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Strategies for Implementing IGES (Initial Graphics Exchange Specification) for the Operations of NAVFAC (Naval Facilities Engineering Command)

Mark E. Palmer

U.S. DEPARTMENT OF COMMERCE
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U.S. DEPARTMENT OF COMMERCE, C. William Verity, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

As part of the transition from the current paper-intensive processes to a highly automated and integrated mode of operation, the Navy is adopting the Initial Graphics Exchange Specification (IGES) for certain digital data exchanges among elements of the Navy and Navy contractors. This report provides strategies and recommendations for implementing IGES for exchanging and archiving digital representations of Naval Facilities Engineering Command (NAVFAC) projects.

NAVFAC plans to benefit from the use of computer-aided design and drafting (CADD) by encouraging outside architecture, engineering, and construction (AEC) firms to acquire CADD capabilities and by requiring the delivery of certain project documentation in digital form. The ability to transmit drawings and specifications between different CADD systems is expected to reduce the time (and resources) that NAVFAC and outside personnel spend reviewing, changing, and managing projects and also to improve the quality of the projects.

In order to effectively integrate CADD technology and contract with the AEC industry, NAVFAC requires a comprehensive and reliable data exchange mechanism. This will require thorough technical information management, long-term planning for the transfer and archiving of digital data, and the allocation of resources for the execution of the recommendations of this report.

Key words: AEC CADD; CADD data exchanges; computer-aided design and drafting; data exchange standards; data translators; IGES; information management; NAVFAC; translation quality assurance; validation of data translators

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1. Introduction

The Naval Facilities Engineering Command (NAVFAC) faces critical technical challenges in optimizing its use of computer-aided design and drafting (CADD) and integrated information systems. During the past three years, NAVFAC has made major commitments to the use of CADD for the planning, design, and operation of Naval Shore Facilities. Traditional paper-intensive engineering, design, and drafting processes are quickly evolving to computer-based technologies.

As NAVFAC and the Architecture, Engineering, and Construction (AEC) industry expand their use of CADD, the communication of project information among participating professionals becomes increasingly complex. This situation requires comprehensive technical information management, long-term planning for the transfer and archiving of digital data, and the immediate allocation of resources for the recommendations of this report.

NAVFAC plans to benefit from the use of CADD by encouraging outside architecture and engineering (A/E) firms to acquire CADD capabilities and by requiring the delivery of project documentation in digital form. The ability to transmit drawings and specifications between different CADD systems is expected to reduce the time (and resources) that A/E and NAVFAC personnel spend reviewing, changing, and managing projects and also to improve the quality of the projects. Additionally, with the design and as-built information stored in a digital database, the planning, operation, maintenance, and renovation of Naval facilities will be greatly enhanced.

However, for NAVFAC to succeed with these goals, data exchange capabilities between multiple, dissimilar CADD systems must be achieved. There are over 80 different CADD systems currently being used for AEC operations, and no one CADD system has yet fulfilled all of the requirements for every type of firm. The AEC industry has committed itself to working in a heterogeneous CADD environment. In order to effectively integrate CADD and contract with the AEC industry, NAVFAC requires a comprehensive and dependable data exchange mechanism.

The Navy is working in concurrence with the DoD goal of increased capability to receive, distribute, and use technical information in digital form. The DoD Computer-Aided Acquisition and Logistic Support (CALS) Program is currently defining the DoD-wide required use of the Initial Graphics Exchange Specification (IGES) for the delivery of digital data (proposed standardization document, MIL-D-28000).

As part of its transition from the "current paper-intensive logistic processes to a highly automated and integrated mode of operation" [1], the Navy is adopting IGES for certain data exchanges among elements of the Navy and Navy contractors. A key step in this transition has been the Navy's decision for mandatory compliance with IGES (current and future versions) in their future purchases of CADD systems.

Naval Sea Systems Command (NAVSEA) has already established a Digital Data Transfer Program for its new class of submarines (Seawolf SSN21), and this program relies heavily upon the use of IGES. The Seawolf Digital Data Program has clearly illustrated that the successful use of IGES by Navy commands will require broad commitments by all participants and significant investments in translator testing and translation quality assurance procedures.

This report presents strategies and recommendations for NAVFAC's implementation of IGES for exchanging and archiving digital representations of AEC projects. The goal of these efforts is to ensure that NAVFAC will have a dependable means of exchanging AEC CADD information.

1.1 Definitions

The following definitions are presented to clarify the terminology of this report.

CADD - Computer-Aided Design and Drafting. The use of a computer system for design and drafting operations.

CADD Model - The representation of the information that is used to describe a project, in the format of the CADD system.

Data - A representation of facts, concepts, or instructions in a formalized manner suitable for communication, interpretation, or processing by human or automatic (i.e., in computer-readable form) means. [2]

Data Exchange Standard - Describes the format and content of the data to be digitally exchanged between different CADD systems.

IGES - Initial Graphics Exchange Specification, a data exchange standard (refer to Section 3.1). [3]

IGES Model - The representation of project definition data in IGES format. This is usually in the form of a library of IGES files.

Information Model - Defines the structure and the semantics of the information that is required for the tasks of the specified applications, such as a NAVFAC AEC project information model for the design, construction, and operation of Naval Shore Facilities.

Processable Data - Structured information partitioned into distinct data elements (fields) that can be transmitted and manipulated by electronic means between various activities engaged in the design, construction, and operation of Naval facilities. [4]

Project Data - All types of data that apply to the project life cycle, including project definition data, engineering calculations, project and facility management data, financial data, quality assurance data, and testing results. This is not an exhaustive list.

Project Definition Data - A subset of project data that includes only those data elements necessary for the planning, analysis, design, and construction of a project.

Technical Information - Encompasses technical documents, engineering information (drawings, calculations, and specifications), and the meanings (information) that can be inferred from project data.

2. Analysis of the Information Requirements of NAVFAC

A key element for improved productivity and the integration of CADD is the effective management of technical information. The lack of a unified approach to information and digital data management can result in inefficient storage and significant potential for errors due to data redundancy. The point that must be made is that the understanding of NAVFAC's data exchange requirements is based upon a thorough analysis of the information flow and data requirements of the organization.

The successful use of IGES will require this comprehensive view of the information flow of NAVFAC's AEC operations and the development of a systematic implementation plan. This should include documenting what information is needed for every task and developing a specification and schedule for how that information, in various forms, will be delivered, managed, and archived.

In order to develop a long-term strategic plan for technical information management, it is essential to understand what information NAVFAC uses and how NAVFAC's systems will process that information. Central to this long-term plan will be the development of a NAVFAC information model. An information model defines the structure and the semantics of the information that is required for the tasks of the specified applications, i.e., a NAVFAC AEC project information model for the design, construction, and operation of Naval Shore Facilities.

The project information model will be used to specify the CADD data modeling conventions and the required data translation conventions. With a documented NAVFAC AEC project information model as a road-map, appropriate structuring or mapping to future CADD systems' data structures and future data exchange standards will require significantly shorter completion schedules.

The central issues are what information is required to accomplish each NAVFAC AEC project function and how that information should be transferred and managed. Since the engineering drawing will continue to be a key construction document, this analysis must identify the relationships between computerized and manually processed information, organizational accountability, and quality assurance procedures.

Initially this analysis will define what information is required to transfer a set of production documents, i.e., "engineering release documents". The next step is to specify which of this information is appropriate to transfer and archive using the Navy's current data exchange standards. (During the short- and mid-term, one of these data exchange standards will be the current version of IGES.) This "technical information management and transfer specification" will define NAVFAC's required use of IGES and will coordinate the use of digital data with the other forms of required information.

2.1 Overview of NAVFAC Operations and AEC Applications

NAVFAC is in charge of the planning, design, construction, operation, and renovation of Naval Shore Facilities. With an annual construction budget of approximately $1.8 billion [5], NAVFAC is one of the largest engineering and construction organizations in the world. More than 85% of this mapping, design, and construction work is done by outside firms, and NAVFAC will often work with more than 1,500 different firms annually.

The NAVFAC process starts with survey data for the Facilities Geographic Information System, and this mapping information, often in the form of a digital terrain model, provides the basis for all subsequent AEC project information. Since NAVFAC is responsible for the entire life cycle of all Naval Shore Facilities, most AEC project information will be essential for at least twenty-five years and possibly far longer. This will require the long-term archiving of digital project databases, in a neutral format, so that they may be effectively used in the future on different CADD systems.

NAVFAC has made major commitments to the use of automation in the planning and design of facilities. Currently there are minicomputer CADD systems (Computervision, CADDS® 4X[1]) installed at multiple locations across the country: NAVFAC Headquarters, 6 Engineering Field Divisions (EFDs), 5 Public Works Centers (PWCs), the Naval Civil Engineering Laboratory, and the Civil Engineering Office. The goals of this investment are:

- to reduce the time A/E and NAVFAC personnel spend reviewing/changing designs and specifications;
- to improve the contract document process;
- to improve the quality of the projects;
- to move from paper-based operations to 3-D digital model-based operations, and
- to enhance facility life-cycle operations with the coordinated use of CADD databases.

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1 Certain commercial equipment, software, or materials are identified in this report in order to adequately specify existing CADD software and data exchange formats. Such identification does not imply endorsement by the National Bureau of Standards, nor does it imply that the software or equipment are necessarily the best available for the purpose.

NAVFAC's operations, which have been the traditional paper-based processes (refer to Figure 2-1), are quickly evolving to computer-based technologies (refer to Figure 2-2). The Department of Navy is now in the Request for Proposal (RFP) process for the second Navy CAD/CAM (Computer-Aided Design / Manufacturing) Acquisition. The selected systems will be used for a broad range of CAD/CAM applications in the Navy. The RFP includes the mandatory compliance to the current version and all future versions of IGES.

Due to continuing advances in CADD technology and the federal requirements for competitive bidding, there is no guarantee that NAVFAC's second CADD acquisition will be the same kind of system as is currently installed. In order to successfully integrate the Navy's phased acquisition of CADD workstations and to effectively contract with multiple outside AEC firms, NAVFAC requires a dependable means of moving CADD information between incompatible systems.

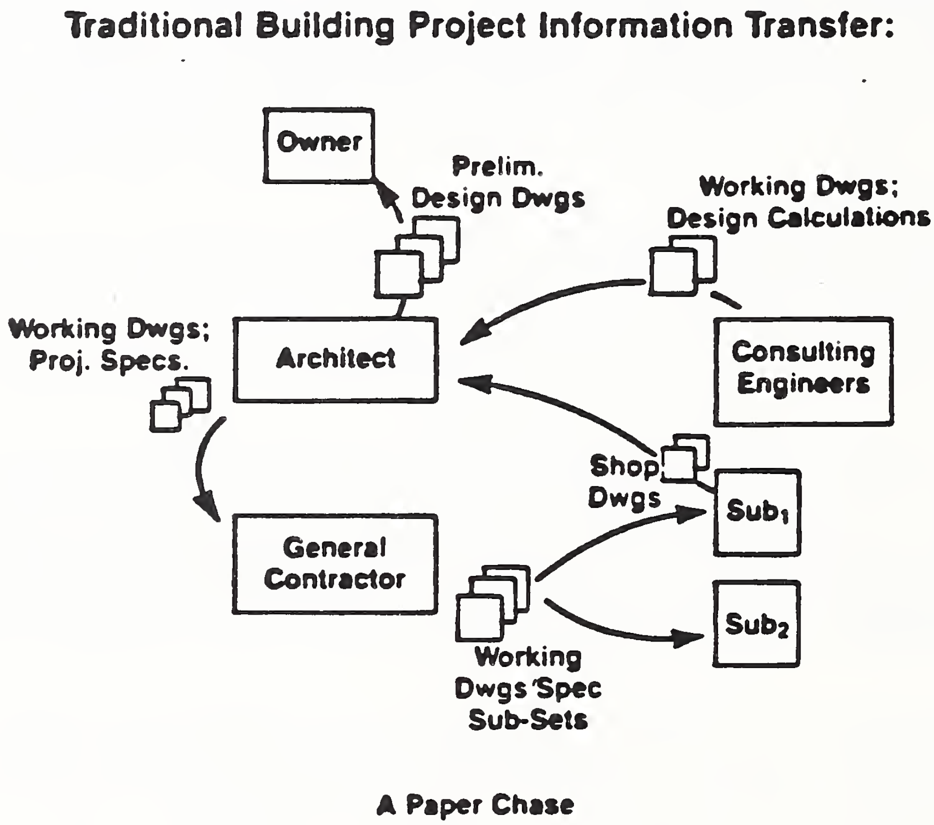

Figure 2-1 Traditional, Paper-Based Project Information Transfer Process

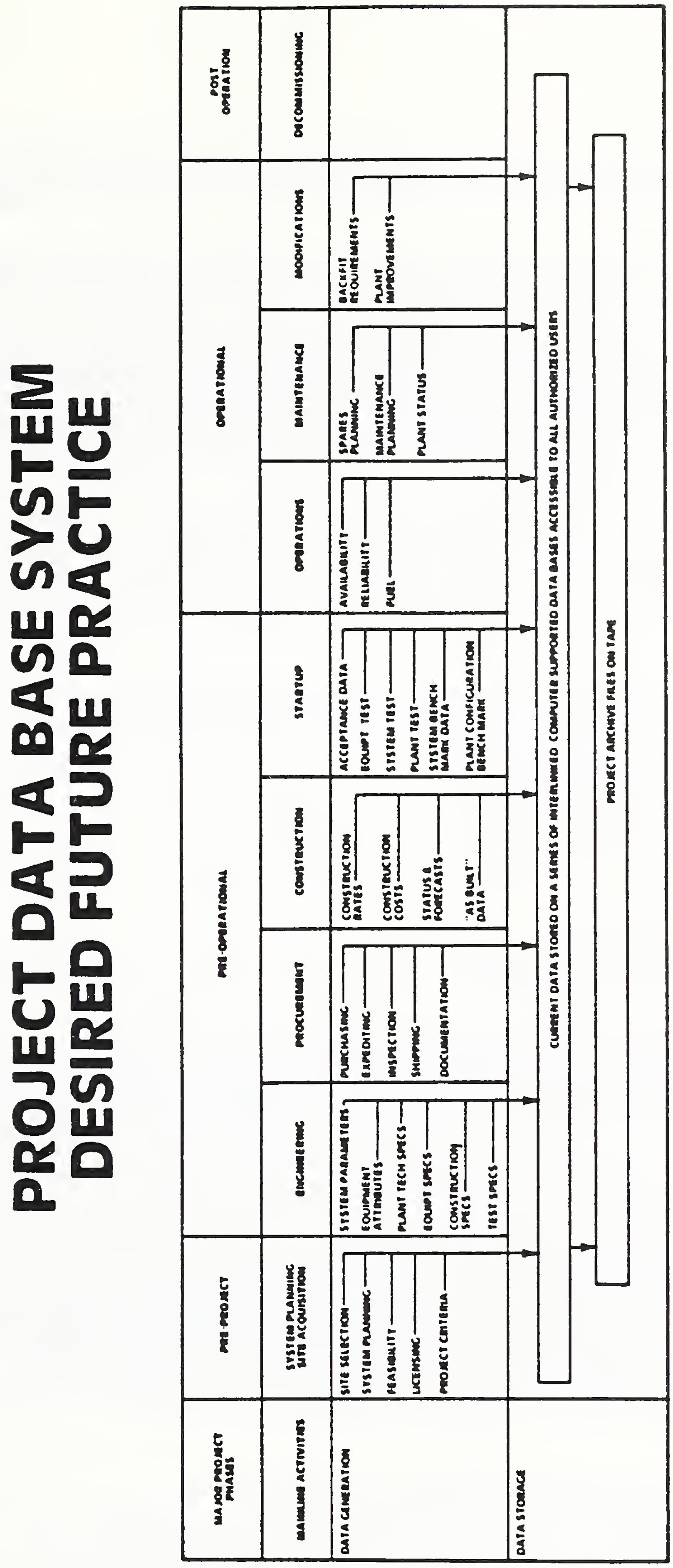

Figure 2-2 Computer-Based Approach to Project Information Transfer Process [6]

2.2 NAVFAC Requirements for the Delivery of Digital Data

NAVFAC has already taken major steps in moving its paper-based design/drafting processes toward computer-based operations. A primary objective of this transition is to be able to generate all drawings from 3-D project models. Procedures have been established for the classification and control of CADD drawings and for creating CADD models of AEC projects. The long-term goal is to use databases of digital project models for comprehensive life-cycle facilities engineering (mapping, planning, design, operation, management, and reuse).

NAVFAC has developed a standard scope of work for the delivery of AEC project information/documentation in digital form. This specification provides a structure for coordinating the delivery of digital data and defines NAVFAC's requirements with respect to:

- File naming conventions (drawings and 3-D model)
- Layering conventions
- Non-graphic properties
- Standard symbols/details
- Part structuring
- Design/drafting process

"The A/E shall deliver as a minimum, part data bases, definitive design modules as directed by the OIC (Officer-in-Charge), drawing parts, figure files and their parent parts, line and text font definition files, pattern-hatch files, non-graphic property files, extract data definition files, computer programs with source codes, and plotting instructions developed as part of the contract. Data base documentation and operational manuals shall be delivered. Design part data bases and other files shall be delivered on 9-track, 1600 bpi standard 1/2 inch magnetic tapes readable by Computervision (CV) software. <u>Both IGES and CADDS 4X data bases are required. The IGES data base file(s) must contain complete and comparable data as in CADDS 4X</u>.
(Note: Non-graphic property files and extract data definition files are not required since IGES does not support them yet.)" [7]

The reasons for requiring IGES files are as follows:

- to give IGES library parts to the A/E to reduce A/E cost;
- to give IGES standard designs to the A/Es for site adaptation to reduce A/E cost;
- to give IGES facility databases to the A/E for rehab work, and

- to give IGES facility databases to PWCs (Public Works Centers) with non-CV systems for operation, maintenance, and rehab work.

2.3 The Importance of Standards for CADD Operations

In order to ensure the quality and the consistency of CADD information and to effectively share this information among project participants, it is necessary to establish comprehensive standards for CADD operations. These standards should be developed as part of a comprehensive information management plan and should define uniform CADD modeling conventions, drawing file setups, layering assignments, and standardized facilities databases. Standardization of procedures and practices helps to more fully utilize personnel skills and reduces the training costs incurred by the continual turnover in staffing.

The Department of the Navy and NAVFAC have already established engineering drawing standards and symbol standards. These standards need to be revised to reflect CADD-based operations. It is important to understand that the introduction of computer graphics and CADD based operations is having major effects on the way the work will be done. Standards must be established for conducting business when using digital project definition data, with the intention of controlling the use, development, exchange, and maintenance of CADD databases.

A key requirement for NAVFAC's CADD standards is the development of the NAVFAC AEC project information model. The information model defines the structure and semantics of the information that is required to accomplish NAVFAC's tasks in the planning, design, construction, and operation of Naval Shore Facilities. This model provides a stable foundation and reference for specifying and managing how each type of technical information will be exchanged and archived.

A critical information management issue within NAVFAC's transition to CADD-based operations, is the use of CADD databases as the sole authority for AEC project information. In most of the manufacturing organizations that have moved to CADD-based operations, the CADD files and the conventional drawings currently have dual authority. Until NAVFAC and its AEC contractors are prepared to make the CADD database the sole authority, there will be significant requirements for duplicate information, configuration management, and project model/drawings control procedures.

As the IGES specification and the quality of the IGES translators improve, it will be possible to exchange more of this information via IGES. Yet, in order to chart and maintain control of NAVFAC's migration to CADD-based operations, this information model will be required. During the short-term, NAVFAC should develop their specification for IGES deliverables and a schedule for phases of development, testing, implementation, and revision of the specification.

3. The Use of IGES for Exchanging Drawings and AEC Project Definition Data

Central to the successful integration of CADD is the development of dependable data exchange methods. Most CADD systems are incompatible because each uses its own concepts, terminology, and encoding schemes (different representation formats) for storing information. This limits or prevents the flow of CADD information between different systems and the various project participants.

There are basically two ways to transfer data between incompatible CADD systems: direct translation and translation via a neutral format. A direct translator is a software program which converts data sets from their original format into the specific format of a receiving system.

Although direct translators can be an efficient way to exchange data between two CADD systems, they do not provide a viable mechanism for exchanging data between multiple dissimilar systems. The writing of direct translators requires a complete understanding of the internal data format used by both the sending and the receiving system. Since this information is subject to periodic revisions and is usually proprietary, the use of direct translators imposes large software support problems.

The use of neutral translators is intended to resolve these limitations. A neutral translator is based on the concept of an intermediate (neutral) format and utilizes two programs (a preprocessor and a postprocessor) to perform the translation. The preprocessor reads the format of system A and writes into the neutral format, and the postprocessor reads the neutral format and writes the output into the format of system B.

There are several advantages to this process. First, the writing of either program only requires an understanding of the internal (proprietary) data format of <u>one</u> system and the neutral format. Second, fewer programs are required (for "n" CADD systems, only <u>2n</u> one-way <u>neutral</u> translators are needed, versus <u>n x (n-1)</u> one-way <u>direct</u> translators). For example, among 10 systems, there needs to be only 10x2 = <u>20</u> one-way <u>neutral</u> translators, versus 10x9 = <u>90</u> one-way <u>direct</u> translators. Additionally, the use of an intermediate format can reduce the users' risks of vendor dependence and can allow greater flexibility in the utilization of CADD resources.

In order to resolve its CADD data exchange requirements, the Navy has selected IGES as an intermediate (system independent) data exchange standard. IGES is an international consensus standard for the exchange of project/product definition data. This standard grew out of the work done by the Boeing Corp., the General Electric Corp., the NASA/Navy sponsored Integrated Program for Aerospace Vehicle Design (IPAD), and the U.S. Air Force Integrated Computer-Aided Manufacturing (ICAM) program. Each of these organizations had identified the lack of a standard for the exchange of

CADD graphics as a critical obstacle to moving toward computer integrated operations (specifically CAD/CAM operations). The IGES/PDES (Product Data Exchange Specification) Organization coordinates the ongoing efforts to enhance future versions of IGES.

Unfortunately, the intelligence and complexity of AEC project definition data (as represented in conventional project documentation and drawings) exceeds that of a typical mechanical part drawing. Partially due to this factor, the current generation of IGES translators (which were primarily designed for CAD/CAM processes) is inadequate for comprehensive AEC CADD operations. Incomplete translators, insufficient documentation, and differing interpretations of specifications have prevented accurate and consistent AEC digital data exchanges. [8]

The current version of IGES (Version 3.0) can support most of the graphics of a typical AEC drawing, and CADD vendors are improving the capabilities of their IGES translators. Future versions of IGES will provide more efficient mechanisms to include all of the graphics and some of the non-geometric information of typical AEC drawings. It is important to understand that the graphics of typical drawings are only part of the information that is required for the comprehensive use of CADD for the planning, design, and operation of Naval Shore Facilities.

3.1 A Description of IGES

The Initial Graphics Exchange Specification (IGES) was designed to accommodate the exchange of product definition data between CADD systems. The IGES standard defines a file structure format, a language format, and the representation of geometric, topological, and non-geometric data in these formats. The specification subdivides product definition data into three categories: geometry entities, annotation entities, and structure entities. The basic element of data in an IGES file is an entity.

In IGES Version 3.0 there are 54 defined entity types, each with a unique entity type number. Some entity types are further subdivided by form numbers. Additionally, the specification provides entity type numbers for user-defined entities.

3.1.1 Geometry Entities

Geometry entities define the geometry of the product/project description (e.g., points, lines, arcs, and ruled surfaces), as shown in Table 3-1.

Entity Type	Entity Type Number
Circular Arc	100
Composite Curve	102
Conic Arc	104
Copious Data	106
Plane	108
Line	110
Parametric Spline Curve	112
Parametric Spline Surface	114
Point	116
Ruled Surface	118
Surface of Revolution	120
Tabulated Cylinder	122
Transformation Matrix	124
Flash	125
Rational B-Spline Curve	126
Rational B-Spline Surface	128
Offset Curve	130
Connect Point	132
Node	134
Finite Element	136
Nodal Displacement and Rotation	138
Offset Surface	140
Curve on a Parametric Surface	142
Trimmed Parametric Surface	144

Table 3-1 IGES 3.0 Geometry Entities

3.1.2 Annotation Entities

Annotation entities define the notes that are added to the description of the product/project, as shown in Table 3-2. In the case of engineering drawings, these include linear and angular dimensions, text, and tolerance information.

Entity Type	Entity Type Number
Angular Dimension	202
Diameter Dimension	206
Flag Note	208
General Label	210
General Note	212
Leader (Arrow)	214
Linear Dimension	216
Ordinate Dimension	218
Point Dimension	220
Radius Dimension	222
General Symbol	228
Sectioned Area	230

Table 3-2 IGES 3.0 Annotation Entities

3.1.3 Structure Entities

Structure entities define various logical relationships within the product/project definition data. They are used to communicate the structure of the CADD data and database. This includes describing subfigures (symbols), associativities, views of the project model, and drawings, as shown in Table 3-3. The intent of the view entity and the drawing entity is to allow the use of two dimensional representations, while maintaining a single model description. The drawing entity also provides a place to collect the annotation entities that are used to clarify the selected view of the model.

Entity Type	Entity Type Number
Associativity Definition	302
Line Font Definition	304
MACRO Definition	306
Subfigure Definition	308
Text Font Definition	310
Text Display Template	312
Color Definition	314
Network Subfigure Definition	320
Associativity Instance	402
Drawing Entity	404
Property Entity	406
Singular Subfigure Instance	408
View Entity	410
Rectangular Array Subfigure Instance	412
Circular Array Subfigure Instance	414
External Reference	416
Nodal Load/Constraint	418
Network Subfigure Instance	420
MACRO Instance (user defined)	600-699 or 10000-99999

Table 3-3 IGES 3.0 Structure Entities

3.1.4 IGES File Structure

The IGES file structure is divided into five sections: Start, Global, Directory, Parameter Data, and Terminate sections. An IGES entity has at least two parts, first a directory entry and then a parameter data entry. Within each section, each entry occupies contiguous records.

An IGES file is written in 80 column records, using the ASCII character set. Each record has a letter in column 73 , which identifies the section (S for Start, D for Directory, etc.) and a right justified number in columns 74 through 80 for the position of the record in that section.

The Start Section provides the human interpretable prologue to the file. This section is used for any text that will label the file and explain its contents. Each IGES file must have at least one Start record. The Global Section describes the preprocessor and other information that the postprocessor may need to translate the IGES file. The Directory Entry Section has one entry, consisting of two records, for each entity in the IGES file.

The Parameter Data Section contains the parameter data for the entities in the Directory Entry Section and is usually the largest section in the file. Every IGES file has one record in the Terminate Section, and it lists the total number of records in each one of the sections.

3.2 Key Issues Concerning the Use of IGES

For an intermediate data format to be completely successful, it must be sufficiently powerful to express all types of information in any originating system, without the receiver having to know the original (internal) data structure. No intermediate format has yet been fully successful in supporting the data exchange requirements of all AEC CADD users.

The early versions of IGES (Ver. 1.0 and 2.0) were inadequate for the data exchange requirements of the AEC industry, produced excessively large files, and did not address the archival requirements. Although IGES is intended to serve as an archival format, the primary focus of the IGES effort has been on successful system to system communication using IGES translator implementations.

Initially, many of the vendors only implemented a small percentage of the specification (although they would advertise IGES capabilities) and did not provide adequate documentation or software tools for diagnosing translation problems. Most IGES translators use only a subset of the specification, do not have comprehensive error recovery capabilities, and do not provide diagnostic transaction reporting. These limitations have frustrated many AEC CADD users.

A key AEC example of this situation is the limited implementation of the subfigure entity in many vendor-provided IGES translators. Each element of data in an IGES file is an entity, and the subfigure entity is a collection of entities which can be used in multiple instances.

AEC project definitions contain a large number of repetitive elements which results in frequent instancing of the same symbol (i.e., subfigure entity). The use of the subfigure entity provides a way to retain the intelligence of the symbols, replicates what A/Es do in practice, and reduces the IGES file size. This is a crucial issue for construction industry firms that need to exchange detailed drawings, and yet many vendor-provided IGES translators still do not support the subfigure entity.

During the past five years (since becoming an ANSI standard), IGES has been expanded to provide more sophisticated capabilities and to support more applications. One consequence of trying to make IGES be all things to all users has been the inclusion of multiple ways to encode the same data. Some of the enhancements to IGES have added to its complexity and ambiguity, and this has increased the difficulty of using IGES effectively.

The quality of IGES translators has significantly improved during 1987, and the Version 3.0 document has resolved some of the earlier problems in the specification. IGES Version 3.0 provides for enhanced user defined MACRO's so as to better represent standard part libraries and defines a new extension for External Reference Files (e.g., to reference libraries of standard symbols).

3.2.1 Flexibility and Limitations of IGES

A primary limitation on the current use of IGES is the ambiguity and the flexibility of the current IGES standard. There are multiple ways of representing the same technical information in IGES format (e.g., multi-segment lines, dimensions, and properties information) and multiple ways to process an IGES file. Since the vendors have not interpreted the specification uniformly, there are incompatibilities in the mappings between the preprocessor of one vendor and the postprocessor of a different vendor.

To date, those organizations that have successfully exchanged information using IGES (Boeing Aerospace, General Motors, Hughes Aircraft, NAVSEA, and Pratt and Whitney) have had to make major investments of time and money to test IGES transfers and to develop their particular IGES specifications and procedures.

Until recently, there had only been limited testing and validation of the accuracy and usefulness of IGES translators. The implementation of IGES must include the development of standard conformance tests for IGES software tools and for the delivery of data in IGES format. In order to effectively exploit both the capabilities of CADD and the benefits of implementing IGES, NAVFAC and the AEC industry will require consistent and reliable IGES translators and uniform procedures for encoding project definition data into IGES format.

3.2.2 Mismatch of Systems' Capabilities and Entities

The exchange of information between dissimilar AEC CADD systems (i.e., within heterogeneous environments) involves several potential problem areas. With just drafting systems, these problems include differences in functionality and terminology, such as levels vs. layers, entity mismatches, conflicting drawing sizes and scales, and incompatible line styles and text fonts. The data translation problems can become far more complex when exchanging information between 3-D modeling and engineering software systems.

The principal cause for these problems is differences in the logical structure of the CADD systems (such as subfigure and connectivity definitions). Most early CADD systems were computerized drafting systems which only produced 2-D drawings. The more advanced CADD systems now work with 3-D models of building projects, from which 2-D drawings can be extracted. A 2-D system will never be able to accurately receive or manipulate a 3-D model. A 3-D system can receive a 2-D drawing and extend it into the third dimension by adding a "z" coordinate, but that extension will only create a subset of any complex 3-D model.

Other types of structural differences between CADD systems are their use of attached databases and the structure of the data components. Each CADD system employs a different database management strategy for managing the non-geometric data (product specifications, responsibility assignments, procurement dates, etc.) that are attached to the geometry. All of these factors can make the exchange of useful CADD data between different systems extremely problematic. When these problems are combined with a lack of common modeling conventions, it is extremely difficult to exchange useful information.

The use of CADD modeling concepts must be clearly specified in NAVFAC procedures so as to ensure complete and useful CADD data exchanges. The use of levels or layers is a key operation in the organization and control of CADD information. The number of levels and the types of information that can assigned to each level varies widely between CADD systems. In the similar manner, there is little consistency between CADD systems as to the use of the terms "model space" and "model size" or "drawing scale" and "plotting scale".

CADD users can expect a mismatch of CADD systems' capabilities and data entities. A native entity may have no direct equivalent in another CADD system or multiple possible representations in IGES. In such instances, the original data will be translated into less sophisticated data elements, and the translated data will not contain the original functionality. This can result in inconsistent, inaccurate, or inefficient translations.

3.3 Key Issues Concerning the Transfer of Drawings and Project Definition Data

The types of project definition data that may be exchanged between CADD systems can be classified into the following categories:

- geometric (points, lines, surfaces, etc.)
- logical relationship (associativity, connectivity, bill of materials, etc.)
- graphic display (line weights, text fonts, drawing definitions, etc.), and
- non-geometric (notes, dimensions, tolerances, etc.).

Conventional AEC drawings and project information can be represented by combinations of these project data types. Although IGES was initially developed for the exchange of computer graphics and digital drawings (geometric and graphic display data), the specification has been revised to accommodate more logical relationship and non-geometric data.

The use of CADD technology and digital project models has added new terms, often with multiple meanings, to the process of exchanging AEC project information. For the implementation of IGES and the control documentation on IGES files, the following terminology should be used [3]:

- Associativity is a logical link or relationship between different entities. This allows entities to be grouped together and manipulated as one.
- Attribute is information, provided in specific fields within the directory entry of an entity, which serves to qualify the entity definition.
- Connectivity defines the physical connections between components and systems.
- Drawing Entity is a structure entity which defines a collection of views of the project model, with any required annotations.
- Level is an entity attribute which defines a graphic display level to be associated with the entity.
- Model is a single definition of a project (usually in 3-D), from which multiple projections can be generated for different views and drawings. Model Space is the right-handed 3-D Cartesian coordinate space in which the project model is represented.
- Property Entity is a structure entity which allows numeric or text information to be related to other entities.
- Subfigure is a structure entity which permits a single definition of a detail or symbol to be utilized in multiple instances.
- View defines a 2-D projection of a selected subset of a model.

At present, AEC firms have had only marginal success with the exchange of drawing information via IGES. The received data sets are usually used as reference outlines for new work and are not intended for revision. Some common problems are:

- problems with units of resolution, scale, and positional units; e.g., match lines do not match-up on segmented drawings.

- entity, symbol, and subfigure mismatches; e.g., parts of drawings are missing, title blocks, text, and dimensions are incorrectly positioned and are no longer associated (logically linked) with the other data elements.
- crosshatching, certain line styles, and most line font patterns are not successfully translated; so A/E's avoid putting section details or material information into their IGES files.

In most cases, translated digital drawings have to be edited in order to make them "visually equivalent" on the receiving system. As of yet, there are very few methods for monitoring the quality of digital drawing exchanges and for ensuring that the data sets were translated correctly.

Data set validation procedures should ensure numerical accuracy and the usability of the translated data. The method used by most AECs is to do a visual comparison between the received "digital drawings" and the original hard copy drawings. This is usually accomplished by plotting the translated data sets and overlaying the plot on top of the original.

Even if a visual inspection is successful, this does not ensure that the translated data sets are "functionally equivalent" on the receiving system. One example of the potential for functional degradation is when subfigures are translated into separate vectors such that the subfigures can no longer be manipulated as single entities on the receiving systems. Any comprehensive measure of successful data set translation must include methods to assess the degree to which the received data sets can be manipulated in an effective manner on the receiving system.

3.3.1 Symbols, Details, and Libraries

As has been stated earlier in this report, the use of symbols and details, or "subfigures" in IGES terminology, is a primary characteristic of AEC drawings. In some CADD systems, symbols can be parameterized, and in other systems, symbols and details are stored by reference to a "master library". Since these libraries are periodically updated, all digital drawings in IGES form must contain the corresponding, time-stamped version of any pertinent libraries.

IGES Version 3.0 does provide a MACRO capability to represent parameterized IGES constructs (such as user defined symbols) and the External Reference File capability for referencing libraries. The vendors' implementations of these enhancements must be fully tested and validated before they can be adopted into NAVFAC's standard IGES operations.

3.3.2 Annotation

All CADD systems provide for some types of annotations and dimensions to be added to drawings. Some CADD systems provide comprehensive annotation capabilities, which include cross-hatch, general labels, and multiple line and text fonts. Many CADD systems do not provide such broad capabilities, and the interchange of complex annotations, via IGES, is still a highly problematic and tedious operation.

The representation of the notes on a drawing may contain such variables as text size, style, line spacing, aspect ratio, character sets, text box size, leaders, and witness lines. These will usually vary between systems, and IGES Version 3.0 can not accommodate all of these variables. Text and dimensions are critical components to the understanding of drawings, and NAVFAC will have to establish procedures to resolve these limitations.

3.3.3 Additional Project Definition Data

Although IGES 3.0 can be successful for exchanging drawings and some annotation data, the current implementations of Version 3.0 are insufficient for exchanging other kinds of project definition data, such as property or attribute information, connectivity, bill of materials, and other forms of tabular data.

Most CADD systems allow the attachment of non-geometric information to elements in a drawing or model (i.e., part number, weight, or maintenance schedule). Tabular data, such as an equipment schedule or bill of materials, play a key role in documenting and conveying project information. These tables may be generated by using key properties that are attached to geometric entities, or they may be built as separate graphics, with no relationship to a drawing or model.

The representation of connectivity is essential to many phases of AEC projects. CADD systems that use connection data will often produce reports on physical connections, logical connections, and "from-to" lists. Although IGES 3.0 can include this information, the current translators do not translate the connection data in a consistent manner.

Each of these situations will have to be resolved in NAVFAC's specifications for digital deliverables and IGES translation procedures. If IGES is to succeed as a comprehensive exchange and archival format for NAVFAC, these additional non-geometric data types must be supported in a uniform manner by all pertinent IGES translators.

4. Recommendations for NAVFAC's Implementation of IGES

In order to successfully implement IGES for the digital exchange of AEC project drawings and project definition data, NAVFAC should allocate resources for the recommendations of this report. These recommendations are designed to address both the short-term and the long-term project data exchange requirements of NAVFAC.

The objectives of these recommendations are:

- to establish digital and auditable drawing exchange capabilities;
- to move beyond the transfer of only the graphics of drawings, in order to accomplish more functional CADD data exchanges, and
- to enhance the quality and usefulness of NAVFAC's IGES resources.

The project databases that are created with and for NAVFAC's CADD systems will have enormous value. A successful strategy for integrating CADD within NAVFAC's operations must permit the migration of these databases from today's CADD systems to the next generation of systems that will replace them. NAVFAC's implementation of IGES must be part of a long-term strategic plan for digital deliverables and technical information management.

4.1 Establish Short- and Long-term Strategies for Digital Deliverables

The effective use of IGES will require a comprehensive view of the information flow of NAVFAC's AEC operations and the development of a systematic IGES implementation plan. This should include documenting what information is needed for each NAVFAC task and developing a specification and timetable for how that information, in various forms, will be delivered, managed, and archived.

Initially, NAVFAC should implement IGES as part of the required deliverables for selected lead projects. Since the current generation of IGES translators (based on Version 3.0), can only support the simple graphics of project drawings, this is the level of capabilities to be required in Phase I of implementing IGES.

NAVFAC's specifications for project deliverables and digital data transfers must define the format and the mechanisms for coordinating the use of the various types of required technical information. These specifications will identify the responsibilities of NAVFAC and of the AEC contractors in the use and maintenance of the digital project data. As the capabilities and reliability of the IGES translators improve, more of the project information can be required in IGES format.

Central to the long-term plan will be the development of a NAVFAC AEC project information model. The project information model will be used to specify the CADD data modeling conventions and the data translation conventions. With a documented NAVFAC AEC project information model as a road-map, appropriate structuring or mapping to future CADD systems' data structures and future data exchange standards will require significantly shorter completion schedules.

IGES does have limitations, and the implementation of IGES requires careful planning, standardized modeling conventions, comprehensive translator testing, and an ongoing data translation quality assurance program.

4.1.1 NAVFAC CADD Objectives and Transition Policies

It is important to clearly document the objectives of NAVFAC's move to CADD-based operations and the policies that will control the organization's transition to these new ways of conducting business. Senior management must demonstrate a strong commitment to achieving effective and efficient digital data exchange capabilities. Without this kind of leadership, the demands for expedience in construction projects may cause some of the long-term goals and policies to be short-circuited.

A team of representatives from the key functional units should be organized as a task force to develop NAVFAC's IGES specifications and to establish a cost-effective transition program. These specifications must include standard conformance tests for the procurement of IGES translators and IGES benchmark test cases for project quality assurance procedures. The establishment of this task force is a high priority item and should receive immediate resource commitments by top management.

4.1.2 The Use of Standardized Modeling Conventions, Component Libraries, and Data Translation Procedures

NAVFAC must establish comprehensive standards for CADD data exchanges procedures. The Department of the Navy and NAVFAC have already established standards for engineering drawings, symbols, and CADD databases. NAVFAC has also initiated a program to address part of its digital data transfer requirements. In cooperation with The Construction Specifications Institute (CSI), NAVFAC distributes project specifications in ASCII form. These specifications must be expanded to include the procedures for controlling the use, exchange, and maintenance of digital project data, both in native format and in IGES format.

The basic IGES implementation strategy is to develop policies and procedures to ensure that the required project information is exchanged by using standardized IGES data structures. These will require user restrictions on the originating system and an evolutionary approach to acquiring and maintaining IGES files.

Central to controlling NAVFAC's evolving standards for CADD operations is the development of the NAVFAC AEC project information model. This model provides a consistent foundation/reference for specifying and managing how each type of information will be exchanged and archived.

In order to chart and maintain control of NAVFAC's long-term migration to CADD-based operations, this information model will be required. During the short-term, NAVFAC should develop specifications for IGES deliverables and a schedule for phases of development, testing, implementation, and revision of these specifications.

4.2 Establish Policies and Procedures for the Delivery and Maintenance of Project Information

NAVFAC must establish policies and procedures for coordinating the use and control of conventional hard copy with both IGES deliverables and the in-house CADD databases. IGES, Version 3.0 or 4.0, is only a partial solution to NAVFAC's data exchange requirements. The current version should initially be used solely for transferring the geometric and graphic information of conventional drawings.

NAVFAC's short and mid-term project information requirements will include:

- NAVFAC's native CADD representations of the project (currently CADDS® 4X files and databases). These will include drawings, the 3-D project model, and any additional project databases.
- IGES representations of the project. Initially, these will be 2-D drawings with annotations. These may well include redundant data. As the proven capabilities of IGES translators expand, the IGES files will include more functional data and eventually the representation of the 3-D project model. These requirements will be updated as new versions of IGES are released.
- ASCII text files for the additional project information which can not be logically linked (associated) with the IGES files and/or the native CADD files. These may include drawing schedules, bills of materials, project management data, purchase orders, and maintenance schedules.
- Conventional, hard copy construction drawings, as-built revisions, and archival drawings (usually stored on microfilm).

NAVFAC's procedures must efficiently manage and control project digital drawings, in at least two different formats, in concert with the other types of required project information.

These procedures must incorporate the transfer of standard component libraries, symbol libraries, engineering change orders, as-built revisions, construction drawings, and any other types of required hard copy documentation. The assignment of sole/prime authority for project information must be clearly documented and monitored. Only by maintaining a single, authoritative definition (representation) of every element of a project can NAVFAC be assured of data consistency.

4.2.1 Phases of IGES Implementation

NAVFAC should implement IGES in phases, building from basic 2-D graphics to complete 3-D project models. Key lead projects will be selected to test and refine each level of application subset and digital data exchange requirements. Once NAVFAC has established the basic digital drawing exchange capabilities, the NAVFAC/IGES task force can begin testing and refining the next level of capabilities.

Phase I / 2-D drawings, with simple graphic annotations (text and dimensions) and visual equivalence to conventional drawings; Level I application subset requirements; no non-standard line fonts, multiple text fonts, splines, or parametric surfaces.

Phase II / 2-D drawings, with functional annotations and associativities; bill of materials, tabular data and external file reference; Level II application subset requirements.

Phase III / 2-D and 3-D drawings, using the model/view/drawing concept and project models, with all of the above information; Level III application subset requirements.

4.2.2 Control and Archiving of Duplicate Information

A key CADD and IGES implementation issue is assignment of prime authority to project documentation. This becomes particularly important when there is a discrepancy between the hard copy documentation and the CADD (or IGES) files. During the short-term NAVFAC should identify the original CADD database or the appropriate engineering drawing as the sole authority for dimensionally stable representations. Once NAVFAC has advanced to Level II requirements, the issue of prime authority should be reexamined in light of NAVFAC's long-term digital data requirements.

Another important issue is the requirement for archiving the design documents, the CADD digital files, and the audit trails of design responsibility. The assignment of responsibility for A/E design decisions usually includes a professional stamp with a dated signature. The signed design document has traditionally become the legal record for all potential liability concerns. With the increasing use of CADD data sets as the primary repository of design decisions, NAVFAC's archival procedures must be revaluated so as to digitally include the required audit trails of responsible individuals and any other information necessary for legal considerations.

Data exchange requirements become even more burdensome when they must accommodate the archiving of data for later use and the updating of CADD software. Often data generated on an early version of a vendor's CADD software will not be completely usable on a later version. These data exchange problems must be anticipated because future use of data may be on a different system.

4.3 Develop NAVFAC's Specifications for IGES Translators and IGES Deliverables

A critical component for the implementation of IGES is the development of the NAVFAC/IGES Translator Specifications. The current version of IGES is not implemented uniformly in all vendor-provided translators, and most IGES translators use different subsets of the specification.

The only way for NAVFAC to ensure some level of data exchange capability is to develop specifications for IGES translators and for the delivery of IGES files. These specifications will be used as part of NAVFAC's CADD purchase requirements and as a non-negotiable item for new construction projects. They must provide sufficiently precise definitions of the subsets and of the standardized IGES encoding procedures to be a legally binding document.

The specification for translators must clearly state which IGES entities and native database entities must be supported. Initially, this will require identifying the graphic entities used in the drawings for a typical AEC project and writing the guidelines for NAVFAC's required use of those entities in IGES. These guidelines, with the relevant IGES test sets, will then be distributed to potential AEC contractors for validation, contract qualification, and baseline quality assurance procedures.

The development and refinement of these specifications and test sets will require considerable effort. This will include developing an implementation timetable, the criteria for selecting a project's required level of IGES deliverables, and comprehensive documentation for all participants.

4.3.1 IGES Application Protocols and Application Subsets

A key mechanism for controlling the flexibility of IGES and achieving reliable data exchanges is the development and use of application protocols. An IGES application protocol is the formal method for specifying how application information is to be encoded into IGES files.

The primary components of an application protocol are a conceptual information model (which describes the information requirements of the application domain; i.e., the NAVFAC AEC project information model), an application subset and format specification, an application protocol usage guide, and a set supporting test cases. An application subset is an unambiguous subset of IGES entities which span the data requirements for that application.

It is important that each item of application information be mapped into a unique set of IGES entities, versus the multiple different representations that are possible with the unrestricted use of IGES. An application protocol dictates how each construct of application information will be translated into IGES entities.

The Department of Defense CALS (Computer-Aided Acquisition and Logistic Support) Program is currently reviewing the use of application protocols/subsets of IGES as part of the Automated Interchange of Technical Information. The NAVFAC/IGES task force should work with this program in the development the DoD/AEC application subsets and application protocols. With commonly defined application protocols throughout DoD, the CADD vendors will be far more likely to provide uniform and compatible IGES translators.

The documentation for NAVFAC's application protocols must include the following:

- Application Area Description - A description of the types of projects, applications, and professional disciplines for which the protocol is defined.
- Application Information Model - A documented representation of the information requirements of the specified application area.
- Application Subset List - The description of each IGES entity, its pertinent forms, and directory and parameter data requirements.
- Data Accuracy and Functionality Requirements - The required accuracy and functionality of the exchanged data. This may include retention of subfigures, connectivity, and various types of associativity.
- Information Requirements Mappings - This describes how each type of application information or function is mapped into IGES entities.

- Standardized Conventions and Procedures - Required procedures for encoding IGES files.
- Testing and Validation Requirements - The test procedures and test cases used to ensure complete and accurate data translations with the application protocol.

NAVFAC's initial application protocol will be designed to only support 2-D drawings with annotations (text and dimensions). In order to define this first application protocol the NAVFAC/IGES task force should:

- select a sampling of the key types of projects and drawings that represent the organization's responsibilities;
- identify the different types of information in the drawings;
- determine the optimum mapping into IGES for each type of information, and
- develop test scripts and files for each element of information and each functional component.

Once NAVFAC is successful with the initial (Level I) application protocol and guidelines, these can be expanded to 2-D drawings with associativity, connectivity, and bill of materials (Level II). The complete NAVFAC application protocol (Level III) will support all of the above information, plus drawings using the model/view/drawing concept.

4.3.2 Translator Requirements

The current generation of IGES translators is insufficient for NAVFAC's digital data exchange requirements. Since there is no public certification or validation program for IGES translators, NAVFAC must independently assure the capabilities of these software tools to accurately accomplish the data translation task.

This will require developing NAVFAC's IGES translator specification and establishing access to a translator validation program. The validation program would be used to identify problems in current translators, to propose recommended practices, and to help ensure the delivery of quality data translation software.

NAVFAC's IGES translator requirements should be based upon its application protocols (Level I, II, or III) and should define the required processor capabilities. The specification for translators should clearly state how the selected IGES entities and native database entities must be supported.

The documentation on many translators is still limited. At best, the documentation shows how to run the translator, but not how to analyze the translation problems. Very few translators provide comprehensive error recovery capabilities, editing utilities, or diagnostic transaction reporting. Each of these issues must be resolved in the functionality and reliability requirements for NAVFAC (and DoD) IGES translators.

The CADD vendors are making their translators more effective, and some are now providing options in their IGES processors so as to accommodate the requirements of the receiving or the originating system. It is critical that the DoD CALS Program and the NAFVAC/IGES task force develop comprehensive translator specifications and conformance tests to encourage and guide the continued refinement of these software tools. Only after the proper tools are available to NAVFAC and the AEC industry, can NAVFAC establish comprehensive digital data exchange capabilities.

Conformance to the NAVFAC/IGES specifications will eventually become a non-negotiable item in RFP's for CADD systems and for new construction when deemed cost-effective. NAVFAC's specifications for CADD deliverables should include the criteria for determining the form(s) in which different types of project information will be required. For some projects it may not be cost-effective to require IGES files, and the criteria for exceptions must be included. NAVFAC should also establish procedures for monitoring and enforcing compliance to these specifications.

4.4 Develop a Program for Coordinating Translation QA Procedures with Translator Testing and Validation

The lack of mature testing procedures has continued to slow the broad implementation of IGES. There are considerable differences in the capabilities of various vendors' IGES translators, and there is limited consistency in how these translators map their native data into IGES.

Although the IGES/PDES Organization is in the process of establishing a translator verification program, no results will be available in the short-term. Therefore, it is essential that NAVFAC establish a program for coordinating translation quality assurance (QA) procedures with the periodic testing and validation of IGES translators.

The quality of a data exchange is dependent upon the correctness and completeness of the translator implementations. Achieving and maintaining quality control is a major consideration in CADD data management.

Comprehensive data translation quality assurance programs, with the appropriate evaluation criteria for monitoring the accuracy and functionality of the received data, must be developed. These should include translation start-up testing procedures which will be used prior to each new project and as part of any request for digital deliverables. In most AEC operations, data translation procedures have not been formalized, and

In most AEC operations, data translation procedures have not been formalized, and NAVFAC will have to provide to the AEC contractors guidelines on the required quality assurance procedures for digital data exchanges.

4.4.1 Translator Testing and Validation

In conjunction with the production of these IGES specifications, NAVFAC must document its IGES test procedures and develop a standard test library for ensuring that any proposed translators will conform to NAVFAC's specifications. This will include developing test scripts and files for each required IGES entity, for each functional component of a required IGES file, and for each element of required technical information. The initial objective will be to establish a baseline of data exchange capabilities.

The science of software testing and software quality control is just beginning to develop, and there is limited consensus as to the purposes of software testing. The primary objectives of software testing are to expose flaws (errors) in the product and to execute the intended functions correctly. Yet, exhaustive input testing is virtually impossible due to resource requirements. This forces an organization to maximize the yield on its testing investment. Therefore, careful attention must be paid to designing the logic of NAVFAC's test procedures and test sets.

The testing of IGES data translations requires two types of benchmarks. The first type, and the most common, is called the IGES reference file, and this uses a "valid" IGES representation of the subject information element to test the capabilities of the postprocessor (from the IGES format to a CADD system's format). The second type of required benchmark is called the reference model script (or reference test script). This provides the instructions for creating the subject information element(s) in an originating CADD system. The output of that process is used to test the preprocessor (from a CADD system's format to the IGES format). (Detailed documentation on testing methods and types of tests is available from the Testing Methodology Committees of the IGES/PDES Organization).

To date, only the largest organizations have started to build their IGES test libraries, and almost all of these are merely IGES reference files. In other words, there has not been any comprehensive testing of multiple IGES preprocessors.

An example of the magnitude of this task is that NASA's Goddard Space Flight Center initially spent six months to develop a 28 Entity IGES Test File (and the file only tested the most basic of IGES capabilities). In the first cycle of testing, no CADD system's translators processed the entire file correctly. NASA's 28 Entity IGES Test File is currently in its third revision (in two years). [9]

NAVFAC should establish access to an unbiased IGES/AEC translator validation program. This program is needed:

- to help develop comprehensive quality conformance test procedures and test sets;
- to test and validate translator software (e.g., to check whether the application protocols are properly implemented);
- to identify problems in current implementations;
- to propose improved recommended practices, and
- to help ensure the delivery of quality data translation software.

The current version of IGES is not implemented uniformly in all vendor-provided translators (partially due to the flexibility and ambiguity of the specification). Most IGES translators support different subsets of the specification, do not have comprehensive error recovery capabilities, do not provide diagnostic transaction reporting, and do not generate any translation error log during execution.

Due to all of these concerns, NAVFAC must develop a program for coordinating the refinement of the data translation procedures with the ongoing testing and validation of IGES translators. Only with this combination will NAVFAC have the necessary resources to successfully advance its IGES capabilities.

4.4.2 Start-up Testing and QA/QM Procedures

As part of the transition to digital-based operations, NAVFAC must develop a program for the quality assurance (QA) and quality management (QM) of digital data exchanges. All quality control and quality improvement programs are based on quantitative measures of the "conformance to specifications" or "fitness for use".

Two critical issues confronting any user of IGES translators are:

- quantitative measures for determining the quality and performance of the translator (or combination of translators) and
- the evaluation criteria and quantitative measures for determining a successful data exchange.

These measures provide feedback to those responsible for implementing the translators and for executing the data exchanges. For NAVFAC's AEC digital data exchanges, conformance to well documented IGES application protocols and the reliable interchange of baseline test cases will be the primary evaluation criteria.

NAVFAC will have to use both types of measures for each level of IGES implementation. A program must be established to use these measures for monitoring the quality of both NAVFAC's IGES translations and of the contracted IGES deliverables.

Quality can not be added to a system or process upon completion; it must be built into the process. As part of the quality management tasks, NAVFAC should develop a quality assurance plan which describes how the quality of the data exchanges will be examined and measured. This document must identify each participant's responsibility and provide a yardstick for measuring improvements.

4.4.3 Evaluation Criteria and Reporting

Digital data validation procedures must ensure the numerical accuracy and the usability of the translated data. The fundamental issue is to determine the criteria for successful data translations. The most important evidence of a successful translation is whether the transferred data can be used effectively by the receiver.

The results of validation testing should be evaluated in relation to the preservation of the original information content and required functionality. Functionality of the received data is defined as the ability to edit, move, scale, or otherwise manipulate postprocessed data elements as if they were created originally on the receiving system.

The evaluation criteria for validation testing and quality assurance should include:

- correctness of the syntax and structure of the IGES file; referencing the NAVFAC/IGES specifications;
- geometric accuracy of the received data files; compare the resulting accuracy to the prescribed precision and tolerances;
- retention of attributes, associativity, and functionality; compare the received file to the original file or model description; modify the generated file with a prescribed sequence of manipulations and compare that result to the intended result;
- completeness of the received data files; compare the received file to the original CADD model, the standard reference model, or the reference IGES model, and
- legibility of the received graphic image; compare the received image to an original plot or image.

Examples of useful measures for these evaluations are:

- How well did the processor retain the entities with the "required functionality"? What percent of these entities were retained? What percent were retained by being translated into different IGES constructs?
- How well did the processor retain the required information content, but used non-standard IGES entities? What percent of the required information was received? What percent was received with the required functionality?
- How well did the processor retain the required accuracy? What percent of the geometric entities were translated with the required accuracy? What was the range of inaccuracy?
- The accuracy and usefulness of the error messages and the translation log files that are generated by the processor.

The use of these measures is usually tied to specific test cases and classes of test sets.

For each level of IGES implementation, NAVFAC must document the relative importance of functional accuracy versus visual equivalence (or pictorial accuracy). Within NAVFAC, the functionality of the received data should be the primary criterion, as long as visual equivalence is not compromised. NAVFAC's measures for successful data translations must include methods to assess the degree to which the received data sets can be manipulated in an effective manner on the receiving system.

Currently, the evaluation method used by most AECs is to do a visual comparison between the received "digital drawings" and the original hard copy drawings. This is usually accomplished by plotting the translated data sets and overlaying the plot on top of the original. Even if a visual inspection is successful, this does not ensure that the translated data sets are "functionally equivalent" on the receiving system.

In order to refine and improve the NAVFAC/IGES specifications and data exchange procedures, the quality management program should also include a mechanism for reporting test results, limitations, and enhancements back to the NAVFAC/IGES task force. During the initial utilization of the specifications for lead projects, every effort should be made to establish a team of the participating professionals that will analyze problems and propose resolutions and improvements.

The first stages of implementing IGES will be resource intensive. If the transition to using IGES is planned as part of a long-term strategy and investment in computer-based operations, these efforts can provide NAVFAC with effective and reliable digital data exchange capabilities.

5. Summary

This report presented the steps that NAVFAC should undertake for the implementation of IGES for digital data exchanges. The successful use of IGES will require a thorough analysis of the information flow of the organization and the development of a systematic implementation plan.

NAVFAC needs to invest resources to ensure that comprehensive data exchange capabilities will be available. IGES provides the best opportunity because it gives NAVFAC the largest leverage on the development of comprehensive data exchange tools. Once the required AEC features are in the standard, all vendors and AEC contractors have equal access to them.

There are two parallel projects which must be undertaken for NAVFAC to resolve its current data exchange problems. First, NAVFAC must establish policies and procedures for the delivery and management of digital data and technical information. Second, NAVFAC must establish access to an unbiased IGES/AEC translator validation program. This program would test and validate translator software (e.g., check whether the identified entities are properly translated) and identify problems in current implementations. The testing and validation of IGES translators are critical to NAVFAC's successful integration of CADD technology.

The quality of a data exchange is dependent upon the correctness and completeness of the translator implementations. By documenting NAVFAC's required use of IGES and by using an IGES/AEC translator validation program to ensure the delivery of quality translation software tools, NAVFAC will be able to fulfill its current CADD data exchange requirements.

A summary of the key recommendations is presented on the next two pages.

SUMMARY OF RECOMMENDATIONS

1. Establish short- and long-term strategies for digital deliverables. These should document:

- NAVFAC's CADD objectives and transition policies, and
- NAVFAC's use of standardized modeling conventions, component libraries, and facilities databases.

2. Establish policies and procedures for the delivery and maintenance of CADD databases. These should include:

- Information Management Plan: documents what information is needed for each NAVFAC AEC task and specifies how that information, in various forms, will be delivered, managed, and archived.
- Phases of IGES Implementation: building from basic 2-D graphics to complete 3-D project models. Key lead projects will be selected to test and refine each level.
- Phase I / 2-D model-mode drawings (single view); simple graphic entities (subfigures, text, and dimensions); no non-standard line fonts, multiple text fonts, or parametric surfaces; Level I application subset requirements.
- Phase II / 2-D model-mode drawings (multiple views), with dimensional associativities and external file references; Level II application subset requirements.
- Phase III / 2-D and 3-D model-mode drawings and project models, with bill of materials and tabular data; Level III application subset requirements.

3. Develop NAVFAC's specifications for IGES translators and IGES deliverables. These should be based on well-defined IGES application protocols.

- NAVFAC's initial IGES application protocol will be designed to only support 2-D model-mode drawings with annotations (text and dimensions). The steps of this process are:
- Select a sampling of the key types of projects and drawings that represent the organization's responsibilities.
- Identify the different types of information in the drawings that will need to be exchanged. Document the required data structure (organization) and prioritize these requirements.
- Determine which of this information is appropriate to transfer and archive using IGES. Document the optimum mappings into IGES format data.
- Develop test scripts and files for each element of information and each functional component.
- Develop a "technical information management specification" which will define NAVFAC's required use of IGES and will coordinate the use of digital data with the other forms of required information.
- Document the IGES translator requirements and develop benchmark test cases and procedures for ensuring compliance.

4. Develop a program for coordinating translation quality assurance procedures with translator testing and validation. This should include:

- Evaluation criteria for monitoring the accuracy and functionality of the received data, and
- Translation start-up testing procedures to be used prior to each new project and as part of any request for digital deliverables.
- NAVFAC will have to provide to the AEC contractors guidelines on the required quality assurance procedures for digital data exchanges.

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Mark E. Palmer

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U.S. Navy/Naval Facilities Engineering Command
200 Stoval Street
Alexandria, VA 22332

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

As part of the transition from the current paper-intensive processes to a highly automated and integrated mode of operation, the Navy is adopting the Initial Graphics Exchange Specification (IGES) for certain digital data exchanges among elements of the Navy and Navy contractors. This report provides strategies and recommendations for implementing IGES for exchanging and archiving digital representations of Naval Facilities Engineering Command (NAVFAC) projects.

NAVFAC plans to benefit from the use of computer-aided design and drafting (CADD) by encouraging outside architecture, engineering, and construction (AEC) firms to acquire CADD capabilities and by requiring the delivery of certain project documentation in digital form. The ability to transmit drawings and specifications between different CADD systems is expected to reduce the time (and resources) that NAVFAC and outside personnel spend reviewing, changing, and managing projects and also to improve the quality of the projects.

In order to effectively integrate CADD technology and contract with the AEC industry, NAVFAC requires a comprehensive and reliable data exchange mechanism. This will require thorough technical information management, long-term planning for the transfer and archiving of digital data, and the allocation of resources for the execution of the recommendations of this report.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

AEC CADD; CADD data exchanges; computer-aided design and drafting; data exchange standards; data translators; IGES; information management; NAVFAC; translation quality assurance; validation of data translators.

13. AVAILABILITY

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