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Guidelines for the Specification and Validation of IGES Application Protocols

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NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
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Preface

This document explains the concept of IGES (Initial Graphics Exchange Specification) application protocols, specifies the technical content of an IGES application protocol, and describes a validation methodology for these application protocols. This publication provides the baseline for broader review and analysis of these ideas by organizations and standards making bodies that may adopt them.

The enclosed material represents ideas that are under active discussion by the IGES/PDES (Product Data Exchange Specification) Organization and the IGES/PDES AVM (Application Validation Methodology) Committee. Once the IGES/PDES Organization has completed the necessary review and approval procedures, this document will be published as an official document of that organization. Your comments on this document are encouraged and should be addressed to:

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Abstract

This document provides a background discussion of product data, describes the concept of IGES (Initial Graphics Exchange Specification) application protocols, specifies the technical content of an IGES application protocol, describes a validation methodology for these application protocols, and provides guidelines for the implementation of an IGES application protocol. A key conclusion of the background discussion of product data is that IGES application protocols must be developed in order to achieve consistent and reliable exchanges of product data within specified application areas.

The technical content of an IGES application protocol includes a conceptual information model for the application area with its supporting documentation, an application protocol format specification with a protocol usage guide, and a set of application protocol format test cases. These test cases must be used in concert with a well-defined testing methodology.

Since no complete IGES application protocols currently exist, this document describes a current implementation of an application protocol process that is based on a partially complete application protocol. The document also includes a specific example of a simple application protocol that meets the technical content requirements.

Key words: application validation; CAD data exchange; computer-aided design and drafting; data exchange standards; data translation quality assurance; data translators; IGES; IGES application protocols; information management; validation of data translators

Table of Contents

List of Figures

1. Introduction

A major objective of many users of CAD/CAM equipment is the effective exchange of data throughout the life cycle of products. This may include the use of computer readable data sets describing the products, their assemblies, subassemblies, and the product support data. A central issue is the exchange of digital representations of product data in various forms: illustrations, 2-D drawings, 3-D edge-vertex models, surfaced models, solids models, and complete product models.

Throughout industry, an increasing number of computer-aided design systems are being used in all phases of design, analysis, manufacturing, and testing of products. Over one hundred vendors offer CAD systems, and most industries have already committed themselves to working in heterogeneous CAD environments.

Even with the great variety of CAD systems available today, no single CAD system possesses the depth and breadth of capabilities to satisfy the needs of all users for all applications. Because of this, users tend to purchase a variety of CAD systems, each selected to support a particular application. Complexity is introduced into the use of CAD systems when product data must be exchanged between different business units and outside participants at major milestones of a project; design to engineering, engineering to manufacturing, manufacturing to inspection, prime contractor to subcontractor, or vendor to customer.

There is a requirement in the normal course of business to be able to exchange the digital product models and drawings that are developed on one system with another dissimilar system. This may be for the internal transfer of product data or for the purchase of product data from external sources. The exchange of digital product models is expected to become as commonplace in the 1990's as the exchange of paper-based engineering drawings is today. In order to effectively integrate CAD technology, industry requires comprehensive and reliable data exchange mechanisms.

1.1 Scope

This document contains a background discussion of product data, specifies the technical content for an IGES (Initial Graphics Exchange Specification) application protocol, describes a validation methodology for IGES application protocols, and provides guidelines for the use of IGES application protocols.

Since no complete IGES application protocols currently exist, this document describes a current implementation of an application protocol process that is based on a partially completed application protocol. The document also includes a specific example of a simple application protocol that meets the technical content requirements.

1.2 Background

IGES is a neutral representation format for the exchange of product definition data between CAD systems. Since the release in 1980 of the first version of IGES, the IGES/PDES (Product Data Exchange Specification) Organization has added increasingly sophisticated data constructs to the IGES specification. As the capabilities of IGES have been expanded to accommodate more applications, the specification has become more pliable. Some of these changes have added to the complexity and ambiguity of the specification, and this has increased the difficulty of using IGES effectively.

At present, no vendor supports all of the entities in the entire specification with their IGES processors. Each vendor has implemented a subset of the specification which best matches the salient capabilities of their CAD system. Hence, there is only limited IGES entity correspondence between the processors of dissimilar CAD systems and no definition for conformance to the IGES specification. This situation has forced users to limit their data exchanges to only those entities that are uniformly supported by both the sending and receiving systems.

Implementations of IGES translators for different CAD systems continue to be uneven in quality and capability. Additionally, the majority of industries have not adopted the level of information control that is required for successful exchanges of CAD information using IGES. IGES application protocols are being developed as a mechanism to address these problems.

2. Fundamental Concepts

In order to successfully use IGES for CAD information exchanges, organizations must have well-defined technical information management plans and documented procedures for creating, delivering, and maintaining technical information in digital form. This documentation must include the standardized modeling conventions by which product information is created and the protocol for precisely transferring that information via the IGES format.

A protocol is a set of conventions or rules that govern the operation of functional units to achieve communication. [1] The concept of IGES application protocols provides a formal procedure for specifying neutral, IGES-based, application specific formats. The procedure for developing application protocols involves identifying the information requirements of an application area and documenting them in an information model. The information model is then used to select the IGES constructs for representing the required information.

2.1 Product Data as a Resource

Industrial users must be able to deal with digital product data in six generic applications:

- Internal transfer of product data;
- Data transfer from design systems to product support systems;
- Acquisition of new manufactured parts and systems;
- Competitive reprocurement of spares;
- Purchase of data for a product; and
- Archival storage of parts and assembly data.

Digital product data is becoming an important consideration in contractual relationships for the purchase of manufactured parts, assemblies, or whole systems and projects. Numerous internal transfers of product models are found in R&D, prototype design, overhaul, and retrofit planning, and each is a candidate for digital exchange in the immediate future.

The economic significance of digital product data is easily seen from these examples. Efficiency, accuracy, and lead time improvements are all substantially enhanced by providing the methods for the reliable interchange of digital product data.

Two terms will be used for classifying data: product definition data and product data. Product Definition Data denotes the totality of data elements that completely define the product. Product definition data includes the geometry, topology, relationships, tolerances, attributes, and features necessary to completely define a component part or an assembly of parts for the purposes of design, analysis, manufacture, test, and inspection. Product Data is more broadly defined than Product Definition Data. Product data includes all of the product definition data plus a larger class of data elements necessary to fully support the product for all applications over its expected life cycle.

2.2 User, Implementor, and Purchaser Views of Product Definition Data

The creation, exchange, and archival storage of product definition data in the form of digital data sets can be viewed from three perspectives: the User, the Implementor, and the Purchaser. In some cases, different units within the same organization may hold each of the perspectives. In other cases, each of the perspectives may be held by individual organizations that have a contractual relationship.

2.2.1 User Perspective

The User perspective is the view held by an end-user of the product definition data (PDD). End-users have specific requirements for the structure and content of PDD. These requirements are a function of the end-user's discipline and application area. An end-user of PDD will be supporting a certain discipline, such as Mechanical or Electrical, and will be working within a certain application area, such as Drafting or Numerical Control Machining. The end-user will also have an application-based view of the information requirements through the use of application specific terminology and rules.

To understand the User perspective of PDD, it is necessary to carefully consider the current environment of hardcopy engineering drawings. In the paper-based environment, the official PDD for any of the disciplines exists as drawings that give the product definition data as prepared by the Drafting application area. Actually, these drawings are only part of the PDD that is necessary to support the needs of the end-user's discipline.

Currently, each end-user must perform an application-based interpretation of the drawing, extract the available information for the receiving application area, and create the missing information that is necessary to satisfy the end-user's information requirements.

One deficiency of paper-based PDD (i.e., drawings) is that in most cases each end-user is required to repeatedly perform an interpretation, extraction, and augmentation of an incomplete set of product definition data. These repeated end-user actions result in more incomplete paper-based PDD.

Initial attempts at preparing digital PDD sets were aimed at providing all of the information that was represented on the paper drawing. However, in the preparation of the digital PDD sets, information was lost, and end-users were forced to perform the same interpretation, extraction, and augmentation of the information contained in the data sets as had been necessary for the paper drawings.

Key concerns of users of digital PDD are: 1) that the requirements for data structure and content are well-defined and stable; 2) that reliable systems and software to use the data are available, and 3) that the data are prepared and read completely and correctly. In order for digital PDD sets to be a valid replacement for paper-based PDD, the information contained in any digital PDD set must be at least as complete as the information on the paper drawing. The other perspectives discussed in this section will rely on this conclusion.

2.2.2 Implementor Perspective

The Implementor perspective is the viewpoint held by an individual who develops systems and software for Users to employ in producing and reading digital PDD. Implementors strive to provide systems and software that meet the end-user's needs for producing and utilizing digital PDD.

In order for the Implementor to develop systems and software to produce and read digital PDD, the implementation requirements for the structure and information content of the digital PDD sets must be given in a well-defined and stable form. These implementation requirements must be based on providing application-based views of a complete set of information that describes the product for a certain discipline(s).

The Implementor must provide the User a set of instructions for using the systems and software appropriately so that complete and correct digital PDD sets can be produced. Users that receive digital PDD sets through an exchange must be able to read them with Implementor developed systems and software with the assurance that the data sets were correctly prepared using the Implementor-supplied instructions.

2.2.3 Purchaser Perspective

The Purchaser perspective is the viewpoint held by an individual or organization that must purchase digital PDD sets. The Purchaser's primary requirement is that the PDD sets contain a complete set of information that describes the product for a certain discipline and provides support for an application-based view of the information. These PDD sets will have been produced by Users with Implementor developed systems and software according to the Implementor-supplied instructions.

The Purchaser must be sure that the received PDD sets were completely and correctly prepared by the Users. Also, the Purchaser must be sure that the Implementor supplied systems and software have the capability to correctly produce and read the digital PDD sets. In addition, the Purchaser requires that User produced PDD sets can be placed in long-term archival storage for future retrieval and use with Implementor developed systems and software.

2.2.4 Summary

In summary, the User must be able to correctly produce and read digital PDD according to the information requirements of the discipline and its associated application areas. The User must depend on Implementor developed systems, software, and documentation to produce and read digital PDD. The Implementor must provide systems and software according to a well-defined and stable set of implementation requirements. The Purchaser must be able to acquire digital PDD, produced by Users with Implementor developed systems, software, and documentation for use by other end-users or long-term archival storage. The Purchaser must depend on both Users and Implementors for acquiring complete and correct digital PDD sets.

Finally, the structure and information content of digital PDD sets must be sufficient to completely describe the product for a certain discipline(s) and must provide support for an application-based view of the information. The implementation requirements for systems and software to produce and read digital PDD must be based on a well-defined and stable information model. Users and purchasers require comprehensive methods for ensuring that digital PDD is produced according to a well-defined set of requirements.

2.3 Concept of IGES Application Protocols

Information, either in the form of a sentence or in the form of a digital product model, consists of syntax and semantics. The IGES specification defines the basic syntax and core semantics of the representation format. In order to ensure complete and reliable information exchange within a specified application area, the application specific data structures and semantics must also be documented and controlled. IGES application protocols (APs) are a formalized methodology for defining this semantic content and the mappings to the data structures of IGES.

Application protocols allow the definition of logical subsets of IGES and their usage, as well as providing a mechanism for validating implementations. The use of an application protocol for the exchange of product information provides a mechanism for participating agencies to agree on the types of information to be exchanged and to employ corresponding information control procedures.

The key concept of application protocols is to explicitly link the application area's information content to the entities and data structures to be exchanged. The procedure for developing application protocols involves identifying the information requirements of an application area and documenting them in an information model. This application reference model is then used to select the corresponding constructs of the standard for representing the required information.

The components of an IGES AP are: 1) an application protocol information model, 2) an application protocol format specification with a protocol usage guide, and 3) a set of application protocol test cases. These test cases must be used in concert with a well-defined testing methodology. The application protocol format consists of a "subset" of IGES entities including the restrictions on the global, directory entry, and parameter data section field values, and a detailed guide for the use of each IGES entity in the "subset" in carrying information from the conceptual information model.

3. IGES Application Protocols

Experience shows that when the IGES format alone is used for the exchange of product definition data, a wide range of entity types are usually required to convey the information for an application area. Vendor IGES processors implement subsets of the IGES specification and express the user's information in these IGES entities. Invariably there is a mismatch between the entities implemented in a preprocessor and those implemented in a postprocessor of a different system. In addition, the wide range of IGES entities used by different processors makes translator implementation an open ended task.

Product information is usually encoded differently by IGES processors, and this results in the loss of some of the information content of the original data files. It is necessary and desirable to exchange the intended information content and not just an IGES data set. Finally, experience suggests that full and functional information exchange for any application area will not, in general, be accomplished by simply abutting the vendor supplied IGES processors of different CAD systems.

IGES application protocols can help solve the above problems and accomplish the successful exchange of product definition data for a specific application area. Because application protocols are based on information engineering techniques, application protocols can be said to allow the exchange of "information," while the use of IGES alone allows only the exchange of "data."

An IGES AP describes the information content that is expected to be encountered in the application area, identifies the mappings of the information content into its representation by particular IGES entities and constructs, and describes the restrictions and conventions to be observed in the use of the supporting IGES entities.

3.1 Process for Developing IGES Application Protocols

The first step in specifying how an application area can exchange its product definition in a heterogeneous computer environment is to define the information content to be exchanged. The definition of information requirements must be done independently of any computer system or product data format. The information content can be described by the use of a conceptual information model. The conceptual information model must be developed by an analysis of the information that is required to support the application area of interest. When the conceptual information model has been produced, it must be validated conceptually as well. This validation must be done using the information model and all of its supporting documentation.

The second step in defining an IGES AP is to specify the AP format, i.e., how the information content from the conceptual information model is to be carried by a subset of IGES entities. The many options for the use of the entities within this subset must be restricted so that only one method is available for carrying each element of information from the conceptual information model. The set of IGES entities and the necessary restrictions on the global, directory entry, and parameter data section field values must be determined by using the conceptual information model as a basis.

The third major step in this process is to develop and document a set of AP test cases. The test cases must successfully implement all of the information content of the accompanying conceptual information model. These test cases will be used to validate the proposed IGES AP and trial implementations of IGES AP processors.

3.2 Required Technical Content of an IGES Application Protocol

An IGES application protocol includes a conceptual information model, an AP format specification with a protocol usage guide, and a set of test cases. The AP format specification must consist of a "subset" of IGES entities, including the restrictions on the global, directory entry, and parameter data section field values, and a detailed guide for the use of each IGES entity in the "subset" in carrying information from the conceptual information model. An example of a simple AP with each of these components is included in Appendices B.1 - B.3 of this document.

An issue in the use of IGES AP formats is whether the formats must be "restrictive". The notion of restrictive AP formats means that a conforming file is allowed to contain only the IGES entities that are identified to carry the required information. Thus, the notion of restrictive AP formats would not allow any other entities, e.g., "volunteer" entities to be included in an AP format file.

Considerable experience with the use of IGES translators for product definition exchange suggests that difficulties will be encountered if the AP formats are not restrictive. Difficulties such as translator failure and/or loss of information may be encountered if the software units are forced to deal with IGES entities not within their capabilities.

The current consensus of the IGES/PDES AVM Committee is that the AP formats will not be completely restrictive. The consensus position is that: additional IGES entities, not in the AP format, which do not detract from the completeness or correctness of the information contained in the AP format, may be included in an AP format file.

However, none of the additional IGES entities may point to or be pointed to by entities that carry information for the AP format. This requirement is to ensure that software which is intended to read files in a particular AP format can correctly process the files by completely ignoring any entities which are not part of the AP format.

3.2.1 Conceptual Information Model

The conceptual information model is called the Application Protocol Information Model (APIM) and will consist of at least two models, the Application Reference Model (ARM) and Application IGES Implementation Model (AIIM). The ARM documents the information requirements of the subject application and provides the baseline from which candidate format implementation models are developed.

A valuable intermediate model is an Application Implementation Model (AIM). The AIM describes the explicit identifiers that will be required for manipulating the product definition data for the subject application. The concluding model is the AIIM, which shows how the information content from the ARM is to be carried by a subset of IGES entities.

A rigorously defined package of supporting documentation must be provided with the completed conceptual information model. This package must be used in the validation of the model and therefore must consist of the following:

a. The information model must be provided in one of the approved information modeling languages, NIAM, IDEF1X, or Express. The PDES project has done modeling work in all of these languages and has designated Express as the documentation language for the integrated models.

b. The information model must be provided with detailed definitions for all of its objects (for NIAM) or entities (for IDEF1X). This documentation must also be supplied for a model in the Express language. A detailed glossary of acronyms and abbreviations, and a detailed list of the assumptions that are inherent in the model must be provided. This glossary must be easily understandable by an expert from the application area under validation.

c. The constraints (for NIAM or Express) and business rules (for NIAM and IDEF1X) must be detailed either in the model itself or in additional supporting documentation. The constraints and business rules must include the relationships between the objects or entities in the information model.

3.2.2 Application Protocol Format Specification

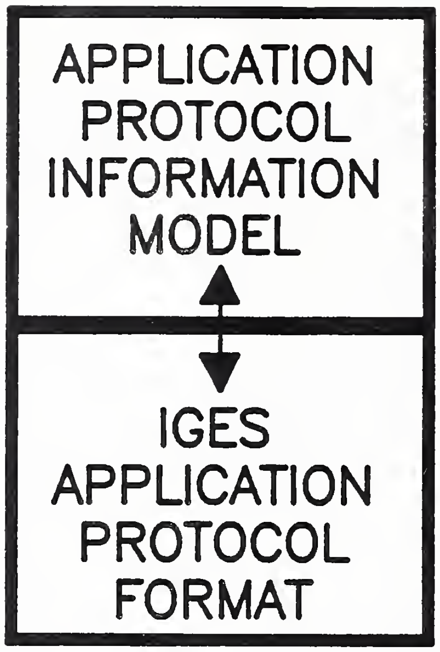
The application protocol format specification includes the list of required IGES entity types, the restrictions on the IGES entities, and the usage guide for the AP. The AP format must be based explicitly on the conceptual information model. The IGES entity list and usage guide must include the restrictions on the global, directory entry, and parameter data section field values.

An AP format specification must use IGES entities that exist in the current IGES specification where possible. It is permissible to specify "gray page" (IGES Version 4.0; Appendix J, Untested Entities [2]) entities for preliminary APs. New entities can be defined for an AP only where there is no existing IGES entity that can be used to carry the necessary information. The IGES entities selected for use in the AP format must be selected so as to minimize the size of resulting files. This means that the "simplest" IGES entity should be selected when there is more than one possible choice.

As part of an AP format specification, a detailed "protocol usage guide" must be developed for the users and implementors of the AP format. This usage guide must specify in detail which IGES entity(s) from the subset is to be used to represent each element of information from the conceptual information model. An AP information mapping table must be included as a summary of these specifications. A sample AP information mapping table for some possible Mechanical Drafting Application Protocol information requirements is shown.

Information Mapping Table for a Mechanical Drafting Application Protocol

Conceptual Information Model's Information Requirement	Application Protocol's IGES Entities Required
Drawing Format	302/402 Associativity Definition and Instance consisting of: 110 Line 212 General Note
Feature Control Frame	302/402 Associativity Definition and Instance consisting of: 102 Composite Curve 110 Line 212 General Note 214 Leader



MAPPING OF INFORMATION FROM AN INFORMATION MODEL INTO AN APPLICATION PROTOCOL FORMAT

Figure 1

This mapping of information from the information model to the IGES entities is represented in Figure 1. The top pane of the diagram represents the APIM, and the lower pane represents the AP format with its selected entities and data structures. The arrows represent the mappings. The usage guide makes explicit these mappings between the application information content and the constructs of the AP format.

3.2.3 Set of Test Cases

A set of test cases, containing examples from the application area, must be included. These test cases must successfully implement all of the information content of the accompanying conceptual information model using the IGES entities in the AP format. The test cases must correctly implement the syntax and restrictions of the AP format according to the usage guide.

The documentation for the test cases must include the following:

a. the objectives of the test case and a description of the data contained within the test case;

b. the expected results of the test case;

c. a pictorial representation of the test case data;

d. the evaluation criteria and variance bounds;

e. a script file for preprocessor testing, and

f. an IGES file for postprocessor testing.

3.3 Application Protocol Validation

The AVM (Application Validation Methodology) Committee of the IGES/PDES Organization is responsible for developing procedures for the application validation of IGES translators and the translation process. As part of these duties, the AVM Committee is charged with reviewing and approving proposed IGES APs. This committee will only approve those candidate APs that have met all of the technical content requirements, specified in Section 3.2, and the success criteria of the validation methodology, described in Section 3.3.1.

The AVM Committee will not perform a detailed validation of the information content of the candidate AP. The detailed validation of the AP information content must be performed by the IGES/PDES technical committee that is responsible for developing the AP. Those organizations planning to implement an AP must validate the AP's correspondence with their information requirements and must develop the necessary digital data quality assurance procedures.

The AVM Committee will perform a limited evaluation of the AP information model set, the AP format specification, and the set of test cases. This review and evaluation will be done for the purpose of assisting the IGES/PDES technical committees in preparing and refining APs.

A summary list of the individual components necessary for AP validation is given below.

a. AP's application-based NIAM, IDEF1X, or Express information model.

b. Detailed glossary and supporting documentation for the information model.

c. Detailed specification of the constraints and business rules for the information model.

d. AP format's list of IGES entities and AP information mapping table.

e. AP format's detailed restrictions for the global, directory entry, and parameter data sections for the IGES entities.

f. AP format's detailed usage guide for the IGES entities.

g. AP format's test cases and accompanying documentation.

3.3.1 Application Protocol Validation Procedures

A summary of the validation procedures for a candidate AP is given below in one sentence statements, followed by a more detailed description of the complete methodology:

1. Content validation is done for the purpose of evaluating the completeness and correctness of the conceptual information model's representation of the information requirements for the application area.

2. Information representation validation is done for the purpose of evaluating the application protocol format's representation of the information requirements as specified by the conceptual information model.

3. Application protocol format compliance verification is done for the purpose of evaluating the completeness and syntactical correctness of the implementation of the AP format in the test cases.

Part 1, the content evaluation part of this validation, will be manpower intensive. Due to the current state of information modeling software tools, it is not possible to simply use a computer program to evaluate the information model for completeness or correctness. This validation will involve a team of experts from the subject application area.

The authoring committee and the AVM Committee must jointly designate the members of this content validation team. For an optimum validation of the information model, these application experts should not be the same experts that participated in the development of the information model. When it is not possible to obtain application experts that did not participate in the information model development, this requirement may be waived if both the authoring committee and the AVM Committee are satisfied with the submitted content validation documentation.

In either case, a group of experts from the application area must be called upon to perform the task of evaluating the content of the conceptual information model and its accompanying documentation. Most, if not all of this evaluation will have to be done manually. It is however possible to provide the group of application area experts some computer tools to aid in the task of preparing different forms of the information model for analysis. For example, a NIAM model is based on the structure of English language sentences that contain a subject and a predicate and give information about the structure and meaning of the information that is required in the application area. For a NIAM model, it may be helpful to use a computer tool to process the entire model into the form of grouped and structured English language sentences that contain the structure and meaning of the information.

This part of the validation most likely will have to be done on a paper form of the model. The conceptual information model must be evaluated on the basis of information requirements, before the AP format is evaluated. It makes no sense to attempt an evaluation of the AP format without validating the candidate conceptual information model first. The success criteria for this validation is that the information model accurately specifies all of the information requirements for the application area.

The evaluation must be done in an incremental way such that each expert will study and evaluate a section of the information model and produce an evaluation report on that section of the model. These experts must use all of the information from items a. through c. in Section 3.3. The evaluation report must identify that expert's assessment of any deficiencies in the information model.

If this step in the validation is not passed successfully, the evaluation report must include a high level summary of the areas where emphasis is required in the next iteration of the AP's conceptual model development. In this case, the validation will not continue into Part 2.

When this step in the validation process is passed, a summary report must be produced to describe the successful information model validation. This must include the incremental validation reports for the sections of the conceptual model, as completed by the application area experts.

Part 2, the information representation validation of the AP, involves the evaluation of the AP format's ability to carry all of the information requirements specified by the validated conceptual information model. This validation must check that all items of information specified by the information model can be carried in the AP format as specified by the usage guide. This part of the validation will require both application area experts and experts in the capabilities and use of IGES.

This validation procedure will include traversing the information model and identifying each element of required information. The AP format specification is required to contain a usage guide for the IGES entities. The usage guide must be used to find the location in the AP format's IGES entity set where each element of information is to be carried. The IGES entity must then be evaluated on its ability to carry the required information, embedded as specified by the usage guide.

This procedure must be completed for the entire conceptual information model. The experts that perform this validation step must use all of the information from items d. through f. in Section 3.3. As an aid in completing this procedure, the AP information mapping table (described in Section 3.2.2) shall be used to check the IGES entity type or types that are specified to carry each element or group of information from the information model.

This validation step will be passed when all information requirements specified by the conceptual information model are verified to be accurately carried by the AP format. If any single information requirement from the conceptual information model cannot be supported by the AP format, this validation step will be failed.

When this step in the validation is passed, a summary report must be produced, consisting of the verified AP information mapping table and a description of the successful AP format validation. If this step in the validation is not passed, the report must give a high level summary of the areas where emphasis is required in the next iteration of the AP format's development. In this case, the validation must not continue into Part 3.

Part 3, the AP format compliance verification, evaluates the completeness and syntactical correctness of the implementation of the AP format in a set of AP format test cases. Test cases must be provided for testing both pre- and postprocessors.

This part of the AP validation must use all of the information in items d., e., and f. in Section 3.3. The protocol usage guide must be used to verify that the semantics (the meaning) from the conceptual information model have been accurately represented in the set of test cases. The supporting documentation for the test cases will be absolutely necessary in this part of the validation. This step must also include checking the syntactic correctness of the AP format test cases.

One tool to assist in this verification procedure would be an IGES file syntax checker. A standard IGES file syntax checker could be modified to use the syntax and entity types of an AP format. Since no AP syntax checkers currently exist, and until IGES file syntax checkers are robust enough to check for AP formats, much of this verification will have to be done manually.

It is imperative that the protocol usage guide be followed to correctly embed the information in the required list of IGES entities. Therefore, if the set of AP format test cases can be verified to: (i) contain syntactically and semantically correct information per the conceptual information model and the protocol usage guide, and (ii) contain an implementation of all information requirements of the AP's conceptual information model, this evaluation will be passed. If any syntactic or semantic deficiency is found, or any information requirement is not implemented, this part of the process will be failed.

This set of AP format test cases may be used as part of the necessary set of test cases for a future AP conformance program for vendors, developers, users, etc. These test cases will undoubtedly not be all of the test cases that would be needed for such a program.

When this step in the validation is passed, the results must consist of a verified set of AP test cases and a summary report documenting the successful verification of the AP format test set. If this step is not passed, the report must give a high level summary of the areas where emphasis is required in the next iteration of the AP format test case development.

3.4 Application Protocol Approval Procedures

The AVM Committee will accept candidate AP packages from the IGES/PDES technical committees that prepare them. Upon receiving an AP package, the AVM Committee will inventory the AP package for the required technical content before any technical evaluation is performed.

If any of the required items are absent from the AP package or are evaluated as insufficient per Section 3.3.1, the AVM Committee will prepare a summary list including an explanation of the missing items. The AP package, with this summary report, will be returned to the appropriate IGES/PDES technical committee. The AVM Committee will work with those committees that are submitting candidate APs to resolve any identified deficiencies.

Application protocols will go through distinct stages of development, testing, and approval. These stages are classified as Preliminary, Trial, Draft, and Recommended, with following meanings.

- Preliminary AP: Under development, not completely validated by the authors
- Trial AP: Submitted by the authors for full testing and validation by interested organizations
- Draft AP: Approved by the lead IGES/PDES technical committee
- Recommended AP: Approved by the IGES/PDES AVM and Edit Committees

Before an AP can be approved by the IGES/PDES Edit Committee, the protocol must be implemented on at least two dissimilar systems, and those two systems must exchange files in both directions according to the protocol. This exchange may require reprocessing the IGES files with software tools in addition to system provided IGES translators, or it may require custom modification of the system provided IGES translators.

Once a candidate AP has been specified and validated per these guidelines, it can be approved by the AVM Committee. With this approval, the candidate AP can be presented to the Edit Committee of the IGES/PDES Organization for approval as a Recommended IGES Application Protocol.

4. Guidelines for the Implementation of an Approved IGES Application Protocol

The exchange of product definition information between dissimilar CAD systems is greatly affected by the sequence of the format translations in the exchange. In order to successfully implement an application protocol process, it is necessary to implement a reliable approach for Information Configuration Control and Software Configuration Control. For some product definition exchange environments, component parts of such an approach are in place or under development. However, for an application protocol process to be successful, the participating organizations must establish Information Configuration Control and Software Configuration Control for their product definition creation and exchange systems.

To understand why Information Configuration Control and Software Configuration Control are needed in an application protocol process, it is necessary to examine the sequence of steps and software units through which CAD information must pass in the translation from the database format of one CAD system through an IGES application protocol format to the database format of another CAD system. In an application protocol process, documentation is required to define each format and the information mappings between the formats. The Application Protocol Information Model and the Application Protocol Format Specification must be used to prepare this documentation.

For an application protocol process, there are two essential points to be made:

1. The syntax (the format) and semantics (the meaning) at each format step must be specified by documentation which is under configuration control. This approach will be called <u>Information Configuration Control</u> (ICC).

2. The Application Protocol Format Specification specifies the IGES entities and the restrictions on the entities that will be used to carry each element of information from the application protocol information model. The ICC documentation provides a basis for documentation of the information mappings between the formats. Therefore, the software that translates the information between the formats must be written on the basis of the ICC syntax and semantics specified in that documentation. This is a first step in <u>Software Configuration Control</u> (SCC).

There are two ways to implement an application protocol process for translating CAD information from the database format of a System A into an IGES AP format, and then translating that information from the IGES AP format into the database format of a System B. Each of the two ways is based on a specific AP process "structure" that consists of certain formats and software units.

Figure 2 illustrates the first AP process structure. Figure 2 shows five rectangles that represent the formats used in translating information from the database format of System A into the IGES AP format, and then into the database format of System B. ICC must be imposed by specifying the syntax and semantics to be used in the creation and translation of CAD information between these formats. For use in SCC, the ICC syntax and semantics documentation must have a version number and a date of release.

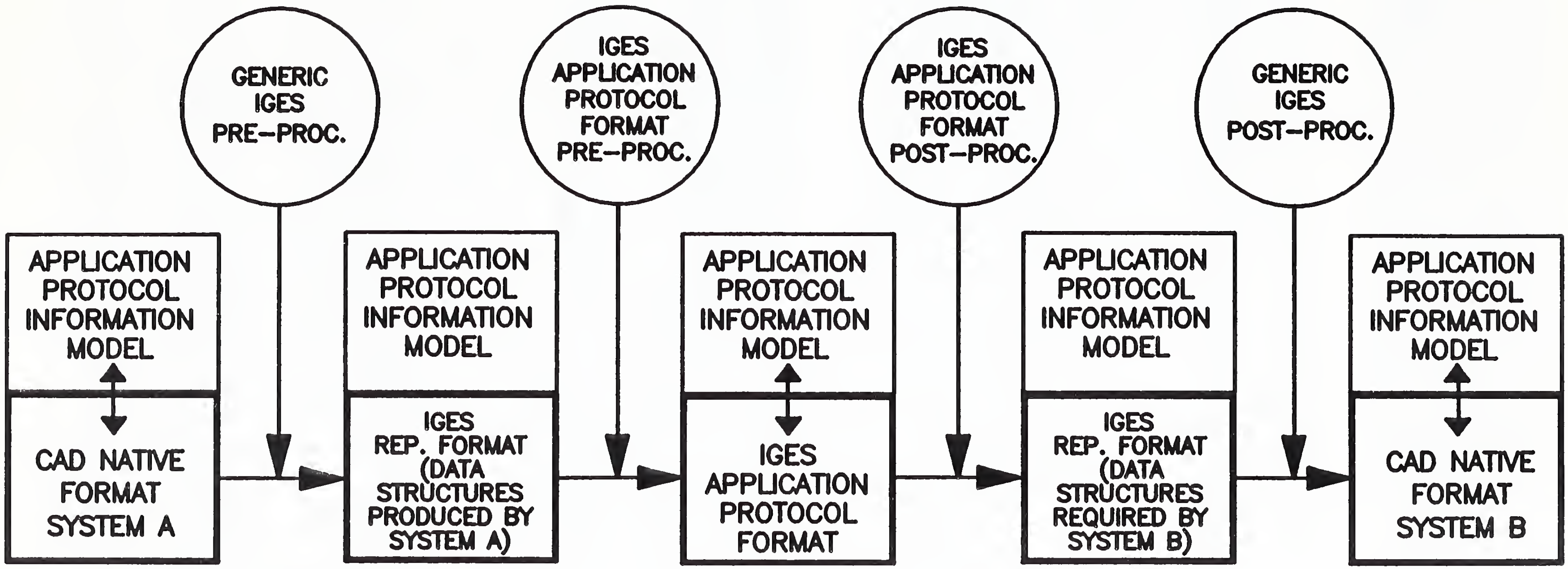
The first rectangle in Figure 2 represents CAD information created in System A. The purpose of this format step is to create the information using a well-defined set of capabilities available on System A such that the constructs in the CAD database conform to the ICC specifications. The ICC syntax and semantics for this format step could be contained in the document called "CAD Standards and Practices for System A". These user modeling standards must define:

> syntax - the choice of the format and structure for creating and manipulating each item of CAD information for the application protocol using the user interface available on System A.
>
> semantics - what each item of CAD information that is to be created and manipulated means for the application protocol.

The second rectangle in Figure 2 represents the CAD information in the IGES representation format of System A. The purpose of this format step is to represent the CAD information from System A in a nonproprietary format for subsequent manipulation as required. The IGES representation format does not have well-defined semantics for the CAD information produced by System A. Therefore, the semantics for this format step must be derived from analysis of the CAD information produced by System A after translation into the IGES representation format. The ICC syntax for this format step is contained in a document called "The Initial Graphics Exchange Specification." The ICC syntax and semantics for this format step must define:

> syntax - the choice of the format and structure for representing each item of CAD information in the IGES representation format for System A. This syntax is a function of the application protocol, the structure of System A, the user interface of System A, and the software unit for System A that translates the CAD information into the IGES representation format.
>
> semantics - result of how each item of CAD information is dispersed when it is translated into the IGES representation format for System A due to the variables associated with the ICC syntax.

The third rectangle in Figure 2 represents the CAD information from System A in the IGES AP format. The purpose of this format step is to prepare the CAD information in an application specific format that is independent of any individual CAD system.



APPLICATION PROTOCOL PROCESS STRUCTURE

BASED ON "GENERIC" IGES TRANSLATORS

Figure 2

The ICC syntax for this format step must be contained in the AP format specification. The semantics for this format step must be contained in the AP information model. The ICC documentation for this format step is required as part of an approved AP. For an approved Mechanical Drafting AP, this documentation could be called the "Mechanical Drafting Information Model" and the "Mechanical Drafting Application Protocol Format Specification." The ICC syntax and semantics for this format step must define:

> syntax - the choice of the format and structure of how each item of CAD information from the AP information model is to be carried in the AP format.
>
> semantics - what each item of CAD information in the AP format means according to the AP information model.

The fourth rectangle in Figure 2 represents the CAD information in the IGES representation format as required by System B. The purpose of this format step is to provide the CAD information from the application specific IGES format into the form required by System B. Again, the IGES representation format does not have well-defined semantics for the CAD information. Therefore, the semantics for this format step must be determined on the basis of how the CAD information must be embedded into the IGES entities as required by System B. The ICC syntax for this format step is contained in a document called "The Initial Graphics Exchange Specification." The ICC syntax and semantics for this format step must define:

> syntax - the choice of the format and structure for representing each item of CAD information for the AP in the IGES representation format for System B. This syntax is a function of the AP, the structure of System B, the user interface of System B, and the software unit for System B that translates the CAD information from the IGES representation format.
>
> semantics - result of how each item of CAD information must be dispersed when it is translated from the IGES representation format for System B due to the variables associated with the ICC syntax.

The fifth rectangle in Figure 2 represents the translated CAD information in the format of System B. The purpose of this format step is to provide the CAD information in System B format such that the original CAD information can be manipulated in the same way as if it were created on System B. The ICC syntax and semantics for this format step could be contained in a document called "CAD Standards and Practices for System B" and must define:

> syntax - the choice of the format and structure for creating and manipulating each item of CAD information for the AP using the user interface available on System B.
>
> semantics - what each item of CAD information that is to be created and manipulated means for the AP.

The four circles in Figure 2 represent the software units that translate the CAD information from the System A database format through the IGES AP format to the System B database format. SCC must be imposed by requiring that two of these software units, the IGES AP format preprocessor and the IGES AP format postprocessor, be written on the basis of the ICC syntax and semantics defined in the documentation above.

The first circle in Figure 2 represents the "generic" IGES preprocessor for System A that translates CAD information from the CAD database format for System A to the IGES representation format. A generic IGES translator is an application independent IGES translator. In general, a generic IGES preprocessor and a generic IGES postprocessor for a certain CAD system can be used to implement different application protocols.

The generic translator implements a single mapping association between an entity in the CAD database format and an entity(s) in the IGES format, or vice versa. The single mapping association is based only on the similarity of the CAD database structure and the IGES data structures. Because the IGES format does not have well-defined semantics, the mapping results in a dispersion of the information in the IGES representation.

The second circle in Figure 2 represents the IGES AP format preprocessor that translates CAD information from the IGES representation format for System A to the IGES AP format. This software unit must be written on the basis of the ICC syntax and semantics contained in the "CAD Standards and Practices for System A," the ICC syntax contained in the IGES specification and the ICC syntax and semantics contained in the AP format specification and the AP information model. The ICC syntax and semantics specified by these documents plus the mappings documented for the generic IGES preprocessor provides the basis for a document called "The Mapping of CAD Information from the IGES Format to the Application Protocol Format for System A." The IGES AP format preprocessor must implement these mappings to prepare the CAD information in the AP format.

The third circle in Figure 2 represents the IGES AP format postprocessor that translates CAD information from the IGES AP format to the IGES representation format for System B. This software unit must be written on the basis of the ICC syntax and semantics contained in the CAD Standards and Practices for System B, the ICC syntax contained in the "Initial Graphics Exchange Specification", and the ICC syntax and semantics contained in the AP format specification and the AP information model. The ICC syntax and semantics specified by these documents plus the mappings for the generic IGES postprocessor for System B provides the basis for a document called "The Mapping of CAD Information from the Application Protocol Format to the IGES Format for System B." The IGES AP format postprocessor must implement these mappings to read the CAD information from the AP format.

The fourth circle in Figure 2 represents the generic IGES postprocessor for System B that translates CAD information from the IGES representation format to the CAD database format for System B. The generic IGES postprocessor is supplied by the vendor of System B and is based only on the capabilities of the CAD system and the system structure. The result of this is that the syntax for the "mapping" of information from the IGES representation format to the CAD database format for System B is based on only the syntax of the CAD database format for System B and the IGES representation format.

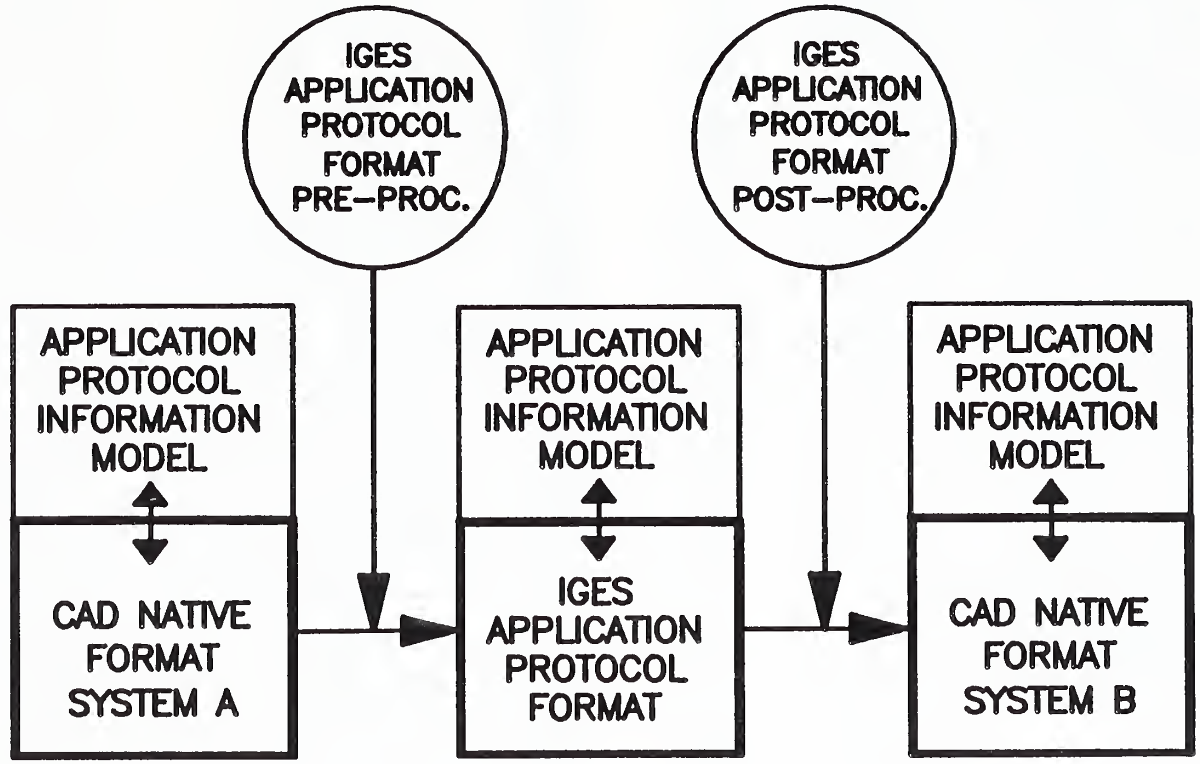
Figure 3 illustrates the second application protocol process structure. This AP process structure is a "direct" process for translating CAD information from the CAD database format of System A into an IGES AP format, and then from the IGES AP format into the CAD database format of System B. Figure 3 illustrates the long-term objective of AP methodology.

Figure 3 shows three rectangles that represent the formats used in transforming CAD information directly from the System A database format through the IGES AP format to the System B database format. ICC must be imposed here by specifying the syntax and semantics to be used in the creation and translation of CAD information between these formats. Again, for use in SCC, the ICC syntax and semantics documentation must have a version number and a date of release.

The first rectangle in Figure 3 represents the creation of CAD information in System A. As shown in Figure 3, the ICC syntax and semantics for this format step are based explicitly on the AP information model. Therefore, the creation of the CAD information in System A is based on embedding each
item of information from the AP information model into the CAD database format of System A. The ICC syntax and semantics for this format step could be contained in a document called "CAD Standards and Practices for an Application Protocol for System A" and must define:

> syntax - the choice of the format and structure for creating and manipulating each item of CAD information for the AP using the user interface available on System A.
>
> semantics - what each item of CAD information in the CAD database format of System A means according to the AP information model.

The second rectangle in Figure 3 represents the CAD information from System A in the IGES AP format. The purpose of this format step is to prepare the CAD information in an application specific format that is independent of any individual CAD system. The ICC syntax for this format step must be contained in the AP format specification.



APPLICATION PROTOCOL PROCESS STRUCTURE

BASED ON APPLICATION PROTOCOL FORMAT TRANSLATORS

Figure 3

The ICC semantics for this format step must be contained in the AP information model. The ICC syntax and semantics must define:

> syntax - the choice of the format and structure for representing each item of CAD information for the AP in the AP format.
>
> semantics - what each item of CAD information in the AP format means according to the AP information model.

The third rectangle in Figure 3 represents the translated CAD information in System B. As shown in Figure 3, the ICC syntax and semantics for this format step are based explicitly on the AP information model. Therefore, the translation of the CAD information into System B is based on embedding each item of information from the AP information model into the CAD database format of System B. The ICC syntax and semantics for this format step could be contained in a document called "CAD Standards and Practices for an Application Protocol for System B" and must define:

> syntax - the choice of the format and structure for creating and manipulating each item of CAD information for the AP using the user interface available on System B.
>
> semantics - what each item of CAD information in the CAD database format of System B means according to the AP information model.

The two circles in Figure 3 represent the software units that translate CAD information directly from the CAD database format for System A through the IGES AP format to the CAD database format of System B. The first circle in Figure 3 represents the IGES AP format preprocessor for System A that translates CAD information from the System A format directly to the IGES AP format. This software unit must be written on the basis of the ICC syntax and semantics contained in the CAD Standards and Practices for the AP for System A and the ICC syntax and semantics contained in the AP format specification and the AP information model. The ICC syntax and semantics specified by these documents provides the basis for a document called "The Mapping of CAD Information to an Application Protocol Format for System A."

The second circle in Figure 3 represents the IGES AP format postprocessor for System B that translates CAD information from the IGES AP format directly to the database format for System B. This software unit must be written on the basis of the ICC syntax and semantics contained in the CAD Standards and Practices for an AP for System B, and the ICC syntax and semantics contained in the AP format specification and the AP information model. The ICC syntax and semantics specified by these documents provides the basis for a document called "The Mapping of CAD Information from an Application Protocol Format for System B."

Figure 2 and Figure 3 describe AP processes that are based on the use of "generic" IGES translators and special AP format translators, respectively. Neither Figure 2 or Figure 3 is intended to imply that a computer-understandable reversible mapping exists between the information in the AP information model and the information contained in the AP format IGES file.

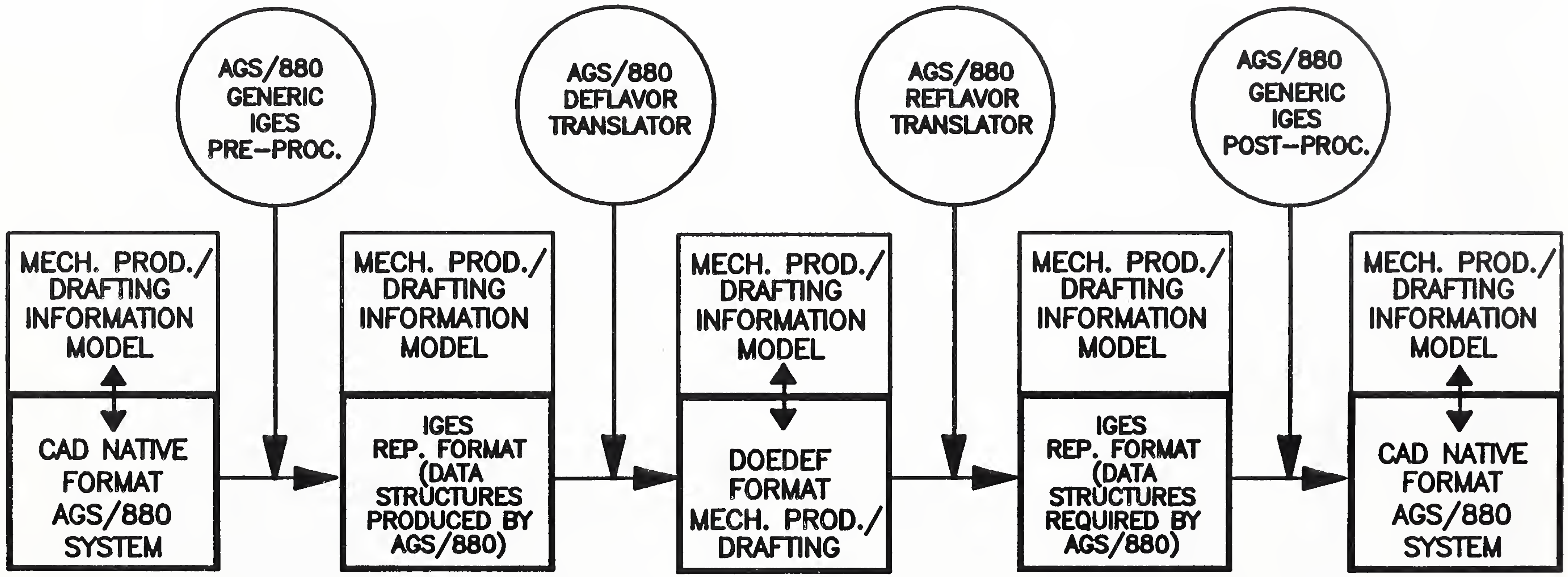
A crucial point of both figures is that there must exist a human-understandable reversible mapping between the information requirements in the AP information model and the system entities needed to carry the information in System A. When obtained, this mapping can be used by a human to develop usage conventions for creating AP information in System A. There must also exist a second human-understandable reversible mapping between the system entities in System A and the IGES entities in the AP format. In addition, since both mappings are reversible, the mappings can be used by a human to prepare computer software to automatically perform the reverse mapping between the IGES entities in the AP format and System A entities or system entities in a dissimilar System B.

The existence of both mappings is critical to accomplishing the successful exchange of the information in the AP information model between System A and System B. With the first mapping established, the second mapping, between the System A entities and the IGES entities in the AP format, can be developed. With human-developed usage conventions for System A, a human can prepare computer software to automatically perform the mapping.

4.1 Example of an Application Protocol Process

Currently, it is not possible to implement an application protocol process based on the structure of Figure 3. This is because no approved IGES APs exist, and because no APs have been implemented by vendors of CAD systems. Therefore, AP processes must currently be developed and implemented by users, and these processes must be based on the structure of Figure 2.

Consider an example of a user developed AP process, shown in Figure 4, and based on the structure shown in Figure 2. The AP described in this example is partially complete, as per the technical content requirements of Section 3.1. This example does not have a complete AP information model with all of the required supporting documentation. It does include an AP format specification, which consists of the IGES entity set, the restrictions on the global, directory entry, and parameter data section field values, and a partial usage guide for the IGES entities.



APPLICATION PROTOCOL PROCESS
DEVELOPED BY DOE/NWC

Figure 4

The example is of an AP format called the "Department of Energy Data Exchange Format, Mechanical Products/Drafting."[1] Specifically, this is an example of a partially complete AP for mechanical part/product drawings. In terms of Figure 2, the AP format will be called the Department of Energy Data Exchange Format, Mechanical Products/Drafting.

This example is based on one of the CAD systems currently in use at Sandia National Laboratories, Albuquerque, New Mexico, the Applicon AGS/880 IMAGE CAD system. For simplicity, this example will discuss the AP process with the notion of "looping" the CAD information out of and back into the AGS/880 system. Therefore, in terms of Figure 2, System A and System B will both be the AGS/880 system.

The first rectangle in Figure 4 represents the creation of mechanical part/product drawing information in the AGS/880 system. The purpose of this format step is to create the information using a well-defined set of capabilities available on the AGS/880 system. The creation is done such that the constructs in the AGS/880 database conform to the ICC specifications. The ICC syntax and semantics for this format step are contained in a document called "General CAD Practices and File Standards" [4], for the AGS/880 system. This documentation defines:

> syntax - the choice of the format and structure for creating and manipulating each item of mechanical part/product drawing information using the user interface available on the AGS/880 system.
>
> semantics - what each item of mechanical part/product drawing information that is to be created and manipulated means for the mechanical part/product drawing application.

The second rectangle in Figure 4 represents the mechanical part/product drawing information in the IGES format for the AGS/880 system. The purpose of this format step is to represent the information in a nonproprietary format for subsequent manipulation as required. The IGES format does not have well-defined semantics for the information.

The syntax for this format step was derived from analysis of the information as it was

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1 Certain commercial equipment, software, or materials are identified in this document in order to adequately specify existing CAD software and data exchange mechanisms. Such identification does not imply endorsement by the National Institute of Standards and Technology or the IGES/PDES Organization, nor does it imply that the software or equipment are necessarily the best available for the purpose.

represented in the IGES format. The ICC syntax for this format step is based on a document called "The Initial Graphics Exchange Specification."[5] The ICC syntax and semantics for this format step are contained in a document called "Requirements for the Applicon AGS/880 IMAGE CAD System Deflavor Translator."[6] The ICC syntax and semantics for this format step define:

syntax - the choice of the format and structure for representing each item of mechanical part/product drawing information for the AGS/880 system in the IGES format. This syntax is a function of the variables: the mechanical part/product drawing application, the structure of the AGS/880 system, and the AGS/880 IGES preprocessor.

semantics - what each item of mechanical part/product drawing information that is to be created and manipulated means for the mechanical part/product drawing application. The semantics cannot be determined by the types of the resulting IGES entities. This is because each item of information is dispersed when it is translated by the AGS/880 IGES preprocessor, due to the variables associated with the ICC syntax.

The third rectangle in Figure 4 represents the mechanical part/product drawing information in the Department of Energy Data Exchange Format, Mechanical Products/Drafting. The purpose of this format step is to prepare the information in an application specific format that is independent of any individual CAD system. The ICC syntax for this format step is contained in the Department of Energy Data Exchange Format. The partial semantics, i.e., the partial mechanical part/product drawing information model, for this format step are also contained in the Department of Energy Data Exchange Format. The ICC syntax and semantics for this format step currently define:

syntax - the choice of the format and structure for encoding each item of information from the mechanical part/product drawing information model in the Department of Energy Data Exchange Format.

semantics - what items of information in the Department of Energy Data Exchange Format mean according to the partial mechanical part/product drawing information model.

The fourth rectangle in Figure 4 represents the mechanical part/product drawing information in the IGES format. The purpose of this format step is to provide the information in the IGES format as required by the AGS/880 system. Again, the IGES format does not have well-defined semantics for the information. The syntax for the information in this format step was determined by how the AGS/880 IGES postprocessor expects the information to be embedded in IGES entities. For the AGS/880 system, the required syntax for this format step is the same as that of the second rectangle in Figure 4. The ICC syntax for this format step is based on a document called The Initial Graphics Exchange Specification. The ICC syntax and semantics for this format step are contained in a document called "Requirements for the Applicon AGS/880 IMAGE CAD System Reflavor Translator."[7] The ICC syntax and semantics for this format step define:

> syntax - the choice of the format and structure for representing each item of mechanical part/product drawing information for the AGS/880 system in the IGES format. This syntax is a function of the variables: the mechanical part/product drawing application, the structure of the AGS/880 system, and the AGS/880 IGES preprocessor.
>
> semantics - what each item of mechanical part/product drawing information that is to be created and manipulated means for the mechanical part/product drawing application. The semantics cannot be determined by the types of IGES entities required by the AGS/880 IGES postprocessor. This is because each item of mechanical part/product drawing information must be dispersed when it is translated by the AGS/880 IGES postprocessor, due to the variables associated with the ICC syntax.

The fifth rectangle in Figure 4 represents the translated mechanical part/product drawing information in the AGS/880 system. The purpose of this format step is to represent the information in the AGS/880 system in the same way as if it were created on the AGS/880 system. Again, the ICC syntax and semantics for this format step are contained in a document called General CAD Practices and File Standards for the AGS/880 system. The ICC syntax and semantics for this format step define:

> syntax - the choice of the format and structure for creating and manipulating each item of mechanical part/product drawing information using the user interface available on the AGS/880 system.
>
> semantics - what each item of mechanical part/product drawing information that is to be created and manipulated means for the mechanical part/product drawing application.

The four circles in Figure 4 represent the software units that must perform the translation of mechanical part/product drawing information. The translation occurs from the CAD database format for the AGS/880 system through the Department of Energy Data Exchange Format, to the CAD database format for the AGS/880 system. SCC has been imposed by requiring that two of these software units, the AGS/880 Deflavor Translator and the AGS/880 Reflavor Translator, be written on the basis of the ICC syntax and semantics defined in the documentation above.

The first circle in Figure 4 represents the "generic" IGES preprocessor for the AGS/880 system. This software unit translates the mechanical part/product drawing information from the AGS/880 system into the IGES format. The IGES preprocessor was originally supplied by Applicon-Schlumberger, the vendor of AGS/880 system. The software unit is based only on the capabilities of the AGS/880 system and the system structure.

This IGES preprocessor was partially rewritten at Sandia using the originally supplied software as a basis.

The syntax for the "mapping" of information from the AGS/880 system into the IGES format is based on the syntax of the AGS/880 database format and the IGES format. The analysis of how the information is translated and dispersed into the IGES entities provided the basis for documenting the mappings for this software. Many of these mappings are contained in a document called Requirements for the Applicon AGS/880 IMAGE CAD System Deflavor Translator.

The second circle in Figure 4 represents the AGS/880 Deflavor Translator. This software unit translates mechanical part/product drawing information from the IGES format to the Department of Energy Data Exchange Format. This software unit was written using the knowledge of the ICC syntax and semantics contained in several documents: (a) the General CAD Practices and File Standards document for the AGS/880 system, (b) the ICC syntax contained in the Initial Graphics Exchange Specification, and (c) the ICC syntax and semantics contained in the Department of Energy Data Exchange Format.

The ICC syntax and semantics specified by these documents, plus the mappings documented for the IGES preprocessor in Requirements for the Applicon AGS/880 IMAGE CAD System Deflavor Translator, provided the knowledge to document the necessary mappings from the IGES Format to the Department of Energy Data Exchange Format. The mappings are included in Requirements for the Applicon AGS/880 IMAGE CAD System Deflavor Translator. The AGS/880 Deflavor Translator implements these mappings to prepare the mechanical part/product drawing information as defined in the Department of Energy Data Exchange Format.

The third circle in Figure 4 represents the AGS/880 Reflavor Translator. This software unit translates mechanical part/product drawing information from the Department of Energy Data Exchange Format to the IGES format. This software unit was written using the knowledge of the ICC syntax and semantics contained in several documents: (a) the General CAD Practices and File Standards for the AGS/880 system, (b) the ICC syntax contained in the Initial Graphics Exchange Specification, and (c) the ICC syntax and semantics contained in the Department of Energy Data Exchange Format.

The ICC syntax and semantics specified by these documents, plus the mappings documented for the IGES postprocessor in Requirements for the AGS/880 IMAGE CAD System Reflavor Translator, provided the knowledge to document the necessary mappings from the Department of Energy Data Exchange Format to the IGES Format. The mappings are included in Requirements for the Applicon AGS/880 IMAGE CAD System Reflavor Translator. The AGS/880 Reflavor Translator implements these mappings to read the mechanical part/product drawing information from the Department of Energy Data Exchange Format.

The fourth circle in Figure 4 represents the "generic" IGES postprocessor for the AGS/880 system. This software unit translates the mechanical part/product drawing information from the IGES format to the CAD database format of the AGS/880 system. The IGES postprocessor was originally supplied by Applicon-Schlumberger, Inc., the vendor of the AGS/880 system. The software unit is based only on the capabilities of the system and the system structure. This IGES postprocessor was partially rewritten using the original software as a basis.

The syntax for the "mapping" of information from the IGES format to the CAD database format of the AGS/880 system is based on the syntax of the CAD database format for the AGS/880 system and the IGES format. The mappings implemented in this software unit are based on reversing the mappings implemented by the IGES preprocessor. Therefore, the structure of the mechanical part/product drawing information must be identical to the structure that resulted from the work of the IGES preprocessor. The knowledge of the necessary CAD information structure for the IGES postprocessor makes it possible to document the necessary mappings for the AGS/880 Reflavor Translator.

After considering the single example above, it is clear that a comprehensive approach for ICC and SCC is necessary to successfully implement an AP process.

Currently, users have only one option for the implementation of an AP process, the structure shown in Figure 2. To successfully implement an AP process based on the structure shown in Figure 2, the user must first become familiar with the CAD system and the vendor supplied IGES translators. This knowledge is necessary to develop the ICC documentation for information creation and translation. The user must then prepare the AP format translators based on the ICC documentation.

Presently, users must do the entire job of developing and implementing AP processes. When approved IGES APs exist, options will also exist for the development of AP processes using vendor supplied AP format translators.

For example, if an approved, "standardized" IGES AP did exist, a contractor or vendor could complete the implementation work. Specifically, a CAD system vendor could be contracted by a user to develop both the ICC documentation and the AP format translators. This would allow users to purchase a "ready made" AP process based on the structure in Figure 3.

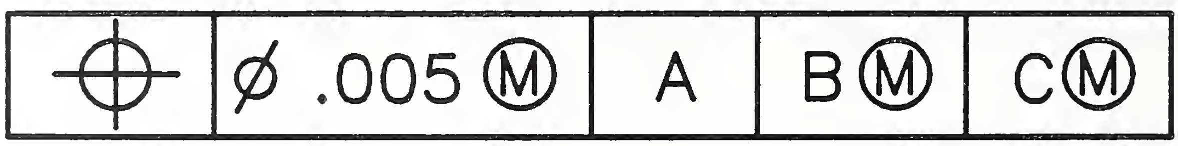
Finally, for any AP process, either user developed or purchased, users must become familiar with their ICC documentation for information creation, manipulation, and translation. A successful AP process will always require that users implement and follow ICC policies and procedures.

4.2 Example of a Simple Application Protocol

This section provides an introduction to an example AP for Feature Control Frames. This example will look at one small portion of the domain that a complete AP for the drafting application would encompass.

The mission of the drafting application is to prepare detailed renderings of the necessary information about a product (part, assembly, or sub-assembly) so that it can be used to analyze or manufacture the product. The first step in accomplishing this mission is to accept the geometry, features, dimensions, tolerances, and other necessary information as input from designers, engineers, etc., and to determine the best way to present the information on a traditional paper drawing sheet. The second step in accomplishing this mission is to actually prepare the rendering, subject to procedures, standards, and rules that are intended to make the resulting drawings more consistent and easier to understand.

In the drafting application, a Feature Control Frame is a means of conveying the geometric tolerance information for an individual feature on a drawing. The Feature Control Frame is one aspect of the rendering of dimensions and tolerances that has been standardized to make drawings more consistent. The rendering of a Feature Control Frame includes the use of graphics, numerals, text, and symbols to represent the information about a geometric tolerance.[8] A typical Feature Control Frame is illustrated in Figure 5.



FEATURE CONTROL FRAME

Figure 5

This example contains the required technical content for an AP as described in Section 3.1. As per Section 3.1, the required technical content consists of an Application Protocol Information Model (APIM) with its supporting documentation, an application protocol format specification (APFS), and a set of application protocol format test cases.

The Application Protocol Information Model for Feature Control Frames is given in Appendix B.1 and consists of three models, the Application Reference Model (ARM), the Application Implementation Model (AIM), and the Application IGES Implementation Model (AIIM). The supporting documentation for the APIM is also given in Appendix B.1 and consists of the NIAM object definitions and the business rules for the APIM.

The NIAM model constraints are given on the graphical NIAM diagrams of Figures B1-B4. In general, the business rules give an explanation of the context of the APIM. For the Feature Control Frame, the basis of the APIM is the American National Standards Institute's Y14.5M (1982) Standard for Dimensioning and Tolerancing. No acronyms and abbreviations were used in the APIM. No assumptions were made that affect the structure or information content of the APIM.

See Appendix B for the complete Feature Control Frame example.

In summary, in a complete AP for the drafting application, this example would be only one small portion. Other portions would be included to handle other information such as dimensions and manufacturing information. This example is intended to illustrate how each small portion of an application domain can be addressed individually, and that, when taken together, all of the small portions can be used to build the complete AP.

4.3 User, Implementor, and Purchaser Views of Application Protocols

Section 2.2 provided a discussion about the creation, exchange, and archival storage of product definition data (PDD) in the form of digital data sets. That discussion examined these aspects of digital PDD from three perspectives: the User, Implementor, and Purchaser perspectives.

This section will examine the same three perspectives of the use of IGES APs for producing and reading digital PDD. Additionally, this section will present some conclusions about the requirements for implementing APs in software systems and for producing and reading digital PDD using AP-based processes.

The User perspective of APs is the viewpoint held by an end-user who is interested in building an AP process to produce and read digital PDD. As stated in Section 2.2, each end-user has requirements for the structure and content of digital PDD, and these requirements are a function of the User's discipline and application area. The User's objective is to build an AP process to produce and read AP formatted data that describes the product for a certain discipline.

The Implementor perspective is the viewpoint held by an individual that develops systems and software for Users that must develop AP processes. For APs, the objective of the Implementor is to provide software systems that support the AP information model and AP format translators that will allow the User to implement an AP process. The Implementor will provide the initial verification of the software components for the AP processes.

The Implementor's main requirement for developing AP systems and software is to have a well-defined and stable set of implementation specifications. These implementation requirements are given by the AP information model and the AP format specification. It will be much easier to develop quality systems and software to support the AP if these requirements are stable. The Implementor cannot guarantee the capability of the software if the support of an AP requires an open-ended development process.

With the AP software, the Implementor will provide to the User instructions for preparing digital PDD in AP processes. The Implementor-supplied instructions must be validated in conjunction with the systems and software for use in AP processes.

The Purchaser perspective is the viewpoint held by an individual or organization that must purchase digital PDD along with the products themselves. These data sets will have been produced by User developed AP processes consisting of systems and software developed by Implementors. The Purchaser's primary requirement is that the data sets meet the specifications of the validated APs.

The Purchaser will be dependent on the correctness of the AP itself, the Users' implementation of the AP process that produced the data, and the Implementors' systems and software that were used as part of the Users' AP process. The Purchaser will require that User implementations of AP processes be validated before the Purchaser agrees to purchase the User's data. In addition, the Purchaser may require that User produced data sets be placed in long-term archival storage for future retrieval and use with User developed AP processes. The Purchaser will be dependent on the validation of the AP, of the Implementors support of the AP, and of the User's AP process.

In summary, the User, Implementor, and Purchaser have different views of APs for use in producing and reading digital PDD. The User must be able to build AP processes for producing and reading digital PDD. The User must depend on Implementor developed systems, software, and documentation to build the AP processes. The Implementor must develop systems, software, and documentation to support validated

APs that allow the User to build AP processes. The Implementor, in order to assist the User in building AP processes, must develop the systems, software, and documentation according to stable APs. The Purchaser must be able to acquire digital PDD in AP formats, produced by Users with AP processes that include Implementor developed systems, software, and documentation. The Purchaser will depend on both Users and Implementors for acquiring complete and correct AP formatted data sets.

Finally, it must be understood that the specification, validation, and implementation of IGES APs will in many cases require that organizations revise their policies and procedures for the creation, exchange, and archival storage of product data.

5. References

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[3] "Department of Energy Data Exchange Format, Mechanical Products/Drafting, Version 1.2.2," Sandia National Laboratories; September 1987.

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[6] Harrison, R.; "Detailed Requirements for the Applicon AGS/880 IMAGE CAD System Deflavor Translator," Sandia National Laboratories; August 1987.

[7] Harrison, R.; "Detailed Requirements for the Applicon AGS/880 IMAGE CAD System Reflavor Translator," Sandia National Laboratories; August 1987.

[8] "American National Standard, Engineering Drawings and Related Documentation Practices, Dimensioning and Tolerancing, ANSI Y14.5M - 1982," The American Society of Mechanical Engineers; December 1982.

[9] "Guide to Developing Entity Test Cases, Draft Version 0.2," IGES Test Case Development Committee; November 10, 1987.

Appendix A. Glossary

Application - A specific function or work area such as Design, Drafting, Analysis, Testing, or Manufacturing that contributes to realization of the product definition data and/or finished product deliverables for one or more disciplines; also, any one of a group of activities that is a part of Design, Drafting, Analysis, Testing, or Manufacturing such as Geometric Modeling, Finite Element Analysis, Dynamic Response of Articulated Machinery, or Numerical Control Machining. The nature of an application may differ depending on several factors, one of which is the discipline(s) that it must support.

Application Area - See Application

Application-based view - A means of interpreting product definition data that is based on an information model for a specific application. In application protocols, the application protocol information model provides this means by facilitating the interpretation of product definition data using the application area's terminology and rules. This term does not include or require a completely computer-understandable representation of the application protocol information model.

Application Implementation Model (AIM) - An information model that is directed towards an implementation of information structures for a particular application area. The information model is based on an application reference model and uses application specific terminology and rules. The information model also contains implementation-based detail that is necessary to specify the items of information that must be identifiable in an application protocol format.

Application IGES Implementation Model (AIIM) - An information model that describes the information structures required to accomplish an implementation using IGES entities. The information model is based on an application implementation model and is prepared at a level of abstraction that is appropriate to select the necessary IGES entities for an application protocol format.

Application Protocol (AP) - A method to achieve consistent and reliable exchange of product definition data within a specified application area. The key components of an application protocol are a conceptual information model for the application area with its supporting documentation, an application protocol format specification, and a set of application protocol format test cases.

Application Protocol Format (APF) - An application specific format that is based on the embedding of items of information from a conceptual information model into IGES entities.

Application Protocol Format Specification (APFS) - A specification that provides a complete, rigorously defined, and unambiguous means to represent the information that is required for a specific application area; consists of an application subset, the restrictions on the global, directory entry, and parameter data sections, and a usage guide for the application subset.

Application Protocol Format Translator - An application specific translator that is based on the imbedding of CAD information from the application protocol information model into the CAD database format and the IGES entities in an application protocol format. The translator implements a single mapping association between a certain entity in the CAD database format and a certain IGES entity (APF preprocessor), or between a certain IGES entity and a certain entity in the CAD database format (APF postprocessor) to satisfy the needs of one application protocol and its associated application protocol format.

Application Protocol Information Model (APIM) - A set of information models that are developed for an application protocol. The information models are an application reference model, an application implementation model, and an application IGES implementation model.

Application Protocol Usage Guide - A set of instructions describing how the IGES entities from the application subset are to be used to carry the information described in the conceptual information model. The usage guide is one required component of the Application Protocol Format Specification.

Application Protocol Validation - The evaluation of a candidate application protocol, including the constituent components (refer to Application Protocol) to confirm its suitability. The goal of the evaluation is to ensure that all of the necessary information requirements are supported by the candidate application protocol. See Validation.

Application Reference Model (ARM) - An information model that describes the information requirements and the information structure for an application area. The information model uses application specific terminology and rules familiar to an expert from the application area. The model is independent of any physical implementation and can be validated by an expert from the application area. See Validation.

Application Subset - An unambiguous set of IGES entities which span the data requirements of the specified application. The set of IGES entities is determined on the basis of the Application Protocol Information Model (APIM). The documentation for an Application Subset is required as part of the Application Protocol Format Specification (APFS).

Application Validation Methodology (AVM) Committee - A technical committee of the IGES/PDES Organization which is developing guidelines and methods to achieve consistent and reliable exchanges of product definition data within a specified application area. This committee is also developing the methodology to validate candidate implementations of these product definition data exchange methods.

Application Validation - The systematic investigation of a system or software capability to determine whether it fulfills the requirements of a specific application area.

Application Validation Testing - See Application Validation

Computer-Aided Design (CAD) System - A unified collection of computer hardware and software whose purpose is to facilitate the creation, storage, distribution, and use of product definition data in digital form.

Conceptual Information Model - A description of the information requirements, information structure, and the relationships between the individual items of information for an application area. Models are usually developed using a formalized, graphical modeling language, such as NIAM or IDEF1X.

Discipline - An area or field of endeavor such as Mechanical Products, Electrical Products, or Architecture, Engineering, and Construction, that has as its deliverable both product definition data and finished products. The structure and content of product definition data and the configuration of finished products for each discipline are a function of the discipline itself.

Entity - The basic unit of data in an IGES file. The term applies to single units which may be individual elements of geometry, individual elements of annotation, or collections of geometry or annotation elements that are combined to form more complex data structures.

Generic IGES Translator - An application independent IGES translator that implements a set of mappings for CAD information from the CAD database format of a certain CAD system to the IGES format (IGES preprocessor), or from the IGES format to the CAD database format of a certain CAD system (IGES postprocessor). The translator implements a single mapping association between an entity in the CAD database format and an entity in the IGES format, or vice versa. The single mapping association is based on the similarity of CAD database format and IGES format data structures.

IGES Postprocessor - A software unit that translates CAD data from the IGES format to the CAD database format of a certain CAD system. The software is usually developed and maintained by a commercial CAD system vendor.

IGES Preprocessor - A software unit that translates CAD data from the CAD database format of a certain CAD system to the IGES format. The software unit is usually developed and maintained by a commercial CAD system vendor.

IGES Application Protocol Format Test Cases - IGES data files of product definition data that meet all of the representational requirements of information for the application protocol. The files must be prepared such that they are in compliance with the application protocol format specification.

Information Model - See Conceptual Information Model

Information Configuration Control (ICC) - An approach that consists of specifying, documenting, and controlling both the creation of information and the subsequent translation and exchange of the information between different systems and formats. The approach requires substantial documentation for both the syntax (the format) and the semantics (the meaning) of the information items at each step in the process.

Product Data - The set of data elements that are necessary to provide full support for a product and meet all of its in-service needs over its expected life cycle. This set of data elements includes all of the product definition data plus other data pertaining to the operation and maintenance of the product until it is removed from service.

Product Definition - See Product Definition Data

Product Definition Data - The set of data elements that completely define a product for a certain discipline. This set of data elements includes the geometry, topology, features, tolerances, and relationships to completely define a component part or an assembly of parts. The data is structured such that it can be used by one or more applications.

Protocol - A set of rules that govern the operation of functional units to achieve communication. (ISO)

Semantics - The meaning that is given or assigned to an item of information. The meaning is assigned to an item of information on the basis its application area.

Syntax - The structure and organization of an item or items of information, as in a format. The format is described in a specification such as IGES.

Software Configuration Control (SCC) - An approach that consists of controlling the capability and make-up of software systems and individual software units through the use of requirements. For information creation, translation, and exchange, the software requirements are prepared from ICC documentation.

User Interface - The set of commands, menu choices, utilities, and options that exist to create and edit information in a CAD system's database.

Validation - The process of evaluating software at the end of the software development process to ensure compliance with software requirements. (ANSI/IEEE Std 729-1983)

Validation Criteria - The properties of an application protocol that will be investigated to determine success or failure in the validation of a candidate application protocol. See Validation.

Verification - The process of determining whether or not the products of a given phase of the software development cycle fulfill the requirements established during the previous phase. (ANSI/IEEE Std 729-1983)

Appendix B.1

FEATURE CONTROL FRAMES - APPLICATION PROTOCOL INFORMATION MODEL

This Appendix will describe the Application Protocol Information Model (APIM) for Feature Control Frames. The APIM consists of three information models, the Application Reference Model (ARM), the Application Implementation Model (AIM), and the Application IGES Implementation Model (AIIM). These three models describe the information requirements and logical structure of the information for Feature Control Frames.

The Feature Control Frames ARM represents the Drafting information that is required for a Feature Control Frame. This ARM is a part of the complete Drafting APIM. The ARM is a model of Feature Control Frames information that can be validated by a Drafting application area expert. The ARM is given in Figure B1. The supporting documentation for this model is given at the end of this Appendix.

From Figure B1, the Feature Control Frame contains the Geometric Characteristic, the Tolerance Specification, the Maximum Tolerance Value Specification, and the Datum Reference. Also, the Feature Control Frame belongs to a Feature Relationship, is represented by a Frame Box, and is compartmentalized by a Frame Box Divider.

From Figure B1, the Tolerance Specification contains the Tolerance Cylindrical Form, the Tolerance Value, the Tolerance Material Condition, the Tolerance Unit Length, and the Tolerance Unit Width. The Maximum Tolerance Value Specification contains a Tolerance Cylindrical Form and a Maximum Tolerance Value. The Datum Reference contains a Datum Identifier and a Datum Material Condition. The Feature Relationship contains a Feature and a Feature Relator. The Feature Relator can be one of four types, a Leader, a Plane Surface Extension, a Dimension of Size, and a Leader Directed Callout. The Frame Box is defined by four coordinate pairs. The Frame Box Divider is defined by two coordinate pairs.

The Feature Control Frames ARM of Figure B1 describes the information requirement and structure for the Feature Control Frame-Feature Relationship part of Feature Control Frames. For simplicity, this Feature Control Frames Application Protocol example will not implement this information requirement.

Figure B2 illustrates the initial AIM. The initial AIM was developed on the basis of the ARM and shows the Drafting information for Feature Control Frames that must be "identifiable" in the IGES entities in the Drafting APF. The meaning of "identifiable" in this context is that it must be possible to have a reversible mapping of Feature Control Frames information from the ARM into the IGES entities in the APF. The initial AIM provides a description of the way that the Feature Control Frames information must be structured to allow an explicit reversible mapping. The initial AIM contains the same application-based information requirements and structure as the ARM, but also contains additional implementation-based identifiers for the information requirements.

From Figure B2, the Feature Control Frame is identified by a Feature Control Frame Identifier. The Geometric Tolerance is identified by a Geometric Tolerance Identifier. The Geometric Characteristic is represented by a Geometric Characteristic Symbol. The Tolerance Specification is identified by a Tolerance Specification Identifier. The Tolerance Cylindrical form is represented by a Diameter Symbol. The Tolerance Value is represented by a Tolerance Value String. The Tolerance Material Condition is represented by a Material Condition Symbol. The Tolerance Unit Length is represented by a Tolerance Unit Length String. The Tolerance Unit Width is represented by a Tolerance Unit Width String.

From Figure B2, the Maximum Tolerance Value Specification is identified by a Maximum Tolerance Specification Identifier. The Maximum Tolerance Value is represented by a Maximum Tolerance Value String. The Datum Reference is identified by a Datum Reference Identifier. The Datum Identifier is represented by a Datum Identifier String. The Datum Material Condition is represented by a Datum Material Condition Symbol. The Frame Box-Coordinate Pair consists of an X Value and a Y Value. The Frame Box is identified by a Frame Box Identifier. The Frame Box Divider-Coordinate Pair consists of an X Value and a Y Value. The Frame Box Divider is identified by a Frame Box Divider Identifier.

As previously discussed, the initial AIM contains implementation-based identifiers for the information requirements from the ARM. Several implementation constraints were used in this Feature Control Frames AP example. These constraints were imposed to make the specification of the AP format possible without major revisions and enhancements to the IGES Specification. These constraints are given below.

> Constraint 1 - The Application Protocol Format Specification must use IGES entities that exist in the current IGES Specification, where possible. It is permissible to define new IGES entities only where there is no existing IGES entity that can be used to carry the necessary information.
>
> Constraint 2 - The IGES entities selected for use in the Application Protocol Format Specification must be selected so as to minimize the size of AP format files as much as possible. This means that the "simplest" IGES entity should be selected when there is more than one possible choice.

Because of the implementation constraints given above, decisions and trade-offs had to be made about the final IGES entity selections for this Feature Control Frames example. This decision process resulted in a final AIM that provides a less explicit "identification" of each item of Feature Control Frames information in the APF entities. For the implementation described by the APFS in Appendix B.2, the Tolerance Specification Identifier, the Maximum Tolerance Specification Identifier, and the Datum Reference Identifier had to be eliminated to produce the final AIM. The final AIM is illustrated in Figure B3. In reality, Figure B3 shows that it will not be possible to have an explicit reversible mapping of Feature Control Frames information into and out of the APF. It is possible to accomplish a reverse mapping of the Feature Control Frames information, but the reverse mapping must be made without the explicit identifiers.

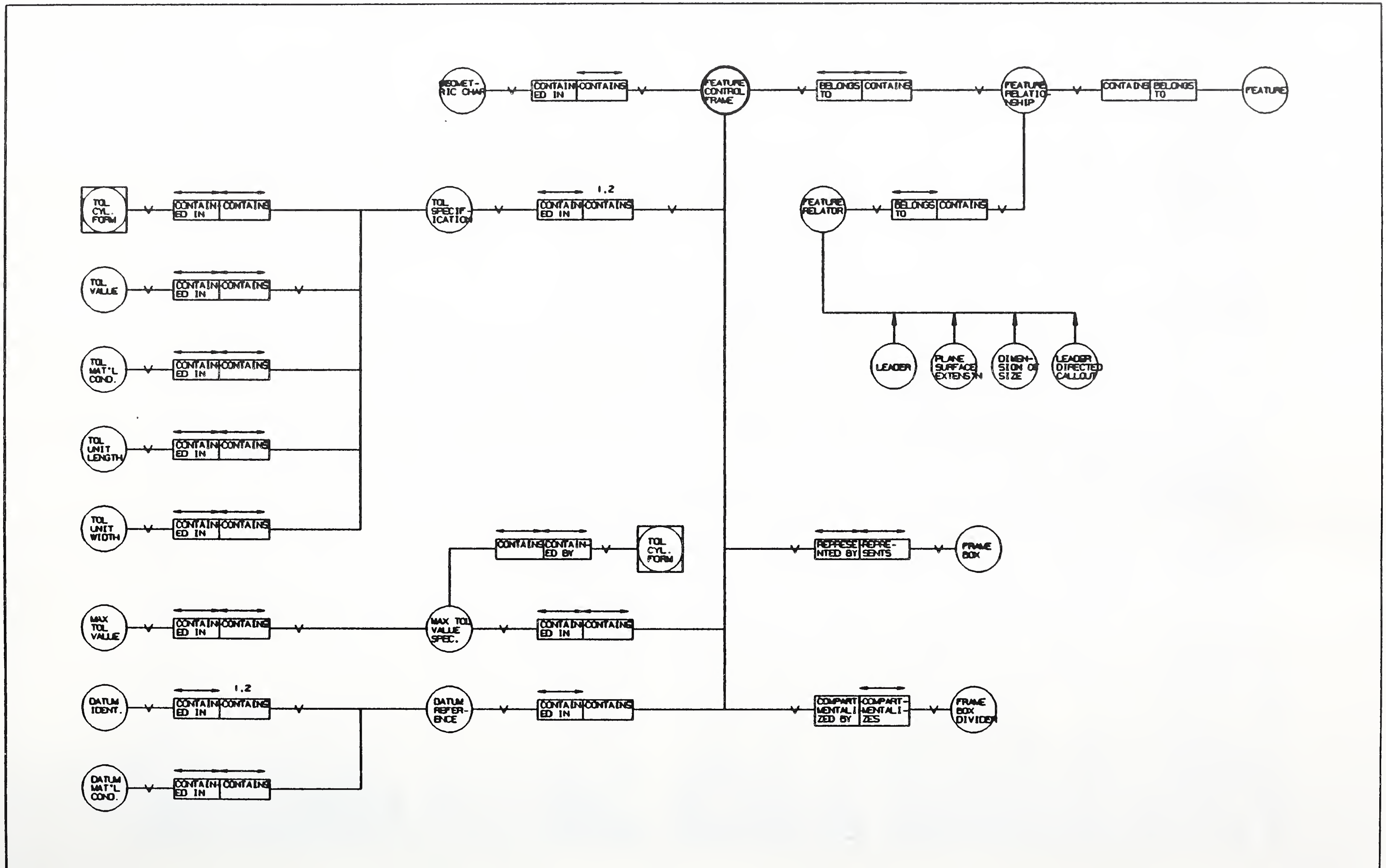
The AIIM is illustrated in Figure B4. The AIIM is a model of the logical structure of Feature Control Frames information after it has been abstracted to an appropriate level for use in selecting the necessary IGES entities to carry the information. This AIIM was developed on the basis of the initial AIM.

From Figure B4, a Feature Control Frame is a sub-type of Drafting Annotation. Drafting Annotation must be identified by an Annotation Identifier. Drafting Annotation must be comprised of two or more Linear Curves and two or more Drafting Components. The Linear Curve must be identified by a Component Identifier. The Linear Curve must be one of two types, a Line or a Copious Linear Curve. The Drafting Component must be identified by a Component Identifier. The Component must be signified by a Symbol or a String. Figure B4 illustrates the logical structure for the Drafting Annotation-Feature Control Frame-Geometric Tolerance. This logical structure will not be implemented in this example.

The AIIM of Figure B4 also illustrates the logical structure for the Feature Control Frame-Feature Relationship structure from Figure B1 in the Drafting Annotation-Feature Relationship. This logical structure will not be implemented in this AP example for Feature Control Frames. As stated above, this AIIM was developed on the basis of the initial AIM. As discussed previously, the final AIM was developed on the basis of implementation decisions and trade-offs that resulted in the elimination of several identifiers. The "X-Outs" in Figure B4 represent the elimination of logical identifiers in the AIIM as was done in the final AIM.

The AIIM of Figure B4 was used to select the IGES General Symbol, General Note, Simple Closed Area, and Line entities for use in carrying the Feature Control Frames information in the AP format. Appendix B.2, the Application Protocol Format Specification, will describe the example Application Protocol Format for Feature Control Frames.

USED AT: IGES/PDES AVM	AUTHOR: R.E.PARKS, SANDIA	DATE: 3/4/88	X WORKING	READER DATE	CONTEXT:
	PROJECT: GUIDLINES FOR IGES APS	REV: A	DRAFT		
			RECOMMENDED		
	NOTES:		PUBLICATION		



IGES/PDES	PROJECT: GUIDLINES FOR IGES APS	REV: A	DRAFT
AVM			RECOMMENDED
	NOTES:		PUBLICATION

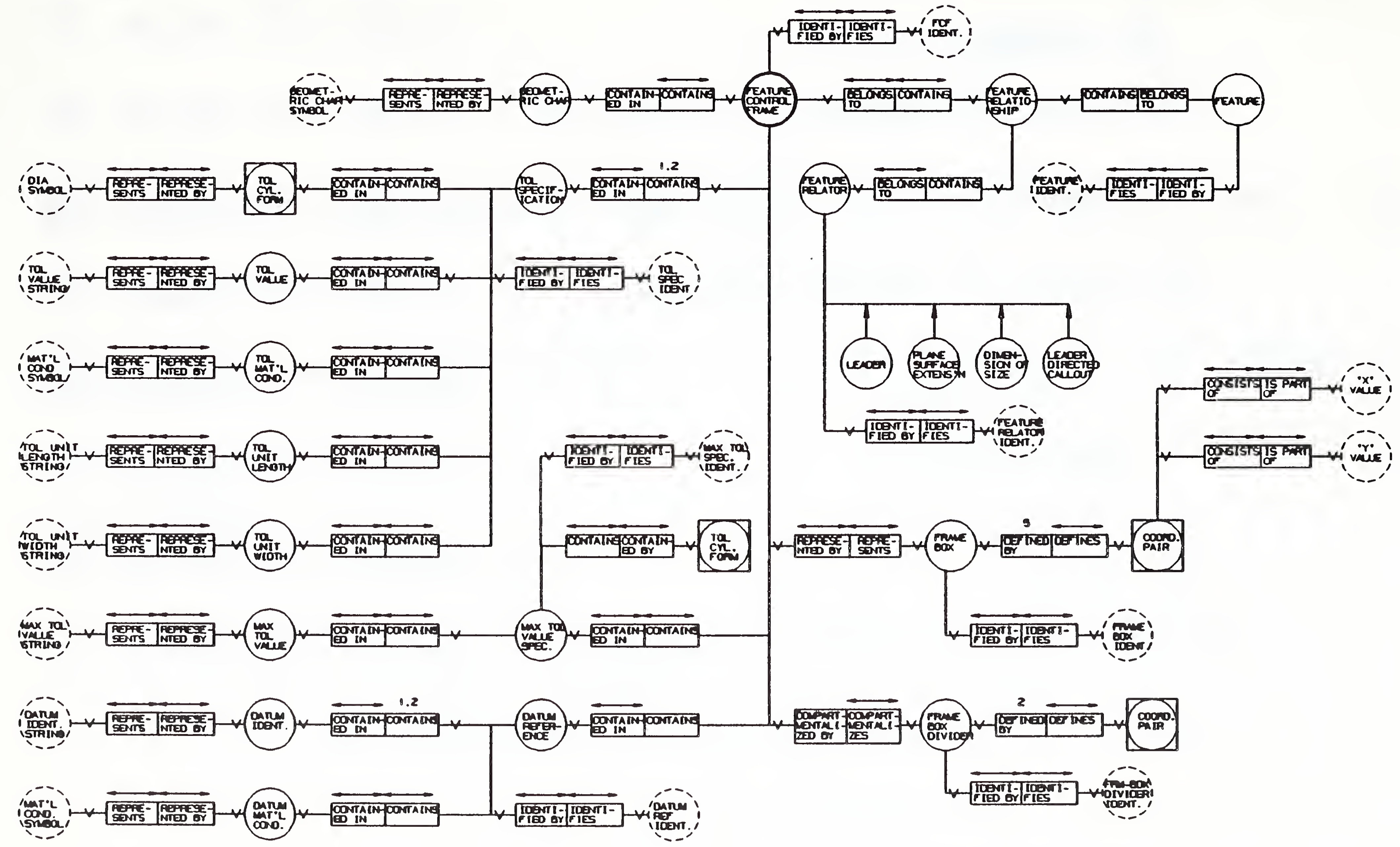
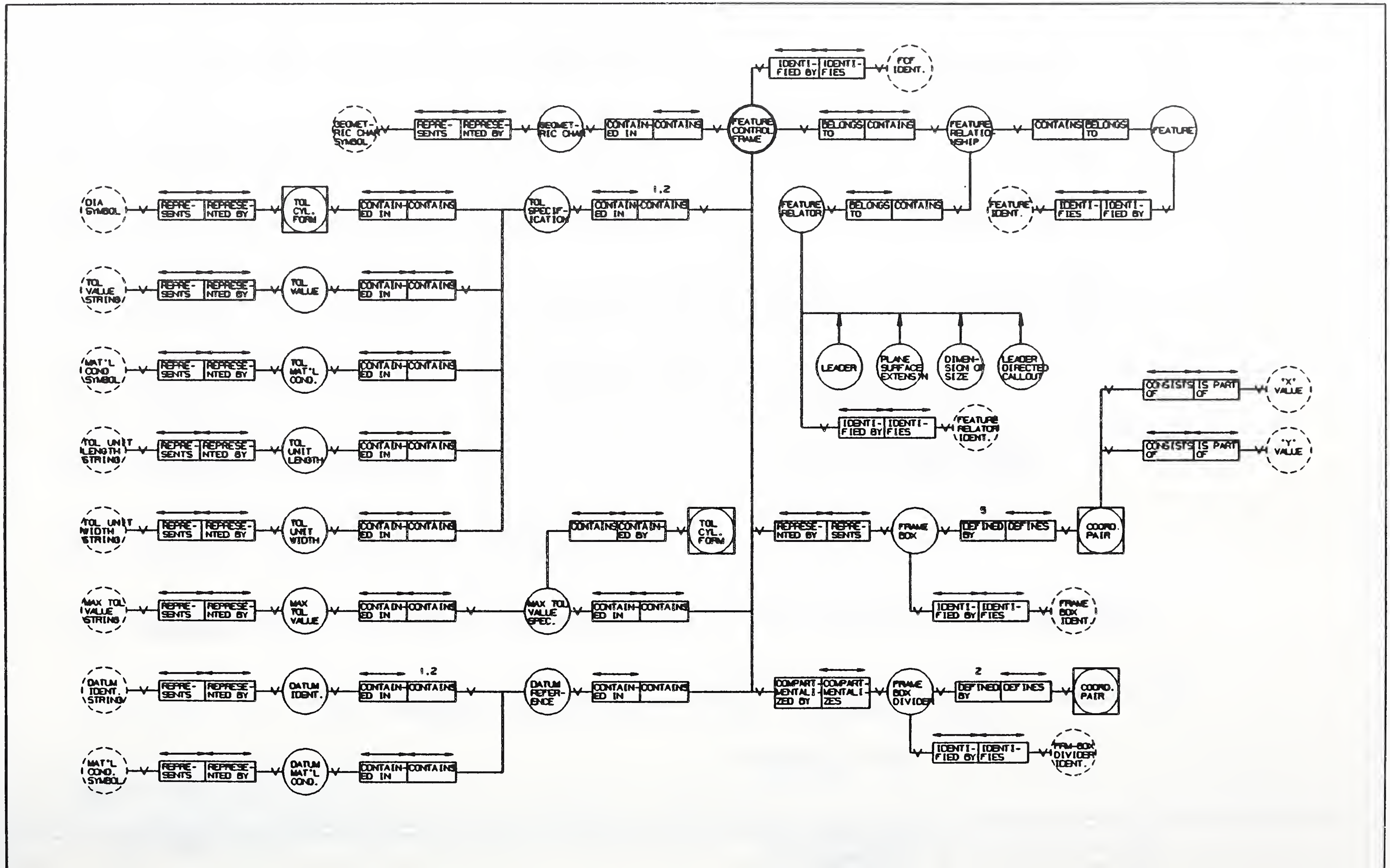


FIGURE B2

TITLE:

FEATURE CONTROL FRAME APPLICATION PROTOCOL
APPLICATION IMPLEMENTATION MODEL (INITIAL)

USED AT:	AUTHOR: R.E.PARKS, SANDIA	DATE: 3/4/88	X	WORKING	READER	DATE	CONTEXT:
IGES/PDES	PROJECT: GUIDLINES FOR IGES APS	REV: A		DRAFT			
AVM				RECOMMENDED			
	NOTES:			PUBLICATION			



USED AT: IGES/PDES AVM

PROJECT: GUIDLINES FOR IGES APS REV: A

NOTES:

DRAFT

RECOMMENDED

PUBLICATION

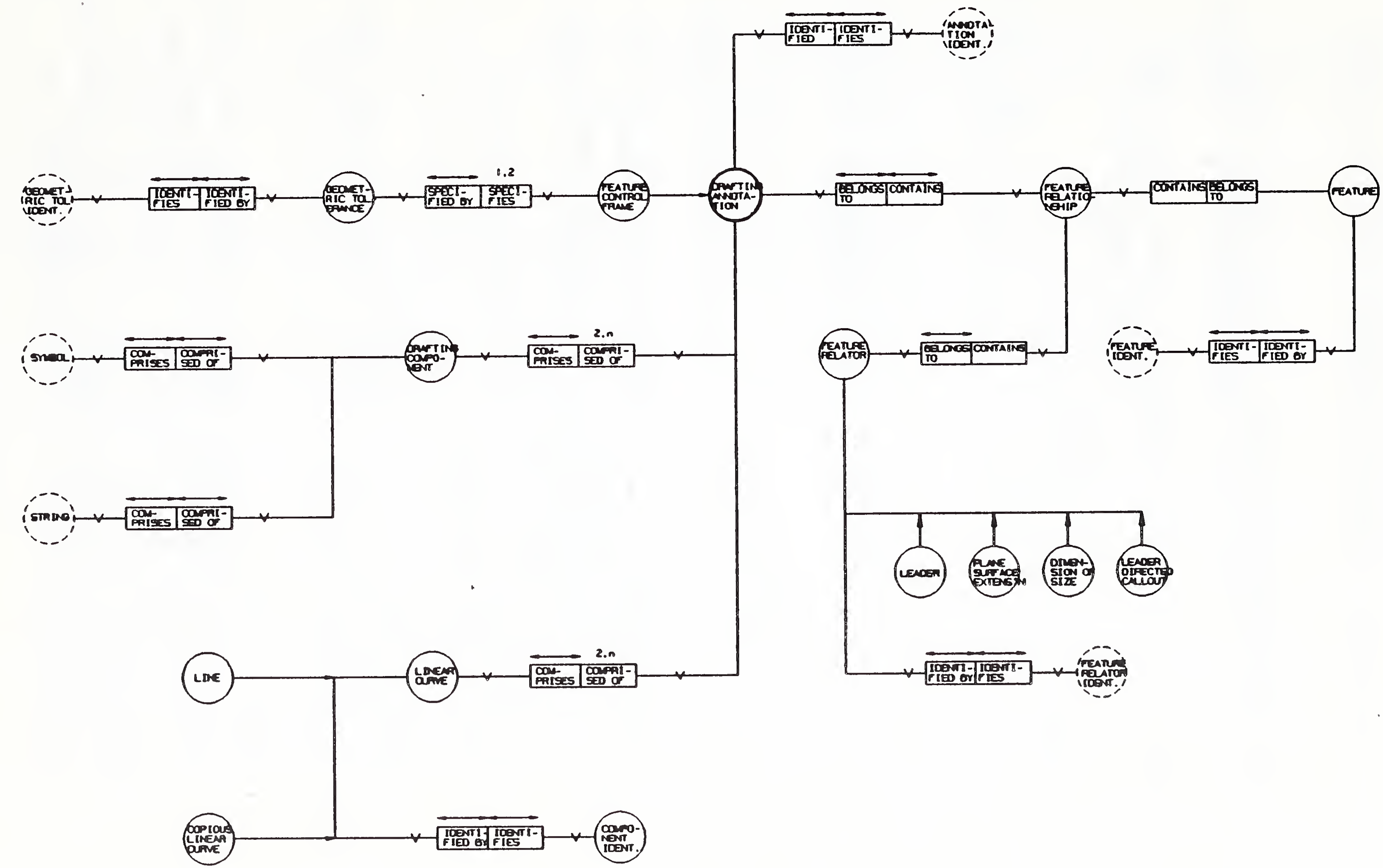
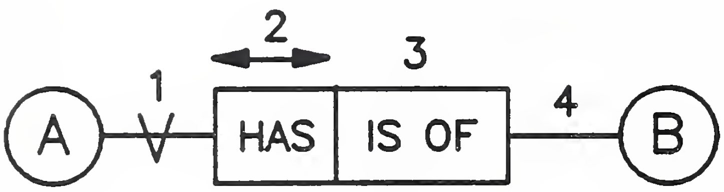


FIGURE B4

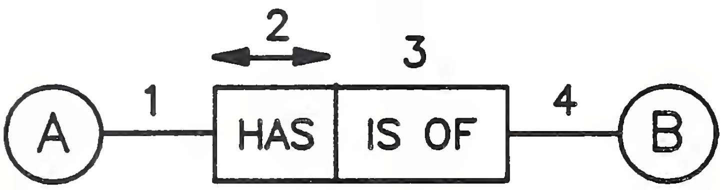
TITLE: FEATURE CONTROL FRAME APPLICATION PROTOCOL APPLICATION IGES IMPLEMENTATION MODEL

NON–LEXICAL OBJECT TYPE (NOLOT): CLASSES OF NON–LEXICAL OBJECTS LIKE PERSON, TOWN, ETC.

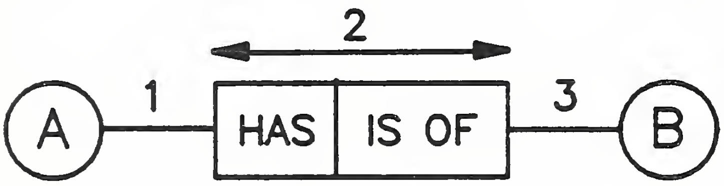
LEXICAL OBJECT TYPE (LOT): CLASSES OF LEXICAL OBJECTS LIKE SURNAME, TOWN–NAME, ETC.



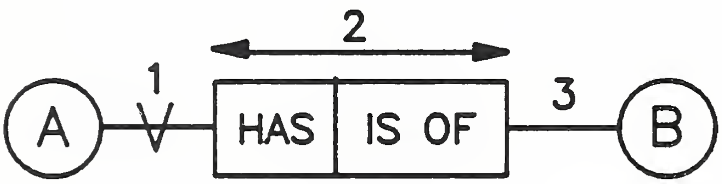
1 1 2
EVERY "A" HAS ONE & ONLY ONE "B"
4 3
A "B" IS OF ZERO, ONE OR MANY "A"



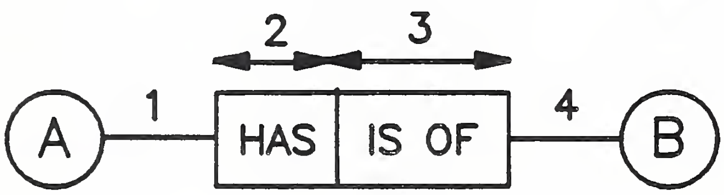
1 1 2
AN "A" MAY HAVE ZERO OR ONE "B"
4 3
A "B" IS OF ZERO, ONE OR MANY "A"



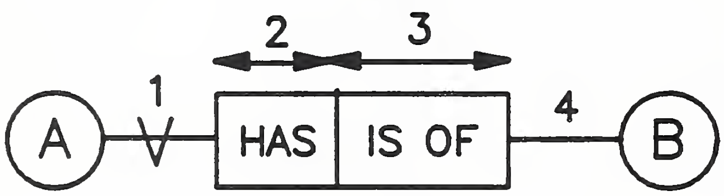
1 2
AN "A" HAS ZERO, ONE OR MANY "B"
3 2
A "B" IS OF ZERO, ONE OR MANY "A"



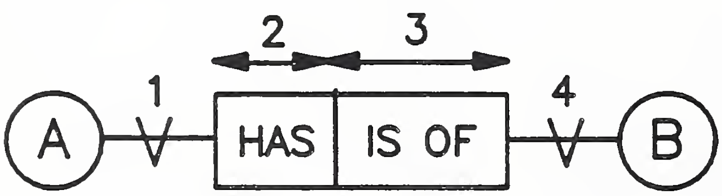
1 1 2
EVERY "A" HAS ONE OR MANY "B"
3 2
A "B" IS OF ZERO, ONE OR MANY "A"



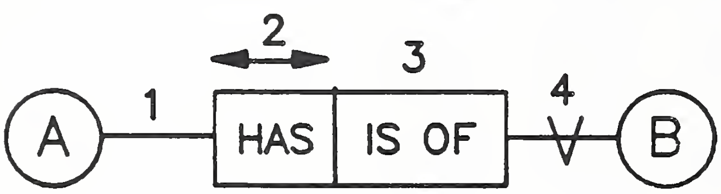
1 2
AN "A" HAS ZERO OR ONE "B"
4 3
A "B" IS OF ZERO OR ONE "A"



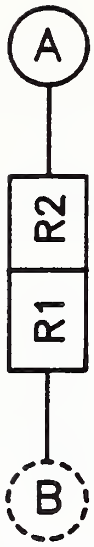
1 1 2
EVERY "A" HAS ONE & ONLY ONE "B"
4 3
A "B" IS OF ZERO OR ONE "A"



1 1 2
EVERY "A" HAS ONE & ONLY ONE "B"
4 4 3
EVERY "B" IS OF ONE & ONLY ONE "A"



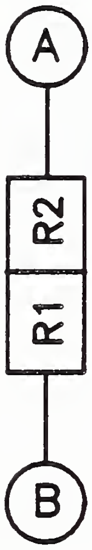
1 1 2
AN "A" MAY HAVE ZERO OR ONE "B"
4 3
A "B" IS OF ONE OR MANY "A"



THERE IS AN ENTITY KNOWN AS "A".
"A" IS AN OBJECT OR A CONCEPT.

BRIDGE WHICH RELATES A NONLEXICAL OBJECT
TO A LEXICAL OBJECT THROUGH ROLES R1 & R2.

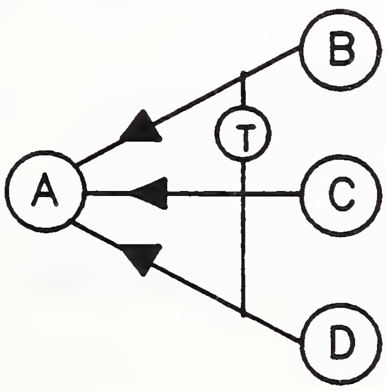
THERE IS AN ENTITY KNOWN AS "B".
"B" IS A LEXICAL REPRESENTATION OF "A".



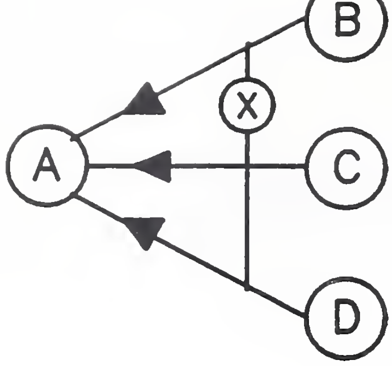
IDEA WHICH RELATES TWO NONLEXICAL OBJECTS
THROUGH ROLES R1 AND R2.

THE OBJECT "A" OCCURS ELSEWHERE
ON THIS OR ANOTHER NIAM DIAGRAM.

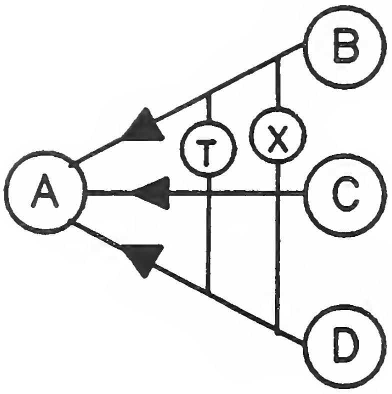
"B" IS A SUBSET OF "A".



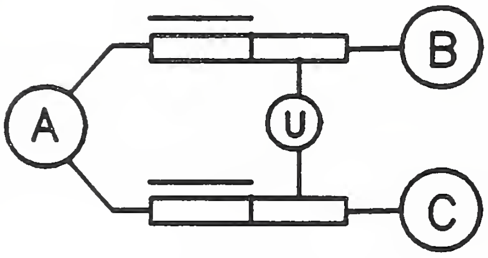
TOTAL CONSTRAINT.
ALL OF THE MEMBERS OF "A" ARE
CONTAINED IN SUBSETS "B", "C"
AND "D". THERE ARE NO OTHER
SUBSETS OF "A".



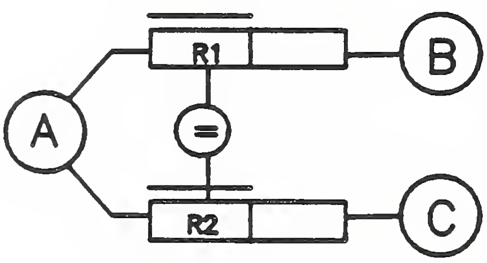
EXCLUSION CONSTRAINT.
"B", "C" AND "D" ARE DISJOINT SUBSETS OF "A".



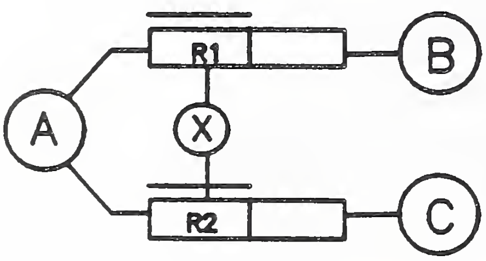
"ONE AND ONLY ONE" CONSTRAINT.
"B", "C" AND "D" ARE DISJOINT SUBSETS OF "A" AND THERE ARE NO OTHER SUBSETS OF "A".



UNIQUENESS CONSTRAINT.
ENTITIES "B" AND "C" ARE BOTH REQUIRED TO UNIQUELY IDENTIFY "A".



EQUALITY CONSTRAINT.
ALL MEMBERS OF "A" THAT ARE RELATED TO "B" THROUGH ROLE R1 ALSO ARE RELATED TO "C" THROUGH ROLE R2.



EXCLUSION CONSTRAINT.
ANY "A" THAT IS RELATED TO "B" THROUGH ROLE R1 CANNOT BE RELATED TO "C" THROUGH ROLE R2 AND VICE VERSA.

I. Application Reference Model (ARM) Object Definitions

Datum - the origin of the dimensional relationship between a toleranced feature and a designated feature on a part.

Datum Identifier - indicates a specified Datum; indicated by an alphabetic letter, such as A, B, etc.

Datum Material Condition - the relative limit of size condition of the designated feature that is to be used as the datum in the dimensional relationship.

Feature Control Frame - the means used in Drafting to specify a geometric tolerance that consists of geometric characteristic symbols, a tolerance value, and datum reference letters; where appropriate, other conditions on the tolerance are expressed, such as material conditions, a maximum tolerance value, and a maximum unit length or unit width.

Frame Box - the combined horizontal and vertical lines that make up the perimeter of the complete Feature Control Frame.

Frame Box Divider - the vertical lines that divide the Feature Control Frame into compartments.

Geometric Characteristic - the aspect of the part feature that the tolerance is directed to, such as straightness, flatness, circularity, etc., for form tolerances, or position for positional tolerances.

Maximum Tolerance Value - the explicitly specified numerical value of the maximum deviation from the specified ideal value.

Maximum Tolerance Value Specification - the explicit enumeration of the maximum deviation, consisting of a Tolerance Cylindrical Form specifier and a Maximum Tolerance Value.

Tolerance Cylindrical Form - precedes the tolerance value in a Feature Control Frame and specifies that the tolerance gives the limit on the deviation of the Geometric Characteristic relative to a cylindrical tolerance zone.

Tolerance Value - the numerical value of the maximum allowed deviation from the specified ideal value.

Tolerance Material Condition - the relative limit of size condition of the feature for which the Tolerance Value is to be applied.

Tolerance Unit Length - the numerical value of the length-wise limit on the part for which the Tolerance Value gives the maximum allowed deviation of the Geometric Characteristic.

Tolerance Unit Width - the numerical value of the width-wise limit on the part for which the Tolerance Value gives the maximum allowed deviation of the Geometric Characteristic; when combined with or multiplied by the Tolerance Unit Length, it gives the size of the unit area for the application of the Tolerance Value.

Tolerance Specification - the enumeration of the required tolerance, consisting of at least the Tolerance Value; may also consist of the Tolerance Cylindrical Form, the Tolerance Material Condition, the Tolerance Unit Length, and the Tolerance Unit Width.

II. Application Reference Model (ARM) Business Rules

1. The structure, information requirements, and drafting representation for a Feature Control Frame are given in the ANSI Standard for Dimensioning and Tolerancing, ANSI Y14.5M, 1982.[6]

Appendix B.2

FEATURE CONTROL FRAME - APPLICATION PROTOCOL FORMAT SPECIFICATION

This Appendix consists of a sample Drafting Application Protocol Format Specification (APFS) for Feature Control Frames. This APFS example consists of the required technical content for an APFS, including the Application Protocol Format (APF). This example for Feature Control Frames gives the IGES entities, the restrictions on the use of the IGES entities, and the usage guide for the IGES entities in carrying information for Feature Control Frames.

In a complete APFS, this section would be only a part of the total APFS that would be required to give the complete IGES entity set for the AP, the restrictions on the Global, Directory Entry, and Parameter Data sections for the AP, and the usage guide for carrying all of the Drafting information from the Application Protocol Information Model (APIM). The AP Information Model consists of three information models, the Application Reference Model (ARM), the Application Implementation Model (AIM), and the Application IGES Implementation Model (AIIM). These three information models are required to completely describe Feature Control Frames for the purpose of developing an APFS.

For maximum utility as an example of an APFS, this APFS will include an example of the Global section restrictions that would normally be included in a complete Drafting APFS. The Global section restrictions in this example are not based on the Feature Control Frames APIM.

I. IGES Entity Set

The IGES entities that are to be used to carry Drafting information for Feature Control Frames are given below. These entities are described in the Initial Graphics Exchange Specification, Version 3.0.[3] These IGES entities were selected on the basis of the final Application Implementation Model (AIM) and the Application IGES Implementation Model (AIIM) from Appendix B.1.

228 - General Symbol
212 - General Note
106 - Simple Closed Area
110 - Line

The General Symbol entity was selected as the "associativity" or "grouping" entity for the Feature Control Frame because it supports the inclusion of a single General Note, one or more geometric entities, and zero, one or more Leaders. These are the basic requirements that are given by the APIM for Feature Control Frames.

The APIM also gives basic requirements that control the selection of the individual entities. The APIM requires the use of multiple text strings in a single text entity, which the General Note entity supports with no problem.

The APIM also requires the use of four grouped straight line segments for the frame box. This requirement can be met by the Simple Closed Area entity. The APIM requires a variable number of individual straight line segments for the variable number frame box dividers. This requirement can be met easily through the use of Line entities.

II. Global, Directory Entry, and Parameter Data Section Restrictions

This section gives the restrictions on the Global, Directory Entry, and Parameter Data section restrictions for each entity in the IGES entity set. These restrictions were specified on the basis of the final AIM and the AIIM from Appendix B.1.

The Global, Directory Entry, and Parameter Data section restrictions will be given separate from the usage guide because the purpose of the restrictions is different from that of the usage guide. The purpose of the restrictions is to reduce the possible field and parameter values of the "general" IGES entities to what is necessary for the APF. In this example for Feature Control Frames, the restrictions are based on supporting only the needs of carrying Feature Control Frame information. The restrictions are based either explicitly or implicitly on the final AIM and the AIIM from Appendix B.1. In contrast, the usage guide for the IGES entities is based explicitly on the structure and meaning expressed in the ARM, the final AIM, and the AIIM and specifies how the Feature Control Frame information is to be carried in the IGES entities.

In a complete APFS, as in this example, the restrictions would be based either explicitly or implicitly on the complete APIM so that the needs of the APIM would be supported and no ambiguities would result. As in this example, the restrictions would be specified for each of the entities in the IGES entity set.

II.1 Global Section

This section gives the Global section restrictions for the APF. As stated above, the Global section restrictions are only an example of the Global section restrictions that would normally be included in a complete Drafting APFS. These restrictions should not be taken as a specification of the correct restrictions for a Drafting APFS. The Global section restrictions given in this example are not based on the Feature Control Frames APIM.

Global Section Field	Field Value Requirement
Parameter Delimiter	1H,
Record Delimiter	1H;
Product ID From Sender	Part Number, see below
File Name	See below
System ID	As Per IGES, non-null
IGES Preprocessor Version	As Per IGES, non-null
Number of Bits for Integer	As Per IGES, non-null
Single Precision Magnitude	As Per IGES, non-null
Single Precision Significance	As Per IGES, non-null
Double Precision Magnitude	As Per IGES, non-null
Double Precision Significance	As Per IGES, non-null
Product ID for the Receiver	Part Number, see below
Model Space Scale	1.0
Unit Flag	1 or 2
Units	4HINCH or 2HMM
Maximum Number of Lineweights	As Per IGES, non-null
Maximum Line Thickness	As Per IGES, non-null
Date and Time of Creation	As Per IGES, non-null
Minimum Resolution	See below
Maximum Coordinate Value	See below
Name of Author	As Per IGES, non-null
Organization	As Per IGES, non-null
Version Number	As Per IGES, non-null
Drafting Standard Code	See below

The Product ID From Sender, field 3, and the Product ID for the Receiver, field 12, must contain the Part Number. Field 3 and Field 12 must always be given values. Field 3 and Field 12 must be equal. The Part Number is defined to be an alpha-numeric string which gives the number that uniquely identifies the part contained in the Drafting APF file.

Examples: 10H0123456789 10H9999999999

The File Name, field 4, must contain the name of the file as it existed on the originating system using the appropriate naming conventions of the originating system. The naming conventions of the originating system may or may not include disk identifiers, node names, directory names, etc. Therefore, no limit is placed on the length of the alpha-numeric string used to carry the name of the file. This field must always be given a value.

```
Examples: 43HDUA0:[CAD.DRAFTING.APF_FILES]SPACER_ROD.DRW
          12HTESTFILE.DAT
          6HN002SA
          20HSAMPLE    XBPART21 A1
          51H'CADFILE.TEST.THIS.IS.A.FAIRLY.LONG.NAME(TESTPART)'
```

The Global section fields that have Field Value Requirements consisting of "As Per IGES, non-null" require that the field always contain a valid value as described by the IGES specification. This means that the syntax and semantics defined by the IGES specification must be used to prepare the required information for the field. This restriction pertains to fields 7-11, 16-18, and 21-23.

The Minimum Resolution, field 19, must contain the value of the largest geometric discontinuity for the geometry in the Drafting APF file, i.e., the largest "gap". Because of the dual role of the Drafting APF, the Drafting APF file is required to carry both the product data, geometry, tolerances, etc., and the graphics necessary to produce a drawing. In many cases, the product data geometry in the Drafting APF file must be used by manufacturing applications to produce a product. Manufacturing applications must rely on the continuity of the geometry, and this reliance requires that the value of Field 19 be the largest geometric discontinuity in the Drafting APF file. With this value, any manufacturing application can consider coordinate locations less than this distance apart to be coincident. This field value must be prepared on the basis of each APF file's contents and not on the basis of the originating system's capability. This field must always be given a value.

Examples: 0.00001 1.0E-5

The Maximum Coordinate Value, field 20, must contain the value of the largest X, Y, or Z geometric position in the Drafting APF file. This field value must be prepared on the basis of each APF file's contents and not on the basis of the originating system's maximum capability. This field must always be given a value.

Examples: 1000.0 1.0E3

The Drafting Standard Code, field 24, must contain the value 3, because the Feature Control Frame example is based on the American National Standards Institute's Standard for Dimensioning and Tolerancing, ANSI Y14.5M, 1982.[6]

II.2 Directory Entry Section

This section gives the Directory Entry section restrictions for the IGES entity set. The restrictions for the Directory Entry section of the IGES entities in this example are based on the APIM for Feature Control Frames and some assumptions about the remainder of the APIM for the Drafting APF. These assumptions would not be necessary for a complete Drafting APF because the complete APIM would be available for use in determining the restrictions.

The restrictions for fields 1, 11, and 15 were determined on the basis of the IGES entity set that was selected to carry the information for Feature Control Frames. The restrictions for fields 3, 4, 6, 7, 8, 9, 12, and 13 were determined on the basis of the APIM for Feature Control Frames.

The restriction for field 5 was determined on the basis of an assumption. The assumption is that the complete Drafting APIM will require a method for separating the Drafting information into specific information categories.

The APFS will use the Directory Entry section level field to carry the information category number. The information category number for tolerance information (Feature Control Frames) is 250.

The restriction for fields 18 and 19 were determined on the basis of an assumption. The assumption is that the complete Drafting APIM will require a method for uniquely identifying each entity in the Drafting APF. The APFS will use the entity label and subscript fields in the Directory Entry section to carry the unique identifier. The requirement is that the combination of the entity label value and the subscript value provide a unique identifier for each entity in a Drafting APF file. This requirement means that a unique entity label value must be identified for each IGES entity type. Also, a unique subscript value N must be supplied for each entity in the APF file, where N can have a value from 1 to the number entities of each type in the APF file. The entity label values for the entities in this example are:

228 General Symbol	"FCF_INFO"
212 General Note	"FCF_TEXT"
106 Simple Closed Area	" FCF_BOX"
110 Line	" FCF_SEP"

The Directory Entry section fields that have Field Value Requirements consisting of "As Per IGES" require that the field always contain a valid value as described by the IGES specification. This restriction pertains to Directory Entry section fields 2, 10, 14, and 20.

II.2.1 General Symbol Entity

Directory Entry Section Field	Field Value Requirement
Entity Type	228
Parameter Data Pointer	As Per IGES
Structure	0
Line Font Pattern	1
Level	250
View	0
Transformation Matrix	0
Label Display Associativity	0
Status Number:	
Blank Status	0
Subordinate Entity Switch	0
Entity Use Flag	1
Hierarchy	1
Section Code and Sequence Number	As Per IGES
Entity Type	228
Line Weight Number	0
Color Number	0
Parameter Line Count Number	As Per IGES
Form Number	0
Reserved Field	Blank
Reserved Field	Blank
Entity Label	FCF_INFO
Entity Subscript Number	N
Section Code and Sequence Number	As Per IGES

II.2.2 General Note Entity

Directory Entry Section Field	Field Value Requirement
Entity Type	212
Parameter Data Pointer	As Per IGES
Structure	0
Line Font Pattern	1
Level	250
View	0
Transformation Matrix	0
Label Display Associativity	0
Status Number:	
Blank Status	0
Subordinate Entity Switch	1
Entity Use Flag	1
Hierarchy	1
Section Code and Sequence Number	As Per IGES
Entity Type	212
Line Weight Number	0
Color Number	0
Parameter Line Count Number	As Per IGES
Form Number	0
Reserved Field	Blank
Reserved Field	Blank
Entity Label	FCF_TEXT
Entity Subscript Number	N
Section Code and Sequence Number	As Per IGES

II.2.3 Simple Closed Area Entity

Directory Entry Section Field	Field Value Requirement
Entity Type	106
Parameter Data Pointer	As Per IGES
Structure	0
Line Font Pattern	1
Level	250
View	0
Transformation Matrix	0
Label Display Associativity	0
Status Number:	
Blank Status	0
Subordinate Entity Switch	1
Entity Use Flag	1
Hierarchy	1
Section Code and Sequence Number	As Per IGES
Entity Type	106
Line Weight Number	0
Color Number	0
Parameter Line Count Number	As Per IGES
Form Number	63
Reserved Field	Blank
Reserved Field	Blank
Entity Label	FCF_BOX
Entity Subscript Number	N
Section Code and Sequence Number	As Per IGES

II.2.4 Line Entity

Directory Entry Section Field	Field Value Requirement
Entity Type	110
Parameter Data Pointer	As Per IGES
Structure	0
Line Font Pattern	1
Level	250
View	0
Transformation Matrix	0
Label Display Associativity	0
Status Number:	
Blank Status	0
Subordinate Entity Switch	1
Entity Use Flag	1
Hierarchy	1
Section Code and Sequence Number	As Per IGES
Entity Type	110
Line Weight Number	0
Color Number	0
Parameter Line Count Number	As Per IGES
Form Number	0
Reserved Field	Blank
Reserved Field	Blank
Entity Label	FCF_SEP
Entity Subscript Number	N
Section Code and Sequence Number	As Per IGES

II.3 Parameter Data Section

This section outlines the Parameter Data section restrictions for the IGES entity set. The restrictions given in this section are intended to reduce the possible Parameter Data section field values to only what is necessary for the Feature Control Frames APF. The usage guide assigns a specific meaning to each Parameter Data section field for carrying Feature Control Frame information. The usage guide is given in a later section.

The restrictions for the Parameter Data section of the IGES entities in this example will be based either explicitly or implicitly on the APIM for Feature Control Frames and an assumption about the remainder of the APIM for the Drafting APF.

The APIM for Feature Control Frames does not require the use of the IGES associativity/general note backpointers or property backpointers. The assumption is that no IGES associativity or general note backpointers will be required by the remainder of the APIM for the Drafting APF. Also, the assumption is that no IGES property backpointers will be required by the remainder of the APIM for the Drafting APF. These assumptions would not be necessary for a complete Drafting APF because the complete APIM would be available for use in determining the restrictions.

II.3.1 General Symbol Entity

Parameter Data Section Field	Field Value Requirement
ENTITY TYPE NUMBER	228
DENOTE	Pointer to associated general note
N	Number of pointers to geometry
GPNT1	Pointer to defining geometry
.	.
.	.
.	.
GPNTN	
L	0; No pointers to Leader entities
NA	0; No pointers to Associativity or General Note entities
NP	0; No pointers to Property entities

II.3.2 General Note Entity

Parameter Data Section Field	Field Value Requirement
ENTITY TYPE NUMBER	212
NS	Number of text strings in general note
NC1	Number of characters in first text string; must be greater than 0
WT1	Box width
HT1	Box height
FC1	Font Characteristic; must be equal to 1, 1001
SL1	Slant angle; must be equal to 1.5708
A1	Rotation angle in radians; must be equal to 0.0
M1	Mirror flag; must be equal to 0
VH1	Rotate internal text flag; must be equal to 0
XS1	First text start point X
YS1	First text start point Y
ZS1	Z depth; must be equal to 0.0
TEXT1	First text string
NC2	Number of characters in second text string
.	.
.	.
.	.
TEXT2	Second text string
.	.
.	.
.	.
NCNS	Number of characters in last text string
.	.
.	.
.	.
TEXTNS	Last text string

NA	0; No pointers to Associativity or General Note entities
NP	0; No pointers to Property entities

The set of General Note Parameter Data section fields may be repeated as many times as necessary to define all of the text strings.

II.3.3 Simple Closed Area Entity

<u>Parameter Data Section Field</u>	<u>Field Value Requirement</u>
ENTITY TYPE NUMBER	106
IP	Interpretation Flag; must be equal to 1
N1	Number of n-tuples; must be equal to 4
ZT	Common Z displacement; must be equal to 0.0
X1	First data point abscissa
Y1	First data point ordinate
.	.
.	.
.	.
X4	Fourth data point abscissa
Y4	Fourth data point ordinate
NA	0; No pointers to Associativity or General Note entities
NP	0; No pointers to Property entities

II.3.4 Line Entity

Parameter Data Section Field	Field Value Requirement
ENTITY TYPE NUMBER	110
X1	X coordinate of start point
Y1	Y coordinate of start point
Z1	Z coordinate of start point; must be equal to 0.0
X2	X coordinate of terminate point
Y2	Y coordinate of terminate point
Z2	Z coordinate of terminate point; must be equal to 0.0
NA	0; No pointers to Associativity or General Note entities
NP	0; No pointers to Property entities

III. Usage Guide for the IGES Entities

This section specifies the use of the IGES entities in carrying Drafting Feature Control Frame information as defined by the APIM. The use of the IGES entities was determined by referring to the Feature Control Frames Application Reference Model (ARM), two Application Implementation Models (AIM), and the Application IGES Implementation Model (AIIM) from Appendix B.1.

The Feature Control Frames ARM represents the Drafting information that is required for a Feature Control Frame. This ARM is a part of the complete Drafting APIM. The ARM is a model of Feature Control Frame information that can be validated by a Drafting application area expert.

Appendix B.1 contains two AIMs, the initial AIM and the final AIM. The initial AIM is the AIM that was developed on the basis of the ARM and shows the Drafting information for Feature Control Frames that must be "identifiable" in the IGES entities in the Drafting APF. The meaning of "identifiable" in this context is that it must be possible to have a reversible mapping of Feature Control Frame information from the ARM into the IGES entities in the APF. The initial AIM provides a description of the way that the Feature Control Frame information must be structured to allow an explicit reversible mapping.

Because of the implementation decisions and trade-offs as discussed in Appendix B.1, the final AIM provides a less explicit "identification" of each item of Feature Control Frame information in the APF entities. In reality, this means that it will not be possible to have an explicit reversible mapping of Feature Control Frame information. It is important to realize that it will be possible to reverse the mapping, but the reverse mapping will require "parsing" the embedded information.

Appendix B.1 contains the AIIM that is based on the initial and final AIMs. The final AIM and the resulting AIIM are based on implementation decisions and trade-offs and can be implemented by using existing IGES entities. The AIIM of Appendix B.1 shows the Drafting information for Feature Control Frames after it has been abstracted to an appropriate level for use in selecting the necessary IGES entities to carry the information. This AIIM was used to select the required IGES entity set for this APFS.

The final AIM and the accompanying AIIM from Appendix B.1 are the models that were used to prepare this APFS for Feature Control Frames. In addition, the final AIM and AIIM models illustrate the required structure for the Feature Control Frame information as it must be carried in the IGES entities in the APF.

Section II of this Appendix, the Global, Directory Entry, and Parameter Data section restrictions, described the field value limitations. This section gives a detailed description of how the information from the information models must be embedded into each IGES entity for the Feature Control Frames. This section will define the meaning of the necessary fields in the Parameter Data section of each entity for carrying Feature Control Frames information. Any fields that do not require a specific meaning as per the APIM will retain the description as given in Section II. Based on the information models, the use of each IGES entity can be given in summary statements as follows.

In terms of the final AIM, the General Note entity will be used to carry the Geometric Characteristic, the Tolerance Specification, the Maximum Tolerance Specification, and the Datum Reference. The Tolerance Specification contains the Tolerance Cylindrical Form, the Tolerance Value, the Tolerance Material Condition, the Tolerance Unit Length, and the Tolerance Unit Width. The Maximum Tolerance Specification contains the Tolerance Cylindrical Form and the Maximum Tolerance Value. The Datum Reference contains the Datum Identifier and the Datum Material Condition.

In terms of the final AIM, the Simple Closed Area entity will be used to carry the Frame Box that is defined by four coordinate pairs. The Line entity will be used to carry the Frame Box Divider that is defined by two coordinate pairs. The General Symbol entity will be used to carry the associativity of the General Note, the Simple Closed Area, and the Line entities.

III.1 General Symbol Entity

The Directory Entry section field value requirements for the General Symbol entity are given in II.2.1. Therefore, this section will not discuss the Directory Entry section for the General Symbol entity.

The Parameter Data section field value requirements for the General Symbol entity are outlined in II.3.1. This section will specify the use of the Parameter Data section fields for the General Symbol entity in terms of the final AIM and IGES.

The General Symbol Entity will be used to carry the associativity for the General Note, Simple Closed Area, and Line entities and to group these entities together into a Feature Control Frame entity. In terms of IGES, this means that the General Symbol entity will be used to carry the pointers to the General Note, Simple Closed Area, and Line entities. The order and meaning of the Parameter Data section fields for the General Symbol entity are given below. The use of each entity that is pointed to by the General Symbol entity will be described in subsequent sections.

The General Symbol entity can carry only one pointer to a General Note entity. The General Symbol can carry multiple pointers to geometry entities. These geometry entity pointers will point to Simple Closed Area and Line entities. There must be one or more pointers to a Simple Closed Area entity and one or more pointers to Line entities. The pointers to the Simple Closed Area entity must be placed in the list before the pointers to the Line entities. The General Symbol entity must contain no pointers to Leader entities.

Parameter Data Section Field	Field Value Requirement
ENTITY TYPE NUMBER	228
DENOTE	Pointer to the general note entity that contains the Geometric Characteristic, the Tolerance Specification, the Maximum Tolerance Value Specification, and the Datum Reference information
N	Total number of pointers to Simple Closed Area and Line entities defining Frame Boxes and Frame Box Dividers; there will be one or more pointers to Simple Closed Area entities and one or more pointers to Line entities
GPNT1	Pointer to a Simple Closed Area or Line entity
.	.
.	.
.	.
GPNTN	
L	0; No pointers to Leader entities
NA	0; No pointers to Associativity or General Note entities
NP	0; No pointers to Property entities

III.2 General Note Entity

The Directory Entry section field value requirements for the General Note entity are given in II.2.2. Therefore, this section will not discuss the Directory Entry section for the General Note entity.

The Parameter Data section field value requirements for the General Note entity are outlined in II.3.2. This section will specify the use of the Parameter Data section fields for the General Note entity in terms of the final AIM and IGES.

From the final AIM, the Feature Control Frame contains the Geometric Characteristic, the Tolerance Specification, the Maximum Tolerance Value Specification, and the Datum Reference. The Geometric Characteristic will be represented by a Geometric Characteristic Symbol.

The Tolerance Specification is identified by a Tolerance Specification Identifier. The Tolerance Specification will contain the Tolerance Cylindrical Form, the Tolerance Value, the Tolerance Material Condition, the

Tolerance Unit Length, and the Tolerance Unit Width. The Tolerance Cylindrical form will be represented by a Diameter Symbol. The Tolerance Value will be represented by a Tolerance Value String. The Tolerance Material Condition will be represented by a Material Condition Symbol. The Tolerance Unit Length will be represented by a Tolerance Unit Length String. The Tolerance Unit Width will be represented by a Tolerance Unit Width String.

The Maximum Tolerance Value Specification is identified by a Maximum Tolerance Specification Identifier. The Maximum Tolerance Value Specification contains a Tolerance Cylindrical Form represented by a Diameter Symbol. The Maximum Tolerance Value Specification contains a Maximum Tolerance Value that is represented by Maximum Tolerance Value String.

The Datum Reference is identified by a Datum Reference Identifier. The Datum Reference contains a Datum Identifier that is represented by a Datum Identifier String. The Datum Reference contains a Datum Material Condition that is represented by a Datum Material Condition Symbol.

Only one General Note entity can be included in a General Symbol entity. However, the single General Note entity can have an unlimited number of strings. The Feature Control Frame will have two or more "compartments" that are represented by the Frame Box and the Frame Box Dividers. Each of the compartments will contain either a Geometric Characteristic, a Tolerance Specification, a Maximum Tolerance Value Specification, or a Datum Reference. Therefore, this APFS will allocate one string in the General Note entity to carry the contents of each compartment in the Feature Control Frame. This means that the contents of each compartment must be contained in a General Note string having a font characteristic such that the contents can be correctly represented. The order of the text and symbol strings in the General Note entity must be from left to right as per the order of the compartments in the Feature Control Frame.

Parameter Data Section Field	Field Value Requirement
ENTITY TYPE NUMBER	212
NS	Number of compartments in the Feature Control Frame; must be >= 2
NC1	Number of symbols and/or text characters in the first string; must be > 0
WT1	Symbol and/or text character string width; must be > 0.0
HT1	Symbol and/or text character string height; must be > 0.0
FC1	Symbol and/or text character string font characteristic; must be equal to 1, 1001
SL1	Symbol and/or text character slant angle; must be equal to 1.5708
A1	Rotation angle in radians; must be equal to 0.0
M1	Mirror flag; must be equal to 0
VH1	Rotate internal text flag; must be equal to 0
XS1	First symbol and/or text character string start point X
YS1	First symbol and/or text character string start point Y
ZS1	Z depth; must be equal to 0.0
TEXT1	First symbol and/or text character string
NC2	Number of symbols and/or text characters in the second string; must be > 0
.	.
.	.
.	.
TEXT2	Second symbol and/or text character string
.	.
.	.
.	.

NCNS	Number of symbols and/or text characters in the last string; must be > 0
.	.
.	.
.	.
TEXTNS	Last symbol and/or text character string
NA	0; No pointers to Associativity or General Note entities
NP	0; No pointers to Property entities

There is no limit on the number of symbol and/or text character strings that may be included in the General Note entity. The number of strings in the General Note entity must be equal to the number of compartments in the Feature Control Frame.

III.3 Simple Closed Area Entity

The Directory Entry section field value requirements for the Simple Closed Area entity are given in II.2.3. Therefore, this section will not discuss the Directory Entry section for the Simple Closed Area entity.

The Parameter Data section field value requirements for the Simple Closed Area entity are outlined in II.3.3. This section will specify the use of the Parameter Data section fields for the Simple Closed Area entity in terms of the final AIM and IGES.

From the final AIM, the Feature Control Frame is represented by a Frame Box. The Frame Box is defined by four coordinate pairs that each consist of an X Value and a Y Value. The Frame Box is identified by a Frame Box Identifier.

The Simple Closed Area entity will be used to carry the Frame Box for the Feature Control Frame. Visually, the Frame Box is made up of four vertices and four curve segments. The Simple Closed Area entity will contain four coordinate pairs of data points that represent the vertices of the box and the four curve segments that make up the box.

Parameter Data Section Field	Field Value Requirement
ENTITY TYPE NUMBER	106
IP	Interpretation Flag; must be equal to 1
N1	Number of Coordinate Pairs for the Frame Box; must be equal to 4
ZT	Common Z displacement; must be equal to 0.0
X1	X Value for the first corner of the Frame Box
Y1	Y Value for the first corner of the Frame Box
X2	X Value for the second corner of the Frame Box
Y2	Y Value for the second corner of the Frame Box
X3	X Value for the third corner of the Frame Box
Y3	Y Value for the third corner of the Frame Box
X4	X Value for the fourth corner of the Frame Box
Y4	Y Value for the fourth corner of the Frame Box
NA	0; No pointers to Associativity or General Note entities
NP	0; No pointers to Property entities

III.4 Line Entity

The Directory Entry section field value requirements for the Line entity are given in II.2.4. Therefore, this section will not discuss the Directory Entry section for the Line entity.

The Parameter Data section field value requirements for the Line entity are outlined in II.3.4. This section will specify the use of the Parameter Data section fields for the Line entity in terms of the final AIM and IGES.

From the final AIM, the Feature Control Frame is compartmentalized by the Frame Box Divider that is defined by two coordinate pairs that each consist of an X Value and a Y Value. The Frame Box Divider is identified by a Frame Box Divider Identifier.

The Line entity will be used to carry the Frame Box Dividers for the compartments of the Feature Control Frame. There must be two or more compartments in the Feature Control Frame. The number of Frame Box Dividers must be one less than the number of compartments in the Feature Control Frame. Each Frame Box Divider must consist of two endpoints that define one curve segment.

Parameter Data Section Field	Field Value Requirement
ENTITY TYPE NUMBER	110
X1	X Value for the start point of the Frame Box Divider
Y1	Y Value for the start point of the Frame Box Divider
Z1	Z coordinate of start point; must be equal to 0.0
X2	X Value for the terminate point of the Frame Box Divider
Y2	Y Value for the terminate point of the Frame Box Divider
Z2	Z coordinate of terminate point; must be equal to 0.0
NA	0; No pointers to Associativity or General Note entities
NP	0; No pointers to Property entities

Appendix B.3

FEATURE CONTROL FRAMES - APPLICATION PROTOCOL FORMAT TEST CASES

This Appendix describes the set of test cases for the Feature Control Frame example. The test cases for this example were prepared as per the technical content requirements given in Section 3.1.

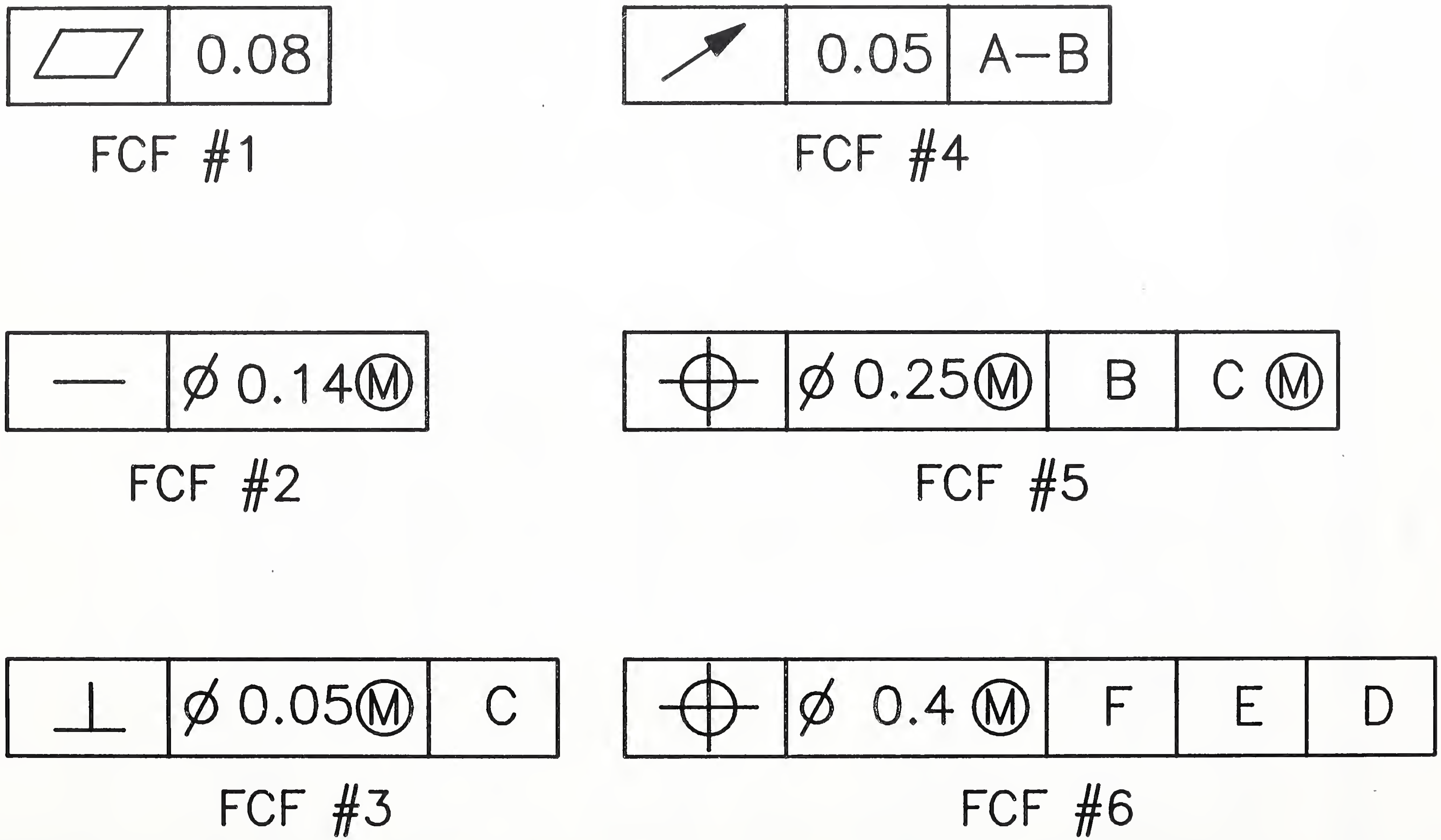
The set includes ten test cases, and the test cases are based on the Feature Control Frames illustrated in Figure B5. These test cases were taken from examples given in the ANSI Standard for Dimensioning and Tolerancing, ANSI Y14.5M, 1982.[6] In Figure B5, the Feature Control Frames are identified by FCF#1, FCF#2, etc. These names identify the test cases and appear in the test case listings.

Test case numbers 1-6, identified as FCF#1-FCF#6 in Figure B5, contain various mixes of Geometric Characteristic Symbols, Tolerance Cylindrical Form-Diameter Symbols, Tolerance Value Strings, Material Condition Symbols, Datum Identifiers, and Material Condition Symbols. Each of test cases 1-6 contain a Frame Box, and one or more Frame Box Dividers.

Test case number 7 contains many of the same information items as test cases 1-6, but also contains a Tolerance Unit Length String. Test case number 8 contains similar information items as the other test cases, but it also contains a Tolerance Unit Width String. Test case number 9 contains an additional information item, the Maximum Tolerance Value String. Finally, test case number 10 is known as a Composite Feature Control Frame.[6] As shown in Figure B5, the Composite Feature Control Frame is made up of a "double" Frame Box with one Geometric Characteristic Symbol and two individual Tolerance Specifications.

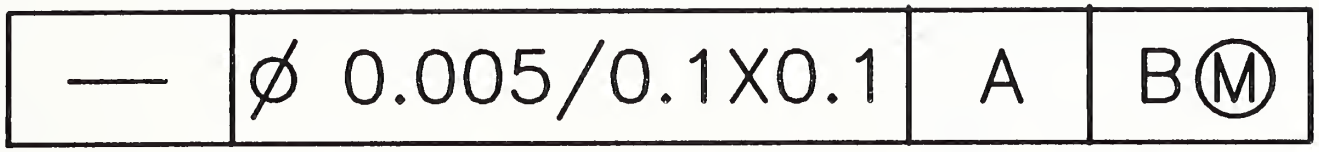
The test cases are handmade test cases and were prepared as per the Application Protocol Format Specification given in Appendix B.2 and the IGES Test Case Development Committee's Guide to Developing Entity Test Cases.[7] Currently, test cases for application protocols are not required to conform to the specifications of the test case development guide. The standard file documentation header is used as an example of one file documentation method.

A listing of the AP format files for these ten test cases is given below. These ten test cases have been thoroughly checked for correctness using both manual methods and software methods. In addition, each test case has been read with an IGES postprocessor into a CAD system, plotted, and visually verified to correctly represent each of the Feature Control Frames illustrated in Figure B5.

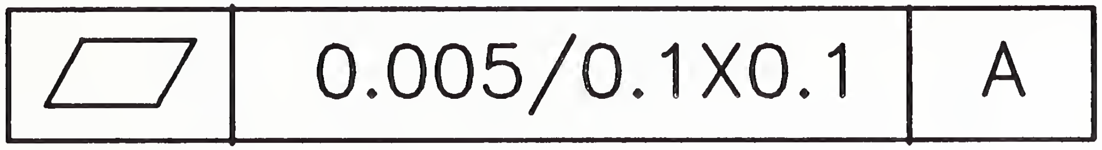


FEATURE CONTROL FRAME TEST CASES

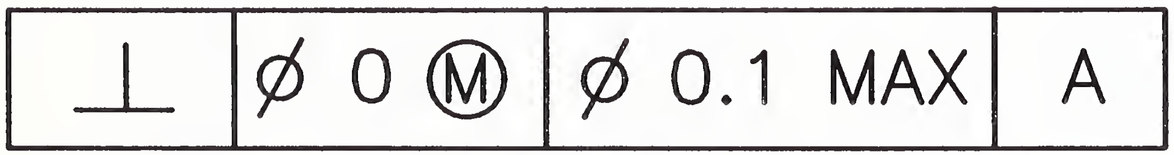
Figure B5



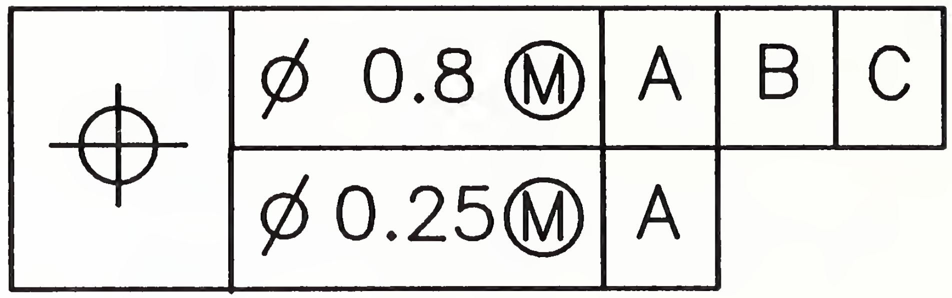
FCF #7



FCF #8



FCF #9



FCF #10

Figure B5 (Cont.)

```
                                                                       S      1
F FCFTC01                                                              S      2
  DAT                                                                  S      3
                                                                       S      4
V IGES 3.0                                                             S      5
                                                                       S      6
I Application Protocol Test Case                                       S      7
  Application Protocol: Drafting                                       S      8
  Information: Feature Control Frames                                  S      9
                                                                       S     10
E ENTITY  FORM                                                   COUNT S     11
     228     0                                                       1 S     12
     212     0                                                       1 S     13
     106    63                                                       1 S     14
     110     0                                                       1 S     15
                                                                       S     16
B This is a test case for the Feature Control Frames Application       S     17
  Protocol example.  This test case implements the Feature Control     S     18
  Frame shown in Figure B5 and labeled as FCF #1.                      S     19
                                                                       S     20
P Not applicable                                                       S     21
                                                                       S     22
R Not applicable                                                       S     23
                                                                       S     24
C This test case was prepared as per the IGES Test Case Development    S     25
  Committee's "Guide to Developing Entity Test Cases",                 S     26
  Draft Version 0.2, November 10, 1987.                                S     27
                                                                       S     28
D IGES Specification, Version 3.0                                      S     29
  Guidelines for the Specification and Validation of IGES Application  S     30
  Protocols, Draft Version 0.04                                        S     31
                                                                       S     32
H 24-Feb-1988 A Created Test Case for AP Example - R.J. Harrison       S     33
                                                                       S     34
L This data was prepared in conjunction with work sponsored            S     35
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  the United States Government nor any agency thereof, nor             S     37
  any of their employees, makes any warranty, express or               S     38
  implied or assumes any legal liability or responsibility             S     39
  for the accuracy, completeness, or usefulness of any                 S     40
  information, apparatus, product, or process disclosed, or            S     41
  represents that its use would not infringe privately owned           S     42
  rights.  Reference herein to any specific commercial                 S     43
  product, process, or service by trade name, trademark,               S     44
  manufacturer, or otherwise, does not necessarily constitute          S     45
  or imply its endorsement, recommendation, or favoring by             S     46
  the United States Government or any agency thereof.                  S     47
                                                                       S     48
1H,,1H;,10H0000011111,11HFCFTC01.DAT,8HHANDMADE,3H1.0,32,38,6,38,15,   G      1
10H0000011111,1.0,1,4HINCH,8,0.08,13H880224.104500,0.0001,8.7500,      G      2
14HR. J. HARRISON,24HDOE/Sandia National Labs,4,0;                     G      3
```

```
     228       1       0       1     250       0       0       000000101D      1
     228       0       0       1       0                 FCF_INFO       1D      2
     212       2       0       1     250       0       0       000010101D      3
     212       0       0       3       0                 FCF_TEXT       1D      4
     106       5       0       1     250       0       0       000010101D      5
     106       0       0       2      63                  FCF_BOX       1D      6
     110       7       0       1     250       0       0       000010101D      7
     110       0       0       1       0                  FCF_SEP       1D      8
228,3,2,5,7,0,0,0;                                                      1P      1
212,2,1,0.3332,0.5000,1001,1.5708,0.0000,0,0,5.2500,5.1500,             3P      2
0.0000,1Hc,4,2.0833,0.5000,1,1.5708,0.0000,0,0,6.5000,5.1500,           3P      3
0.0000,4H0.08,0,0;                                                      3P      4
106,1,4,0.0000,5.0000,5.8000,8.7500,5.8000,8.7500,5.0000,               5P      5
0.0000,5.0000,0,0;                                                      5P      6
110,6.2500,5.8000,0.0000,6.2500,5.0000,0.0000,0,0;                      7P      7
S      48G       3D       8P       7                                     T      1
```

```
F FCFTC02
  DAT

V IGES 3.0

I Application Protocol Test Case
  Application Protocol: Drafting
  Information: Feature Control Frames

E ENTITY  FORM                                                  COUNT
     228     0                                                      1
     212     0                                                      1
     106    63                                                      1
     110     0                                                      1

B This is a test case for the Feature Control Frames Application
  Protocol example.  This test case implements the Feature Control
  Frame shown in Figure B5 and labeled as FCF #2.

P Not applicable

R Not applicable

C This test case was prepared as per the IGES Test Case Development
  Committee's "Guide to Developing Entity Test Cases",
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D IGES Specification, Version 3.0
  Guidelines for the Specification and Validation of IGES Application
  Protocols, Draft Version 0.04

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  product, process, or service by trade name, trademark,
  manufacturer, or otherwise, does not necessarily constitute
  or imply its endorsement, recommendation, or favoring by
  the United States Government or any agency thereof.

1H,,1H;,10H0000022222,11HFCFTC02.DAT,8HHANDMADE,3H1.0,32,38,6,38,15,
10H0000022222,1.0,1,4HINCH,8,0.08,13H880224.134000,0.0001,10.5000,
14HR. J. HARRISON,24HDOE/Sandia National Labs,4,0;
```

```
     228       1       0       1     250       0       0        000000101D      1
     228       0       0       1       0                  FCF_INFO       1D      2
     212       2       0       1     250       0       0        000010101D      3
     212       0       0       3       0                  FCF_TEXT       1D      4
     106       5       0       1     250       0       0        000010101D      5
     106       0       0       2      63                   FCF_BOX       1D      6
     110       7       0       1     250       0       0        000010101D      7
     110       0       0       1       0                   FCF_SEP       1D      8
228,3,2,5,7,0,0,0;                                                       1P      1
212,2,1,1.0000,0.5000,1001,1.5708,0.0000,0,0,5.2500,5.1500,              3P      2
0.0000,1H-,6,3.5000,0.5000,1001,1.5708,0.0000,0,0,6.7500,                3P      3
5.1500,0.0000,6Hn0.14m,0,0;                                              3P      4
106,1,4,0.0000,5.0000,5.8000,10.5000,5.8000,10.5000,5.0000,              5P      5
5.0000,5.0000,0,0;                                                       5P      6
110,6.5000,5.8000,0.0000,6.5000,5.0000,0.0000,0,0;                       7P      7
S      48G       3D       8P       7                                      T      1
```

```
                                                                       S      1
F FCFTC03                                                              S      2
  DAT                                                                  S      3
                                                                       S      4
V IGES 3.0                                                             S      5
                                                                       S      6
I Application Protocol Test Case                                       S      7
  Application Protocol: Drafting                                       S      8
  Information: Feature Control Frames                                  S      9
                                                                       S     10
E ENTITY  FORM                                                   COUNT S     11
     228     0                                                       1 S     12
     212     0                                                       1 S     13
     106    63                                                       1 S     14
     110     0                                                       2 S     15
                                                                       S     16
B This is a test case for the Feature Control Frames Application       S     17
  Protocol example.  This test case implements the Feature Control     S     18
  Frame shown in Figure B5 and labeled as FCF #3.                      S     19
                                                                       S     20
P Not applicable                                                       S     21
                                                                       S     22
R Not applicable                                                       S     23
                                                                       S     24
C This test case was prepared as per the IGES Test Case Development    S     25
  Committee's "Guide to Developing Entity Test Cases",                 S     26
  Draft Version 0.2, November 10, 1987.                                S     27
                                                                       S     28
D IGES Specification, Version 3.0                                      S     29
  Guidelines for the Specification and Validation of IGES Application  S     30
  Protocols, Draft Version 0.04                                        S     31
                                                                       S     32
H 24-Feb-1988 A Created Test Case for AP Example - R.J. Harrison       S     33
                                                                       S     34
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  for the accuracy, completeness, or usefulness of any                 S     40
  information, apparatus, product, or process disclosed, or            S     41
  represents that its use would not infringe privately owned           S     42
  rights.  Reference herein to any specific commercial                 S     43
  product, process, or service by trade name, trademark,               S     44
  manufacturer, or otherwise, does not necessarily constitute          S     45
  or imply its endorsement, recommendation, or favoring by             S     46
  the United States Government or any agency thereof.                  S     47
                                                                       S     48
1H,,1H;,10H0000033333,11HFCFTC03.DAT,8HHANDMADE,3H1.0,32,38,6,38,15,   G      1
10H0000033333,1.0,1,4HINCH,8,0.08,13H880224.140500,0.0001,11.5000,     G      2
14HR. J. HARRISON,24HDOE/Sandia National Labs,4,0;                     G      3
```

```
     228       1       0       1     250       0       0       000000101D      1
     228       0       0       1       0                FCF_INFO       1D      2
     212       2       0       1     250       0       0       000010101D      3
     212       0       0       4       0                FCF_TEXT       1D      4
     106       6       0       1     250       0       0       000010101D      5
     106       0       0       2      63                 FCF_BOX       1D      6
     110       8       0       1     250       0       0       000010101D      7
     110       0       0       1       0                 FCF_SEP       1D      8
     110       9       0       1     250       0       0       000010101D      9
     110       0       0       1       0                 FCF_SEP       2D     10
228,3,3,5,7,9,0,0,0;                                                   1P      1
212,3,1,0.5547,0.5000,1001,1.5708,0.0000,0,0,5.2500,5.1500,            3P      2
0.0000,1H1,6,3.5000,0.5000,1001,1.5708,0.0000,0,0,6.7500,              3P      3
5.1500,0.0000,6Hn0.05m,1,0.5000,0.5000,1,1.5708,0.0000,0,0,            3P      4
10.7500,5.1500,0.0000,1HC,0,0;                                         3P      5
106,1,4,0.0000,5.0000,5.8000,11.5000,5.8000,11.5000,5.0000,            5P      6
5.0000,5.0000,0,0;                                                     5P      7
110,6.5000,5.8000,0.0000,6.5000,5.0000,0.0000,0,0;                     7P      8
110,10.5000,5.8000,0.0000,10.5000,5.0000,0.0000,0,0;                   9P      9
S      48G       3D      10P       9                                    T      1
```

```
                                                                        S      1
F FCFTC04                                                               S      2
  DAT                                                                   S      3
                                                                        S      4
V IGES 3.0                                                              S      5
                                                                        S      6
I Application Protocol Test Case                                        S      7
  Application Protocol: Drafting                                        S      8
  Information: Feature Control Frames                                   S      9
                                                                        S     10
E ENTITY  FORM                                                    COUNT S     11
     228     0                                                        1 S     12
     212     0                                                        1 S     13
     106    63                                                        1 S     14
     110     0                                                        2 S     15
                                                                        S     16
B This is a test case for the Feature Control Frames Application        S     17
  Protocol example.  This test case implements the Feature Control      S     18
  Frame shown in Figure B5 and labeled as FCF #4.                       S     19
                                                                        S     20
P Not applicable                                                        S     21
                                                                        S     22
R Not applicable                                                        S     23
                                                                        S     24
C This test case was prepared as per the IGES Test Case Development     S     25
  Committee's "Guide to Developing Entity Test Cases",                  S     26
  Draft Version 0.2, November 10, 1987.                                 S     27
                                                                        S     28
D IGES Specification, Version 3.0                                       S     29
  Guidelines for the Specification and Validation of IGES Application   S     30
  Protocols, Draft Version 0.04                                         S     31
                                                                        S     32
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                                                                        S     34
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  product, process, or service by trade name, trademark,                S     44
  manufacturer, or otherwise, does not necessarily constitute           S     45
  or imply its endorsement, recommendation, or favoring by              S     46
  the United States Government or any agency thereof.                   S     47
                                                                        S     48
1H,,1H;,10H0000044444,11HFCFTC04.DAT,8HHANDMADE,3H1.0,32,38,6,38,15,    G      1
10H0000044444,1.0,1,4HINCH,8,0.08,13H880224.144500,0.0001,10.7500,      G      2
14HR. J. HARRISON,24HDOE/Sandia National Labs,4,0;                      G      3
     228       1       0       1     250       0       0        00000101D      1
```

```
     228         0         0         1         0                 FCF_INFO      1D      2
     212         2         0         1       250        0        0        000010101D      3
     212         0         0         4         0                 FCF_TEXT      1D      4
     106         6         0         1       250        0        0        000010101D      5
     106         0         0         2        63                  FCF_BOX      1D      6
     110         8         0         1       250        0        0        000010101D      7
     110         0         0         1         0                  FCF_SEP      1D      8
     110         9         0         1       250        0        0        000010101D      9
     110         0         0         1         0                  FCF_SEP      2D     10
228,3,3,5,7,9,0,0,0;                                                         1P      1
212,3,1,0.5547,0.5000,1001,1.5708,0.0000,0,0,5.2500,5.1500,                  3P      2
0.0000,1Hh,4,2.0000,0.5000,1,1.5708,0.0000,0,0,6.5000,                       3P      3
5.1500,0.0000,4H0.05,3,1.5000,0.5000,1,1.5708,0.0000,0,0,                    3P      4
9.0000,5.1500,0.0000,3HA-B,0,0;                                              3P      5
106,1,4,0.0000,5.0000,5.8000,10.7500,5.8000,10.7500,5.0000,                  5P      6
5.0000,5.0000,0,0;                                                           5P      7
110,6.2500,5.8000,0.0000,6.2500,5.0000,0.0000,0,0;                           7P      8
110,8.7500,5.8000,0.0000,8.7500,5.0000,0.0000,0,0;                           9P      9
S      48G       3D      10P       9                                          T      1
```

```
                                                                        S      1
F FCFTC05                                                               S      2
  DAT                                                                   S      3
                                                                        S      4
V IGES 3.0                                                              S      5
                                                                        S      6
I Application Protocol Test Case                                        S      7
  Application Protocol: Drafting                                        S      8
  Information: Feature Control Frames                                   S      9
                                                                        S     10
E ENTITY  FORM                                                    COUNT S     11
     228     0                                                        1 S     12
     212     0                                                        1 S     13
     106    63                                                        1 S     14
     110     0                                                        3 S     15
                                                                        S     16
B This is a test case for the Feature Control Frames Application        S     17
  Protocol example.  This test case implements the Feature Control      S     18
  Frame shown in Figure B5 and labeled as FCF #5.                       S     19
                                                                        S     20
P Not applicable                                                        S     21
                                                                        S     22
R Not applicable                                                        S     23
                                                                        S     24
C This test case was prepared as per the IGES Test Case Development     S     25
  Committee's "Guide to Developing Entity Test Cases",                  S     26
  Draft Version 0.2, November 10, 1987.                                 S     27
                                                                        S     28
D IGES Specification, Version 3.0                                       S     29
  Guidelines for the Specification and Validation of IGES Application   S     30
  Protocols, Draft Version 0.04                                         S     31
                                                                        S     32
H 24-Feb-1988 A Created Test Case for AP Example - R.J. Harrison        S     33
                                                                        S     34
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  the United States Government nor any agency thereof, nor              S     37
  any of their employees, makes any warranty, express or                S     38
  implied or assumes any legal liability or responsibility              S     39
  for the accuracy, completeness, or usefulness of any                  S     40
  information, apparatus, product, or process disclosed, or             S     41
  represents that its use would not infringe privately owned            S     42
  rights.  Reference herein to any specific commercial                  S     43
  product, process, or service by trade name, trademark,                S     44
  manufacturer, or otherwise, does not necessarily constitute           S     45
  or imply its endorsement, recommendation, or favoring by              S     46
  the United States Government or any agency thereof.                   S     47
                                                                        S     48
1H,,1H;,10H0000055555,11HFCFTC05.DAT,8HHANDMADE,3H1.0,32,38,6,38,15,    G      1
10H0000055555,1.0,1,4HINCH,8,0.08,13H880224.150500,0.0001,12.7500,      G      2
14HR. J. HARRISON,24HDOE/Sandia National Labs,4,0;                      G      3
     228       1       0       1     250       0       0        000000101D      1
```

```
     228       0       0       1       0                 FCF_INFO      1D      2
     212       2       0       1     250       0       0        000010101D      3
     212       0       0       5       0                 FCF_TEXT      1D      4
     106       7       0       1     250       0       0        000010101D      5
     106       0       0       2      63                  FCF_BOX      1D      6
     110       9       0       1     250       0       0        000010101D      7
     110       0       0       1       0                  FCF_SEP      1D      8
     110      10       0       1     250       0       0        000010101D      9
     110       0       0       1       0                  FCF_SEP      2D     10
     110      11       0       1     250       0       0        000010101D     11
     110       0       0       1       0                  FCF_SEP      3D     12
228,3,4,5,7,9,11,0,0;                                                  1P      1
212,4,1,0.4167,0.5000,1001,1.5708,0.0000,0,0,5.2500,5.1500,            3P      2
0.0000,1Hj,6,3.5000,0.5000,1001,1.5708,0.0000,0,0,6.2500,              3P      3
5.1500,0.0000,6Hn0.25m,1,0.5000,0.5000,1,1.5708,0.0000,0,0,            3P      4
10.2500,5.1500,0.0000,1HB,2,1.2500,0.5000,1001,1.5708,                 3P      5
0.0000,0,0,11.2500,5.1500,0.0000,2HCm,0,0;                             3P      6
106,1,4,0.0000,5.0000,5.8000,12.7500,5.8000,12.7500,5.0000,            5P      7
5.0000,5.0000,0,0;                                                     5P      8
110,6.0000,5.8000,0.0000,6.0000,5.0000,0.0000,0,0;                     7P      9
110,10.0000,5.8000,0.0000,10.0000,5.0000,0.0000,0,0;                   9P     10
110,11.0000,5.8000,0.0000,11.0000,5.0000,0.0000,0,0;                  11P     11
S      48G       3D      12P      11                                   T      1
```

```
                                                                        S      1
F FCFTC06                                                               S      2
  DAT                                                                   S      3
                                                                        S      4
V IGES 3.0                                                              S      5
                                                                        S      6
I Application Protocol Test Case                                        S      7
  Application Protocol: Drafting                                        S      8
  Information: Feature Control Frames                                   S      9
                                                                        S     10
E ENTITY  FORM                                                    COUNT S     11
     228     0                                                        1 S     12
     212     0                                                        1 S     13
     106    11                                                        1 S     14
     110     0                                                        4 S     15
                                                                        S     16
B This is a test case for the Feature Control Frames Application        S     17
  Protocol example.  This test case implements the Feature Control      S     18
  Frame shown in Figure B5 and labeled as FCF #6.                       S     19
                                                                        S     20
P Not applicable                                                        S     21
                                                                        S     22
R Not applicable                                                        S     23
                                                                        S     24
C This test case was prepared as per the IGES Test Case Development     S     25
  Committee's "Guide to Developing Entity Test Cases",                  S     26
  Draft Version 0.2, November 10, 1987.                                 S     27
                                                                        S     28
D IGES Specification, Version 3.0                                       S     29
  Guidelines for the Specification and Validation of IGES Application   S     30
  Protocols, Draft Version 0.04                                         S     31
                                                                        S     32
H 24-Feb-1988 A Created Test Case for AP Example - R.J. Harrison        S     33
                                                                        S     34
L This data was prepared in conjunction with work sponsored             S     35
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  any of their employees, makes any warranty, express or                S     38
  implied or assumes any legal liability or responsibility              S     39
  for the accuracy, completeness, or usefulness of any                  S     40
  information, apparatus, product, or process disclosed, or             S     41
  represents that its use would not infringe privately owned            S     42
  rights.  Reference herein to any specific commercial                  S     43
  product, process, or service by trade name, trademark,                S     44
  manufacturer, or otherwise, does not necessarily constitute           S     45
  or imply its endorsement, recommendation, or favoring by              S     46
  the United States Government or any agency thereof.                   S     47
                                                                        S     48
1H,,1H;,10H0000066666,11HFCFTC06.DAT,8HHANDMADE,3H1.0,32,38,6,38,15,    G      1
10H0000066666,1.0,1,4HINCH,8,0.08,13H880224.153000,0.0001,12.5000,      G      2
14HR. J. HARRISON,24HDOE/Sandia National Labs,4,0;                      G      3
     228       1       0       1     250       0       0       000000101D      1
```

```
     228         0         0         1         0                 FCF_INFO       1D       2
     212         2         0         1       250         0         0        000010101D       3
     212         0         0         6         0                 FCF_TEXT       1D       4
     106         8         0         1       250         0         0        000010101D       5
     106         0         0         2        63                  FCF_BOX       1D       6
     110        10         0         1       250         0         0        000010101D       7
     110         0         0         1         0                  FCF_SEP       1D       8
     110        11         0         1       250         0         0        000010101D       9
     110         0         0         1         0                  FCF_SEP       2D      10
     110        12         0         1       250         0         0        000010101D      11
     110         0         0         1         0                  FCF_SEP       3D      12
     110        13         0         1       250         0         0        000010101D      13
     110         0         0         1         0                  FCF_SEP       4D      14
228,3,5,5,7,9,11,13,0;                                                        1P       1
212,5,1,0.4167,0.5000,1001,1.5708,0.0000,0,0,5.2500,5.1500,                   3P       2
0.0000,1Hj,5,3.0000,0.5000,1001,1.5708,0.0000,0,0,6.2500,                     3P       3
5.1500,0.0000,5Hn0.4m,1,0.5000,0.5000,1,1.5708,0.0000,0,0,                    3P       4
9.7500,5.1500,0.0000,1HF,1,0.5000,0.5000,1,1.5708,0.0000,0,                   3P       5
0,10.7500,5.1500,0.0000,1HE,1,0.5000,0.5000,1,1.5708,0.0000,                  3P       6
0,0,11.7500,5.1500,0.0000,1HD,0,0;                                            3P       7
106,1,4,0.0000,5.0000,5.8000,12.5000,5.8000,12.5000,5.0000,                   5P       8
5.0000,5.0000,0,0;                                                            5P       9
110,6.0000,5.8000,0.0000,6.0000,5.0000,0.0000,0,0;                            7P      10
110,9.5000,5.8000,0.0000,9.5000,5.0000,0.0000,0,0;                            9P      11
110,10.5000,5.8000,0.0000,10.5000,5.0000,0.0000,0,0;                         11P      12
110,11.5000,5.8000,0.0000,11.5000,5.0000,0.0000,0,0;                         13P      13
S      48G       3D      14P      13                                          T       1
```

```
                                                                        S      1
F FCFTC07                                                               S      2
  DAT                                                                   S      3
                                                                        S      4
V IGES 3.0                                                              S      5
                                                                        S      6
I Application Protocol Test Case                                        S      7
  Application Protocol: Drafting                                        S      8
  Information: Feature Control Frames                                   S      9
                                                                        S     10
E ENTITY  FORM                                                    COUNT S     11
     228     0                                                        1 S     12
     212     0                                                        1 S     13
     106    63                                                        1 S     14
     110     0                                                        3 S     15
                                                                        S     16
B This is a test case for the Feature Control Frames Application        S     17
  Protocol example.  This test case implements the Feature Control      S     18
  Frame shown in Figure B5 and labeled as FCF #7.                       S     19
                                                                        S     20
P Not applicable                                                        S     21
                                                                        S     22
R Not applicable                                                        S     23
                                                                        S     24
C This test case was prepared as per the IGES Test Case Development     S     25
  Committee's "Guide to Developing Entity Test Cases",                  S     26
  Draft Version 0.2, November 10, 1987.                                 S     27
                                                                        S     28
D IGES Specification, Version 3.0                                       S     29
  Guidelines for the Specification and Validation of IGES Application   S     30
  Protocols, Draft Version 0.04                                         S     31
                                                                        S     32
H 24-Feb-1988 A Created Test Case for AP Example - R.J. Harrison        S     33
                                                                        S     34
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  for the accuracy, completeness, or usefulness of any                  S     40
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  manufacturer, or otherwise, does not necessarily constitute           S     45
  or imply its endorsement, recommendation, or favoring by              S     46
  the United States Government or any agency thereof.                   S     47
                                                                        S     48
1H,,1H;,10H0000077777,11HFCFTC07.DAT,8HHANDMADE,3H1.0,32,38,6,38,15,    G      1
10H0000077777,1.0,1,4HINCH,8,0.08,13H880224.153000,0.0001,15.7500,      G      2
14HR. J. HARRISON,24HDOE/Sandia National Labs,4,0;                      G      3
     228       1       0       1     250       0       0       000000101D      1
```

```
     228       0       0       1       0                  FCF_INFO      1D       2
     212       2       0       1     250       0       0         000010101D       3
     212       0       0       5       0                  FCF_TEXT      1D       4
     106       7       0       1     250       0       0         000010101D       5
     106       0       0       2      63                   FCF_BOX      1D       6
     110       9       0       1     250       0       0         000010101D       7
     110       0       0       1       0                   FCF_SEP      1D       8
     110      10       0       1     250       0       0         000010101D       9
     110       0       0       1       0                   FCF_SEP      2D      10
     110      11       0       1     250       0       0         000010101D      11
     110       0       0       1       0                   FCF_SEP      3D      12
228,3,4,5,7,9,11,0,0,0;                                                 1P       1
212,4,1,1.0000,0.5000,1001,1.5708,0.0000,0,0,5.2500,5.1500,             3P       2
0.0000,1H-,11,6.0000,0.5000,1001,1.5708,0.0000,0,0,6.7500,              3P       3
5.1500,0.0000,11Hn0.005/0.10,1,0.5000,0.5000,1,1.5708,0.0000,           3P       4
0,0,13.2500,5.1500,0.0000,1HA,2,1.2500,0.5000,1001,1.5708,              3P       5
0.0000,0,0,14.2500,5.1500,0.0000,2HBm,0,0;                              3P       6
106,1,4,0.0000,5.0000,5.8000,15.7500,5.8000,15.7500,5.0000,             5P       7
5.0000,5.0000,0,0;                                                      5P       8
110,6.5000,5.8000,0.0000,6.5000,5.0000,0.0000,0,0;                      7P       9
110,13.0000,5.8000,0.0000,13.0000,5.0000,0.0000,0,0;                    9P      10
110,14.0000,5.8000,0.0000,14.0000,5.0000,0.0000,0,0;                   11P      11
S      48G       3D      12P      11                                     T       1
```

```
                                                                        S      1
F FCFTC08                                                               S      2
  DAT                                                                   S      3
                                                                        S      4
V IGES 3.0                                                              S      5
                                                                        S      6
I Application Protocol Test Case                                        S      7
  Application Protocol: Drafting                                        S      8
  Information: Feature Control Frames                                   S      9
                                                                        S     10
E ENTITY  FORM                                                    COUNT S     11
     228     0                                                        1 S     12
     212     0                                                        1 S     13
     106    63                                                        1 S     14
     110     0                                                        2 S     15
                                                                        S     16
B This is a test case for the Feature Control Frames Application        S     17
  Protocol example.  This test case implements the Feature Control      S     18
  Frame shown in Figure B5 and labeled as FCF #8.                       S     19
                                                                        S     20
P Not applicable                                                        S     21
                                                                        S     22
R Not applicable                                                        S     23
                                                                        S     24
C This test case was prepared as per the IGES Test Case Development     S     25
  Committee's "Guide to Developing Entity Test Cases",                  S     26
  Draft Version 0.2, November 10, 1987.                                 S     27
                                                                        S     28
D IGES Specification, Version 3.0                                       S     29
  Guidelines for the Specification and Validation of IGES Application   S     30
  Protocols, Draft Version 0.04                                         S     31
                                                                        S     32
H 24-Feb-1988 A Created Test Case for AP Example - R.J. Harrison        S     33
                                                                        S     34
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  any of their employees, makes any warranty, express or                S     38
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  represents that its use would not infringe privately owned            S     42
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  product, process, or service by trade name, trademark,                S     44
  manufacturer, or otherwise, does not necessarily constitute           S     45
  or imply its endorsement, recommendation, or favoring by              S     46
  the United States Government or any agency thereof.                   S     47
                                                                        S     48
1H,,1H;,10H0000088888,11HFCFTC08.DAT,8HHANDMADE,3H1.0,32,38,6,38,15,    G      1
10H0000088888,1.0,1,4HINCH,8,0.08,13H880224.140500,0.0001,15.0000,      G      2
14HR. J. HARRISON,24HDOE/Sandia National Labs,4,0;                      G      3
     228       1       0       1     250       0       0       000000101D      1
```

```
     228        0       0       1       0                FCF_INFO      1D      2
     212        2       0       1     250       0       0       000010101D      3
     212        0       0       4       0                FCF_TEXT      1D      4
     106        6       0       1     250       0       0       000010101D      5
     106        0       0       2      63                 FCF_BOX      1D      6
     110        8       0       1     250       0       0       000010101D      7
     110        0       0       1       0                 FCF_SEP      1D      8
     110        9       0       1     250       0       0       000010101D      9
     110        0       0       1       0                 FCF_SEP      2D     10
228,3,3,5,7,9,0,0,0;                                                   1P      1
212,3,1,0.5547,0.5000,1001,1.5708,0.0000,0,0,5.2500,5.1500,            3P      2
0.0000,1Hc,13,7.0000,0.5000,1,1.5708,0.0000,0,0,6.7500,                3P      3
5.1500,0.0000,13H0.005/0.1X0.1,1,0.5000,0.5000,1,1.5708,               3P      4
0.0000,0,0,14.2500,5.1500,0.0000,1HA,0,0;                              3P      5
106,1,4,0.0000,5.0000,5.8000,15.0000,5.8000,15.0000,5.0000,            5P      6
5.0000,5.0000,0,0;                                                     5P      7
110,6.5000,5.8000,0.0000,6.5000,5.0000,0.0000,0,0;                     7P      8
110,14.0000,5.8000,0.0000,14.0000,5.0000,0.0000,0,0;                   9P      9
S      48G       3D      10P       9                                    T      1
```

```
                                                                       S      1
F FCFTC09                                                              S      2
  DAT                                                                  S      3
                                                                       S      4
V IGES 3.0                                                             S      5
                                                                       S      6
I Application Protocol Test Case                                       S      7
  Application Protocol: Drafting                                       S      8
  Information: Feature Control Frames                                  S      9
                                                                       S     10
E ENTITY  FORM                                                   COUNT S     11
     228     0                                                       1 S     12
     212     0                                                       1 S     13
     106    63                                                       1 S     14
     110     0                                                       3 S     15
                                                                       S     16
B This is a test case for the Feature Control Frames Application       S     17
  Protocol example.  This test case implements the Feature Control     S     18
  Frame shown in Figure B5 and labeled as FCF #9.                      S     19
                                                                       S     20
P Not applicable                                                       S     21
                                                                       S     22
R Not applicable                                                       S     23
                                                                       S     24
C This test case was prepared as per the IGES Test Case Development    S     25
  Committee's "Guide to Developing Entity Test Cases",                 S     26
  Draft Version 0.2, November 10, 1987.                                S     27
                                                                       S     28
D IGES Specification, Version 3.0                                      S     29
  Guidelines for the Specification and Validation of IGES Application  S     30
  Protocols, Draft Version 0.04                                        S     31
                                                                       S     32
H 24-Feb-1988 A Created Test Case for AP Example - R.J. Harrison       S     33
                                                                       S     34
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  manufacturer, or otherwise, does not necessarily constitute          S     45
  or imply its endorsement, recommendation, or favoring by             S     46
  the United States Government or any agency thereof.                  S     47
                                                                       S     48
1H,,1H;,10H0000099999,11HFCFTC09.DAT,8HHANDMADE,3H1.0,32,38,6,38,15,   G      1
10H0000099999,1.0,1,4HINCH,8,0.08,13H880224.153000,0.0001,14.2500,     G      2
14HR. J. HARRISON,24HDOE/Sandia National Labs,4,0;                     G      3
     228       1       0       1     250       0       0       000000101D      1
```

```
     228       0       0       1       0                FCF_INFO      1D       2
     212       2       0       1     250       0       0       000010101D       3
     212       0       0       5       0                FCF_TEXT      1D       4
     106       7       0       1     250       0       0       000010101D       5
     106       0       0       2      63                 FCF_BOX      1D       6
     110       9       0       1     250       0       0       000010101D       7
     110       0       0       1       0                 FCF_SEP      1D       8
     110      10       0       1     250       0       0       000010101D       9
     110       0       0       1       0                 FCF_SEP      2D      10
     110      11       0       1     250       0       0       000010101D      11
     110       0       0       1       0                 FCF_SEP      3D      12
228,3,4,5,7,9,11,0,0,0;                                               1P       1
212,4,1,0.5547,0.5000,1001,1.5708,0.0000,0,0,5.2500,5.1500,           3P       2
0.0000,1H1,3,1.5000,0.5000,1001,1.5708,0.0000,0,0,6.7500,             3P       3
5.1500,0.0000,3Hn0m,7,3.7500,0.5000,1001,1.5708,0.0000,               3P       4
0,0,9.2500,5.1500,0.0000,7Hn0.1MAX,1,0.5000,0.5000,1,1.5708,          3P       5
0.0000,0,0,13.5000,5.1500,0.0000,1HA,0,0;                             3P       6
106,1,4,0.0000,5.0000,5.8000,14.2500,5.8000,14.2500,5.0000,           5P       7
5.0000,5.0000,0,0;                                                    5P       8
110,6.5000,5.8000,0.0000,6.5000,5.0000,0.0000,0,0;                    7P       9
110,9.0000,5.8000,0.0000,9.0000,5.0000,0.0000,0,0;                    9P      10
110,13.2500,5.8000,0.0000,13.2500,5.0000,0.0000,0,0;                 11P      11
S      48G       3D      12P      11                                   T       1
```

```
                                                                        S      1
F FCFTC10                                                               S      2
  DAT                                                                   S      3
                                                                        S      4
V IGES 3.0                                                              S      5
                                                                        S      6
I Application Protocol Test Case                                        S      7
  Application Protocol: Drafting                                        S      8
  Information: Feature Control Frames                                   S      9
                                                                        S     10
E ENTITY  FORM                                                    COUNT S     11
     228     0                                                        1 S     12
     212     0                                                        1 S     13
     106    63                                                        3 S     14
     110     0                                                        4 S     15
                                                                        S     16
B This is a test case for the Feature Control Frames Application        S     17
  Protocol example.  This test case implements the Feature Control      S     18
  Frame shown in Figure B5 and labeled as FCF #10.                      S     19
                                                                        S     20
P Not applicable                                                        S     21
                                                                        S     22
R Not applicable                                                        S     23
                                                                        S     24
C This test case was prepared as per the IGES Test Case Development     S     25
  Committee's "Guide to Developing Entity Test Cases",                  S     26
  Draft Version 0.2, November 10, 1987.                                 S     27
                                                                        S     28
D IGES Specification, Version 3.0                                       S     29
  Guidelines for the Specification and Validation of IGES Application   S     30
  Protocols, Draft Version 0.04                                         S     31
                                                                        S     32
H 24-Feb-1988 A Created Test Case for AP Example - R.J. Harrison        S     33
                                                                        S     34
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                                                                        S     48
1H,,1H;,10H0000101010,11HFCFTC10.DAT,8HHANDMADE,3H1.0,32,38,6,38,15,    G      1
10H0000101010,1.0,1,4HINCH,8,0.08,13H880224.153000,0.0001,13.0000,      G      2
14HR. J. HARRISON,24HDOE/Sandia National Labs,4,0;                      G      3
     228       1       0       1     250       0       0        000000101D      1
```

```
     228        0        0        1        0                  FCF_INFO       1D        2
     212        2        0        1      250        0        0        000010101D        3
     212        0        0        8        0                  FCF_TEXT       1D        4
     106       10        0        1      250        0        0        000010101D        5
     106        0        0        2       63                   FCF_BOX       1D        6
     106       12        0        1      250        0        0        000010101D        7
     106        0        0        2       63                   FCF_BOX       2D        8
     106       14        0        1      250        0        0        000010101D        9
     106        0        0        2       63                   FCF_BOX       3D       10
     110       16        0        1      250        0        0        000010101D       11
     110        0        0        1        0                   FCF_SEP       1D       12
     110       17        0        1      250        0        0        000010101D       13
     110        0        0        1        0                   FCF_SEP       2D       14
     110       18        0        1      250        0        0        000010101D       15
     110        0        0        1        0                   FCF_SEP       3D       16
     110       19        0        1      250        0        0        000010101D       17
     110        0        0        1        0                   FCF_SEP       4D       18
228,3,7,5,7,9,11,13,15,17,0,0,0;                                        1P        1
212,7,1,0.3332,0.5000,1001,1.5708,0.0000,0,0,5.4500,5.5500,             3P        2
0.0000,1Hj,5,3.0000,0.5000,1001,1.5708,0.0000,0,0,6.7500,               3P        3
5.9500,0.0000,5Hn0.8m,1,0.5000,0.5000,1,1.5708,0.0000,                  3P        4
0,0,10.2500,5.9500,0.0000,1HA,1,0.5000,0.5000,1,1.5708,                 3P        5
0.0000,0,0,11.2500,5.9500,0.0000,1HB,1,0.5000,0.5000,1,1.5708,          3P        6
0.0000,0,0,12.2500,5.9500,0.0000,1HC,6,3.5000,0.5000,1001,              3P        7
1.5708,0.0000,0,0,6.7500,5.1500,0.0000,6Hn0.25m,1,0.5000,               3P        8
0.5000,1,1.5708,0.0000,0,0,10.7500,5.1500,0.0000,1HA,0,0;               3P        9
106,1,4,0.0000,5.0000,6.6000,6.5000,6.6000,6.5000,5.0000,               5P       10
5.0000,5.0000,0,0;                                                      5P       11
106,1,4,0.0000,6.5000,6.6000,13.0000,6.6000,13.0000,5.8000,             7P       12
6.5000,5.8000,0,0;                                                      7P       13
106,1,4,0.0000,6.5000,5.8000,11.5000,5.8000,11.5000,5.0000,             9P       14
6.5000,5.0000,0,0;                                                      9P       15
110,10.0000,6.6000,0.0000,10.0000,5.8000,0.0000,0,0;                   11P       16
110,11.0000,6.6000,0.0000,11.0000,5.8000,0.0000,0,0;                   13P       17
110,12.0000,6.6000,0.0000,12.0000,5.8000,0.0000,0,0;                   15P       18
110,10.5000,5.8000,0.0000,10.5000,5.0000,0.0000,0,0;                   17P       19
S      48G       3D      18P      19                                    T        1
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NBS-114A (REV. 2-8C)

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4. TITLE AND SUBTITLE

Guidelines for the Specification and Validation of IGES Application Protocol:

5. AUTHOR(S)

Randy J. Harrison; Mark E. Palmer

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period C

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

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)

This document provides a background discussion of product data, describes the conce of IGES (Initial Graphics Exchange Specification) application protocols, specifies technical content of an IGES application protocol, describes a validation methodolo for these application protocols, and provides guidelines for the implementation of IGES application protocol. A key conclusion of the background discussion of produc data is that IGES application protocols must be developed in order to achieve consi tent and reliable exchanges of product data within specified application areas.

The technical content of an IGES application protocol includes a conceptual informa model for the application area with its supporting documentation, an application pr col format specification with a protocol usage guide, and a set of application prot format test cases. These test cases must be used in concert with a well-defined testing methodology.

Since no complete IGES application protocols currently exist, this document describ a current implementation of an application protocol process that is based on a part complete application protocol. The document also includes a specific example of a simple application protocol that meets the technical content requirements.

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

application validation; CAD data exchange; computer-aided design and drafting; data exchange standards; data translation quality assurance; data translators; IGES; IGE application protocols; information management; validation of data translators

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