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Data Modelling for Electromagnetic and Stress Analysis Integration

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Data Modelling for Electromagnetic and Stress Analysis Integration

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Abstract

This report describes the data modelling performed within the EC ESPRIT Project MIDAS (Project 7294). MIDAS was a three year project which brought together software from different vendors in the areas of solid modelling, advanced mesh generation, stress analysis and electromagnetic analysis into a totally integrated suite of software with a common user interface and a common database.
Data modelling and the use of a data base were a very important component of the integration process. As a result the ISO STEP standard (ISO 10303) and its methodology were adapted by the project to meet its data modelling and data management needs. This report reviews the parts of STEP relevant to the MIDAS Project and how these were brought together within the project. Also described is the data modelling which can be used as a basis for the common database.

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Contents

1 Introduction

The International Standard for data exchange ISO 10303, known as STEP, is now being extensively used as an integration tool between CAD applications. The need for uniform standards to aid integration has been long recognised and STEP is the latest international collaboration to develop such a tool. Finite Element Analysis (FEA) for stress analysis was a late addition to STEP but it is now approaching stability and will be an International Standard (DIS) in a short time. However, other applications areas that exploit finite element technology have not been include in the FEA part. In particular electromagnetic analysis (EM) is not covered presently by STEP but the existing models and methodology can be used and extended into this area.

This report describes how parts of STEP have been brought together and extended to provide a common data model for the MIDAS (ESPRIT 7294) Project. This data model then formed the basis for a common database for the integration within the project.

The report describes how the STEP Finite Element Analysis data model, although initially only covering linear static analysis, has been designed in such a way as to make extension into other areas relatively straightforward. It then describes the exercise used to establish the specific data needs of electromagnetic analysis and how these were incorporated into the data model. Finally the difference between a logical data model and an implementation schema and what changes were necessary to the STEP data model to allow direct implementation into a database are described.

The data model developed for the MIDAS project, the MIDAS Data Model for Electromagnetic Applications, is described in detail in a related report [1].

2 MIDAS Overview

The MIDAS project was a three year project funded by the EC ESPRIT Programme. The aim of the project was the integration of advanced CIME (Computer Integrated Manufacturing & Engineering) processes into a single design environment. In particular, the project addressed the area of design and analysis of electric and magnetic devices, integrating advanced and existing software tools over a standard Database (DB) and a flexible Data Base Management System (DBMS).

The overall goal was to design and implement an open client/server environment which would improve the designer's productivity in the end-user companies. The tools considered for integration in the environment included: geometric modeller, EM analysis and visualisation. The MIDAS Environment and each of these tools are described below.

The project aimed to prove that such an open environment could be used by users of EM software and that a number of different vendors could contribute to the complete design tool. Part of the demonstration was the interfacing of a stress analysis package with an EM package using the common data base and the inclusion of two and three-dimensional analyses.

STEP was very important component of the project. STEP data modelling methods and the SDAI data base interface were used in the data management. The project had allocated effort to developing the STEP data modelling to include elements that would meet the needs of the electromagnetics community.

The partners in the project were:

- Ansaldo Richerche (Italy)
- Vector Fields Ltd (United Kingdom)

- Labein (Spain)
- Rutherford Appleton Laboratory (United Kingdom)
- University of Genova (Italy)
- Cranfield Institute of Technology (United Kingdom)

A major result of the project was to be a prototype of a fully integrated two and three dimensional analysis system for electromagnetic components.

3 MIDAS Environment

The software used and developed within the MIDAS project can be divided into three categories: Control and User Interface, Applications and Database. Each of these are described in more detail in the following sections.

3.1 Control and User Interface

The parts of the MIDAS environment which fall in this category consist of two programs: the Master Control Process (MCP) and the Graphical User Interface (GUI).

When the MIDAS environment is started, the MCP begins execution and remains in control until the environment is terminated. The MCP looks after the following operations:

- starting an X graphics server,
- starting applications processes,
- starting the GUI and
- closing processes.

The MIDAS project has a Graphical User Interface (GUI) which controls all the programs in the MIDAS environment. This GUI is a special case of an application and is controlled by the MCP. The GUI fulfills three main functions:

- it controls the environment as a whole, that is, it allows the user to switch between applications programs,
- it allows the user to input information into each applications program and
- it displays information to the user.

The GUI uses the X protocol to pass graphical information from application to display.

3.2 Applications

The following applications have been integrated into the MIDAS environment:

- geometric modeller: an object oriented C++ development for non-manifold geometries.
- pre-processor: this includes a fully automatic mesh generator.

- analysis packages: two- and three-dimensional analysis with adaptive meshing.
- post processor: a visualisation tool for the results of the analyses.

In addition the structural analysis package, ANSYS, was interfaced to the environment although not integrated into it.

3.3 Database

The database used by the MIDAS environment is called DEVA. This provided a database management system, I/O control and a data access interface. DEVA was written at Rutherford Appleton Laboratory under the ESPRIT II program, Project 5172 (IDAM) and was further developed under MIDAS.

One of the first tasks undertaken in MIDAS was to enhance DEVA to run as a client/server database. In this mode a server database is initiated on any accessible machine. This server is then available for any application to act as a client to access the data. Each application may perform various actions i.e. place data, access data, save datasets and rollback, via function calls. When application processes are closed the server database remains active until explicitly closed.

Like any other database, the DEVA database needs a schema which describes the data to be stored and accessed. DEVA is STEP compatible because it uses as a starting point the entity definitions of the Application Protocols and Integrated Resource Models of STEP. MIDAS has added to and modified the *EXPRESS* descriptions of these to include EM analysis.

DEVA is closely linked to the Express compiler `ex` which was developed in the IDAM project. One of the outputs from `ex` is a Keyword Definition File (KDF) which forms the basis of the DEVA data dictionary. Additional information is required by the DEVA database about block sizes which may be added by using the syntax sensitive *EXPRESS* editor, DFED, also developed in IDAM. Figure 1 illustrates the way that these packages work together.

4 STEP Overview

ISO 10303, known informally as STEP (STandard for Exchange of Product model data), is an International Standard for the computer-interpretable representation and exchange of product data. The objective is to provide a neutral mechanism capable of describing product data throughout the life cycle of a product independent from any particular system. The nature of this description makes it suitable not only for neutral file exchange, but also as a basis for implementing and sharing product databases and archiving.

There are two types of information models being developed in STEP:

- Resource information models which provide information in a well defined, generic domain such as units, geometry, topology, product structure and finite element analysis. They provide integrated resources which may be used by several applications.
- Application protocols which provide information in a specific application domain such as explicit and associative draughting, and composite and metallic structural analysis and related design.

These information models are defined using the formally defined data specification language, *EXPRESS* [2], which was developed as part of STEP.

Implementation methods are also defined as part of STEP, these are:

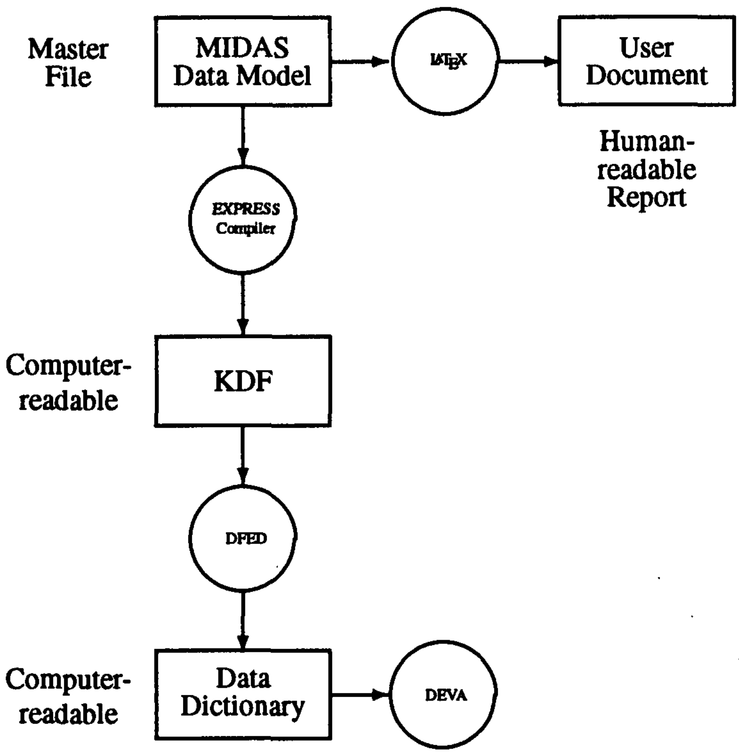

Figure 1: MIDAS Software File Structure

physical file: sequential, free format file exchange [3]. Defines the mapping from *EXPRESS* to the physical file. The syntax is defined in Wirth Syntax Notation (WSN).

SDAI: Standard data access interface (SDAI) [4]. Formal specification of the interface between an application and instances of data in a form specified by an *EXPRESS* schema. The data may be stored in a database, a file or an in-memory working form. This specification is independent of any implementation language.

late bindings: specification of the SDAI in specific languages, Fortran, C, C++, which is independent of the *EXPRESS* schema being implemented.

early bindings: specification of the SDAI in specific languages, Fortran, C, C++, which is dependent on the *EXPRESS* schema being implemented.

The way that information models are implemented into a specific type of database will not be defined in STEP, only the interface to access the data conforming to the model.

5 STEP data models

Only a few of the great many parts which make up STEP are relevant to the MIDAS project. These are as follows:

Part 11 Description methods: The *EXPRESS* language reference manual

Part 21 Implementation methods: Clear text encoding of the exchange structure

Part 22 Implementation methods: Standard data access interface specification

Part 41 Fundamentals of product description and support

Part 42 Geometric and topological representation

Part 43 Representation structures

Part 45 Materials

Part 104 Finite Element Analysis

Part 209 Application Protocol: Composite and Metallic Structural Analysis and Related Design

Each of these documents is in a different state. Some of the parts are about to be released as an International Standard (IS) while others are only Committee Draft (CD). Once the parts are Draft International Standard (DIS) the document is copyright by ISO and it is more difficult to obtain.

6 STEP Documentation and SOLIS

Many of the STEP documents are available on an electronic bulletin board called SOLIS but they are not always the most up to date version. The Internet address of SOLIS is `ftp.cme.nist.gov`. The documents are still in a state of change and the stability of each varies widely. Consequently, personal judgement has been used for each part of the MIDAS model on whether to use a particular version of the STEP model.

The documents that have been referenced for Parts 41 [5], 42 [6], 43 [7] and 45 [8] were the most recent versions on SOLIS when the MIDAS data model was being developed. They are virtually the versions which were being released as International Standard (IS). The documents for Part 104 [9] and Part 209 [10] were obtained at the ISO TC184/SC4 meeting held in Greenville, October 1994. These documents were updated to reflect changes agreed at Greenville. The changes that were agreed have been taken into account in the MIDAS data model where appropriate.

7 Data Requirements

It was important in the MIDAS project to establish exactly what data each application process would need to store in the common DEVA database. If all the applications are to access their data from the same database then they need to have a common definition of all data including the data that is common to more than one application.

To gather the data requirements of the MIDAS partners, a questionnaire was sent to all project partners asking for details of the data which they would need to store in or access from the database. This was requested in plain English form rather than a data modelling form to avoid pre-judging the way in which the data would be modelled. It was then necessary to follow up individually with partners to further understand the underlying nature of the data entities and their relationships. The following sections describe the MIDAS data requirements which emerged from this exercise.

7.1 Geometry

There are two main areas of MIDAS in which geometry is used. The full geometrical descriptions of the component are generated using the geometrical modeller. These are accessed by the analysis programs via the geometric modeller and as a result did not form pat of the MIDAS data model. The second area of geometry is the simplified geometry which is used for input to the analysis packages. This consists only of a simple boundary representation. This data was the first to be included in the MIDAS data model.

In more detail, MIDAS had the following data requirements for analysis input geometry:

points - defined by coordinates

edges - defined by points

surfaces - defined by edges

volumes - boundary representation, defined by surfaces

The STEP data model for geometric and topological representation, Part 42 [6], contains entities which cover all this data adequately for the needs of the MIDAS project. The only changes which have been made to the model are to take out any unnecessary entities and to simplify the model as explained in a later section of this report.

7.2 Finite Element Mesh

In performing an analysis with FEA a continuum is discretised into an approximate model which consists of a mesh of points in the continuum (nodes) that are connected with elements. These elements have associated physical and material properties. There are also coordinate systems, groups (of nodes, elements and groups) and administrative data associated with the discretising mesh model. Load, constraint and output control data along with analysis selection information are combined with the discretising mesh model to form a complete input to an analysis. Once an analysis is performed, results data are output at the nodes and at one or more positions within an element. There may be other output data not associated with the mesh model such as eigenvalues or total strain energy.

This section looks at the analytical model, i.e.. the nodes and elements, together with their physical properties, coordinate systems and groups. The other data will be dealt with in the following sections.

The data needs of the partners as identified were:

nodes

nodal coordinate systems

elements defined by a set of nodes: the more usual way of defining elements

elements defined by geometry: needed for automatic mesh adaption

element types

degrees of freedom: the extra ones that are needed for electromagnetic analysis are:

> **electric_scalar_potential, magnetic_scalar_potential, magnetic_vector_potential, electric_field_intensity, magnetic_field_intensity, electric_flux_density, magnetic_flux_density, electric_charge_density and electric_current_density.**

physical properties

materials: a wide range of material properties were needed including the ability to represent tables of properties which vary with another property and will be calculated and extrapolated by the analysis package.

groups: a method of grouping nodes and elements together for a variety of purposes.

units: the ability to define what units are being used for the definitions including the possibility of units which do not conform to a certain standard.

Volume elements were a top priority for the partners in the MIDAS project as these were mostly used within the project. It was important that the data model includes entities to cover all the materials and physical properties required to support the full range of volume elements for both structural and electromagnetic analyses.

Part 104 [9] of the STEP standard defines an integrated application resource data model for Finite Element Analysis. The standard is concerned with the data associated with the mesh model, the associated analysis controls, boundary conditions and analysis results data. Part 209 [10] is the related Application Protocol which, although it has been developed for composite structures, may also be used for non-composite ones. Part 45 [8] contains the data model to be used for materials.

Although the STEP data models in Part 104 and Part 209 are currently restricted to linear static analysis, the entities have been well defined to allow easy extensions into other application areas. Several entities have been extended in the MIDAS data model to included extra keywords relevant to electromagnetic analysis.

The STEP finite element data model only allows elements to be defined by its nodes, therefore an additional attribute has been added to the element definition entity to allow a reference to a geometry entity. This gives the required capability of defining an element by its full associated geometry rather than its nodes.

The way that the STEP finite element data model references materials was changed at the ISO TC184/SC4/WG3 meeting in Greenville, October 1994. The current mechanism is improved from the previous version but still does not include the capability to group a set of material properties which can be named and referenced from many elements. It also does not include the possibility of tables of properties. For these reasons the MIDAS data model was changed to enable these requirements to be fulfilled.

The only other changes which have been made to the model take out any unnecessary entities and to simplify the model as explained in a later section of this report.

7.3 FE Analysis Control

The FE Analysis Control data model covers all those areas of data which are needed by the FE code, in addition to the FE mesh, to perform an analysis. It describes the operations to be carried out upon the model as a set of analysis steps. A model may have one or more sets of control information. The control information also includes the administrative and configuration control information and the constraints upon the model which act for each analysis step.

The data needs of the partners as identified were:

- prescription for analysis

- constraints
  - on single nodes
  - on sets of nodes
  - on geometric points
  - including real and imaginary parts
  - including time dependency
- loads
  - nodal
  - elemental (body force)
  - element face (pressure)
  - including all options as for constraints
- including the possibility to set values for the following variables which are specific to electromagnetic analysis:

  electric_scalar_potential, magnetic_scalar_potential, magnetic_vector_potential, electric_field_intensity, magnetic_field_intensity, electric_flux_density, magnetic_flux_density, electric_charge_density and electric_current_density

- excitations not related to boundary conditions (e.g. currents in coils)

It was a priority that the MIDAS data model should cover all the above requirements. The only restriction was that they will only be applicable to volume elements initially.

Part 104 of the STEP standard defines a resource application data model for Finite Element Analysis controls and results. There is a fundamental concept in this data model of a state. A state describes the value of an analysis variable of a model at an instant. The state information includes:

- the nodal variable values (such as deflections);
- the field variable values within the elements;
- the values of constraints.

The state information is defined in **state_definitions**.

The type of information to be output is specified by **state_definition_without_value** entities.

The control state information may be either specified, derived, or a linearly superimposed combination. Control state or analysis output state information are contained in **state_definition_with_value** entities.

A **state_definition** therefore either:

- defines an output request set by specifying the variable for which values are to be calculated;
- defines a state of a node, element, or a portion of the model by specifying the values of a variable (this is used for either loads/constraints or results);

The variable may be:

- a variable expressed with respect to solution degrees of freedom at a node of the model;
- a field variable at a point within an element of the model, or aggregated within one or more elements;

The above concept of a state allows flexibility in the use of the data model and the MIDAS data model can fulfill most of the data requirements by using the relevant entities from the STEP data model.

Use is made of the **AND/OR** construct for **SUPERTYPEs** in the definition of the **state_definition** entity. In the MIDAS model this has been removed. One of the **SUPERTYPEs** (the one specifying the type of state being defined e.g. **field_variable** or **nodal_freedom_and_value**)has been replaced by an entity for each lowest level **SUBTYPE**, the other (which selects whether the **state_definition** is an output request or a specified state) has been replaced by two OPTIONAL attributes, one of which is to be used to specify an **output_request_set** for a **state_definition_without_value** (in this case the **OPTIONAL** value for the state should be omitted), the other is used to specify a **state** for a **state_definition_with_value**.

Extensions have been made to the data model to introduce extra keywords which are specific to electromagnetic analysis. In particular extensions have been made to the following entities:

volume_scalar_variable: used to describe scalar field variables.

volume_vector_3d_variable: used to describe three dimensional vector field variables.

degree_of_freedom: used to define constraints.

volume_element_purpose: used to define the intended purpose of a volume element.

The FE Analysis Control part of the STEP data model uses the type **measure_or_unspecified_value** instead of **OPTIONAL** attributes which results in the enumerated type **.UNSPECIFIED.** appearing in the file whenever a value is not specified. This has been replaced in the MIDAS data model by optional attributes.

The only other changes which have been made to the model are to take out any unnecessary entities and to simplify the model as explained in a later section of this report.

8 Data Modelling

All of the STEP data models were designed deliberately to be implementation independent. This results in models which can be used to generate either physical files or different types of database schemas. However, the schema which would be generated automatically may not be directly applicable to a specific type of database, or may result in inefficient use of that database. STEP includes a description of how to map from *EXPRESS* to a physical file but does not include a mapping from *EXPRESS* to database schemas.

When deriving the MIDAS data models every effort has been made to keep as close as possible to the available STEP models. However, there are restrictions in DEVA, as in almost any database, which do not allow the full *EXPRESS* language to be implemented without some modifications.

For example, the **SUB/SUPERTYPE** constructs cannot be implemented in DEVA. Where these occur in the STEP data models they have been removed and replaced by a single entity for each of the subtypes. The supertype has been replaced by a select type which allows other entities to reference any of the subtype entities. Where there are subtypes of subtypes forming a tree structure, entities have been included in the MIDAS model for each of the subtypes at the lower extremities of the structure. All the supertypes above this have been removed and their attributes inherited down to the subtype entities. This is in accordance with the STEP physical file mapping. There are a few entities where a slightly different approach has been taken and this has been explained in the data model together with the relevant **ENTITY** definition.

The other change which has been made to all entities is the removal of some of the strong typing. For example, many of the entities have an attribute **name** which has a type **label**. **label** is further defined to be of type **STRING**. This has been simplified in the MIDAS model so that the attribute **name** is of type **STRING**. This has been done to simplify the model and to aid implementation by those unfamiliar with STEP.

For each **ENTITY** in the data model the text gives the reference to the STEP entities on which that entity is based. This reference is given in terms of a reference to the relevant document as given in the bibliography and a section number in that document. To find out the names of the referenced entities a cross-reference table is given in Appendix A.

References

[1] MIDAS.RAL.95.2 (submitted for publication as a RAL report), "The MIDAS Data Model for Electromagnetic and Stress Analysis Integration", Mrs D Thomas and Dr C Greenough, March 1996

[2] ISO 10303-11, "Part 11: Description methods: EXPRESS Language reference manual".

[3] ISO 10303-21, "Part 21: Implementation Methods: Clear text encoding of the exchange structure",

[4] ISO 10303-22, "Part 22: Implementation Methods: Standard data access interface specification",

[5] ISO 10303-41, "Part 41: Integrated generic resources: Fundamentals of product description and support", IS Draft, 23 August 1994.

[6] ISO 10303-42, "Part 42: Integrated generic resources: Geometric and topological representation", IS Draft, 29 August 1994.

[7] ISO 10303-43, "Part 43: Integrated generic resources: Representation Structures", IS Draft, 15 August 1994.

[8] ISO/TC184/SC4/WG3 N258 , "Integrated generic resources: Materials".

[9] ISO TC184/SC4/WG3 N263x (P9), STEP Part 104, Integrated Application Resources: Finite Element Analysis, 9 September 1994.

[10] ISO TC184/SC4/WG3 N350 (P9), Part 209, Composite and Metallic Structural Analysis and Related Design, 17 October 1994.

[11] MIDAS Deliverable T 1.3a/R, September 1993, B.F.Colyer.

A STEP Data Model Entities Used

This appendix lists all the STEP data model entities which have been used in constructing the MIDAS data model. A separate list is given for each of the referenced documents. For each document the table gives the section number of the entity, the entity name and a code which designates the level of change made to that the entity for inclusion in the MIDAS data model. The meaning of this code is as follows:

- U the entity is unchanged from the STEP entity.
- M minor changes have been made according to the general principles described in the main report.
- C specific changes have made to the entity which will vary in type and degree for each entity changed, these include extensions to entities to deal with the additional requirements for electromagnetic analysis.

A.1 Part 104 Finite Element Analysis

Section no.	Entity or Type name	Changes
5.3.1	axi_or_plane	U
5.3.2	coordinate_system_type	U
5.3.3	element_order	U
5.3.4	plane_2d_elememt_assumption	U
5.3.5	volume_element_purpose	C
5.3.8	volume_3d_element_shape	C
5.3.9	element_2d_shape	C
5.3.10	matrix_property_type	U
5.3.14	degree_of_freedom	C
5.3.16	integration_rule	U
5.3.17	shape_function	U
5.3.18	additional_node	M
5.3.20	volume_2d_element_representation	U
5.3.23	volume_2d_element_descriptor	U
5.3.26	volume_3d_element_coordinate_system	U
5.3.27	volume_2d_element_coordinate_system	U

5.4.1	fea_model	C
5.4.2	fea_3d_model	C
5.4.3	fea_2d_model	C
5.4.4	structural_response_property	M
5.4.5	fea_representation_item	M
5.5.2	fea_axis2_placement_3d	M
5.6.1	node_representation	M
5.6.2	node_shape_representation	M
5.6.3	node	C
5.7.1	element_representation	C
5.7.2	element_shape_representation	C
5.7.3	higher_order_element_representation	C
5.7.4	volume_3d_element_representation	C
5.7.5	axisymmetric_volume_2d_element_representation	C
5.7.6	plane_volume_3d_element_representation	C
5.7.13	element_descriptor	M
5.7.14	volume_3d_element_descriptor	M
5.7.15	axisymmetric_volume_2d_element_descriptor	M
5.7.16	plane_volume_2d_element_descriptor	M
5.7.17	volume_3d_element_basis	U
5.7.18	volume_2d_element_basis	U
5.9.2	arbitrary_volume_3d_element_coordinate_system	M
5.9.3	parametric_volume_3d_element_coordinate_system	M
5.9.4	arbitrary_volume_2d_element_coordinate_system	M
5.9.5	parametric_volume_2d_element_coordinate_system	M
5.9.18	euler_angles	M
5.10.6	volume_3d_element_integrated_matrix	M
5.10.8	volume_3d_element_field_integration	U
5.10.9	element_integration_algebraic	U
5.10.10	volume_3d_element_field_integration_rule	U
5.10.11	volume_3d_element_field_integration_explicit	U
5.10.12	volume_position_weight	U
5.10.13	volume_2d_element_integrated_matrix	M
5.11.1	fea_parametric_point	M
5.11.2	volume_element_location	U
5.12.1	fea_material_representation	C
5.13.20	axisymmetric_2d_element_property	M
5.13.21	plane_2d_element_property	M

5.14.1	fea_group	M
5.14.2	element_group	M
5.14.3	node_group	M
6.3.3	volume_3d_face	U
6.3.9	field_value	U
6.3.10	unspecified_value	U
6.3.12	boundary_variable	M
6.3.14	volume_variable	C
6.3.21	volume_scalar_variable	C
6.3.23	boundary_surface_scalar_variable	M
6.3.25	volume_angular_variable	C
6.3.33	volume_vector_3d_variable	C
6.3.35	boundary_surface_vector_3d_variable	M
6.3.40	volume_tensor2_3d_variable	U
6.3.49	volume_3d_element_representation_or_descriptor	U
6.4.1	control	M
6.4.2	analysis_step	M
6.4.3	control_analysis_step	M
6.4.7	control_linear_static_analysis_step	M
6.4.9	constraint_element	M
6.4.10	single_point_constraint_element	M
6.4.13	freedom_and_coefficient	M
6.4.15	control_static_load_increment_process	C
6.4.16	output_request_set	C
6.5.1	result	U
6.5.2	result_analysis_step	M
6.5.3	result_linear_static__analysis_step	M
6.6.1	state	M
6.6.3	specified_state	M
6.6.3	calculated_state	M
6.7.1	state_definition	M
6.7.2	state_definition_without_value	M
6.7.3	state_definition_with_value	M
6.7.4	field_variable_definition	M
6.7.5	field_variable_element_definition	M
6.7.6	volume_3d_element_field_variable_definition	M
6.7.10	volume_3d_element_constant_specified_variable_value	M
6.7.11	volume_3d_element_nodal_specified_variable_value	M
6.7.14	volume_3d_element_boundary_constant_specified_variable_value	M
6.7.15	volume_3d_element_boundary_nodal_specified_variable_value	M
6.7.85	field_variable_node_definition	M
6.7.86	volume_3d_node_field_variable_definition	M
6.7.100	nodal_freedom_and_value_definition	M
6.7.105	freedom_and_value	M

7.3.2	scalar	M
7.3.4	tensor1_2d	M
7.3.5	tensor1_3d	M
7.3.7	anisotropic_symmetric_tensor2_2d	M
7.3.8	symmetric_tensor2_3d	U
7.3.9	isotropic_symmetric_tensor2_3d	M
7.3.10	orthotropic_symmetric_tensor2_3d	M
7.3.11	anisotropic_symmetric_tensor2_3d	M
7.4.1	symmetric_tensor4_3d	C
7.4.2	anisotropic_symmetric_tensor4_3d	M
7.4.3	fea_isotropic_symmetric_tensor4_3d	M

A.2 Part 41 Fundamentals of product description and support

Section no.	Entity or Type name	Changes
2.4.3.1	characterized_definition	M
2.4.3.3	shape_definition	M
2.5.3.1	shape_representation	C
2.5.3.2	property_definition_representation	M
4.13.3.1	identifier	M
4.13.3.2	label	M
4.13.3.3	text	M
4.14.3.1	measure_value	M
4.14.3.22	unit	U
4.14.3.23	si_unit_name	U
4.14.3.24	si_prefix	U
4.14.4.1	named_unit	C
4.14.4.2	si_unit	M
4.14.4.3	conversion_based_unit	C
4.14.4.17	dimensional_exponents	U
4.14.4.18	derived_unit_element	U
4.14.4.19	derived_unit	U
4.14.4.20	global_unit_assigned_context	M
4.14.4.21	measure_with_unit	C

A.3 Part 42 Geometric and topological representation

Section no.	Entity name	Changes
4.4.1 hline 4.4.2	geometric_representation_context geometric_representation_item	M C
4.4.3	point	M
4.4.4	cartesian_point	M
4.4.10	direction	M
4.4.12	placement	M
4.4.14	axis2_placement_2d	M
4.4.15	axis2_placement_3d	M
5.4.1	topological_representation_item	C
5.4.2	vertex	M
5.4.3	vertex_point	M
5.4.4	edge	M
5.4.7	path	M
5.4.10	loop	M
5.4.12	edge_loop	M
5.4.13	poly_loop	M
5.4.14	face_bound	M
5.4.16	face	M
5.4.20	connected_face_set	M
5.4.25	closed_shell	M
5.4.26	oriented_closed_shell	M
6.4.1	solid_model	M
6.4.2	manifold_solid_rep	C
6.4.3	brep_with_voids	C
6.4.4	faceted_brep	C

A.4 Part 43 Representation Structures

Section no.	Entity name	Changes
4.4.2	representation_context	M
4.4.4	representation_item	C
4.4.5	representation	M
4.4.12	definitional_representation	M

A.5 Part 45 Materials

Section no.	Entity name	Changes
4.4.1	material_property	C
5.3.1	material_property_representation	C
5.3.2	data_environment	C