AFRL-IF-RS-TR-1999-83
In-House Report
September 1999

THE INTEGRATED COMPUTATIONAL ENVIRONMENT (ICE) FOR PRODUCT DESIGN AND ACQUISITION

Kenneth R. Siarkiewicz

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 1999	**3. REPORT TYPE AND DATES COVERED** In-House Feb 94 - Sep 98

4. TITLE AND SUBTITLE THE INTEGRATED COMPUTATIONAL ENVIRONMENT (ICE) FOR PRODUCT DESIGN AND ACQUISITION	**5. FUNDING NUMBERS** PE - 62702F PR - 2338 TA - 03 WU - 1Q
6. AUTHOR(S) Kenneth R. Siarkiewicz	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Research Laboratory/IFSB 525 Brooks Road Rome NY 13441-4505	**8. PERFORMING ORGANIZATION REPORT NUMBER** AFRL-IF-RS-TR-1999-83
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory/IFSB 525 Brooks Road Rome NY 13441-4505	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER** AFRL-IF-RS-TR-1999-83

11. SUPPLEMENTARY NOTES

Air Force Research Laboratory Project Engineer: Kenneth R. Siarkiewicz/IFSB(315) 330-2465

12a. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution unlimited.	**12b. DISTRIBUTION CODE**

13. ABSTRACT *(Maximum 200 words)*

This is the final report documenting the research and development to define, prototype, and validate the concept of an integrated computational environment. The focus of this environment is the low-level computationally intense phenomenological codes which have been developed and used in many engineering disciplines to aid in the design and performance evaluation of devices, equipments, subsystems, and systems. The first part of the report identifies the need for a geographically dispersed design environment, describes the deficiencies in the state-of-the-art in distributed processing and collaborative design and analysis, and the objectives of this effort. Following a brief overview of the accomplishments of this in-house effort and its associated contractual efforts, there are several chapters devoted to a more in-depth treatment of each of the various broad areas addressed: data models and product databases, remote access of data and analysis tools, visualization of input and output data, and rule-based, expert-system pre-processors. The final sections of this report present a summary of the work done, recommended areas for further study and implementation, and an extensive list of references for further study of the details of each of the programs pursued under the over-all project.

14. SUBJECT TERMS Computational Environment, Data Model, Distributed Processing, Computational Electromagnetics, Collaborative Engineering	**15. NUMBER OF PAGES** 56
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	**18. SECURITY CLASSIFICATION OF THIS PAGE** UNCLASSIFIED	**19. SECURITY CLASSIFICATION OF ABSTRACT** UNCLASSIFIED	**20. LIMITATION OF ABSTRACT** UL

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Section 1. Introduction

Air Force equipments, subsystems, and systems are becoming even more complex in terms of the number, type, and operating parameters of functions which must be performed with reliability and effectiveness. Shared frequency bands and antennas and limited real estate create a matrix leading to electromagnetic interference and component burn-out. Numbers of components are increasing at a high rate, and even a minor or temporary failure of any one component can result in degraded operation of the system, aborted missions, and unacceptable safety hazards to personnel and ordinance.

At the same time that the design and development requirements are becoming more stringent and system- and function-unique, the time and funding available for these activities are being minimized. It is no longer possible to employ the "cut-and-try" method. The goal in product design is "first pass" acceptance to achieve affordable system acquisition costs.

Furthermore, due to the complexity of the system and the operational requirements, it is no longer possible to test every possible combination of environmental factors and operational scenarios to ensure combat readiness. The components and equipments must work satisfactorily every time, even when the system first enters a severe environment.

Modeling and simulation during all phases of the acquisition cycle, as shown in Figure 1, especially during early concept and design studies, is perhaps the only viable avenue available within the above acquisition constraints. Alternative product and system concepts can be postulated and investigated without costly experimentation. A broader range of possibilities can be studied on the computer than at an experimental facility. A larger set of environmental factors can be applied under very controlled circumstances on the computer than can be done experimentally. Sensitivity analyses of operational performance, failure predictions, time to repair, etc. as a function of incremental changes in the operational environment and product design can be obtained which provide information for training, for product improvement, and for the determination of safety margins and reliability factors.

Test resources, schedules, processes, and testability issues (e.g., integrated diagnostics and built-in-test) can also be addressed through modeling and simulation. This can reduce the costs associated with DT&E and OT&E, and periodic test and maintenance.

Conceptually, then, computerized modeling and simulation provide a solution to today's complex technological explosion and acquisition environment of reduced available resources. As a result the Air Force, DoD in general [A.5, A.7, A.9], and the civilian sector, are placing increasing emphasis on the use of modeling and simulation (M&S) in the design, acquisition, and performance evaluation of their various products. "Product," and alternatively "object," can be defined as a device, a board, a module, a subsystem (e.g., communications), or a system (e.g., F16). The concept of a product model includes not only the physical characteristics of the product, but also the processes associated with its manufacture and operation. For completeness there must also be included the environment in which it will operate and a consideration of its interaction with and relationship to other products.

In response to these circumstances the topics of M&S frameworks and product databases are seeing greater emphasis. A framework can be thought of as an environment in which a particular simulation is executed in concert with a number of other simulations. The framework establishes a set of specifications for the execution of the simulation, specifications for input/output data management, and a run-time infrastructure to coordinate and facilitate the execution of the individual simulations and management of the data. The framework functions invisibly behind the scenes to allow a particular application to run while others are also executing. The activities are coordinated. Data are managed, and the user concentrates on his or her work.

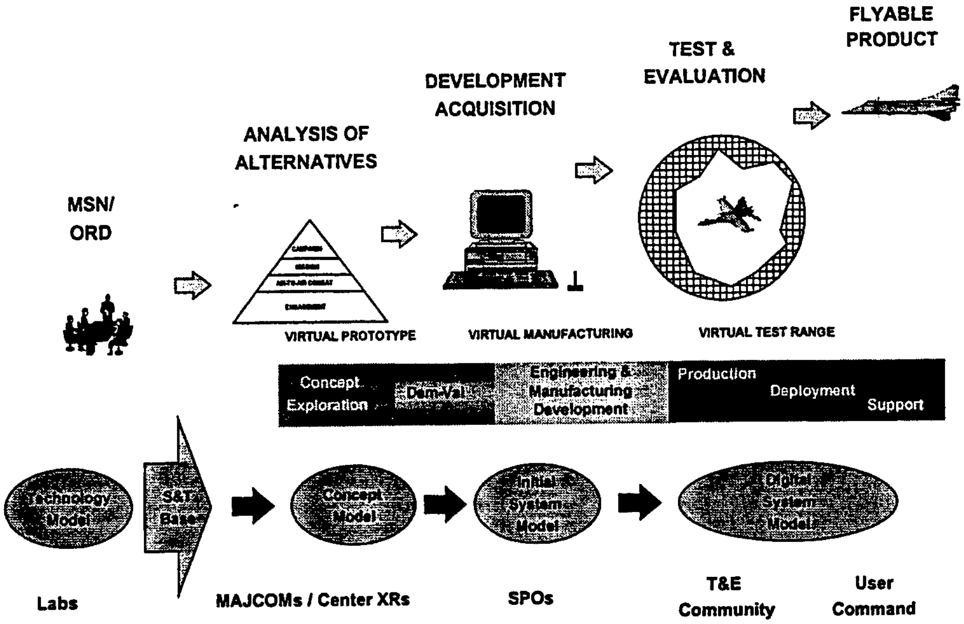


Figure 1. Modeling & Simulation in the Acquisition Cycle

The DoD and the Services are developing M&S frameworks to accomplish a broad variety of collaborated simulations. DARPA is in the final year of a five-year effort to develop a Simulation Based Design (SBD) environment. Its objective is to develop and demonstrate the concept of Virtual Prototyping in order to exploit the cost and time saving benefits of simulation technology in the design of complex mechanical systems. An overview can be found at http://www.arpa.mil/asto/SBD/sbd.html.

The Defense Modeling and Simulation Office (DMSO) is developing a High-Level Architecture (HLA) scheme to establish a common technical framework to facilitate the interoperability of all types of models and simulations among themselves and with C4I systems, as well as to facilitate the reuse of M&S components. The overall DMSO program encompasses M&S specifications, object model definitions, and a run-time infrastructure (RTI) to coordinate the execution of the multiple simulations. Further details can be found on the Web at http://hla.dmso.mil/.

The framework and the modeling and simulation environment address one need for computer-aided distributed, collaborative design and analysis. A second equally important and pervasive requirement is intelligent management of the data associated with the product being designed and developed. Figure 2 shows that there are many ways to categorize the modeling and simulation opportunities throughout the life cycle of the product. It is expensive to collect the quantity and quality of data required within any one compartment It is equally expensive and necessary to ensure continuity and consistency horizontally among neighboring compartments and vertically among levels of sophistication.

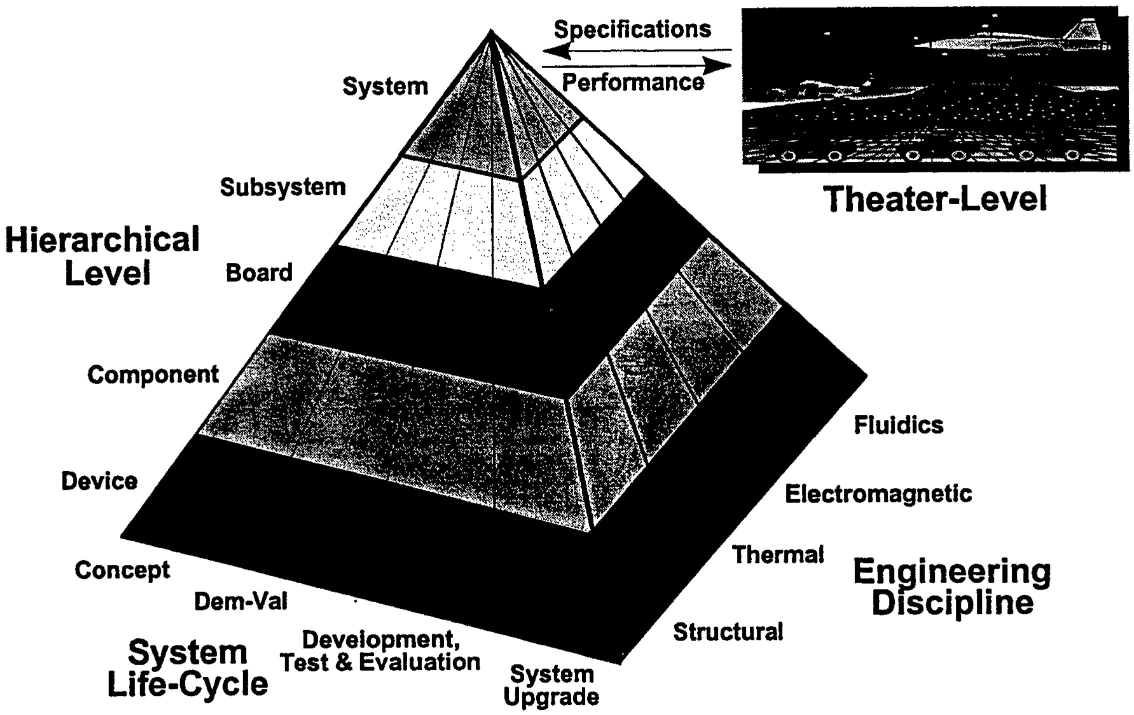


Figure 2. Life-Cycle Modeling and Simulation

There is a hierarchy which begins with the fine details of a circuit and extends "upward" to a less detailed but more inclusive system description and analysis. Numerous intermediate levels can also be defined depending on the nature of the object under analysis. At each level, as noted previously, the analysis tools of the many engineering disciplines are interactively exercised.

Each hierarchical level will be evaluated at the many steps which comprise the system cycle. At the concept stage there is very little detail available, and analysis provides only very general conclusions regarding product performance. Succeeding stages will involve more detail regarding the product design specifications, and therefore more sophisticated analysis tools will provide a more accurate and complete assessment of product performance. After it is initially fielded or integrated into a large system, the product and/or the system will undergo modifications. Models and data that were developed and obtained during the initial acquisition cycle will increase the efficiency of the enhancement design process.

The framework that has been under development will facilitate the transfer of data and maximize its reuse during the various stages of the design and acquisition cycle. It is generic in that it is applicable to all levels of product, from devices and boards to equipments and systems. What is of extreme importance is that a tremendous amount of very detailed and very accurate high resolution performance data are generated and stored using the built-in functions and utilities of the framework. These data can, and more importantly should, contribute to the performance analysis of the product and/or system when it is being evaluated in even higher levels of analysis (e.g., theater, order of battle). As an example, Figure 3 demonstrates how the acquisition cycle engineering analysis data could be interfaced into the Joint Modeling and Simulation System (JMASS). The high resolution data could be collected in the form of look-up tables which are accessed by the high-level simulations to, for example, determine air/ground communication performance in the presence of a hostile stand-off jammer. An alternative is to reduce the analysis data by casting it into the form of equations which are specific to a system in a high-level analysis. The specific data would then be calculated on-the-fly rather than accessed through a look-up table. In either case the best available data would be utilized, thereby reducing the probability of uncertainty associated with a command-level decision.

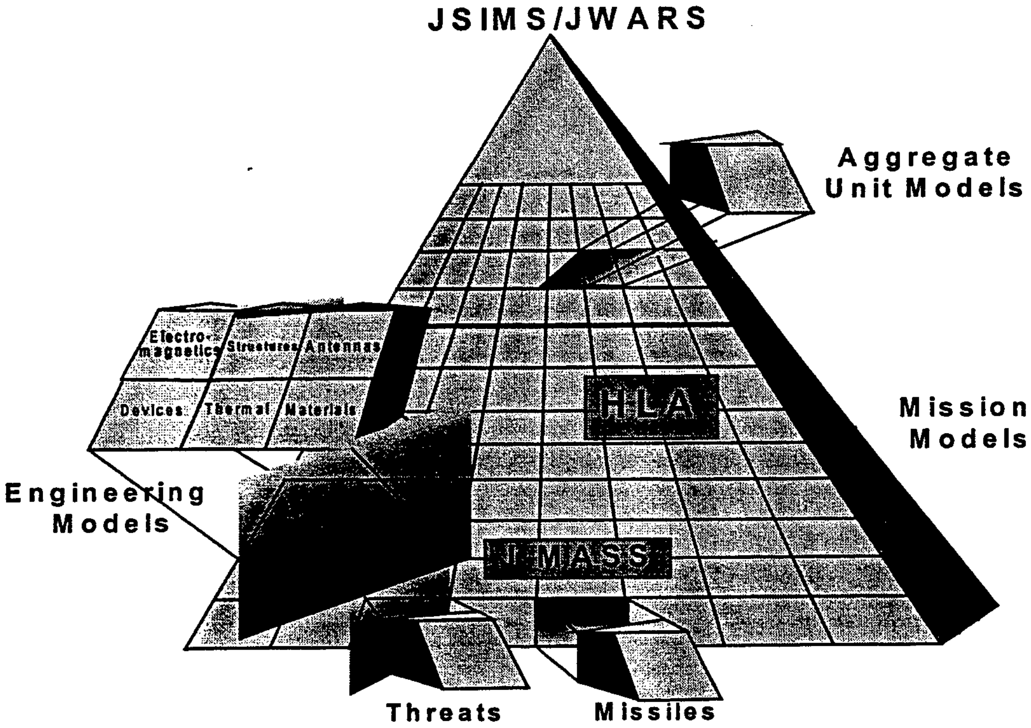


Figure 3. Joint Modeling and Simulation System Interface Concept

This illustrates another advantage of the proposed product. Once the model has been exercised in the theater-level simulation, data may be fed back to the acquisition and development teams in the form of revised specifications. It may happen that the antenna performance was not as expected, or that the original specification may not have provided adequate coverage. The feedback can then flow down the pyramid to the appropriate level, engineering domain(s), and resolution of analysis. In this way this new information can result in a product and performance that are more responsive to the operational requirements of the system and its components.

Section 2. Deficiencies

Today's modeling and simulation environment can be characterized as disjointed in the sense that each engineering and support discipline (e.g., thermal analysis, software reliability) operates in its own microcosm, even though many analysis tools are applied to the same product under development.

Generally, there is no efficient mechanism for the results of an analysis in one engineering discipline to be used in the analysis process of another. The translations that are necessary to prepare the output data of one analysis for use as a driving function for a second analysis are performed by some locally generated, poorly documented utility program. For example, an electromagnetic analysis can be performed to determine how the presence of an airborne platform will affect the performance of a phased array antenna and to locate the antenna to maximize some performance parameter of the antenna. This will in turn affect the flight dynamics of the aircraft, but the data needed by an aeronautical analyst to ascertain the affect on platform performance is not readily available from the results of the electromagnetic analysis.

Another loss of opportunity is in the area of system and environmental database use and reuse. All computer models of physical objects begin with the geometrical and electrical description of the system. Through some manual, or in rare cases automated, process this physical geometry is translated into a computer model which is understandable to only one, or at most a small number of, computer-aided simulation codes. This leads to repetitive and redundant modeling, incomplete models, inaccurate models, models not being available, or models not at the appropriate level of detail for the simulation currently being performed.

Finally, it is very difficult to ensure that all members of the development team are working with the same edition of the design data. This is especially true when there exist several subcontractors interfacing with an integrating contractor, who is under contract to a system program office (SPO). In the early phases of the design process the data are in a very fluid state, and it is quite possible that some engineering disciplines are developing a model and performing simulations using geometrical and/or electrical data that are one or more editions out of date.

To eliminate these drawbacks in the modeling and simulation technology it is necessary for the product development team to carry out its effort within a defined workspace which includes the appropriate toolsets and a self-consistent set of product data on which the tools within a set operate. The environment must accommodate numerous, diverse engineering, support, and management disciplines, including, but not limited to, circuit analysis, reliability, testability, maintainability, electromagnetic hardness, signal processing, and computer-aided design. It will also provide for the configuration control functions of all data associated with the product under development.

Section 3. Objective and Scope of the Current Effort

The overall objective of this program is the design, development, and demonstration of an "open architecture" computer-based environment which will be applicable to products at all levels of complexity (i.e., from device to system) and at all phases of the acquisition cycle, including subsequent modification of the system in which the product is operating. This environment will be capable of supporting the computer-aided design and analysis tools for all engineering disciplines, management function, and configuration control of all data associated with the development of the product. This is depicted graphically in Figure 4.

The focus of this in-house effort has been:

- Design and develop a robust, open-architecture environment
- Populate the environment with the available tools which can characterize the reliability, maintainability, and testability of the product, as well as those tools which will be needed for the demonstrations; and,
- Demonstrate the utility of the environment via the integration of sensors on an airborne surveillance platform.

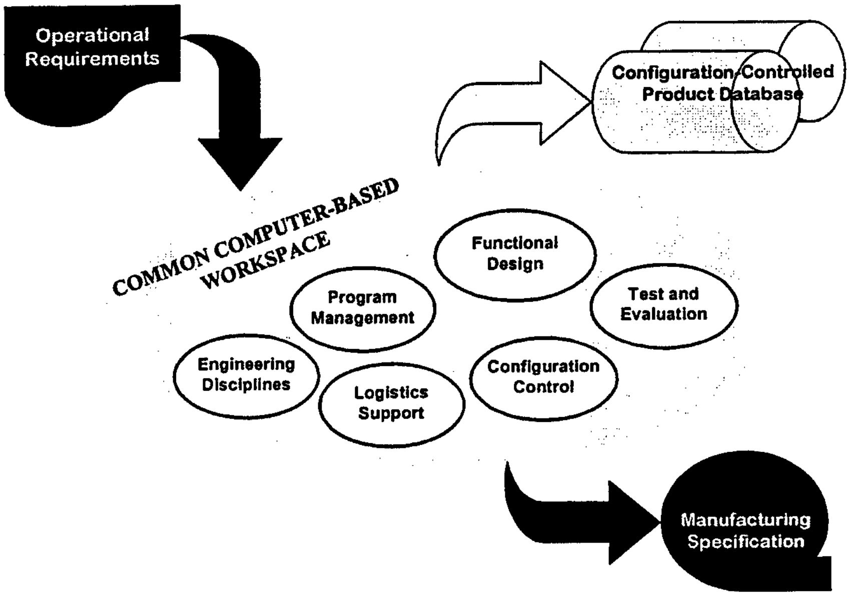


Figure 4. Integrated Computational Environment Concept

A prototype of the Integrated Computational Environment (ICE) suitable for dissemination and use by the DoD and its contractors, as well as by the civilian sector for the design and development of consumer electronics products, will exist as a result of this effort. Included will be complete documentation for its maintenance and enhancement, as well as training courses for the use, maintenance, and enhancement of the ICE. The initial population of tools will include those inserted for reliability, maintainability, testability, system- and circuit-level electromagnetic effects, and those tools used for the demonstrations. The architecture and structure of the ICE will be robust such that the tools of any engineering and physics disciplines can be inserted with minimum modification to the coding and execution of the tool.

The following is a list of features of Integrated Computational Environment, for which the design and implementation must take account:

- Modular design allowing user flexibility and customizability
- Standard suites of simulation tools for numerous engineering disciplines
- Software utilities to "plug and play" user design and analysis codes
- Graphical User Interface (GUI) with an extensive menuing system
- Context-sensitive HELP system with hypertext links
- Use of standard protocols for user choice of geometry drawing and database packages
- Ability to spawn processes on remote computers
- Configuration control utilities for design data management
- Main control panel allows user total control over design process
- Expert System module available to support analysis model development
- Full-Feature data visualization package available
- Telephone and on-site support

Section 4. Overview of Accomplishments

This section contains a summary of each of the efforts which have been a part of the overall ICE program. Some details of each of the efforts are contained in succeeding sections of this report. Complete information for each effort is contained in the supporting documentation for that effort, which is listed in the bibliography at the end of this report.

Figure 5 shows the flow of the efforts associated with the development of the ICE. The bottom element is the in-house program which has been described in the previous sections of this report. The current effort ends at the beginning of FY99. The "Enhancement" is an unfunded, "unprogrammed" in-house program at the present time.

The top line represents the last phase of the development of the Microwave and Millimeter-Wave Advanced Computational Environment (MMACE), which was funded by the Naval Research Laboratory. The Information Directorate of the Air Force Research Laboratory (formerly known as Rome Laboratory) was the technical manager of the MMACE development effort. The MMACE program developed and fielded a UNIX-based computational environment for the design and analysis of high-power microwave tubes. The elements of this environment were integrated into and distributed as the Research and Engineering Framework (REF), which is depicted in figure 6. The MMACE program also integrated numerous tube design tools with the REF and each other. Structural, thermal, electromagnetic, and particle-in-cell design and analysis tools now seamlessly exchange data and interactively design the tube. Version 3 of MMACE has been fielded to the high power microwave tube community and is being used at the Naval Research Laboratory for its research and development in the technology underlying the operation and application of these tubes for surveillance and communication.

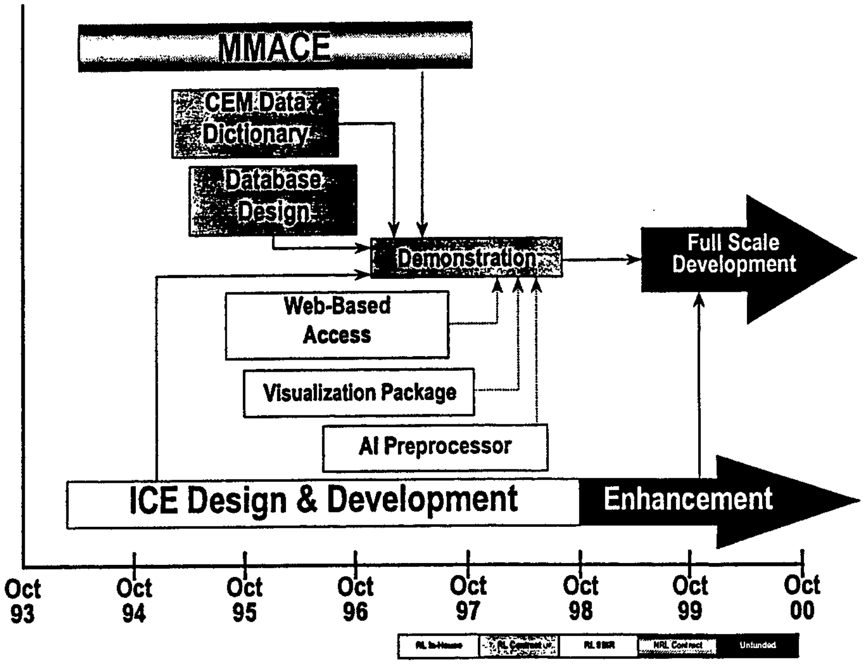


Figure 5. Integrated Computational Environment Development Roadmap

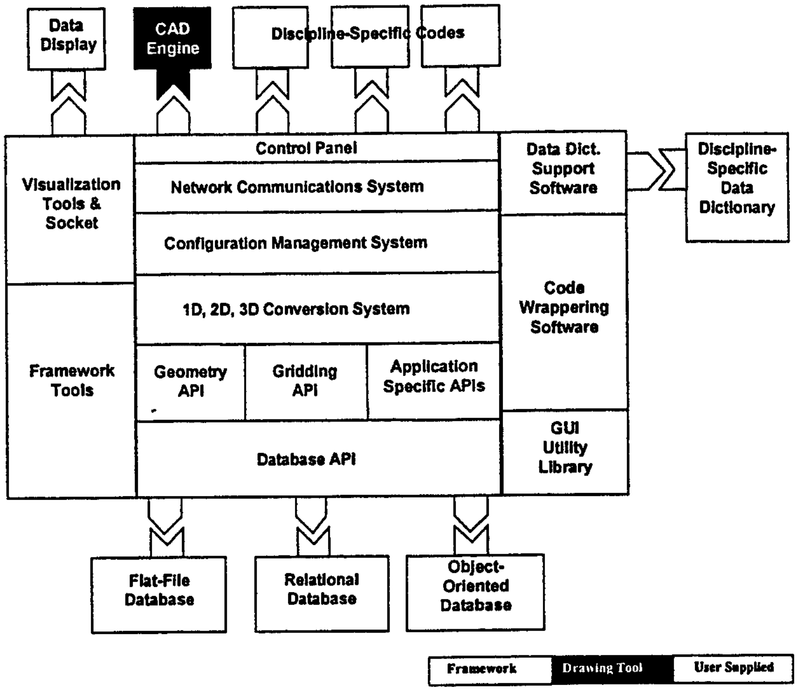


Figure 6. Elements of Research & Engineering Framework

The REF contains application program interfaces, documented specifications, and software utilities to aid the integration of design and analysis codes with the REF. In addition, it provides the data management, networking, visualization, and "Master" geometry needed to drive analysis codes. The REF also provides the utilities needed to construct graphical user interfaces including the top-level control panel. The REF can be compared to a computer operating system: generic, powerful, and providing much functionality, but of little interest to the end user who requires software that is written to operate on top of it.

The REF was designed and developed to be generic with respect to the engineering disciplines that would make use of it. To that end an interface called the data dictionary support software was included. It provides the link between the generic REF and the discipline-specific data model which applies to the design and analysis tools associated with a specific engineering discipline.

During FY94 and FY95 the Air Force funded the design and development of a data dictionary for computational electromagnetics. Recognizing that many such disciplines interact with each other and share much of the structural and analysis data, a separate effort was initiated (FY94-FY95) to investigate the issues associated with a global database for use in the design and analysis process of an object. The intent is to have the global database mature with the object it describes and be available to all members of the development team, as well as be available to all team members for all future enhancements to the object. A more detailed description of this work is given in Section 6 of this report.

As seen in Figure 5, all arrows lead to a "Demonstration." The objective of this contractual effort is to interface and integrate the various products, concepts, and processes that have been developed under the broad umbrella of the ICE program and enhance and modify them as necessary for operation within the Windows95/NT environment (rather than UNIX). The demonstration focuses on the placement of antennas on board a selected aircraft to characterize and maximize their functional performance and minimize interference from and to other antenna-driven equipments and subsystems. This effort will identify areas requiring further work to be done under a more substantially funded full-scale development program, identify the processes and develop the software to facilitate the interface of computer-aided design and analysis tools to the REF, validate the CEM data dictionary and provide a template for the development of data dictionaries for other engineering disciplines, and aid in the design and development of one or more training courses for the use of the ICE and REF in product design and acquisition. A more detailed description of this work is given in Section 5 of this report.

Three SBIRs have been associated with the development of the ICE. They each have addressed a generic technology associated with product design and acquisition, and each has used CEM as a focus technology area to demonstrate the interfaces, tools, and processes associated with implementing simulation-based design and acquisition. The first area is the use of the world-wide web for remotely managing data and performing design and analysis within the paradigm of distributed processing. Ultra Corp. initially parallelized the GEMACS (General Electromagnetic Model for the Analysis of Complex Systems) code in order for it to perform its analysis process in a shorter turn-around time, or to more completely characterize the electromagnetic posture of a system within the time it took to perform a more limited characterization using a traditional sequential processor. As part of its commercialization effort the contractor developed web-based forms and procedures for submitting the input data, remotely executing GEMACS, and downloading analysis output upon completion of the execution. One element within the "Demonstration" contract is to demonstrate this analysis process within the confines of the REF Control Panel. A more detailed description of this work is given in Section 7 of this report.

A second area critical to product design and analysis is visualization. This includes seeing the geometrical representation of the structure, the definition and modification of the analysis model, and the presentation and annotation of the analysis data. The objective of this effort is to develop a flexible capability to capture a digitized representation (e.g., IGES, DXF) of the object and aid the analyst in developing an appropriate analysis model. The visualization package will allow for many of operations that can be found in commercially available photo and presentation graphics packages (e.g., PowerPoint, Photoshop), such as zoom, hide, align, and group. Analysis tool-specific translators will generate an input data stream from the model. A third function of the visualization package will collect, process, and display the data in a format and annotation that is most appropriate for the data being displayed, the purpose of the display, and the intended audience for the display. A more detailed description of this work is given in Section 8 of this report.

The third area of technology is investigating the use of Artificial Intelligence (AI) technology to aid in the development of analysis models. The analysis tools are becoming more and more capable of treating very high resolution models which are composed of hundreds of thousands of modeling elements. Curved surfaces, the interface of two or more elements (e.g., wing connection to the fuselage of an aircraft), and material properties as a function of surface location and layered can now be modeled with higher-order expansion functions. Indeed they must be if the designer or system integrator needs to get a true measure of product or system performance. Model development packages must incorporate AI technology to make the process manageable for the analyst, both when the model is first being developed (perhaps from the computer-generated specification which guides the computerized machining tools) and for modification of an existing model to reflect a structural change in the physical object or to increase or decrease the resolution of the model in certain regions caused by a change in the requirements or objective of the analysis. The particular effort shown in Figure 5 is an SBIR contract to develop an intelligent preprocessor for use in CEM analysis. GEMACS is again one of the focus codes, but several other CEM codes (e.g., CARLOS, NEC, BSC) are driving the design and development of the preprocessing tool. This is to ensure that the tool is generic with respect to the CEM formulations and instantiations of the formulations, and to aid in the interface of several formulations, each of which is more or less appropriate for the observables to be calculated, regions of interest in which the performance is to be characterized, and the degree of fidelity and resolution to which the material properties of the physical structure are to be modeled. Although the original release of the preprocessor will focus on electromagnetics, it is planned that future releases will fold in other engineering disciplines (e.g., thermal, structural, fluid dynamics). It should be noted that the data dictionary schema is being used as one of the foundational elements underpinning the design and development of the preprocessor and its local data storage scheme. A more detailed description of this work is given in Section 9 of this report.

The in-house program has brought these various elements together, analogous to the role of an integrating contractor. One of the functions being performed has been the coordination among the numerous contracts and contractors to develop tools and processes which complement each other and work together to achieve the vision. This is accomplished by conducting common review meetings and maintaining a fairly free flow of information among the participants. Products in progress have been installed on AFRL computers, or access to products have been provided remotely. Ad hoc testing and demonstrations have shown where there are inconsistencies or shortcomings, which need to be addressed either under the current series, or more likely under follow-on efforts (shown as "Full Scale Development" in Figure 5). Funding for this work must be provided in order that the Air Force and DoD will have a computer-aided acquisition capability available. See Section 10, "Summary and Recommendations," for more detailed information.

Section 5. Research & Engineering Framework Control Panel

As mentioned in Section 4, the REF acts as the interface in a number of ways:

- Between the user and the application codes and data
- Between the application codes and the computer
- Among the various application codes with each other and with the product database

Figure 6 has been modified to show the current elements of the PC-based REF, which has been developed under the Demonstration effort. See Figure 7. A major achievement has been the port from the UNIX platform to the Windows95/NT platform.

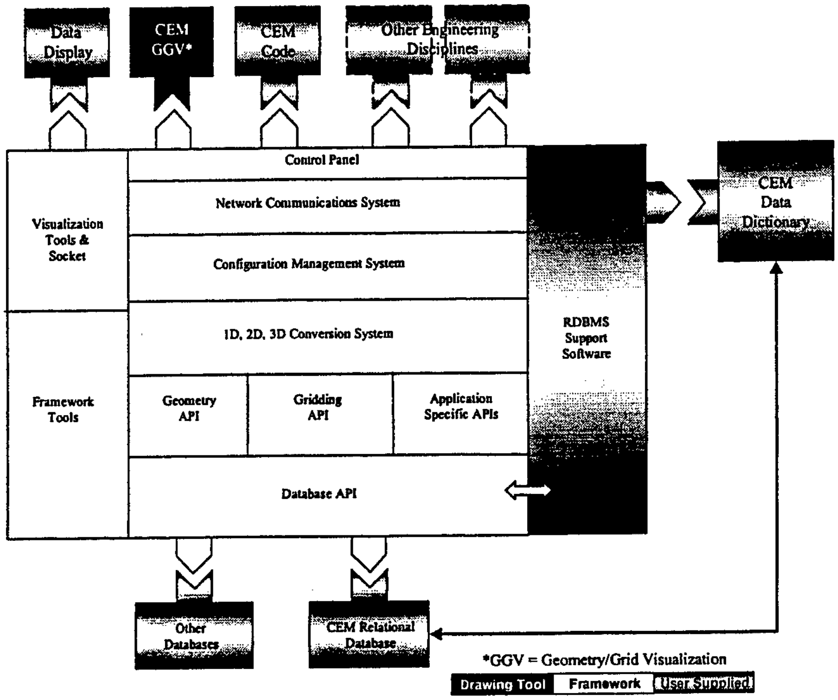


Figure 7. Elements of the PC-Based Research & Engineering Framework

The Graphical User Interface, called the Control Panel (CP), has been a main focus of attention of the Demonstration effort. Figure 8 shows the present state of the CP. As can be seen in the figure, the look and feel have been designed to look and act very much like the standard Windows95/NT program screens. There is a menu bar which provides access to the functions and operations available within REF. Figure 9 shows these functions. Of particular interest is the menu item called "Code Pool." This is a list of the analysis tools and utilities which have been interfaced with the REF. It is a relatively simple matter to add codes to the pool and provide the parameters via the properties box. Figure 10 shows a screen shot of the CP after the user has clicked on the Code Pool menu item. Double-Clicking or right-clicking on one of the executable icon brings up the properties box in which the user sets such parameters as location of the executable of the code and location of input and output data files, if appropriate.

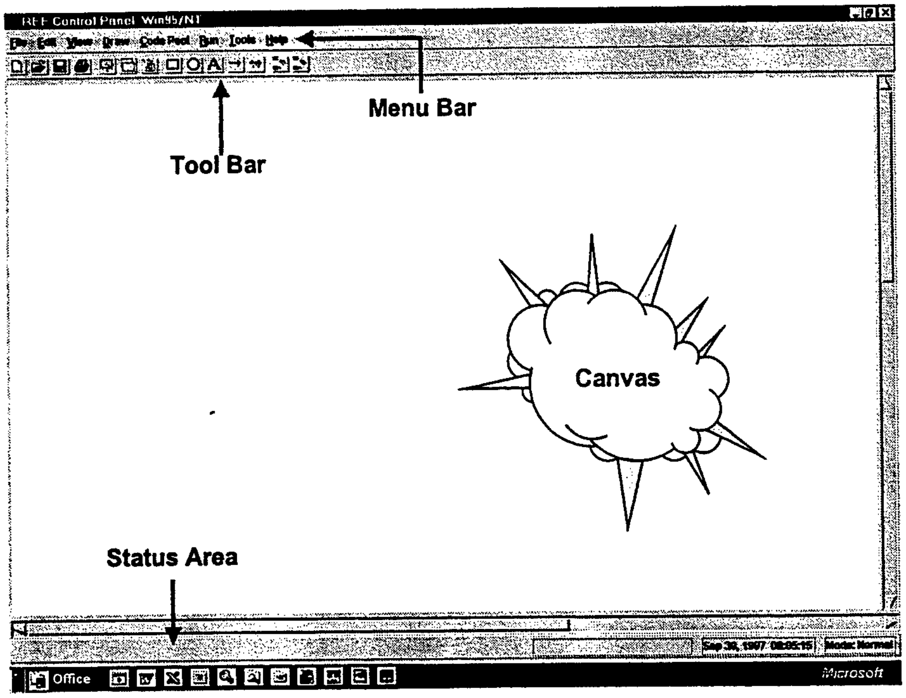


Figure 8. PC-Based REF Control Panel

File
- New
- Open
- Save
- Save As
- Revert
- Print
- Exit

Edit
- Copy
- Delete
- Properties

View
- Tool Bar
- Script Area
- Status Bar
- Drag Update

Draw
- Rectangle
- Circle
- Label
- Connect
- Disconnect

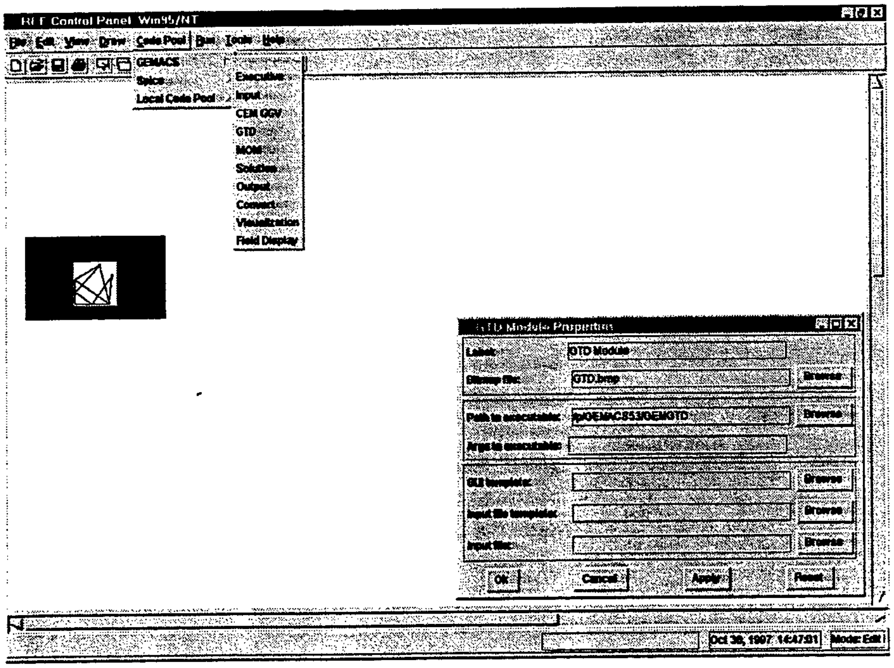
Code Pool
- GEMACS
  - Executive
  - Input
  - CEM GGV
  - GTD
  - MOM
  - Solution
  - Output
  - Postprocess
- TechPlot
- Spice
- Local Code Pool
  - Add
  - Show

Run
- Start
- Stop
- Reset

Tools
- Script Editor
- Converter
  - GEMACS to DB
- Calculator
- Matlab
- Explorer
- Notepad

Help
- Overview
- Tool Bar
- Work Area
- Status Bar
- Script Area
- Code Pool
  - GEMACS
  - Spice
  - TechPlot
- About REF

Figure 9. Control Panel Functions and Operations



Label: GTD Module

Bitmap file: GTD.bmp

Path to executable: p/GEMACS53/GEMGTD

Args to executable:

GUI template:

Input file template:

Input files:

Oct 30, 1997 14:47:01

Mode: Edit

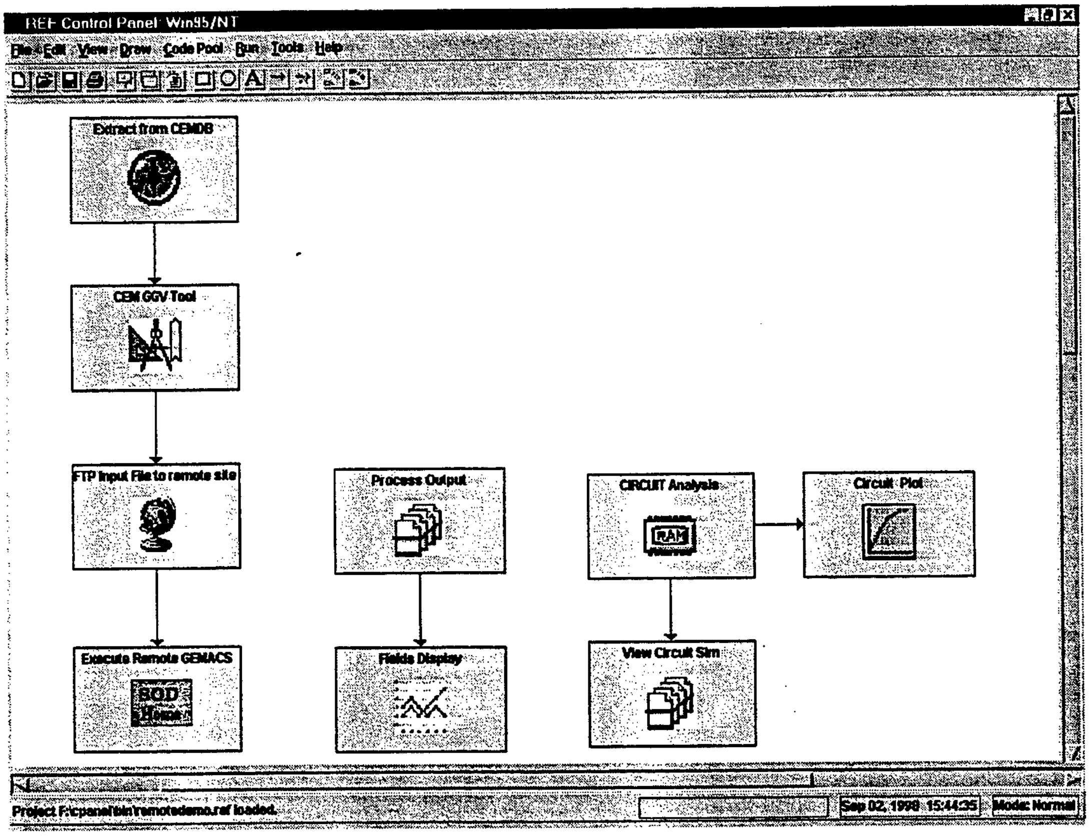
Figure 10. Code Pool and Properties Box

The CP allows the user to define in the Canvas area an analysis process using the various analysis codes that have been interfaced with the REF and whose names appear on the Code Pool menu item. Figure 11 shows a process that could be used to analyze the performance of one or more antennas located on an aircraft. Users define not only what analysis codes are to be used, but they define as well the sequence in which those codes are executed. Decision points and looping can also be accomplished in the definition of the analysis process. The process shown is notable for two reasons. First, it shows that an analysis may be executed remotely. The bottom icon in the left-hand column spawns a process called "Simulation on Demand" which is provided by the Ultra Corporation (see Section 7). Notification of completion is provided via e-mail to the owner of the workspace. The data are returned to the local machine via ftp. They can then be processed locally. As part of this processing data necessary to initiate a circuit analysis (e.g., on the transmit/receive module connected to the antenna terminals) can be extracted or developed to provide a driving function or terminal load for the circuit simulation. Thus, the example process shown in the figure demonstrates that two of the major requirements for the Integrated Computational Environment have been achieved.

The CP Tool Bar, shown in Figure 8 and in greater detail in Figure 12, contains the icons for many of the functions and operations that are available via the menu. Notice that the icons are consistent with those that are found in any typical Windows95/NT application. This minimizes the learning curve for the user as well as the long-term maintenance for the Control Panel if the operating system or conventions should change.

The Status Area, shown in Figure 8 and in greater detail in Figure 13, contains information about the operation of the REF, the CP, and the code being executed. Again, the format and data are very similar to those found in most Windows95/NT applications, and for the same reasons as noted for the Tool Bar.

The documents cited in section B of the References Section contain more detailed information about the work performed in this technology area.



Project F:\cpanel\bin\remotedemo.ref loaded.

Figure 11. Sample Antenna Analysis Process

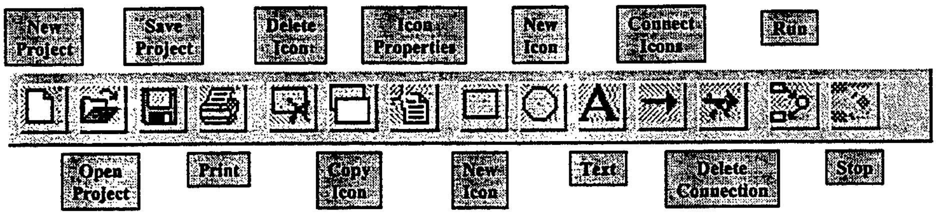
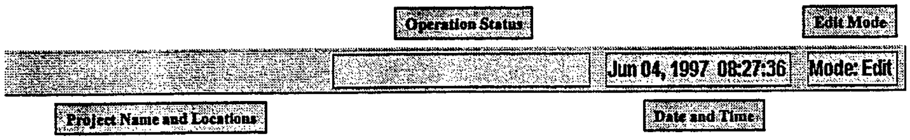


Figure 12. REF Control Panel Tool Bar



Jun 04, 1997 08:27:36

Mode: Edit

Figure 13. REF Control Panel Status Area

Section 6. Data Dictionary and Product Database

As mentioned in Section 4, it is the Data Dictionary which is the link between the generic REF and a specific engineering design and analysis domain. A data dictionary is a catalog that thoroughly details all the entities, their attributes, and relationships. It is "data about the data." A relational database system needs to maintain data about the relations among the data. Included in the types of information the data dictionary stores on the product or object are:

- Names of the relations
- Names of the attributes within each relation
- Domains of attributes
- Names of views defined on the database, and the definition of those views
- Integrity constraints for each relation (for example, allowable ranges for attributes in the relations)

As part of this program a data dictionary for CEM was begun and continually refined, both in terms of its structure and its growth in the number of CEM modeling elements that have been incorporated within the schema. The objective has been to develop a dictionary that is applicable to all CEM formulations (e.g., method of moments (MoM) , uniform theory of diffraction (UTD), finite element methods [FEM]), encompasses both frequency domain analysis and time domain analysis, and is code-independent. The dictionary must treat three-dimensional objects, taking into account layered materials and accounting for differing material properties in each layer. Furthermore, it must reference foundational elements for simplicity, ease of extension, and minimal redundancy. For example, the simplified schema shown in Figure 14 identifies a region as planar. This is a class of CEM modeling elements which has a flat face with one or more layers of arbitrary thickness in the third dimension. This includes the patch used in MoM and the brick in FEM, the flat plate used in GTD, and the facets used to model a geometry to be analyzed by the shooting-and-bouncing ray (SBR) technique.

The hierarchical nature of the schema can easily be seen in the figure. This facilitates data re-use. There is the MASTER which points to two major groups of data, each of which is found in any typical computational electromagnetics code. A code will have an input file comprised of execution commands which identify frequencies, global parameters, and output quantities to be calculated. The second part of the input defines the computational electromagnetics model of the structure to be analyzed. Within the schema as drawn in Figure 14 the execution elements are grouped on the left-hand side ("Execution"). Sources, loads, and output specifications are found here. The right-hand side of the figure ("Region") describes the geometry in terms of the modeling elements which are used within the various formulations and codes. Three general categories are present: planar, conic, and ellipsoid. These correspond respectively to the three common coordinate axes: Cartesian, cylindrical, and spherical. Each of these can also have materials associated with the modeling elements. The properties of the various materials, as a function of frequency or power level, are found in a look-up table within that part of the schema labeled "Materials." In addition to the three-dimensional objects, there may also be defined two-dimensional wires, and individual points can also be used to model the object.

An arbitrary number of coordinate systems can be defined and referenced. This allows an analyst to decompose geometrical structures into regions, such as the fuselage, left and right wings, or vertical, left, and right stabilizers of an aircraft. Each region would be referenced to a local coordinate system, whose orientation with respect to a global coordinate system has been defined and stored in the database. Engines can be modeled separately in their own coordinate systems and then can be applied to numerous aircraft. The same is true of widely used communication and radar antennas. Larger entities can be developed by bringing together a number of commonly used, smaller entities. The local coordinate systems are oriented with respect to the global coordinate system within which all elements of the model reside.

This is all accomplished within a database management system (DBMS), as shown in Figure 7. The figure also indicates that the DBMS is specified by the user, requiring only that it is SQL-compatible, which is true for all commonly used database management systems. Therefore, a company can use whatever may be a standard for that company, reducing start-up costs and user training resources. The CEM database was implemented using Microsoft Access.

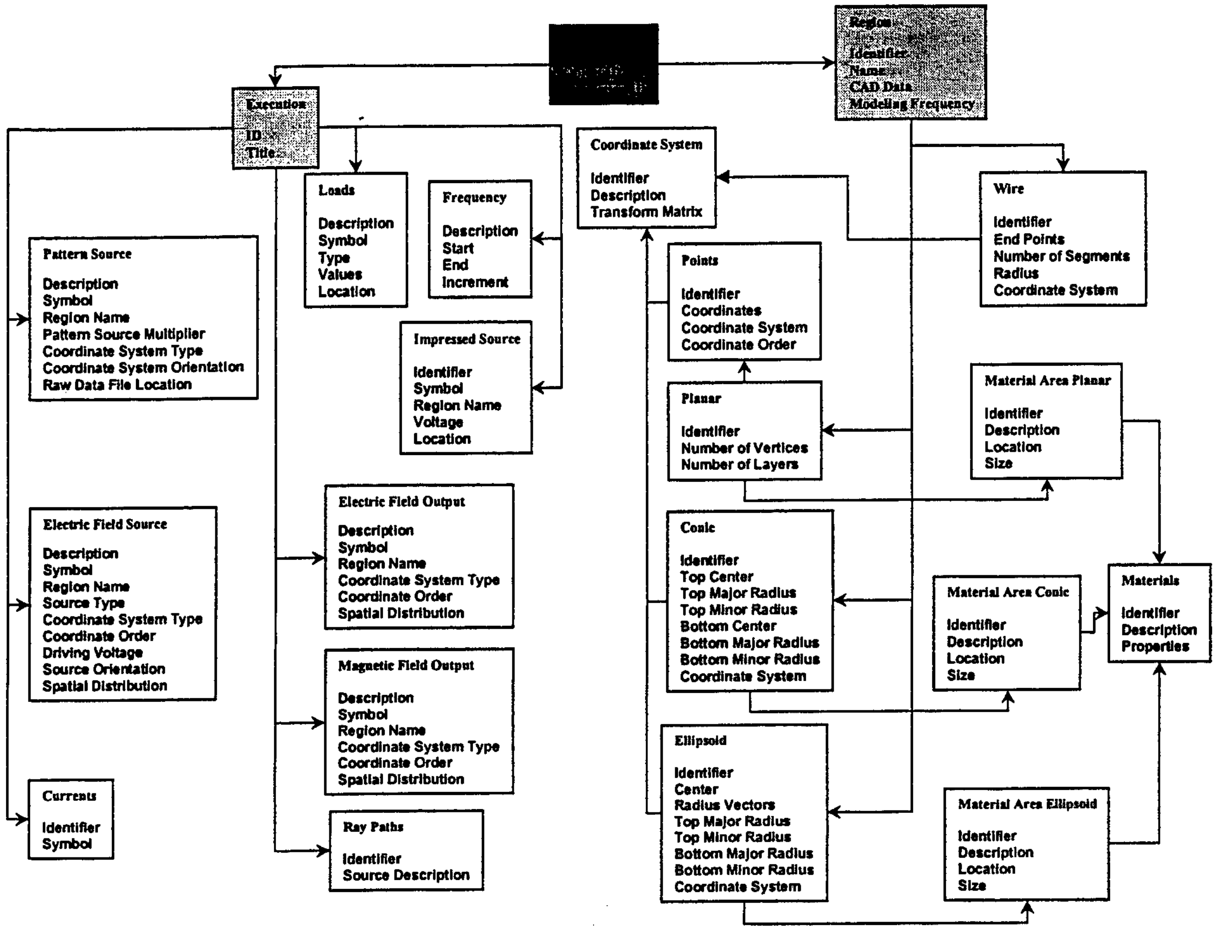


Figure 14. Simplified CEM Data Dictionary Schema

The CEM database is accessed through the REF by software tools that provide the means to take application-specific CEM data, convert it into a data dictionary compliant format, and either insert it into or extract it from the database. Figure 15 depicts this process as it begins from and returns to the REF. Within the REF the user can develop a computational electromagnetics file for a specific analysis requirement. This can be done either from scratch or as a modification of an existing analysis file. A menu item on the Control Panel (Tools, database) is then accessed to convert the input file from the GEMACS format into a data dictionary compliant file. A utility within the DBMS manager imports this file and inserts the data into the database. Once in the database the entire file or portions of it (e.g., engine model) is identified by the same or other users, and the process is reversed. An export utility translates the data into a data dictionary compliant file. Use of the Control Panel database-to-GEMACS menu item results in a GEMACS input file.

The significance of this work and these products is two-fold. It is the first attempt to develop a generic data model for the phenomenological computer-aided design and analysis tools in any engineering discipline. Presently each code requires the input data to be in a somewhat standard sequence and format. Different identifiers are used to refer to the same modeling element. Patch, facet, and plate all refer to an area on the surface. The description can be either a number of nodes connected in a clockwise or counter-clockwise direction or an area and a normal to the surface. These are all the same modeling element, but one code's syntax will not understand that of another. This severely restricts data re-use and interchange among analysis tools, even within the same engineering discipline. The schema shown in Figure 14 will among other things resolve the differences among homonyms.

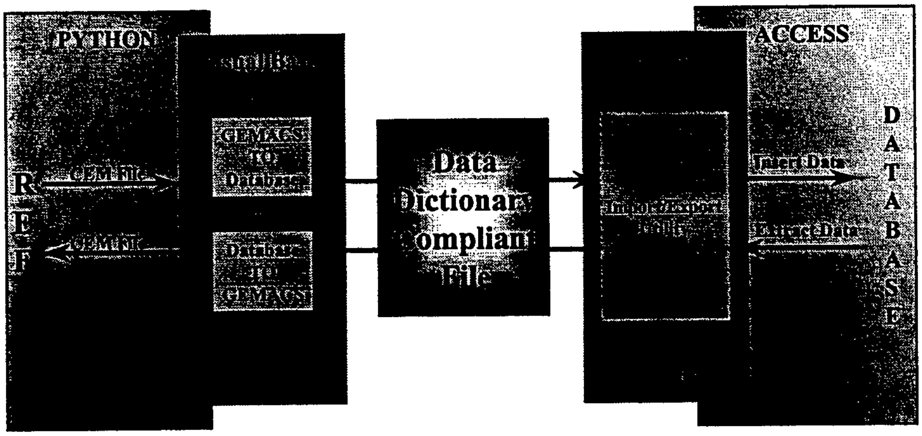


Figure 15. Data Flow between REF and CEM Database

Secondly, the data model developed for computational electromagnetics can be used as a template for the design and development of a data model for the phenomenological design and analysis codes used in other engineering disciplines, such as thermal analysis and fluid dynamics. Many of the modeling elements are very similar in nature and form as well as description. Object descriptors such as material constants may change, and they may be dependent on a parameter other than frequency; but they all share the characteristic of parametric description.

Developing data dictionaries for other engineering disciplines while using that developed for computational electromagnetics as a model or template has obvious advantages when one considers a global database for the product under development. The proliferation of names and data types will be reduced. Long-term maintenance and training will also be reduced. The development and understanding of DBMS queries will be simplified as one crossed engineering domain boundaries. Finally, it will naturally lead to an object oriented database for phenomenological data.

The existence of such uniform data dictionaries across engineering disciplines will also ease the burden on the many tools and utilities that would interact with the global database. As an example, consider the knowledge-base expert system preprocessor for computational electromagnetics (Section 9). In its most basic sense it takes user requirements for analysis data over specified spatial regions, the structural description, and the driving functions, and it forms the input data stream for the analysis code. It obtains the data it needs by forming queries. If the queries can be made very similar in each of many engineering domains, then it is a much simpler matter to compatibly revise all the queries when something changes (e.g., the database management system in use or the name of the dataset being requested).

As a second example, consider the use of intelligent agents (IA) as proposed in [C.3] and shown in Figure 16 (Figure 12 in the reference). In this case the IA monitors the global database on behalf of a specific user, for whom and whose function it has been specifically designed and developed. A SPO officer would have different data needs than an antenna designer or system integrator. The IA would periodically query the status of specific data and download updates as they occur, formatting and presenting the data so that it is most useful for the user. Uniform data dictionary entities will again facilitate the query design, development, and maintenance process.

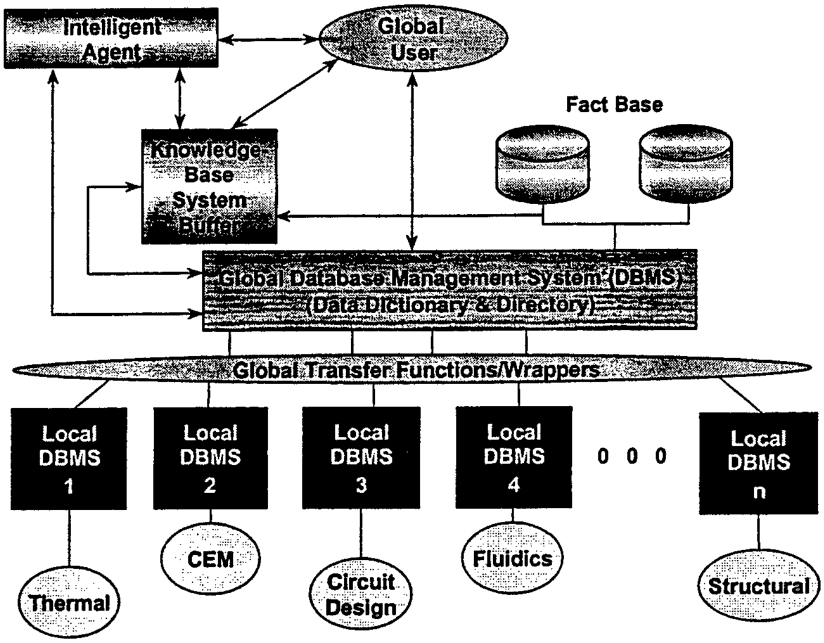


Figure 16. ICE Data Management Concept

The global user is only one of many categories of users who will ultimately access the object's database. At the other end of the spectrum of users is the individual engineer/analyst or designer. In Figure 16 these individuals or members of a design team are grouped according to engineering discipline (e.g., structural). Each discipline may be involved with only a specific portion of the total object, or a single performance parameter of the object. The results of their individual queries will be stored in a local DBMS over which they have total control and can modify without affecting the "approved" design stored in the global database. The IA in their case would look for specific types of data, changes in the structural geometry, or requests for studies which are initiated by others who need the data in order to determine the effect of design changes in one discipline on the object's performance with respect to another engineering discipline.

It should also be explicitly pointed out that the concept of a global database does not imply that all the data are stored at one physical location or on a single computer. The database management system may simply maintain a reference library which is used to seamlessly redirect the user to the site at which the requested data actually reside. This also facilitates configuration control of the data, especially with respect to identifying and authenticating who can access some or all the data, and more importantly, who can modify the data. The data contained in the global database must represent the current version of the object, whether that object is a component or an entire system. Proposed designs and the data for those designs will always be present, and they are expected to be found at the local sites and managed by the respective local DBMS. Depending on the type of the object, the degree to which the design in one engineering discipline affects the performance in another, and the observable parameter set, the data for these proposed designs may be shared among a number of engineers and analysts, both at the local site and at sites that are geographically distributed. If one or more of these proposed designs should prove to be a strong candidate for acceptance, then they would be submitted to the group having overall responsibility for the project. It is the members of this group who would be the only ones authorized to decide for a new version of the design and update the global database. This update would be made known to all or an appropriate subset of the design team using the communication processes and facilities and the intelligent agents that have been set in place.

The documents cited in section C of the References Section, especially C.3, C.4, and C.6, contain more detailed information about the work performed in this technology area.

Section 7. Web-Based Access

Between August 1995 through September 1998 the Ultra Corporation, Syracuse, NY, developed a parallelized version of the GEMACS (General Electromagnetic Model for the Analysis of Complex Systems) computational electromagnetics design and analysis tool. This is a system-level antenna performance analysis code which provides a sophisticated analysis on a very detailed model of a structure, such as an aircraft. The use of the massively parallel processor allows for code execution in hours rather than days and weeks. Alternatively, it provides the ability to test many more possible configurations over a broader range of frequencies.

In addition to performing the parallelization of GEMACS Ultra also developed a very powerful web-based commercial access to the code from remote sites. There are several reasons for this:

- Relative ease of ability to access the world wide web
- Provide accessibility with a commonly used graphical user interface (e.g., web browsers)
- Browser plug-ins provide forms capabilities which allow for data submission
- Browser plug-ins provide tools and utilities to catalog, display, and access selected records in the global database
- Browser plug-ins provide static and dynamic visualization capabilities for data presentation and viewing
- Browsers and plug-ins have commercial support and are available for a wide range of operating systems

Figure 17 (part of Figure 4 of [D.1]) shows some of the input data requirements that are to be provided by the analyst. This does not show all the functional level inputs that are to be provided. The reader is referred to the full paper for more detail. Figure 17 does show a strong correlation with the concepts of the data dictionary and global database that are discussed in section 6. The user provides the execution and geometry input data for the computational electromagnetics code. Databases are identified, as well as output data content and presentation form and format. Much of these data are identical to the data items named in the data dictionary schema shown in Figure 14, and they can be directly used to augment the content of the global database, if so approved by the configuration control manager.

Figure 18 shows an example of the web pages that are used to develop the input data file for a computational electromagnetics code execution. A typical screen will present command choices with an explanation of each of the options. The user points and clicks and supplies the appropriate parametric information to describe the problem space to the code

Figure 19 shows another type of input web page available. In this example the GEMACS input file is listed and can be edited. Commands can be inserted, modified, or deleted. This is useful when an analyst is taking an existing data input stream and modifying it slightly (e.g., change in frequency, change in load conditions) in order to perform a study of a proposed design as a function of one or more specific parameters or ranges of a parameter. It is also an efficient way to do a "proof-read" of an input file before executing the code to ensure that the data are correct. If one or more data items are not correct, the edit capability provides a chance to modify the file on the fly.

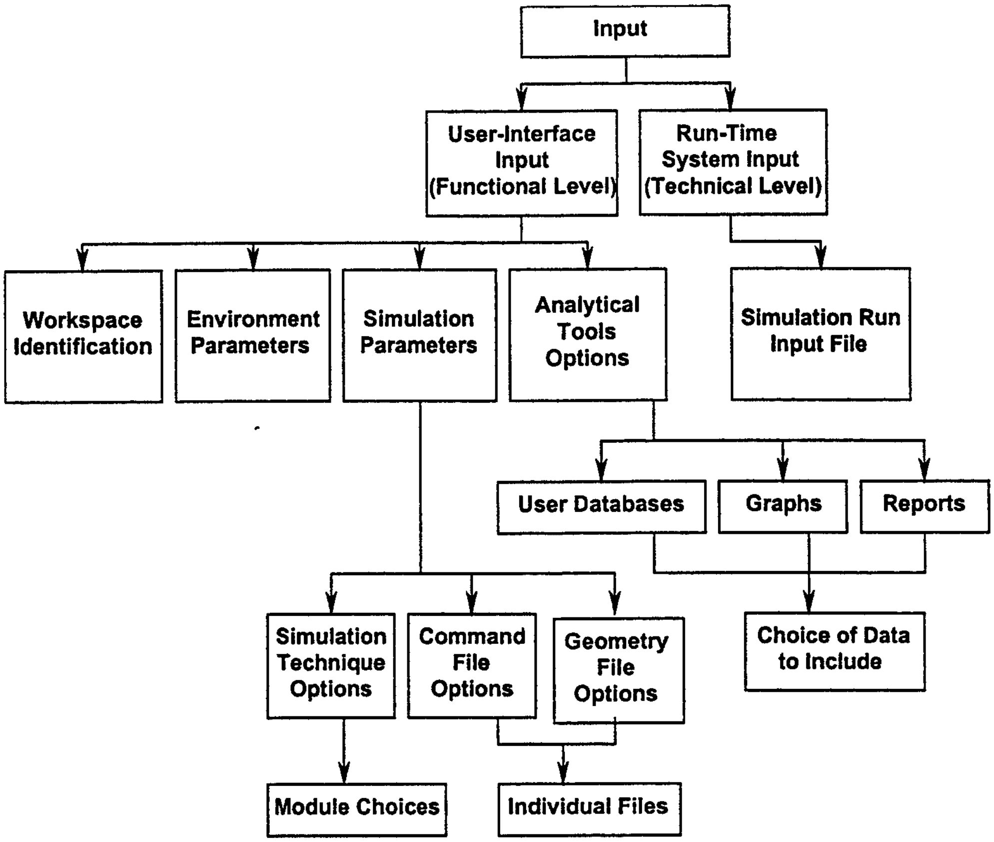
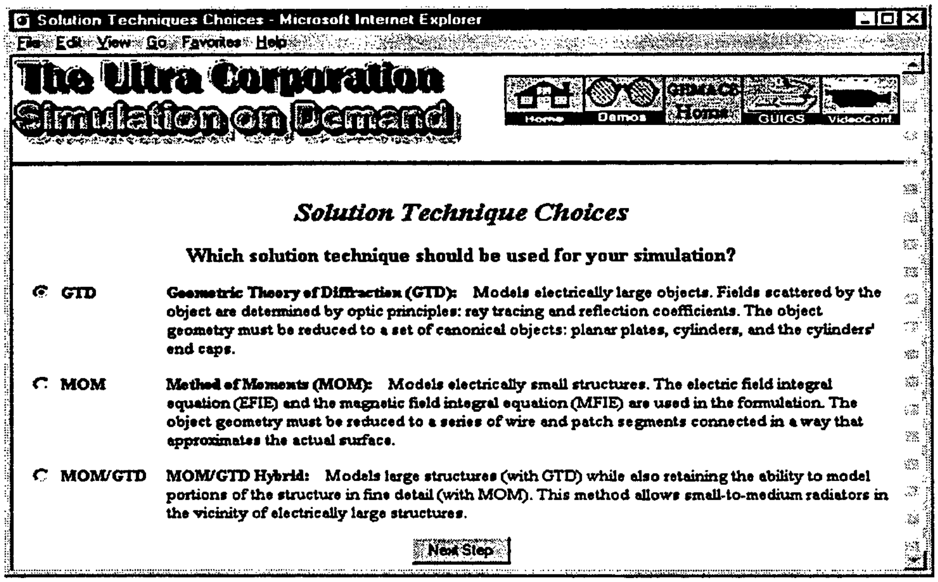


Figure 17. Web-Based Access Input Module Structure



Solution Technique Choices

Which solution technique should be used for your simulation?

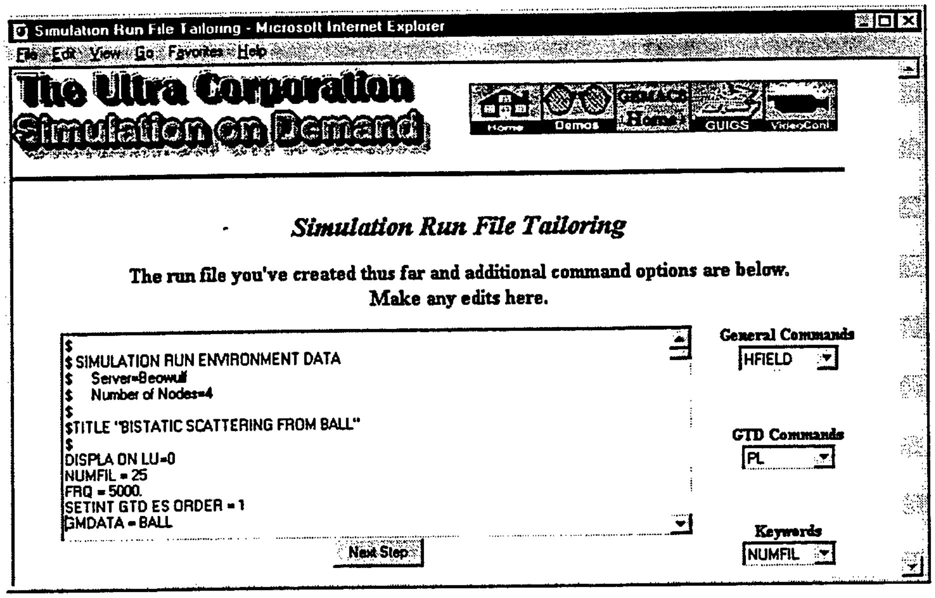
● **GTD** — **Geometric Theory of Diffraction (GTD):** Models electrically large objects. Fields scattered by the object are determined by optic principles: ray tracing and reflection coefficients. The object geometry must be reduced to a set of canonical objects: planar plates, cylinders, and the cylinders' end caps.

○ **MOM** — **Method of Moments (MOM):** Models electrically small structures. The electric field integral equation (EFIE) and the magnetic field integral equation (MFIE) are used in the formulation. The object geometry must be reduced to a series of wire and patch segments connected in a way that approximates the actual surface.

○ **MOM/GTD** — **MOM/GTD Hybrid:** Models large structures (with GTD) while also retaining the ability to model portions of the structure in fine detail (with MOM). This method allows small-to-medium radiators in the vicinity of electrically large structures.

Figure 18. Sample Web Input Page Choosing Solution Method

An entire series of such input web pages is available. Other screens provide the opportunity to specify the work space and to identify files that will be required for input or generated on output. Mandatory screens supply authentication data prior to a user accessing the system.



Simulation Run File Tailoring

The run file you've created thus far and additional command options are below. Make any edits here.

```
$
$ SIMULATION RUN ENVIRONMENT DATA
$    Server=Beowulf
$    Number of Nodes=4
$
$TITLE "BISTATIC SCATTERING FROM BALL"
$
DISPLA ON LU=0
NUMFIL = 25
FRQ = 5000.
SETINT GTD ES ORDER = 1
GMDATA = BALL
```

General Commands HFIELD

GTD Commands PL

Keywords NUMFIL

Figure 19. Sample Web Input Page to Edit Input File

Figures 17 through 19 have described the input processes associated with the Ultra "Simulation on Demand" concept. The user is authenticated into the system, defines a workspace and the files associated with that workspace, develops the input data which drive the analysis, and then initiates the analysis using the code on a computer and at a site specified by the user. There is an analogous series of figures for managing the output data handling process available to the user.

Figure 20 shows the system flow diagram for the output. The analyst can format and view the output data in a variety of formats, either remotely or more often at the local site once the data have been electronically transferred to the user's facility. Commercial graphing packages are available, which allow the user to specify rectangular or polar plots, include legends, the plotting of multiple runs as a function of a parameter, labeling, and color coding.

The data can also be added to an existing database at the local facility or made available to other members of the design team for use in other engineering disciplines or system management. The data, if warranted, can also be proposed as a candidate for inclusion in the global database, in which case a pointer to its location would then be established and catalogued.

Of special note is the box in the lower left-hand side of the figure which refers to a master database of pointers. This is completely in consonance with the concepts and proposed implementation of the global database which was discussed in Section 6 of this report. The data associated with the accepted version of the design of the object reside where it makes the most sense. The practice of building up a complex model from a set of constituent models is made easier. Consistency within the hierarchy of numerous levels of model complexity (See Figure 2.) is made easier. Tracking and updating of models is made possible and manageable. The use of commercially available web browsers as proposed in the scheme and implementation developed by The Ultra Corporation eases the user's task of searching for a particular model or a set of models from which to choose.

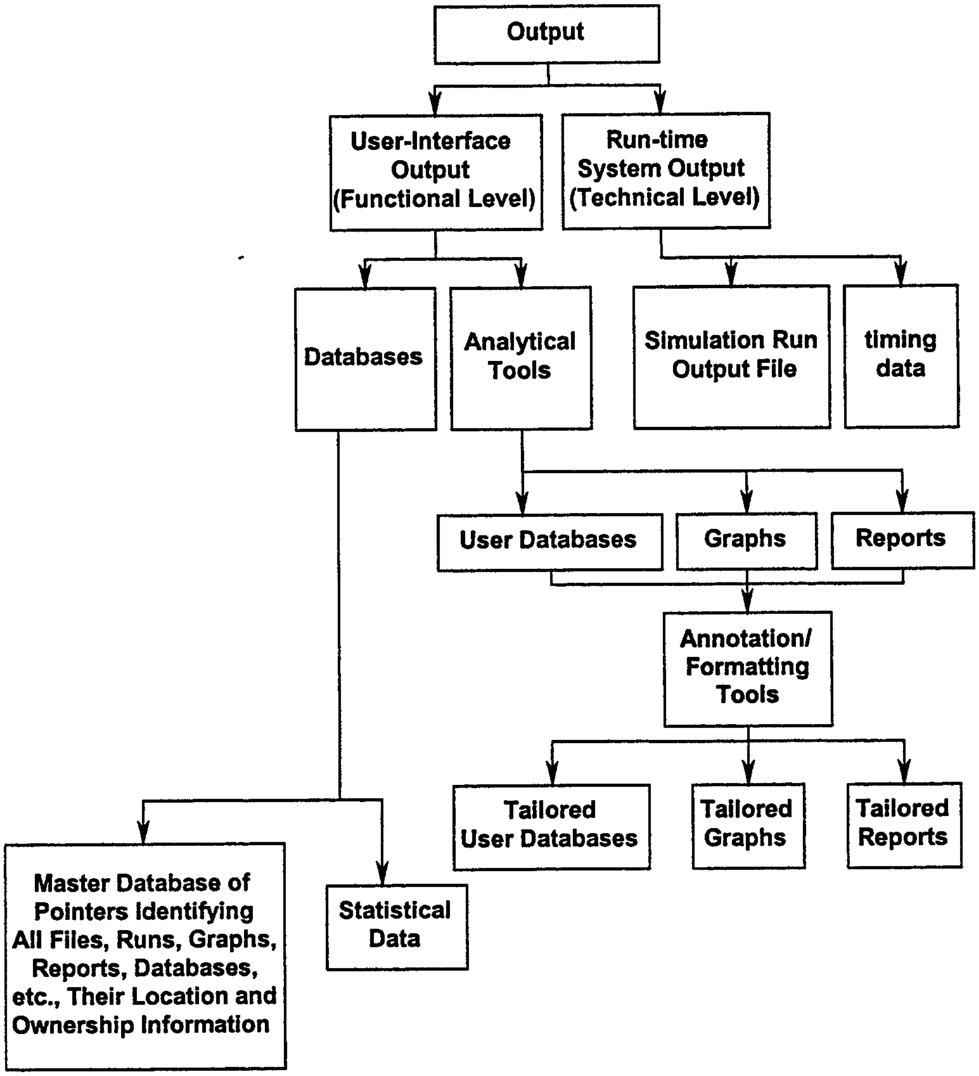
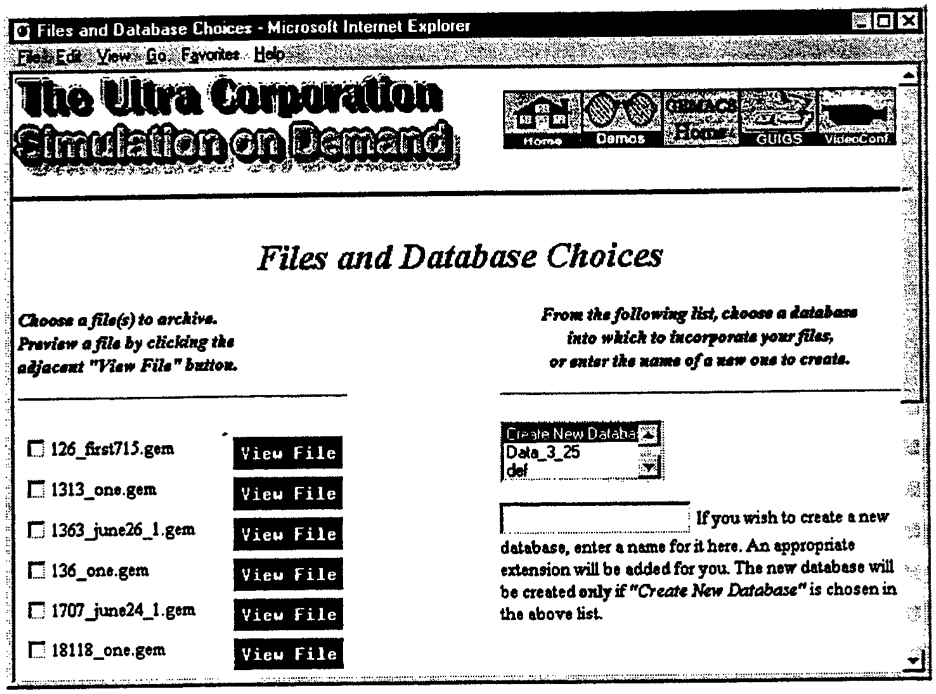


Figure 20. Web-Based Access Output Module Structure

Figure 21 is an example of this last point. The left-hand side of the figure shows a display of files that can be accessed and archived. These files could have resulted from a study that had been performed by the user, or they could have resulted from a search initiated by the user in accordance with a set of criteria established by the user. The user can view the file by clicking on the "View File" button. If it is of interest to the user, it can be selected by checking the box next to its name. The right-hand side of the screen shows the available databases that have been established and into which the chosen file(s) can be inserted. The user also has the opportunity to create a new database and insert the selected file(s) into it.



Files and Database Choices

Choose a file(s) to archive.
Preview a file by clicking the adjacent "View File" button.

From the following list, choose a database into which to incorporate your files, or enter the name of a new one to create.

☐ 126_first715.gem
☐ 1313_one.gem
☐ 1363_june26_1.gem
☐ 136_one.gem
☐ 1707_june24_1.gem
☐ 18118_one.gem

If you wish to create a new database, enter a name for it here. An appropriate extension will be added for you. The new database will be created only if *"Create New Database"* is chosen in the above list.

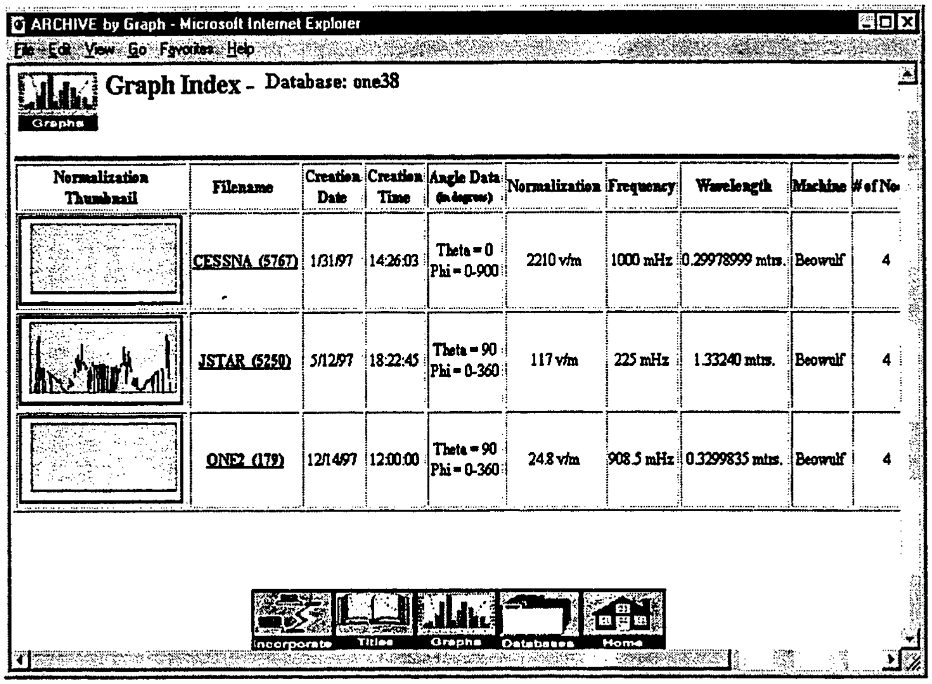
Figure 21. Example Web Search Results

Figure 22 shows an example of displaying archived files by graph. In this option a thumbnail can be viewed prior to fully accessing a file and loading it into an appropriate display program. Catalog information is also available, and comments can appear in a text box. These comments can provide further information regarding the data within the file, such as identification of the object whose performance is being quantified, the engineering discipline, the formulation used for the analysis, and the code used to perform the analysis. Data in the comments field can also point to other files which may contain information relevant to the performance of this object.

Figures 23 and 24 contain examples of the output data display capabilities of the Ultra system. These capabilities are provided with the browser or within a plug-in associated with the browser. The system is unusually robust and provides for the relatively easy addition of different plot types or the modification of existing plot templates. Because these displays are Windows95/NT-compatible, it is an extremely easy matter to insert the files into user-specified word processors and presentation programs for reports and presentations, respectively. All the advantages of user-friendliness, short learning periods, commercial maintenance and upgrade, and numerous sources of extensive help are built into the design of this package and its implementation by The Ultra Corporation.

The documents cited in section D of the References Section contain more detailed information about the work performed in this technology area.

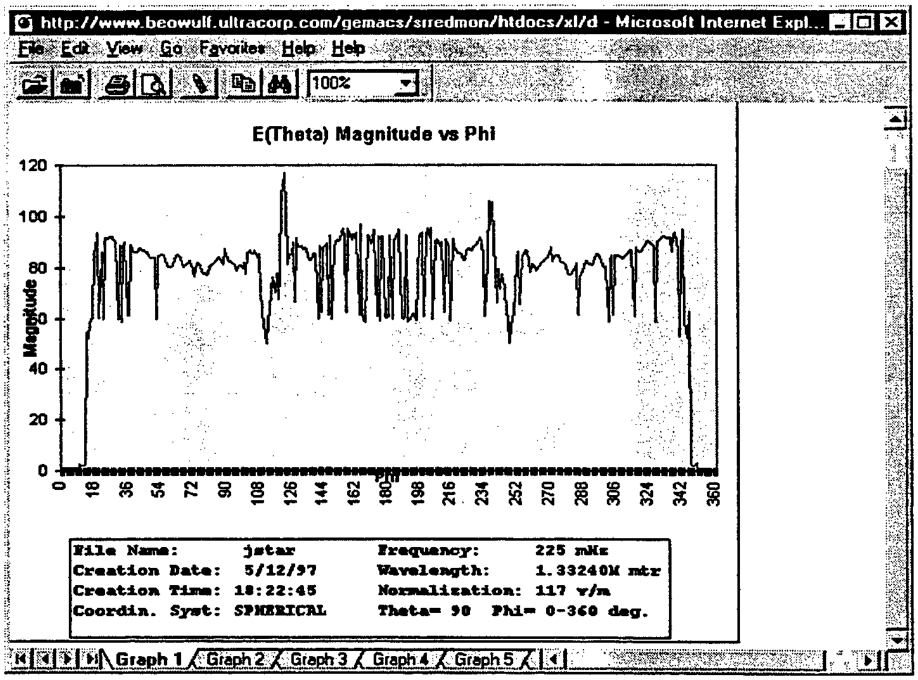
Further information can be obtained by contacting Dr. Donald Leskiw at The Ultra Corporation. His contact information is P.O. Box 50, University Station, 1004 E. Adams St., Syracuse, NY 13210. The internet address is <www.ultracorp.com>.



Graph Index - Database: one38

Normalization Thumbnail	Filename	Creation Date	Creation Time	Angle Data (in degrees)	Normalization	Frequency	Wavelength	Machine	# of No
	CESSNA (5767)	1/31/97	14:26:03	Theta = 0 Phi = 0-900	2210 v/m	1000 mHz	0.29978999 mtrs.	Beowulf	4
	JSTAR (5250)	5/12/97	18:22:45	Theta = 90 Phi = 0-360	117 v/m	225 mHz	1.33240 mtrs.	Beowulf	4
	ONE2 (179)	12/14/97	12:00:00	Theta = 90 Phi = 0-360	24.8 v/m	908.5 mHz	0.3299835 mtrs.	Beowulf	4

Figure 22. Example Database Directory Display



```
File Name:       jstar          Frequency:      225 mHz
Creation Date:    5/12/97       Wavelength:     1.33240M mtr
Creation Time:  18:22:45        Normalization:  117 v/m
Coordin. Syst:  SPHERICAL       Theta= 90  Phi= 0-360 deg.
```

Figure 23. Web Browser Display of Electric Field Magnitude

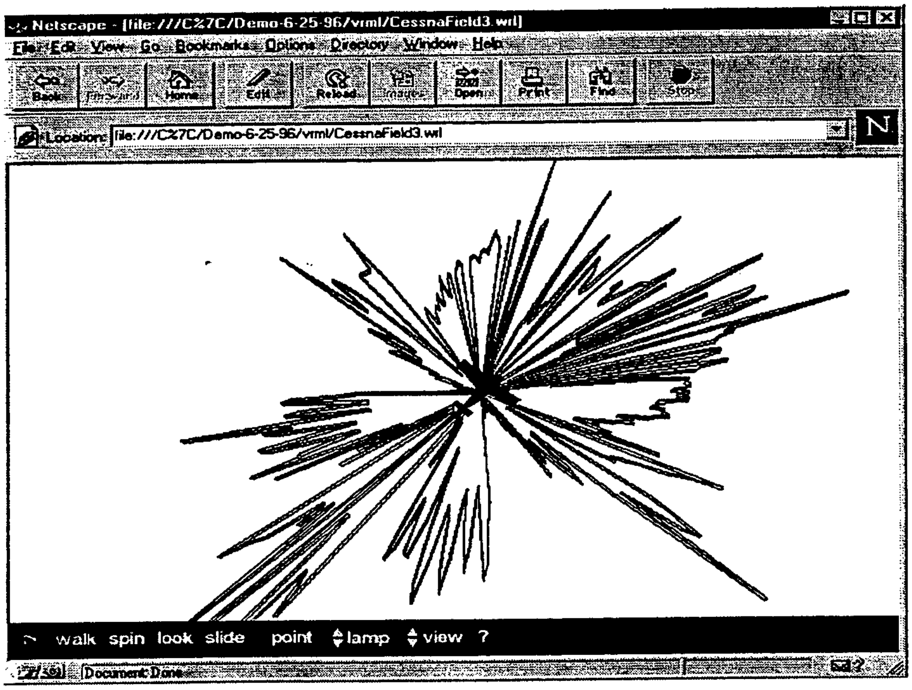


Figure 24. Web Browser Display of Antenna Pattern

Section 8. Visualization Package

A second phase II SBIR was awarded in support of the ICE development program. The objective of this effort was to:

- Develop a generic visualization system for electromagnetic simulation computer codes
- Expand the capability of this visualization system to apply visualization techniques to simulation codes used in other engineering fields, such as mechanical and environmental engineering
- Develop a version of the visualization system for use as an engineering and scientific educational tool.

At the time that this effort began there were no commercially available engineering analysis data visualization packages that could be used to display the data generated by the phenomenological codes. Most of the analysis codes have an associated native display capability. Each of these display packages contained some very specific syntax rules for the data, which were tailored to match the output format of the analysis code. Hence, data interchange and re-use were limited. Code developers and users could not modify the output format without requiring a modification of the input format for the display code. Trying to match the data from codes in the same engineering discipline was very difficult because data display size, labeling, and legends were not consistent among the display codes. This limited one valuable technique for establishing code validity.

It was also intended that the development of a generic capability would reduce the development and maintenance burden on phenomenological analysis code developers. Instead of expending resources on developing, maintaining, and enhancing a visualization capability specific to the analysis code, the code developer could design the output data format to be compatible with the input requirements of this generic visualization package and not worry about generating code to obtain a display of the output data. More and more powerful, user-oriented features would be available in the generic package, compared to those features present in a locally developed visualization package.

Finally, the package would be transportable across various platforms, from UNIX workstations to PCs on an analyst's desktop. Being commercially supported, updates, enhancements, and revisions would not be the concern of the analysis code developer or end user. Experience with government-developed computational electromagnetics software has shown that this can be a time-intensive, resource-consuming activity.

ARCON Corporation developed a prototype product called *ArconViz* consists of three principal sections:

- An input geometry processor to interpret drafting package files (e.g., IGES, dxf)
- A graphical user interface to enter non-geometric input data, such as global parameters and execution options
- An output analysis data processor to provide visualization of the computational results for a number of scientific and engineering simulation programs (specifically, electromagnetic, circuits, atomic particle transport, and thermal analyses)

During the course of this effort several high quality software products were released. These products accomplished many of the goals that had been set out for this program, but on a single analysis code basis. The results of this program were to have a single look and feel across many design and analysis codes and engineering disciplines. This reduces learning time and long-term maintenance. It allows for a degree of model interoperability that is much greater than that possible with the use of analysis code-specific interface and visualization programs. This program used a bottom-up approach in the design of the interface capability, but it did so within an overarching design for coherence and consistency throughout the individual, bottom-up designed elements.

As an example of this correlated bottom-up/top-down approach to the design and implementation approach of ARCON, consider the generic set of foundational modeling elements which are used in the *ArconViz* geometry modeler:

- Rectangular parallelepiped (aligned along coordinate axes): Coordinates of two diagonally opposite corner points;
- Rectangular parallelepiped (arbitrary orientation): Coordinates of all 6 corner points;
- Right circular cylinder: Coordinates of base center; coordinates of top center; cylinder height; cylinder radius;
- Right elliptic cylinder: Coordinates of top center; coordinates of bottom center; semi-major axis; semi-minor axis;
- Right circular cone: Coordinates of base center; base radius; coordinates of apex; cone height;
- Truncated right circular cone: Coordinates of base center; base radius; coordinates of top center; top radius; height;
- Sphere: Coordinates of center; radius;
- Spherical ellipsoid: Coordinates of foci; semi-minor axis;
- Wedge: Coordinates of the six corner points.

It is to be noted that these foundational modeling elements correlate extremely well with the foundational set found in the data dictionary, as discussed in Section 6. They are equally applicable to many engineering disciplines and thus encourage data re-use and exchange.

The graphical user interface of *ArconViz* provides a "standard" way across all the analysis codes to add non-geometrical data to the input data stream for an analysis code. Each of the codes selected as initial targets for *ArconViz* has its own unique format and syntax for the execution commands which govern the particular execution of the code, specifying the excitation, global parameters, and observable dataset to be generated. The approach to achieve this uniformity is to use pull-down menus. A menu selection will lead to a predetermined sequence to develop the execution command stream for an analysis code's input.

Figure 25 shows the main graphical user interface screen for the Windows95/NT version of the code. The UNIX displays are slightly different (See [E.1].), but they perform essentially the same functions. It can be seen that the display is modeled after the standard Microsoft Windows format. The menu, tool, and status bars are labeled and perform functions identical to those which most commercially available Windows software perform. The screens for the various drawing packages which can be accessed through the Launch menu item (the interface for the DesignCAD drawing package is currently in place), the dialog boxes for the various analysis codes (shown in the figure under the Analysis menu item), and the analysis output visualization screens appear within the central display area.

Figure 26 shows the first of many dialog boxes that the user encounters after the GEMACS code has been selected from the opening *ArconViz* screen. Through the use of the dialog boxes, each of which addresses a particular aspect of the GEMACS command language, such as the location and type of external excitation and the identification of the observable quantities, the problem to be analyzed is fully specified and the execution can be initialized. This is graphically illustrated in Figure 27 (Figure III.4a of [E.1]). This figure identifies each of the functions that are available behind the menu items of the GEMACS opening screen shown in Figure 26.

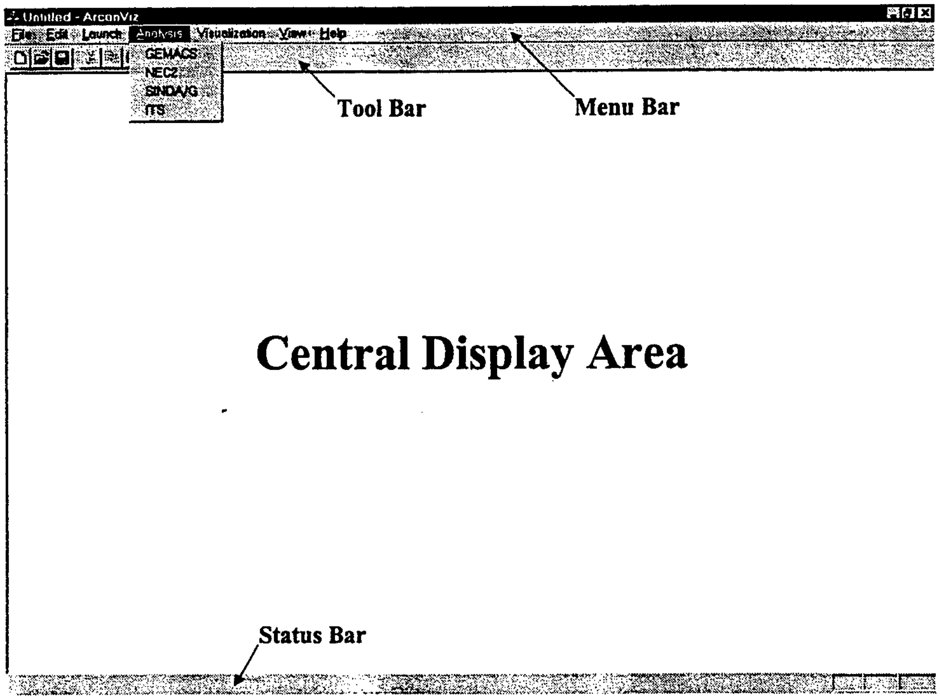


Figure 25. ArconViz Main Screen

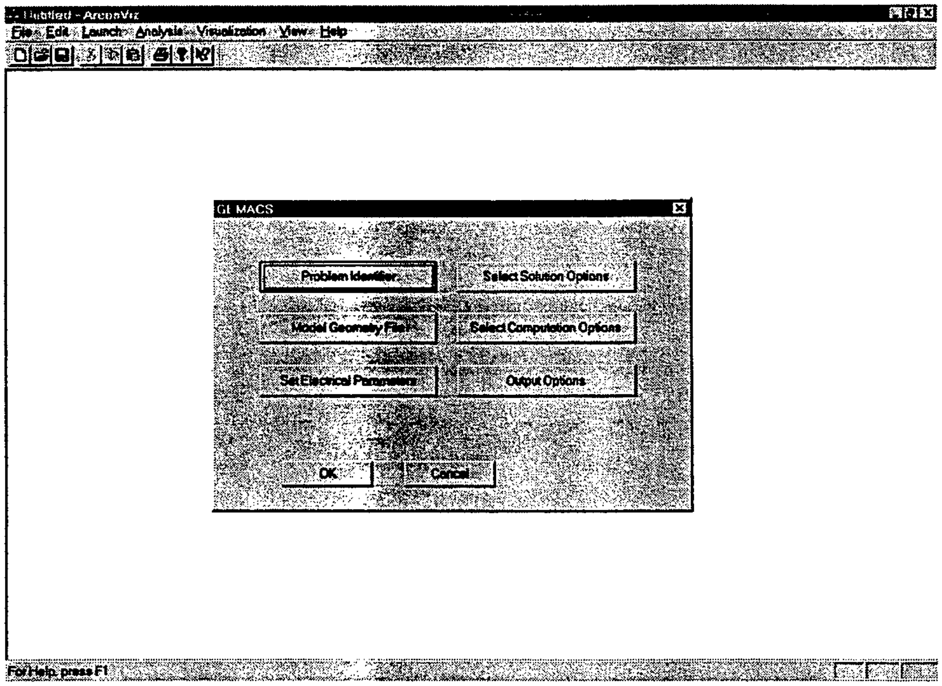


Figure 26. ArconViz Opening Screen for GEMACS

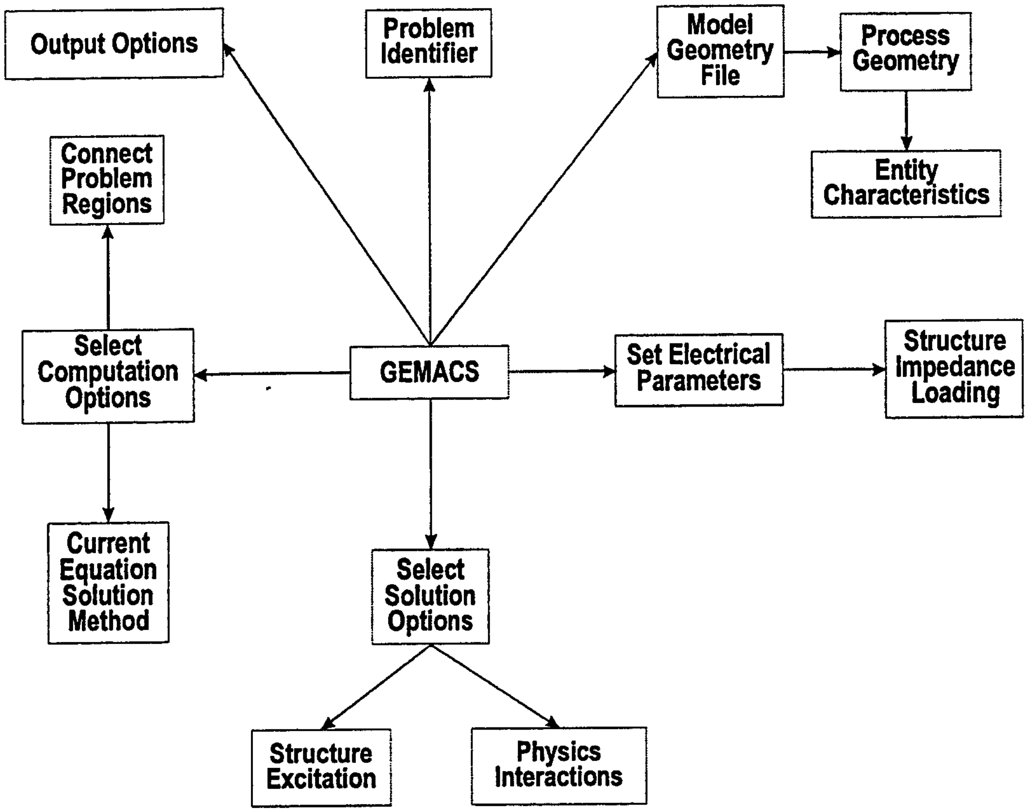
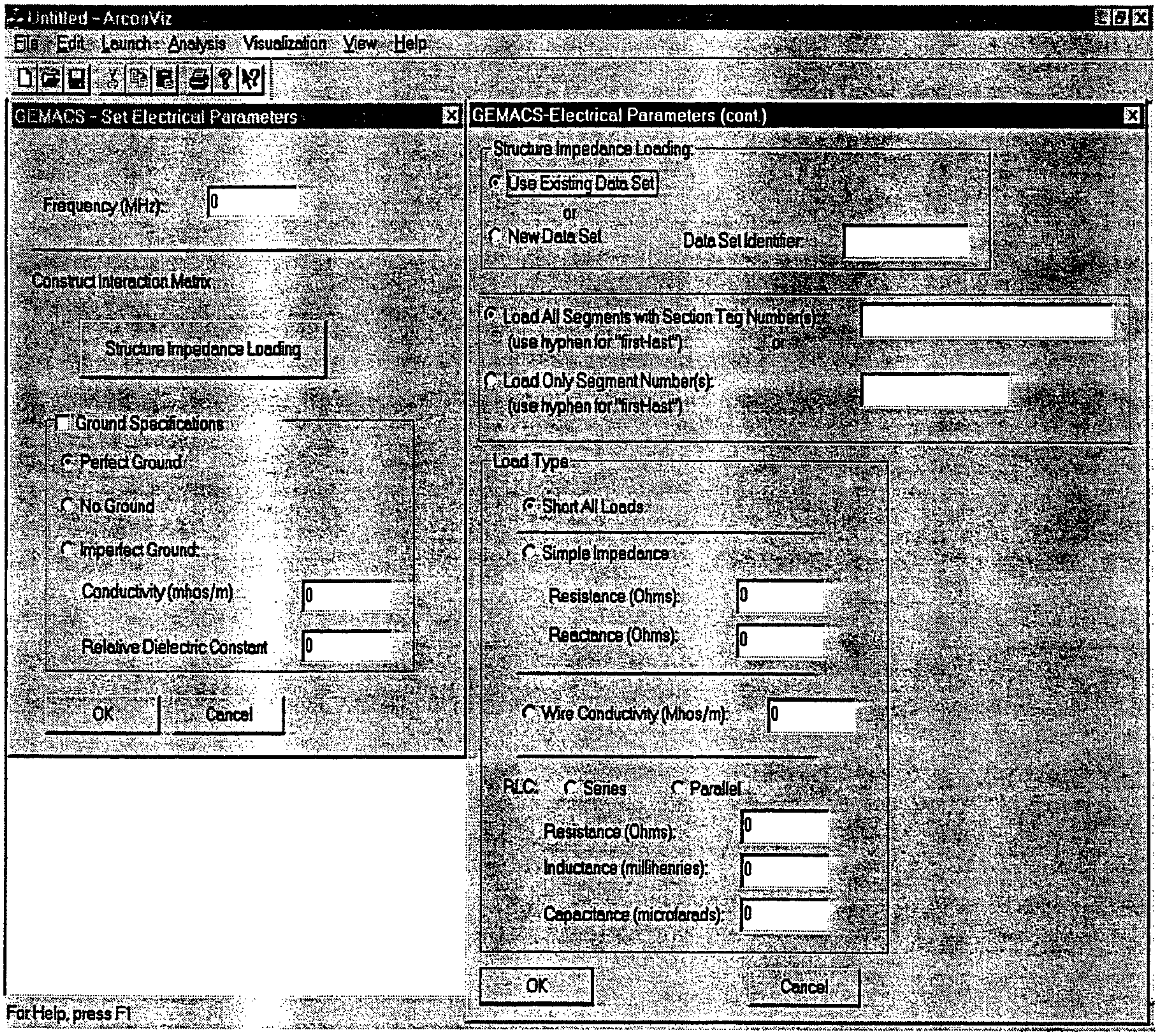


Figure 27. ArconViz Electromagnetic Analysis Process

The *Problem Identifier* option allows the user to name the project for future reference and files storage. This option also allows the user to limit the computer resources expended for the analysis by specifying a limit on the CPU time.

The *Model Geometry File* option allows the user to specify the location and file name(s) of single- or multiple-domain geometry region(s). Graphics formats currently supported include IGES and dxf. Once the geometry file has been loaded, the user can process the geometry. In addition to viewing the geometry the user can define some of the characteristics of the model which will be used in the analysis of the structure. Clicking on an entity within the structure will bring up a dialog box which describes the entity type and allows the user to identify a material for that entity. This in effect associates an intrinsic parameter set with that entity.

The *Set Electrical Parameters* option brings up the screens shown in Figure 28. The user is able to define the discrete loads and distributed impedances associated with a method of moments model of a structure. This is especially useful for loading an antenna to represent the receiver, or to define an area that is not perfectly conducting. Both of these modeling options allow the user to more accurately represent the structure being analyzed and to more completely define the environment in which a radiator is expected to operate.



GEMACS - Set Electrical Parameters

Frequency (MHz): 0

Construct Interaction Matrix

Structure Impedance Loading

☐ Ground Specifications

● Perfect Ground

○ No Ground

○ Imperfect Ground:

Conductivity (mhos/m): 0

Relative Dielectric Constant: 0

GEMACS-Electrical Parameters (cont.)

Structure Impedance Loading:

● Use Existing Data Set

or

○ New Data Set Data Set Identifier:

● Load All Segments with Section Tag Number(s): (use hyphen for "first-last") or

○ Load Only Segment Number(s): (use hyphen for "first-last")

Load Type

● Short All Loads

○ Simple Impedance

Resistance (Ohms): 0

Reactance (Ohms): 0

○ Wire Conductivity (Mhos/m): 0

RLC: ○ Series ○ Parallel

Resistance (Ohms): 0

Inductance (millihenries): 0

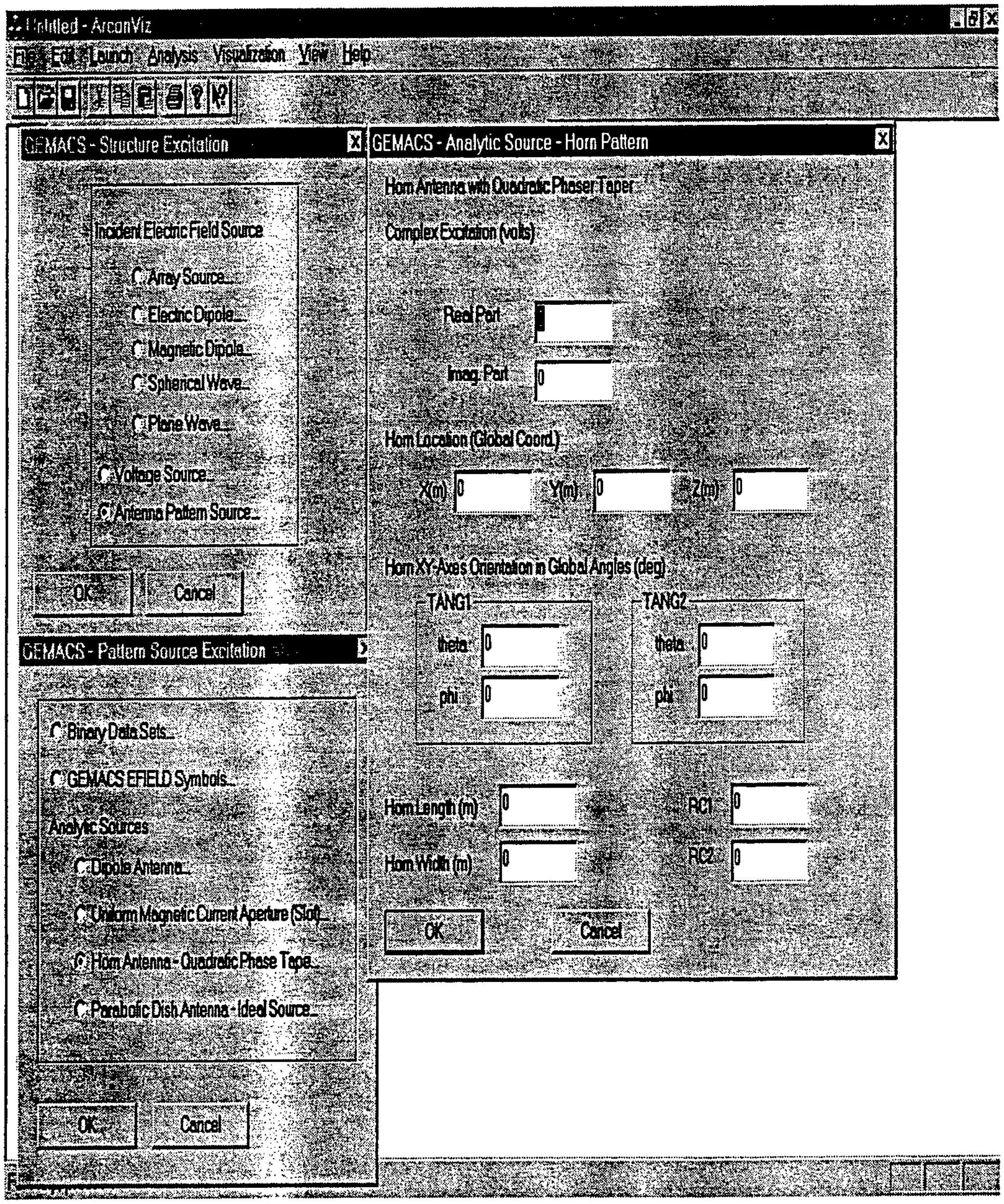
Capacitance (microfarads): 0

Figure 28. Setting Electrical Parameters in ArconViz

Select Solution Options enables the user to define the structure excitation and the physics interactions. The latter options are:

- Method of Moments (MoM) — a low frequency solution technique used for structures that are no more than a few wavelengths in size
- Geometrical Theory of Diffraction (GTD) — a high frequency solution technique used for structures that are tens of wavelength and larger in size
- MoM/GTD Hybrid — a combination of the two techniques in which the user models the radiator and its near region with MoM elements and the larger structure (e.g., aircraft fuselage) with GTD elements
- Finite Difference — a discrete solution technique for interior structures, such as cavities and waveguides

The analyst also uses this option to define the excitation associated with the problem, whether it is a source located on the structure or an incident source in which the structure is immersed. Figure 29 shows that an extensive set of sources is available for selection by the analyst. At the top-left of the figure is shown the initial excitation screen. As an example the Antenna Pattern Source has been chosen. The lower-left of the figure shows the dialog box that would next appear. A pattern source can be generated in a number of ways. For this example the pattern is that of a horn antenna with a quadratic phase taper. The dialog box for this option is shown on the right-hand side of Figure 29. With this rich set of parameters the analyst is able to define almost arbitrarily the excitation for the problem. Each of the other options available also provides an opportunity to very specifically define one or more excitations which can be used to drive the analysis.



GEMACS - Structure Excitation

Incident Electric Field Source

○ Array Source...
○ Electric Dipole...
○ Magnetic Dipole...
○ Spherical Wave...
○ Plane Wave...

○ Voltage Source...
● Antenna Pattern Source...

GEMACS - Pattern Source Excitation

○ Binary Data Sets...
○ GEMACS EFIELD Symbols...

Analytic Sources

○ Dipole Antenna...
○ Uniform Magnetic Current Aperture (Slot)...
● Horn Antenna - Quadratic Phase Tape...
○ Parabolic Dish Antenna - Ideal Source...

GEMACS - Analytic Source - Horn Pattern

Horn Antenna with Quadratic Phaser Taper

Complex Excitation (volts)

Real Part
Imag. Part 0

Horn Location (Global Coord.)

X(m) 0 Y(m) 0 Z(m) 0

Horn XY-Axes Orientation in Global Angles (deg)

TANG1
theta 0
phi 0

TANG2
theta 0
phi 0

Horn Length (m) 0
Horn Width (m) 0
RC1 0
RC2 0

Figure 29. Setting the Excitation in ArconViz

Select Computation Options provides the user with the capability to select regions which are to be connected (e.g., the fields exterior to a fuselage coupling through an aperture in the skin and propagating throughout the interior of the fuselage) or remain distinct. The user also selects the equation solution method, whether matrix inversion or banded matrix iteration. If the latter, the user may then specify the number of bands and a maximum number of iterations allowed, as well as the convergence criterion to be used and percentage for the process.

These five options enable the analyst to fully describe the structure model and specify the set of execution commands to the GEMACS code. A similar set of dialog boxes exists for each of the other codes which have been interfaced into the ArconViz system. Because of the design of this computational environment, other sets of dialog boxes can be similarly generated for other analysis codes. Thus, the system is readily extensible.

The final option available to the analyst is the specification of the output and its display. This is controlled by the *Output Options* menu shown in the left-hand side of Figure 30. Options that are available are:

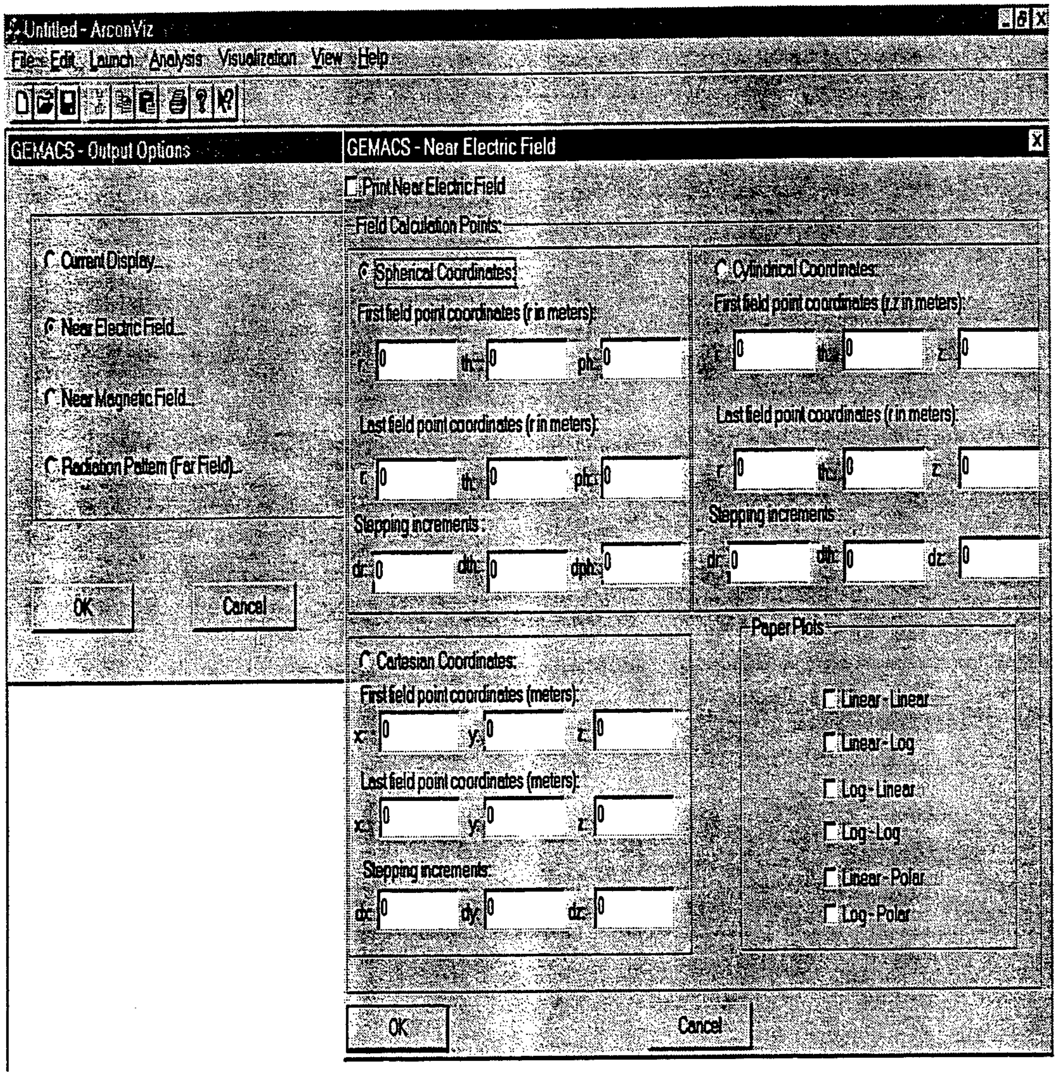
- Currents on wires and current density on surfaces
- Far-field radiation pattern
- Near-field electric field pattern
- Near-field magnetic field pattern

The right-hand side of Figure 30 shows the dialog box that appears when the analyst chooses the near-field radiation pattern option. The user specifies the coordinate system in which the field is to be calculated, as well as the beginning and end coordinates specifying the region and the resolution of the plot in that region. The user also has the flexibility to specify whether the plot is to be linear or polar and whether one or both scales are to be linear or logarithmic. This flexibility is available for all the output options.

Finally, ArconViz can produce a color plot of the currents directly on the structure model. This is shown (in gray-scale) in Figure 31. Such a plot provides "hot-spot" information to the system designer. This is vital information if there is an aperture in the vicinity through which the electromagnetic field could enter the interior of the structure and cause upset to collocated equipment.

As a product ArconViz is unfinished at this time. Work will continue as time and resources become available. What is presented here are an "artist's conception" of the first release of the product and a description of some of what is currently implemented in the prototype. It must also be kept in mind that this presentation focuses on the PC version of ArconViz. A version for UNIX systems is also available. The graphical interface and presentation are slightly different, but the functionality is identical. The UNIX version is the more complete of the two versions.

The documents cited in section E of the References Section contain more detailed information about the work performed in this technology area. Further information may be obtained directly from Arcon. The project engineer was Dr. Bob Joseph, 260 Bear Hill Road, Waltham, MA 02154.



○ Current Display...
● Near Electric Field...
○ Near Magnetic Field...
○ Radiation Pattern (Far Field)...

☐ Print Near Electric Field

Field Calculation Points:

● Spherical Coordinates:

First field point coordinates (r in meters):

r: 0 th: 0 ph: 0

Last field point coordinates (r in meters):

r: 0 th: 0 ph: 0

Stepping increments :

dr: 0 dth: 0 dph: 0

○ Cylindrical Coordinates:

First field point coordinates (r,z in meters):

r: 0 th: 0 z: 0

Last field point coordinates (r in meters):

r: 0 th: 0 z: 0

Stepping increments :

dr: 0 dth: 0 dz: 0

○ Cartesian Coordinates:

First field point coordinates (meters):

x: 0 y: 0 z: 0

Last field point coordinates (meters):

x: 0 y: 0 z: 0

Stepping increments:

dx: 0 dy: 0 dz: 0

Paper Plots

☐ Linear - Linear
☐ Linear - Log
☐ Log - Linear
☐ Log - Log
☐ Linear - Polar
☐ Log - Polar

Figure 30. Specifying the Output in ArconViz

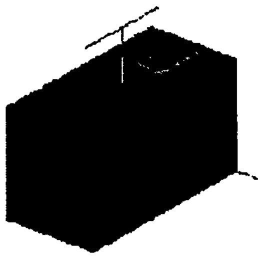


Figure 31. ArconViz Plot of Current Density on a Hut

Section 9. Knowledge-Based Expert System Pre-Processor

If modeling and simulation is to be of any effective and efficient use in the design and analysis of modern-day warfighter systems, they must be founded on highly accurate computational algorithms and very detailed digital models of the object. Experience in the computational electromagnetics domain has determined that an aircraft model must contain on the order of 500,000 to 1,000,000 elements to characterize antenna pattern performance, and backscatter and radar cross section. Typically, these modeling elements are curved triangular facets which account for the material properties as well. Other engineering disciplines have similar modeling requirements to levy on the analyst.

The development, modification (caused by a change in physical design or frequency in the case of computational electromagnetics), and management of models of such magnitude is an intense activity in terms of time and analyst attention and experience. Yet, such highly detailed models are not always required. In the early phases of a design, such as the Concept Exploration phase shown in Figure 1, an aircraft model may only require a cylinder for the model of the fuselage, or a detailed model may only be needed in the vicinity of a new antenna installation. Figure 32 shows two extremes of computational electromagnetics models. The number of variations in between is limited only by the requirements of the analysis and ingenuity of the analyst. How can one convert a huge number of facets into a few plates and one or more cylinders? Conversely, how can one generate a model with an area of high resolution which must be properly coupled to adjacent areas modeled with a high degree of approximation? This requires a very careful electrical coupling among all the regions.

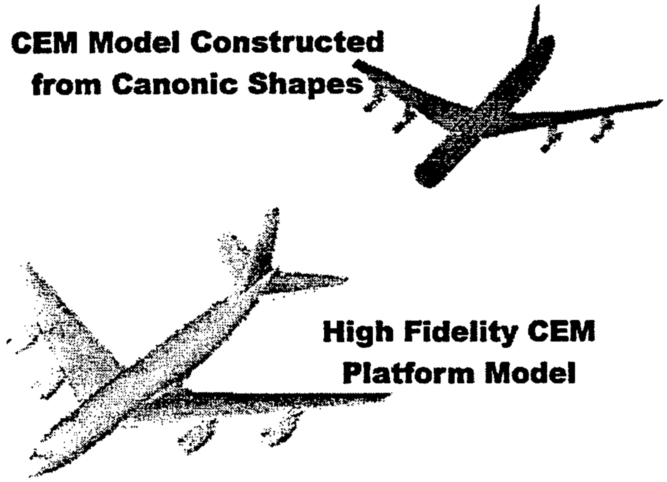


Figure 32. Computational Electromagnetic Model Extremes

In response to these requirements a contract was awarded under the Small Business Innovative Research (SBIR) program to develop a knowledge-based intelligent preprocessor that will be used by an analyst as an aid to develop a computational model. This tool, called the Intelligent Computational Electromagnetics Modeling Expert System (ICEMES), would not replace the analyst, but would provide utilities and services to check for model self-consistency, assure conformance with the modeling rules associated with the engineering simulation, perform model viewing and editing, and develop a first-cut model based on user requirements, observables desired, excitation, and global parameters (e.g., frequency, resolution). The first version addresses computational electromagnetics modeling and simulation. There will eventually be a suite of interactive tools, one for each engineering domain, as shown in Figure 33.

The top part of this figure shows that ICEMES operates within the Integrated Computational Environment. ICEMES has its own Graphical User Interface (GUI) which the analyst uses to set up the problem, generate and edit the model, and fire a prioritized set of computational electromagnetics modeling rules against that model. ICEMES reads and writes to an internal database using the data model described in the data dictionary. Thus, consistency and data re-use with the other elements of the Integrated Computational Environment will be maintained. ICEMES will have its own graphical geometry and modeling element editor which allows the analyst to import a representation from another CAD package and/or modify the geometry and the computational model for that geometry.

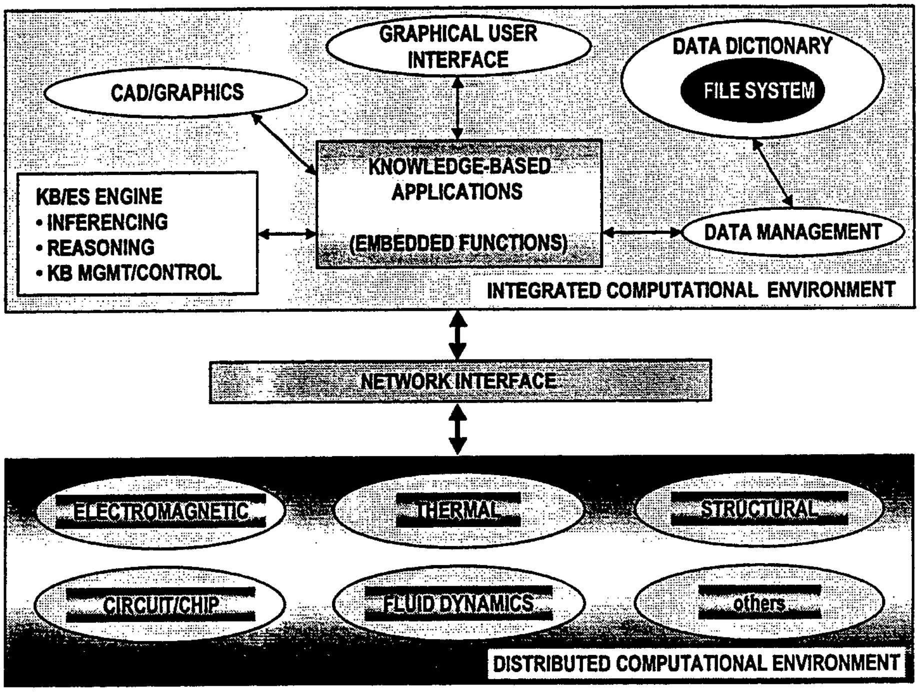


Figure 33. Knowledge-Base Expert System Pre-Processor Suite

The design and analysis codes are expected to reside on other machines. This is shown in the lower part of Figure 33. This is consistent with the overall concept of the Integrated Computational Environment, as has been described previously. It is the Integrated Computational Environment which provides the link between the network interface and ICEMES.

Figure 34 shows the process which the analyst will employ. Once ICEMES has been started, the analyst specifies the name and path of the geometry file. This is followed by a series of dialog boxes in which the analyst enters global parameters and information which will later be used by ICEMES to generate the input data file for the analysis code. ICEMES will then use the geometry and execution information to generate what it deems to be an appropriate computational electromagnetics model. The analyst then displays the model in the ICEMES viewer and can make modifications to the proposed model using a Smart 3-D Graphical Editor or Smart Editor ("smart" because it is tied to the inference engine which will perform validations of any changes to the model in an iterative manner). These changes are then subjected to validity checks based on the rules within ICEMES. Modifications to the user-modified file may be made. This resulting model is then viewed by the user. This process of modification, checking, and viewing is repeated as often as necessary, until the analyst decides that the model satisfies the analysis requirements. ICEMES will then generate the data file and exit. The analyst then executes the analysis, remotely if necessary, using the Integrated Computational Environment control panel environment.

The Smart Editor that is being developed as part of ICEMES is based on the Apple Computer Corp. QuickDraw 3D application. Information can be found on the world wide web at http://www.apple.com/quicktime/qd3d/index.html. Figure 35 shows the basic viewer which is the foundation of the visualization package associated with ICEMES. The basic viewer allows for rotation, translation, and zoom of the object. Data are stored in the QD3D metafile format, which Apple is making freely available to developers. According to the referenced website QuickDraw 3D "is a cross-platform application program interface (API) for creating and rendering real-time, workstation-class 3D graphics. It consists of human interface guidelines and toolkit, a high-level modeling tool kit, a shading and rendering architecture, a cross-platform file format and a device and acceleration manager for plug and play hardware acceleration."

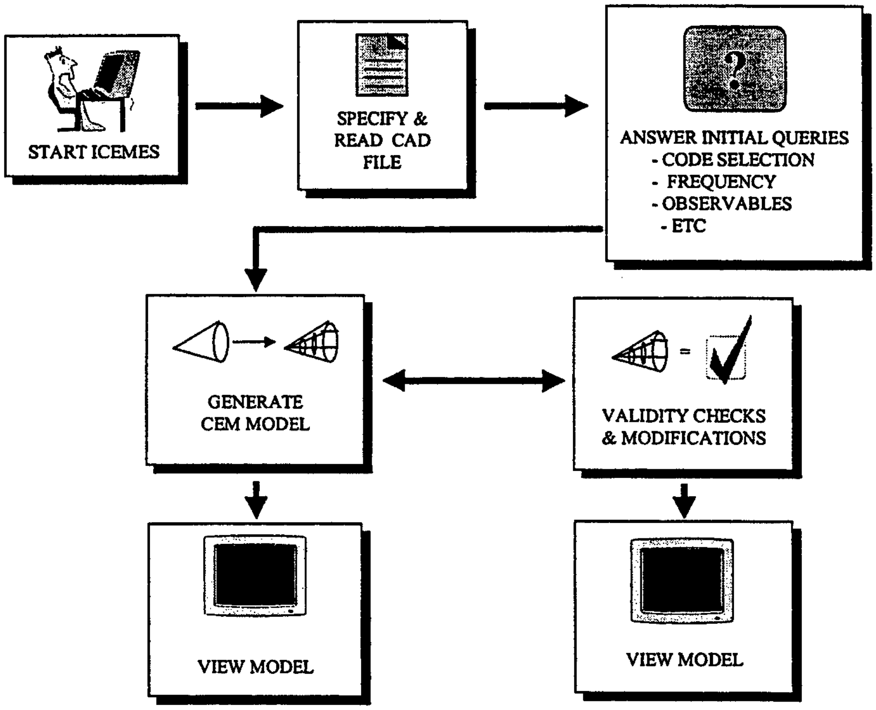


Figure 34. ICEMES Modeling Process

The Smart Editor is being designed to read data from commercial drawing programs (e.g., IGES, DXF) or from computational electromagnetics program input files (e.g., GEMACS). Translators are being developed to convert the geometry data to the 3D metafile format native to QuickDraw 3D. As shown in

Figure 36, the output of the translation process is then displayed within the Smart Editor visualization package. In following the modeling process shown in Figure 34, the expert system then tests the model against the rule set, performs modifications as necessary, and submits its version of the geometry model to the user within the Smart Editor visualizer. The final result is the validated computational electromagnetics model shown in the lower right-hand side of Figure 36.

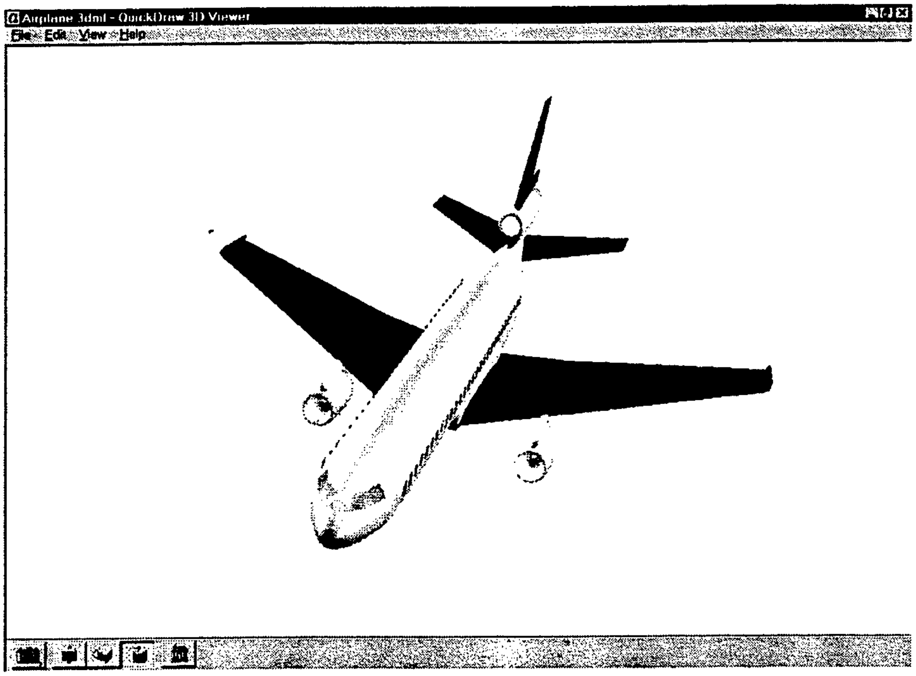


Figure 35. ICEMES Visualization Package

A significant element of the ICEMES design is that the translation of the CAD drawing or an existing CEM model results in a "mapping" of the model data into an object-oriented metafile environment which mirrors the generic KB object network resident within the inference engine. This approach allows for firing the rules directly on the QuickDraw metafile version of the models and executive commands. The rules operate upon the generic KB objects to produce the desired modeling results. In addition, the translation of one CEM tool command set to another is accomplished in the metafile environment and using the generic KB object definitions, rather than directly performing file translations (e.g., GEMACS to NEC-BSC input formats, and so on). This reduces long-term maintenance and minimizes the impact on the user when the command or geometry model syntax of any of the computational electromagnetics analysis tool is changed.

The heart of ICEMES is the knowledge base, the set of rules which are used to develop an analysis model (in this specific case a computational electromagnetics model) and against which a proposed analysis model is checked for validity and self-consistency (especially when the model is composed of a combination of a number of object models). The rules have been generated from a number of sources, most notably code developers and documentation and electromagnetics modelers, and they can be broadly categorized as follows:

- Geometry self-consistency and syntactical checks
- Top-Level rules, generally applicable to the geometrical description and computational electromagnetics modeling (i.e., CAD data are initially checked for integrity and completeness, which is then followed by the CEM modeling and reasoning processes)

- Rules applicable to a specific formulation (e.g., Method of Moments)
- Rules applicable to a specific code (e.g., Numerical Electromagnetics Code)
- Rules applicable to the observables desired (e.g., near-field electromagnetic field distribution)
- Rules applicable to a platform type (e.g., massively parallel processor). Within the initial release of ICEMES this section will be limited, but it is considered to be a critical area for future growth.
- Rules applicable to the stage of a product design (e.g., concept study phase). Within the initial release of ICEMES the rules are not segmented to look at the level of modeling fidelity as a function of life-cycle stage. This difficult-to-define category can be automated in some simple fashion, but a considerable amount of research and development must precede the inclusion within ICEMES of any powerful and robust body of rules.

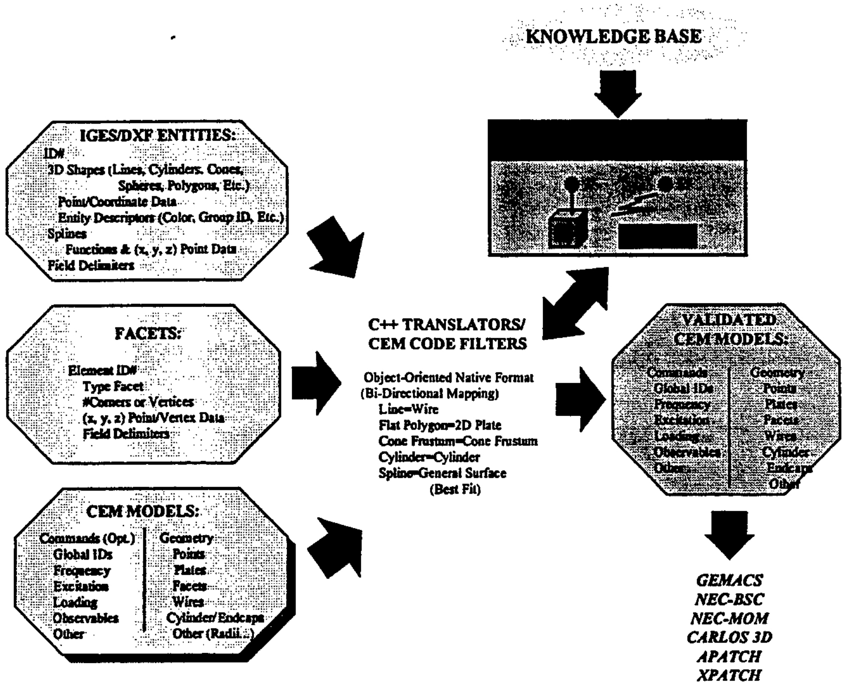


Figure 36. ICEMES Data Translation and Flow

Through their use a non-expert can make minor modifications to an analysis model and have a reasonable assurance that the revised model is still valid. This reduces reliance on and dilution of the personal resources of the expert. Model performance and efficacy are increased because only a minimum resolution model, yet very qualified for the problem at hand, is generated and used in the execution of the analysis. Thus, the time required for modeling and simulation is reduced; or alternatively, the number of cases which can be investigated for a given resource pool is increased.

In summary, the initial version of ICEMES is focused on computational electromagnetics. The design and architecture allow for extensibility to other engineering disciplines which base their analysis models on a structural geometry (e.g., fluid dynamics to test the air worthiness of a design with a proposed antenna location). The QuickDraw 3-D metafile will easily accommodate the material properties and parametric relationships associated with such engineering domains. The use of the metafile to translate geometry and analysis model meshing will reduce overhead and the need for an extensive set of translators. The correspondence between the metafile structure and the data dictionary structure ensures data reusability and self-consistency within the global database for the product. Interoperability with the distributed processing and data management elements within the Integrated Computational Environment (e.g., the Ultra web-based access system) is assured through the use of the utilities within the Control Panel.

The documents cited in section F of the References Section contain more detailed information about the work performed in this technology area. Further information may be obtained directly from Andro Consultants. The project engineer is Mr. Andrew Drozd, P.O. Box 543, Rome, NY 13442-0543.

Section 10. Summary & Recommendations

When this project was in its early stages, there was very little in the way of available distributed, collaborative software environment technology available. Since then, hardware and software advances, driven by the commercial market, especially the world wide web, have made this mode of operation and personal interaction commonplace. Hence, one of the original objectives (proof of concept and the development of a testbed) has been accomplished, although not primarily through the effort put forth under this project.

This project has sponsored technology and its implementation in the form of a number of tools for distributed, collaborative modeling and simulation at the phenomenological level. The most significant advance is the high-level identification of the requirements for a global database for a product and the articulation of the access, maintenance, and configuration control issues associated with such a database. Structural data, performance data, engineering analysis and design models, as well as process data, and all information related to the design and manufacture, maintenance, etc. will be resident in the database [C.3, C.4, C.6].

The work performed under this effort focused on computational electromagnetics as a way to validate the database concepts [C.1, C.2, C.5, C.7]. As has been pointed out, that can be extended to other engineering disciplines which develop computational models from a geometrical description of the structure. Work needs to be done to determine whether and to what extent the models of one engineering discipline can be used in the development of computational models for other disciplines. Early work in this area has shown that data re-use is a highly subjective and objective science (art?) and that a great amount of research and development, and testing and validation, are needed before this can become commonplace [A.2, A.3].

A second area of significant contribution is the implementation of a prototype web-based database access and display package and simulation on demand (i.e., remote execution of a suite of engineering-level analysis codes) [D.1, D.2, D.3]. The current set of tools allows an analyst to display a thumb-nail view of the data and a textual description of a file. The analyst can then quickly scan the contents of a database and select only the appropriate files for download. The analyst uses simulation on demand to remotely create project workspaces, transfer input files for an analysis, spawn analysis jobs, and download the output from the analysis code. These capabilities increase efficiency and reduce the time required to prepare data and execute an analysis. In this way the system analyst or equipment designer can test a larger parameter space or obtain data at increased resolutions for selected regions of critical parameters.

The third significant contribution is the development of a smart pre-processor to aid the analyst to efficiently develop an appropriate model which is commensurate with the requirements of the analysis [F.4, F.5, F.6, F.7, F.9]. This includes both a Smart Editor which provides a graphic display of the model and a rule base against which the model can be tested for self-consistency and conformity of the model with general computational electromagnetics modeling rules and with modeling rules specific first to a class of analysis formulations and second to specific codes within each class. This will reduce the time needed to develop an analysis model and also reduce the possibility of human error which can arise in the generation and handling of analysis models which have hundreds of thousands of elements within them.

While a significant amount of progress has been made in achieving the goal of distributed design and analysis and intelligent data management for an equipment, subsystem, and system-level product, there is much that remains to be done. The simpler task will be to take the existing body of work and extend it to include other engineering disciplines, other work areas associated with product design and manufacture, and other parameters that characterize the object under consideration. This will be a continual process which logically derives from the body of technology and capability which exists at any given moment. This is a matter of funding and time. There are no technology show-stoppers here.

It should be pointed out that this presupposes the existence of a hardware infrastructure and set of protocols which enable the electronic transfer of information. Needless to say, this presupposition is quickly becoming the spatially and temporally efficient pervasive reality it needs to be.

The more difficult task will be to make its use the standard and accepted way for design and analysis. Ingrained culture and the current way of doing things are comfortable and hard mentalities to convert. Fiscal and time-critical requirements will go a long way toward forcing this conversion. A voluntary transition, however gradual, will happen only when there is a demonstrable product to show potential users.

A possible scenario is as follows. A global database for a system such as the F-22 or the Global Hawk must be developed and presented to the SPO and the various integrating and contributing contractors who are designing equipment changes to meet evolving operational requirements and to the manufacturers who are implementing those changes. In the beginning this will be an exercise of catch-up to make the database reflect the current production block. As modifications are designed and implemented the database can be concurrently modified to reflect the physical hardware. Deliverable data items can be added to the contract to ensure that the appropriate data are delivered. The Air Force and DoD will need to invest the money to develop the initial database.

Concurrent with this effort is the need to increase the tool set to facilitate and accomplish the design and analysis process. The computational electromagnetics domain must be completed. The computational tools of other engineering disciplines (e.g., structural, aerodynamic, thermal as a minimum) must be incorporated within the framework. The database schema for each of these engineering disciplines, modeled on the one for computational electromagnetics, must be developed and validated. Smart pre-processors and visual editors must also be developed. Perhaps in this case a better design (rather than a suite of pre-processors) may be a core set of routines and utilities with the engineering discipline-specific rule base incorporated as plug-in modules. This would encourage consistency among data items and formats, encourage data re-use, and reduce the long-term maintenance and enhancement requirements. As mentioned previously, a long-term investment must be made to address the question of data and model re-use across engineering domains. As with the database development program, the Air Force and DoD will need to invest the money to develop the software, the documentation, the processes, and the technology.

In both of these program areas it is an attractive alternative to develop and pursue a dual-use program which is funded by both the government and industry. The software and the database concepts are useful to both the military and civilian sectors. Narrowly focused company-funded programs (e.g., Boeing and 777 airplane) have shown that what is proposed in this body of work is both technically feasible and economically more sensible. What needs to be achieved is applicability to a broad range of products, robustness, and the capability to expand and the software tools to enable user expansion.

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