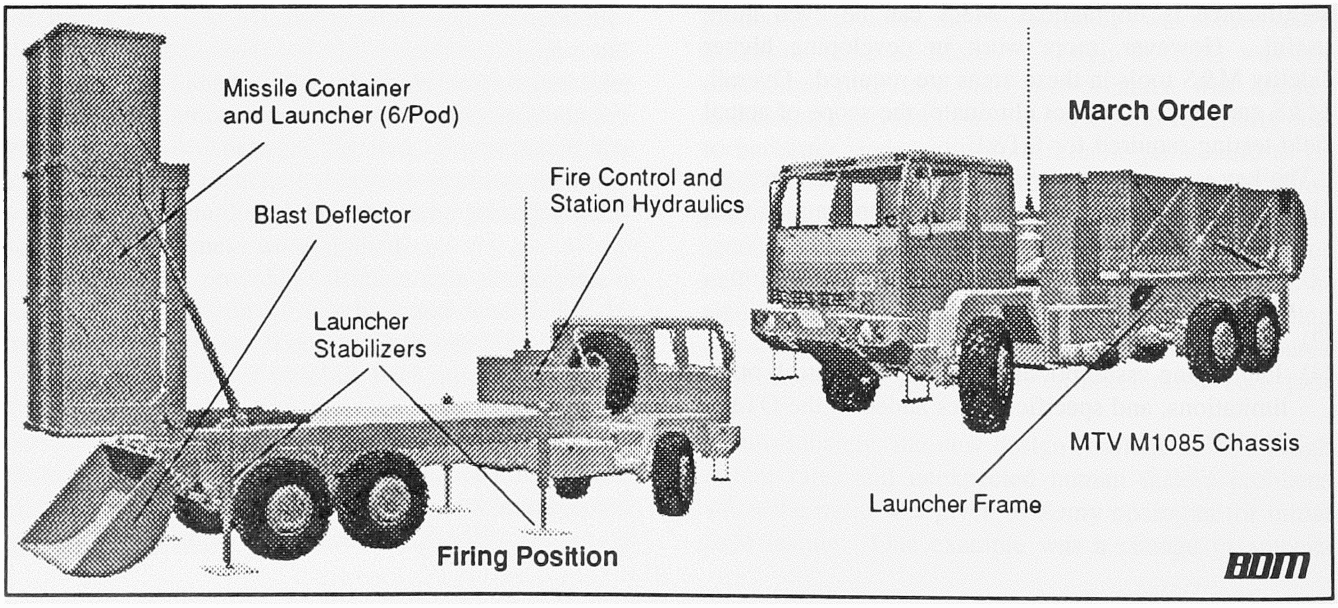


Figure 1: TMD Concept Virtual Prototype Example

This allows several geometric constraints to be quickly identified. The physical location of the various components and their relative movement dictated some key dimensions and locations: 1) launcher configuration and height to meet C-130 air transport restrictions, 2) location, travel, and bracing for the hydraulic jacks, 3) launcher erector hydraulic piston length and location, and 4) blast deflector shape, location, and clearance for the towing pintle.

Virtual prototypes are derived from concept drawings or blueprints, and contain as many details as are required to support the immediate need. The same model can be expanded later as more detail is required. For example, testing the fit of a proposed weapon system load onto a truck may initially require only the length, width, and general shape of the truck frame. Later, as more weapon system details such as outriggers, hydraulic tanks, etc., are required, these can be added along with the truck underbody details to test for available space and interference.

Why Virtual Prototypes: Virtual prototypes are useful in visualizing the end item during planning and development before production; supporting feasibility analysis, and identifying form, fit, and human engineering problems before pouring concrete or bending metal. The output can be printed in color or black and white and used alone as illustrated in this paper, animated in the computer and transferred to video tape, or inserted into a virtual reality "world." Computer programs are available to translate the results into blueprints for full-scale prototype fabrication and/or manufacturing

Why Low-End Virtual Prototypes: For the purpose of this article, a "low-end" application is defined as being within a cost range of $ 400 - $ 1,500, and running on a desk-top computer rather than a work station. Although applications within the $ 1,500 end of the scale and higher produce superior photograph-like picture quality, the authors have been very successful with a $ 500 application that produced all the examples used in this paper. The photo-realistic quality and rendering aids such as see-through cut-aways, although convenient, are not essential to the production of useful virtual prototypes during the early development phase. The lower cost permits more and smaller contractors to be involved in contracts supporting equipment design and development during the various concept phases noted in the next paragraph.

2 VIRTUAL PROTOTYPING IN THE SYSTEM DEVELOPMENT CYCLE

Figure 2 shows an abbreviated overview of the Army system acquisition cycle including the emerging roles of the Army Training and Doctrine Command (TRADOC) Battlelabs and Office of the Secretary of Defense (OSD) and Department of the Army (DA) directed Top Level Demonstrations (TLDs). The current acquisition process defined in Department of Defense Instruction 5000.2 (1993) and the Army

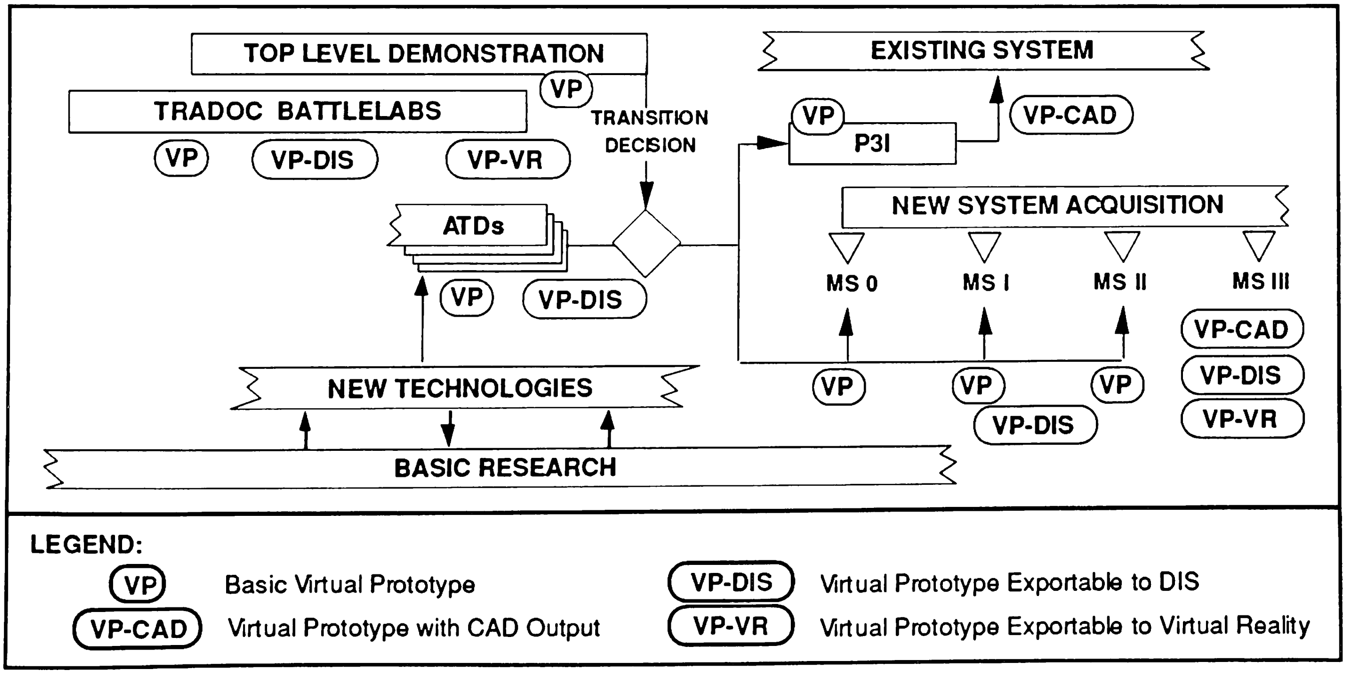


Figure 2: Virtual Prototyping in the Acquisition Process

Science and Technology Guide (1992) for new system development includes the Advanced Technology Demonstrations (ATDs) that incorporate new technology into a hardware demonstration and simulation; the planned product improvement (P3I) process that modifies existing equipment; or the initiation of a new system acquisition program with its formal milestone (MS) decision process. Emerging additions to the front end of the existing process are the OSD and DA directed TLDs that integrate new concepts into systems of systems demonstrations and simulations, and the Battlelabs that drive new concept developments to meet battlefield deficiencies as well as manage the Distributed Interactive Simulation (DIS) for training and mission analysis.

Virtual prototypes provide a basic tool to support initial concept development throughout the acquisition process shown in Figure 2. For example, scale models of proposed equipment can be added to vehicles and repeatedly repositioned to study and determine the best fit. Figure 3 shows a Land Rover model that has a conceptual air defense missile launcher added to the cargo bed. The launcher can be rotated in azimuth and elevation in the computer to test clearances. Figure 4 shows how the addition of a correctly proportioned and jointed human figure can assist in early identification of potential human engineering issues. The size and components positions of human operated equipment can be quickly determined by positioning the human model first, and then constructing the equipment model around him or her.

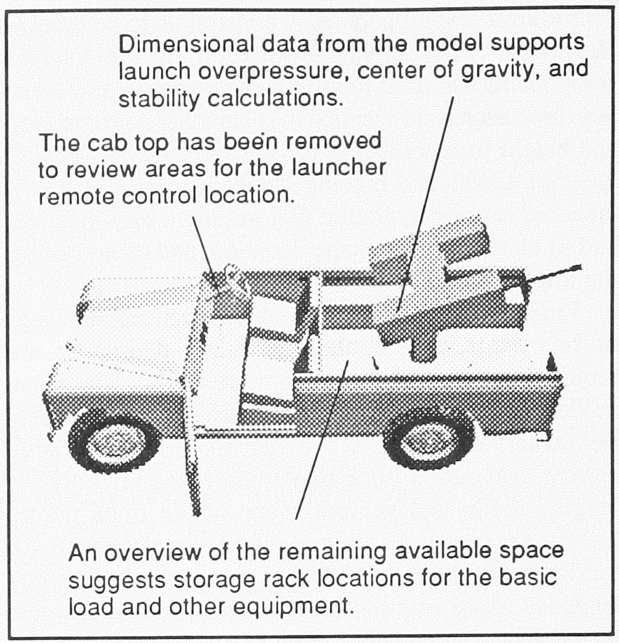


Figure 3: Vehicle Space and Fit Review

Low-end virtual prototypes are useful throughout the various phases of the system development process to show concepts details; identify form, fit, and size issues that in turn support weight, performance and function issue development. These, in turn, support one-on-one and force-on-force performance evaluations. During certain phases of these activities, low-end 3D programs are not adequate and must be exported,

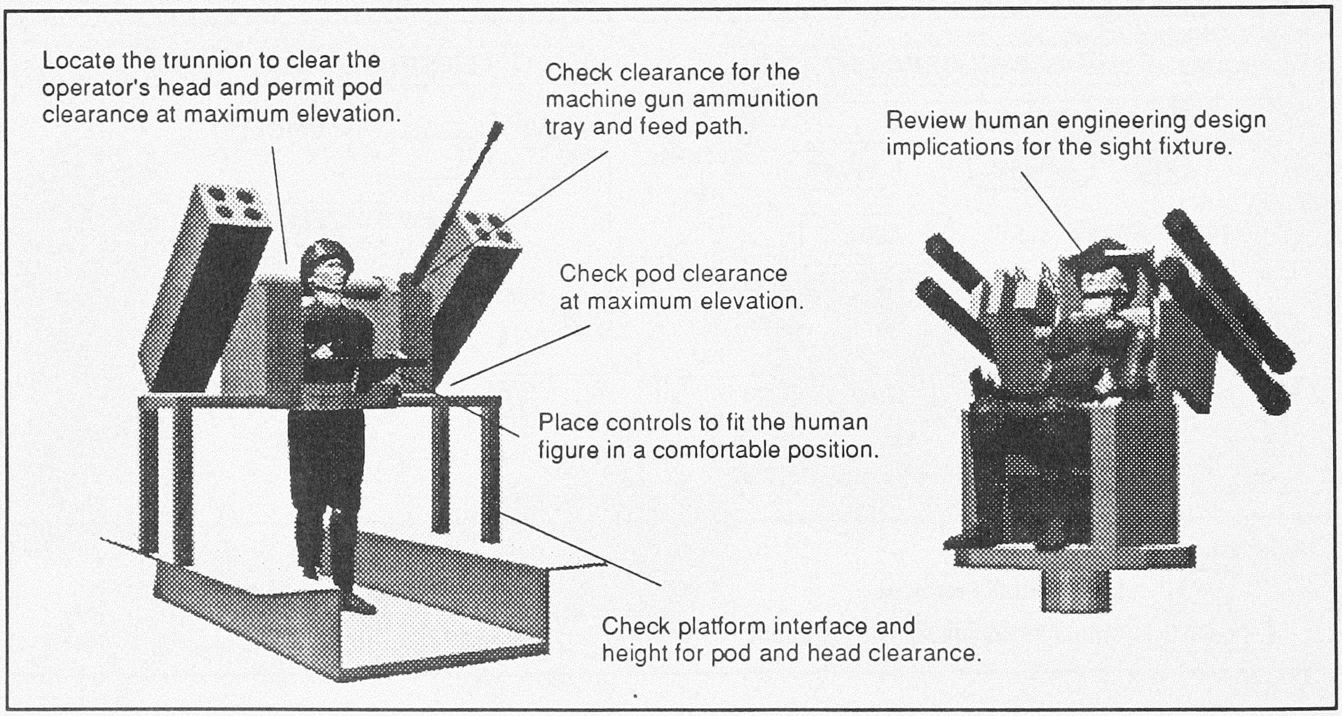


Figure 4: Human Engineering Issues

through appropriate compatible software, to other programs providing computer aided design (CAD), virtual reality, and DIS. The legend of Figure 2 identifies several levels of virtual prototypes and their application areas are shown in the figure. Table 1 provides a suggested strawman hierarchy to categorize 3D programs for use in supporting the defense acquisition system. If the low-end 3D model cannot be exported or converted, the model must be re-created in a program with the correct output format.

Table 1: Strawman Hierarchy

Level 1:
  Basic 3D modeling program
Level 2A:
  Basic or enhanced level 1 program exportable in a format compatible with DIS standards. The model is capable of being used in DIS scene generators.
Level 2B:
  Basic or enhanced level 1 program supporting insertion of the model in a virtual reality environment.
Level 3:
  Basic or enhanced level 1 program supporting CAD output to create engineering drawings.

Growth and Transition: The convenience of using virtual prototypes in CAD, virtual reality, and DIS software systems presents a growth and transition challenge. The use of low-end 3D programs early in the system development process is desirable from the viewpoints of lower contract costs and increased number of available support contractors. The challenge to the Government is to establish software standards for DIS and virtual reality compatibility. The challenge to the software industry is to develop compatibility in the cross-program import and export functions.

3 DEVELOPING A VIRTUAL PROTOTYPE CAPABILITY

To begin the development of a company virtual prototype capability, people must be matched with a 3D graphics program, and provided training or time for self-training and exploration of the program. Engineers and computer artists who are already familiar with mechanical assemblies and reading engineering drawings will require the least training time because they can already visualize concepts in three dimensions.

Numerous 3D graphics programs are commercially available. Their quality and number of features have grown rapidly over the past several years and continue to improve. The quality, features, and lowering prices tend to blur the distinction between basic applications, making it increasingly difficult to choose one application over another. The minimum complement of features for a 3D program supporting useful virtual prototype work is listed in Table 2 and discussed in the following paragraphs.

Table 2: Minimum 3D Application Requirements

Minimum Requirements

- Reference grid and scale
- Line and shaded surface rendering
- Variable light source
- 2D and 3D rendering
- Export to 2D drawing application

Other Useful Features

- Shadow casting
- Animation
- Linking and motion control

Reference Grid and Scale: A scaled grid provides construction reference points that simplify the development of model components. This is similar to drawing on graph paper. A workable but cumbersome alternative is to create three rulers as models lying in the x, y, and z planes. Even with a reference grid, the rulers are useful for checking dimensions during assembly of the components into a complete model.

Line and Shaded Surface Rendering: Both formats, illustrated in Figure 5, are useful depending upon the complexity of the model and features to be

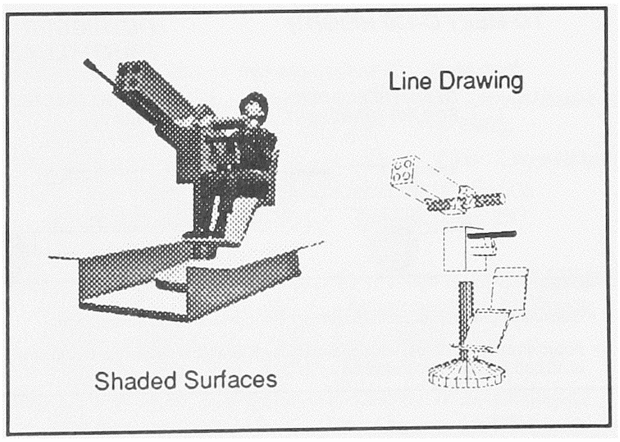


Figure 5: Line and Shaded Drawings

emphasized. The shaded rendering provides a photograph-like picture of the model while the line drawing is useful for producing engineering illustrations similar to conventional mechanical drawings.

Variable Light Source: Varying the incident angle of the light source controls the shading contrast on surfaces with different incident angles relative to the light source. These shading variances help define complex surfaces and component details such as hatch covers, handles, etc.

2D and 3D Rendering: Although we want to examine and study the model in three dimensions, a two dimensional or orthographic display is essential for accurate construction and alignment during component creation and model assembly. The 2D format is also used with the line drawing mode to produce standard front, side, and top mechanical drawings.

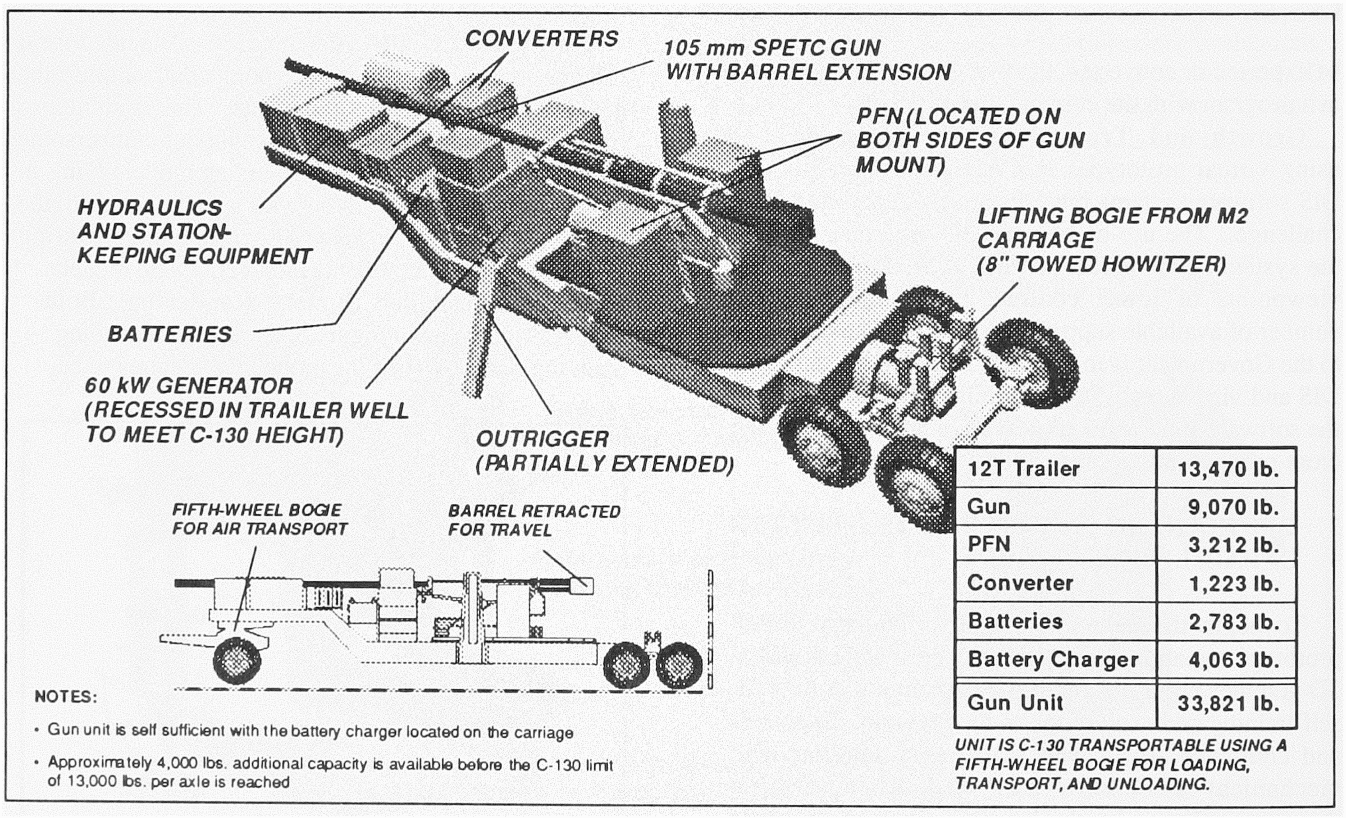
Export to 2D Drawing Program: Moving the 2D or 3D figure from the 3D application to a conventional 2D drawing application facilitates the addition of text, labels and other data needed for figures in reports and viewgraphs. It also reduces computer memory requirements. Figure 6 is an extract from an electric gun study illustrating both the merging of a 3D figure into a drawing application, and the use of the 2D line drawing format.

Other Useful Features: Some features are available that are not essential for creating virtual prototypes, but can enhance the drawing and save time. These include: 1) shadow casting, 2) animation, and 3) linking and motion control.

Shadow Casting: A light source that casts shadows on the model helps to highlight details and emphasizes shapes and components that might otherwise blend into the background and be invisible. This has an added advantage of enhancing the image quality of art illustrating the model in a scene.

Animation: The animation of components helps the viewer develop a better understanding of how a system functions. The lack of this feature in a low-end program can be compensated for by making many 2D renderings, each with a small displacement of the part to be moved. When these separate renderings are run sequentially in a properly timed presentation program, the object will appear to move smoothly.

Linking and Motion Control: This function allows pivot points and sliding components to be locked into the model so that they move with their parent component and follow their built-in motion



12T Trailer	13,470 lb.
Gun	9,070 lb.
PFN	3,212 lb.
Converter	1,223 lb.
Batteries	2,783 lb.
Battery Charger	4,063 lb.
Gun Unit	33,821 lb.

UNIT IS C-130 TRANSPORTABLE USING A FIFTH-WHEEL BOGIE FOR LOADING, TRANSPORT, AND UNLOADING.

NOTES:

- Gun unit is self sufficient with the battery charger located on the carriage
- Approximately 4,000 lbs. additional capacity is available before the C-130 limit of 13,000 lbs. per axle is reached

Figure 6: 3D Drawing Pasted into a 2D Drawing Application

constraints. This simplifies repositioning moving parts and is particularly useful for studying the fit and interference of moving parts. Figure 7 illustrates a concept for a folding interferometer radar system mounted on an MLRS chassis. In the computer, the pivot points and sliding features identified in the drawing move, facilitating the analysis of design clearances and interference points associated with changing the system from march order to its deployment configuration.

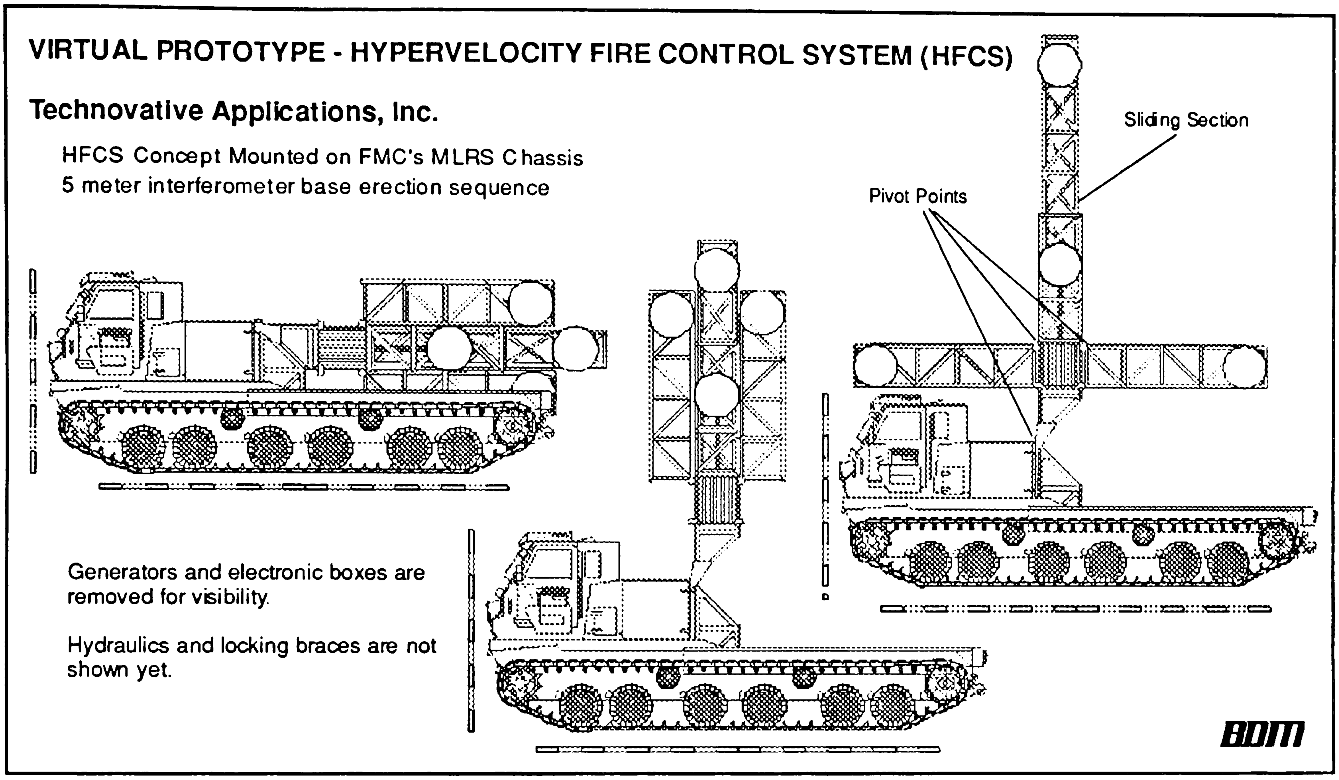


Figure 7: Linking and Motion Control Illustration

4 SUMMARY

Through careful development of details, low-end 3D graphics programs run on low-cost computers can generate virtual prototypes that provide a useful engineering tool supporting concept development and analysis. The virtual prototype also supports detailed design and human factors analysis. This early analysis and identification of design issues offers potential to reduce development costs since mistakes will be made in the computer rather than on bent metal. The lower cost of low-end software and equipment permits more small businesses to enter this arena and provides a larger competitive support contractor base.

Although military equipment examples have been used in this article, virtual prototyping applies equally well to the commercial arena. Typical application areas can include fitting a new manufacturing line into an existing warehouse, or installing new seating designs in buses.

The quality and number of features in the various commercial 3D programs are constantly improving and expanding. Significant challenges remain for the software industry in the area of cross-program compatibility.

REFERENCES

Defense Acquisition Management Policies and Procedures, DoD Instruction 5000.2, Department of Defense, Washington, DC, February 1993.

Army Science and Technology Master Plan, Department of the Army, Deputy Assistant Secretary for Research and Technology, Washington, DC, November 1992.

Advanced Land Combat, Strategic Plan for DoD Science and Technology Thrust 5, Department of Defense, Deputy Director of Defense Research and Engineering, Washington, DC, July 1993.

The DIS Vision, A Map to the Future of Distributed Simulation. Institute for Simulation and Training, University of Central Florida, Orlando, May 1994.

AUTHOR BIBLIOGRAPHIES

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