NASA Conference Publication 3346

Computational Tools and Facilities for the Next-Generation Analysis and Design Environment

Compiled by
Ahmed K. Noor and John B. Malone

Proceedings of a workshop sponsored by the
National Aeronautics and Space Administration,
Washington, D.C., and the University of Virginia
Center for Advanced Computational Technology,
Hampton, Virginia, and held at
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and Science Universities
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PREFACE

This document contains the proceedings of the Workshop on Computational Tools and Facilities for the Next Generation Analysis and Design Environment, held in Hampton, Virginia, September 17-18, 1996. The workshop was jointly sponsored by the University of Virginia's Center for Advanced Computational Technology and NASA. Workshop attendees came from government agencies, industry and universities. The objectives of the workshop were to assess the level of maturity of various computational tools and facilities and their potential application to next generation integrated design environment; and to provide guidelines for focused future research leading to effective use of these facilities in the design/fabrication and operation of future aerospace systems. The presentations addressed several simulation, optimization training and design tools and facilities.

Certain materials and products are identified in this publication in order to specify adequately the materials and products that were investigated in the research effort. In no case does such identification imply recommendation or endorsement of products by NASA, nor does it imply that the materials and products are the only ones or the best ones available for this purpose. In many cases equivalent materials and products are available and would probably produce equivalent results.

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CONTENTS

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INTRODUCTION

In response to increasing economic stresses and social concerns, the U.S. aeronautics and space program is being restructured with a shift in mission strategy for future space activities and a change in design philosophy for aerospace systems. This shift is from long-term, complex expensive space missions to smaller, cheaper, faster ones. The future mission set will be more affordable, involve more frequent space activities and will speed up the evolution of technology.

To meet the goals of design cycle reduction, cost reduction, improved performance, and technology insertion time reduction for future aerospace systems, the NASA/UVA/JPL Next-Generation Analysis and Design Environment Project was initiated. The overall objective of the project is to build/assemble a prototype distributed virtual environment for designing, testing and prototyping aerospace vehicles and spacecraft configurations. The environment is expected to radically advance the process by which complex aerospace systems are designed, manufactured and operated. The distributed virtual environment will link design teams, manufacturing teams, customers, suppliers and consultants that play a part in designing and manufacturing aerospace systems. It will incorporate the state-of-technology computational, communication and networking facilities and tools, and will take advantage of existing and evolving capabilities in industry, government and academia.

The aerospace systems which will be the focus of this activity are new millennium spacecraft, space transportation systems, high-speed aircraft, and advanced configuration subsonic aircraft. The design environment will include generic modules and facilities which are used for all the systems and application-specific tools for individual systems.

The joint University of Virginia/NASA workshop held in Hampton, Virginia, September 17-18, 1996 provided an opportunity to assess the level of maturity of various computational tools and facilities and their potential application to the next generation analysis and design environment.

1. The Design Process and Design Environment

Future aerospace systems will have a number of major characteristics which will significantly impact their design, including:

- a high degree of autonomy - thinking, self-healing vehicles will feature embedded sensors, actuators and elaborate information processing systems
- miniaturization of subcomponents and/or the entire vehicle
- modularity - using modules to tailor vehicle capabilities to specific mission needs. Examples of modular vehicles are provided by the Joint Strike Fighter modular aircraft and the multifunctional bus used in a number of spacecraft.
- incorporation of engineered multifunctional materials.

1.1 *Design Drivers*

Today design and production are being driven by revolutionizing forces. Technology is moving rapidly and competitive forces require new products with increasing capabilities to come to market quickly and be affordable - delivering lasting value at competitive cost. Products must be affordable, maintainable and safely disposable. Consequently, the design process must, not only allow for, but encourage, new technology insertion into products and do so at an affordable cost.

The traditional design process does not provide the flexibility required for low-cost technology insertion and affordability in a global, rapidly changing, competitive environment. The current move towards integrated product and process design (IPPD) systems represents a paradigm shift aimed at incorporating manufacturing, maintenance and repair, initial and life-cycle costs, risk management, and disposal concerns into the early stages of the design process.

Although significant advances have been in concurrent engineering and IPPD systems, revolutionary changes are still required in the design tools and the whole design process, such as the revolutionary design tools needed for rapid insertion of new product technology and affordability.

1.2 *Technology Insertion*

In the traditional design process of high-tech engineering systems, each discipline (e.g., structures, aerodynamics, propulsion, controls, avionics, optics, manufacturing, etc.) uses product models of varying fidelity at different stages of design, from early conceptual design to detail design. Generally, the models used for conceptual design consist of simplified rules (relative to those used in detail design) and formulas which have been embedded into complex spreadsheets. The spreadsheet entries are filled with formulas developed over many years of experience in that discipline. It is therefore not too bold a statement to make that conceptual design in the aerospace business is to a large degree experience-based. This results in incremental advancements in technology because experience-based design makes large step design extrapolations too risky. The incremental approach makes it increasingly difficult to compete in today's aggressive and demanding competitive environment.

In the case of new consumer products, they have, in general, a short "half-life" and an incremental approach for them makes it difficult to respond to changing customer needs; thus there is a growing need to insert new technology rapidly and confidently. Most aerospace vehicles are usually expected to have a longer life than consumer products, but this also tends to make it important to infuse in them the latest technology to ensure that the vehicle's long life will produce the best long-term performance. Moreover, insertion of new technology is meant to drive down life-cycle costs.

1.3 *Product Cost Reduction*

As the design process progresses, the level of sophistication of the product model increases. However, the more detailed data derived from these models usually occurs too late to impact design decisions that affect the majority of costs. It is well documented that product costs are set in the early conceptual phase of the design process. Moreover, the change-over of model type presents its own set of issues because this change-over is not smooth and gradual, but discontinuous. Hence, there is a need for a seamless model progression from conceptual to more detail design. For example, in the case of structures, it means discontinuously translating from spreadsheet modeling in the conceptual design to finite element modeling in the preliminary design phase. Then, because the preliminary models are physics-based, they can be continuously refined with more detail added as the design process progresses. However, if available early in the design process, the critical detail in the finite element models could provide the data needed for better design decisions and avoidance of costly and time-consuming re-designs. Costs, design cycle-time and risk could be reduced if more knowledge of the design were available earlier. Thus, it is desirable to have a seamless design process in which analysis at any level of detail is possible. This completely integrated seamless analysis and design capability will form an important facet of a revolutionary change in the design process.

1.4 *Vision for Revolutionary Design Process Changes*

The new design process that will likely emerge in the early part of the next century will provide revolutionary changes allowing the designer to readily insert new technology advances into products while keeping costs under control or reducing them. The environment will integrate advanced computing, communication and networking technologies to support global project design and management. Novel paradigms and new methodologies will be developed to represent and incorporate imprecision and uncertainties as an integral part of the early design process. New computational tools will facilitate new technology insertion because they will not be based on extrapolations of experience. They will be easy to use because their employment will be intuitive. No steep learning curve will be required nor can be afforded because the computational tool technology will itself be rapidly progressing. Changes in tools will be transparent to the user. Tools to assess manufacturing costs and issues, uncertainty, risk and product value will be commonly used. The designer will have multimodal real-time interactions with the product model, involving several human senses (vision, hearing and tactile). Rich sensorial interaction, coupled with real-time simulation responses will produce a compelling and captivating feeling of being immersed in the product model environment.

The immersive environment will also be distributed because design teams will be geographically dispersed as global partnerships develop, and will be able to collaborate via high-speed high-bandwidth communication networks. This is being done now on a limited scale with two-dimensional screen displays, but in the future will be done in three-dimensions (immersive virtual environment). As with two-dimensional displays which now allow the opening of multiple two-dimensional windows, the immersive environment of the future will allow for three-dimensional windows. Designers in different localities will be able to interact with one another and with the product models. To accomplish this vision will require new classes of revolutionary tools and facilities, which are briefly described in subsequent sections. Many of these tools and facilities will be provided by commercial CAD/CAM/CAE systems and other government-supported programs. In order to maximize the benefits of the design environment to future aerospace products and processes, close collaboration with industry will be maintained.

2. Major Components

The following four major components, which are critical to the next generation design environment, have been identified:

- distributed synthetic environment and advanced human-computer interfaces
- infrastructure for collaborative computing
- rapid computational tools and modeling methods
- system integration tools and databases

each component described in subsequent subsections.

2.1 *Distributed Synthetic Environment and Human-Computer Interfaces*

The objective of this component is to increase the productivity of the design/manufacturing team by significantly enhancing the communication bandwidth between researchers/designers and machines. The environment will be highly interactive and capable of dynamically mapping information into visual, auditory or kinesthetic representations. This multimedia information will be presented to the user in an intuitive and coordinated form.

Virtual reality facilities for modeling, presentation, personal and group VR are integrated into the design environment. Interaction paradigms and techniques which allow researchers/engineers to see, hear, touch and interact with the product model will be used. The devices used in the environment include position trackers and sensing gloves as well as facilities for visual, audio and haptic feedback (e.g., head-mounted displays, three-dimensional audio localization and touch master). The current rendering tools and the speed of new graphics engines (such as the SGI Onyx2 Reality Monster with a rendering speed of 80 million polygons per second) can provide near photo-realistic visualization of the product model.

An immersive virtual environment is beneficial for many phases of the design, including mission operations planning; interactive visualizations of data from physics-based simulations; real-time simulations of assembly and manufacturing processes; creating virtual prototypes that can be manipulated in real time; assessing the accessibility of the different parts of the vehicle for maintenance and repair; checking the different parts of aerospace vehicles for fit and interference before building the physical prototypes. By being immersed into the virtual design environment, engineers can create and modify their designs in real time, seeing the effects of their modifications immediately. Designers can address operational issues such as, how close must a spacecraft approach a comet to get the required image resolution? What is the cost trade between resolution, image smear and attitude control requirements? How far can a rover traverse on a rock-strewn surface given a certain wheel design before another stereo image set is required? Immersive environments also provide design teams with a means of looking at ergonomics and other ease-of-use aspects of commercial aircraft. However, for the full benefits of immersive synthetic environment to be realized in the design and product development process, a number of technical problems need to be solved, including the development of both realistic force-feedback mechanism which enables engineers to feel when they are coming in contact with the virtual prototype, and a smooth interface with CAD/CAE systems which allows the creation and modification of product models in real time.

An attempt will be made to identify the promising human-computer interaction paradigms and techniques which allow the researchers/engineers to see, hear, touch and interact with the product models. In addition, traditional access mechanisms based on flat screen displays will also be supported.

2.2 *Infrastructure for Collaborative Computing*

This component will provide a multimedia environment for enabling collaborative design and integrated product viewing among geographically dispersed teams (e.g., NASA centers, JPL, industry and universities). A multiperspective approach to collaborative design will be supported. The Internet, with commercial and public domain software, provides the communication infrastructure between design and manufacturing teams using a mixed environment of hardware and operating systems. For large design projects, Intranets (which are networks within individual organizations) are used for communicating design information among members of each organization, and Extranets are used to provide secured connection between Intranets. The next-generation Internet is expected to alleviate the performance problems associated with constricted network bandwidth and to provide rapid communication of the latest product model data, which is one of the key requirements to reducing time to market and lowering product cost. The future Internet will also enable high-quality real-time interaction between users.

One aspect of collaborative computing is the virtual collocation facility - a new concept of a three-dimensional telepresence conference (3DTC) room. The concept is somewhat analogous to that envisioned by the creators of the Star Trek Holodeck where a distributed meeting takes place at specially-designed conference rooms located at remote sites. A major feature of 3DTC is that participants are able to fully interact with each other in three dimensions, i.e.,

- exchange objects in three dimensions
- walk around each other (eventually with full-scale systems)
- no special glasses, wands or gloves are required.

The 3DTC is based on combining some of the optical principles with modern electro-optics, digital image processing and display techniques in a special system configuration.

2.3 *Rapid Computational Tools and Modeling Methods*

Deterministic design and analysis tools based on mathematical models derived from first principles of physics (e.g., computational models used in various fields of mechanics and engineering science) have improved considerably in recent years. Graphical user interfaces (GUIs) have made the codes easier to use, and postprocessing graphical systems have made the results easier to understand. Advances in computer hardware and software have resulted in much faster computations. CAD/CAM/CAE systems have made design easier, aided engineers in coordinating design activities, and replaced expensive physical mockups with much less expensive digital mockups. Automatic meshing technology has reduced the time needed to create finite element models. Equation solvers have reduced computation times by orders of magnitude. Moreover, high-performance computers, high-end workstations and powerful PCs have done much to dramatically reduce execution times.

Nevertheless, the critical path to achieving the visionary revolutionary design environment requires significant reductions in modeling time and increases in analysis speeds which are presently not achievable. There are, however, ways of meeting these challenges. The objective of this program element is to develop, implement, validate and demonstrate computational tools which will provide the real-time simulation-based response capability required by the immersive design environment described in section 2.1.

2.3.1 *Rapid "Plug and Play" Structural Modeling.* Today, modeling is a long, tedious process often taking several months of intense activity. To change this, object-oriented technology will be used to develop a "plug and play" capability. The "plug" portion refers to an object-oriented user interface for the rapid assembly of component models, while the "play" portion refers to immediately available predictions of response, risk, cost and performance information. Interestingly, while modeling is difficult, assembly is relatively easy. Therefore, the next-generation design environment will significantly utilize model assembly of part and component models which are envisioned to be available on demand over the Internet. Tools will be developed to size, and manipulate shared or purchased component models. Once these enabling tools have been created, the end result is real-time modeling.

A new technology called "interface technology" facilitates the application of plug and play modeling capability. The technology provides a means of rapidly assembling diverse structural models subject to mechanical, thermal or dynamic loads. Collaborative modeling will arise as models come from different sources such as different organizations or from previous designs where similar components were used. It is possible that a business venture may arise in model leasing over the worldwide web. The technology has been formulated to handle grid point incompatible FEM models, FEM and BEM models and other models generated by other discretization techniques. The use of this technology opens a new door to expeditious modeling.

For a new aerospace vehicle under development, an object-oriented library of components and parts is created with a CAD (computer-aided design) system. These objects will contain all the information about the component as well as its response-generating models. The components are next assembled to create the vehicle using visual object-oriented technology in an immersive three-dimensional environment. Because these components are stored as intelligent knowledge-based objects, they know what components (or objects) they can connect to, where they connect and how they connect. When the CAD geometry components are joined, so are their predictive response and performance models. Before joining, each component is sized or scaled as desired and their related predictive models are scaled automatically. When the geometries are assembled, the predictive models are also coupled for multiphysics simulations. Simulation facilities will be embedded in, and operate seamlessly within, the CAD system. The analysis will be provided from within the CAD system and will be moved up into the early phase of the design process. Also, Internet-enabling software will be incorporated to allow the designers to access the product model data without leaving their application software.

2.3.2 *Physics-Based Modeling Tools*. Physics-based modeling tools are derived from such disciplines as aerodynamics, structures and controls and are used to evaluate the response and performance of any aerospace vehicle. Generally, all aerospace systems experience excitations resulting from internal and operational disturbances, such as instrument scanning in space systems and aerodynamic turbulence in aircraft. These excitations can potentially interfere with the mission of the system. For example, in space systems, excessive vibrations could be detrimental to science instruments which usually require consistent steady pointing in a specified direction for a prescribed time duration, or excessive vibrations due to turbulent aerodynamics could diminish the ride quality of an aircraft. Typically, in the course of the design of a spacecraft, as the definitions and the designs of the spacecraft and its components mature, several detailed dynamics and controls analyses are performed in order to insure that all mission requirements are being met. These analyses, although necessary, have historically been very time consuming and costly due to the large size of the aerospace system analysis model, large number of disturbance scenarios involved, and the extent of time domain simulations that need to be carried out.

Current physics-based deterministic computational simulation tools are inadequate for finding globally optimal designs which take uncertainties and risk into consideration. It is anticipated that the utilization of nondeterministic methods, such as the ones described in a subsequent subsection, will provide solutions to these problems.

2.3.3 *Cost and Manufacturing Models*. Design decisions must incorporate life-cycle costs and, in turn, costs must incorporate manufacturing, assembly, maintenance and disposal. The designer needs to have early access to reasonable estimates of cost, product development risk and product value, since all of these affect design decisions.

Much work is being done to develop cost and manufacturing/assembly models in the aerospace industry. Though this is still a relatively immature field, there is already considerable work that can be adopted for the design environment. From a component assembly viewpoint, it will be necessary to perform cost analysis on components and their assembly/integration. Estimating component costs, where components have been used before in almost the same form, should be relatively easy and accurate. However, estimating costs associated with the component or part assembly is much more difficult. Considerable effort is currently devoted to the development of virtual manufacturing capabilities for simulating both the manufacturing processes and equipment. This includes software tools for producibility analysis, process planning, and predicting the accuracy of parts produced. The envisioned design environment will take full advantage of existing and emerging capabilities.

2.3.4 *Nondeterministic Analysis and Design Tools*. It is anticipated that the utilization of computational intelligence technology and its associated soft computing tools will provide solutions to complex design problems with system uncertainties. The principal constituents of soft computing are neurocomputing, fuzzy logic and genetic algorithms. Soft computing tools exploit the tolerance for imprecision and uncertainty in real-world problems to achieve tractability, robustness and low solution cost.

Neurocomputing was inspired by biological neural networks. Neural networks are pattern-computers-information processing devices (either algorithms or actual hardware). They use simplified mathematical functions to approximate some of the behavior of neurons in the brain. Operations performed by neural networks include classification, pattern matching, optimization, control, and noise removal. They are particularly useful in situations where good mathematical models are either unknown or extremely complex, and where pattern recognition is involved. They also provide a means of storing data in a compressed form and of generating interpolation from retrieved data.

Fuzzy logic provides a mathematical tool for dealing with uncertainty and imprecision. It aims at rapidly finding acceptable solutions by permitting quantification of information in linguistic form. A useful role of fuzzy logic in the project is to process large volumes of design and response data which have been derived from past experiences.

Genetic algorithms are biologically inspired evolutionary processes. They provide an adaptive, robust, parallel and randomized technique in which a population of solutions goes through a sequence of variations until a globally optimal solution is identified. Genetic algorithms are best suited for complex, poorly understood systems where innovative design solutions are sought and where analytical tools for assessing relative goodness of a design are available.

Judicious integration of neural networks, fuzzy logic and genetic algorithms can result in systems that are better in terms of parallelism, fault tolerance, adaptivity, and uncertainty management. The reasoning power of fuzzy systems, when integrated with the learning capabilities of neural networks and the search capabilities of genetic algorithms, can lead to effective engineering systems.

2.4 *System Integration Tools and Databases*

Simulation and testing of all the life-cycle phases of an aerospace system is essential for a truly integrated design environment, from conceptual to detailed design, manufacturing, operations, and update for reuse or retirement of the vehicle. The environment will be accessible, integrated and information based. To aid in making design decisions, tools for providing a global view of the development process, including information about product assembly, test, vehicle and total mission costs should be part of the environment. These tools include knowledge discovery in databases (KDD), knowledge sharing, and product data management (PDM) software. They enable the evaluation of several design alternatives, and the global optimization of the aerospace vehicle relative to the mission goals.

The capabilities described in the next-generation design environment require and assume the existence of globally-accessible object-oriented multi-database systems, which will be initially used to store simple objects such as drawings, but later to become repositories of information and applications such as intelligent agents. The database system supports "plug-and-play" capabilities and uses a hierarchy of intelligent software facilities at various levels, from tool integration to knowledge discovery and organization, intelligent query and knowledge additions. The salient components for semi-autonomous agent-based integration of the tools and facilities include:

- mediators
- agents
- knowledge-based systems/design advisors
- software architecture for design environments, and
- authoring tools and requirements tracking.

A hierarchy of computer processing ranging from large volumes of raw data to information and knowledge is provided by using the techniques of knowledge discovery in databases (KDD).

Mediators enable the user to view databases of aerospace vehicle components and parts from different vendors without needing to learn the particular attributes and database schemes of each individual vendor to retrieve the desired information. It also enables tools to search, retrieve and analyze what appear to be global databases but which are actually composed of heterogeneous databases.

A software agent is a migrateable object that can operate on different computer platforms. For example, an agent could originate with a request by a designer (e.g., find commercial parts that satisfy a specification), migrate to various vendor databases, and finally to different vendors. This technology is expected to become one of the key integrating features of the evolving information design systems (IDS). Agents will be able to perform much of the work required between various other elements to enable the human operator to use an environment at the human level of abstraction.

Knowledge-based systems/design advisors are discrete software programs which provide high-level assistance in performing specific design processes such as manipulating and evaluating alternative design concepts.

The configuration of complex design environments will be based on reusable families of design system architectures, with standardized interfaces for plug-and-play components. The base level of these systems will incorporate a scaleable, cross-platform virtual hardware and operating system, with standardized protocols and interfaces. Families of design system architectures will be defined on top of this base level.

Document/design management tools address the issues of authoring, updating (hence configuration management) of documents and designs, and tools for project management (such as work flow, requirements/specifications tracking). Automated design capture and document production will be enabled by intelligent software agents.

3. Future Directions

Future advances in computer performance, communication and networking technologies will include teraflop and petaflop-scale machines, mobile computing, wireless communications, new modes of human-computer interaction, and the next-generation Internet. These will occur alongside equally significant changes in distributed heterogeneous immersive virtual environment and CAD/CAM/CAE suites. The latter will include miniature wearable computing devices for immersive environment, and facilities for enabling concurrent engineering teams to look at key design criteria early in the design process (such as the What-if Alternative Value Engineering - WAVE facility of EDS Unigraphics). All these advances will enable rapid accommodation of new design paradigms and dramatic improvements in the design and development processes of aerospace vehicles.

The intelligent design environment will allow separate groups to work together and share information, in a synergistic manner, to develop efficient virtual prototypes of aerospace vehicles. This will significantly reduce the development times, lower life-cycle costs, and improve the quality and performance of future aerospace systems.

In the next decade, simpler, more efficient design and development tools, including a design language, will likely be discovered. The next-generation design environment will evolve into a shared, highly-flexible, information-based, responsive multimedia design environment with plug-and-play interoperability across dispersed and disparate organizations, including hardware and software facilities. It will expand the scope of trade-off analysis; allow multicriteria evaluation of design and manufacturing options; optimize the product characteristics for quality, manufacturability, assembleability, and maintainability; and quickly prototype complex products and processes.

Realizing the full potential of the next-generation design environment will entail educating and training design and manufacturing teams, not only in the component technologies but also in new approaches for collaborative, distributed design and virtual product development. Universities should work with industry and government labs in developing effective instructional and training facilities for the new design approach. The challenge facing large aerospace companies is to effect a cultural change that will transform their design and manufacturing sectors into rapidly configurable, flexible learning organizations which are relentless in their focus on improving processes and products.

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Highlights of the Workshop

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OUTLINE

Economic stresses are forcing many industries to reduce cost and time-to-market, and to insert emerging technologies into their products. Engineers are asked to design faster, ever more complex systems. Hence, there is a need for novel design paradigms and effective design tools to reduce the design and development times. Several computational tools and facilities have been developed to support the design process. Some of these are described in subsequent presentations. The focus of the workshop is on the computational tools and facilities which have high potential for use in future design environment for aerospace systems. The outline for the introductory remarks is given in Fig. 1.

First, the characteristics and design drivers for future aerospace systems are outlined; second, simulation-based design environment, and some of its key modules are described; third, the vision for the next-generation design environment being planned by NASA, the UVA ACT Center and JPL is presented. The anticipated major benefits of the planned environment are listed; fourth, some of the government-supported programs related to simulation-based design are listed; and fifth, the objectives and format of the workshop are presented.

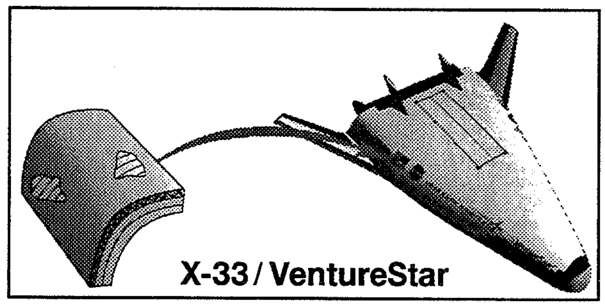
- **Future aerospace systems**
  - **characteristics**
  - **design drivers**
- **Simulation based design environment**
  - **description of some key modules**
- **Next generation design environment**
  - **vision**
  - **major benefits**
- **Related, government supported programs**
- **Objectives and format of the workshop**

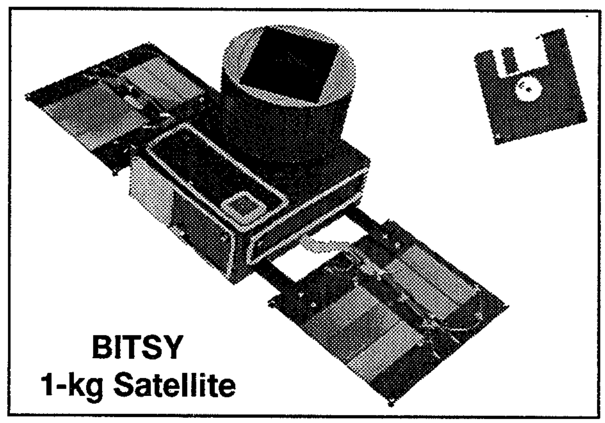
Figure 1

CHARACTERISTICS OF FUTURE AEROSPACE SYSTEMS

Some of the major characteristics of future aerospace systems are listed in Fig. 2. The systems will incorporate engineered multifunctional materials and intelligent/smart structures. They will have embedded sensors, actuators and elaborate information processing systems. They will allow miniaturization and modularity, like the 1-kg Bitsy satellite built by AeroAstro and the modular aircraft concept shown in Fig. 2. Some of the future systems will operate in harsh environment (such as very high temperatures).

- **Intelligent (smart) engineered multifunctional materials and structures**
- **Have embedded sensors, actuators and elaborate information processing systems**
- **Allow miniaturization and modularity**
- **Operate in a harsh environment**





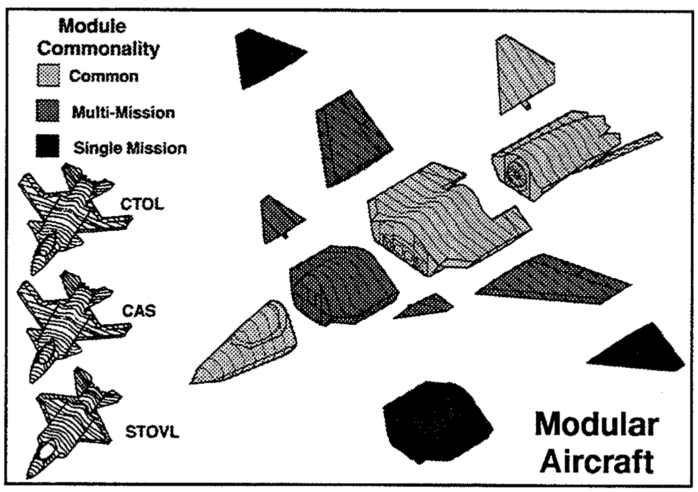


Figure 2

DESIGN DRIVERS

The design drivers for future aerospace systems include (Fig. 3):

• Affordability - emphasis will be placed on reducing life-cycle cost.

• Improved performance - this is accomplished through rapid insertion of new and emerging technologies.

• Rapid prototyping - which requires reducing both the design and development times.

The design objectives can be achieved through the use of intelligent simulation-based design environment, which is described subsequently.

- **Affordability – reduce life-cycle cost**
- **Improved performance – rapid insertion of new technologies**
- **Rapid prototyping – reduce design and development times**
- **Achieved through intelligent simulation-based design environment**

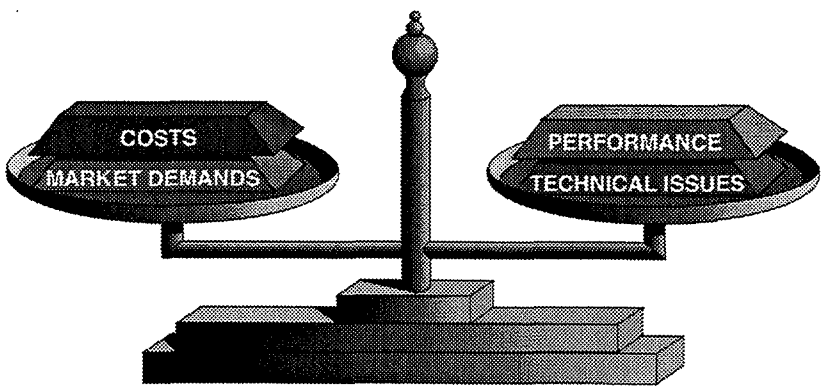


Figure 3

SIMULATION-BASED DESIGN ENVIRONMENT

A schematic of the simulation-based design environment, which simulates the entire life-cycle of the aerospace system, is shown in Fig. 4. The modules and facilities of the environment include: mission requirements; concept development; modeling, multidisciplinary analysis and design; simulation of manufacturing, assembly planning and prototyping; cost modeling; risk management; simulation of testing; simulation of operations, maintenance, repair and disposal; and system optimization tools. All of the modules will be embedded in an immersive virtual environment. A dynamic digital mockup of the aerospace system will evolve as the design progresses, and an object-oriented multi-database system is used to support its entire life cycle.

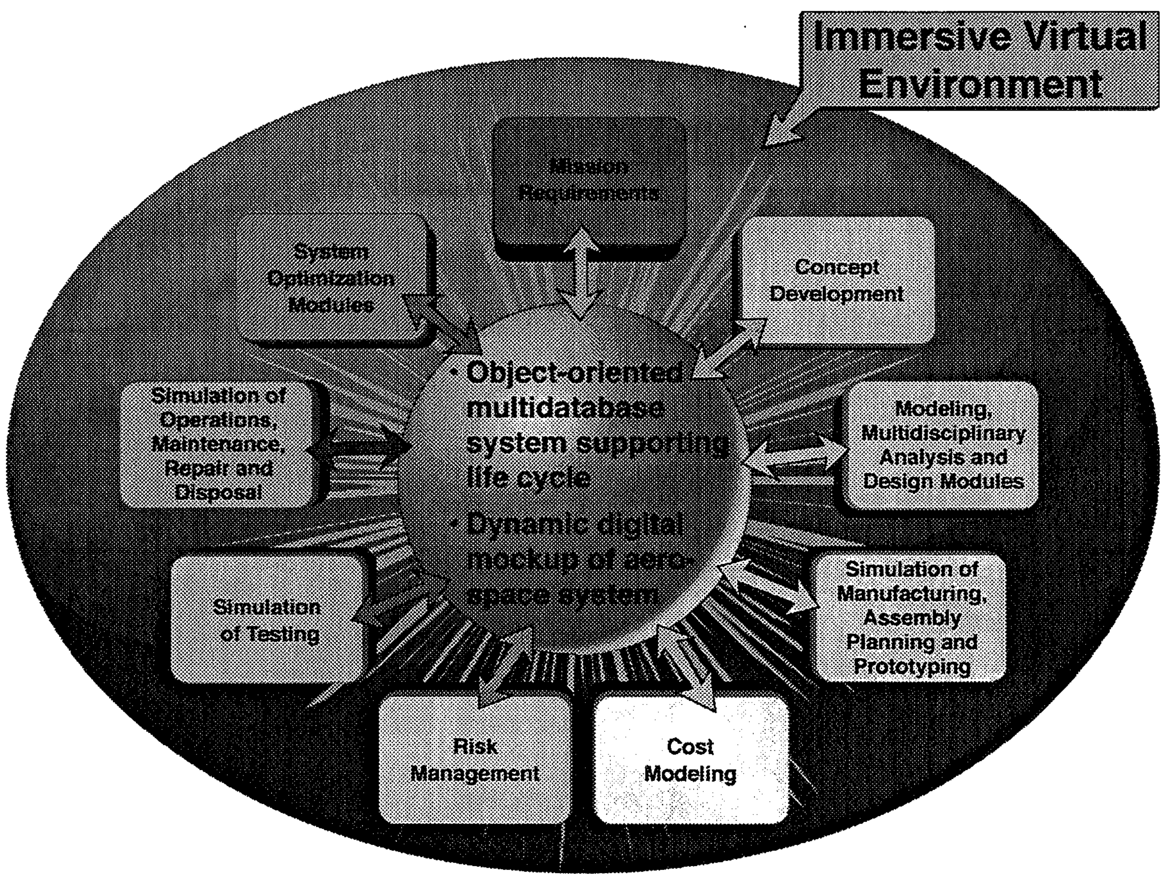


Figure 4

MODEL GENERATION FACILITIES

Model generation remains one of the pacing items of large-scale numerical simulation. Among the different facilities that can expedite model generation are (Fig. 5):

- preprocessing codes, such as the paving and plastering codes of Sandia National Laboratories;
- use of visual object-oriented technology facilities;
- collaborative model-generation facilities such as the Shastra System of Purdue University;
- real-time modeling using special gloves and virtual reality facilities; and
- knowledge-based modeling assistance tools.

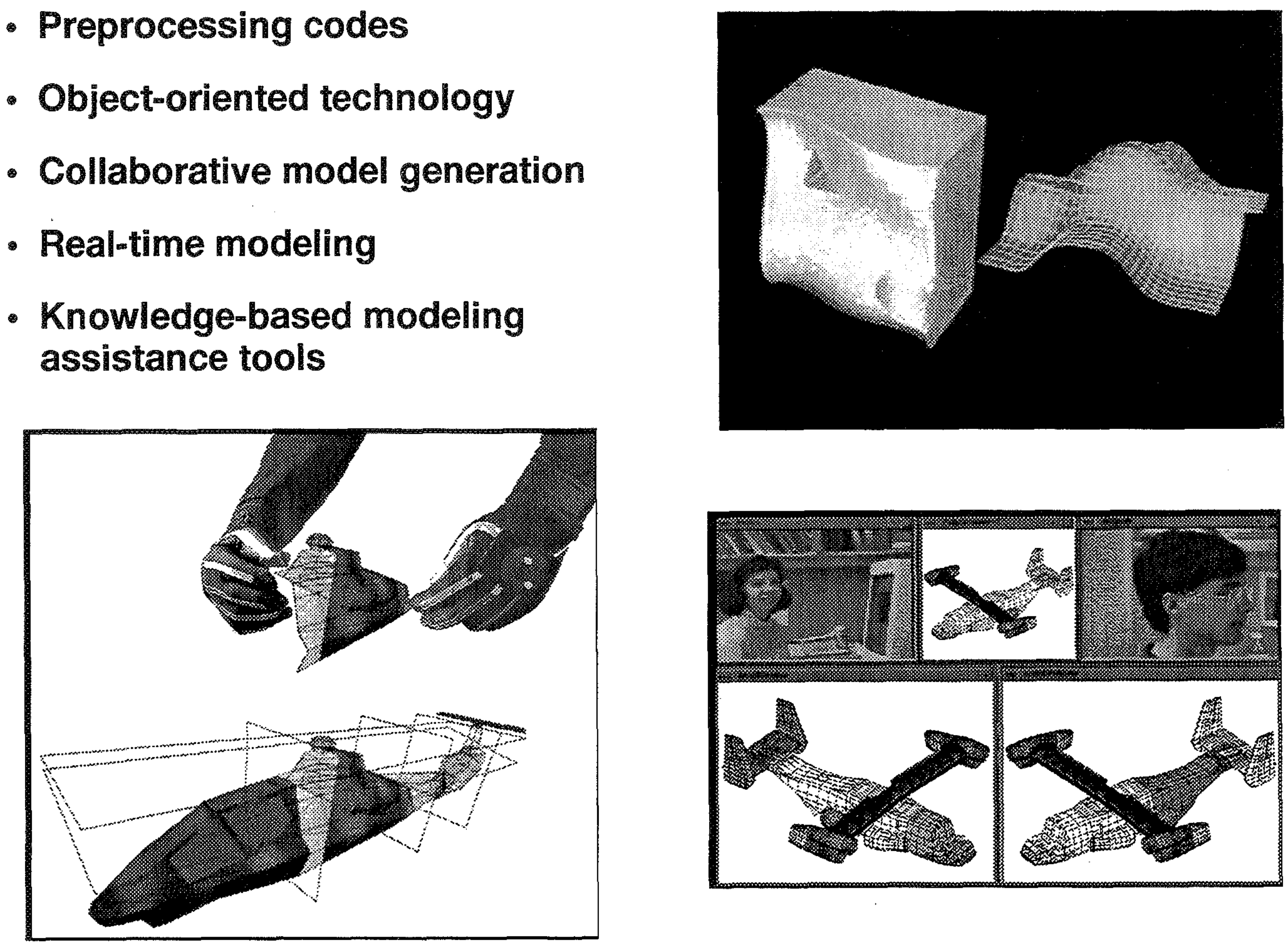


Figure 5

INTELLIGENT COMPUTATIONAL MODULES

Among the major features of the computational modules of the simulation-based design environment for future aerospace systems are:

Close integration of numerical simulation programs with CAD systems, viz. CAD-embedded simulation products. The simulation tools will be integrated inside the CAD package, and will look, act and feel like CAD modules. This paradigm shift will provide for design verification early in the process and allow cost-effective changes.

Aerospace system project information is organized in a hierarchy with many defaults and shortcuts. Users can select a set of goals, type of vehicle, model type, material choices, physical environment, and analysis type. Figure 6 shows the concept of a DesignSpace Explorer, which is accessed through tool bar, menu pick and comments in the CAD system. No complex series of functions or data transfer processes will be required to move geometry.

Treatment of uncertainties in the aerospace system and its environment will be incorporated into the design process. This is further elaborated subsequently.

- **Paradigm shift – CAD embedded simulation products**
- **Aerospace system information organized in a hierarchy with many defaults**
- **Treatments of uncertainties**

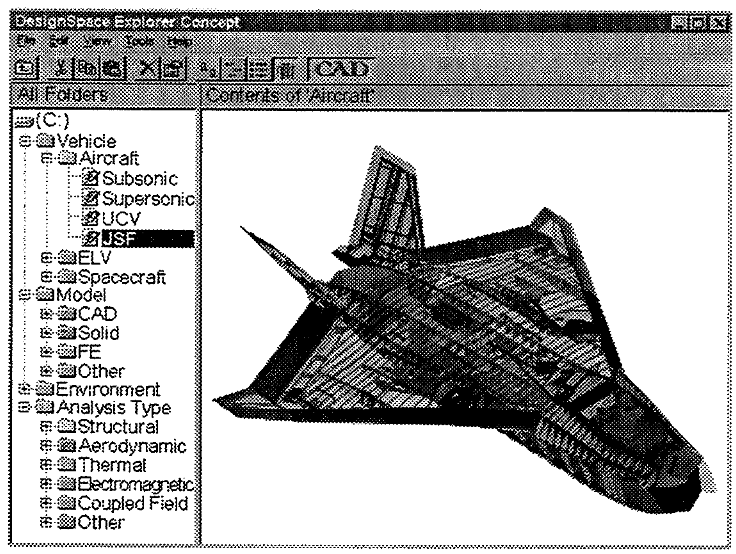


Figure 6

TREATMENT OF UNCERTAINTIES

Although it is difficult to list all sources and kinds of uncertainties, the following three are identified (Fig. 7):

• Probabilistic uncertainty, which arises due to chance or randomness;

• Resolutional uncertainty, which is attributed to limitation of resolution (e.g., sensor resolution); and

• Fuzzy uncertainty, due to linguistic imprecision (e.g., set boundaries are not sharply defined such as a set of real numbers close to 7).

One of the important consequences of uncertainty is its effect on precision. As the uncertainty and/or complexity of an engineering system increases, our ability to predict its response diminishes, until a threshold is reached beyond which precision and relevance become almost mutually exclusive. Consider, for example, numerical simulations in which sophisticated computational models are used for predicting the response, performance, and reliability of the engineering system, but the system parameters are little more than guesses. Such simulations can be characterized as Correct But Irrelevant Computations (CBIC); that is, forcing precision where it is not possible.

Sources and kinds of uncertainties include:

- **Probabilistic (randomness)**
- **Resolution (e.g., sensor resolution)**
- **Fuzzy uncertainty (boundaries are vague – not sharply defined)**

CBIC ≡ Correct But Irrelevant Computation

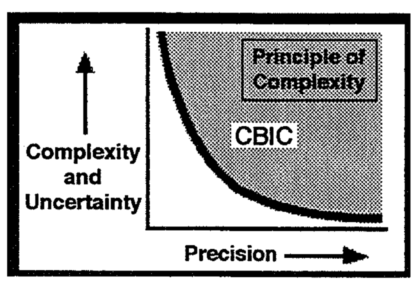


Figure 7

ANALYSIS APPROACHES FOR TREATING UNCERTAINTIES

Three general approaches can be used for the analysis of systems with uncertainties, namely (Fig. 8): Probabilistic methods for random processes; fuzzy sets; and set-theoretical or anti-optimization methods.

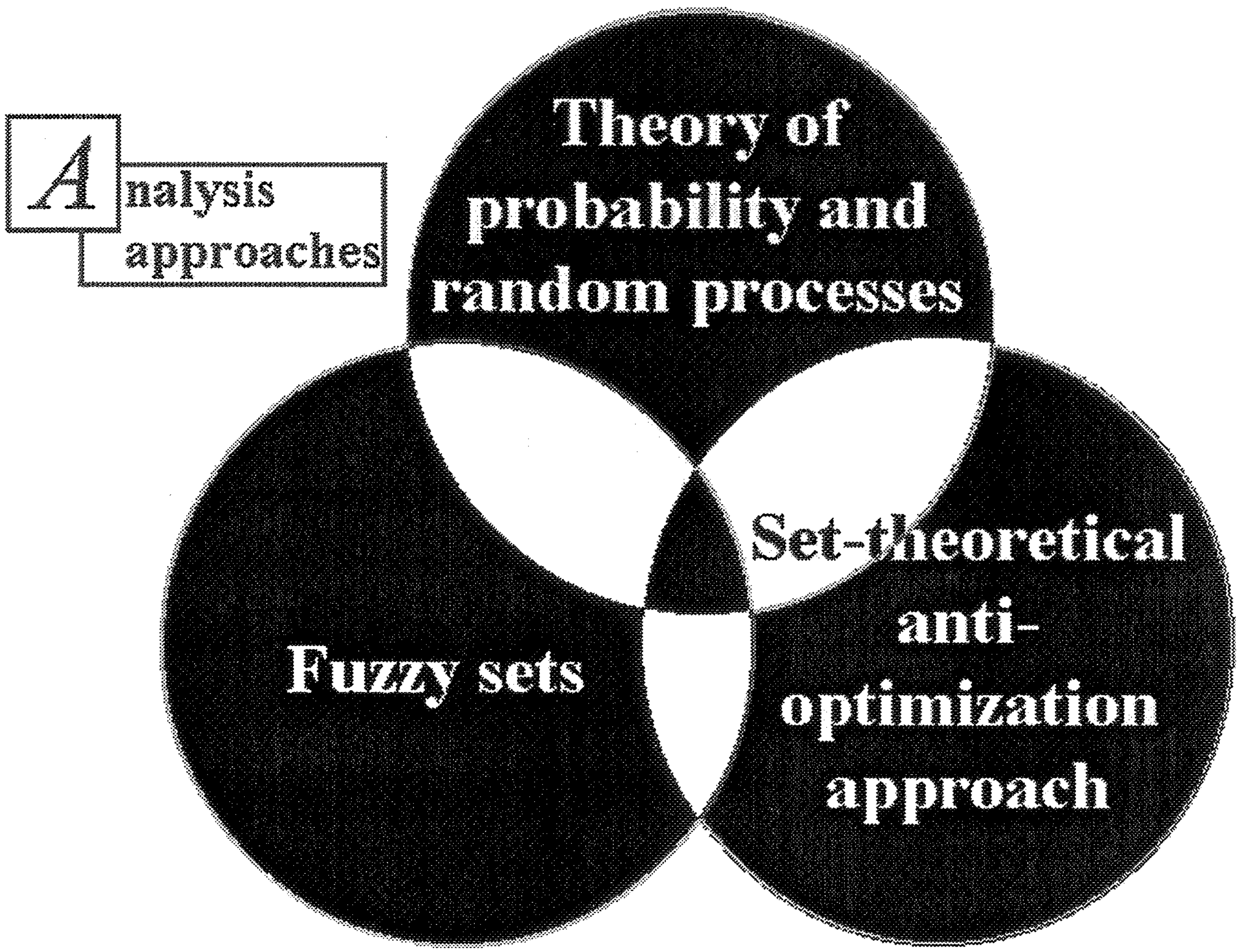


Figure 8

COMPUTATIONAL INTELLIGENCE AND SOFT COMPUTING TOOLS FOR NONDETERMINISTIC ANALYSIS

Computational intelligence is a new paradigm for solving complex problems with system uncertainties. Its associated tools have been referred to by Lotfi Zadeh, of the University of California, Berkeley, as soft computing (SC). SC describes several novel modes of computation which exploit tolerance for imprecision and uncertainty in real-world problems to achieve tractability, robustness and low-solution cost (Fig. 9).

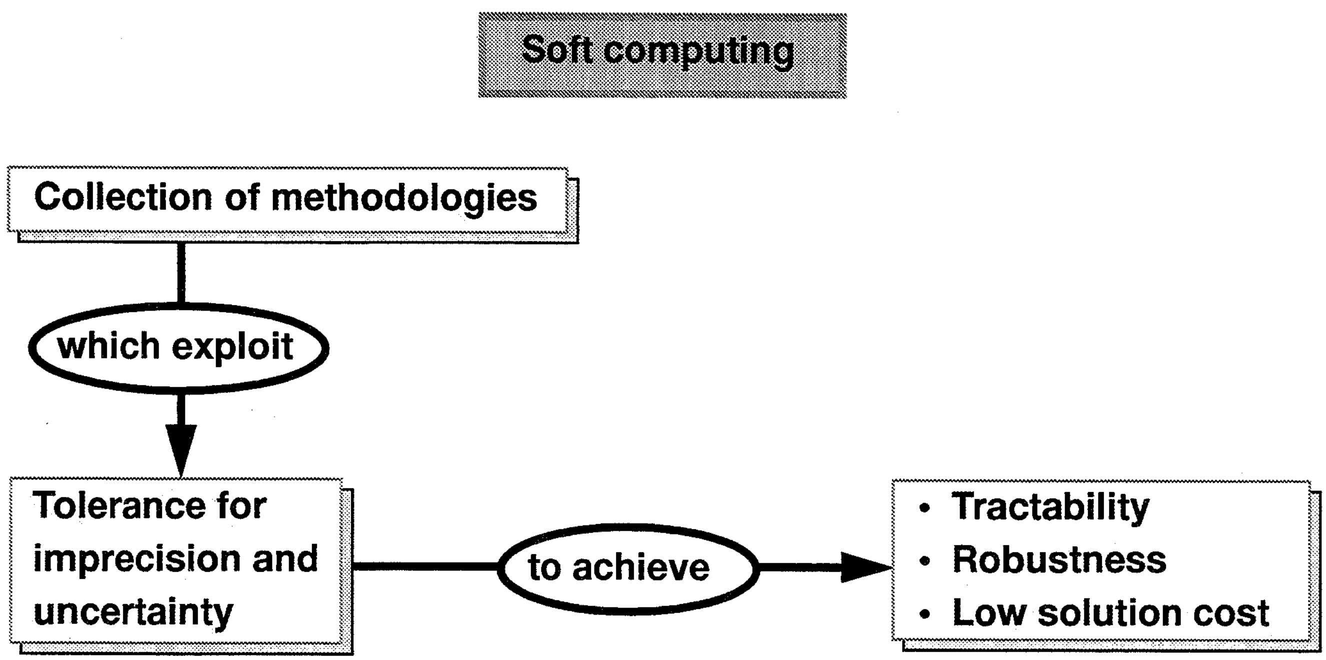


Figure 9

BASIC COMPONENTS OF AN INTELLIGENT AEROSPACE VEHICLE

The concept of an intelligent aerospace vehicle is depicted in Fig. 10. The vehicle has sensors, actuators, an information-processing system, and uses soft computing tools and facilities. The three major components of soft computing are: Fuzzy logic, used for handling the imprecision and uncertainty; neuro-computing, used for performing the learning and adaptation functions; and genetic algorithms, used for the search and optimization functions.

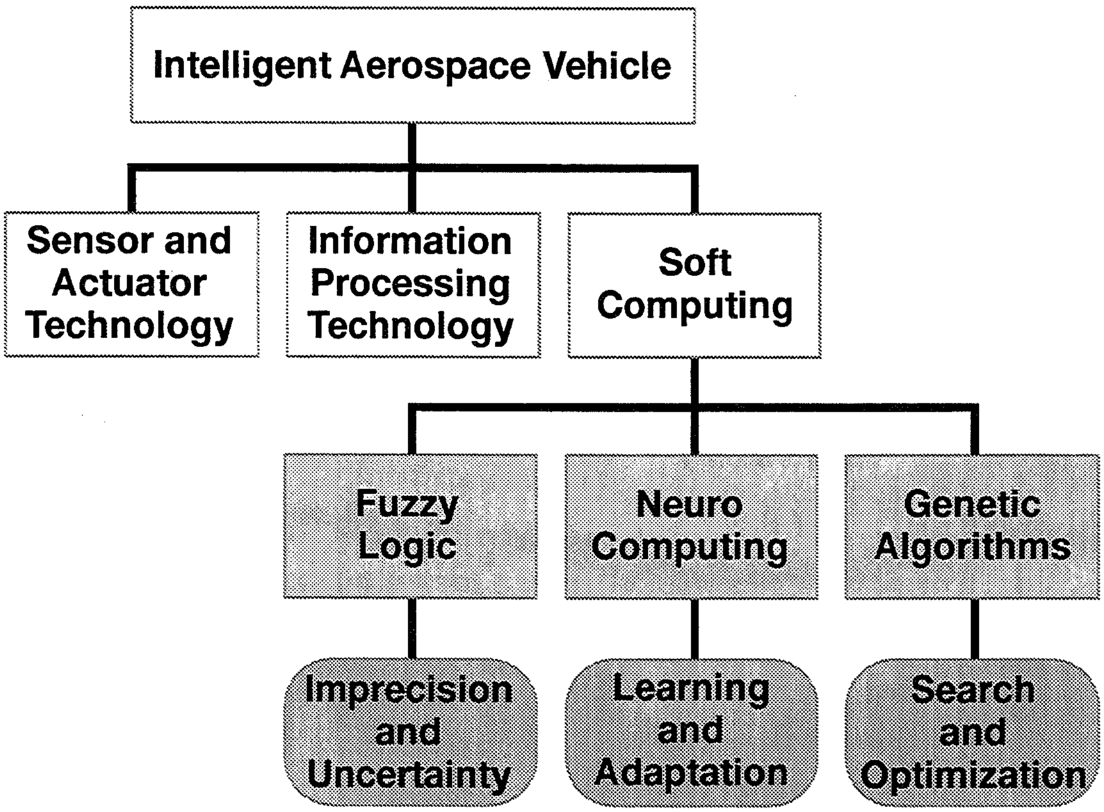


Figure 10

SOFT COMPUTING VERSUS AI EXPERT SYSTEMS

The distinction between expert systems (the most mature and resilient product of AI), fuzzy logic, neural nets, genetic algorithms, and conventional computational methods can be illustrated by the extent to which they use nonnumeric (symbolic) and numerical computations (Fig. 11).

Soft computing has been used in the design and development of a wide variety of engineering products, including intelligent consumer goods, auto components, robots, and manufacturing equipment.

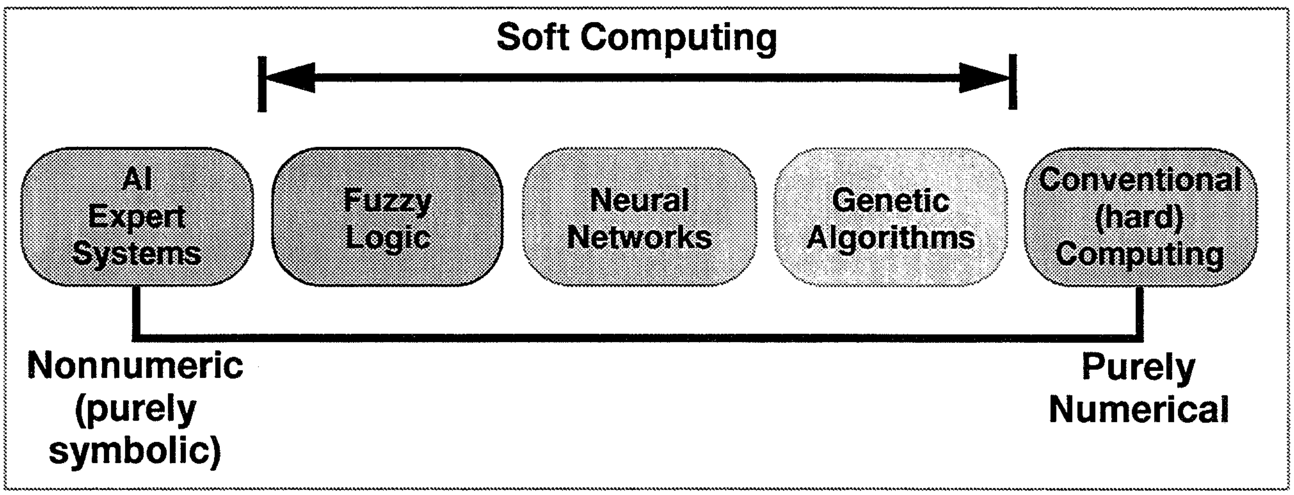


Figure 11

MODELING APPROACHES FOR COMPLEX SYSTEMS WITH UNCERTAINTIES

Future aerospace systems will include complex dynamic vehicles and subsystems, such as autonomous "thinking" aircraft and spacecraft, and advanced propulsion systems. Three types of models can be identified depending on the complexity and the precision, namely: mathematical models, model-free methods, and fuzzy systems (Fig. 12). In a typical complex system a combination of the three should be used. Soft computing tools are likely to emerge as an essential technology for the conception, modeling, analysis and design of future aerospace systems.

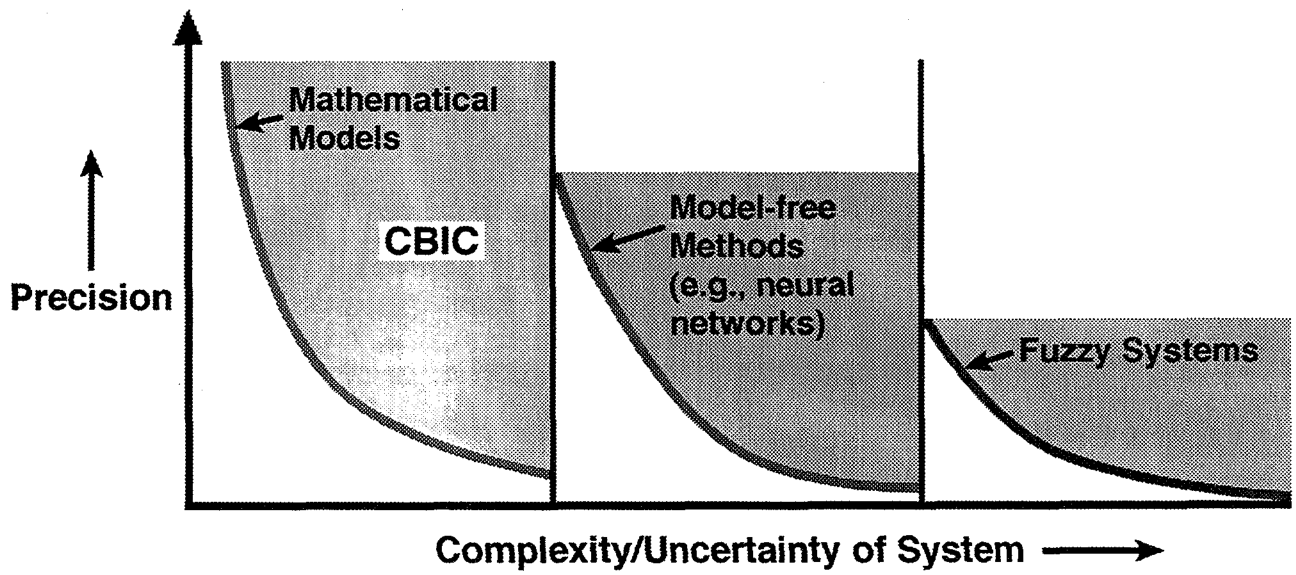
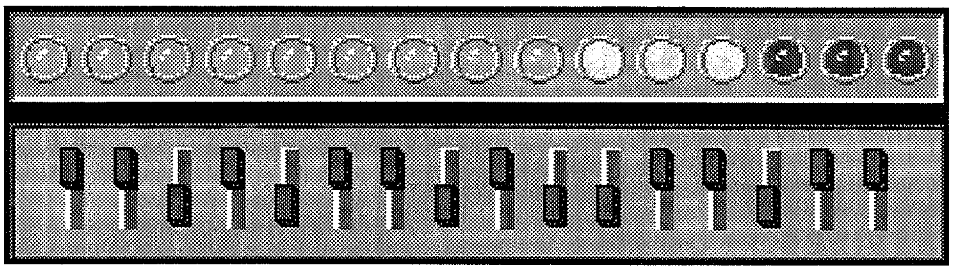


Figure 12

MEASURE OF INTELLIGENCE

To assess the degree of intelligence built into a vehicle, a metric is needed - Vehicle Intelligence Quotient (VIQ). The dimensions of this metric include: execution of high-level instructions; unstructured storage and retrieval of information; decision making; self-diagnostics; real-time damage assessment; and self repair (Fig. 13).

Vehicle Intelligence Quotient – VIQ
Dimensions of VIQ



- **self repair**
- **self diagnostics**
- **decision making**
- **real-time damage measurement**
- **execution of high-level instructions**
- **unstructured storage and retrieval of information**

Figure 13

ADVANCED HIGH BANDWIDTH HUMAN-COMPUTER INTERACTION FACILITIES

A number of facilities are now available for high bandwidth human-computer interaction, including:

• Multimedia workstations which can significantly reduce the time for postprocessing and understanding the data;
• Sonification facilities for mapping data into the sound domain; and
• High definition technology and advanced visualization engines such as the virtual reality and augmented reality facilities.

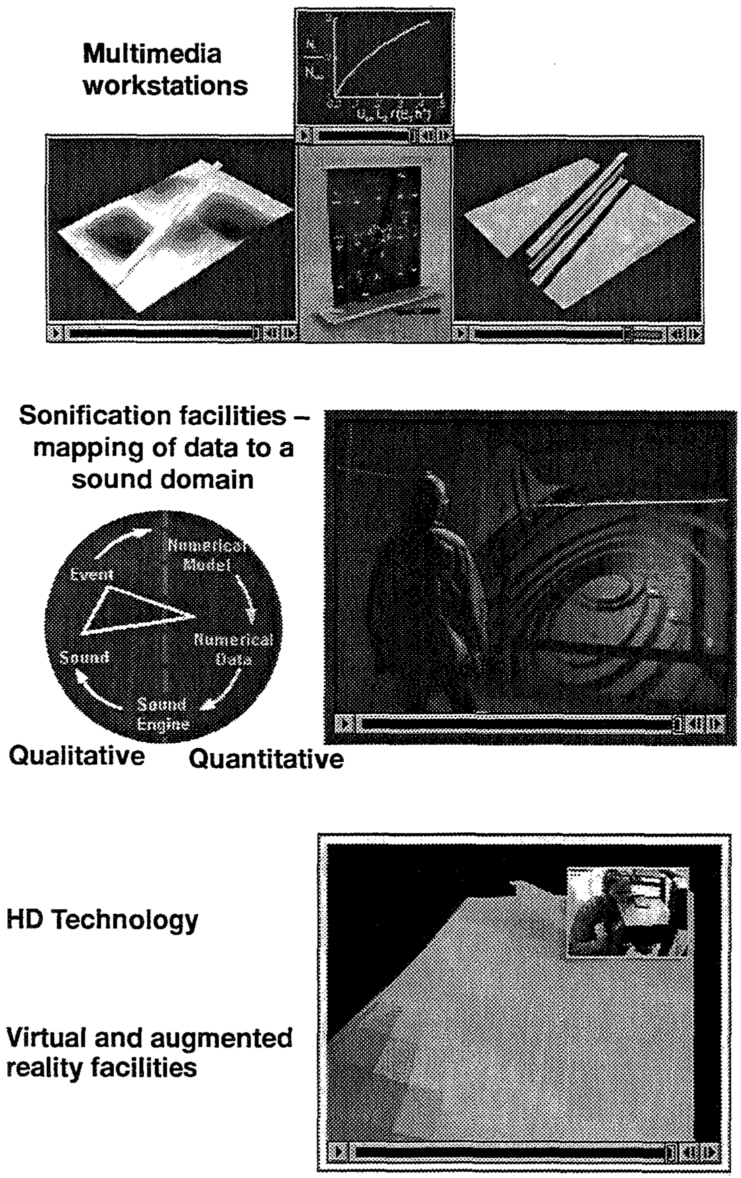


Figure 14

INTEGRATED VR FACILITIES

A wide variety of virtual reality facilities are now available in support of simulation-based design activities. These facilities can be grouped into four categories (Fig. 15):

- Presentation VR - such as the IWALL;
- Peer VR - such as the Vision Dome of Alternate Reality in Raleigh, North Carolina, the CAVE at the Electronic Visualization Laboratory of the University of Illinois at Chicago and the Reality Centre of Panoram Technologies, Inc. in Burbank, California;
- Personal VR - such as the Immersadesk; and
- VR modeling and visualization facilities on desktop and laptop computers.

The different VR facilities can be connected together as is done at the National Center for Supercomputer Applications (NCSA) at the University of Illinois at Urbana-Champaign.

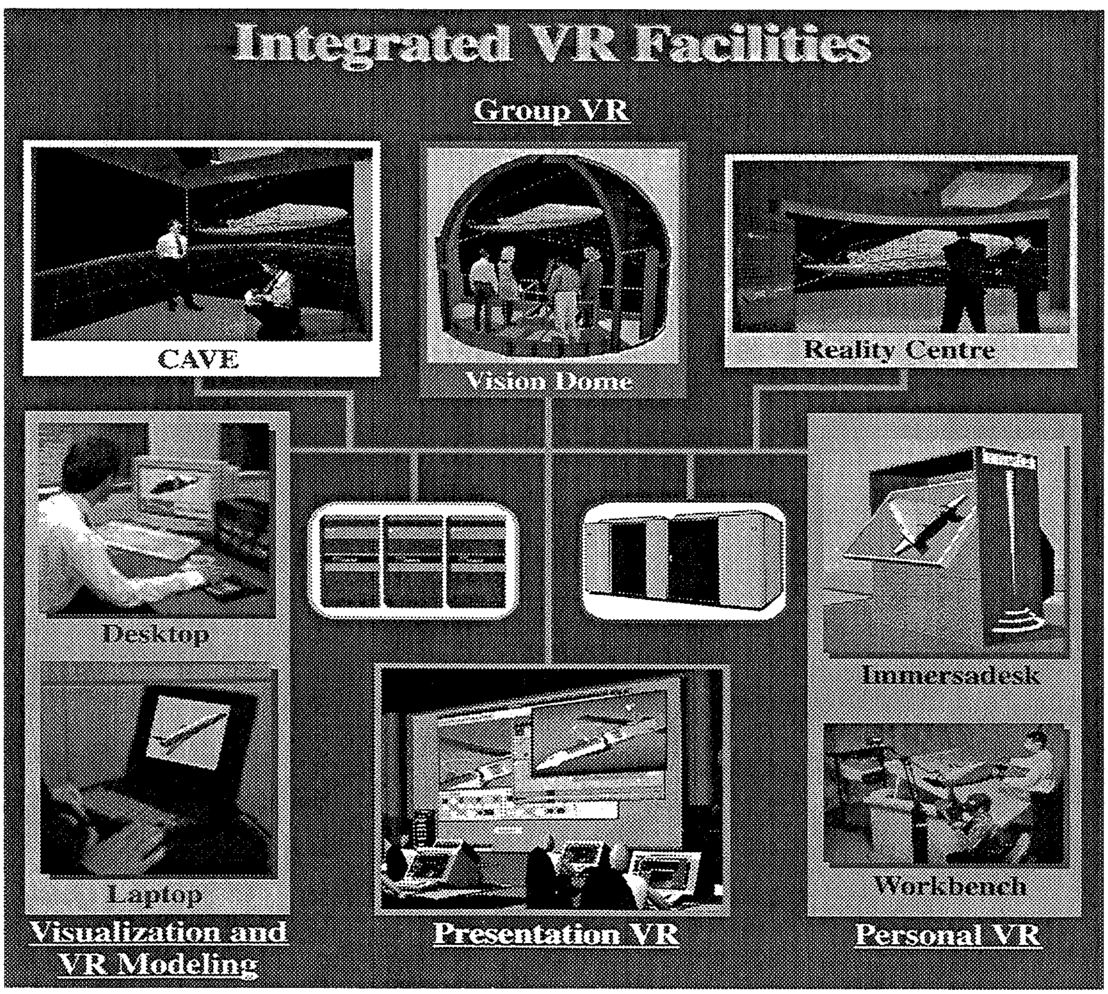


Figure 15

INTELLIGENT COLLABORATIVE COMPUTING INFRASTRUCTURE

Since the design of future aerospace systems will be performed by geographically dispersed teams, an intelligent collaborative computing infrastructure needs to be developed to allow sharing information and product viewing by the different teams. The infrastructure should also support a multi-perspective approach to collaborative design. Figure 16 shows examples of collaborative work between NASA Langley researchers and those at the CAVE, University of Illinois, Chicago; and between NASA Langley, NASA Ames and JPL researchers.

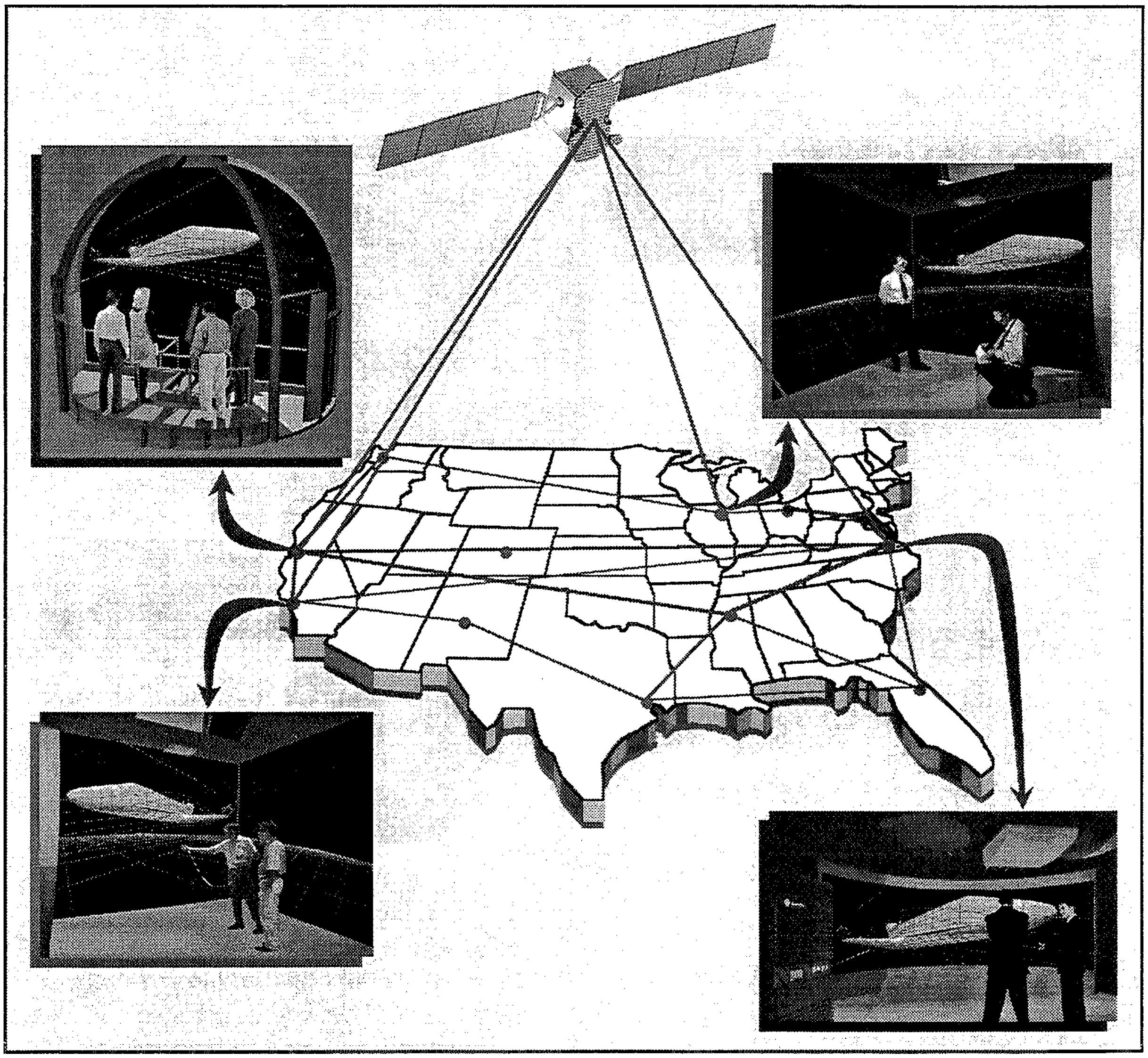


Figure 16

SYSTEM INTEGRATION TOOLS AND DATABASES

Since the design activities will be performed on several computing platforms, a portable, self-describing data format is needed for moving and sharing data in a networked, heterogeneous computing environment. The Hierarchical Data Format (HDF) developed by NCSA at the University of Illinois, Urbana-Champaign (Fig. 17), can store several different kinds of data objects: multidimensional arrays, raster images, color palettes, and tables. It allows individual researchers and engineers to mix and group different kinds of data in one file according to their needs.

- **Hierarchical data format (HDF)**
- **Different kinds of data objects**
- **Moving and sharing data in networked heterogeneous computing environment**

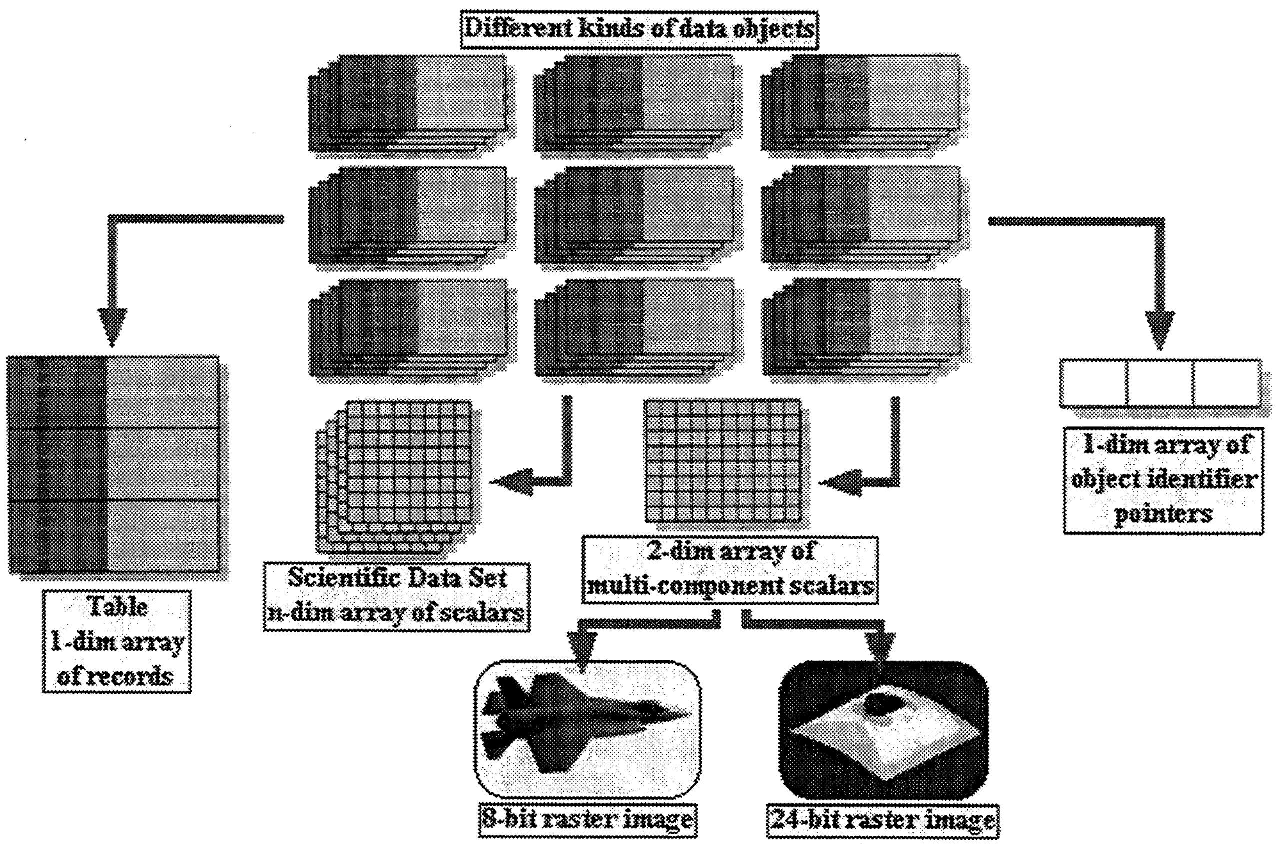


Figure 17

HIERARCHY OF COMPUTER PROCESSING AND ORGANIZATION

Figure 18 shows the hierarchy of computer processing. Raw data (small unstructured items) can be organized and refined into more efficient representations. Information, knowledge and intelligence are progressively smaller subsets of increasingly more organized data. Information is a collection of structured data items. Data items become structured as information when they are linked by semantic and syntactic relationships. Knowledge is represented by linking information items together and manipulating them symbolically. The application can be quite powerful, as with knowledge-based diagnostics. AI applications are concentrated in the area of knowledge processing. The emerging field of Knowledge Discovery in Databases (KDD) deals with data preparation, selection, cleaning and mining (i.e., extracting patterns and knowledge from fused data - data coming from different sources in real time). Most of today's computer processing belongs to the category of data processing. There has been no intelligence processing to date, but it is a goal of the AI community.

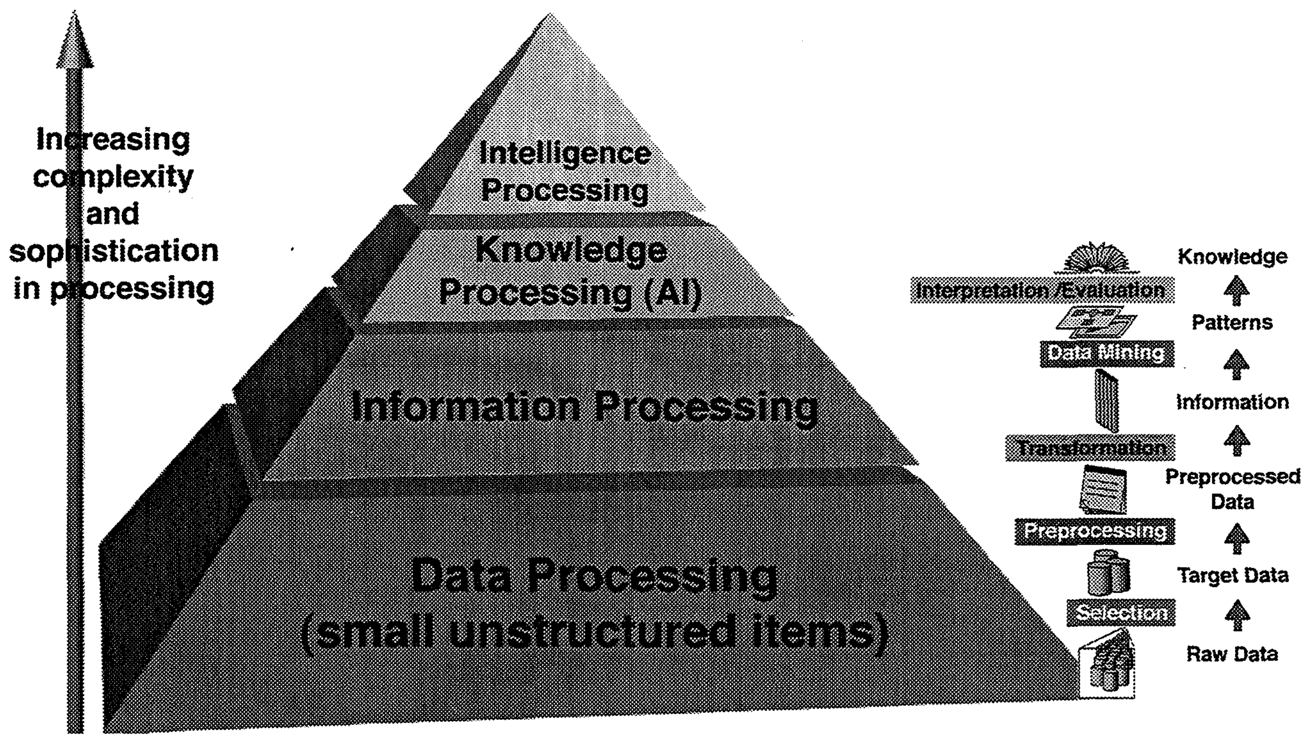


Figure 18

NEXT GENERATION INTEGRATED DESIGN ENVIRONMENT

The overall goal of the next-generation integrated design environment project is to build/ assemble an advanced analysis/design environment for aerospace systems which incorporates the state-of-technology computational and communication facilities and tools. The environment will allow the simulation of the entire life cycle of the aerospace system from concept development to detailed design, prototyping, testing for qualification, operations, repair and disposal. The environment is expected to significantly shorten the design and development times of future systems, reduce their life-cycle cost and improve their performance (Fig. 19).

Vision

- **Significantly shorten design and development times of aerospace vehicles**
- **Reduce their life-cycle cost**
- **Improve their performance**

Through

- **Creating leading-edge computational and synthetic environment for simulating the entire life cycle from concept development, detailed design, prototyping, testing for qualification, operations, repair and disposal**

Figure 19

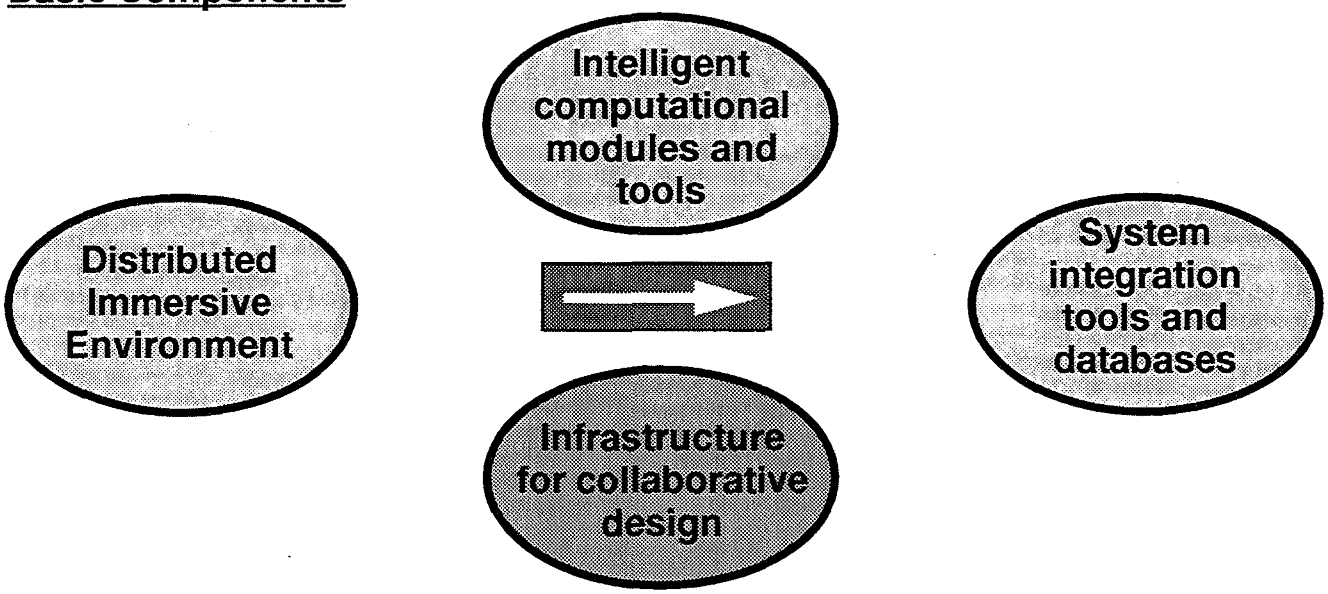
BASIC COMPONENTS OF NEXT GENERATION ANALYSIS AND DESIGN ENVIRONMENT AND EXPECTED BENEFITS

The four major components of the next-generation analysis and design environment are:

- Distributed immersive environment and human-computer interfaces
- Infrastructure for collaborative computing
- Intelligent computational modules and modeling facilities
- System integration tools and databases.

The immersive environment will increase the productivity of the design/manufacturing team by significantly enhancing the communication bandwidth between researchers/designers and machines. The environment will be highly interactive and capable of dynamically mapping information into visual, auditory or kinesthetic representations. The computational tools cover the entire life cycle of the aerospace system. The system integration component will use object-oriented technology to facilitate the linking of different modules of the environment.

Basic Components



Benefits

Reduced
- **Design and development times**
- **Life cycle cost**
- **Technology insertion time**

Improved
- **Performance**

Figure 20

RELATED TECHNOLOGY PROGRAMS

A number of related government supported programs are listed in Fig. 21. They include programs supported by NASA, DARPA, DoD, DOE and NIST. An attempt will be made to incorporate the useful components from these programs into the design environment.

NASA
- Small Spacecraft Technology Initiative (SSTI)
- Information Technology Strategic Program
- New Millennium Program (NMP)
- Human Explorations and Development of Space (HEDS)
- HPCCP
- EOS
- Space Science
- HSCT
- Affordable Design and Manufacturing program (ADAM)

NASA Supported Programs and Grants
- MDO
- IClass (Illinois)

DARPA
- Simulation-Based Design (SBD)
- Rapid Design Exploration and Optimization (RaDEO) / Manufacturing Automation and Design Engineering (MADE)
- Agile Infrastructure for Manufacturing Systems (AIMS)
- Rapid-Prototyping of Application Specific Signal Processors (RASSP)

DOE
- Accelerated Strategic Computing Initiative (ASCI)

DoD
- Simulation Assessment Validation Environment (SAVE)
- DoD Distributed Simulation Multi-modal Virtual Environment

NIST
- National Advanced Manufacturing Testbed (NAMT)

Figure 21

OBJECTIVES AND FORMAT OF THE WORKSHOP

The objectives of the workshop are to assess: a) the level of maturity of a number of computational tools and facilities, and b) their potential for application to the next-generation integrated design environment (Fig. 22).

The workshop including thirteen presentations, discussions and software demonstrations, illuminate some of the key issues in developing the design environment and provide fresh ideas for novel design paradigms.

Objectives

- **To assess level of maturity of computational tools and facilities**
- **To assess potential applications to next generation integrated design environment**

Format

- **Presentations**
- **Software demonstrations**
- **Discussion**
- **Proceedings**
  - **printed (NASA CP)**
  - **electronic (on the web)?**

Figure 22

Next-Generation Design and Simulation Tools

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Parametric Technology Corporation
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NEXT GENERATION DESIGN AND SIMULATION TOOLS

Tod A. Weber
Federal Region Director
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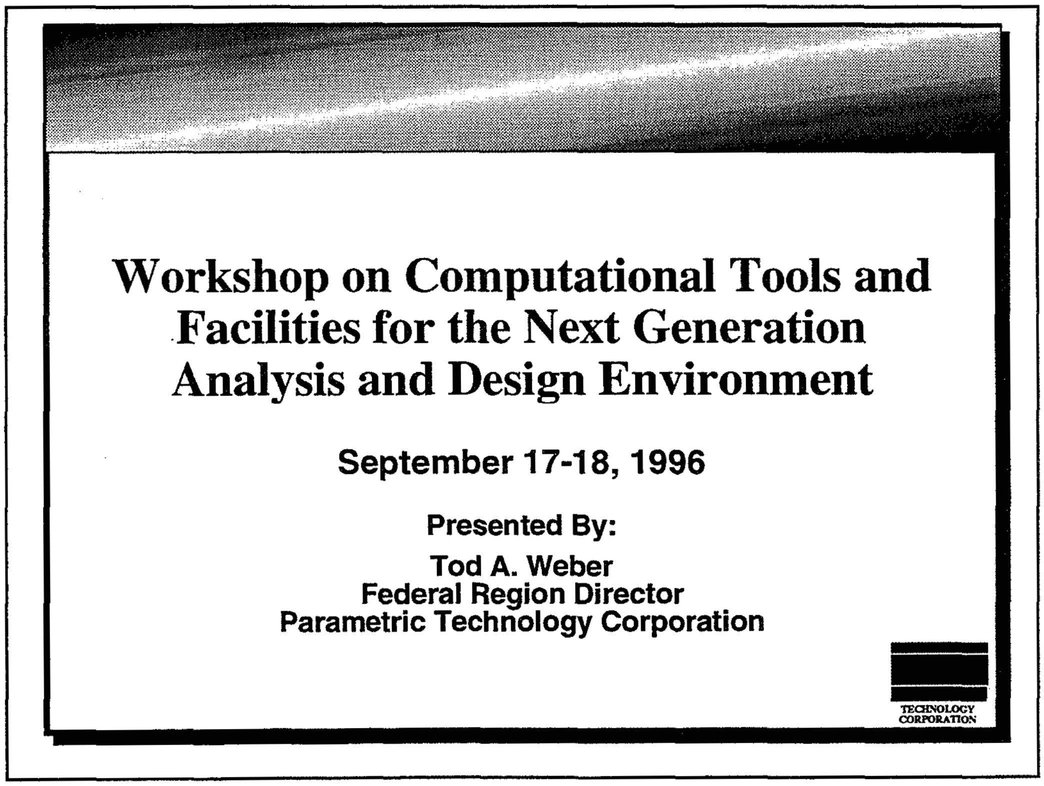


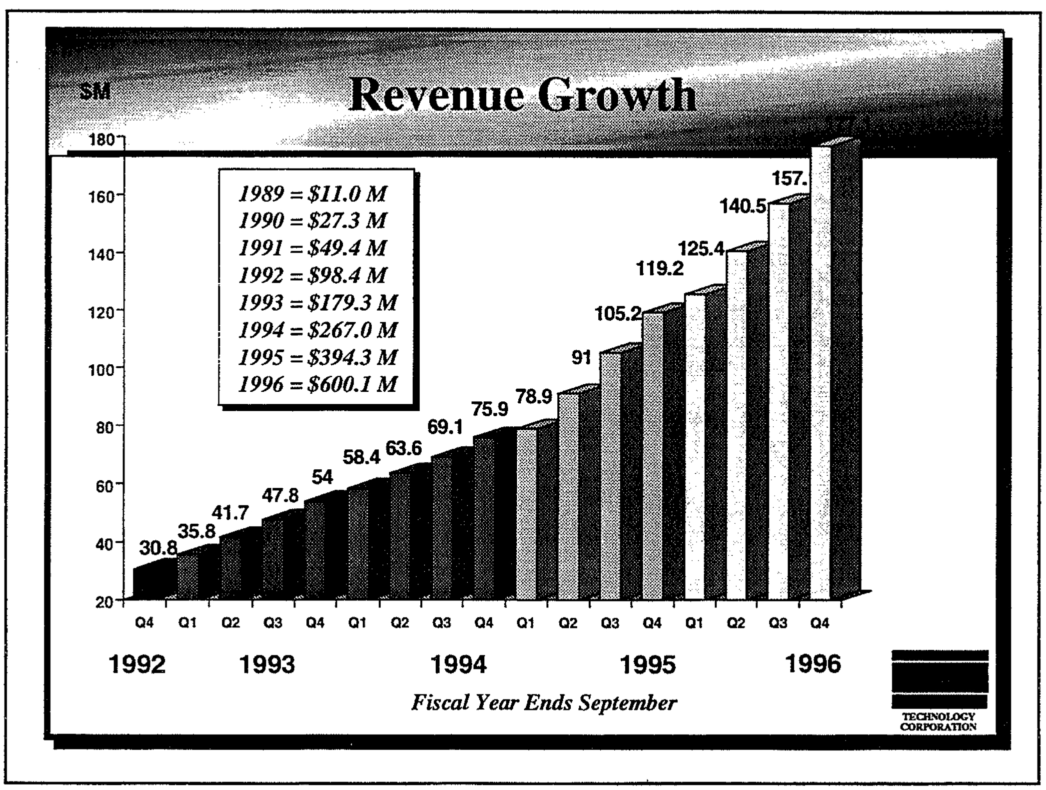
REVENUE SLIDE

Parametric Technolody Corporation is the developer of the Pro/Engineer software which has revolutionized the mechanical design automation industry.

- PTC exhibits the second highest growth rate in the history of the software industry (Microsoft is the highest).

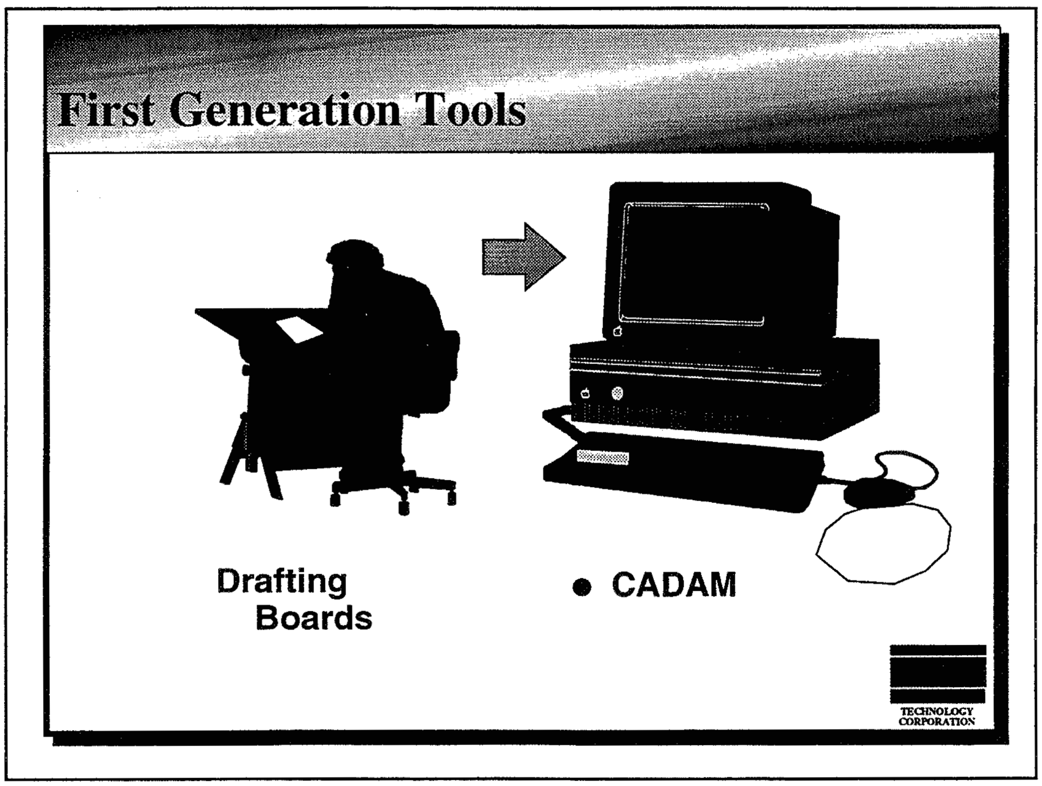
- PTC has the fourth highest performing stock on the NASDAQ stock market over the past five years.

- For PTC to step into a thirty-year old, well established industry and achieve such recognition in only eight short years indicates different and unique attributes of our software.



FIRST GENERATION TOOLS

Thirty years ago, the CAD industry was created as electronic drafting tools were developed to move people from the traditional two-dimensional drafting boards. While these tools provided an improvement in accuracy (true perpendicular lines, etc.), they did not offer a significant improvement in productivity or impact development times. They electronically captured a manual process.



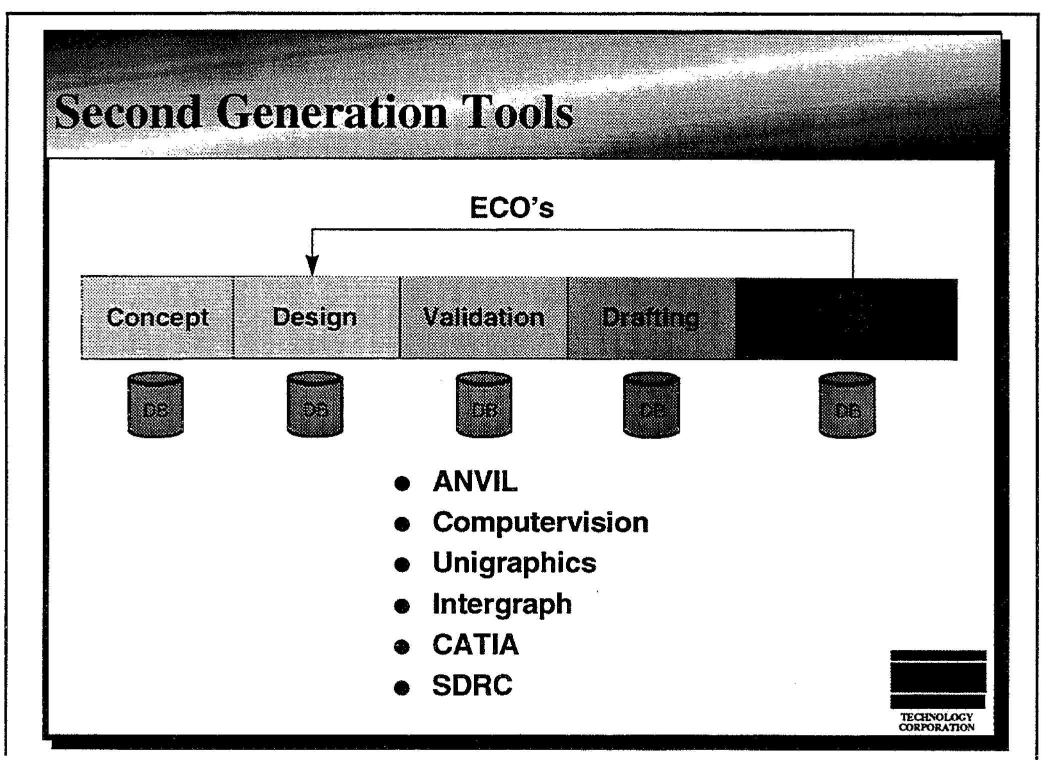
SECOND GENERATION TOOLS

The second generation evolved as the industry developed specific task-oriented codes (software) to address discrete pieces of the design process, which means that there were additional tools developed to do two-dimensional drafting, separate tools developed to do manufacturing, other tools focused on analysis, while others focused on three-dimensional modeling. These tools were "glued" together creating massive bundles of layer- upon-layer of code. With a total lack of communication between the different pieces within the bundle, the design process was forced to be sequential as data was recreated with each new stage of the design process. You cannot get a detailed drawing started if upstream changes to the model will obsolete all of your work. The same is true for analysis, manufacturing, etc.

Other Problems:

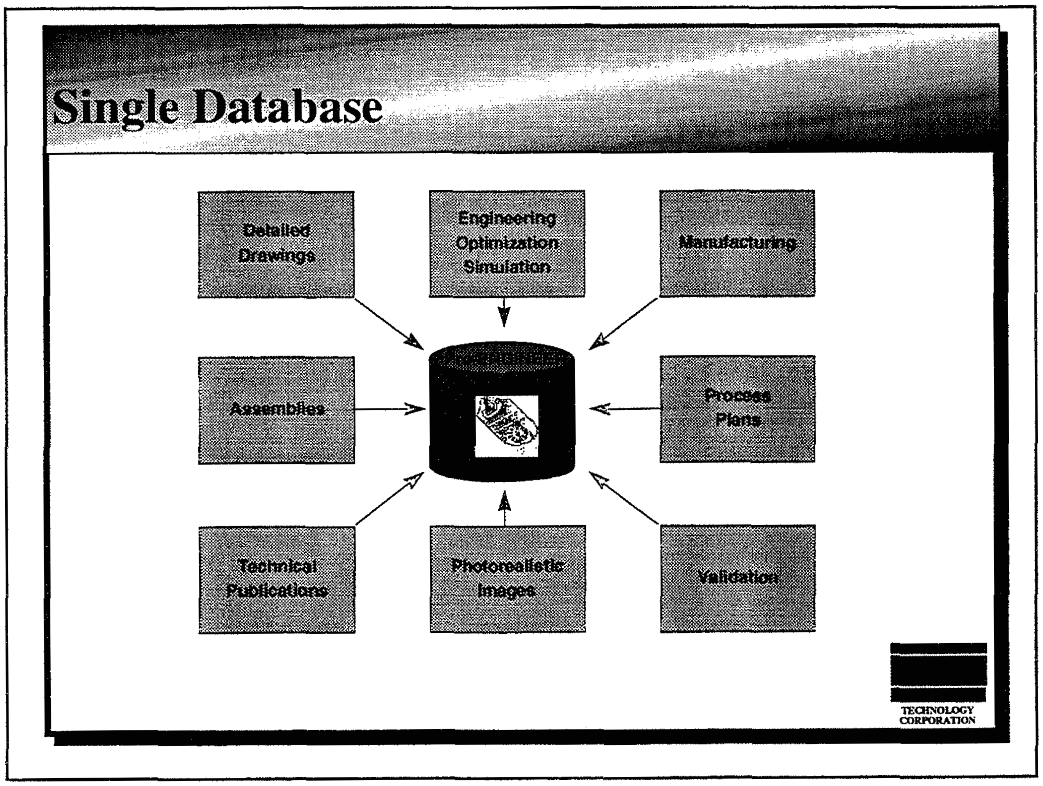
- The constant recreation of data results in design integrity problems as the final product is not necessarily identical to the original version.
- Unintelligent data (wireframe, surface, solid) make modifications very costly.
- Problems discovered when the parts are finally produced (interferences, structural failures, etc.) result in an ECO (engineering change order) which takes you all the way back and drops you into the initial design phase to rerun the entire sequential process.

This is the failed architecture of traditional systems which have produced the all-too- familiar cost/schedule overruns of organizations worldwide. All of the major tools in our industry have evolved from this same core engine. This includes EDS, UG, SDRC, Intergraph, CV, etc.



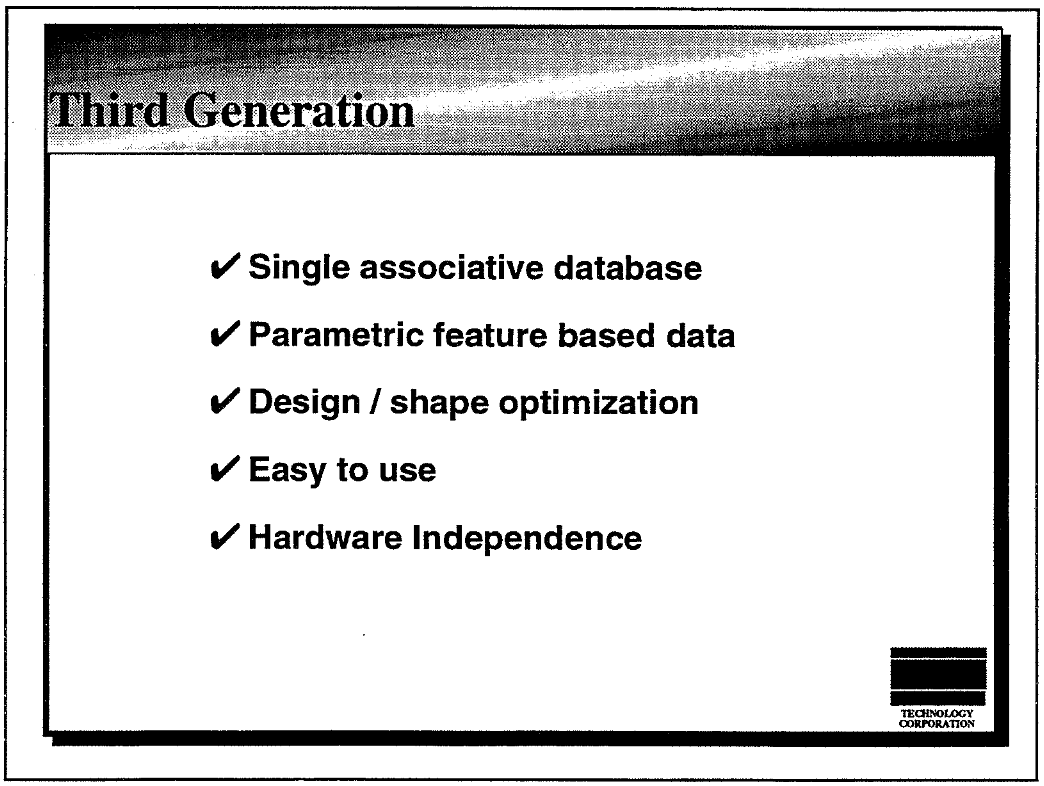
SINGLE DATABASE

PTC developed a unique architecture which would create a highly intelligent model at the core - from which all deliverables would be created. All drawings, assemblies, manufacturing toolpaths, process plans, exploded views, etc., would simply point back to the single location for the model geometry and obtain the necessary information to create that specific deliverable. The data would never be copied or translated. As a result of this unique architecture, changes made in any deliverable automatically propagate (with the appropriate approvals) and update throughout every other deliverable which has been created. In addition, engineers/designers work concurrently on their tasks focusing exclusively on their input rather than the recreation of work that has already been performed.



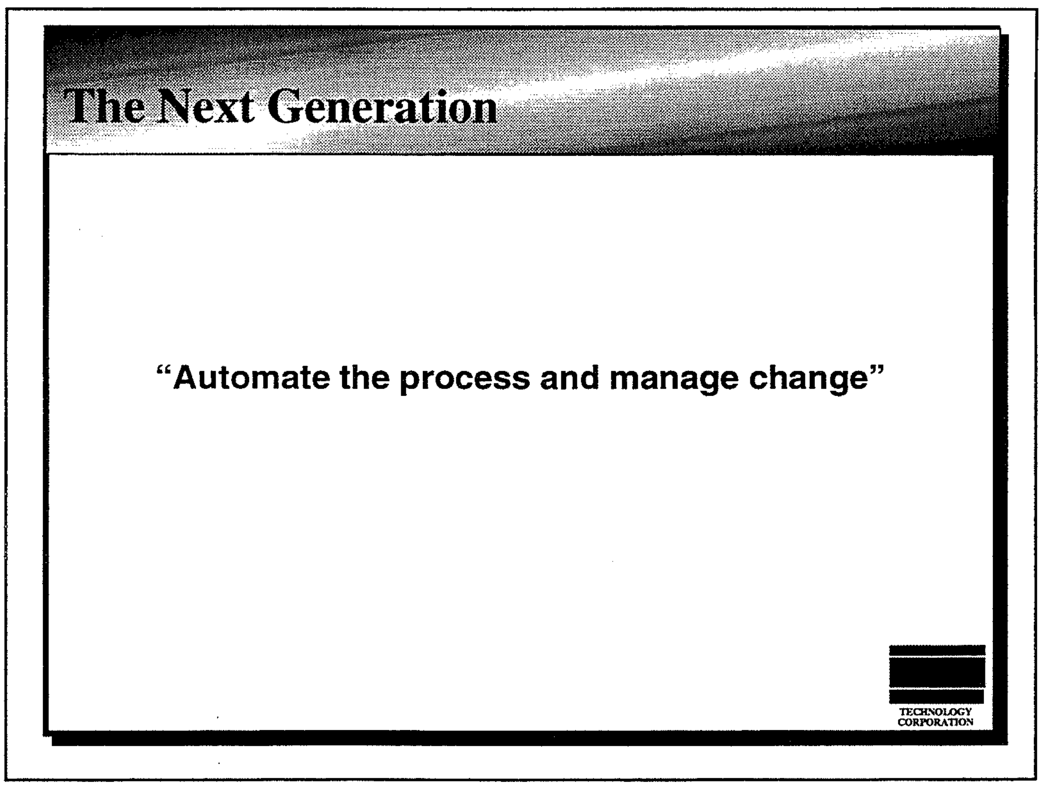
THIRD GENERATION

PTC then created a unique way in which the core model could be created as a solid object through the use of highly intelligent feature-based construction techniques. Solid geometry is not something new - it has been around our industry for about twenty-five years. The way solid geometry has been created in the past, however, has been through the use of Boolean operations which some of you may be familiar with. Pro/E uses intelligent features such as rounds, chamfers, slots, etc., to intuitively build solid geometry. Most important, however, is that these features understand what they represent and how to co-exist with their surroundings.



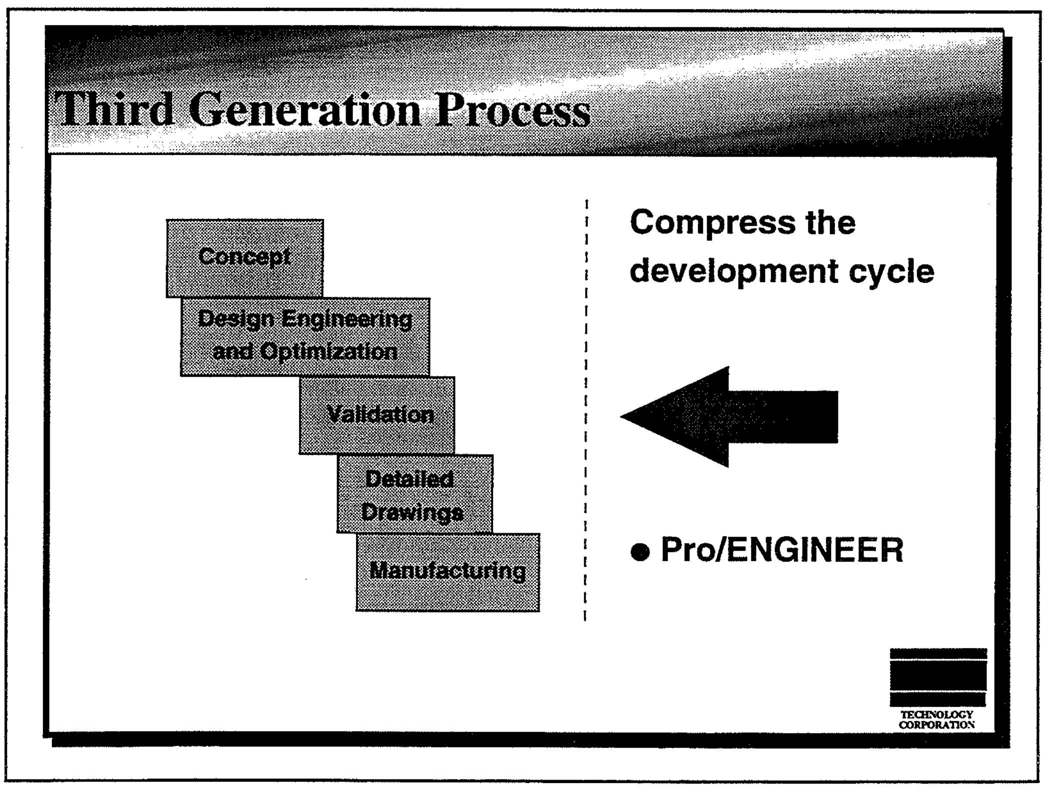
THE THIRD GENERATION

PTC realized that it had to start with a clean sheet of paper to develop a tool which could automate the entire development process (not a task in the process) and manage the change which is a natural part of the process.



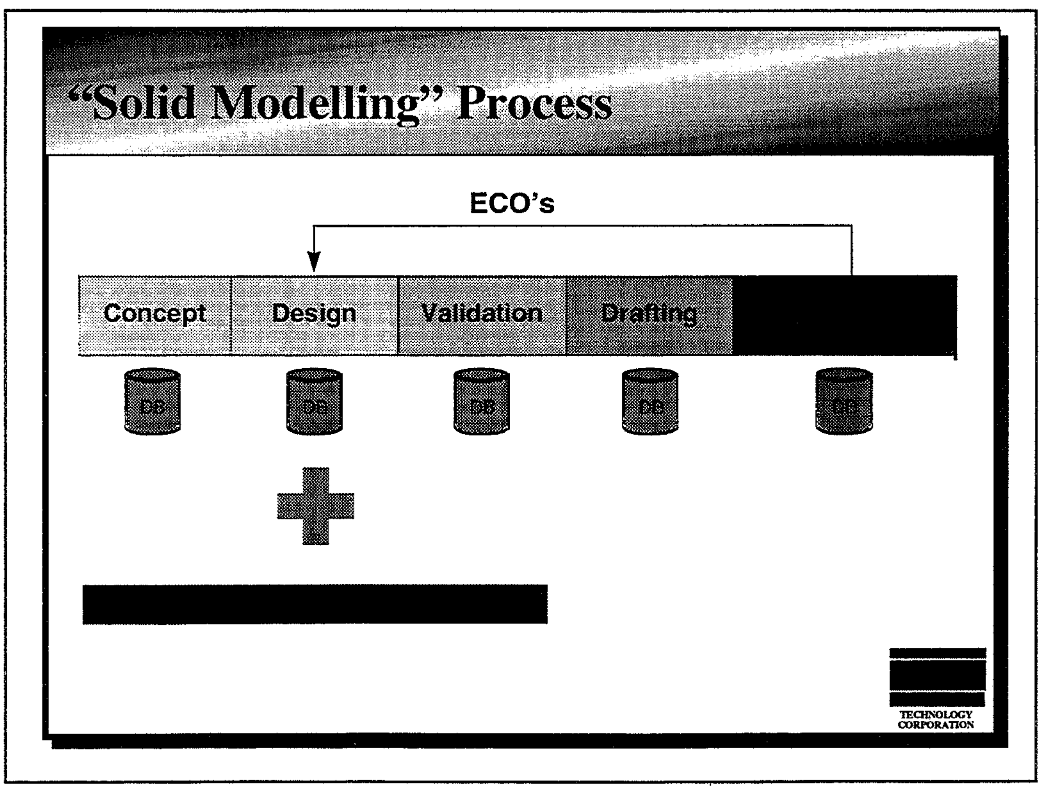
THIRD GENERATION PROCESS

If you take this highly intelligent, modifiable model and drop it down onto this fully associative architecture, you have the ability to dramatically impact the development cycle. This is what companies such as Lockheed Martin, Caterpillar, Hughes and Texas Instruments do. We could not have walked into these organizations with a 5 or 10% improvement over their traditional tools and convinced them to invest millions in our software - we had to show them it was a generation leap in technology that offered a dramatic impact on their operations.



WHAT ARE OUR COMPETITORS DOING?

Because of PTC's dramatic impact on the industry, every company that might be represented here today would probably tell you they have everything that PTC has including parametric feature-based modeling with some form of associativity. The fact is that they have added yet another layer to their mass of code that may have some limited ability to create some basic features. This layer is purchased at the "CAD" grocery store and comes in the form of a parasolids kernel, acis kernel, or some other front end. The bottom line is that all of the other companies in our industry have refused to abandon their thirty year old installed base to re-write their code from scratch. You can see this in many ways - from the size of their codes which take 5 to 15 times the disk space of Pro/ENGINEER to PTC's market value - $6.0 billion. Wall street knows that what I am telling you is real or that market value would not be anywhere near that level.



THIRD GENERATION USERS

All of these organizations have invested in excess of $1 million in Pro/ENGINEER software.

Third Generation Users

Lockheed Martin	Department of Energy	ITT Cannon
McDonnell Douglas	NASA	Midmark
Chrysler Aerospace	U.S. Navy	Knorr-Bremse
United Defense	U.S. Army	Eaton Corporation
Loral Vought Systems	U.S. Air Force	Shin Nihon Koki
Hughes Aircraft Co.	Carrier Corporation	Hitachi, Ltd.
Ford Motor Corporation	Kohler Company	Toshiba
Caterpillar Inc.	Paccar Inc.	Matsushita
Deere & Company	Siemens AG	Sanyo Corporation
Cummins Engine Co.	Whirlpool Corporation	American Standard Europe
Texas Instruments	Sharp Corporation	Seiko Epson
Polaroid Corporation	Mannesman AG	Mollins Tobacco
Cincinnati Milacron	Steelcase Inc.	MagneTek
Volkswagen	AMP	Schulmberger
Hewlett Packard	Allied Signal	Pirelli
J. I. Case Company		

TECHNOLOGY CORPORATION

NASA INSTALLATIONS

Pro/ENGINEER has become the clear choice throughout NASA.

NASA Installations

Facility	Seat Count
Langley Research Center	48
Johnson Space Center	82
Goddard Space Flight Center	54
Marshall Space Flight Center	28
Ames Research Center	47
Dryden Flight Research	7
Jet Propulsion Lab	41
Stennis Space Center	1
Kennedy Space Center	6
Lewis Research Center	2
	316

TECHNOLOGY CORPORATION

SNAP: SIMULATING NEW ACQUISITION PROCESSES

Louis E. Alfeld
Decision Dynamics, Inc.
Silver Spring, MD

SNAP

SIMULATING NEW ACQUISITION PROCESSES

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INTRODUCTION

Simulation models of acquisition processes range in scope from isolated applications to the "Big Picture" captured by SNAP technology. SNAP integrates a family of models to portray the full scope of acquisition planning and management activities, including budgeting, scheduling, testing and risk analysis. SNAP replicates the dynamic management processes that underlie design, production and life-cycle support. SNAP provides the unique "Big Picture" capability needed to simulate the entire acquisition process and explore the "what-if?" tradeoffs and consequences of alternative policies and decisions. Comparison of cost, schedule and performance tradeoffs help managers choose the lowest-risk, highest payoff at each step in the acquisition process.

MODEL OVERVIEWS

Design Engineering - Capturing the integrated product and process development (IPPD) activities reveals the interdependencies among design teams and shows how design success depends upon the quality and availability of shared information among all teams.

Production - Simulating the planned sequence of purchase, fabrication, assembly and testing actions necessary to produce a final product provides a baseline for exploring the schedule and cost impacts of alternative designs, process technologies and management decisions.

Operation and Maintenance - Maintenance actions and technology upgrades aim to slow the inevitable aging and obsolescence during the operational lifetime of products and components. Simulation shows how logistical resources respond to variable maintenance needs and alternative planning and mission scenarios.

Industrial Base - Supplier chains replicate the production delays and inventory oscillations that result from changes in product order rates. Long lead times can create bottlenecks in key suppliers, particularly under rapid buildups or accelerated production programs.

Personnel - Overtime, the mix of an organization's personnel skills, and experience change. Individuals join an organization, advance, gain experience and retire. Turnover is constant; organizational budgets and productivity vary in response to changing requirements and changing manpower.

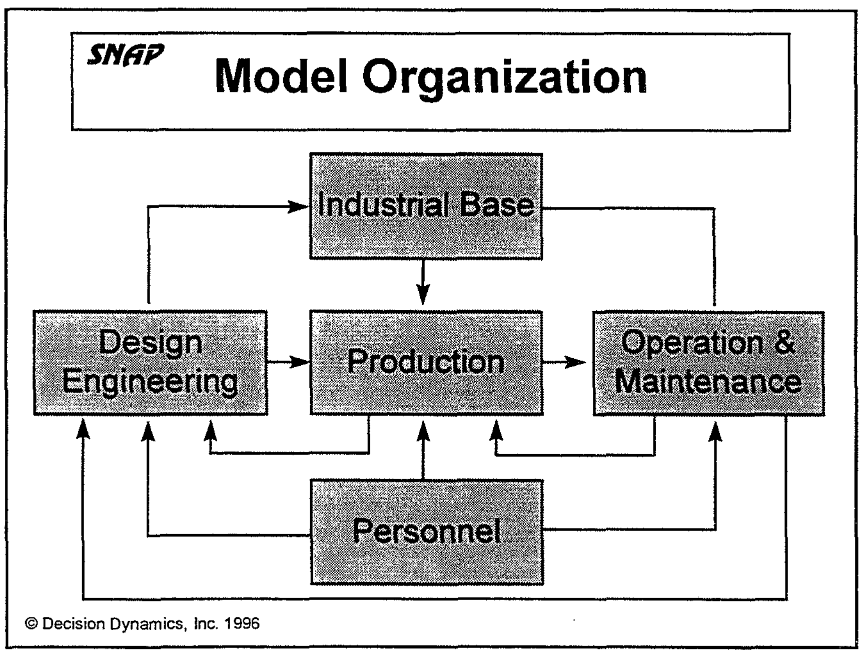

Figure 1.

Printed with permission, Louis Alfeld, Decision Dynamics, Inc.

MODEL STRUCTURE

The SNAP model consists of two independent submodels, one for production tasks and one for the resources required to perform the tasks. SNAP views each of the tasks as an "independent agent" whose purpose is to get its work backlog completed. To accomplish the work, each task broadcasts a request for the resources it needs along with its priority. Management "rules" govern priorities for facility resource allocation so that whenever a task satisfies the rules, resources are assigned and work commences.

Thus, SNAP will automatically transform a list of task backlogs and a list of facility resources into a schedule and manning forecast. Final results include:

- schedules for all tasks
- overall production schedule
- labor manning, labor hour for all tasks, and
- total labor hours for the finished product.

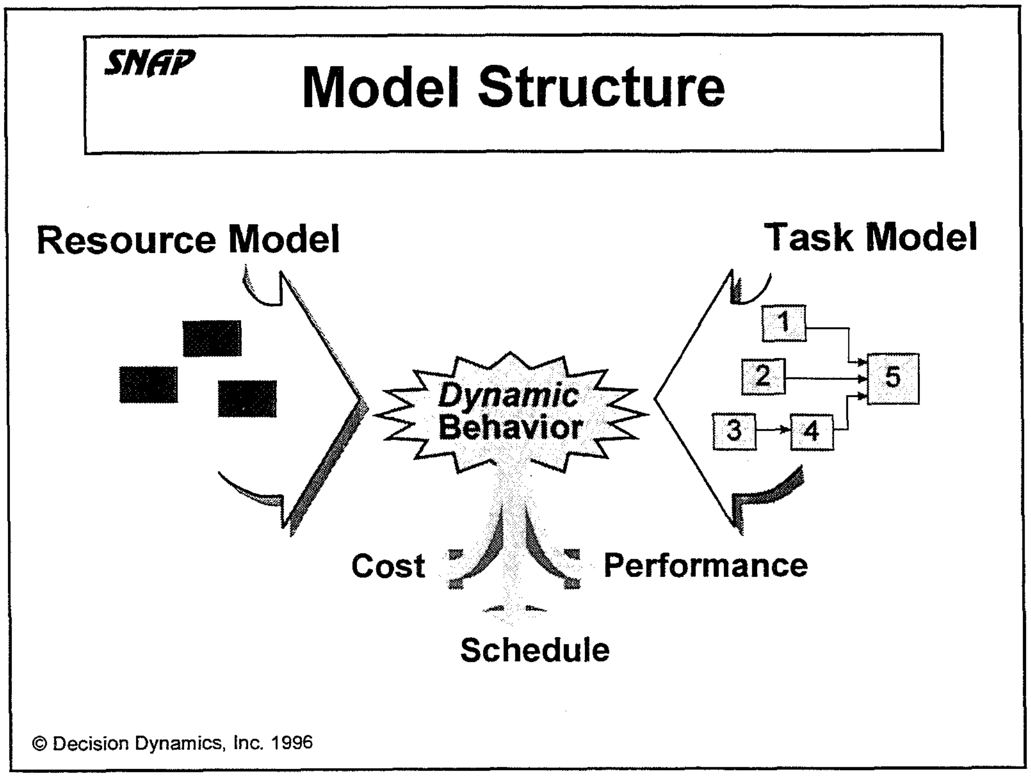

Figure 2.

DATABASE FLEXIBILITY

SNAP organizes its product database around common definitions by following a standard work breakdown structure that can make direct use of existing data elements with a minimum of reconfiguration. The diagram shows that the design, production, and maintenance and operation model, share the same product and component definitions while still allowing flexible aggregation of components as either systems or assemblies. At the lowest level, each model invokes its own unique task "simulation engine" to perform the work, whether design, fabrication or maintenance.

SNAP is designed to link to other databases, both for automatic data exchange to models and for quick cross reference to existing plans and specifications. Direct links to manufacturing data are also planned.

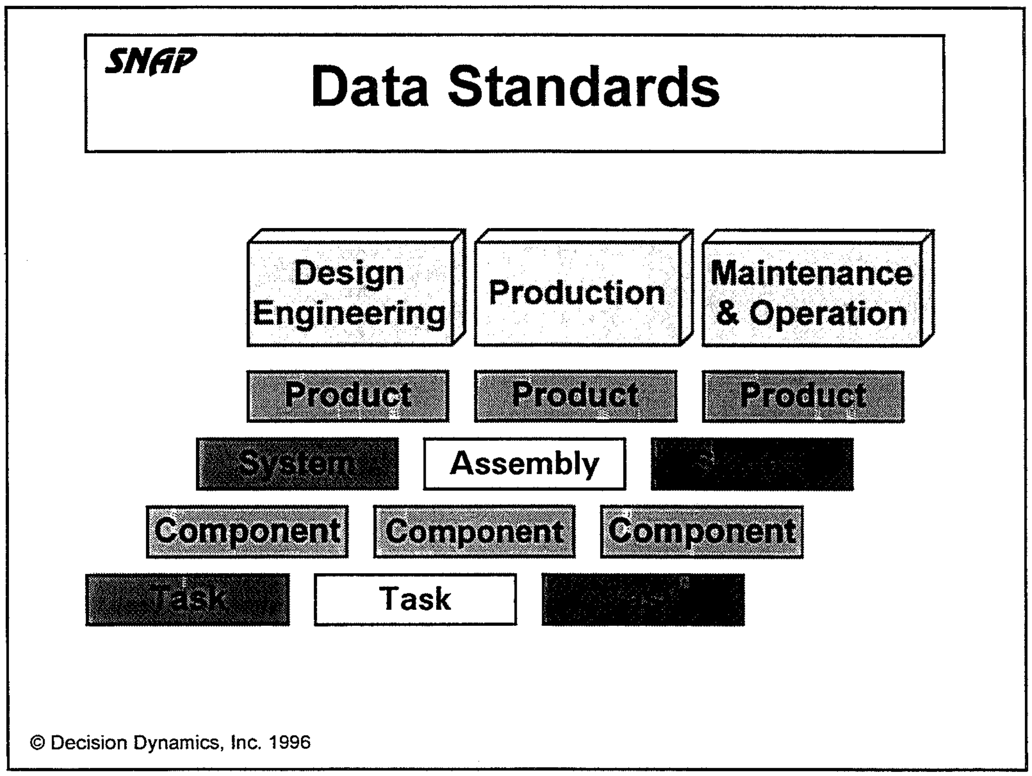

Figure 3.

DATA HIERARCHY

SNAP follows a work breakdown structure and simulates the production process at the detailed task level. The tasks come together to create interim products, or subassemblies. Subassemblies, in turn, combine to create assemblies and finally a completed product. The elements in this hierarchy are further defined by sequence dependencies in which the fabrication, assembly or testing of any element may depend upon the prior completion (or partial completion) of one or more other elements.

At the lowest level, each task is defined by only four variables:

- work backlog
- labor resources needed to accomplish the work
- equipment needed to accomplish the work, and
- dependencies upon other tasks.

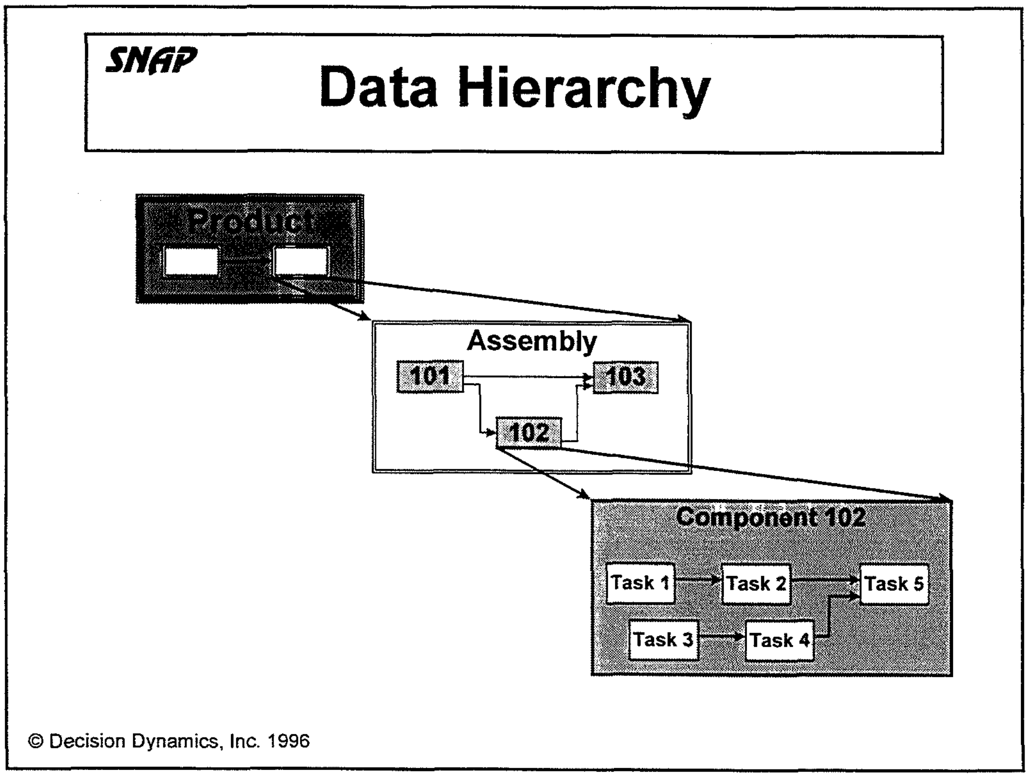

Figure 4.

BASIC TASK MODEL

In the SNAP model, task schedules are not inputs, but outputs. Task work loads are defined as work backlogs (manhours or units) of work to be done. Model operation then applies a variable resource availability (labor) and a variable resource productivity to compute a variable rate of work accomplishment (work rate). (For example, overmanning a task can speed completion but at a cost of extra manhours due to lowered productivity.) SNAP quantifies the cost and schedule tradeoffs for alternative resource capacities. This allows planners to determine the best mix of resources to meet the most realistic schedule.

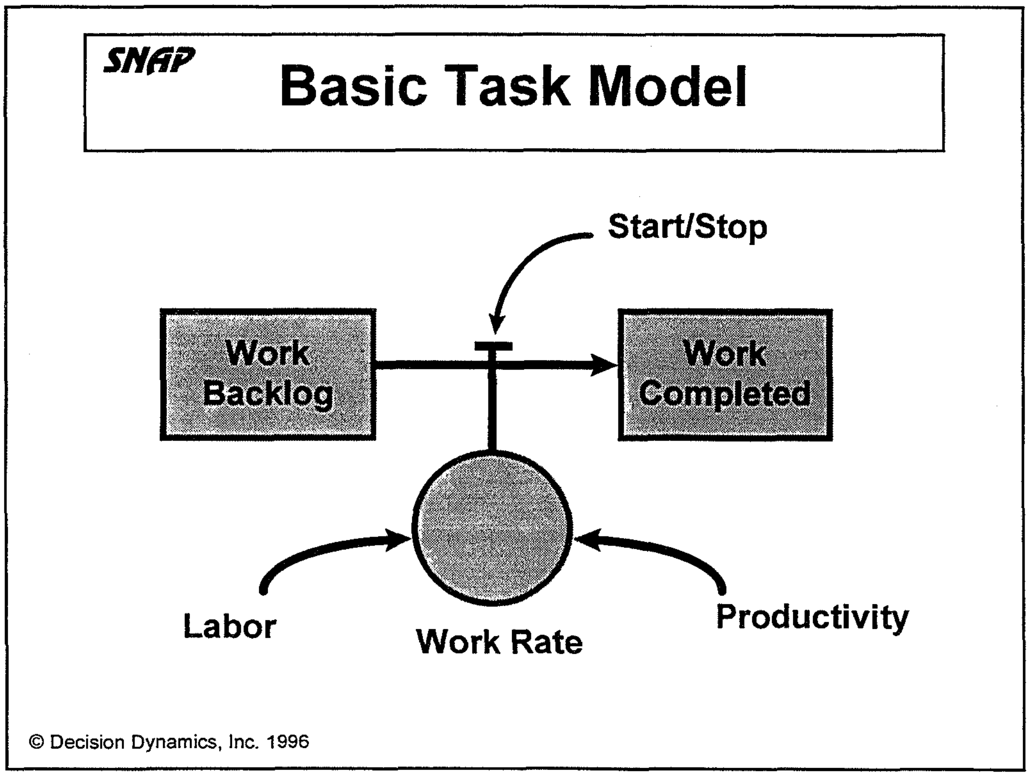

Figure 5.

FEEDBACK DRIVES BEHAVIOR

Nonlinear feedback interactions govern every acquisition process of interest. Such processes are too complex for intuitive analysis. They require simulation. The diagram traces the primary feedback loops present during a program design stage. One need only imagine a change at any point in the diagram and then trace the impact of that change as it propagates through the system. No matter where you start, the ripples eventually touch every variable in the system and ultimately impact the final program cost and schedule. Programs are far too costly and schedules far too fragile to be unwittingly altered by actions and events that make sense at one point in the system but create problems elsewhere. The power of dynamic feedback simulation promises to cut costs and shorten schedules while, at the same time, reducing risk and boosting management performance.

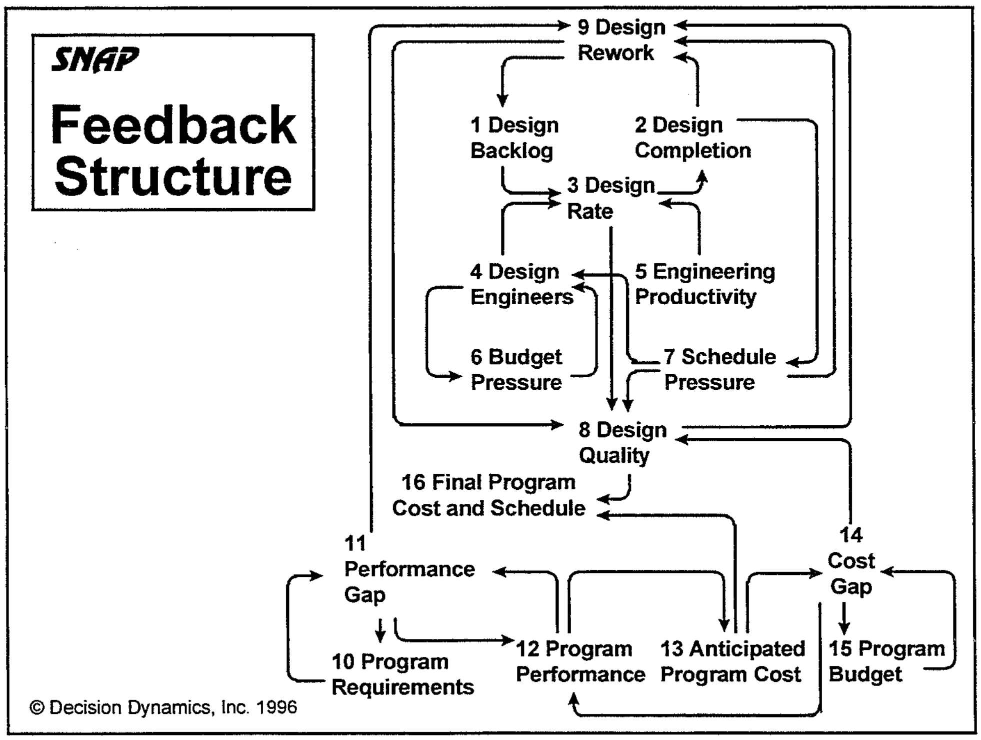

Figure 6.

DATA REQUIREMENTS

The Resources submodel is populated with information concerning facilities and labor while the Product/Task submodel is concerned with data associated with the components and tasks. However, SNAP does not require refined, detailed data in order to produce valid simulation results. Because the system dynamics modeling methodology begins with statements about the structural relationships that define the system and that are capable of producing the observed behavior, the statements are not dependent upon data availability. Instead, they incorporate all of the important system variables, whether or not the variables have ever been measured. In the vast majority of cases, the values needed to define the variables are readily found in the data, in anecdotal evidence or in logical inferences. In the few cases where critical data values are missing, the model permits one to establish a range of reasonable values and to test the sensitivity of model behavior over the range in a search for the correct value.

SNAP

Data Requirements

Resources

- **Facilities**
  - Equipment
  - Space
  - Management
- **Labor**
  - Skills
  - Cost
  - Productivity

Product/Task

- **Components**
  - WBS Hierarchy
  - Dependencies
- **Tasks**
  - Backlog
  - Resource Needs
  - Precedence

Figure 7.

LIFE CYCLE AGING

The Operation and Maintenance model simulates the cost and performance over time for products and components. As the products age over time and as maintenance and upgrade efforts attempt to stem this aging process, cost will rise. The model forecasts these costs against changing performance to provide managers with the information they need to make intelligent choices concerning the cost, timing and expected outcomes of alternative scenarios.

In the diagram, P1, P2 and P3 represent products in three different stages of their life cycle. P1 products are relatively new or top performing and P2 and P3 products are active and available in successive stages of aging and obsolescence. Over time, aging will push products from the P1 performance category to the P3 category. The arrows at the top and bottom of the diagram indicate how maintenance and upgrades maintain or increase the performance and extend the useful life of the products.

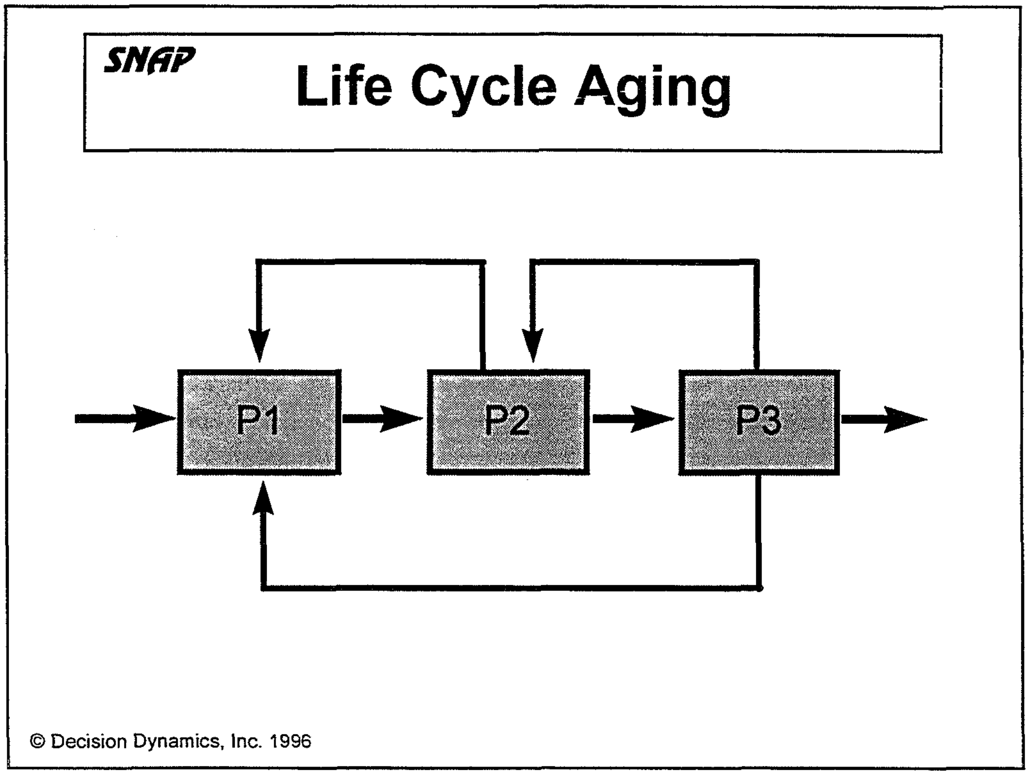

Figure 8.

LIFE CYCLE DYNAMICS

The dynamics of the life cycle are demonstrated by defining the tasks required to maintain and upgrade products and components in units or manhours. This maintenance requirement is then matched against personnel resources and backlogs available to calculate the time required to perform the maintenance task list. The work accomplished on the products or components directly impacts the system performance which feeds back to the task list and maintenance resources.

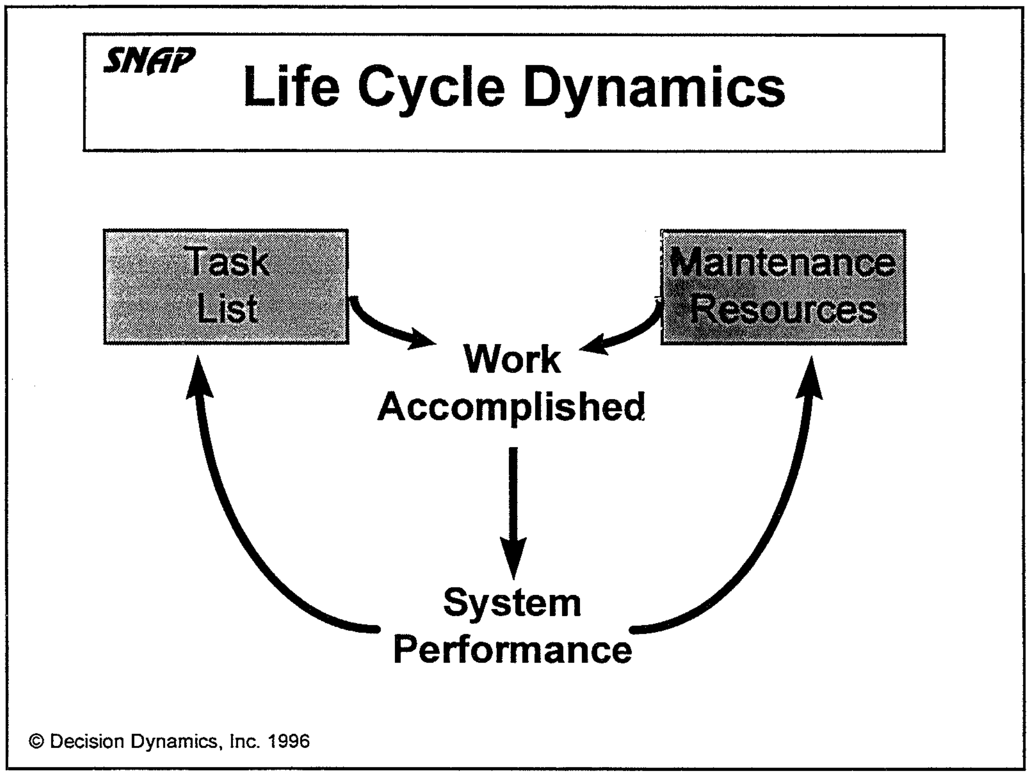

Figure 9.

INDUSTRIAL BASED ANALYSIS MODEL (IBAM) FEEDBACK STRUCTURE

IBAM simulates changes in enterprise capacity and capabilities, identifies critical industries, quantifies essential capabilities and helps to prioritize intervention options. The model represents production-supplier relationships as production chains. IBAM production chain simulations then capture the essential time-varying dynamic nature of the production process.

The system dynamics methodology incorporates explicit feedback linkages to capture the cause-and-effect structure of the production process. Just like the real world, feedback acts to match shipments to orders by altering production capacity. The model uses incoming orders, averages past demands and current backlog to calculate a desired production rate.

Results from IBAM simulation can assist industrial planners in spotting potential bottlenecks and in devising policy responses that will eliminate them.

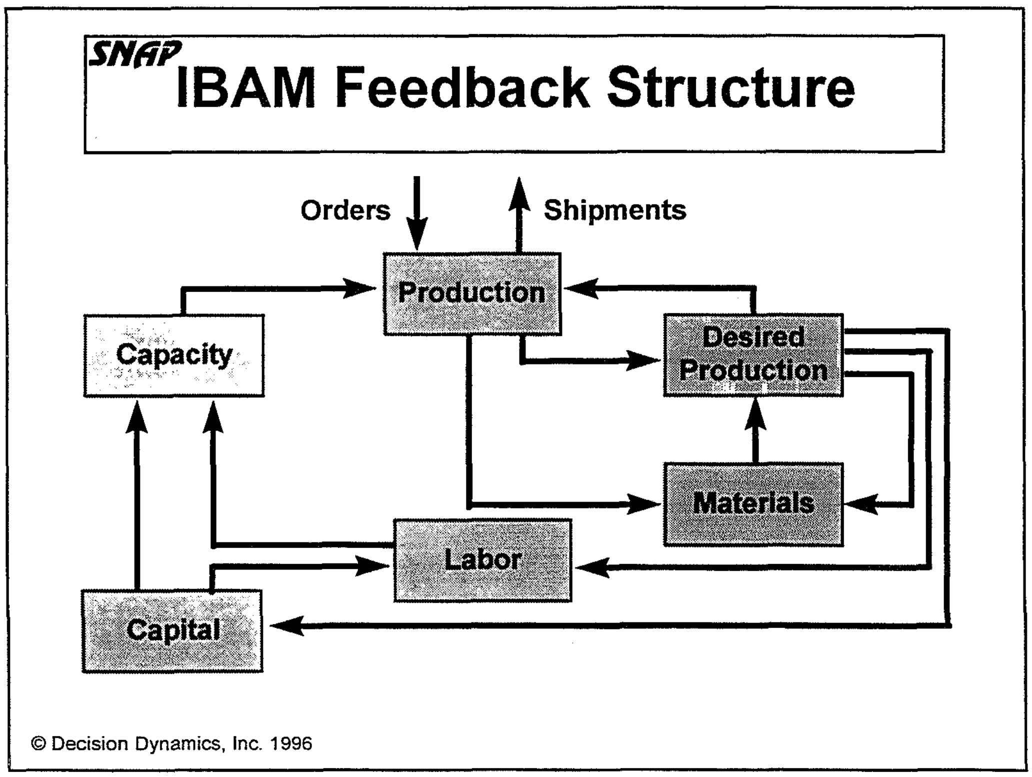

Figure 10.

IBAM PRODUCTION CHAIN - TREE STRUCTURE

IBAM represents production-supplier relationships as production chains. Orders flow down through the system from higher-tier suppliers to lower-tier suppliers. In return, products and subassemblies flow up.

Each element in the chain is an entire simulation model of a manufacturing enterprise. By setting the appropriate parameter values, any of the elements may represent production on any scale, whether a single commodity, a product line, an enterprise, a group of enterprises, or even an entire industrial sector.

A model user can select a pre-defined production chain from a database or build a new chain in order to simulate the effects of alternative policies or programs on the capacity and capabilities of each element of the industrial base. The model can also simulate the consequences of alternative technologies, either as process improvements or changes to product lines.

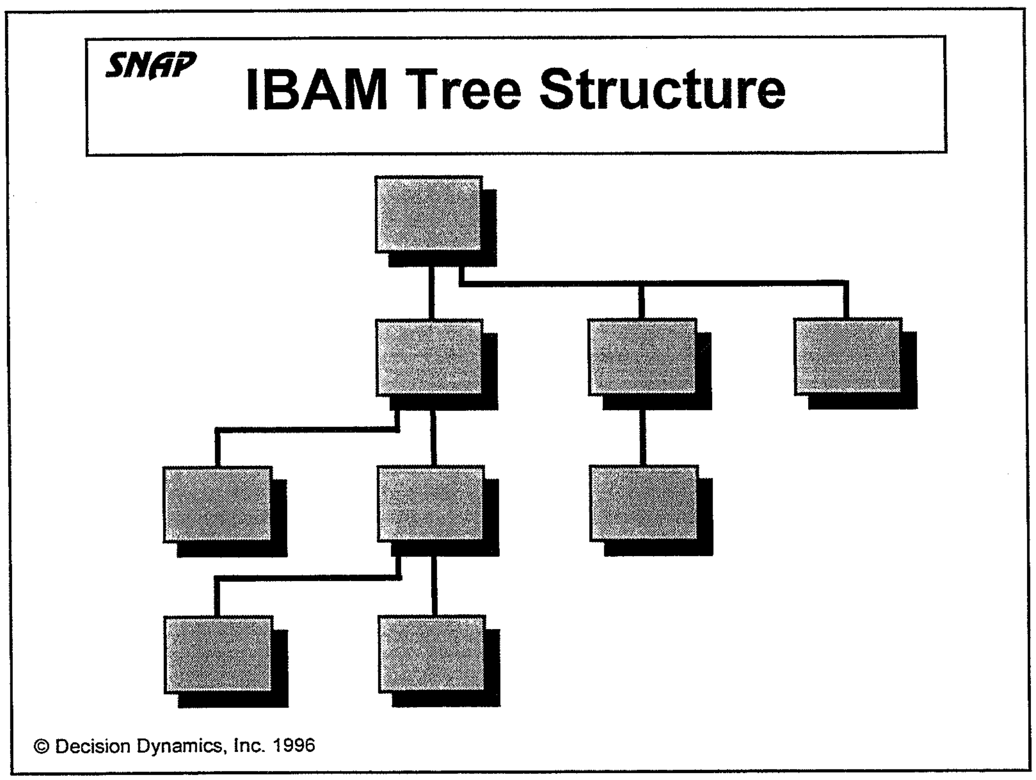

Figure 11.

WHAT MAKES SNAP DIFFERENT

SNAP models treat cost, schedule and performance as interdependent variables. Model users creat "what-if?" scenarios to simulate the impact of alternative task configurations, different resource capacities and/or possible mission options. Comparison of cost, schedule and performance tradeoffs help managers choose the lowest-risk, highest payoff at each step in the acquisition process.

SNAP model users can define schedule as <u>either</u> a dependent or an independent variable. Productivity and rates of work accomplishment are dynamic variables that can change during the course of a simulation. The rich feedback structure enables simulation to quantify the impact of changes and delays. In addition, a built-in suite of analytical tools helps users identify the best decision options.

SNAP models capture the underlying cause-and-effect feedback relationships that drive system behavior. During simulation, user-defined management policies match task backlogs against available resources to mimic real-world system behavior. Combining product, process and management decision making into an integrated modeling environment provides a powerful analytical tool capable of realistic forecasts of system behavior.

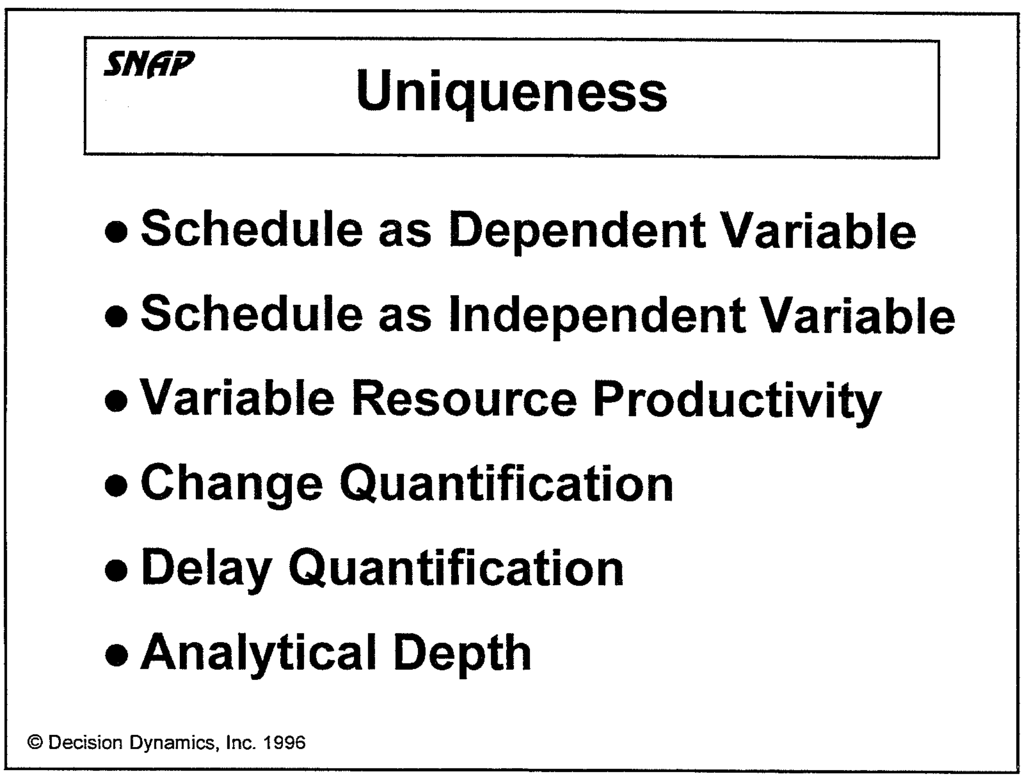

Figure 12.

Managing Technical and Cost Uncertainties During Product Development in a Simulation-Based Design Environment

Harsh M. Karandikar
Science Applications International Corporation
McLean, VA

MANAGING TECHNICAL AND COST UNCERTAINTIES DURING PRODUCT DEVELOPMENT IN A SIMULATION-BASED DESIGN ENVIRONMENT

H. M. Karandikar
Science Applications International Corporation
McLean, Virginia

An approach for objective and quantitative technical and cost risk analysis during product development, which is applicable from the earliest stages, is discussed. The approach is supported by a software tool called the Analytical System for Uncertainty and Risk Estimation (ASURE). Details of ASURE, the underlying concepts and its application history, are provided.

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McLean, Virginia U.S.A.

Workshop on Computational Tools and Facilities for the Next Generation Analysis and Design Environment
September 17-18, 1996

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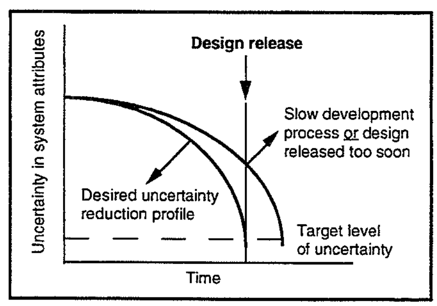
FOCUS OF OUR WORK

It is postulated that the key underlying goal of a product development process is to reduce the uncertainty associated with product and process attributes. Problems frequently arise in development because the developers have not sufficiently reduced the range of variability in system attributes such as cost, quality and performance, by the time the design is released to production or is deployed (see figure).

SAIC has been working on developing methods and software tools that can be used throughout the development process to monitor the maturity of a design. This maturity is gauged by the degree of uncertainty (or variability) associated with the product and process attributes.

Focus of Our Work

Application of computer simulation in system development to identify areas of technical, cost, and schedule risk.



A system can be a product, process or strategy.

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SIMULATION BASED DESIGN (SBD)

We refer to the next generation of computer-based design systems as Simulation Based Design (SBD) systems or Synthetic Design Environments (SDE). Using these systems, our goal is to revolutionize the entire process by which complex products are conceived, designed, fabricated, tested, deployed, operated, maintained, refurbished and eventually decommissioned.

In an SBD system, the emphasis is on simulations as a unifying method of representing and analyzing products throughout their life cycle. As used here, "simulation" has a broad connotation and encompasses modeling/ analysis for various purposes and at various levels of fidelity. SBD will use and combine virtual, constructive, engineering and physics-based simulations within a single framework to create different views of the product and its behavior throughout its life.

The term SDE highlights another fundamental aspect of the system - the creation of virtual design environments within which diverse representations and models of the product are created, viewed, analyzed and operated. SDE is the design space for building and conducting product simulations. These simulations may include approximate parametric models for rapid design tradeoffs and requirements development; complex, detailed performance prediction models; virtual models for real-time war gaming; manufacturing process models; and virtual reality representations in which customers and designers can examine the product prior to its actual physical creation.

Simulation Based Design (SBD)

We refer to the next generation of computer-based design systems as Simulation Based Design (SBD) Systems or, alternately, as Synthetic Design Environments (SDE).

Why Simulation?

- **... the emphasis on simulations as a unifying method of representing and analyzing products throughout their life cycle.**

Why Synthetic?

- **... the creation of artificial or virtual design environments within which diverse representations and models of the product are created, viewed, analyzed and operated.**

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KEY SBD/SDE FEATURES

Although the constituent capabilities of SDEs are still evolving, several critical features of such systems have emerged. The following chart lists five features. This presentation is concerned with two in particular:

- Smart Product Model (SPM) - In SBD, a model of a product will be constructed at the instance of its conception. This model will be expanded and refined throughout the product's life to capture and evaluate the evolving design. We call the model an SPM. It includes a physical description of the product as well as the data and models necessary to fully characterize and evaluate it. The model is also "smart" as it knows where, among a myriad of voluminous and distributed databases, to find the data it needs to perform and display the results of any analysis. The SPM is "smart" in a third sense; it is structured as a collection of objects, each of which has its own set of associated attributes and behaviors.
- Cost and Risk Modeling - The ability to reliably predict cost and accurately evaluate the risk associated with proposed alternatives in design and manufacture is essential to product development. A tool to do this, the subject matter of this presentation, provides enterprise decision makers with dynamic, quantitative measures of critical product parameters and the relative uncertainty with which they are known. These metrics are dynamic in that they are automatically updated as the design evolves. Values change as a function of specific design changes and the knowledge accumulated throughout the design cycle.

Key SBD/SDE Features

- **Smart Product Model (SPM)**
- **Virtual Design Environment (VDE)**
- **Cost and Risk Modeling**
- **Collaborative Environment**
- **Code Wrapping and Megaprogramming**

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VIRTUAL PROTOTYPE (VP)

To qualify as a true Virtual Prototype (VP), a model must have five characteristics:

1) Geometry - must correctly and accurately model the geometry of the product and its environment.
2) Appearance - must appear relatively realistic to the human observer.
3) Response - must respond and/or move in real time.
4) Function - must represent some function or process of the product.
5) Behavior - must obey the proper laws of physics relevant to the function being simulated.

It is neither necessary nor practical for a single VP to completely capture every aspect of a complex product. For example, the exterior shape of an aircraft may be sufficient to study its aerodynamic performance, whereas the internal geometry and various hydraulic and electrical system aspects are needed to study the layout and functioning of the control systems. In a comprehensive SDE for aircraft design, both of these VPs, together with many more, would be available for "viewing" the vehicle; all data and models needed to create the VPs would be accessible through the SPM.

Virtual Prototype (VP)

A computer generated model of a product capable of functioning properly and appearing realistically in a responsive virtual environment, representative of the physical environment in which the actual product will or may function.

- **Geometry**
- **Appearance**
- **Response**
- **Function**
- **Behavior**

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REQUIREMENTS FOR A TECHNICAL AND COST RISK ESTIMATION TOOL

We can identify a number of requirements for a risk analysis tool that integrates a technical and cost risk analysis capability with an SBD system and the resulting design processes. We view these requirements in four categories listed in the chart.

The model underlying the tool must represent all the facets of a system such as the physical and functional descriptions. We must also model the uncertainties in the system description and the system attributes.

As part of the SBD system, it is imperative that the risk analysis tool be integrated with other information sources and that the integration allow for two-way data transfer. The translation from an object-oriented SPM to a simple analysis tool can, however, be a major hurdle. In addition, it is currently difficult for most databases to represent the uncertainties associated with product attributes.

Requirements for a Technical and Cost Risk Estimation Tool

- **Modeling Approach**
  - system modeling
  - modeling of uncertainty
- **Computational Capability**
- **Interfaces**
  - information import
  - data export
- **Scenario Management**

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THE ANALYTICAL SYSTEM FOR UNCERTAINTY AND RISK ESTIMATION (ASURE)

SAIC's ASURE (Analytical System for Uncertainty and Risk Estimation) is a software tool for technical and cost risk analysis. ASURE is best suited for system or subsystem level performance and cost analysis and trade studies. ASURE can be used to answer critical questions, such as those listed in the chart, in any technical decision scenario.

The current version of ASURE is layered upon the Wingz spreadsheet.[1] This yields a familiar interface, i.e., a spreadsheet, to a user and also buys multi-platform portability. ASURE can be executed on Macintosh, PC and Unix workstations.

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[1] Wingz was originally developed by Informix Software, Inc., a leading vendor of database products. It is now sold and supported by Investment Intelligence Systems Corporation (http://wingz.iisckc.com).

The Analytical System for Uncertainty and Risk Estimation (ASURE)

ASURE is used for answering questions such as:

- » **How mature is my design?**
- » **What technical and cost risks am I exposed to and how are they related?**
- » **What is the effect of different assumptions on my decision?**
- » **Which uncertainties are critical and which can be ignored?**
- » **Which alternatives (technologies or strategies) are superior?**
- » **How can I synthesize better alternatives?**

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ASURE APPLICATIONS

The concepts underlying ASURE are rooted in the study of design theory, probabilistic engineering design, design optimization, design of experiments, and quality function deployment.

The SAIC team laid the foundation for ASURE in 1988 and has been consistently building upon that foundation through a series of R&D programs. Some of these programs are listed below.

ASURE Applications

- **Producibility Study (Lockheed ASC, Marietta, GA) - Producibility analysis during concept formulation - F-22 side-of-body joint.**
- **Technical and Operational Assessment Analysis of Countermine Systems (BRDEC, Ft. Belvoir, VA).**
- **Simulation Based Design (DARPA MSTO) - Dynamic life cycle cost and risk analysis using the virtual prototyping methodology and integration with Smart Product Models (OODBs).**
- **Affordable Multi-Missile Manufacturing (DARPA) - Modeling and simulation of a product development enterprise (products, processes, and organization infrastructure) to verify cycle time reductions due to deployment of advanced information technologies and CAD/CAE tools.**
- **Joint Strike Fighter (JSF) Simulation And Validation Environment (SAVE) (Lockheed ASC/U.S. Air Force) - Evaluation of manufacturing technical risks for aircraft subassemblies during EMD phase.**

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KEY CAPABILITIES OF ASURE

The key capabilities of ASURE are summarized below. The most significant capability is that of structured and hierarchical system modeling. The details of this are provided in the following charts. Another important capability is that of fitting of distributions to uncertainty data for a system attribute. The minimal input data required for uncertain variables is the range of variation for their values. ASURE uses the Jaynes' principle of entropy maximization to determine the appropriate distribution. Often, this method provides the best as well as the most conservative measure of uncertainty if there is no physical basis for assigning distributions to design parameters.

Key Capabilities of ASURE

- **Capture and manage system descriptions**
- **Easy access to documented data and models**
- **Integration of multiple life-cycle perspectives**
- **Rational estimation of input uncertainties**
- **Uncertainty propagation**
- **System-based and time-based comparisons of decision criteria confidence profiles**

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ASURE INPUTS

The ASURE software embodies two concepts:

1) creation of a product or process life cycle model using Systematic Design principles.[2]
2) uncertainty modeling and analysis using the Virtual Prototyping (VP) methodology.

Using Systematic Design principles, a product or a process is modeled as a system with Form, Function, and Process Model hierarchies.

There are three main components in the VP methodology:

1) Construction of influence diagrams that trace the dependence of a decision criterion on system attributes with uncertainties.
2) Rational and conservative estimation of input uncertainties by probability distributions derived using the maximum entropy principle.
3) The propagation of the uncertainties across an influence diagram, resulting in the confidence profile on a decision criterion.

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[2] G. Pahl and W. Beitz, *Engineering Design: A Systematic Approach*, Springer-Verlag, 1996.

ASURE Inputs

- **System description: hierarchical and parametric**
  - Form decomposition.
    system -> components -> sub-components, etc.
  - Functional decomposition.
- **Simple yet high fidelity process and environment models**
  - A hierarchy of models - Models can be algebraic expressions, tables of values, stand alone codes, etc.
- **Reliable estimates of uncertainties and variabilities in the input parameters**

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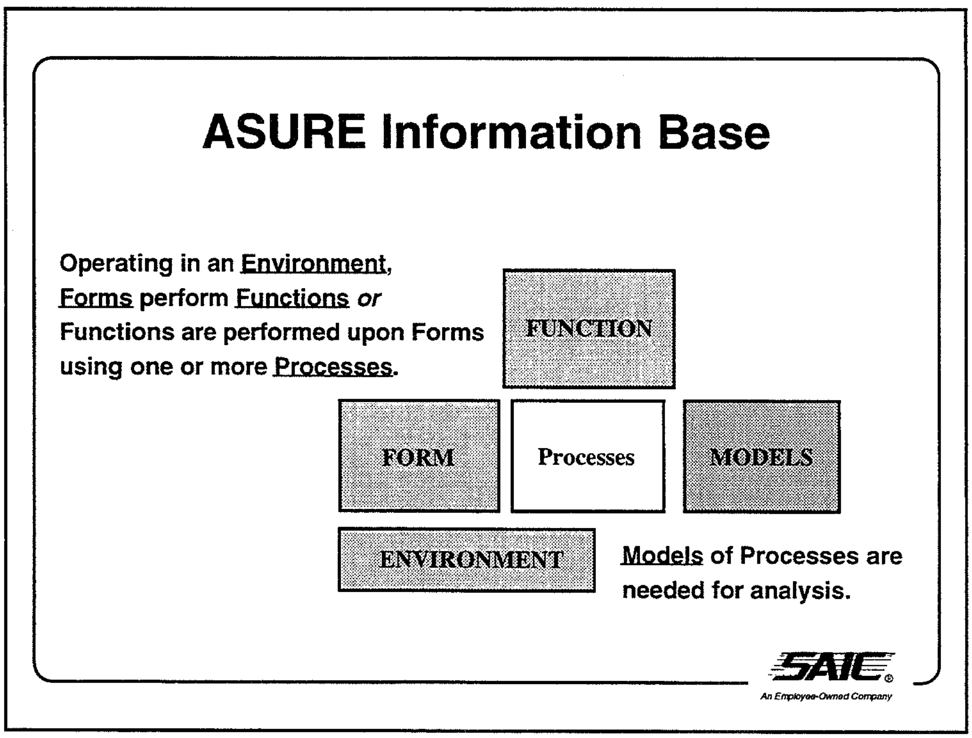
ASURE INFORMATION BASE

For ASURE to function, the system must be described using four hierarchies: Form, Function, Models and Environment. The linkages between these entities are described below.

In using ASURE, the principal efforts are directed at representing relevant portions of the life cycle of a product or process as Form and Function hierarchies, identifying the key processes that need to be modeled, and developing such models and validating them. The level of detail in a system description is matched to the analysis needs of the ASURE user. Further, the description evolves from coarse to detailed as the development process progresses.



ASURE FUNCTIONAL CONCEPT

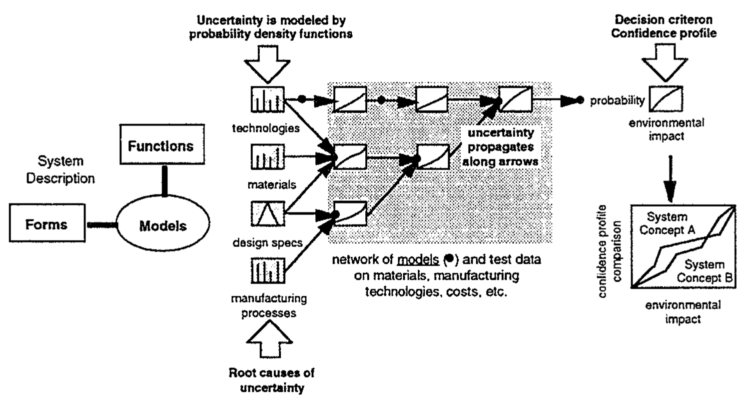
The principal output of ASURE is a confidence profile on any decision criteria of interest, e.g., ROI, life-cycle cost, performance, and environmental impact. The confidence profile characterizes the uncertainty on a variable and is expressed as a cumulative distribution on the variable values.

A number of other results are derived from the confidence profiles:

- Different product or process alternatives may be compared using the confidence profiles for the same attribute.
- The confidence level is a measure of design maturity and a change in it is a useful technical project management metric since the reduction of risk over time becomes apparent.
- An indication of the input uncertainties contributing to the uncertainty in the value of a product or process attribute, such as cost, is evident from an influence diagram.

We next discuss two example applications of ASURE.

ASURE Functional Concept



- Selection of input samples using DOE techniques.
- All computations using cumulative distribution functions.

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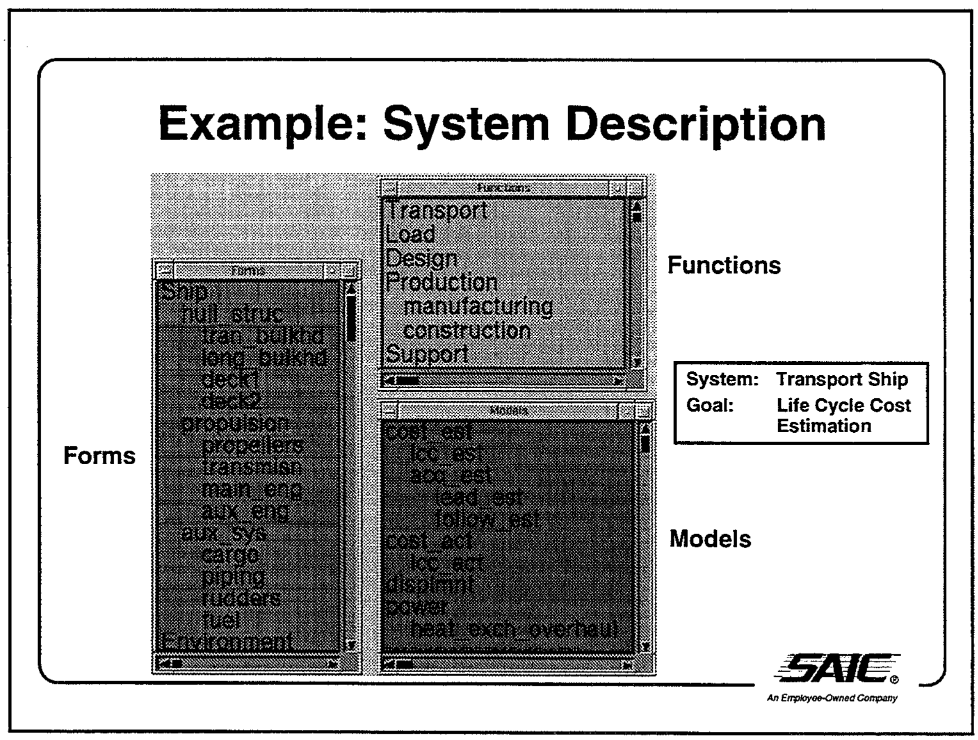
EXAMPLE: SYSTEM DESCRIPTION

ASURE was used in DARPA's SBD (Simulation Based Design) Phase I Program for the design of a ship (called the Notional Baseline Ship, NBS). The principal roles of ASURE were to (1) compute the total ship life-cycle cost (with estimate of uncertainty) for a baseline ship design and deployment strategy; (2) explore options for changes in ship design and deployment strategy in response to a change in the force build-up requirement; and (3) compute the cost and uncertainty for each option. The identification of the best option triggered a full-scale ship redesign. On the completion of the redesign, the cost and uncertainty were recomputed. The changes in the cost estimates were tracked throughout the redesign process.

The NBS was represented in ASURE as shown in the figure below. For the NBS design, the ship was the primary form and contained parts such as the hull structure, propulsion system, and auxiliary systems. Function descriptions included the NBS's ability to transport, be loaded, be designed and be produced affordably, and to be supported. In this case, most of the models related to predicting life cycle cost.

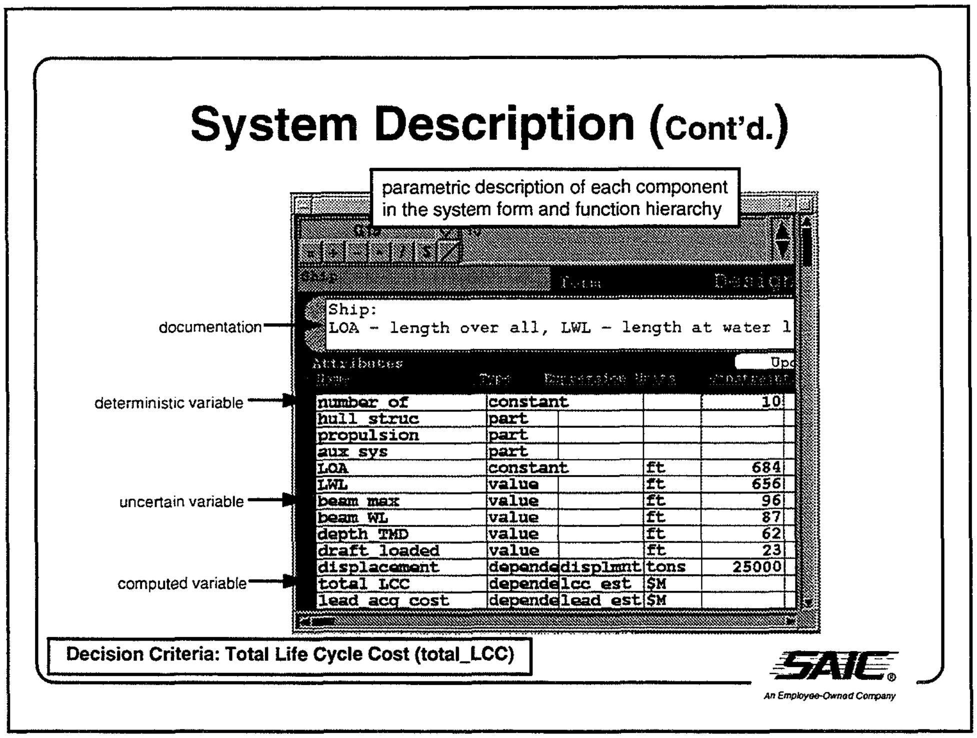


SYSTEM DESCRIPTION (CONT'D.)

Each of the element names in the three hierarchies in the previous chart points to corresponding parametric descriptions. An example description for the top level ship element, shown below, contains background documentation and a set of attributes. Attributes can be parts, values, dependencies and constants.

- Parts refer to other descriptions which are to be assembled.
- Values contain numerical data associated with the attribute.
- Dependent attributes either reference a model or expressions.
- Constants contain single text or numerical values.

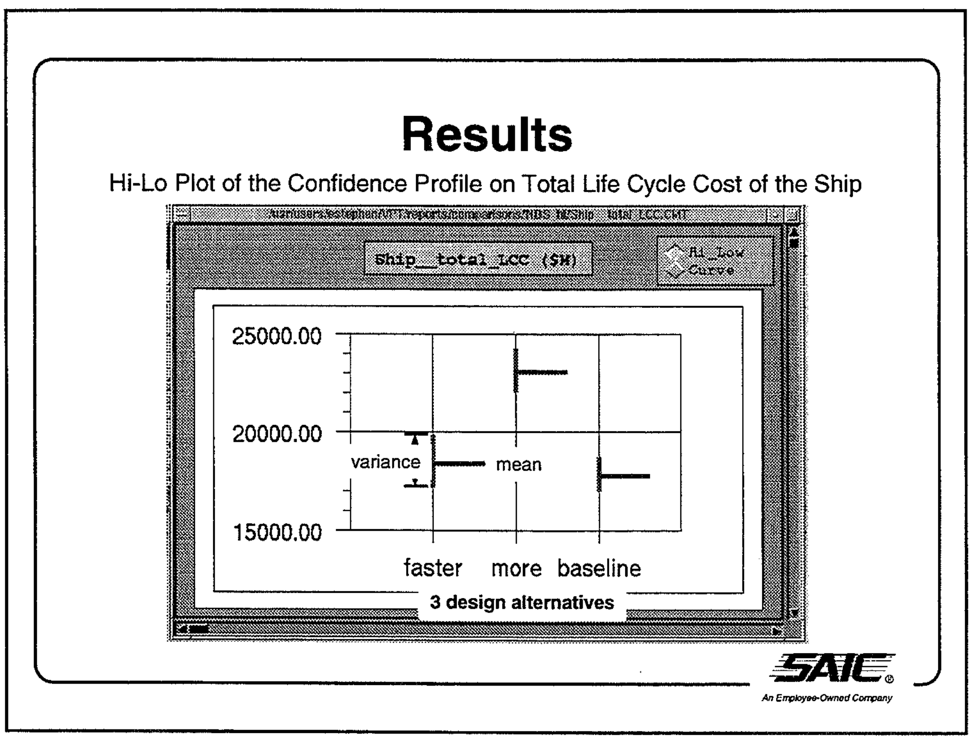
In the ship element description, the total_LCC attribute was dependent on a model for estimating life cycle cost, lcc_est. Models access information from throughout the design description. The figure shows the historical LCC model. This model consists of a curve fit to past cost data. Models can also access external computational resources such as a propulsion simulation.



RESULTS

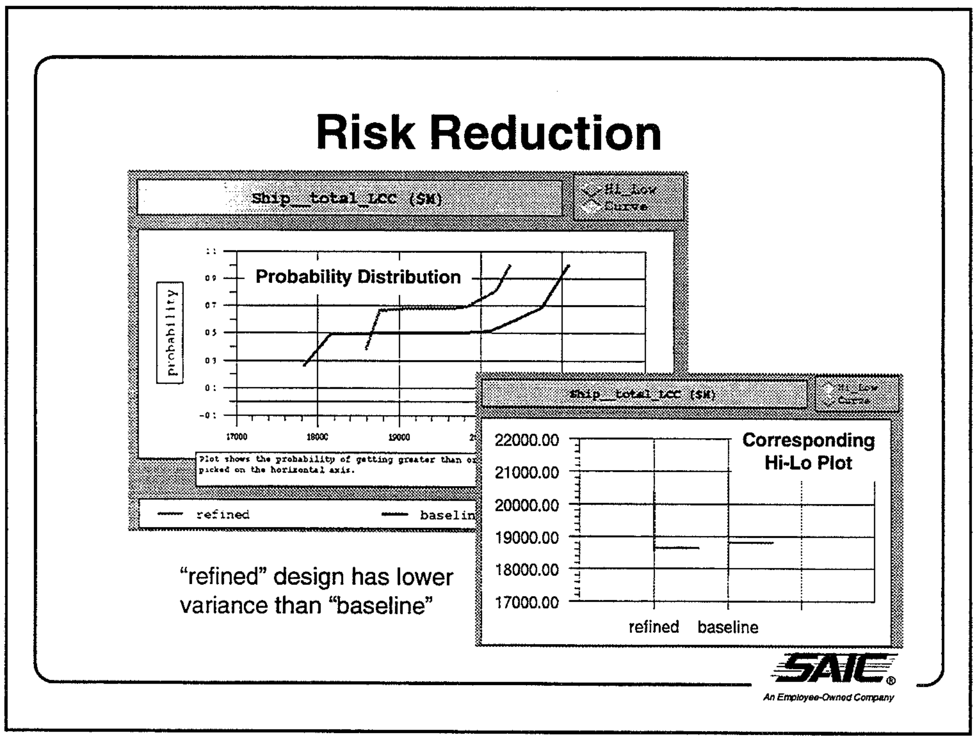
Once a system is modeled, ASURE is used by the analyst to estimate life-cycle cost for the study options and to generate life-cycle-cost distributions, reflecting uncertainty in the cost estimates. In this application, the total life cycle cost was the metric used; however, ASURE can perform these kinds of analyses on other parameters such as performance or schedule. ASURE used an historical cost model to assess the life cycle cost of the options. This involved connecting to the SPM and gaining access to latest NBS information and models. Investigations were performed on the life cycle cost (total_LCC) attribute for two alternatives: (1) to increase the number of ships from 10 to 13; and (2) to increase top speed from 19 to 22 knots.

As seen in the figure, the ASURE model performs the comparison of selected alternatives, and displays the most probable result together with the spread representing the uncertainty associated with that result. One can see that the "faster" option has lower life-cycle cost compared to the "more" option; however, the variability (the length of the vertical bar) and hence, the uncertainty, is higher for the "faster" option. The "faster" option appears worthy of further consideration. A more detailed design study is recommended to reduce uncertainty in this preliminary estimate; current results are then archived in the SPM.



RISK REDUCTION

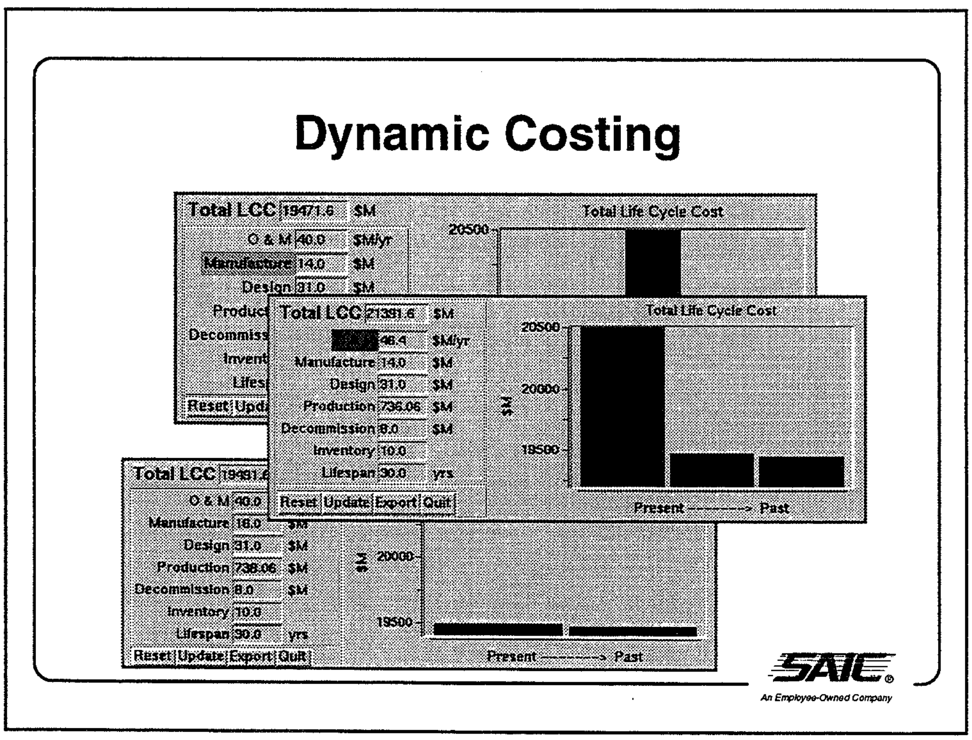
ASURE was used to quantify the impact of the information accumulated during the design exercise, to estimate cost with greater accuracy, and to determine the risk of cost exceeding this estimate. ASURE accessed the SPM to obtain the detailed description and rollup cost model for the refined estimate. A comparison was then performed between the refined life-cycle cost estimate based on the rollup cost model and the preliminary cost based on an historical model. This comparison is shown in the figure. From the comparison plot, the change in vertical bar heights indicated that the refined rollup model for life-cycle cost has less uncertainty than the historical cost model. The horizontal lines indicated that the most likely life-cycle cost would be slightly more than originally predicted.



DYNAMIC COSTING

During the redesign exercise, the SPM also provided "instantaneous" cost feedback. The current life-cycle cost was estimated using an NBS cost model. This deterministic model was based on a summation of all component costs and includes no uncertainty. It was, however, very quick and tracked all decision consequences. This estimate was displayed using a "cost meter" as shown in the figure. The cost meter shows the cost impact of each major design change. The principal components of the total LCC are shown on the left hand side of the figure. The leftmost bar on the right hand side of the figure indicates the present life cycle cost for the current NBS design. The rightmost bar indicates the baseline cost. Intermediate bars show the effects of other changes: new engines, new (but inefficient) heat exchangers, and subsequent heat exchanger redesign.

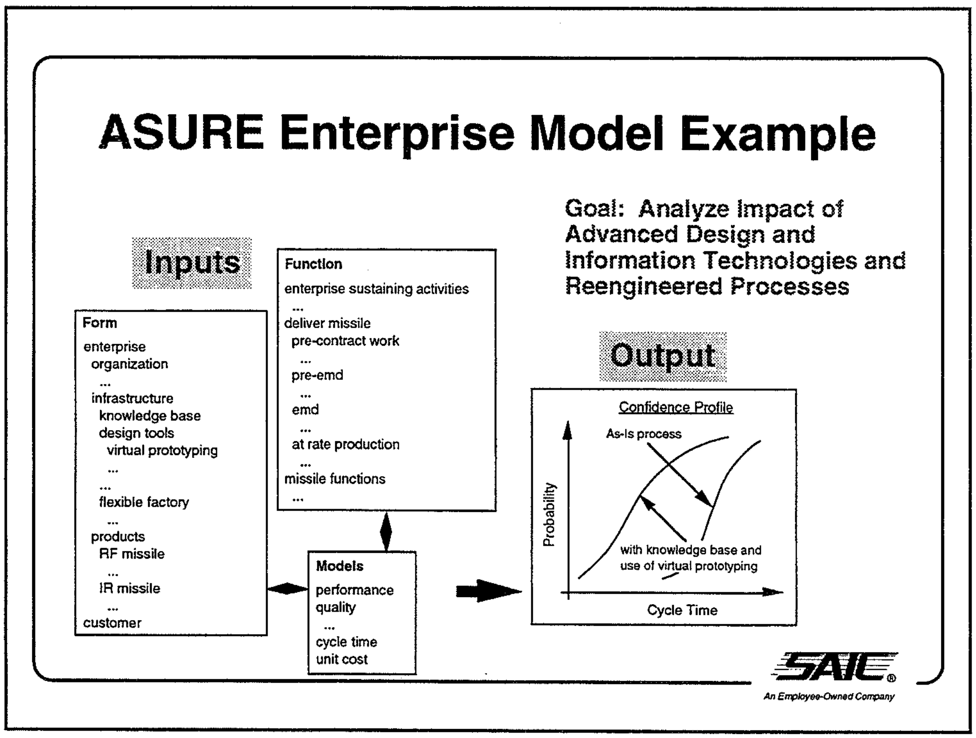
Significant contributors to the total life cycle cost are displayed to the left of the bar chart. Each time the cost meter was updated, the contribution of each factor was determined. Whenever the relative contribution of any factor changed by more than 5% between successive design changes, that factor was highlighted on the cost meter. As an example, in the figure below, the factor labeled "manufacture" is highlighted in green, because its contribution dropped by at least 5%.



ASURE ENTERPRISE MODEL EXAMPLE

The application of ASURE within the DARPA AM3 (Affordable Multi-Missile Manufacturing) program is presented next. Here the goal was to assess the impact of advanced design and information technologies in reducing the design cycle time for a missile design enterprise. The figure shows the Form and Function elements for an enterprise. The models capture the relationship between the elements of the design process. The output is a sample of the type of result that can be generated.

The resources devoted to developing a system description are dependent upon the scope of the analysis desired, and the model development effort is strongly dependent upon the depth of analysis desired. Finally, there is effort in collecting input data for the product and process attributes. The input of this information into ASURE and the subsequent generation of results consumes very little time.

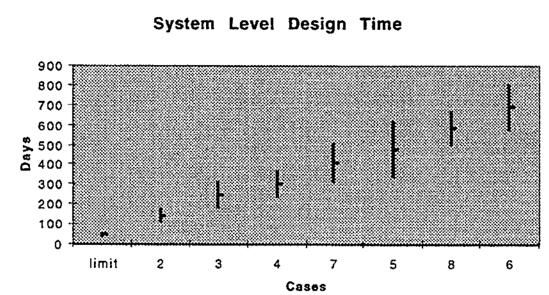


ENTERPRISE MODEL SIMULATION RESULTS

Some results from the AM3 application are shown in the following chart. We can see the impact of different design technologies on the detailed system design cycle time for a missile seeker. For example, in comparing Cases 2 and 3, we see that the use of virtual prototyping tools significantly reduces the design cycle time while simultaneously increasing the confidence (lower variance) of achieving these reductions. A comparison of Cases 2 and 7 shows the dramatic impact of design reuse on the detailed system design cycle time.

Enterprise Model Simulation Results

Case	KB Quality	Design Reuse	VP used?	Case	KB Quality	Design Reuse	VP used?
1	high	100%	yes	5	low	0%	yes
2	high	60%	yes	6	low	0%	no
3	high	60%	no	7	high	0%	yes
4	low	60%	no	8	high	0%	no



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SUMMARY

In summary, virtual prototyping provides an opportunity to dramatically reduce the product development cycle time by allowing the investigation of many design alternatives. The key to success, however, is to properly reflect real-world uncertainties in the virtual prototype and to use the resulting analysis to manage the development process. This is the function served by ASURE.

Summary

Why should we prototype?

To understand how real-world (manufacturing, warfighting, logistics, etc.) variability and uncertainty impacts cost to achieve satisfactory performance of system functions.

What do we gain from virtual prototyping?

Variants are cheap, almost free.

What do we stand to lose?

Variability and uncertainty are endemic in the real world.
In a virtual world, they must be introduced artificially.
How this is done often determines the answer.

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Realtime Three-Dimensional Simulation

Craig Ramsdell
Paradigm Simulation, Inc.
Chevy Chase, MD

PARADIGM SIMULATION INC

What Does Paradigm Do?

- Develop, sell, and support real-time software tools
  - Real-time 3D *visual* applications
  - Real-time 3D *audio* applications
- Resell related software products
- Develop visual and sound databas
- Develop custom applications
- Resell and integrate Silicon Graphics computers
- Develop tools, content, systems for entertainment

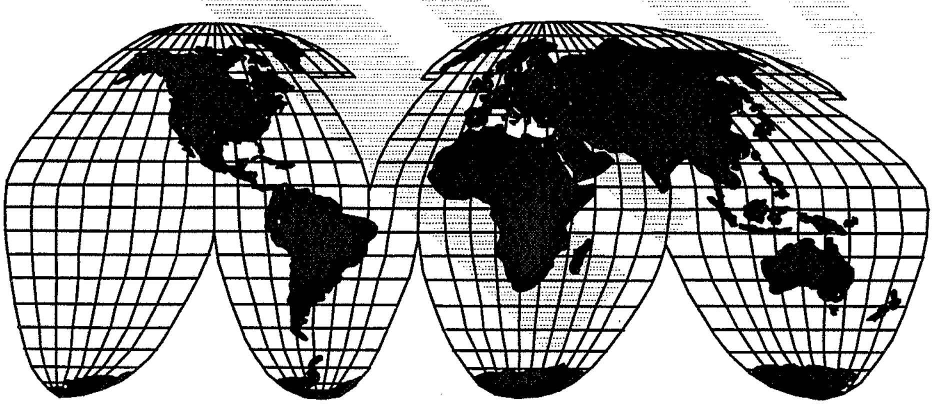
Details About Paradigm

- **Incorporated:** July, 1990
- **Ownership:** Privately held, non-public
- **Personnel:** 100+ employees
- **Growth:** Continuous 2X+ each year
- **Performance:** Continuous annual profitability - No long-term debt
- **Headquarters:** Dallas, Texas - 30,000 sq. ft. facility

  Sales offices in Dallas, Cleveland, Los Angeles, DC, Tampa, plus 21 international distributors

Sales and Support

– Sales/Support Offices and Distributors Worldwide



Sales and Support

- **Company Offices:**
  - Dallas, Texas
  - Washington, DC
  - Irvine, California
  - Cleveland, Ohio
- **Independent Sales Agents and Distributors:**

– Florida	Australia	Germany	
– Spain	Russia	India	
– Japan	Taiwan	China	
– Israel	France	Egypt	Korea
– Turkey	Sweden	Pakistan	United Kingdom

What's Needed for Simulation & VR?

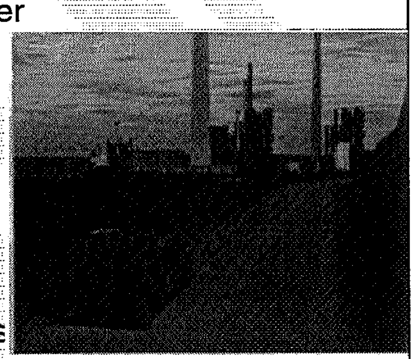
- **A Database "World" and Models** (what you see and hear)
  - 3D geometric polygon structure
  - Multiple levels of detail (complexity)
  - Sound sample waveforms
  - Optimized for interactive, real time use
- **Software Application** (how you interact and move)
  - Software program that controls input devices, visual channels, scene objects, interaction, collision detection, special effects, time of day, weather, I/O, communication, and much, much more.
- **Hardware** (for interaction, control and processing)
  - Computer, sound processor, monitors, control sticks, position trackers, head-mounted displays, amplifiers, speakers, communications.

Creating the Application

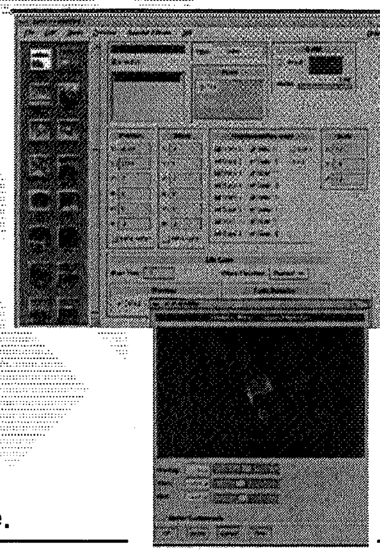
- **Paradigm's Vega and AudioWorks2 Tools**
  - Easy to use, intuitive, very robust
  - Rapid prototyping, reduce programming time
  - Improve productivity and performance
  - Optimized for interactive, real-time use
  - Easily extensible, modular, cost effective
- **Traditional Low/Mid-Level Programming**
  - Slow, time-consuming, non-intuitive
  - Difficult, iterative process of *"program-test-break-fix"*
  - Hard to achieve consistent performance
  - Difficult to maintain, support, modify, extend

Vega™

- Easy to use, reduces programming, increases productivity
- Modular, real-time application builder
- C and C++ API
- Includes SGI Performer
- Graphical user interface
- High, real-time performance
- User extensible environment
- Runs on all SGI computers
- Supports 3D real time audio options
- Optional modules for extended functionality



LynX™

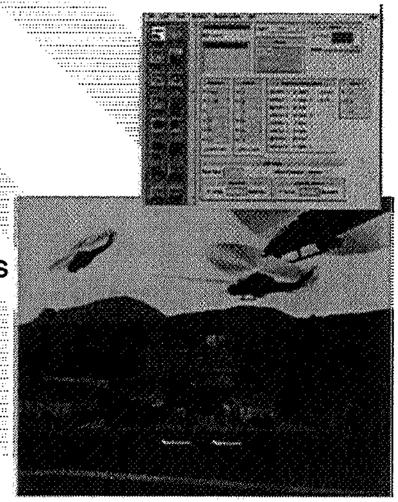


- X-Motif graphical user interface
- Included with VEGA
- Very rapid prototyping
- Increases productivity
- Sets simulation variables
- Define and control observers
- Define and control visual channels
- Control positioning of objects
- Controls computing system
- User extensible and reconfigurable.

Vega Optional Modules

- Extend and specialize the functionality of Vega
- Reduces need to build specialty tools, functions, utilities
- Dramatically improves programmer productivity
- Buy only what you need
- Add other modules later as needs change
- Fully integrated with LynX
- Available from Paradigm and Solution Group members.

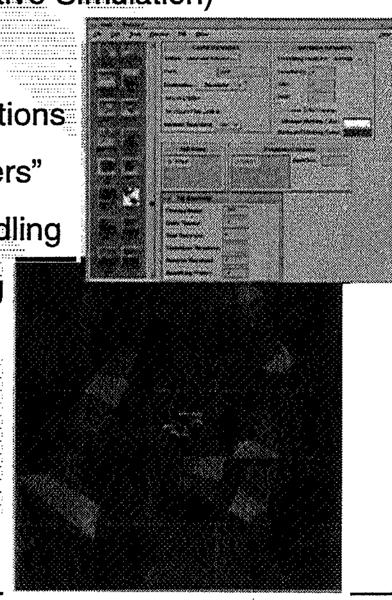
Special Effects Module



- User-defined visual effects library
- Explosions, smoke, fires, flares
- Tracers, missile trails, contrails
- Propellers, rotors, exhaust plumes
- Configurable, modifiable
- Supports OpenGL™ and IrisGL™

DIS Module

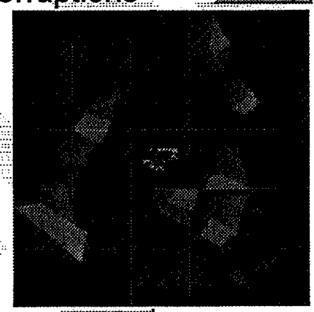
(Distributed Interactive Simulation)

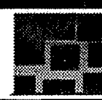


- Easy support for networked simulations
- Rapid connection of multiple "players"
- Fast definition of PDU criteria, handling
- Supports data filtering & smoothing
- Includes articulated parts tool
- Full control of object states
- Based on VRLink™ from MaK Technologies

Large Database Management

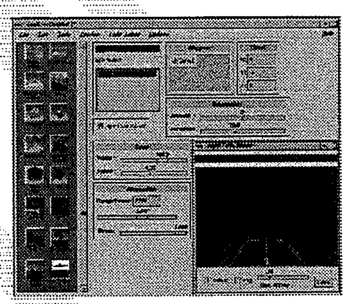
- Supports use of very large visual databases
- Continuous movement without reload interruptions
- Maintains real time area-of-interest
- Supports curved or flat earth data
- Supports multiple data formats
- Manages data tile segmentation
- User defined paging algorithms

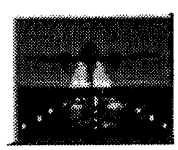




Light Lobes Module

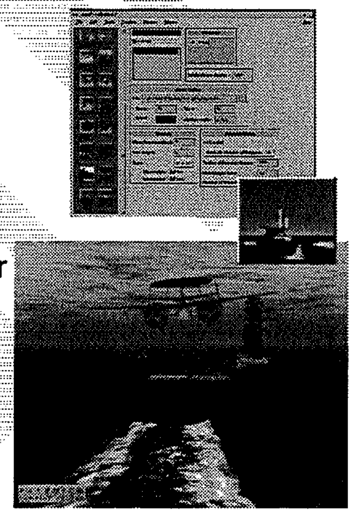
- Creates effects of landing lights/headlamps as viewed from pilot/driver position
- Full control through LynX GUI
- High performance
- Supports overlapping light lobe patterns
- Supports time-of-day settings
- Proper illumination of scene without sky lighting artifacts





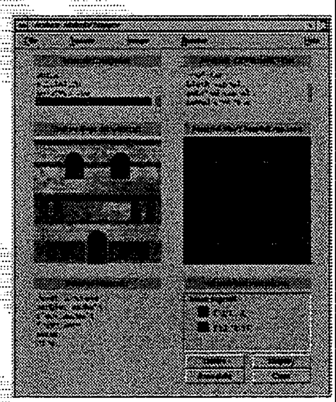
Marine Module

- Ready-to-use special effects for marine/nautical applications
- Six dynamic sea motion states
- Bow waves, stern wakes, eddies, currents
- Constant tension, constant length or variable length lines
- Tow, mooring, phone, flag lines
- Moored buoys
- Smoke plumes, man overboard



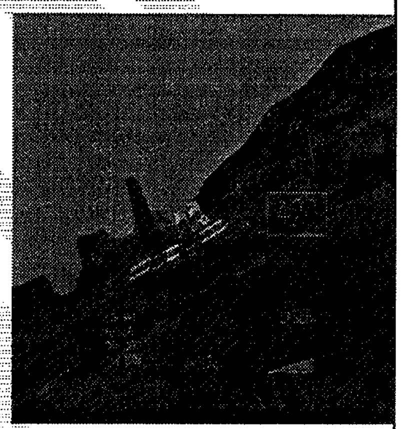
SensorVision™ Module

- Real-time interactive sensor simulation
- Full range of spectral bandwidth
- Radiometrically and analytically accurate
- High performance
- Texture & material properties mapping
- Atmospherics, location and time of day selection
- Real time diurnal cycles
- Co-developed with Photon Simulations



Symbology Module

- High-speed rendering of 2D and 3D instrumentation in Vega channels
- Displays like HUDs, status screens and map grids seamlessly overlay visual scenes
- Virtual cockpit instruments and indicators are synchronized with visual simulation
- MultiGen™ Instrumentation Option files are automatically loaded
- Symbology objects can be created and manipulated in real time via API



Nav and Signal Lighting Module

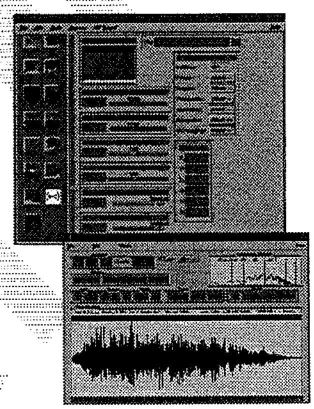
- Low-level API makes simpler, more flexible lightpoints
- Large library of aviation and marine light systems reduces modeling time
- LynX allows rapid placement of airfield and marine lights
- "Signal" class provides complex flash patterns

Paradigm Databases

- Terrain and models
- Tailored to suit application domains
- Air, Ground, Marine, Virtual Reality
- Built for performance w/Vega and AudioWorks2
- Realistic, geospecific and geotypical textures
- Articulated parts, multiple appearance states, environment effects

AudioWorks2™

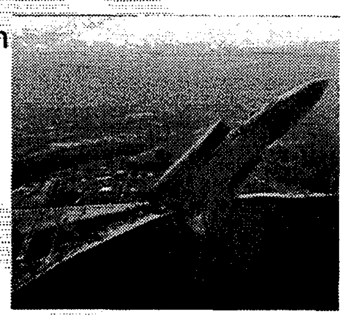
- Interactive, real time 3D sound
- Multiple, independent moving sounds and earpoint
- Doppler shift, distance attenuation, bandpass filtering, pitchbend, looping
- 4 channel, quadraphonic output
- Supports SGI Audio Library (AL)
- Supports Paradigm's Sound Engine II, Crystal River's Acoustetron, All SGI Audio Hardware
- AWLynX GUI & Audition tool included



DIRECT IMPACT!™

- Integrated hardware and software for visual simulation developers
- Cost-effective solution from a single vendor
- Specific configurations tailored to meet customer's unique requirements
- Features the SGI Indigo² IMPACT line of workstations
- Customized suite of software tools
- Choose from Vega, AudioWorks2 and a variety of application modules
- Includes sample flight application, database, training and support

APEX™



- Turn-key visual simulation application
- Integrator-ready IG for operational flight, weapon systems and commercial flight trainers
- Features atmospheric and meteorological effects, lighting systems and database management
- Hosted on SGI's Infinite Reality Engine
- Includes documentation, extensive training and quality support

Clarus CAD Real-Time Link™

- *Import* various CAD file formats
- *Import* of NURBS or polygons
- Tessellation processing with various options
- Manipulation of textures
- Level of Detail (LOD) creation
- Radiosity
- Gap elimination
- Preview the model
- *Export* to Vega Fast File format

Clarus Interactive™

- Module for Vega
- Rapidly design 3D behavior and interaction
- Create sensors linked to actions
- Connect actions to objects
- Sensor support for devices, trackers, 3D mouse, HMDs
- Predefined actions:
  - aim at, start/end special effects, relative motion
  - absolute motion, play sound, switch environment
- Complete C++ API for advanced programmers

Clarus Drive™

- Vehicle dynamics motion module for Vega
- GUI interface to setup dynamic driving parameters for:
  - steering, brake, wheel, transmission, body
  - clutch, engine and spring parameters, gear ratios
  - drag coefficient, vehicle mass, width, height length
- Manual or Automatic gear switching
- External I/O support for pedals, gearstick, steering wheel
- Complete API for advanced programmers
- Sound support available (body, engine, wheels)

Clarus VR™

- Peripheral support module for Vega
- Tracker support for Flock Of Birds, Polhemus Fastrak
- HMD support for:
  - Kaiser VIM PV 500, VIM PV1000
  - Virtual Research Flight Helmut, EyeGen3
- All features accessible through Lynx interface
- C++ API for advanced programmers

The Solution Group

- Consortium founded by Paradigm
- Promotes product compatibility and integration
- Solution Group products are Vega-compatible
- Combines "best of breed" companies and products
- Focuses on partner strengths and customer solutions

Solution Group Members

- ATS Aerospace
- Glass Mountain Optics
- Immersion Corporation
- Kaiser Electro-Optics
- MaK Technologies
- MultiGen, Inc.
- ObjectForm
- Paradigm Simulation, Inc.
- Photon Simulations
- Prosolvia Clarus AB
- Ternion Corporation
- ViewPoint DataLabs

Systems Integrators

- Provide turnkey solutions
- Utilize Paradigm's products
- Add other products, skills, expertise
- Deliver complete, integrated systems
- Offer specialized application expertise
- Independent contractors

Paradigm Systems Integrators

(partial list)

- **Advanced Marine Enterprises** - Nautical/marine simulators
- **Nichols Research Corp.** - Military programs
- **Computer Sciences Corp.** - Military programs
- **ATS Aerospace** - Air traffic control, flight, nautical simulators
- **Krauss Maffei** - Train, truck, tank simulators, entertainment systems
- **Clarus AB** - Vehicle, flight simulators, VR systems
- **Jason & Associates** - Nautical simulators
- **Enzian Technology** - Nautical, vehicle simulators.

Aerospace/Defense Customers
(partial list)

- **Lockheed Martin** - Aircraft design, flight handling, marketing
- **McDonnell Douglas** - Aircraft design, flight handling, marketing
- **NASA** - Astronaut trainers, flight handling, marketing
- **Nichols Research** - Military tank tactics trainers
- **Computer Sciences Corp.** - Military tank tactics trainers
- **Grumman Corp.** - Aircraft design, flight handling
- **Pratt & Whitney** - Jet engine design, flight handling, marketing
- **U.S. Navy** - Landing Signal Officer, Officer of the Watch trainers
- **U.S. Army** - Military tank tactics trainers
- **U.S. Air Force** - Flight handling trainers
- **SAIC** - Integrated warfare/mission planning systems
- **Argonne National Laboratory** - Maritime simulation

Automotive Customers
(partial list)

- **Ford Motor Co.** - Audio engineering, design, analysis
- **Chrysler Corp.** - Human factors engineering
- **General Motors** - Human factors engineering
- **Volvo** - Human factors engineering, CAD validation
- **BMW** - Audio engineering, design, analysis
- **Nissan** - Future design, concept prototyping
- **Toyota** - Audio engineering, design, analysis
- **Skoda (Czech Republic)** - Future design, concept prototyping
- **Kelsey Hayes** - Audio engineering for brake design

Commercial Customers
(partial list)

- **Evans & Sutherland** - Simulator manufacturer
- **Hughes Training Systems** - Simulator manufacturer
- **Marine Safety International** - Nautical training centers
- **Sime Darby** - City/urban planning systems
- **Bergmann Associates** - City planning, architectural design
- **de Havilland Aircraft** - Flight handling characteristics simulator

Entertainment Customers
(partial list)

- **Nintendo** - Next generation home entertainment systems
- **Namco** - Location-based entertainment centers
- **Magic Edge** - Location-based entertainment centers
- **Disney** - Epcot/Location-based entertainment centers

Why Select Paradigm?

- Experience
- Expertise and Depth
- Customer-Service Oriented
- Solution Group Benefits
- Superior Products, Training, Support
- Financial Strength and Growth
- Stable, Low Risk Partner

The Portable War Room Research Project

Francis X. Govers III
and
Mark Fry

TASC, Inc.
Reston, VA

THE PORTABLE WAR ROOM RESEARCH PROJECT

Francis X. Govers III, Program Manager
and
Mark Fry, Program Development
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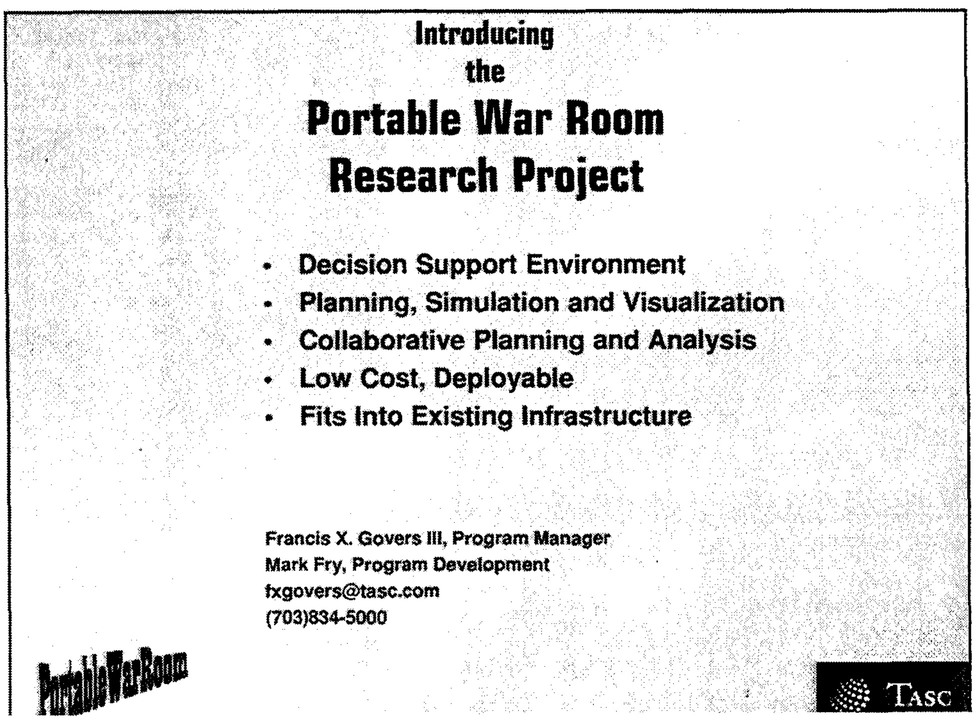
12100 Sunset Hills Road
Reston, VA 22090

Executive Summary

The Portable War Room is an internal TASC project to research and develop a visualization and simulation environment to provide for decision makers the power to review the past, understand the present, and peer into the future - a crystal ball.

All decision makers have to collect data, interpret it, make plans, determine a best plan, and then implement that plan. The Portable War Room provides "Power Tools" to streamline, accelerate, and increase the capability of decision makers to utilize the large quantities of data that digital network assets are providing.

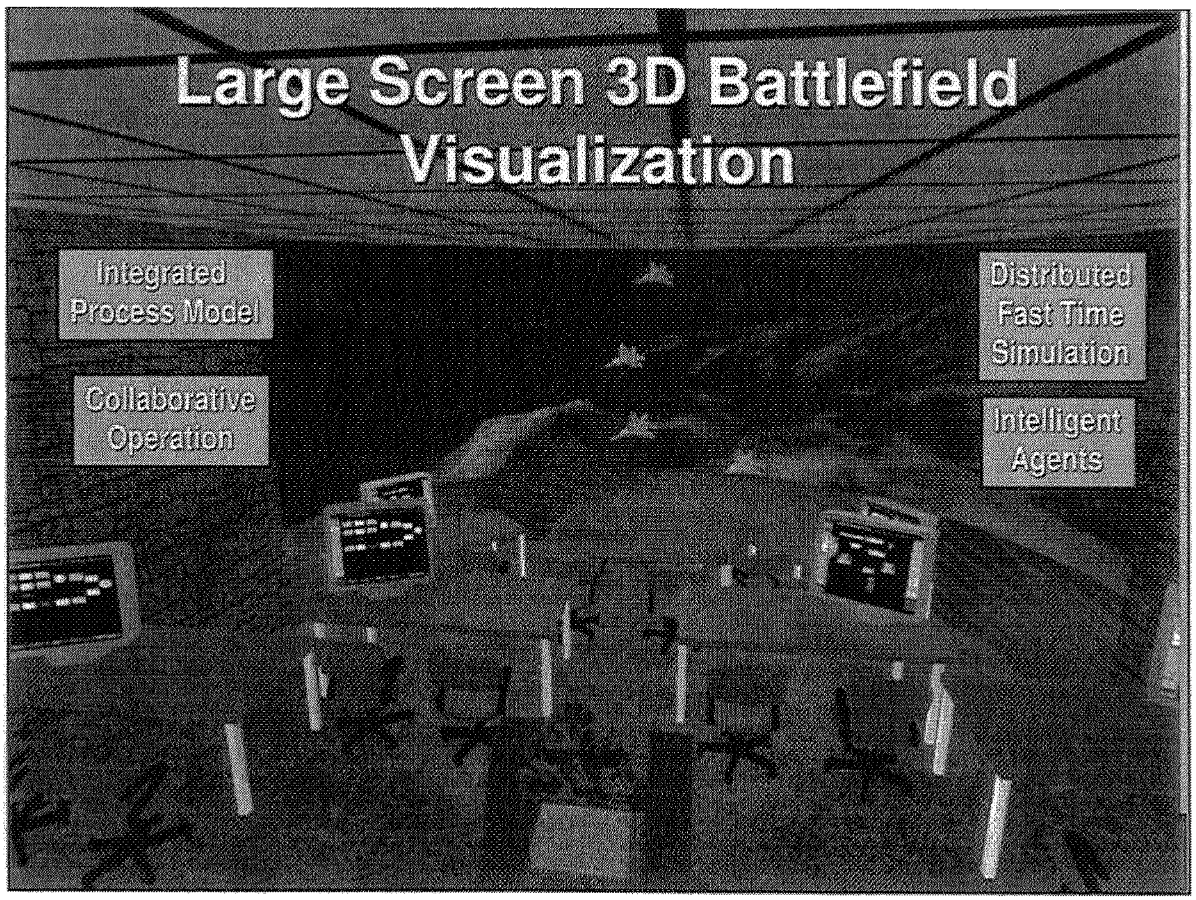
The vision of the Portable War Room includes using advanced concepts in virtual reality interfaces, support for head-mounted displays, touch screen interfaces, planning aids, software agents, and tight integration between live data, and fast-time constructive simulation.



LARGE SCREEN THREE-DIMENSIONAL BATTLEFIELD VISUALIZATION

This picture illustrates one concept of a "war room" for decision making. In the front of the room is a large-screen projection display with 180 degrees of visualization. Around the room are several analysts' workstations which provide input into the "big picture" going on in the front.

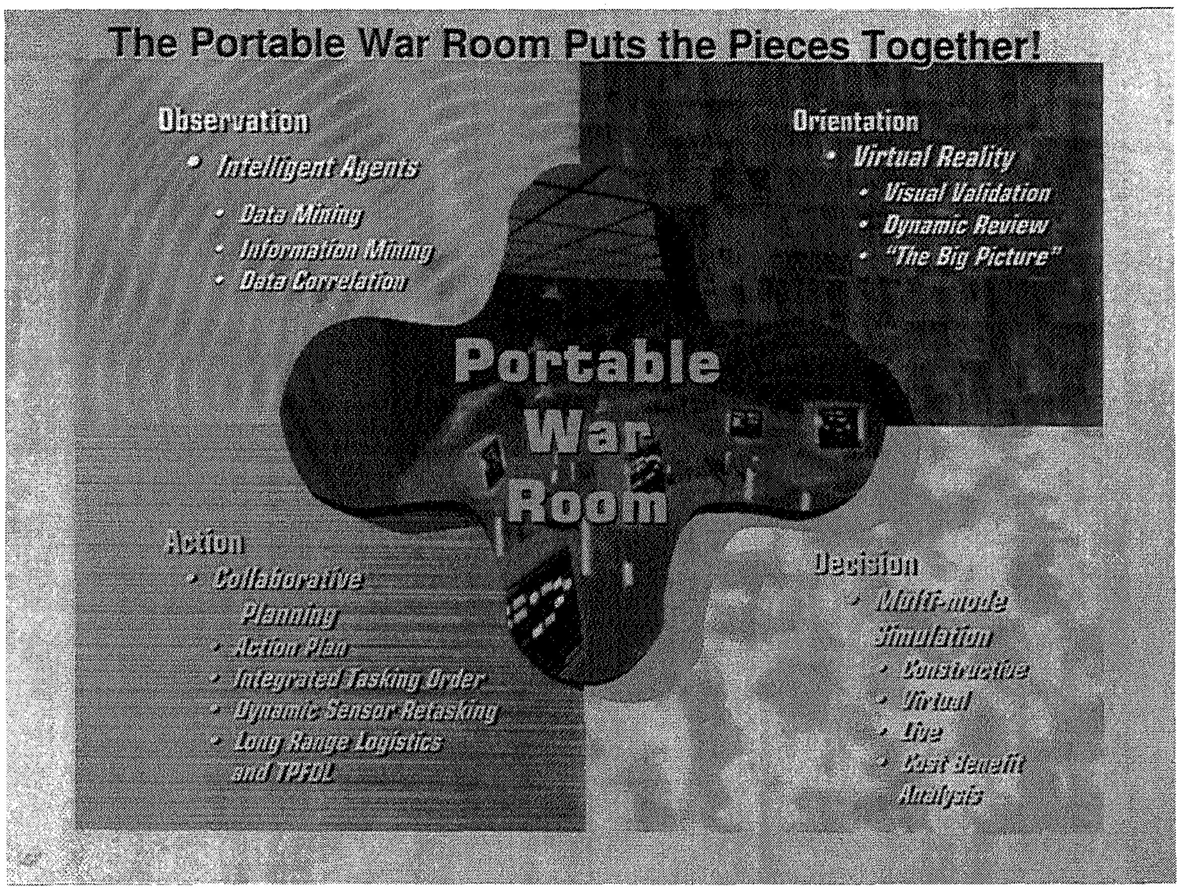
The workstations do not have mice or keyboards, but use touch screen, light pen and voice recognition capability as an interface.



THE PORTABLE WAR ROOM PUTS THE PIECES TOGETHER!

The Portable War Room is designed to bring together several technologies in the quest for better decision making:

- Intelligent Agents
- Virtual Reality
- Multi-Mode Simulation
- Collaborative Planning

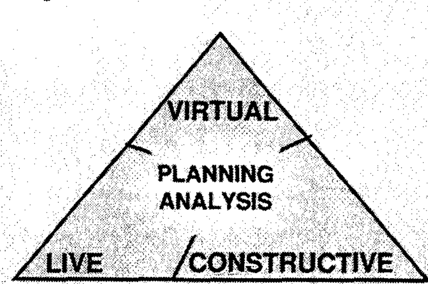


WHAT IS THE PORTABLE WAR ROOM?

What Is the Portable War Room?

- An End-to-End Planning, Execution, and Management Infrastructure
  - A system of distributed object interfaces which enable collaborative, real time planning by joining real time data, virtual simulation, and fast-time constructive simulation in a common "data space"
  - Provides common, large scale view of the battlespace with Virtual Reality-type displays

- TASC's evolving tool to leverage solid experience in Military Operations and Intelligence Support
- The Portable War Room enabling technologies are being developed under IRAD at TASC, University Research and existing, ongoing contracts.



PortableWarRoom

4

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What Can the PoWR do?

What Can the PoWR do?

- Speed Planning from weeks to days, days to hours
- Goal-directed System
  - Creates Courses of Action to meet goals
  - Measures results against campaign goals
- Visual Validation and Battlespace Awareness
- Measure the Value of Information, Strategy, Tactics, and Doctrine to the Campaign
- Process Management for Command and Control and Process Re-engineering
- Distributed Collaborative Planning

PortableWarRoom

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APPLIED TECHNOLOGY

This diagram illustrates the overall technology architecture of the Portable War Room concept. PoWR is designed to have a layered, "plug in" architecture to accommodate a variety of missions and needs.

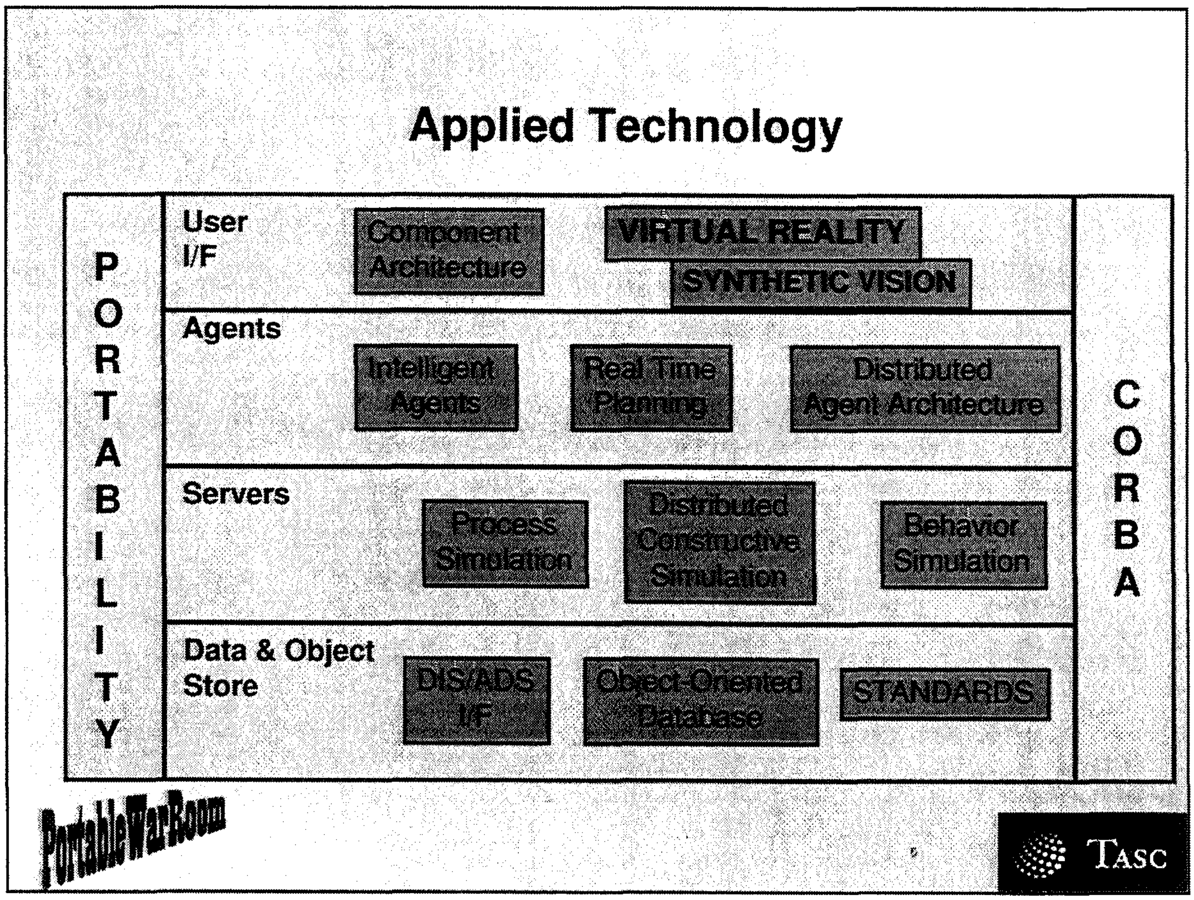
The top level, user interfaces, includes control panels and visualization tools for input and output to the user.

Intelligent agents provide planning and organization capability via an artificial intelligence expert system.

The server architecture level has the simulation components for constructive (analytical), process and behavior simulation.

All components are collected, managed and distributed via the Data and Object Store at the bottom of the diagram.

The connectivity between the components is accomplished via a CORBA network service.



FUNCTIONS OF PORTABLE WAR ROOM

This list presents the functional capabilities that the Portable War Room is designed to meet.

Functions of Portable War Room

- Collaborative Planning
- Threat Analysis
- Situational Awareness
- Objectives, Strategy, Tasks, and Doctrine
- Planning and Prioritizing
- Communications and C4I Networks Planning
- Campaign and Mission Planning
- Rapid "what if" assessment
- Command and Control
- Real Time Re-Tasking

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7

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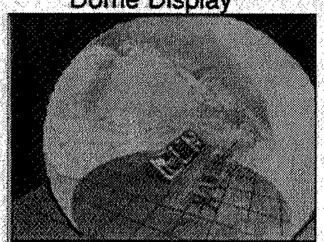
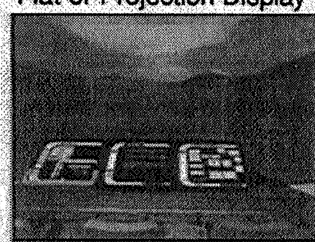
VIRTUAL REALITY

- Situational awareness requires the use of very large map displays
  - Peripheral vision is key to permitting the user to maintain a sense of spatial relationships
- VR displays allow the user to deal with large data spaces in an intuitive manner
- The PoWR display system can include:

Dome Display



Flat or Projection Display



Head Mounted Display

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SYNTHETIC VISION

SYNTHETIC VISION

- We define synthetic vision as the synthesis of abstract and concrete spatial data to produce simplified displays which provide large quantities of information which are easily interpreted.
- The goal of Synthetic Vision is to "increase the human bandwidth" to absorb data and make sense of it.
- The Portable War Room visualization environment will combine object-oriented data with 3-D graphics and techniques borrowed from virtual reality to create new views of "data space" which greatly speed decision making and reduce training time.
- The net result is a reduction in the amount of <u>cognitive overhead</u> required to interpret information and form situational awareness.

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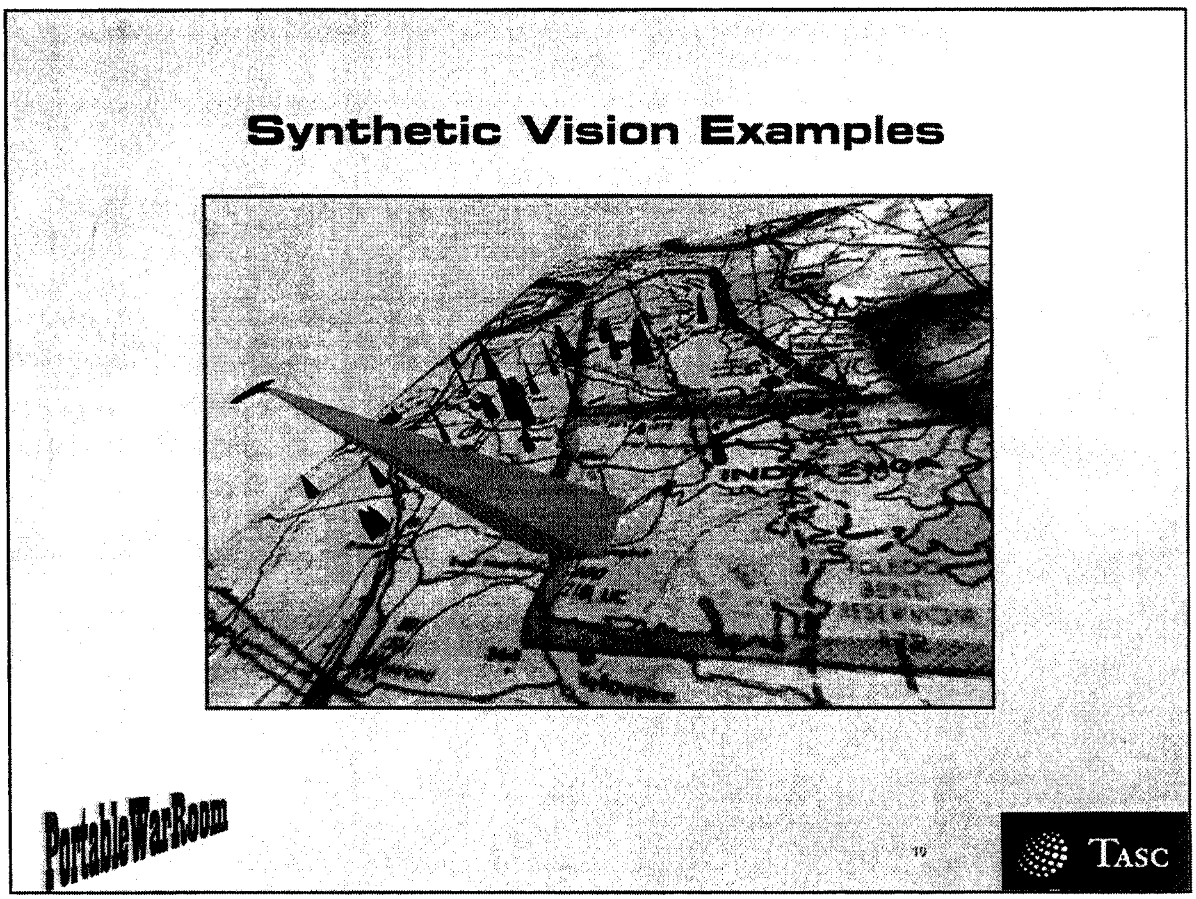
SYNTHETIC VISION EXAMPLES

The synthetic vision example illustrates the use of high-resolution maps in the PoWR visual system.

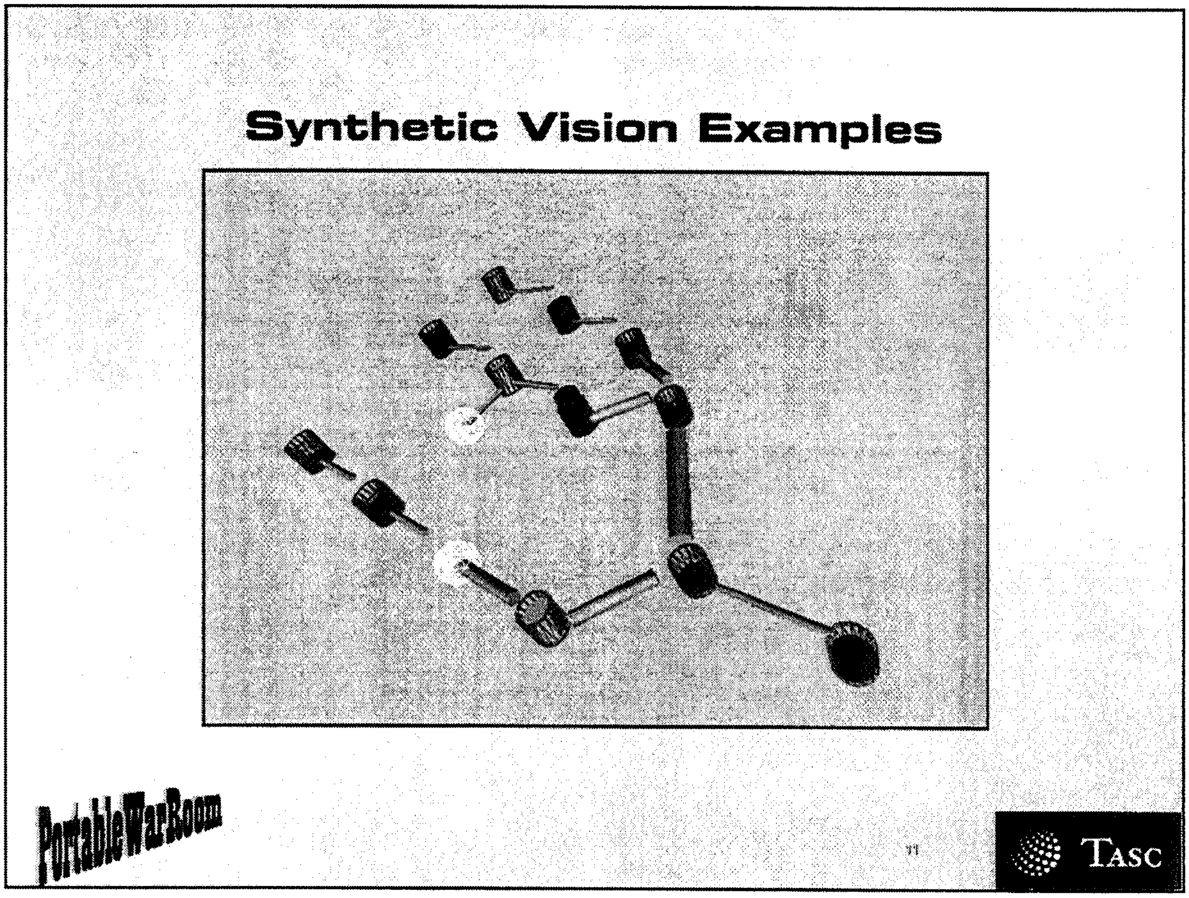
The red cones represent different data intelligence items, in this case, signals. Different variables, such as power, classification, or duration, can be coded into the height, length, color, transparency, and any of twenty other variables.

The PoWR visual system can combine any number of variables in a data representation and display over a map, timeline, or other three-dimensional space. All of the three-dimensional elements are completely under user control.



SYNTHETIC VISION EXAMPLES

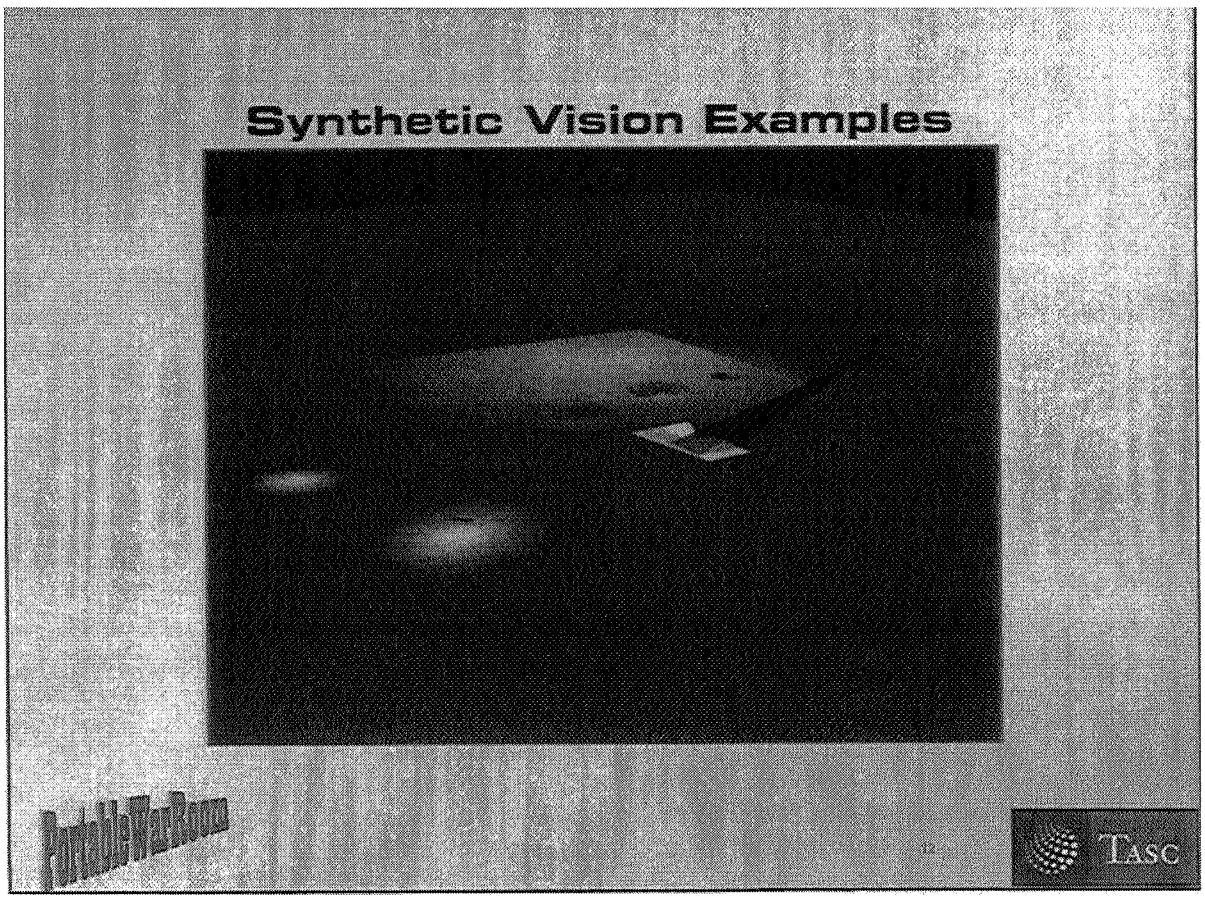
This example shows a process model rendered as "pipes and buckets." Two of the steps, shown in red, are not functioning adequately, while others, shown in yellow, are getting critical.



SYNTHETIC VISION EXAMPLES

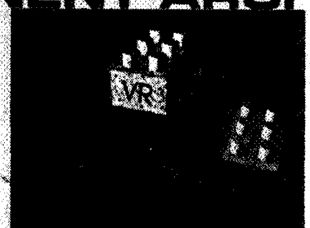
In this rendering we have mapped data on radar signal strength into the lighting equation of the visual system. The different lighted areas represent different radar coverages. Color indicates the ownership of the different signals.

These examples illustrate the simple and easy-to-understand nature of the PoWR visual representations.



COMPONENT ARCHITECTURE

COMPONENT ARCHITECTURE



- Component Architecture describes a technique for building applications and systems out of discrete, independent objects
- Differs from Object Oriented Programming in that objects can be lifted in run time from their context and placed into a different application without loosing their functionality
- The Portable War Room uses component architecture to make objects, attributes, and methods independent and reusable.
- This allows any constructive simulation tool to be used as a planning aid. Especially useful in this role would be Semi-Automated Forces (SAF's)
- We can also mix and match components to provide rapid reconfiguration.

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INTELLIGENT AGENTS

INTELLIGENT AGENTS

- An Agent is a piece of software which performs a task or series of tasks for the user. They may also be referred to as *associates*, *embedded experts*, or *virtual staff.*
- The Portable War Room uses agents as independent software components which can attack individual problems.
- Agents will be used for planning, timeline management, logistics simulation, and database access. They will provide local expertise for areas where the user may not be familiar, such as managing satellites or tasking aircraft.
- Agents can also provide "intelligent interfaces" that can handle translation, formatting, network access, database conversion, and data synthesis. The also manage the joint collaborative planning protocols and handle aggregation.
- Portable War Room agents use the behavior modeling server to provide goal-driven programming with interpreted scripts that can be changed in run-time. This system is also capable of learning and adapting to changing situations. The more the Portable War Room is used, the more powerful it becomes.

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14

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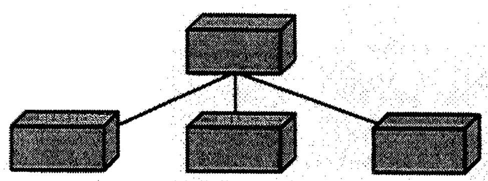
DISTRIBUTED AGENTS

DISTRIBUTED AGENTS

- The Portable War Room will be using it's agent architecture in a unique way to provide scaleability.
- The agent system is capable of spawning multiple recursive agents which can attack problems in parallel, and work cooperatively in teams to accomplish tasks.
- If a task is too large for one agent, then the agent system can create dozens of helper agents, each on separate, distributed hardware platforms.
- The Goal-Oriented basis of the agent system is specifically created to deal with asynchronous, long-transmission delay tasks over a global network.



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15

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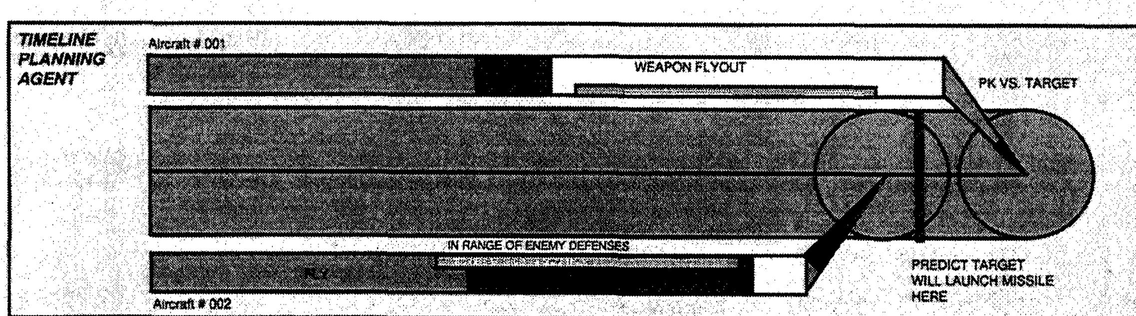
REAL TIME PLANNING

REAL TIME PLANNING

- The Intelligent Agent system, along with the simulation tools, are designed to allow commanders to see, react, and adjust plans in real time to meet the situation on the battlefield as it evolves.
- At any time, the user can shift from a real-time view of the battle to a predictive constructive simulation to provide rapid "what if" analysis.
- The simulation tools also allow the commander to closely coordinate the time dimension of the battle, by answering such questions as "when my tanks reach the river, where will my air support be? And, can the enemy move fast enough to cut me off?"
- Timeline agents work forward and backwards in time to control the time dimension, provide set-up, laydown, and to manage "logistics tails"



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MEASURES OF SUCCESS

MEASURES OF SUCCESS

- Reduces time and effort to:
  - Create synthetic view of battlefield
  - Plan Contingencies and exercises
  - Develop Campaign ISR Plan
- Increases the military effectiveness in terms of Quality and Timeliness:
  - The Large Numbers of intelligence data sources
  - The Digital Battlefield
  - Battlefield Awareness
- Faster and Easier Planning (less training)
- Complements existing Mods and Sims
- Easy Transition from Peace to War with Same System
- "Train Like You Fight"

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17

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PORTABLE OPERATIONALLY OPEN ARCHITECTURE

Portable
Operationally Open Architecture

- The Modular construction of the Portable War Room is designed to permit it to operate with a variety of computer hosts, including PC's.
- Can take advantage of existing networks and computer systems
- It is possible to use the system:
  - Onboard an aircraft enroute
  - On the ground
  - In an armored vehicle
  - At a fixed ground installation
  - In an assault command post

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19

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Legacy Tools

- A major feature of the PoWR infrastructure is the ease with which legacy simulation and planning tools can be integrated into the system
  – In-place Investments – Evolving Systems
- The component architecture and distributed systems allow "mix and match" object usage -- even from systems not designed to be object oriented
- The Control Panel system allows unsophisticated users to develop custom capability using low-cost, easy to learn tools (spreadsheets, ToolBook, Visual Basic)
- PoWR is designed to allow almost any simulation tool to be used as a planning tool
- *The "producer-consumer" architecture is specifically designed to allow simulations and models with different views of TIME to work together*

PortableWarRoom

19

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SmartScene: An Immersive, Realtime, Assembly, Verification and Training Application

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SMARTSCENE

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THE SMART AGENDA

It is my pleasure to be talking to you today about SmartScene - MultiGen's innovative product that was named *Product of the Year* by Cyberedge Journal. First, we are going to talk in detail about how markets are applicable to SmartScene. We will then talk about some of the key technologies that make SmartScene so unique. Last, we will talk about how much it costs and when it will be available.

The Smart Agenda

- What is SmartScene?
- Markets
- Key technologies
- Pricing and availability

WHAT IS SMARTSCENE?

There are four major components to SmartScene. First, it is shipped with everything necessary to quickly be able to do productive work. It is immersive in that when a user is working in SmartScene he or she cannot see anything except the world being manipulated.

SmartScene ships with ready to use building blocks enabling a new user to create a new world.

These building blocks have behaviors associated with them that are consistent with their use and position.

Last, but not least, is the Two-Handed Interface - probably the best method currently available for assembling a three-dimensional world. We live in a three-dimensional world and interact with it day to day with our hands. While it is very intuitive, it is technically difficult to achieve, but once done allows a user's unprecedented productivity.

What is SmartScene?

- Turnkey immersive application for assembly and visualization
- Millions of realtime models for free
  - Models, plus SmartKits and SmartPalettes
- ModelTime Behaviors
- Two-Handed Interface

THE SMARTSCENE APPROACH

A traditional and accepted method of creating a world is to "model" it. This requires not only a great deal of skill to use an application sufficiently complex to capture an object's characteristics, but also requires a user to be adept enough to use the application and be knowledgeable and familiar with the object and its characteristics in order to be able to "describe" it to the application. These models are usually "one-offs."

This approach is alright for objects, but it is very cumbersome to use this approach to "model" large, complex scenes. Wouldn't it be better if an object's behavior was built into the model? The model could then be assembled into new scenes without having to create new objects from scratch.

For those cases when an object's geometry already exists in another application format, SmartScene has the ability to import these objects so that the SmartScene modeling and assembly time can be reduced.

The SmartScene Approach

- Modeling is difficult, technical, expensive
- Assembly is easy, library availability is rising, and therefore, assembly is cheaper
- Efficiencies built into the models; they know how to behave
- Import customer's unique database through MG/GG: 3DS, Alias, SoftImage, VRML, OpenInventor

BUNDLED MODELS, SMARTKITS AND SMARTPALETTES

SmartScene ships as a complete product. It includes a set of models, kits and the ability to change them. In addition, it allows users to import custom models from the world's leading real-time three-dimensional modeling tools: GameGen and MultiGen.

Bundled Models, SmartKits and SmartPalettes

- Over 400 individual models
- 10 shipped 7/31: 10 Kits by 12/96
- SmartPalettes for each SmartKit
- Import customer's unique database and add Smarts with Smarts Editor Option to MG/GG

BUNDLED MODELS OF "ONE-OFFS" WITH ASSOCIATED SMARTPALETTES

SmartScene includes over 400 models in generally applicable areas. While these models do not include all the flexibility of SmartKits, they do include LOD's. This results in efficient processing and display during rapid point of view movement.

Bundled Models of "One-Offs" with Associated SmartPalettes

- Over 400 unique models with 3-4 LOD's
  - Fast-food: Architectural copies
  - Banks
  - Car dealerships
  - Bookstores
  - Drugstores
  - Grocery stores

TWENTY KITS PROVIDE MILLIONS OF VARIETIES FROM A FINITE LIBRARY

There are twenty kits in SmartScene. These kits include all the pieces needed to "snap together" a custom high-rise, house, etc. Given the assembly approach that is fundamental to SmartScene, this snapping together happens very rapidly.

Twenty Kits Provide Millions of Varieties From a Finite Library

• Industrial:	bridges, power poles, etc.
• Park:	playgrounds, swings, etc.
• Factory:	walls, roofs, etc.
• High-rise:	bottom, middle, top floors
• Restaurant:	walls, roofs, add-ons, etc.
• House kit:	walls, roofs, etc.
• Shopping center:	storefronts, entry, etc.
• Municipal bldg.:	lights, parking signs
• Parking lot:	meters, wheel stops
• Block:	mail box, trees, etc.

SMARTPALETTES

For the models and the kits, the ability to change aesthetic qualities is called SmartPalettes in SmartScene. Through a "palette" a user can change color and texture of a surface. For example, a user could change the exterior of a building from wood clapboard to brick with one hand motion. With the same hand motion, he could change the type of windows and doors in a high-rise and evaluate different color schemes for the windows, trim and doors.

SmartPalettes

- Color and texture modification on a surface by surface basis
  - Change exteriors from brick to wood
- Create unique high-rises with simple window pane texture replacement (use Photoshop to create, then add to the SmartPalette)

The Smart Agenda

- What is SmartScene
- Markets
- Key technologies
- Availability and pricing

APPLICABLE MARKETS

These are the markets upon which we are focusing. Each shares the fact that they require the placement of objects, and those objects have characteristics in their environment based on their location and position.

Applicable Markets

- Entertainment
- Mission planning/training
- Urban planning
- Digital prototyping/mechanical assembly
  - Training
- Applications development

KEY BENEFITS OF SMARTSCENE IN MISSION PLANNING

It is vitally important that the time between acquiring data and briefing on that data is as short as possible. This is to ensure the accuracy of the information and guarantee the realism of the training in preparation for the actual event.

The Two-Handed Interface provides access to an unlimited number of Viewpoints and Perspectives, and despite its power, a new user can be trained in an hour.

Key Benefits of SmartScene in Mission Planning

- 48-hour turnaround for updates/debriefings
- Unlimited Viewpoints/Perspectives
- Non-modeling professional in the loop
- Training time under one hour
- Rich library of models and parts

Beta Site: NAWCTSD, Virtual Quantico

KEY BENEFITS OF SMARTSCENE IN URBAN PLANNING

Instead of having long turnaround times, SmartScene enables sufficiently rapid turnaround that a planner can be in the planning loop. This is in contrast to changes having to be "modeled" and then reviewed.

The unlimited Viewpoints enables a planner to ask and *see* the answer to "what if" questions:

- What if this building were 20 stories instead of 15?
- Would we still be able to see the river from the building across the street?
- If we cut down these trees what would the view be like from the playgound?

Key Benefits of SmartScene in Urban Planning

- Architect/planner in the loop
- Develop asset for planning (3D model) vs. expense (animation)
- Insert POI in a site-approximated scene
- Rapid iterations
- Quick, unlimited access to Viewpoints
- Rich part and model library

KEY BENEFITS OF SMARTSCENE IN ENTERTAINMENT

Storyboarding is the process of defining the sequence of events and the environment that will be filmed. SmartScene is directly applicable because of its ability to assemble a scene and modify it faster than any other method. This flexibility and rapid turnaround allows the director to be in the loop at a very early point in the process and thus reduces the possibility of an expensive rework later.

Key Benefits of SmartScene in Entertainment

- Set/scene creation with camera and lights
  - 3D storyboarding, leverage scene for artists
  - Director in the loop
  - Creativity through interaction/iterations
  - Unlimited camera path
  - Unlimited Viewpoint
  - Develops realtime scene

Beta: Electronic arts, motion tracking through scenes
Full sail, scene/set lights controller

KEY BENEFITS OF SMARTSCENE IN ENTERTAINMENT (Cont'd.)

The turnaround time is fast enough that changes could be made while on the air.

Game developers could use the capabilities of SmartScene to experience a new game environment and assess a player's perspective and experience of the game.

Key Benefits of SmartScene in Entertainment

- Virtual sets: realtime modification of sets while on the air
- Game developers: prototype interaction and evaluate limitations of movement

KEY BENEFITS OF SMARTSCENE IN DIGITAL PROTOTYPING/MECHANICAL ASSEMBLY

The ability of SmartScene to assemble objects quickly is applicable to digital prototyping and mechanical assembly. Using Smarts, a user could evaluate the fit of a wheel on an axle and *see* if it interferes with the wheel while the tire is rotating.

A user could evaluate ergonomics by seeing if his hand could fit into a cutout.

Education and training could be streamlined by showing procedures that are difficult, expensive or hazardous.

Key Benefits of SmartScene in Digital Prototyping/Mechanical Assembly

- Verify procedures/layout/fit
- Visually/functionally trace sub-systems
- Evaluate ergonomics
- Education and training
- Safety
- EASY TO TRAIN PERSONNEL

Beta: LEGO; fit and function of parts, ease of use

KEY BENEFITS OF SMARTSCENE IN APPLICATIONS DEVELOPMENT

SmartScene can be used to experience three-dimensional GUI development by being able to see and move it before it is actually implemented.

These three-dimensional GUI's could be used to create a virtual control process for a processing plant. A user manipulating the control panel would be learning how to control the plant processes.

The Two-Handed Interface could be used to train people in how to deal with hazardous materials.

Key Benefits of SmartScene in Applications Development

• 3D GUI Dev.:	See it, move it
• Medical: - Beta: Univ. of Missouri	Training and education
• Data Visualization:	Two-Handed Interface
• Virtual Control Panel: - Beta: Full Sail	Control/training
• Virtual Robotics:	Hazardous materials

The Smart Agenda

- What is SmartScene
- Markets
- Key Technologies
- Pricing and Availability

KEY SMARTSCENE TECHNOLOGIES

There are several key technologies that are embodied with SmartScene.

• ModelTime Behaviors is the technology that allows SmartScene to know that a wheel goes on an axle and rotates in a plane at a right angle to the axle.

• The Two-Handed Interface of Intuitive, since it deals with our real three-dimensional day to day world. It can be learned in less than an hour.

• The SmartKits and Palettes allow rapid assembly and customization of any scene.

• Finally, it is based on widely-used technology that is itself extensible if a user wants to add his own capabilities to SmartScene.

Key SmartScene Technologies

- ModelTime Behaviors: Attributes for behavior in an assembly environment
- Two-Handed Interface: Intuitive!
- SmartKits: 20 Kits by 12/96
- SmartPalettes: associated with each Kit
- Based on Performer (SGI), customer may add on SmartScene functionality

The Smart Agenda

- What is SmartScene
- Markets
- Key Technologies
- Pricing and Availability

SMARTSCENE: PRICING AND AVAILABILITY

The stand-alone application is $30K. It includes all of the kits and palettes that we have talked about thus far.

The option that allows a user to give Smarts to a model is an option to MultiGen, the application. MultiGen itself is $15K and the option that adds Smarts is $10K.

SmartScene: Pricing and Availability

- For use with bundled models and kits
  - SmartScene Application $30K US
  - Available today
- To import and educate new or existing models
  - MultiGen II $15K US
  - Smarts Editor Option $10K US

THE HARDWARE PIECES

SmartScene currently runs on SGI systems only. The minimum configurations are listed.

The rest of the peripherals needed can be purchased as a bundle from FakeSpace.

A cable kit needs to be ordered with the MultiGen software.

The Hardware Pieces

- Silicon Graphics W/S Only
  - Min: Indigo2 High IMPACT with ICO, TRAM
    - Functionally strong; not a price point
    - Onyx RE2, iR (anti-aliased polygons)
- FakeSpace: "SmartScene Peripheral Pack"

- Headmount:	Virtual Research VR4
- Tracker:	Polhemus/Ascension
- Gloves	FakeSpace

- Cable Kit (order with s/w from MGI)

Virtual Collaborative Simulation Environment for Integrated Product and Process Development

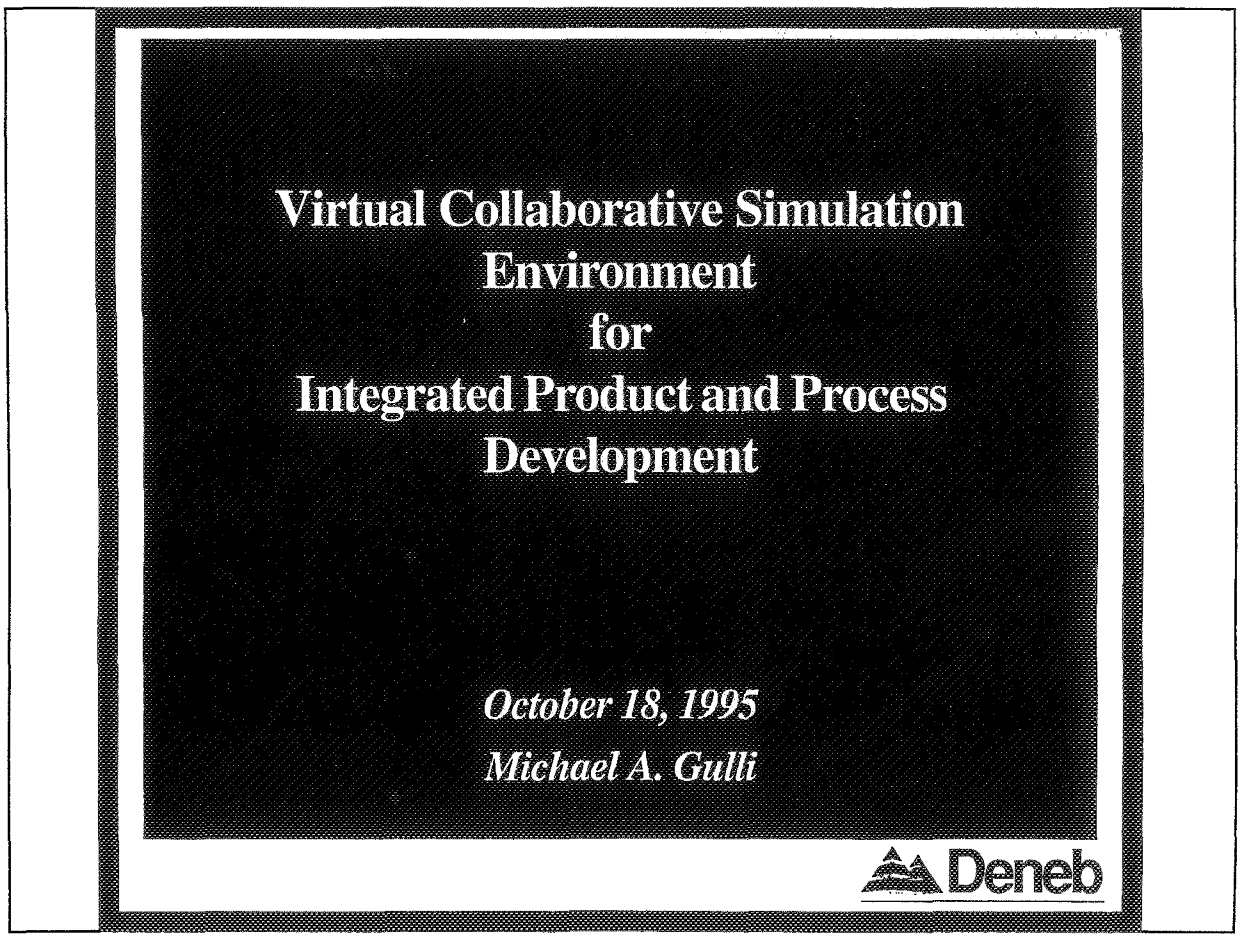
Michael A. Gulli
Deneb, Inc.
Auburn Hills, MI

VIRTUAL COLLABORATIVE SIMULATION ENVIRONMENT FOR INTEGRATED PRODUCT AND PROCESS DEVELOPMENT

Michael A. Gulli
Deneb Robotics
Auburn Hills, Michigan

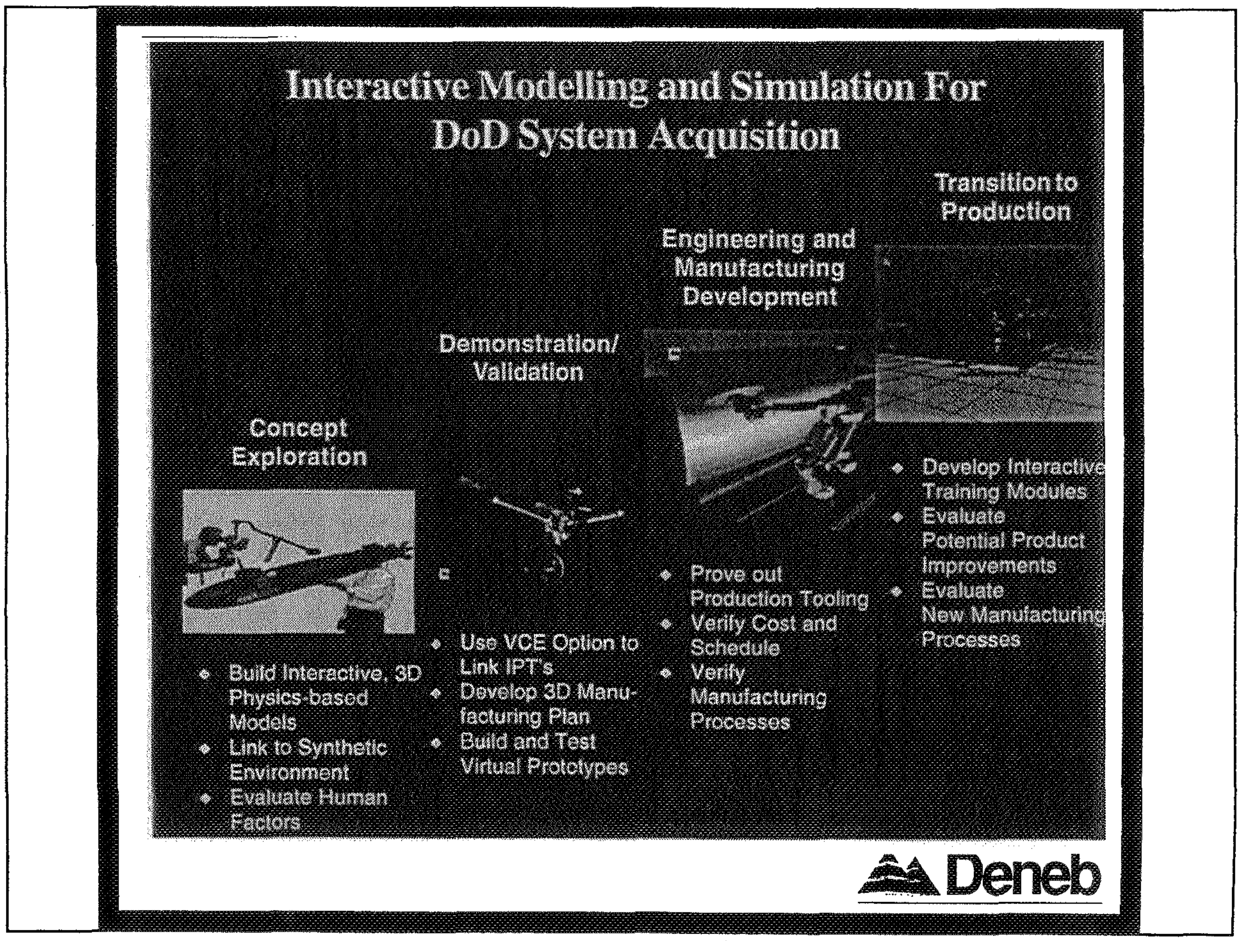
Introduction

Deneb Robotics is a leader in the development of commercially available, leading edge three-dimensional simulation software tools for virtual prototyping, simulation-based design, manufacturing process simulation, and factory floor simulation and training applications. Deneb has developed and commercially released a preliminary Virtual Collaborative Engineering (VCE) capability for Integrated Product and Process Development (IPPD). This capability allows distributed, real-time visualization and evaluation of design concepts, manufacturing processes, and total factory and enterprises in one seamless simulation environment.



INTERACTIVE MODELING AND SIMULATION FOR DOD SYSTEM ACQUISITION

Deneb's commercial-off-the-shelf (COTS) interactive three-dimensional simulation tools support the entire DOD system acquisition process from concept exploration through production and training. Physics-based virtual prototypes can be rapidly developed and evaluated by integrated product teams during concept exploration. In the demonstration/validation phase, virtual prototypes can be tested in synthetic environments and supportability, maintainability and producibility issues can be addressed very early in the design cycle. Then manufacturing processes can be proved out during engineering and manufacturing development using the engineering and tooling models and alternative production scenarios and factory layouts can be developed and evaluated. Finally, training modules for users, operators and manufacturing personnel can be developed reusing the engineering models to ensure a smooth transition to production and deployment in the field.

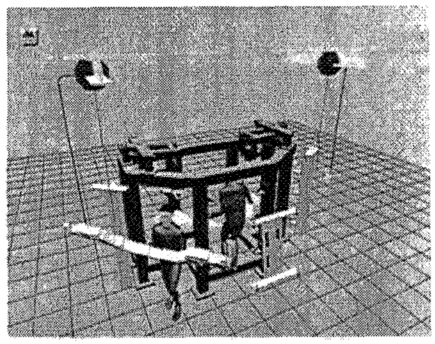


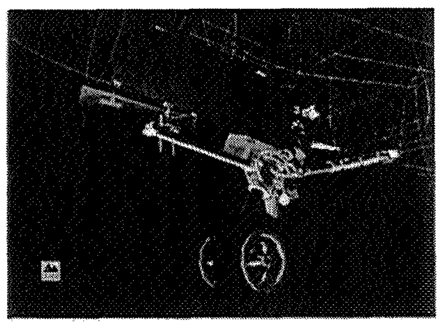
INTERACTIVE THREE-DIMENSIONAL SIMULATION PRODUCTS - ENVISION

Deneb's ENVISION software provides tools including kinematics and dynamics for rapid prototyping of design concepts, the application of physics-based analyses, assembly modeling, process modeling, human factors evaluation, and mission planning tasks. Vertical application packages for arc welding, spot welding, painting, deburring and other manufacturing processes are also available.

Interactive 3D Simulation Products

- ENVISION
  - Rapid Prototyping
  - Real-time Kinematics and Dynamics
  - Real-time Collision Detection
  - High-speed Rendering
  - Level of Detail Management
  - Camera Model for Visualization
  - Integrated Ergonomics Option
  - Assembly Modelling
  - Customizable User Interface





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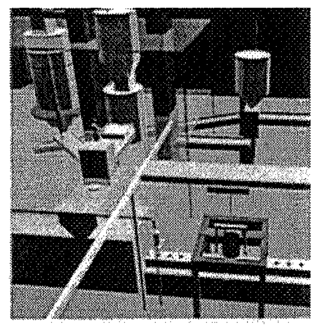
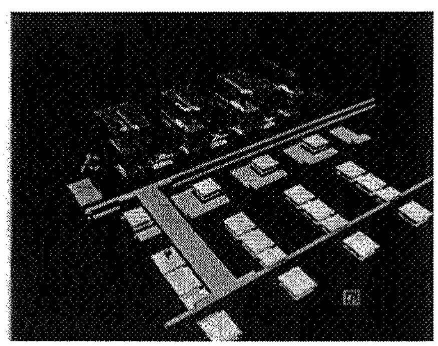
INTERACTIVE THREE-DIMENSIONAL SIMULATION PRODUCTS - QUEST

Deneb's QUEST software is a three-dimensional graphics-based discrete event simulation tool for modeling, visualization, and evaluation of manual and automated manufacturing systems. Geometrically accurate equipment models provide the user a realistic simulation environment to analyze multiple "what if" production scenarios to determine the optimum manufacturing system based on throughput, cost, utilization, productivity, and other user defined parameters. Models created in ENVISION or other Deneb software can be directly imported into QUEST to create one seamless environment to facilitate IPPD.

Interactive 3D Simulation Products

- QUEST
  - Logistics Modelling
  - Simulate Material Flow and Identify Physical Bottlenecks
  - Rich Library of Geometric Models
  - Evaluate Machine and Labor Utilization
  - Perform Batch Simulation Runs
  - Link to ENVISION and Virtual NC Simulations
  - Full Feature Statistical Analysis





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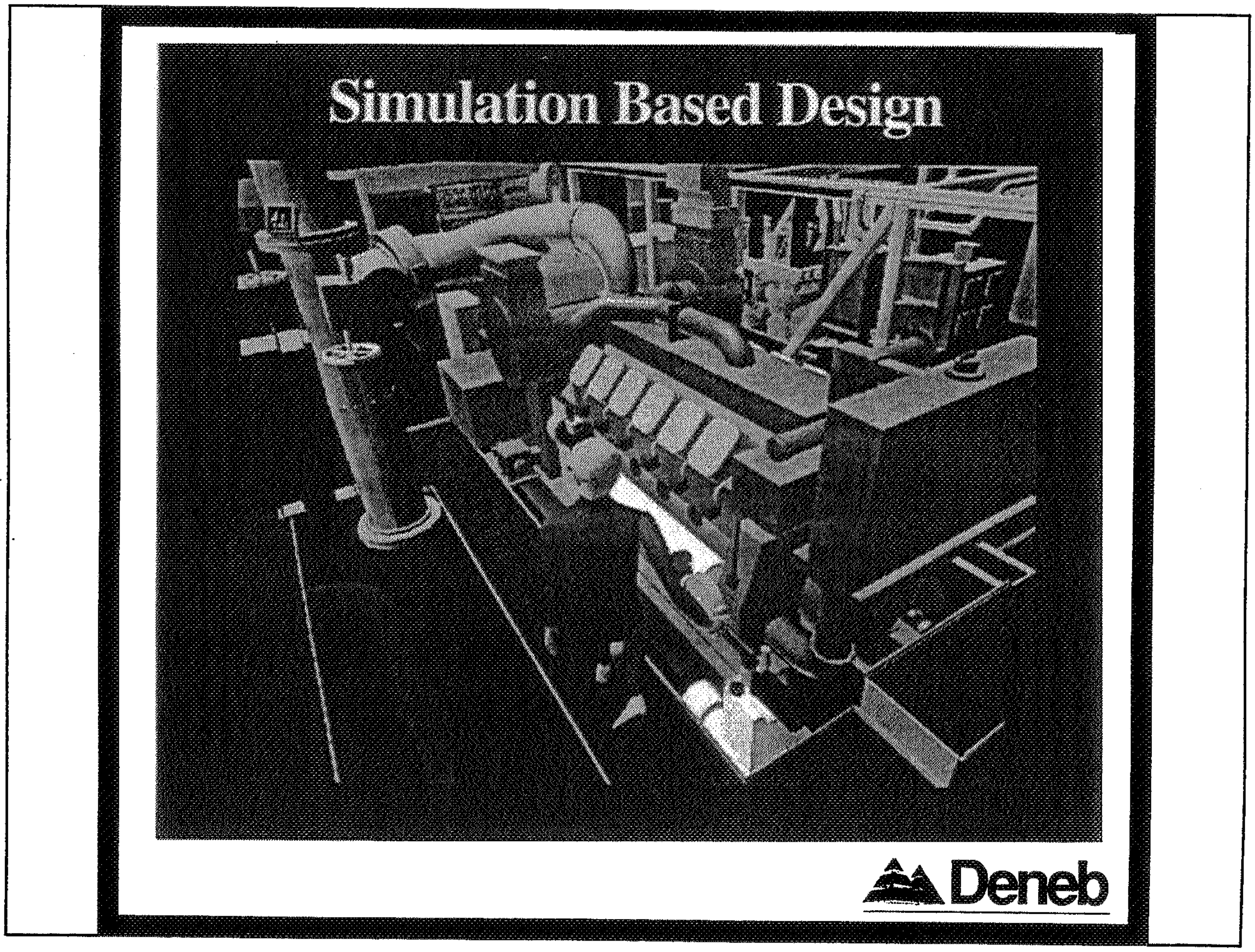
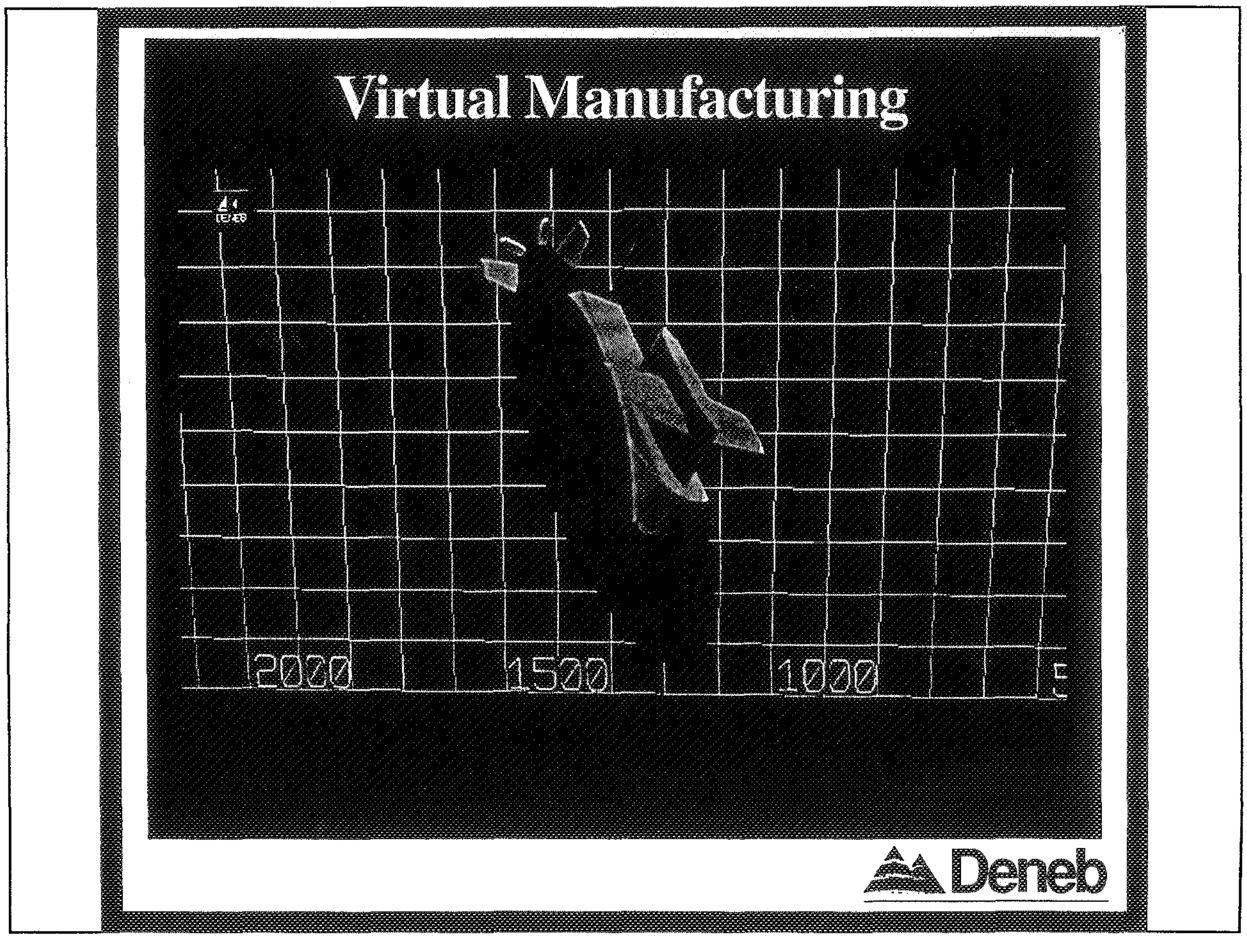
SIMULATION BASED DESIGN (HELPER)

Deneb's ENVISION (with Deneb/ERGO option) simulation tool was used on the DARPA Simulation Based Design Program by General Dynamics' Electric Boat Division to provide seamen a virtual environment in which to train for the operation of various submarine systems. Simulations included the startup sequence for the emergency diesel engine and firefighting scenarios in the engine room.



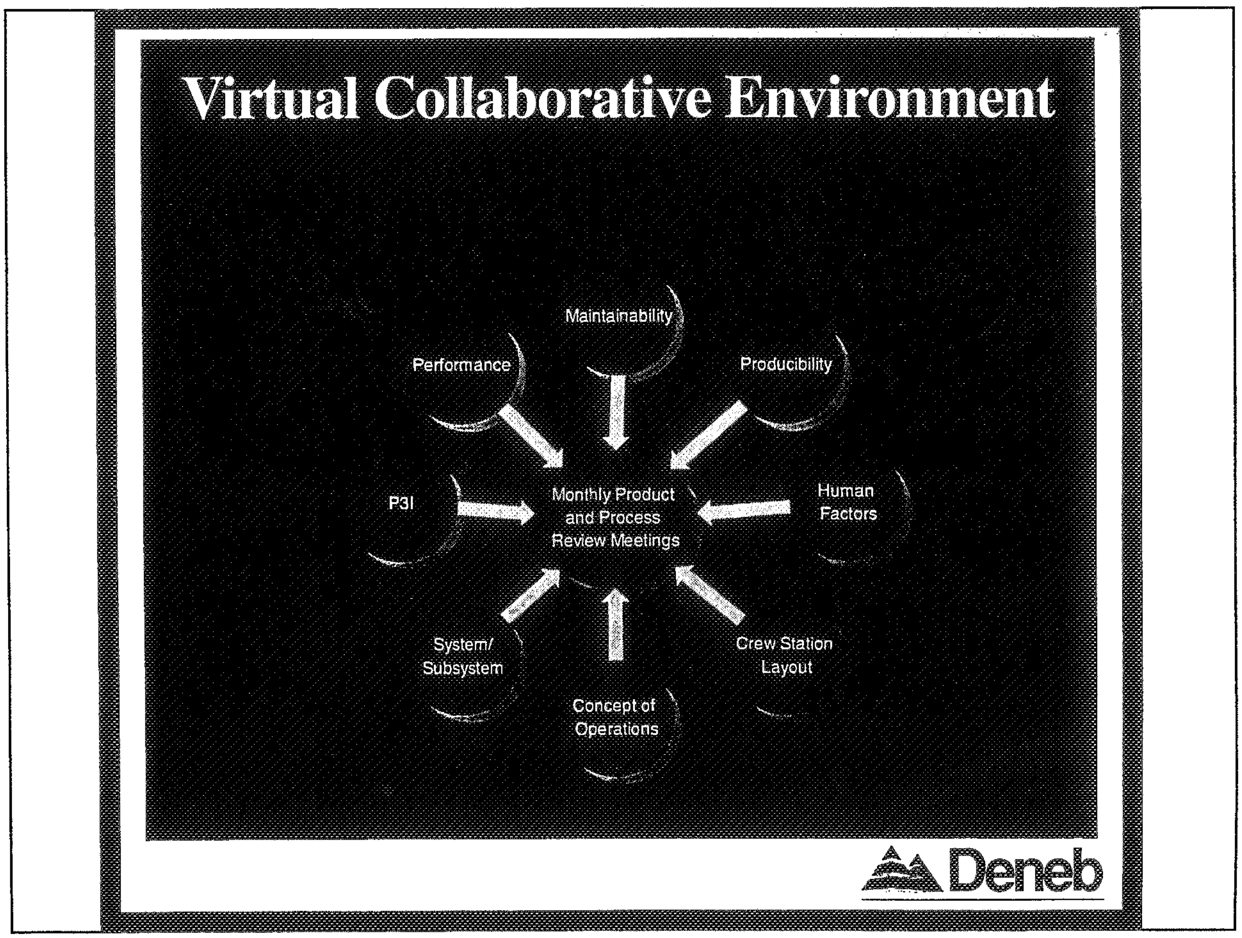
VIRTUAL MANUFACTURING (SUBMARINE)

The ENVISION software was also used to perform virtual manufacturing. For example, Electric Boat simulated the assembly of decks and hull sections of a submarine in an effort to optimize the loading sequence. The loading sequence becomes a critical concern when a vendor cannot meet their delivery date. In order to avoid shutting down the assembly process, it is necessary to determine which other components can be loaded and assembled out of sequence while still providing space to later put in the late component.



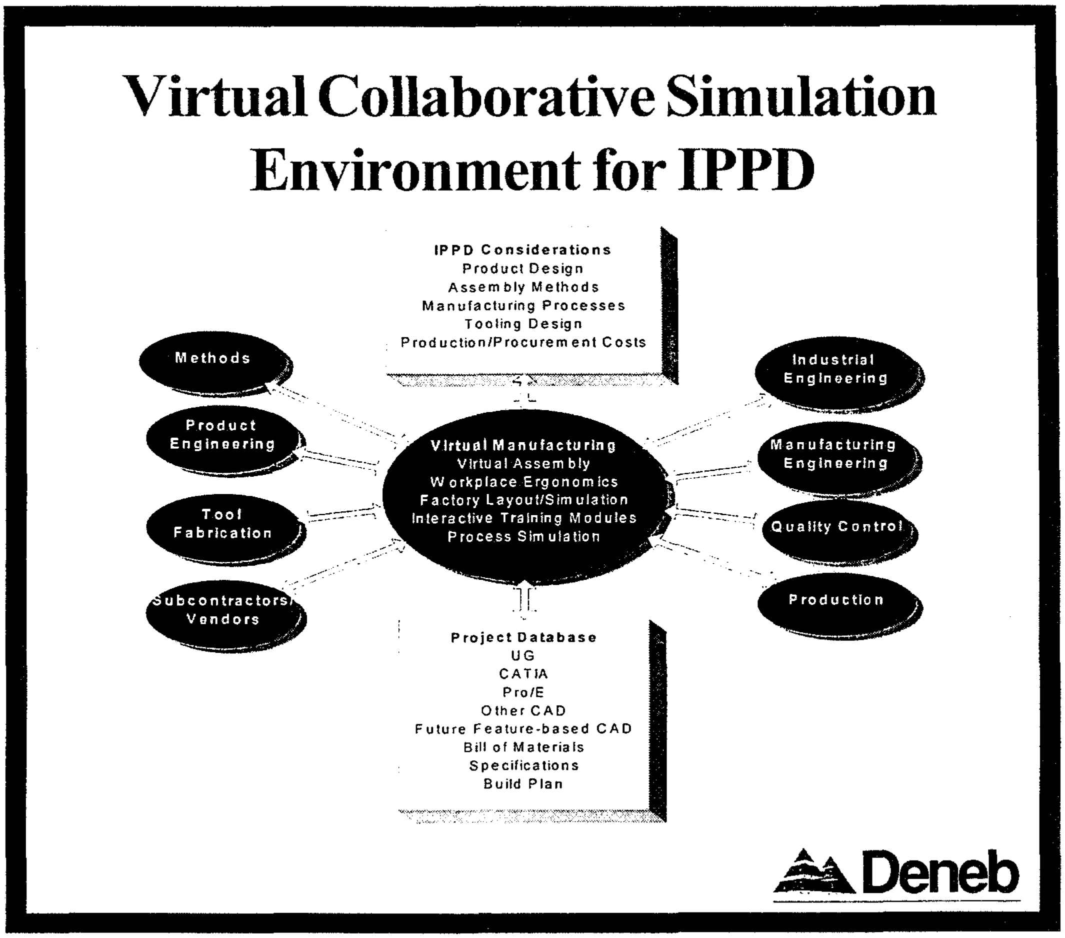
VIRTUAL COLLABORATIVE ENVIRONMENT

Deneb's Virtual Collaborative Engineering (VCE) environment provides a distributed, real-time interactive capability for realistic engineering three-dimensional simulations to link integrated product teams over wide area networks. It allows any participant to assume simulation control in real-time. Deneb's VCE is based on TCP/IP stream sockets utilized in a hub architecture. The simulation environment information is passed in a dynamic client/server relationship, allowing either side to become server, automatically switching all other collaborators to client operation. VCE supports UNIX workstations and Windows NT PC's to allow a wide variety of disciplines to participate.



VIRTUAL COLLABORATIVE SIMULATION ENVIRONMENT FOR IPPD

Engineers, manufacturing personnel, system operators and suppliers are able to interactively evaluate design concepts, manufacturing work cells, processes and factory layouts in the Deneb simulation environment at geographically remote locations. VCE facilitates the evaluation, analysis and modification of complex system and subsystem designs and complex manufacturing cells. For example, on a typical aircraft development program, with tool design activities performed at one site, production scheduled for another, and method planning at a third location, the process of refining the basic system configuration to facilitate assembly operations would require the interaction of these disciplines along with product engineering personnel participation.



VCE BENEFITS

Using Deneb's three-dimensional environment coupled with the current and future VCE capabilities increases productivity and reduces cost and time to market for large, multi-company IPPD teams collaborating on complex projects. A significant savings is achieved through interactive engineering and manufacturing reviews while minimizing travel needs and improving communications across multi-company IPPD team disciplines.

Virtual Collaborative Environment

- **Benefits**
  - Facilitate Design Reviews
  - Link Integrated Product Teams
  - Integrate Suppliers and Users Early
  - Facilitate Integrated Product and Process Development
  - Reduce Costs
  - Improve Communications

Deneb

An Integrated Product Environment

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AN INTEGRATED PRODUCT ENVIRONMENT

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INTRODUCTION

Arthur C. Clarke once stated that *"any sufficiently advanced technology should be indistinguishable from magic."* We are pleased to offer to you our *"magic show,"* the Advantage Series. This paper will specifically detail only one of our Advantage Series products, Cost Advantage. However, I would like to briefly describe our other product, Mechanical Advantage, which completes what we call an *"Integrated Product Environment."*

Mechanical Advantage is a mechanical design decision support system. Unlike our CAD/CAM cousins, Mechanical Advantage addresses true engineering processes, not just the form and fit of geometry. If we look at a traditional engineering environment, we see that an engineer starts with two things - performance goals and design rules. The intent is to have a product perform specific functions and accomplish that within a designated environment. Geometry should be a simple byproduct of that engineering process - not the controller of it. Mechanical Advantage is a performance modeler allowing engineers to consider all these criteria in making their decisions by providing such capabilities as critical parameter analysis, tolerance and sensitivity analysis, math driven geometry, and automated design optimizations. If you should desire an industry standard solid model, we would produce an ACIS-based solid model. If you should desire an ANSI/ISO standard drawing, we would produce this as well with a virtual push of the button. For more information on this and other Advantage Series products, please contact the author.

Now for the focus of this paper, we present Cost Advantage.

ADVANTAGE SERIES
AN INTEGRATED PRODUCT ENVIRONMENT (IPE)

Cognition Corporation offers a sophisticated suite of products creating an "Integrated Product Environment" - the Advantage Series. This paper will put forth one of these products - Cost Advantage.

TRADITIONAL METHODOLOGY

Before we go too far, let's first look at the traditional methodology for approaching the design and manufacturing process.

Loop 1 (Figure 1) - An engineer gets an idea and passes it to a designer to create a shape. The engineer evaluates the design and makes changes. This loop continues until the engineer is satisfied that the design will work.

Loop 2 - The finished design is then passed to manufacturing. Soft tooling is built, prototypes are created, tests are performed, and feedback is given to the engineer. The engineer makes changes and passes it back to the designer. The designer passes it back to the engineer where eventually it is passed back to manufacturing.

If you follow the arrows closely from the engineer to the designer, to the engineer, to the manufacturer, to the engineer, etc., through the normal 5-15 prototype cycles, you will see a suspicious likeness to the symbol for infinity. Is it any wonder that products are delivered before the design is fully complete, validated, adjusted, or with poor quality?

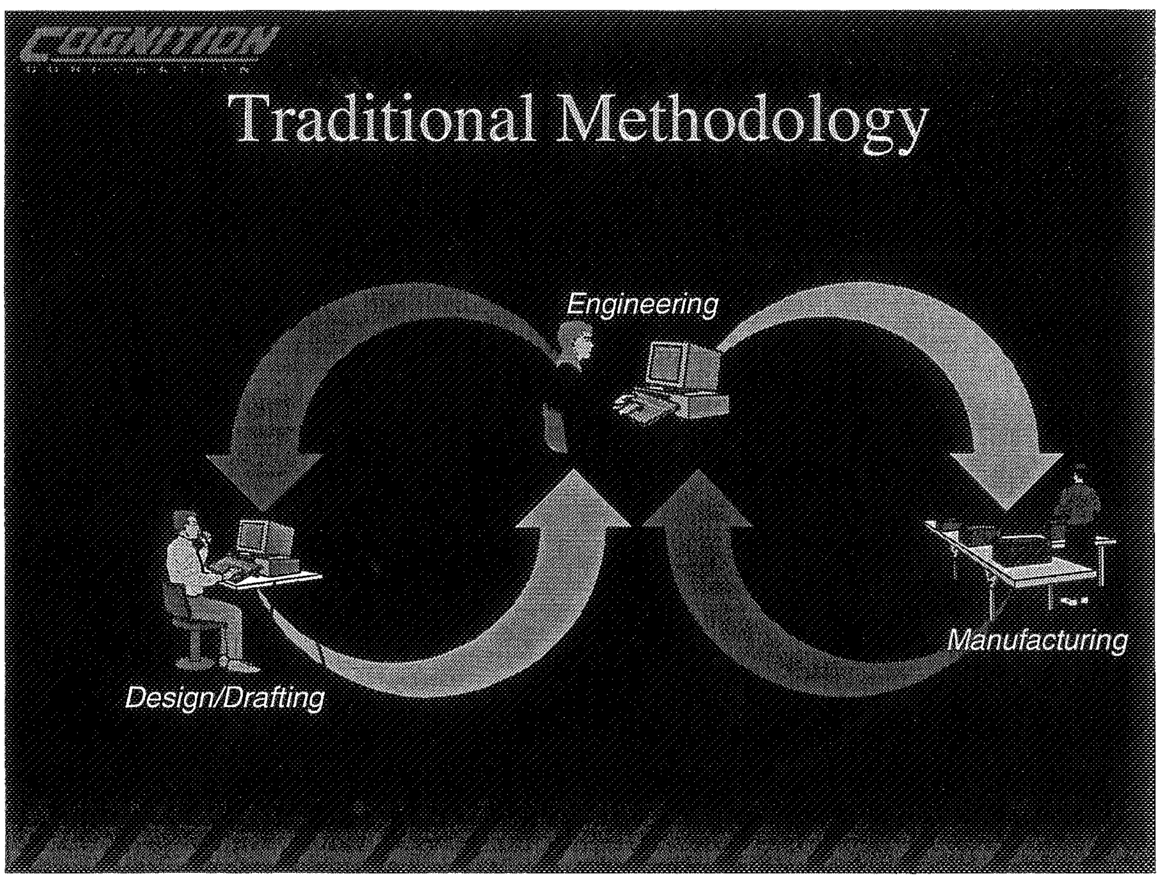

Figure 1

TRADITIONAL SOLUTIONS

Traditional methodologies require traditional solutions. In Figure 2 we see many of the islands of technology used in companies today to address this need for an "Integrated Product Environment." It is our contention that before you can have a true "Integrated Product Environment," you must provide engineers with as much knowledge about designs, processes and capabilities as you can, and make that knowledge easily accessible at the desktop. The key to an Integrated Product Environment is that the user can access whatever data is necessary from his desktop without having to attend another meeting.

However, before we can go to this promised land, we must realize what obstacles tradition has left for us.

Figure 2

OBSTACLES TO IPE

There are two primary obstacles to sharing information between engineering and manufacturing and creating an "Integrated Product Environment."

First, until now the technology to capture knowledge and make it easily available to engineers was limited and the lack of integration of this knowledge into the design environment kept this technology from being widely used.

Second, the adversarial cultures between engineering and manufacturing would not allow it, as shown in Figure 3.

Business Week has reported that, *"A high wall has always stood between design and manufacturing, with designers essentially ignorant of how their creations are transformed into products."* Another report further comfirming this problem was seen in Automation magazine stating, *"The typical American factory spends one quarter of its operating budget to fix mistakes. Yet only 20% can be traced to the way we produce our products. The other 80% rests largely in the way we design them."*

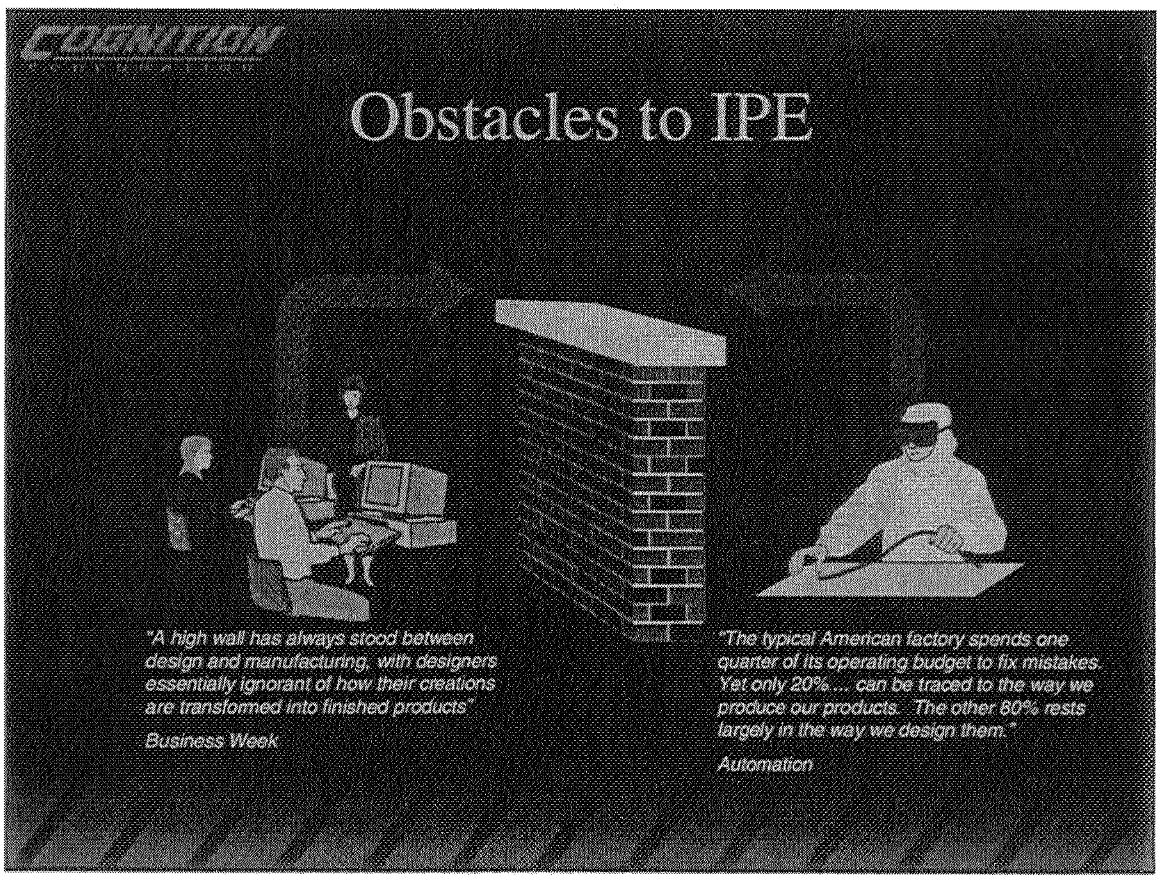

Figure 3

COST ADVANTAGE

As you suspected, there is now an answer - the Cost Advantage.

The Cost Advantage product has been adopted by several major corporations as their cost and producibility tool. Many government-sponsored initiatives have also selected Cost Advantage. We will discuss some of these in the next few pages.

Figure 4

PROGRAM INVOLVEMENT

Many government programs are using the Cost Advantage to make significant impact.

DMLCC - *Design and Manufacture of Low Cost Components* headed by G.E. Aircraft Engine is tasked with costing component manufacture of aircraft engine parts.

JSF/JMD - *Joint Strike Fighter / Manufacturing Demonstration* focuses on the integrated design and cost of JSF aircraft components.

JSF/SAVE - *Joint Strike Fighter / Simulation Assessment Validation Environment* will create a common environment for the integration and exchange of data from conceptual design to shop floor planning, risk analysis, cost and manufacturing.

RRM & IRFPA/FM - *Rapid Response Manufacturing* and *Infrared Focal Plane Array / Flexible Manufacturing* Initiatives are ARPA funded programs tasked with the reduction of design to manufacturing cycle times by as much as 25% by utilizing cost and producibility rules in design phase.

ACP - Affordable Composites Processing is a consortium effort among industry leaders in the manufacture of composites. The result of this effort will be an "industry standard" definition for composites manufacturing.

PCM - *Probabilistic Cost Modeling* is a program at Pratt & Whitney to predict costs based on floating variable inputs rather than specific rigid inputs.

NIST - *National Institute of Standards and Technology* uses Advantage Series products on several projects.

TEAM - *Technology Enabling Agile Manufacturing* (DOE) program also utilizes all the Advantage products in their efforts to address the Agile Manufacturing initiative.

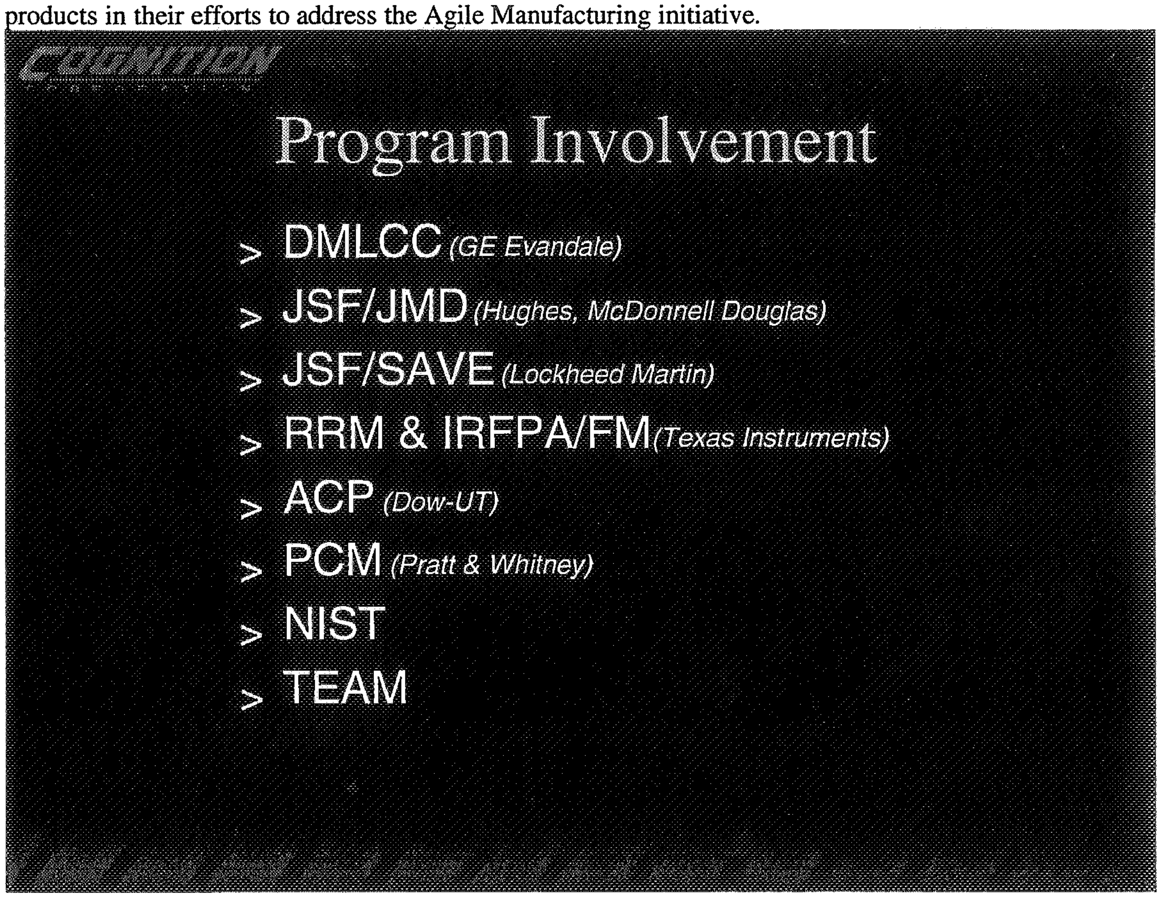

Figure 5

CUSTOMER SAMPLING

Many major corporations have also adopted Cost Advantage for automation of their product design process. A sample listing is seen in Figure 6.

Figure 6

ARCHITECTURE

Cost Advantage can be used in several configurations. One is in a "stand-alone" mode where the user simply inputs the requested information and receives instantaneous feedback. The second is in what we call "batch" mode, where the user first extracts feature information from a design to an ASCII file. That file is then read by Cost Advantage and the same feedback given as to cost and producibility. Figure 7 shows a diagram of a fully Integrated Product Environment using Cost Advantage in an integrated mode with the design engineer.

In this scenario, an engineer can sit at his/her workstation and utilize manufacturing expertise and any process knowledge needed to make design decisions based on cost and producibility. Those decisions can then be evaluated against the engineer's own rule sets and best practices and produce cost reports, summary reports, etc.

In the following pages we will further explain the details of each piece of this scenario.

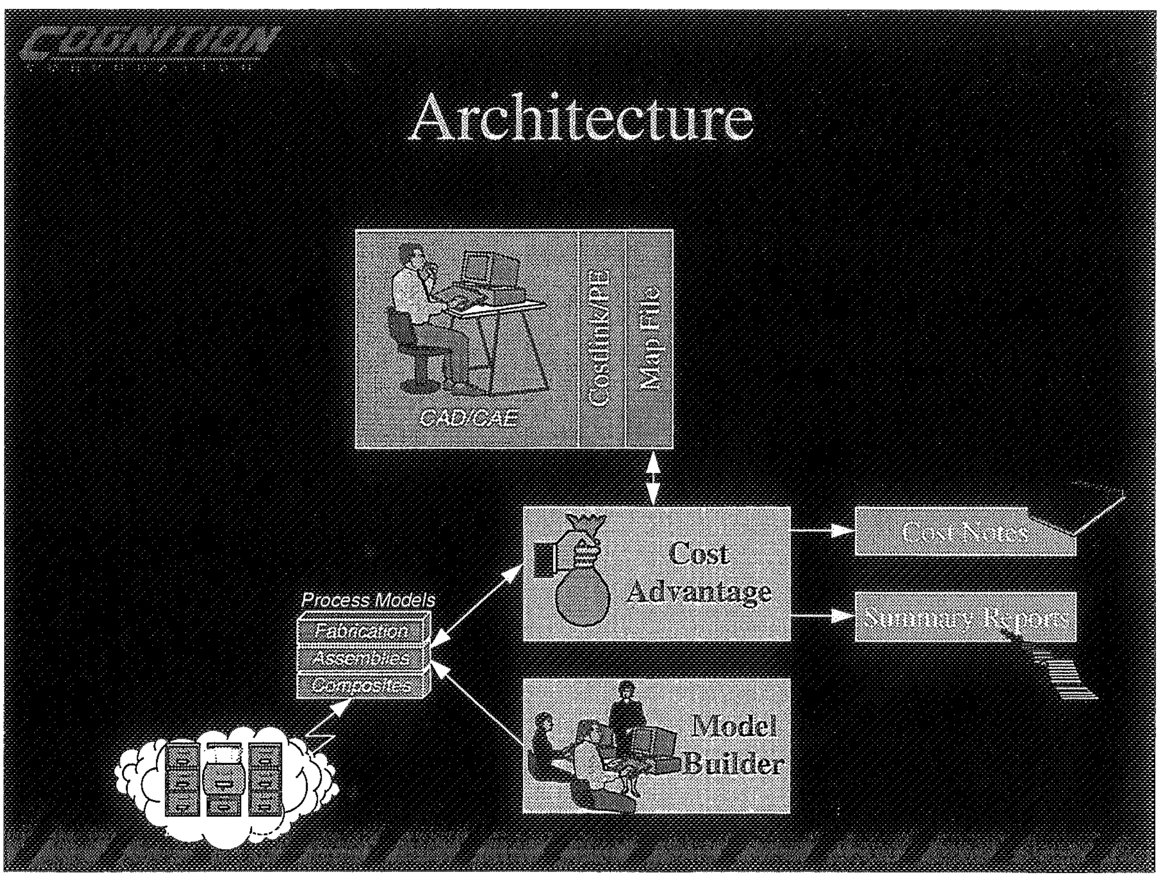

Figure 7

MODEL BUILDER

The "Model Builder" is an expert system shell which provides a forms-based programming interface utilizing a natural language format. This allows your experts, regardless of programming background, to capture very specific process knowledge. This knowledge is stored in process-specific knowledge bases defining your process characteristics, design rules, manufacturing rules, cost formulas, restrictions, capacity, design handbook guidance, and DFM/A instruction.

Additional needed information from such databases as materials libraries, tool libraries, MRP-II systems, capacity planning, etc., can easily be accessed through simple external functions.

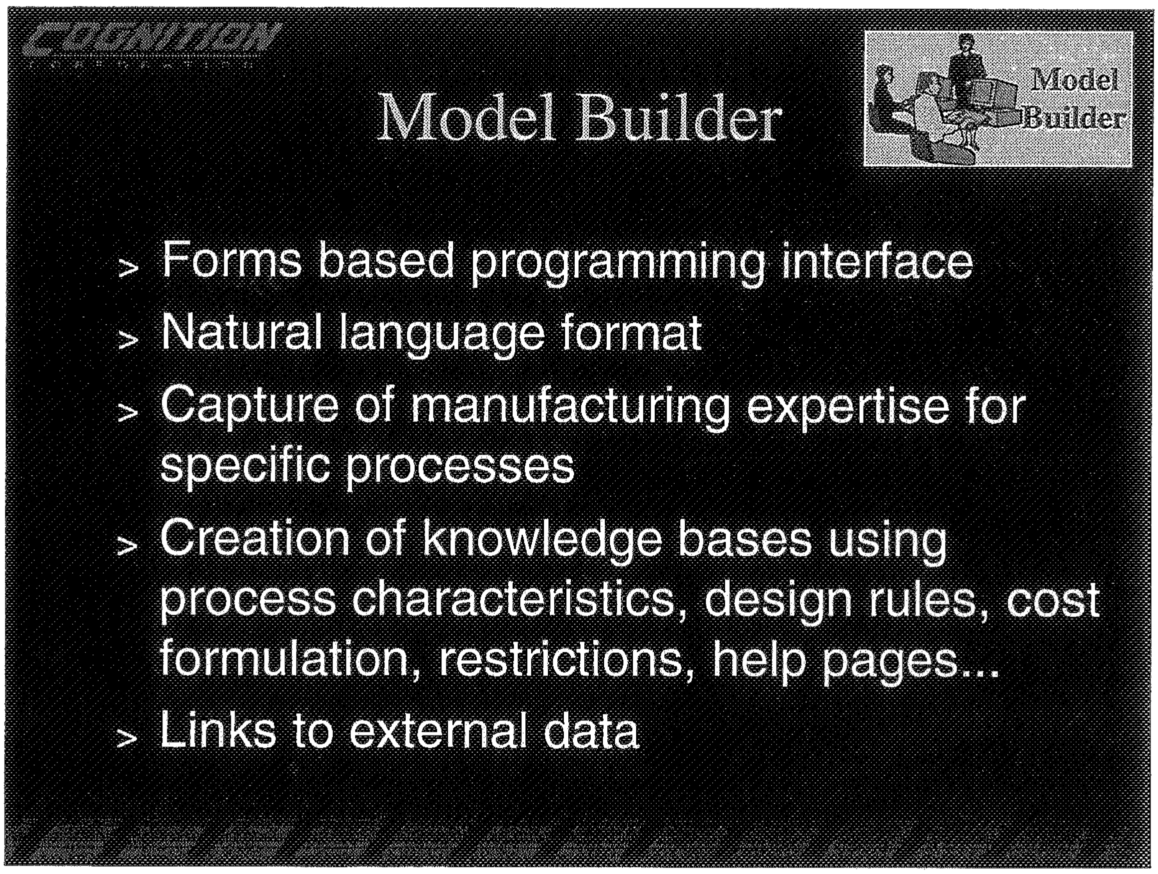

Figure 8

PROCESS MODELS

The process knowledge bases which are created in Cost Advantage allow you to capture "your" expertise in manufacturing, design engineering, industrial engineering, planning, etc., not some outside source's idea or formulation as to how you should do business. This is accomplished through our expert system shell in a hierarchical fashion. See Figure 9.

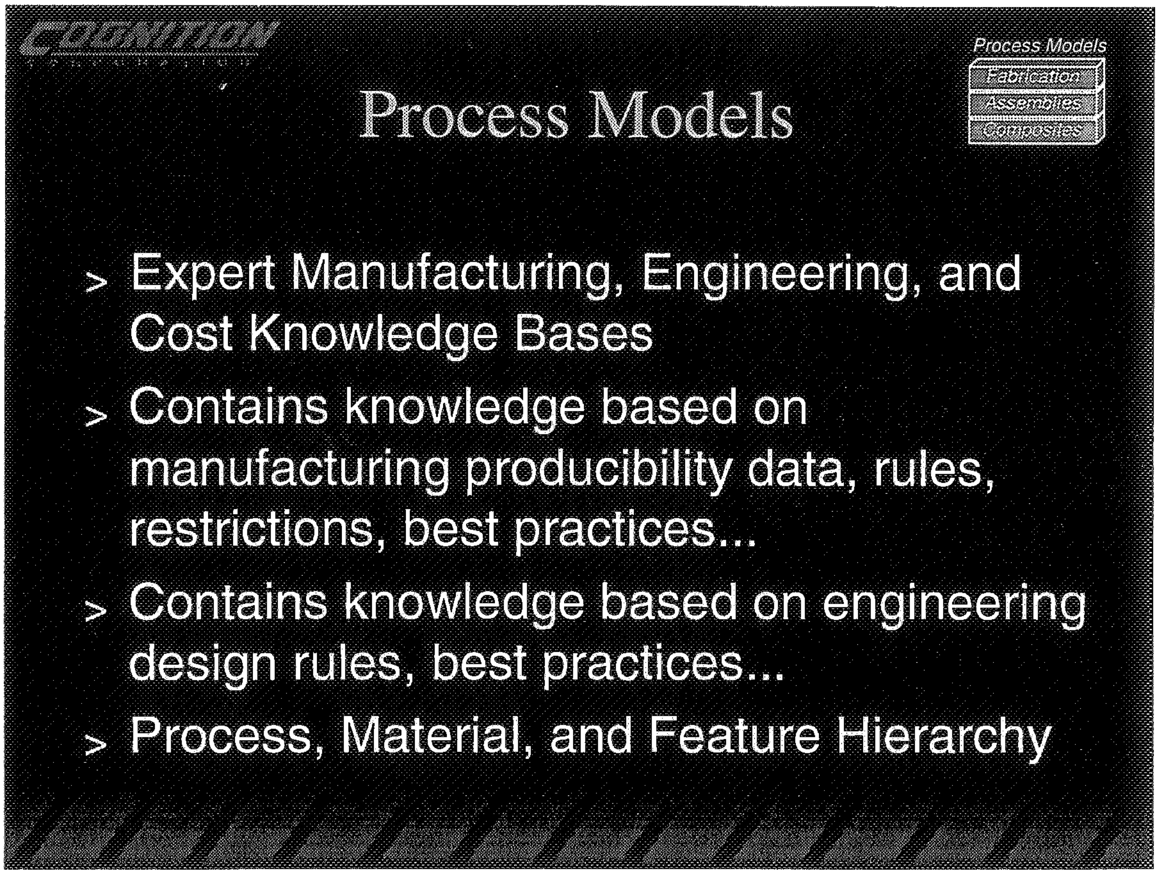

Figure 9

COST ADVANTAGE

The knowledge bases can then be used to query specific part designs as well as assemblies.

Cost Advantage will provide automated cost assessment for both parts and assemblies, producibility analysis, design guidance, manufacturing alternatives, DFM/A review, easy identification of possible cost drivers, automated trade studies, and provide detailed summary reports and audit trails.

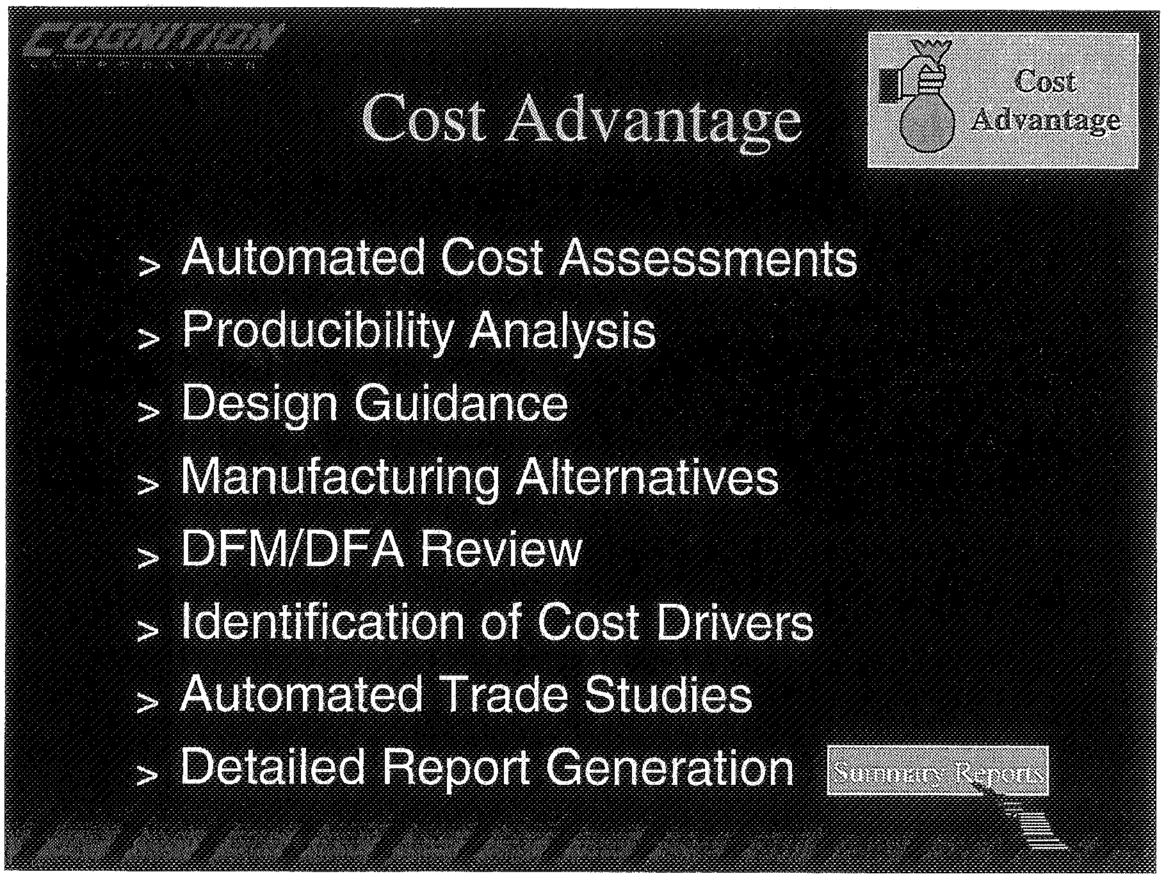

Figure 10

COSTLINK

We have now gone one step farther by providing a direct interface to many of the leading CAD/CAE packages on the market. This interface is called the CostLink.

To date we have integrated Cost Advantage with our own Mechanical Advantage, Pro/ENGINEER, and SDRC Master Series. We will soon be releasing the newest CostLink products for CATIA and Mentor Graphics. Other product integrations are also planned for the near future.

The CostLink provides an embedded application environment so it appears to the end user that he is simply utilizing another capability within the comfort of his familiar surroundings. This is done by embedding menu picks within the normal environment and providing bi-directional interface for highlighting. The CostLink will automatically extract feature and tolerance data directly from the geometry and then translate the specific design terminology to manufacturing terminology via a simple ASCII map file filter.

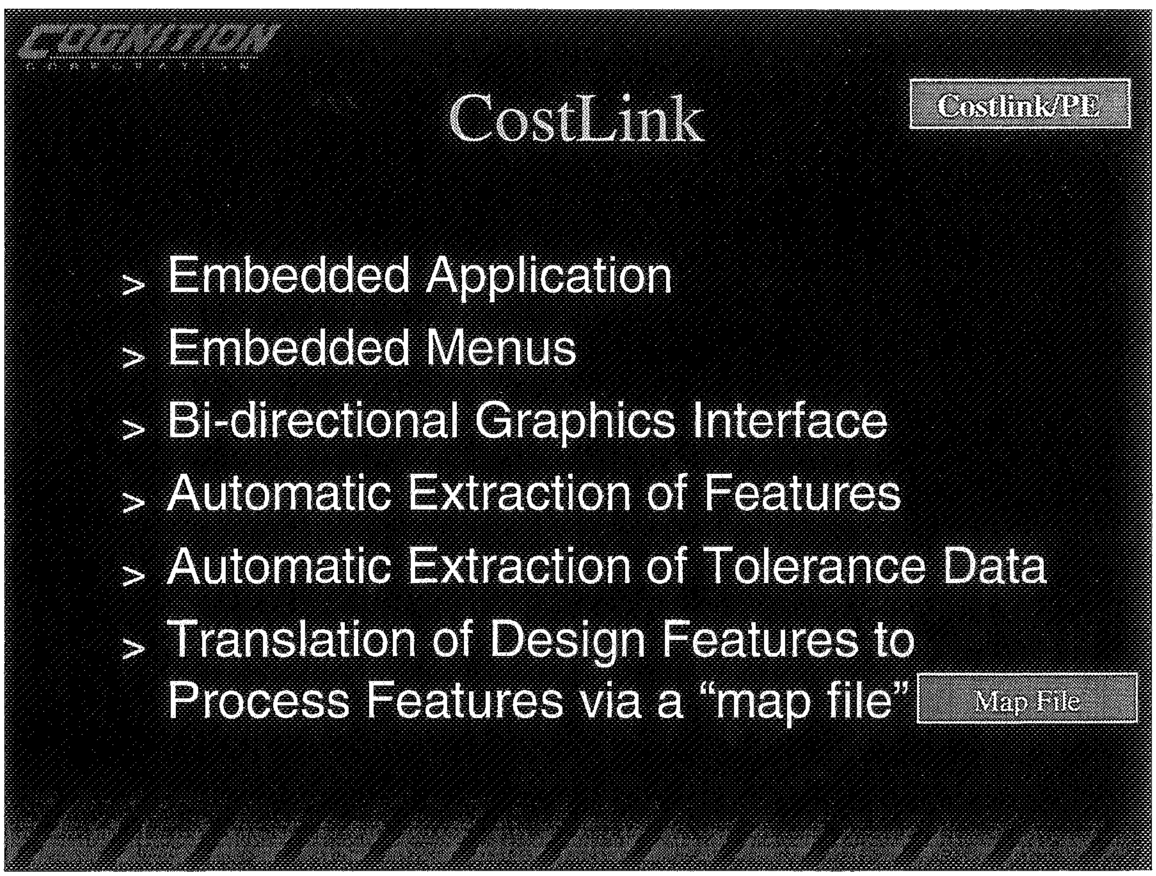

Figure 11

HOW DOES IT WORK?

What does this mean, creating an "Integrated Product Environment"?

By utilizing a knowledge-based approach to design and manufacturing, an engineer has at his fingertips the design expertise of the company, tolerance analysis, critical parameter analysis, mechanisms, complete performance design and analysis, easily usable test and validation results, detailed cost analysis, as well as complete manufacturing process knowledge. This knowledge can then be used to synthesize an accurate design through math driven design optimization routines.

Engineers' decisions can now be based on all the available information within the corporation, not just his own personal contacts or research abilities.

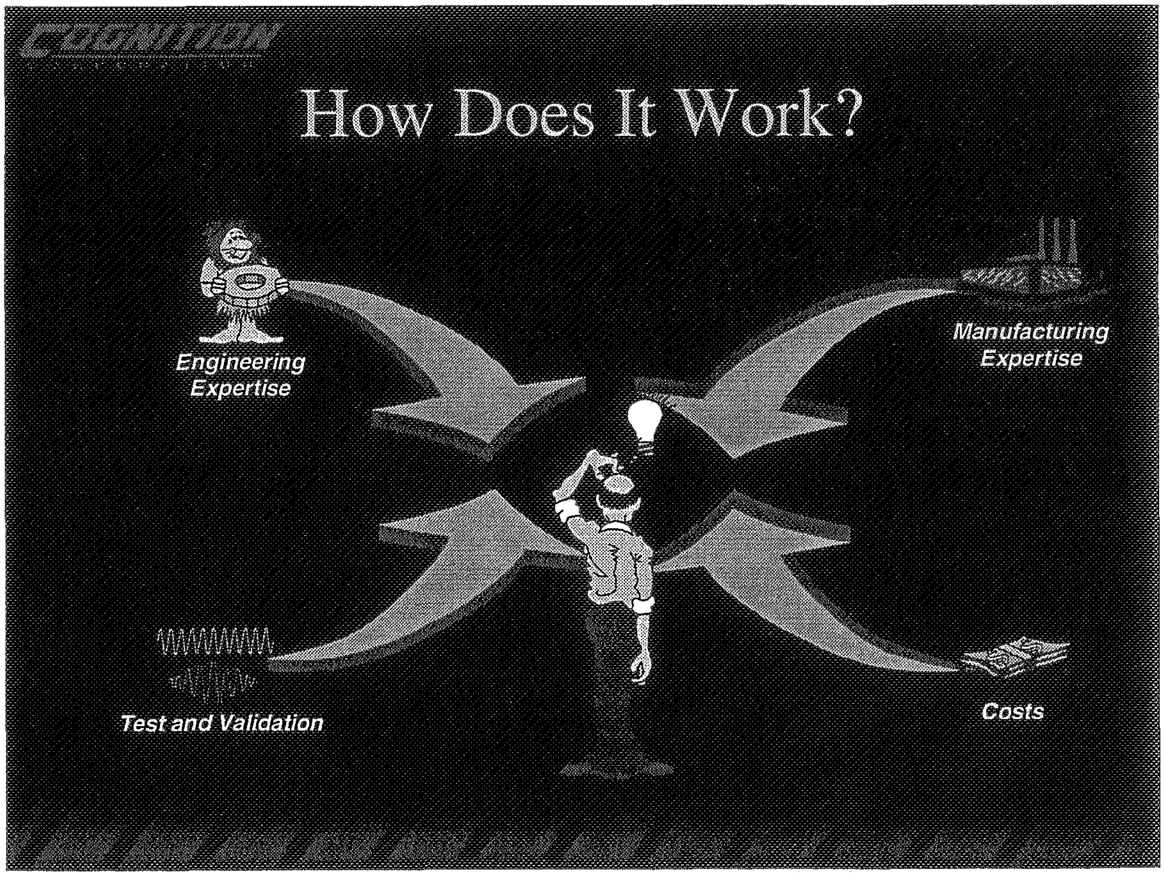

Figure 12

BENEFITS

What affect does this have on how we do business?

It will allow you to capture "your" expertise, integrate diverse knowledge across departmental boundaries, provide query on demand, and create a fully integrated environment. By integrating this KNOWLEDGE into the engineering process your manufacturing experts can concentrate on more proactive projects to improve the process rather than planning yet another meeting. Re-work and re-design loops are virtually a thing of the past. Complete traceability of every decision is automatic. But perhaps most importantly, every design is evaluated consistently with repeatable results, and as we all know, consistency is the foundation of quality.

Figure 13

DEMONSTRATION

You've read about it in the trade magazines, you've heard about it from your friends in the hallways, now, we invite you to contact us to see this revolutionary suite of products for yourself.

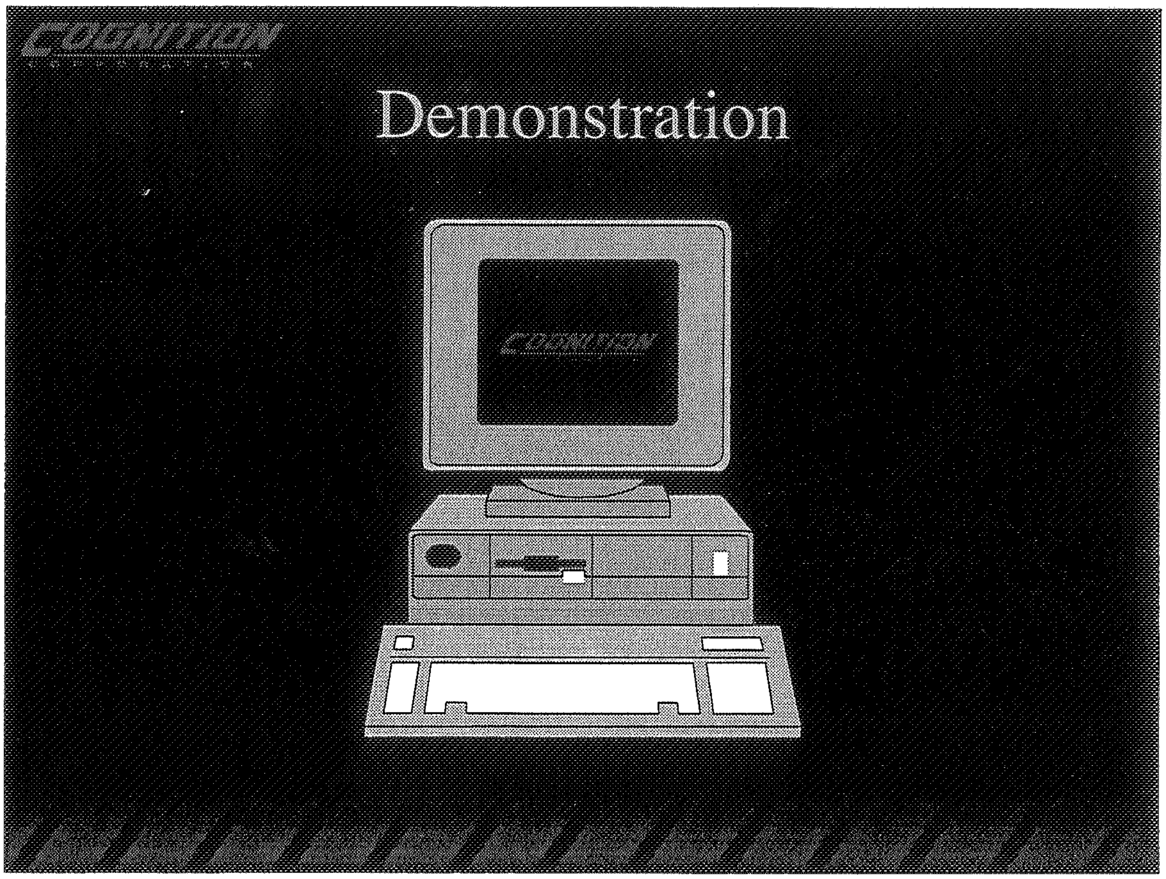

Figure 14

The Einstein Suite: A Web-Based Tool for Rapid and Collaborative Engineering Design and Analysis

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BEAM TECHNOLOGIES - MISSION

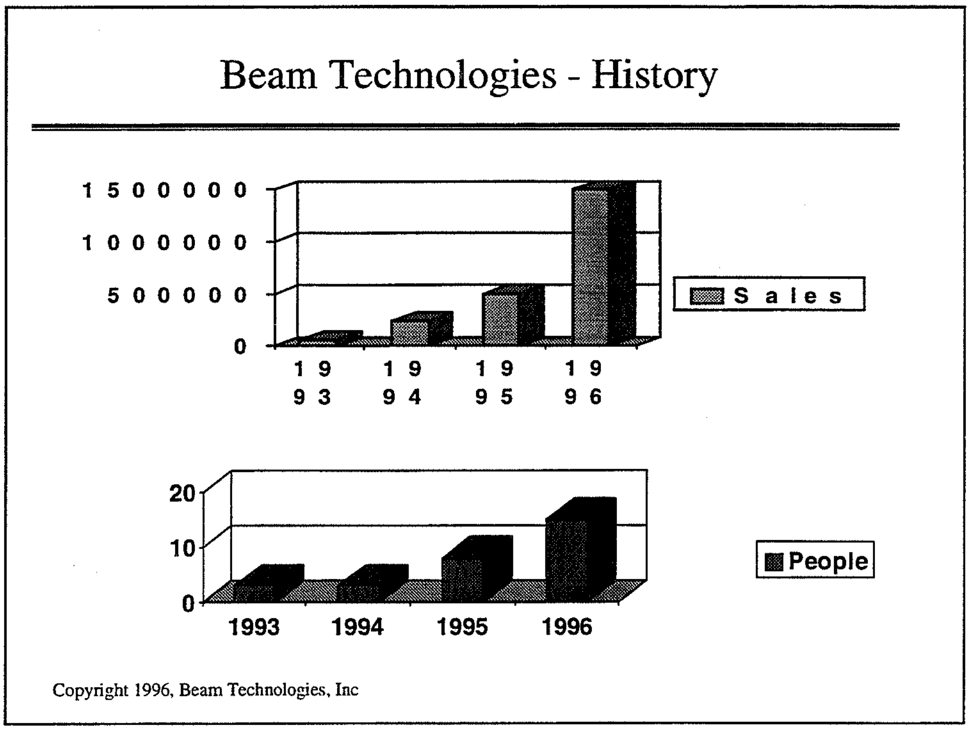
Beam Technologies provides World Wide Web based modeling and simulation software for financial and mechanical engineering applications. The range of simulators is broad and includes systems described by any combinations of ordinary differential equations (ODEs), partial differential equations (PDEs), hybrid systems (i.e., systems including both differential equations and discrete events such as rigid body dynamics with collisions, battlefield simulations, etc.).

Beam Technologies - Mission

- To deliver low-cost, high value, industrial strength WWW-based design, analysis and simulation environments for use in engineering and finance
- Specializing in:
  - PDE, PDE/ODE, hybrid PDE/ODE simulators
  - Computational fluid dynamics
  - Simulator generation technology
  - WWW interfaces for engineering and scientific computation

BEAM TECHNOLOGIES - HISTORY

Beam Technologies was started in 1993, and has grown rapidly since then.



THE EINSTEIN SUITE: A WWW-BASED ENGINEERING ENVIRONMENT

The *Einstein Suite*: A WWW-Based Engineering Environment

- ***Einstein Objects*** - Composable, scalable objects to represent electro-mechanical systems
  - Automatic generation of analysis and simulation from ***Einstein Objects*** with minimal additional time or cost. (***Einstein Objects*** contain multi-level, multi-discipline math models that represent their behavior.)
  - Distributed collaboration via communication of design components via Internet (WWW)
- Impact: Order of magnitude improvement in ***cost, time and quality*** of designing electro-mechanical systems
  - Integrate engineering models into system level simulation (e.g., battlefield simulation)

THE EINSTEIN SUITE

The Einstein Suite is a set of software components that together provide solutions to the broad range of problems previously described.

The Einstein Suite

- ***Einstein Objects*** **-** Composable encapsulation of mathematically described objects (e.g., physical properties of electro-mechanical products) - simulators ***automatically constructed on demand***
- ***PDESolve*** **-** Software environment for rapid construction of partial differential equation simulators
- ***HybridSolve*** **-** Large-scale distributed simulation of hybrid ODE/DAE systems (e.g., battlefield scenarios, rigid bodies, active controllers)
- ***WebVis*** **-** Web-based visualization environment for engineering and scientific computing
- ***PowerMath*** **-** Parallel HPC implementation of Einstein Objects and PDESolve computational substrate

EXAMPLES OF EINSTEIN SUITE APPLICATIONS

The following three examples illustrate the range of applications for the Einstein Suite:

The first is an examples of a coupled fluids-structure interaction. In this case the goal is to model the aeroelastic effects of a wing at transonic speeds.

The second shows the use of HybridSolve in battlefield simulation.

Finally, the third describes use of EinsteinObjects in creating a "live" model of an aileron actuator assembly in a C-141.

Examples of ***Einstein Suite*** Applications

- Coupled fluid-structure interaction
- Electronic warfare (EW) simulation scenario generation and simulation generation for cost effectiveness analysis (COEA)
- C-141 electro-mechanical aileron actuator

ANALYTIC SENSITIVITIES METHOD FOR EFFICIENT MULTI-DISCIPLINE ANALYSIS IN DESIGN

The "Analytic Sensitivities Method for Multi-Discipline Analysis in Design" provides a breakthrough in solving coupled problems such as an aeroelastic wing as described above. Using a new computational algorithm that minimizes the amount of costly CFD calculations required, the method augments the traditional CFD code with sensitivity calculations, enabling a reduction from approximately 600 Cray hours + 7.5 workstation hours to 21 Cray hours and 7.5 workstation hours - essentially a 30 times speedup.

Analytic Sensitivities Method for Efficient Multi-Discipline Analysis in Design

- Structures model (FEA) $M\ddot{x} + Kx = F$
- Fluids model (Euler CFD) $\frac{\partial u}{\partial t} + \nabla \cdot F = 0$

Previous approaches: (alternating iteration)
1. Compute flow u (CFD) (20 Cray hours)
2. Obtain forces on nodes
3. Solve deflection (FEA) (15 workstation minutes)
4. Reform geometry based on structural deformation due to fluid
5. If converged, exit, otherwise go to 1 and repeat

Typically 30 iterations required for convergence - 600 Cray hours per design iteration! Not cost effective!

ANALYTIC SENSITIVITIES FLUID-STRUCTURES COUPLING

This slide provides some details on the "Analytic Sensitivities Method for Multi-Discipline Analysis in Design."

Analytic Sensitivities Fluid-Structures Coupling

- **Rewrite structures equation**

$$M\ddot{x} + Kx = F$$

$$M\ddot{x} + Kx = F_0 + \frac{DF}{Dx}x$$

$$M\ddot{x} + (K + \frac{DF}{Dx})x = F_0$$

Parameterize deformations with parametric family (Bernstein-Bezier basis)

Basic idea: precompute DF/Dx and use repeatedly in structures FEA

- **Formulate sensitivities equation for fluid (a linearized form of the Euler equations)**

$$\frac{\partial u}{\partial t} + \nabla \cdot F(u) = 0$$

$$\frac{\partial u'}{\partial t} + \nabla \cdot (\frac{DF}{Du}|_{u_0} u') = 0$$

New Algorithm:

1. Compute fluid flow (20 Cray hours)
2. Compute sensitivities (1 Cray hour)
3. Compute deformation (15 workstation minutes)

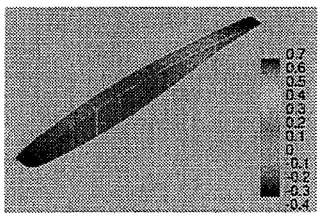
Bottom line: After a single 21 hour Cray run (a single iteration of the old algorithm) a design iteration takes 15 workstation minutes - instead of 600 Cray hours!

EXAMPLE: AEROELASTIC DESIGN AND ANALYSIS

Here we see the value of the Analytic Sensitivities Method for Multi-Discipline Analysis in Design as shown in the JAST Program.

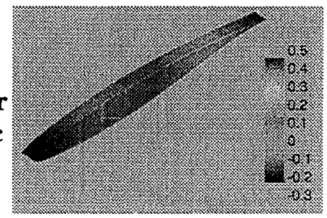
Example: Aeroelastic Design and Analysis

Problem: Integrate flow and elasticity disciplines to analyze the aeroelastic response of a wing.



Deformation with no aeroelastic response

A torsion spring is attached in front of the center of lift. Aeroelastic effects reduce deformation



Deformation with aeroelastic response

Enabling Technology: Allows design of JAST wing that tailors aeroelastic response of camber and twist. Support Structures and Aero IPT. Joint work with Lockheed Ft. Worth

HYBRIDSOLVE APPLICATION: ELECTRONIC WARFARE SCENARIO GENERATION

HybridSolve is the component of the Einstein Suite that provides the ability to rmodel systems that can be described as coupled and uncoupled ODEs together with discrete event state changes - such systems are called HODE (Hybrid Ordinary Differential Equations). In addition to providing the computational substrate for performing large-scale, distributed simulation of HODE systems, HybridSolve provides an object-oriented syntax for defining HODE objects, such as ships, tanks, missiles, etc.

HybridSolve Application: Electronic Warfare Scenario Generation

- Generate scenarios to exercise electronic warfare models and develop strategies.
- Generate scenarios that enable quantitative decisions in the procurement process - **revolutionize COEA**.
- Integrate engineering design information into operational simulations.
- Simulations contain differentially updated and algebraically updated variables in different objects.
- Substrate must be object oriented and enable generation of code compliant with DIS, HLA/RTI and J/MASS.
- Demo: Anti-Ship Missile Defense (ASMD)

EINSTEIN SUITE APPLICATIONS DRIVER: C141 ELECTRO-MECHANICAL AILERON ACTUATOR

Here we discuss how the Einstein Suite will be used to represent a "real world" component from a Lockheed C-141 plane. In this case, the subsystem is an electro-mechanical/hydraulic aileron actuator that replaces a hydraulics-only system containing a central hydraulic pump, a mass of tubing and controls, and a cylinder at the aileron. This subsystem has been chosen as representive of a broad range of DoD upgrade requirements. Because the system has already been designed using traditional methods, this provides an excellent metric with which to measure the effectiveness of the Einstein Suite.

Einstein Suite Applications Driver: C141 Electro-Mechanical Aileron Actuator

- Replace existing hydraulic system for aileron actuation with an electro-mechanical system.
- Increase reliability, reduce maintenance, increase performance.
- Lockheed is a subcontractor to Beam as part of this contract.
- Design of the C141 electro-mechanical aileron actuation system will be carried out in the Einstein Suite environment.
- This is a real-world program which Lockheed is performing for the Air Force.
- Representative of **many upgrade requirements** the DoD is faced with.

Einstein Objects

- An ***Einstein Object*** is a "syntactic form" that characterizes a electro-mechanical product - can be saved and communicated via Internet.
  - Geometry, assembly structure, materials, control algorithms, physics models
- Simulation and analysis modules defined by coupled math and engineering models:
  - Partial Differential Equations (PDEs)
  - Ordinary Differential Equations (ODEs)
  - Differential-Algebraic Equations (DAEs)
  - Discrete events (HODEs, HPDEs)
  - Combinations of above

EINSTEIN OBJECT CONCEPTS

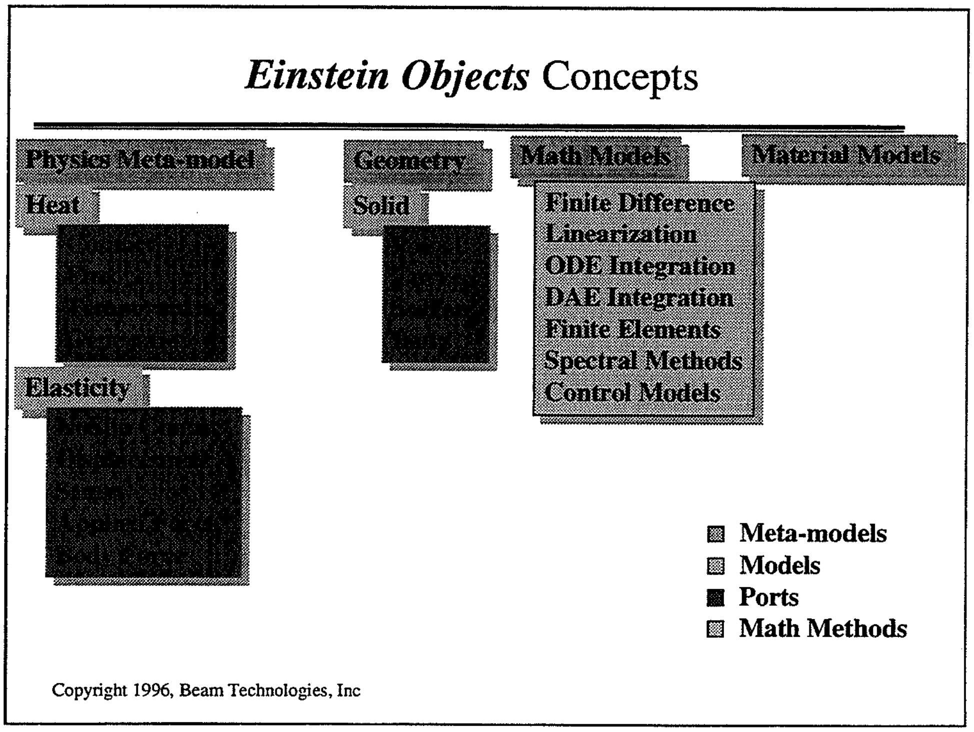
Here we describe the fundamental components used in representing electro-mechanical (and other) systems as Einstein Objects.

Einstein Objects Concepts

- ***Primitive*** - an ***Einstein Object*** that is a basic building block in a design - typically contains shape, material properties, interaction ports
- ***Assembly*** - an ***Einstein Object*** assembled from other Einstein Objects
- ***Port*** - "publishes" an Einstein Object's state variables for use in interactions
- ***Interaction*** - an object that represents interaction between ***Interaction Ports*** defined on two ***Einstein Objects***, e.g., contact, hinges
- ***Physics meta-model*** - contains equations and rules for constructing a simulator for an ***Einstein Object*** Examples: Heat transfer, elasticity, kinematics

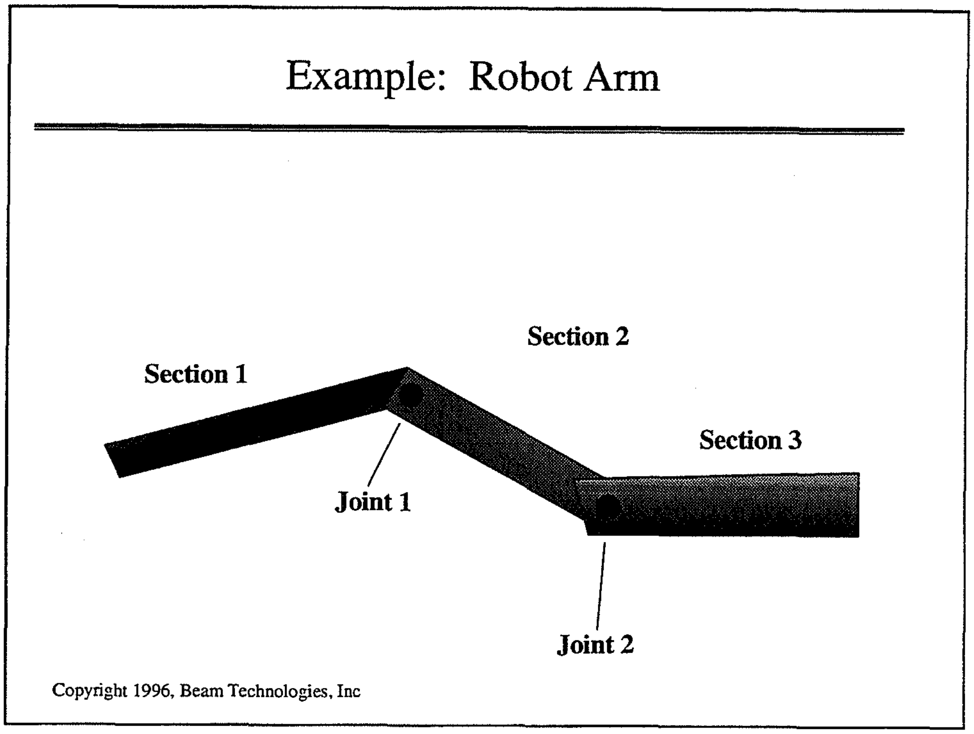
EINSTEIN OBJECT CONCEPTS

Here we see some examples of Einstein Object components: MetaModels, Geometry and MathModels.



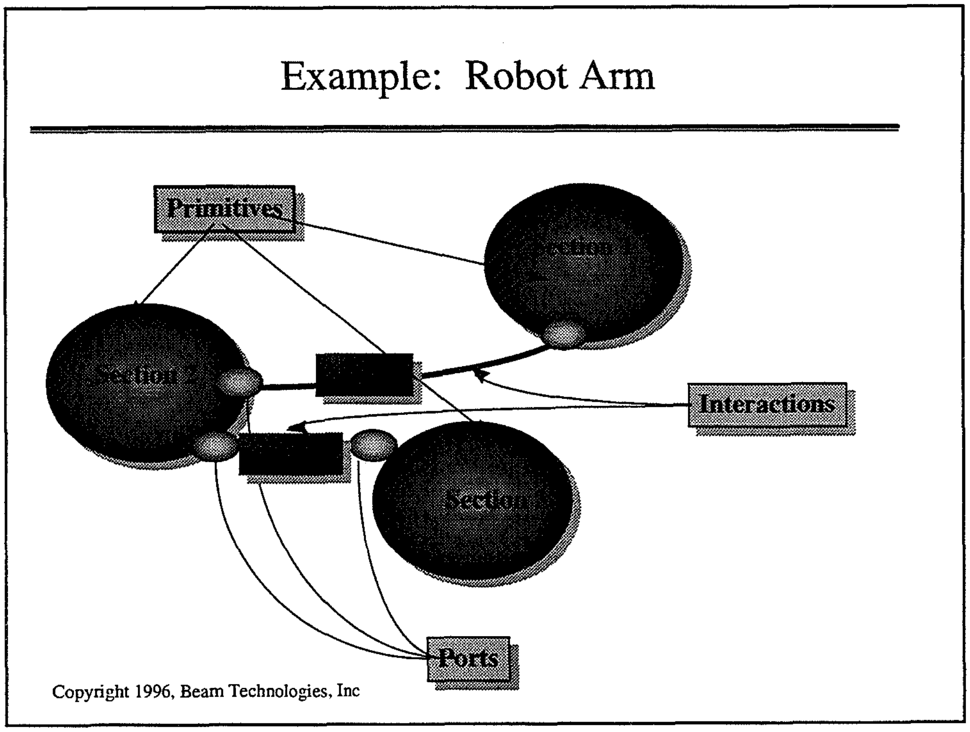
EXAMPLE: ROBOT ARM

We first consider the following simple two-dimensional robot arm with two "pin joints." The Einstein Object representation is described on the next slide.



EXAMPLE: ROBOT ARM

Here we see that for each rigid body we have constucted an Einstein Object Primitive. Each primitive contains one or more Einstein Object Ports, which provide a "docking mechanism" for Einstein Object Interactions. In this case the Einstein Object Interactions represent "pin joints." Each of the components in the illustration contribute 0 or more state variables, parameters, ODEs, boundary conditions, etc.



PDESolve

PDESolve is the computational substrate that supports the other components of the Einstein Suite. It is a C++ class library that allows a user to specify a problem using partial differential (and/or ordinary differential) equations, together with a spatially discretized geometry specification (a mesh of some kind), define boundary conditions, and call a "solve" method to get an answer.

PDESolve

- Simulators specified directly in terms of partial differential equations
  - PDESolve applications are easy to create, debug, modify and understand
  - Resulting cost and time savings
  - PDESolve simulators are typically 1/100th the size of equivalent FORTRAN or C++
- Finite difference (soon: FEM, Spectral)
- VRML, Java, Matlab interfaces

WebGraph

WebGraph is a VRML-based visualization subsystem for visualizing engineering and financial data on the World Wide Web.

WebGraph

- VRML/Java/C++ based visualization tool
- Visualize using standard Web tools, e.g., Cosmo Viewer, Netscape, etc.
- Interactively define, visualize, solve and explore solutions to Einstein Objects designs
- Import/export standard formats, e.g., Draw3D

PowerMath

An important aspect of the Einstein Suite is that applications run *unchanged* on PCs, workstations, and supercomputers. This guarantees that models built on PCs do not need to be rewritten when the PC is no longer capable of providing the necessary performance.

PowerMath

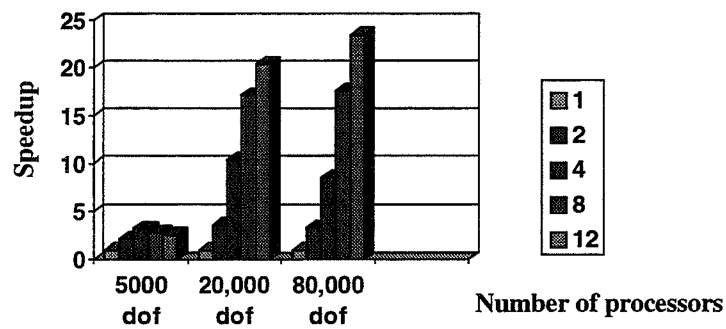
- HPC Compute Engine for PDESolve, ***Einstein Objects***
- PDESolve programs and Einstein Objects ***execute unchanged*** on SP2, NoW (Network of Workstations), etc.
- Standards-based implementation: MPI, PETSc - maximizes portability, performance
- Provides top end of a suite of computation solutions for ***Einstein Objects*** - PC for early design, workstations for intermediate analysis (e.g., structural), and HPC for highly compute intensive (e.g., coupled three-dimensional fluids/structures)

PowerMath TIMING RESULTS

The graph shows promising speedup with our initial implementation of PowerMath.

PowerMath Timing Results

- IBM SP2 (CTC)
- 3D Elliptic Partial Differential Equation
- Speedup (wall clock time, averaged)



PRODUCTS

Taken together, the components of the Einstein Suite provide two revolutionary capabilities - they have the potential to change the way engineering and financial engineering are performed by: 1) providing currently unavailable functionality, and 2) providing a 10-100 times improvement over currently available but impractical or costly functionality.

1. Currently, there is no computer theory or methodolgy for representing "composable" models of electro-mechanical objects that are capable of automatically simulating the components' behavior. By composable, we mean that no programming must be performed to create a simulator for a composite object from component models - the Einstein Suite is fully capable of performing this task automatically.

2. The ability to use the World Wide Web to create and communicate representations of electro-mechanical objects that can be "dragged and dropped" over the Internet will allow designers to perform web searches for components, drag and drop them into their design, simulate the product, and ultimately purchase the components over the World Wide Web to complete the design.

Products

- ***Einstein Objects***: Computer executable design and simulation objects that enable:
  - Internet communication of executable electro-mechanical designs, ***composable in browser***
  - Prediction of behavior before physical prototype
- ***The Einstein Suite***: A WWW-enabled design and simulation environment:
  - Search web for design components - "drag and drop" into design - perform analysis, design optimization
  - Seamless transition from PC to HPC - identical Einstein Objects execute on Pentium, workstations and SP2

Interactive Media and Simulation Tools for Technical Training

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INTERACTIVE MEDIA AND SIMULATION TOOLS FOR TECHNICAL TRAINING

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ABSTRACT

Over the last several years, integration of multiple media sources into a single information system has been rapidly developing. It has been found that when sound, graphics, text, animations, and simulations are skillfully integrated, the sum of the parts exceeds the individual parts for effective learning. In addition, simulations can be used to design and understand complex engineering processes. With the recent introduction of many high-level authoring, animation, modeling, and rendering programs for personal computers, significant multimedia programs can be developed by practicing engineers, scientists and even managers for both training and education. However, even with these new tools, a considerable amount of time is required to produce an interactive multimedia program. The development of both CD-ROM and Web-based programs are discussed in addition to the use of technically oriented animations. Also examined are various multimedia development tools and how they are used to develop effective engineering education courseware. Demonstrations of actual programs in engineering mechanics are shown.

VIDEO ANIMATIONS

Animations, simulations, and interactive movies are not only useful for advertising and marketing, but are very effective in multimedia programs for everything from on-demand customer support to product analysis to training. Just as people are willing to pay to see special effects at the box office, your employees and customers will learn faster, retain more, and pay closer attention to interactive media.

First, consider how multimedia might be used for training. It may surprise you at the number of possible uses and the cost effectiveness of providing more than just text and pictures (garnished with a few videos) in your development, training, and support materials. Animations are an important part of design analysis at the Jet Propulsion Lab (JPL), one of the premier NASA research and development facilities. Recently, they have used animation to illustrate how their new rover (Fig. 1, from JPL Pathfinder Animation, published by Engineered Multimedia) will operate when they arrive on Mars next July. With animation, scientists and engineers can visualize how the rover will navigate over the rocks and terrain. This enables them to determine what may go wrong before the equipment is actually sent.

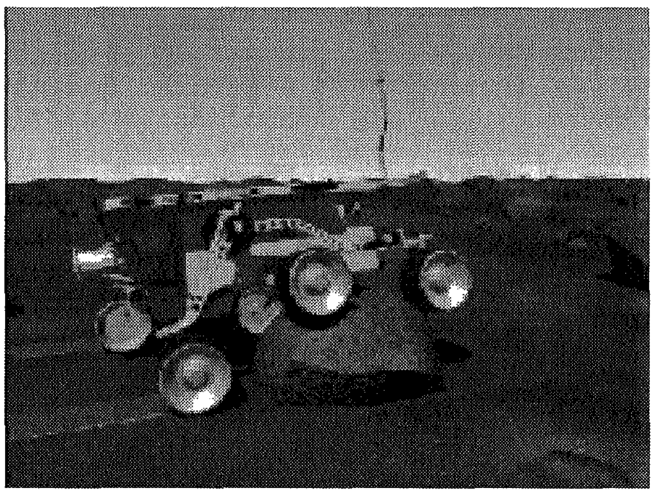

Fig. 1. JPL's Mars Pathfinder Rover.

PRODUCT SIMULATION

Multimedia is more than just animations however. Any teacher knows that people learn by hearing, reading, seeing and finally by doing. A good multimedia program integrates sound, graphics, text, simulations, and other digital components into a user-friendly interface with a value that exceeds the sum of the parts.

Consider how multimedia might be used as a sales tool. Whether it is a spacecraft or a toaster, you need to make sure your employees and customers know what your product can do and how it works. A well constructed multimedia program could illustrate how a new car jack (Fig. 2) works and at the same time show off its stylish looks to the customers. An animation can show how it is used or what happens when it is not used properly. Sound will add realism and more advice on the proper operation. Finally, the customer will be given the opportunity to operate the jack through computer simulation and quickly see what forces are acting on it at different heights.

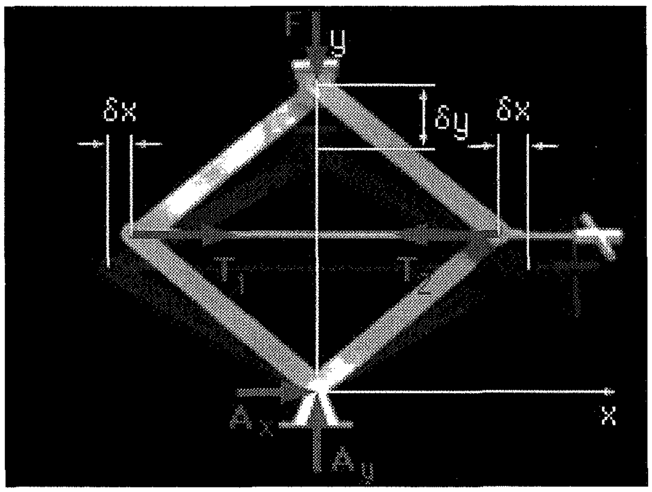

Fig. 2. Car Jack Simulation.

PRODUCT VISUALIZATION

Multimedia will even let you design and test something as strange as a watermelon catapult. The throwing mechanism and a possible construction method were animated as shown in Fig. 3 for a training program, and a simulation was created to test its performance, all before the device was actually built.

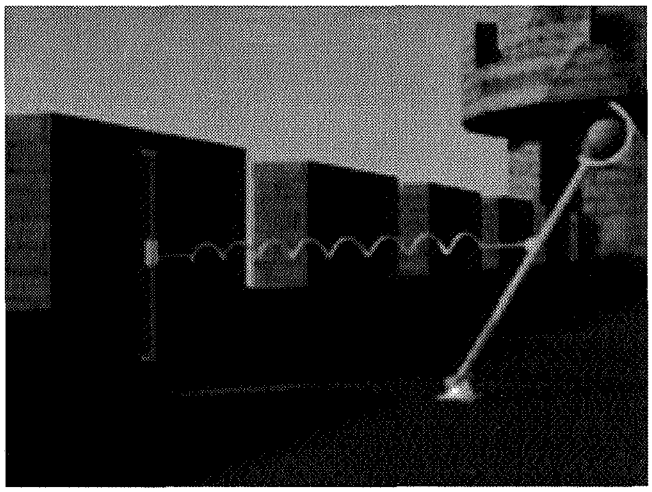

Fig. 3. Watermelon Catapult Animation.

USING MULTIMEDIA TO ENHANCE TRAINING

Training can be many things to many people. Multimedia could be used to train the sales staff on how to sell that new copy machine by illustrating selling techniques, operation of the machine, and situation analysis. (Just think, sales people might actually understand how their high-tech products work!) Or how about an in-house training program for engineers and technical managers? Multimedia can be structured like an on-line book that uses animations and simulations to show how to analyze and solve technical problems, such as designing an underwater arch (Fig. 4, from Multimedia Engineering Statics, published by Addison Wesley Interactive).

Training is difficult, even with the best instructors. Why not liven it up with multimedia? It can be delivered on a single CD-ROM or over the internet (given a fast connection). It saves everybody time by allowing the training to be done at their convenience, which translates into reduced costs and increased productivity.

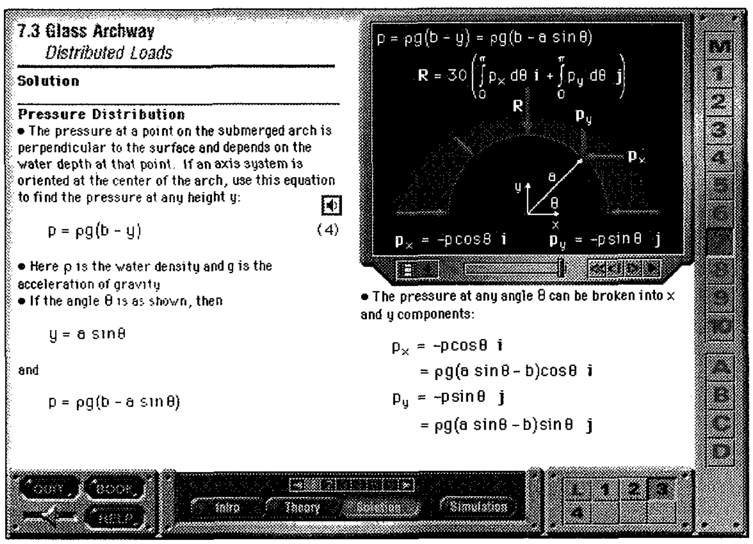

Fig. 4. Design of an Underwater Arch.

In addition to training, there is the technical education at pre-college, industry and universities. It will not be long before students and employees will have the opportunity to learn about almost any technical subject through their computer. No, multimedia will not replace the good old textbook or even a good teacher (but maybe a bad one), but it can supplement and complement any subject. For industry where education and training can be costly, on-line tutorials and instructions are a pressing need. So what is the advantage to multimedia? Figure 5 notes various advantages that multimedia has over traditional printed media. The two most important being three-dimensional visualization and user-controllable simulations.

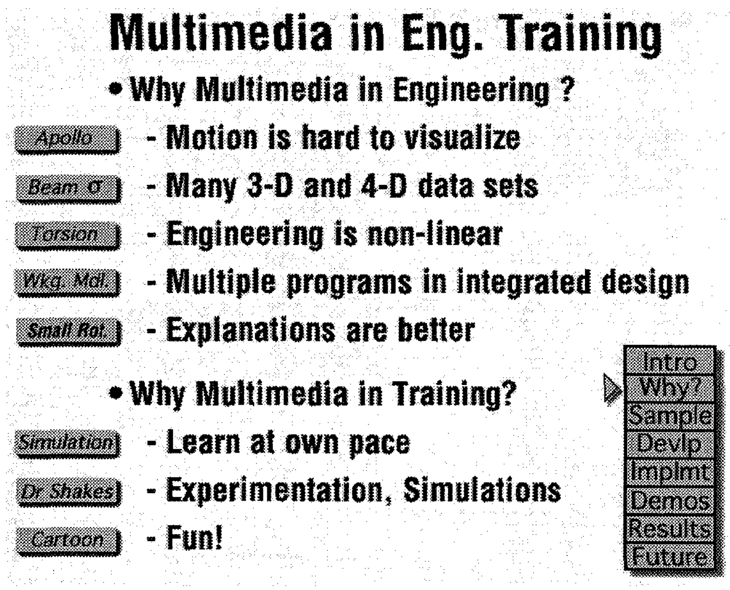

Fig 5. Multimedia in Engineering

A simple, yet powerful illustration of a simulation is the module used to instruct students about building simple truss structures. The simulation window is shown in Fig. 6. The user can construct any type of plane truss, including indeterminate trusses. With this simple and easy-to-use simulation, the student can go beyond the book or lecture and analyze complex structures (it is assumed that the student can already do simple structures by hand).

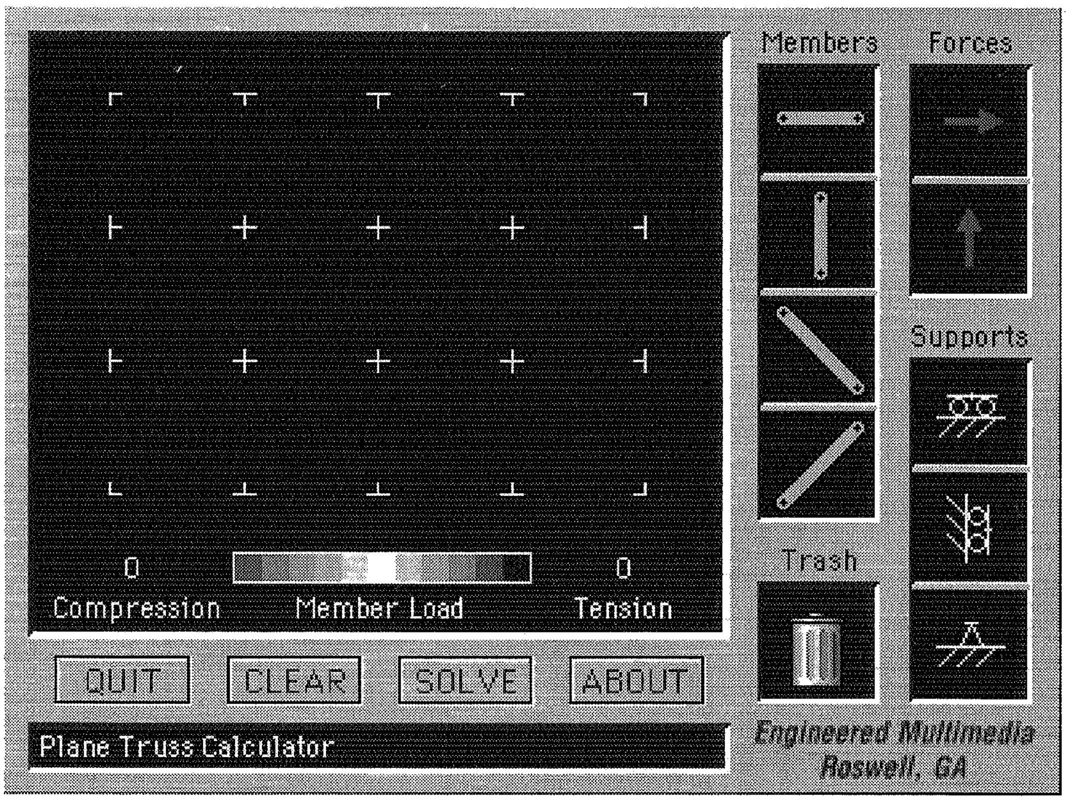

Fig. 6. Truss Simulation.

TYPES OF MULTIMEDIA

It would be wrong to say that there is only one type of multimedia (Fig. 7). Even though a book is not considered multimedia, it generally does have both graphics and text, and thus is indeed multi-media. Generally, computer-based multimedia involves three different concepts: visualization, simulations, and nonlinear navigation. Computers excel in all three areas and set multimedia apart from books or lectures. The visualization part includes three-dimensional graphics, animations, and videos. The application programs are simulations that act as side programs and let the user create designs while learning. These simulations can be simple programs or large commercial level programs that share data with the multimedia shell.

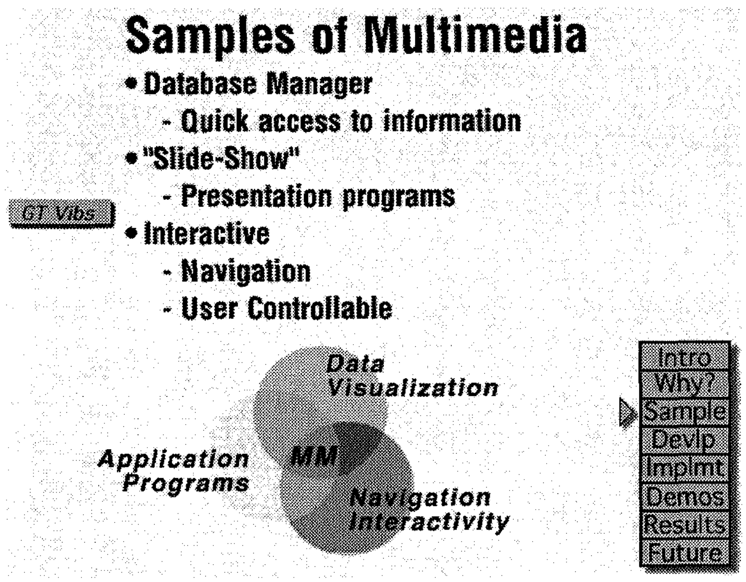

Fig. 7. Different Types of Multimedia.

INTERFACE ISSUES

The last component is the user interface that allows quick and easy access to data within the multimedia program. It should be intuitive and simple to use, and still allow the user to jump to any section. Figure 8 (Mars Navigator, published by Engineered Multimedia) shows an example of simple interface where the main topic buttons are to the left, the sub-topic buttons are to the right and the pages or screen are at the bottom. Databases are accessed directly from the main interface.

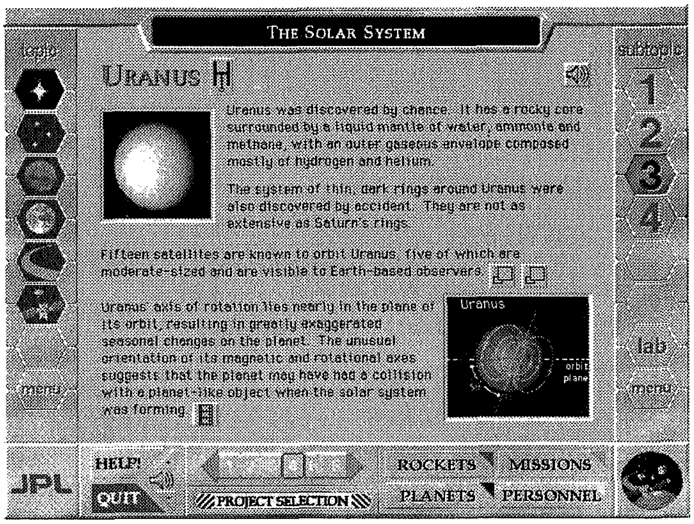

Fig. 8. Mars Navigator CD-ROM.

DEVELOPMENT OF MULTIMEDIA

With today's inexpensive computers, almost anyone with a relatively new computer can put together multimedia (Fig. 9). However, one will need to invest in software. A separate software program is required for each media type, such as graphics, animations, video, equations, sound, etc. The cost for these 7 to 8 programs will range from $2,000 to $10,000. However, many low-cost alternatives are available for both Mac and Windows platforms. The most important program is the authoring shell. This is where all the other media pieces are placed. The big three are Director, Authorware and Toolbook. A low-cost alternative to the authoring shell is a web browser such as Netscape or Explorer. One of the downsides of interactive media is the time needed for development. Each animation or detailed graphics or simulation can take days to put together.

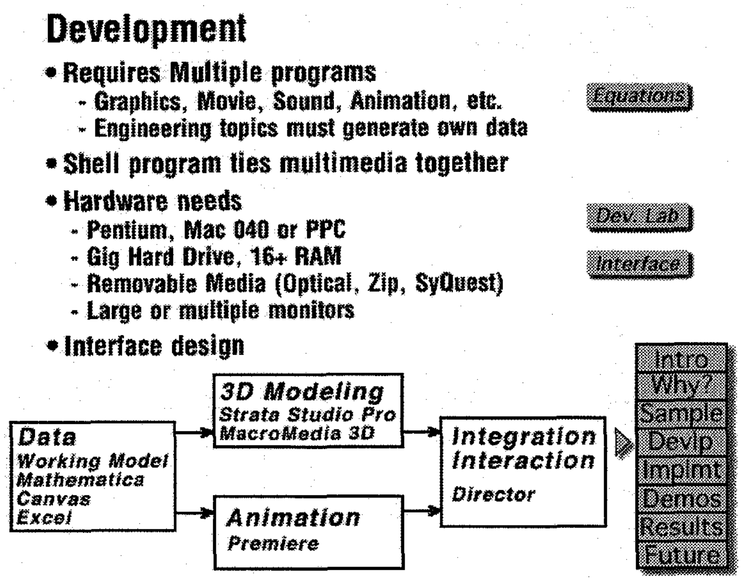

Fig. 9. Development of Multimedia

RESULTS

Through the actual use of multimedia in higher education and performing control-group testing, multimedia has become an effective tool in learning (Fig. 10). However, through testing, it has become apparent that the multimedia must be interactive. Programs such as the original GT Vibs, which did not have simulations, was not used much by students because it was too much like a book. However, when case studies and simulations were added, students used the programs more and actively learned. Studies on the GT Vibs program suggest that multimedia allows users to learn more effectively and develop better qualitative skills. It should be noted that multimedia does not equal, but can effectively compliment, a skilled teacher.

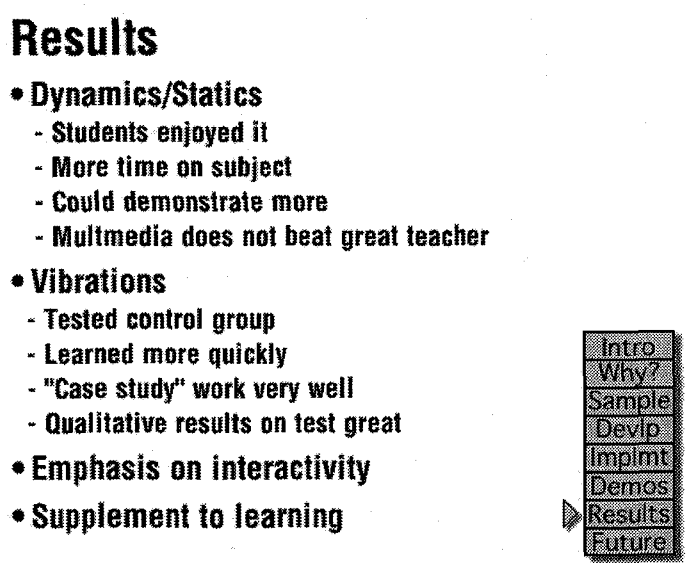

Fig. 10. Some Results Using Interactive Media.

SUMMARY

In the workshop, multimedia was demonstrated as an effective tool for learning and training. The key to any interactive computer-based learning system is incorporating both visuals and simulations. Multimedia must be active, not passive, to retain the imagination and curiosity of the user. The format of multimedia can range from slide shows to highly-integrated multimedia. The future brings great promise for the use of interactive media for learning and training.

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This document contains presentations from the joint UVA/NASA Workshop on Computational Tools and Facilities for the Next-Generation Analysis and Design Environment held at the Virginia Consortium of Engineering and Science Universities in Hampton, Virginia on September 17-18, 1996. The presentations focused on the computational tools and facilities for analysis and design of engineering systems, including real-time simulations, immersive systems, collaborative engineering environment, Web-based tools and interactive media for technical training. Workshop attendees represented NASA, commercial software developers, the aerospace industry, government labs, and academia. The workshop objectives were to assess the level of maturity of a number of computational tools and facilites and their potential for application to the next-generation integrated design environment.

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