NIST Advanced Manufacturing Series 200-12

STEP File Analyzer and Viewer
User Guide (Update 7)

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PREFACE

This guide describes how to use the STEP File Analyzer and Viewer, a software tool that analyzes and generates a spreadsheet or a set of CSV (comma-separated value) files from an ISO 10303 STEP (STandard for the Exchange of Product model data) file. The spreadsheets simplify inspecting information in the STEP file at an entity and attribute level. STEP files can also be checked for conformance to recommended practices for Product and Manufacturing Information (PMI) representation, PMI presentation, and validation properties.

The STEP File Analyzer and Viewer also generates views of part geometry, graphical PMI annotations, tessellated part geometry, sketch geometry, supplemental geometry, datum targets, and finite element models.

More information about the software and sample spreadsheets and views can be found at https://www.nist.gov/services-resources/software/step-file-analyzer-and-viewer. The source code for the software is available at https://github.com/usnistgov/SFA.

In this report the acronym SFA will be used for the STEP File Analyzer and Viewer.

UPDATES

For update 7, in addition to some updated figures, new content is found in sections: (3.4) Options tab, (3.5) Spreadsheets tab, (4.2.1) Saved Views, (4.2.3) Holes, (4.5) Augmented Reality, (5.5.2) Text String and Numbers, (6.1.3.1) Rounding, and (6.3.1) Semantic Text. The old section 10 was merged into the renamed section 2.4 Crash Recovery. Some figures are from older versions of SFA.

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Dr. Soonjo Kwon, a former guest research at NIST now at the Kumoh National Institute of Technology in South Korea, developed the software that converts STEP to X3D [1] for viewing part geometry as described in Sec. 4.1.

The image on the cover page was generated by SFA from a STEP file downloaded from GrabCAD https://grabcad.com/library/gtcp85-98d-1.
# TABLE OF CONTENTS

1 **INTRODUCTION** ............................................................................................................. 1

2 **GETTING STARTED** ........................................................................................................ 2

   2.1 **INSTALL SFA** ........................................................................................................... 2

   2.2 **RUN SFA** ............................................................................................................... 2

       2.2.1 **Install IFCsvr** ................................................................................................. 2

   2.3 **GENERATE OUTPUT** ............................................................................................. 3

   2.4 **CRASH RECOVERY** ................................................................................................ 3

   2.5 **UNINSTALL SFA** ...................................................................................................... 4

3 **USER INTERFACE** ......................................................................................................... 5

   3.1 **MENU BAR** ............................................................................................................ 6

       3.1.1 **File Menu** ....................................................................................................... 6

       3.1.2 **Websites Menu** ............................................................................................. 7

       3.1.3 **Examples Menu** ............................................................................................ 7

       3.1.4 **Help Menu** .................................................................................................... 8

   3.2 **TABS BAR** .............................................................................................................. 9

   3.3 **STATUS TAB** ......................................................................................................... 9

   3.4 **OPTIONS TAB** ...................................................................................................... 10

       3.4.1 **Generate** .......................................................................................................... 10

       3.4.2 **Selectively Process Entity Types** ................................................................... 11

       3.4.3 **Analysis Reports** ........................................................................................... 12

       3.4.4 **View Options** ............................................................................................... 12

       3.4.5 **Open STEP File in App** ............................................................................... 12

       3.4.5.1 **Tree View for Debugging** ......................................................................... 13

   3.5 **SPREADSHEET TAB** ............................................................................................. 14

4 **VIEWER** ........................................................................................................................ 15

   4.1 **PART GEOMETRY** .................................................................................................. 15

       4.1.1 **Part Quality and Normals** ............................................................................. 19

       4.1.2 **Sketch Geometry** .......................................................................................... 20

       4.1.3 **Supplemental Geometry** ............................................................................. 21

   4.2 **GRAPHICAL PMI** .................................................................................................. 22

       4.2.1 **Saved Views** .................................................................................................. 23

       4.2.2 **Datum Targets** .............................................................................................. 25

       4.2.3 **Holes** .............................................................................................................. 26

   4.3 **AP242 TESSELLATED PART GEOMETRY** .............................................................. 26

   4.4 **AP209 FINITE ELEMENT MODEL** ....................................................................... 27

       4.4.1 **Finite Element Mesh** .................................................................................... 27

       4.4.2 **Boundary Conditions, Loads, and Displacements** .................................... 29

   4.5 **AUGMENTED REALITY** ....................................................................................... 32

5 **SPREADSHEETS** ........................................................................................................... 33

   5.1 **SUMMARY WORKSHEET** ..................................................................................... 33

   5.2 **HEADER WORKSHEET** ........................................................................................ 34

   5.3 **ENTITY WORKSHEETS** ...................................................................................... 34

   5.4 **SKIPPED ATTRIBUTES** ....................................................................................... 36

   5.5 **OPTIONS** ............................................................................................................... 36

       5.5.1 **Maximum Rows** ......................................................................................... 36
Figure 7: Help menus ................................................................. 8
Figure 8: Tooltip help .............................................................. 9
Figure 9: Options tab ................................................................. 10
Figure 10: Tooltip help for Shape Aspect entities ......................... 11
Figure 11: Open STEP File in other applications ......................... 12
Figure 12: Tree View output ..................................................... 13
Figure 13: Spreadsheet tab ...................................................... 14
Figure 14: Part geometry view .................................................. 16
Figure 15: Part geometry view with edges switched off ................. 16
Figure 16: Part geometry view with rod-assembly switched off ....... 17
Figure 17: Part geometry view with bracket assembly and plate switched off ........................................... 17
Figure 18: Part geometry view with approximate transparency ....... 18
Figure 19: Part geometry view with edges only .......................... 18
Figure 20: Part geometry view with low quality ......................... 19
Figure 21: Part geometry view with high quality and normals ....... 19
Figure 22: Part geometry view with sketch geometry ................. 20
Figure 23: Part with supplemental geometry .............................. 21
Figure 24: Graphical PMI ......................................................... 22
Figure 25: Graphical PMI with multiple saved views ................. 23
Figure 26: Graphical PMI with multiple saved view viewpoints .... 24
Figure 27: Graphical PMI with a datum target .......................... 25
Figure 28: AP242 tessellated part geometry ............................. 26
Figure 29: AP209 FEM of ultra-lightweight glider ..................... 27
Figure 30: AP209 FEM, no mesh ............................................. 28
Figure 31: AP209 FEM, nodes only .......................................... 28
Figure 32: AP209 FEM ............................................................. 29
Figure 33: AP209 nodal boundary conditions ........................... 30
Figure 34: AP209 nodal load vectors ...................................... 30
Figure 35: AP209 displacement vectors ................................... 31
Figure 36: AP209 mode shape displacements ............................ 31
Figure 37: Augmented reality application of SFA output ............. 32
Figure 38: Summary worksheet .............................................. 33
Figure 39: Header worksheet .................................................... 34
Figure 40: datum_system entities .......................................... 34
Figure 41: Entity worksheet (datum_system) ............................. 35
Figure 42: Entity worksheet (draughting_model) ......................... 35
Figure 43: Entity worksheet (b_spline_surface_with_knots) ....... 36
Figure 44: Maximum rows example ....................................... 36
Figure 45: Entity worksheet with Unicode characters ............... 37
Figure 46: Entity worksheet (shape_aspect) with tables for sorting ......................................................... 38
Figure 47: Rounding numbers example ................................... 38
Figure 48: ANCHOR section in a STEP file .............................. 39
Figure 49: ANCHOR section worksheet .................................. 39
Figure 50: ANCHOR ID reported on datum worksheet ............. 39
Figure 51: NIST test case CTC 3 ............................................ 41
Figure 52: Summary worksheet with entities highlighted for PMI .... 42
Figure 53: Entity worksheet (datum) ....................................... 43
Figure 54: Entity worksheet (datum_reference_compartment) .... 43
Figure 55: Datum reference frame example ............................ 44
Figure 56: Dimensional tolerance example (columns A-C) ........ 45
Figure 57: Dimensional tolerance example (columns A, D-I) ....... 46
Figure 58: Flatness tolerance example (columns A-H) ................................ ................................ ............. 47
Figure 59: Flatness tolerance example (columns I-K) ................................ ................................ ............. 47
Figure 60: Position tolerance example (columns A-G) ........................................................................ 48
Figure 61: Position tolerance example (columns H-J) ........................................................................ 48
Figure 62: Position tolerance feature control frame ........................................................................... 49
Figure 63: Toleranced geometry for position tolerance ....................................................................... 49
Figure 64: Associated geometry for dimensional tolerance ............................................................. 50
Figure 65: Associated geometry for datum feature ............................................................................. 50
Figure 66: Warning message for multiple dimensions ........................................................................ 51
Figure 67: Multiple dimensions example (columns D-H) .................................................................... 51
Figure 68: Multiple dimensions example (column K) ......................................................................... 51
Figure 69: PMI Representation Summary worksheet ........................................................................ 52
Figure 70: PMI Representation Coverage worksheet ......................................................................... 53
Figure 71: PMI presentation example (columns A-D) ........................................................................ 55
Figure 72: PMI presentation example (columns E-H) ........................................................................ 56
Figure 73: PMI presentation example (columns I-K) ........................................................................... 56
Figure 74: PMI Presentation Coverage worksheet .............................................................................. 57
Figure 75: Validation properties example (columns A-D) ................................................................... 58
Figure 76: Validation properties example (columns E-O) ................................................................... 59
Figure 77: Validation properties example with expanded columns (columns E-J) ............................. 59
Figure 78: Entity worksheet (shape_aspect_relationship) ................................................................. 60
Figure 79: Inverse Relationships and Used In example (columns A-F) ............................................... 60
Figure 80: Inverse Relationships and Used In example (columns G-H) ............................................. 61
Figure 81: Syntax error related to annotation_curve_occurrence ...................................................... 61
Figure 82: Warning message related to dimensional_characteristic_representation........................ 61
Figure 83: Entities with errors or warnings highlighted on Summary worksheet .................................. 62
Figure 84: Syntax error on (characterized_representation)(draughting_model) ..................................... 63
Figure 85: Warning message on dimensional_characteristic_representation ...................................... 63
Figure 86: Cell comment for dimensional tolerances .......................................................................... 64
Figure 87: Color-coded PMI Representation Summary worksheet for CTC 5 ..................................... 66
Figure 88: Feature from NIST CTC 5 ................................................................................................. 67
Figure 89: Color-coded PMI Representation Coverage worksheet .................................................. 69
Figure 90: Syntax Checker results .................................................................................................... 70
Figure 91: File Summary worksheet, multiple files (rows 31-56) ....................................................... 72
Figure 92: PMI Representation Coverage worksheet, multiple files (rows 1-34) ............................... 73
Figure 93: PMI Representation Coverage worksheet, multiple files (rows 35-62) ............................. 74
Figure 94: PMI Presentation Coverage worksheet, multiple files ..................................................... 75
Figure 95: Command-line version options .......................................................................................... 76
Figure 96: Command-line version output ........................................................................................... 77
1 Introduction

The STEP File Analyzer and Viewer [2] processes STEP (ISO 10303 – informally known as the STandard for Exchange of Product model data) [3, 4] files. A STEP file refers to a file that is typically exported by CAD (Computer-Aided Design) software in a format described by ISO 10303-21 and known as a Part 21 file [5, 6].

In this report the acronym SFA is used for the STEP File Analyzer and Viewer. SFA supports current and some older editions of the following STEP Application Protocols (AP), also known as STEP schemas. An AP is the implementable part of ISO 10303 upon which STEP import and export translators are based on for a particular engineering domain. A complete list of supported APs can be found in the SFA Help menu under Supported STEP APs.

- AP203 – Configuration Controlled 3D Design of Mechanical Parts and Assemblies [7], the older version of AP203 is known as Config Control Design
- AP209 – Multidisciplinary Analysis and Design [8, 9], the older version of AP209 is known as Structural Analysis Design
- AP210 – Electronic Assembly Interconnect and Packaging Design [10]
- AP238 – Model Based Integrated Manufacturing Schema [12, 13], the older version of AP238 is known as Integrated CNC Schema
- AP239 – Product Life Cycle Support (PLCS) [14, 15]
- AP242 – Managed Model Based 3D Engineering [16-18]

Some other schemas are also supported.
- ISO 13399 Cutting Tools Data [19]
- ISO 13584 Parts Library (PLIB) [20]
- IFC (Industry Foundation Classes) [21-23]
- CIS/2 (CIMsteel Integration Standards) [24, 25]

There are four main features of SFA.

1. SFA is a viewer for parts, sketch and supplemental geometry, graphical PMI annotations, tessellated part geometry, datum target, and finite element models. The viewer is described in section 4.

2. SFA generates a spreadsheet or a set of CSV (comma-separated value) files from a STEP file. The spreadsheets or CSV files simplify inspecting information from the STEP file at an entity and attribute level. Spreadsheets are described in section 5.

3. SFA can also analyze a STEP file for conformance to recommended practices for Product and Manufacturing Information representation (semantic PMI), PMI presentation (graphical PMI), and validation properties. Recommended practices are defined by the CAx Interoperability Forum (CAx-IF) [26]. Checking recommended practices is described in section 6.

4. SFA can check for basic syntax errors and warnings in STEP files related to missing or extra attributes, incompatible and unresolved entity references, select value types, illegal and unexpected characters, and other problems with entity attributes. Some errors might prevent SFA and other software from processing a STEP file. The syntax checker is described in section 7.
2 Getting Started

2.1 Install SFA

SFA runs on Windows 7 or higher computers. The viewer for part geometry (Sec. 4.1) requires a 64-bit computer. Microsoft Excel is required to generate a spreadsheet. Excel 2007 and higher is supported. If Excel is not installed, then CSV files will be generated instead of a spreadsheet.

The link to the download request form for SFA can be found on https://www.nist.gov/services-resources/software/step-file-analyzer-and-viewer. You will receive instructions about where to download SFA after submitting the download request. SFA is downloaded as a zip file named SFA-n.nn.zip where n.nn is the version number.

The installation process does not require anything more than unzipping SFA-n.nn.zip. The zip file contains six files:

1. STEP-File-Analyzer.exe – Graphical user interface (GUI) version of SFA
2. STEP-File-Analyzer-CL.exe – Command-line version (Sec. 9)
4. SFA-README-FIRST.pdf – Readme file
5. STEP-File-Analyzer-changelog.xlsx – Summary of new and updated features
6. nist_ctc_05.stp – Sample STEP AP242 file with semantic PMI

There are no restrictions as to where the files are located on your computer’s file system.

2.2 Run SFA

To run SFA, simply double click on the icon for STEP-File-Analyzer.exe. Several setup functions are performed the first time you run SFA:

1. Welcome message is shown in the Status tab.
2. Option to create a shortcut in the Start Menu and an icon on the Desktop.
4. Crash Recovery dialog is shown (Sec. 2.4).
5. STEP-File-Analyzer-options.dat is created in your home directory that stores the current state of SFA options. Do not edit this file.
6. Installation of the IFCsvr toolkit.

2.2.1 Install IFCsvr

Although the IFCsvr toolkit\(^1\) was originally written to process IFC files [21] used in the building and construction industry, it has been adapted to read and process STEP files. The IFCsvr installation program is automatically started. You might need administrator privileges to install the toolkit. The installation program might cause antivirus software to respond that there is an issue with the toolkit. The toolkit is safe to install. For example, if the Windows Defender antivirus software responds that there is an issue with the toolkit, select More Info and Run Anyway.

Two of several installation dialogs are shown in Figure 1. Use the default installation folder as shown in the right dialog. You must let the installation process complete before processing any STEP files.

\(^1\) The IFCsvr toolkit used to be available in a Yahoo Group. https://web.archive.org/web/20090726182959/tech.groups.yahoo.com/group/ifcsvr-users/
Sometimes an updated version of SFA will prompt you to reinstall IFCsvr to update the STEP schemas. This requires removing the existing version of IFCsvr and installing the new version.

If you Cancel the IFCsvr toolkit installation, you will still be able to user the Viewer for Part Geometry (Sec. 4.1). Select View and Part Only in the Generate section of the Options tab (Sec. 3.4.1).

2.3 Generate Output

After the IFCsvr toolkit is installed, you can generate a spreadsheet and view from a STEP file. Go to the File menu, select Open STEP File(s), select a STEP file on your computer, click Open in the dialog, and then click on the Generate Spreadsheet and View button.

Feedback will appear in the Status tab indicating the progress of processing the STEP file. The spreadsheet will be opened after it has been generated and the view will open in the default web browser. If CSV files are generated, the directory where the CSV files were generated will be opened. One CSV file is generated for each entity type.

2.4 Crash Recovery

Sometimes SFA will unexpectedly stop (crash) when processing a STEP file. This is usually due to either bugs in the STEP file or limitations of the IFCsvr toolkit. If this happens, simply restart SFA and process the same STEP file again by using function key F1 or F6 if processing multiple STEP files. SFA keeps track of which entity type caused the crash for a particular STEP file and will not process that type again. A message will be shown in the Status tab if a particular type of entity will not be processed.

Use the Syntax Checker (Sec. 7) to check for syntax errors and warnings related to entities that might have caused the crash.

The entity types that will not be processed again are stored in a file myfile-skip.dat. No matter what the reason is for the crash, that file will always be generated. Even if you stop SFA in the middle of processing a STEP file, the file *-skip.dat will be generated. Therefore, the next time SFA is run, the entity type that was being processed when you stopped SFA will not be processed. In this case, or if the syntax errors related to the bad entity are corrected, the *-skip.dat file can be deleted or edited.
Another way to prevent that entity type from being processed is to deselect, in the Process section of the Options tab, the category of entities that contains the entity that caused the crash. That will prevent that entity from being processed along, however, with all other entities of that category.

SFA might also crash when processing very large STEP files. Popup dialogs might appear that say, “unable to alloc xxx bytes”. In this case, deselect some entity types to process in the Options tab or use a User-Defined List of entities to process (Sec. 3.4.2).

Figure 2 shows the Crash Recovery dialog that is shown the first time SFA is run.

![What to do if the STEP File Analyzer and Viewer crashes?](image)

Figure 2: What to do if the STEP File Analyzer and Viewer crashes

### 2.5 Uninstall SFA

SFA can be uninstalled by manually deleting the two executable files and PDF files, the STEP-File-Analyzer-options.dat file in your home directory, and the desktop icon for SFA. The IFCsvr toolkit can also be deleted from Apps in Windows Settings. Temporary files can also be deleted from C:/Users/username/AppData/Local/Temp/SFA.
3 User Interface

Figure 3 shows the SFA user interface on a computer running Windows 10. At the top of the user interface is the Menu bar with the File, Websites, Examples, and Help menus. Below that is the Tabs bar with tabs for Status, Options, and Spreadsheet. Below that is the Status window that shows text feedback when SFA is running. Clicking on the Options and Spreadsheet tabs will switch to the user interface for those tabs. At the bottom of the user interface is the Generate Spreadsheet and View button, NIST logo, and progress bar.

Figure 3: User interface
3.1 Menu Bar

The menu bar contains four items: File, Websites, Examples, and Help menus.

3.1.1 File Menu

From the File menu, shown in Figure 4, you can select a single STEP file to process with Open STEP File(s). STEP files with extensions of .stp, .step, and .p21 are recognized. Compressed STEP files with an extension of .stpZ are also recognized. ISO 10303 Part 21 Edition 3 STEP files are also supported [5, 27] (Sec. 5.6). AP238 files with a .stpc file extension are supported if the file extension is changed to .stp.

Multiple STEP files can be processed at one time by selecting the Open Multiple STEP Files in a Directory option where you will be asked to select a directory to search for STEP files. The search for multiple files can be restricted to only the selected directory or to include all subdirectories.

Multiple STEP files can also be selected in the Open STEP File(s) dialog by holding down the control or shift key when selecting files. When spreadsheets from multiple STEP files are generated, a File Summary spreadsheet is also generated as described in Sec. 8.1.

Below the first solid line in the File menu is a list of up to 24 of the most recently translated STEP files that can be opened directly. Function keys, defined in the Help menu, can be used to access features of the File menu and other functions.

![STEP File Analyzer and Viewer](image)

Figure 4: File menu
3.1.2 Websites Menu
The Websites menu, shown in Figure 5, provides links to useful resources related to SFA, NIST research, CAx-IF resources, AP242, related organizations, and the STEP format, schemas, and software.

![Figure 5: Websites menu](image)

3.1.3 Examples Menu
The Examples menu, shown in Figure 6, has links to several sources of sample STEP files and sample views and spreadsheets generated by SFA.

![Figure 6: Examples menu](image)
3.1.4 Help Menu
The main Help Menu, shown in Figure 7, has five sections and two submenus. User Guide a link to this
document. Changelog opens the spreadsheet of changes for each version of SFA. Check for Update
opens up a web page that checks for the latest version of SFA. Follow the instructions on that web page
to download a new version of SFA if one is available. This feature runs automatically if an update has
not been checked for in the last 30 days.

The other topics in the Help menu show information in the Status tab and are similar to most information
in this User Guide. The submenus have information about View and Analyze options.

Figure 7: Help menus
Help is also available in the form of tooltips related to some of options in the tabs. Holding the mouse over any text in a tab for a second or two will show a tooltip. The Spreadsheet tooltip help in the Options tab is shown in Figure 8.

![Figure 8: Tooltip help](image)

### 3.2 Tabs Bar

The Tabs bar is located directly below the menu bar in Figure 3. Clicking on a tab will switch from the current tab to the selected tab. Except for the Status tab, the tabs contain the options that affect how a spreadsheet and view is generated from a STEP file. The Options and Spreadsheet tabs are described in Secs. 3.4 and 3.5, respectively.

### 3.3 Status Tab

The Status tab shows important feedback during the generation of a spreadsheet from a STEP file. You should not ignore the feedback as it provides useful information related to the success in processing the STEP file. Some of the error, warning, or informational messages in the Status tab have a yellow background, red background, red, blue, or green text. Syntax error messages highlighted with a red background are for nonconformance of some aspect of the STEP file to a CAx-IF recommended practice [28]. Information in the Status tab is shown in Figure 3 and Sec. 6.5.
3.4 Options Tab

Figure 9 shows the Options tab with five sections to control what type of output is generated from a STEP file.

![Options Tab](image)

**Figure 9: Options tab**

### 3.4.1 Generate

A Spreadsheet (Sec. 5) and/or View (Sec. 4) can be generated from a STEP file.

If Excel is installed, then a spreadsheet and CSV files can be generated. If Excel is not installed, only CSV files can be generated, and some features are not available such as Analysis reports (Sec. 6). CSV files do not contain any cell colors, comments, or links. For CSV files, PMI annotations will look correct only with Excel 2016 or newer.

The Syntax Checker can be run when processing a STEP file (Sec. 7).

Text in the Status tab can be saved in a log file named `myfile-sfa.log`. In the log file, color-coded messages in the Status tab (Sec. 3.3) are preceded by two or three asterisks (*).
3.4.2 Selectively Process Entity Types

SFA can process any entity type for any schema listed by Supported STEP APs in the Help menu. The checkboxes in the Process section of the Options tab allow you to selectively process different types of entities. Each checkbox corresponds to a category of entities that is also used to group and color-code entities on the File Summary worksheet as shown in Figure 38.

All entities unique to APs and schemas other than AP203, AP214, and AP242 are always processed. The All button selects all categories except Geometry and Coordinates. The Reset button deselects all categories, except Common.

Selecting any Analyze option automatically includes the necessary entity categories related to that analysis. For example, selecting the analysis for AP242 PMI Representation automatically selects the entity categories for Common, Representation, Measure, Shape Aspect, and Tolerance, and disables deselecting them.

Holding your mouse over the checkboxes for a second or two will show a tooltip that lists all of the entities in that category. The tooltip for the Shape Aspect entities is shown in Figure 10 and shows that there are 60 entities in the Shape Aspect category. The first set of entities are found in STEP AP203, AP214, and AP242. The second set of entities is only in AP242 with some only in AP242 edition 2.

![Shape Aspect entities](https://doi.org/10.6028/NIST.AMS.200-11)

**Figure 10: Tooltip help for Shape Aspect entities**

A User-Defined List can also be used to set which entities will be processed. The list is defined in a plain text file with the name of one entity type per line in lower case. When the User-Defined List option is selected, the Browse button will be activated to select the file that contains the list of entities. This option allows you more control to process only the required entity types. It is also useful when processing large STEP files that might crash SFA.
3.4.3 Analysis Reports
SFA checks the STEP file for conformance to recommended practices which are specifications that provide common implementation guidance associated with specific functionalities for data exchange. The CAx-IF has published recommended practices for communicating PMI representation, PMI presentation, and validation properties in STEP files [28]. Recommended practices are not part of ISO 10303 EXPRESS schemas [29, 30].

Non-conformance to recommended practices is shown with messages in the Status tab and spreadsheet cells that are highlighted in red.

Section 6.1 discusses the report for PMI representation. Section 6.2 discusses the report for PMI presentation. Section 6.3 discusses the report for validation properties.

3.4.4 View Options
Views for part geometry, graphical PMI annotations, AP242 tessellated part geometry, and AP209 finite element models can be generated. Section 4 describes the view options.

3.4.5 Open STEP File in App
The Open STEP File in App option is a convenient way to open a STEP file in other applications. Figure 11 shows the pull-down menu listing some of the applications that can open a STEP file on the author’s computer. The pull-down menu will always contain a text editor, Default STEP Viewer, and Tree View (for debugging) which is described below. The Default STEP Viewer is whichever application is associated with STEP files (.stp file extension). Several STEP file viewers and conformance checkers also appear in the pull-down menu. Applications will appear in the pull-down menu if they are installed in their default location. To open a STEP file in one of the applications, select the application from the pull-down menu and click the Open button.

Figure 11: Open STEP File in other applications
3.4.5.1 Tree View for Debugging

The option for the Tree View (for debugging) will show the STEP file in a text editor; however, the STEP entities will be rearranged and indented to show the hierarchy of information in the STEP file. This is a useful feature to help debug a STEP file, however it is not recommended for large STEP files. Figure 12 shows a sample of the tree view output. In this sample, it is easy to see how flatness_tolerance (#5584) refers to length_measure_with_unit (#5585) and datum_feature (#5583). The tree view output of the STEP file starts with entities that will generate useful output and stops with other entities to prevent the tree view file from getting too large. Basic geometric and styled item entities can optionally be included in the tree view file, which will increase the size of the file. The resulting tree view file is named myfile-sfa.txt

```
#5584=FLATNESS_TOLERANCE('GT1',$,#5585,#5583);
#5585=LENGTH_MEASURE_WITH_UNIT(LENGTH_MEASURE(0.02),#24);
  #24=(LENGTH_UNIT()NAMED_UNIT(*)SI_UNIT(.MILLI.,.METRE.));
#5583=DATUM_FEATURE('F116',$,#37,.T.);
  #37=PRODUCT_DEFINITION_SHAPE('None','None',#36);
    #36=PRODUCT_DEFINITION('None','None',#34,#35);
    #34=PRODUCT_DEFINITION_FORMATION('','None',#32);
  #32=PRODUCT('GDT_Test_Part_2011_1-id','','None',(#12273));
    #12273=PRODUCT_CONTEXT('part',#29,'');
    #29=APPLICATION_CONTEXT('automotive design');
  #35=PRODUCT_DEFINITION_CONTEXT('part definition',#29,'design');
```

Figure 12: Tree View output
3.5 Spreadsheet Tab

The Spreadsheet tab, shown in Figure 13, contains several more options that affect how information is written to the spreadsheet.

![Figure 13: Spreadsheet tab](image_url)

Section 5.5.1 shows how Maximum Rows can be used to limit the number of rows on any worksheet.

Formatting options:
- Section 5.5.2 describes processing text strings with symbols and non-English characters.
- Section 5.5.3 shows an example of generating tables for sorting and filtering.
- Section 5.5.4 shows an example of not rounding real numbers in spreadsheet cells.

Other options:
- The Viewer generates an X3D file which can be saved and displayed in X3D viewers or processed by other software (Sec. 4.5) [31].
- Section 4.2.1 describes generating viewpoints for graphical PMI saved views.
- Table 2 shows all PMI Elements that can appear on a PMI Representation Coverage worksheet.
- For the semantic PMI analysis report, analyze only dimensional tolerances and no geometric tolerances, datums, or datum targets.
- Not generating links on the File Summary worksheet is useful when sharing spreadsheets.

Output files can be written to the same directory as the STEP file or to a user-defined directory.
4 Viewer

SFA can generate views for part geometry, graphical PMI annotations, AP242 tessellated part geometry, and AP209 finite element models. The views are shown in the default web browser using X3DOM [32]. Internet Explorer is not supported. The resulting view file is named myfile-sfa.html. The HTML file is self-contained and can be shared with other users, including those on non-Windows systems, although an Internet connection is required. Viewer examples are available in the Examples menu.

The origin of the model at '0 0 0' is shown with a small colored XYZ coordinate axis that can be switched off. The background color can be changed between white, blue, gray, and black.

In the view, use key 'a' to view all (+Y axis up) and 'r' to restore to the original view (+Z axis up). Sometimes the model might be located far away from the origin. In this case, turn off the Origin and use 'a' to view all. The function of other keys is described in the link 'Use the mouse'. Navigation uses the Examine Mode. Use PageDown to cycle between front, side, and top viewpoints. The last viewpoint in the cycle is an orthographic projection. Section 4.2.1 describes viewpoints for graphical PMI saved views that can be generated instead of most front, side, and top viewpoints.

4.1 Part Geometry

Figure 14 shows the part geometry view for a simple assembly. Part edges are shown in black. Generating edges can be selected in the View section on the Options tab. If only part geometry needs to be viewed, select Part Only in the Generate section on the Options tab.

There is a list of checkboxes for the parts and/or assemblies in the model. Most assemblies and parts can be switched on and off depending on the assembly structure. The Show/Hide checkbox reverses the checkboxes for the parts and/or assemblies. Some names in the list might have an underscore and number appended to their name. Processing sketch geometry might also affect the list of names. Some assemblies have no unique names assigned to parts, therefore there is no list of part names. Names that use non-English characters might have different or missing characters. In this case, try to convert the encoding of the STEP file to UTF-8 with the Notepad++ text editor2 or other software (Sec. 5.5.2).

The bounding box min and max XYZ coordinates are based on the faceted geometry being shown and not the exact geometry in the STEP file. There might be a variation in the coordinates depending on the Quality option described below. The bounding box also accounts for any sketch geometry if it is displayed, but not graphical PMI and supplemental geometry.

Nested assemblies are supported where one STEP file contains the assembly structure with external file references to individual assembly components that contain part geometry.

Clicking on the model shows the part name (rod) in the upper left. A small dot might be visible where the model was clicked. The part name shown may not be in the list of assemblies and parts on the right. The part might be contained in a higher-level assembly that is in the list.

For very large STEP files, it might take several minutes to process the STEP part geometry. The resulting HTML file also might several minutes to display in the web browser. Select 'Wait' if the web browser prompts that it is running slowly when opening the HTML file.

The part geometry viewer is based on the STEP to X3D translator [1] and only runs on 64-bit computers.

---

2 https://notepad-plus-plus.org/
Figure 14: Part geometry view

Figure 15 shows the assembly with edges switched off with a white background.

Figure 15: Part geometry view with edges switched off
Figure 16 shows the assembly with the rod-assembly switched off with a gray background.

Figure 16: Part geometry view with rod-assembly switched off

Figure 17 shows using the Show/Hide checkbox to switch all parts on or off.

Figure 17: Part geometry view with bracket assembly and plate switched off
Figure 18 shows the assembly partially transparent by using the transparency slider bar. Transparency is only an approximation as shown by the missing three red nuts and the bottoms of the three blue bolts on the right. This limitation might cause parts inside assemblies to be invisible. The approximation is due to how transparency is implemented in X3DOM [32]. The bounding box is also shown.

Figure 18: Part geometry view with approximate transparency

Figure 19 shows only part edges by making the assembly completely transparent.

Figure 19: Part geometry view with edges only
4.1.1 Part Quality and Normals

Three levels of part quality (low, normal, high) can be selected in the View section of the Options tab. Quality controls the number of facets used for curved surfaces. For example, the higher the quality the more facets used around the circumference of a cylinder. A part geometry view with low quality selected is shown in Figure 20. The facets around the cylindrical surfaces are clearly visible. Although the part geometry is always displayed by default with smooth shading, a discontinuity in the shading is also apparent. Figure 21 shows the same part with quality set to high and normals selected. Normals improve the smooth shading by explicitly computing surface normals and improves the appearance of curved surfaces.

![Figure 20: Part geometry view with low quality](image1)

![Figure 21: Part geometry view with high quality and normals](image2)
4.1.2 Sketch Geometry

The white lines in Figure 22 are an example of sketch geometry that is usually created in a CAD system to aid in modeling geometry. The option for sketch geometry is in the View section of the Options tab. Sketch geometry is not the same as supplemental geometry described below. The assembly also has eight different types of parts that can be switched on and off. See the Examples menu to view the assembly.

![Figure 22: Part geometry view with sketch geometry](image)

---


4.1.3 Supplemental Geometry

Figure 23 shows a part with supplemental geometry including planes, lines, and coordinate systems. Supplemental geometry is shown only if part geometry or graphical PMI is also viewed. Supplemental geometry is not associated with graphical PMI saved views. Supplemental geometry is not the same as sketch geometry described above.

The following types of supplemental geometry and associated text are supported.

- Coordinate System: red/green/blue axes
- Plane: blue transparent outlined surface
- Cylinder: blue transparent cylinder
- Line/Circle/Ellipse: purple line/circle/ellipse
- Point: black dot
- Tessellated Surface: faces outlined in black

Colors defined in the STEP file override the default colors above. Unbounded planes are shown with a square planar surface.

Supplemental geometry is also counted on the PMI Coverage Analysis worksheet (Sec. 6.1.7) if a View is generated.

![Image of part with supplemental geometry](https://example.com/image.png)

Figure 23: Part with supplemental geometry
4.2 Graphical PMI

Graphical PMI (PMI presentation) can be viewed by selecting the option in the View section of the Options tab. STEP AP203, AP214, and AP242 support graphical PMI.

Figure 24 shows the graphical PMI that corresponds to the annotations shown in Figure 51. The view file contains the line segments defined by the polylines in column F of Figure 72. In this example, each part of the graphical PMI is assigned a different color to help differentiate them from each other.

There is a checkbox for the graphical PMI associated with saved view MBD_0. In this case, there is only one saved view for the PMI.

Figure 24: Graphical PMI
4.2.1 Saved Views

A saved view is a subset of all graphical PMI. Multiple saved views will have multiple checkboxes as shown in Figure 25. In this example the graphical PMI in each of the three saved views is assigned a different color.

Figure 25: Graphical PMI with multiple saved views

A viewpoint position and orientation can also be associated with a saved view. Saved view viewpoints can be included in the view instead of front, side, and top viewpoints. Using PageDown in the viewer to cycle through the saved views, switches to the associated viewpoint and subset of graphical PMI. Figure 26 shows the saved views for MBD_A, MBD_B, and MBD_C. The saved views correspond to what is shown in the link to the NIST Test Case Drawing. Sometimes some graphical PMI is not in a saved view and will be labeled ‘Not In a Saved View’ in the list of saved views.

Saved view viewpoints might not be implemented correctly in older versions of software that exports STEP AP242 files. The option on the Spreadsheet tab in the Other section will display the geometry of the view frustrum for a saved view viewpoint.
Figure 26: Graphical PMI with multiple saved view viewpoints
4.2.2 Datum Targets
Datum targets are shown only if a spreadsheet is generated with the analysis for semantic PMI selected and when part geometry or graphical PMI is also viewed. Figure 27 shows an example of a part with a rectangular datum target highlighted in red. The graphical PMI also has a datum target symbol, C1 in the circle, pointing to the datum target.

There are two methods to represent and view the position, orientation, and dimensions of a datum target in a STEP file. For the first method, the position, orientation, and target length, width, and diameter are specified parametrically. Point, line, circle, circular curve, and rectangle datum targets are supported. A small coordinate axes is shown at the origin of a datum target except for point datum targets in addition to the datum target label.

For the second method, the shape and location of arbitrarily shaped area and curve datum targets is specified with geometric entities. Supported geometric entities, that lie in plane, are line, circle, trimmed curves, and faces bounded by lines, circles, or ellipses. If other geometric entities are used, then either the datum target will not be shown or some of the edges of the datum targets will be missing. Datum targets defined by multiple types of curves and non-planar datum targets are not supported.

Both types of datum targets are shown in red and can be switched on and off in the view. Datum target feature geometry, also specified with geometric entities similar to the second method, is shown in green.

![Figure 27: Graphical PMI with a datum target](image-url)
4.2.3 Holes
Hole features, including basic round, counterbore, and countersink holes, and spotface are supported in AP242 edition 2 but have not been widely implemented. If the semantic PMI analysis report is not generated, then holes are shown only with a drill entry point.

If the report is generated, then cylindrical or conical surfaces are used to view the depth and diameter of the hole, counterbore, and countersink. If there is no depth associated with the hole (a through hole), then a very thin cylindrical surface with the correct diameter is shown. The bottom of a hole is also shown if the hole is not a through hole and the hole has a depth. Usually, only the counterbore or countersink is shown for through holes. Semantic information related to holes is reported on *hole_definition and basic_round_hole worksheets.

Holes can be switched on and off in the viewer. Cylindrical surfaces are green and conical surfaces are blue. Holes are viewed regardless of whether or not they were explicitly modeled in the part geometry.

4.3 AP242 Tessellated Part Geometry
Tessellated part geometry can be viewed by selecting the option in the View section of the Options tab. STEP AP242 supports tessellated part geometry, but not AP203 and AP214. It is typically written to a STEP file instead of or in addition to b-rep part geometry (Sec. 4.1). Figure 28 shows tessellated part geometry where each tessellated facet is outlined. Individual parts can be switched on and off. Parts in an assembly might be in the wrong position and orientation or be missing.

![Figure 28: AP242 tessellated part geometry](image-url)
4.4 AP209 Finite Element Model

The finite element model in a STEP AP209 file can be viewed by selecting the option in the View section of the Options tab. Nodes, 1D elements, 2D elements, and 3D elements are shown along with the finite element mesh. Viewing boundary conditions, loads, and displacements is also supported. Multiple coordinate systems and viewing of stresses and strains is not supported. There might be insufficient memory for SFA to process very large finite element models.

4.4.1 Finite Element Mesh

Figure 29 shows the view of the finite element model (FEM) of an ultra-lightweight glider [9]. 2D elements are cyan, 1D elements are magenta, nodes are blue, and the mesh is black. To the right of the view are checkboxes for Nodes, Mesh, and 1D and 2D Elements. The number of nodes and different element types are also listed.

![Figure 29: AP209 FEM of ultra-lightweight glider](image-url)
Figure 30 shows the same FEM without the mesh where the magenta-colored 1D elements are visible because the 2D elements are partially transparent.

Figure 30: AP209 FEM, no mesh

Figure 31 shows only the nodes of the same FEM.

Figure 31: AP209 FEM, nodes only
4.4.2 Boundary Conditions, Loads, and Displacements

Figure 32 shows the AP209 FEM that is used to show boundary conditions, loads, and displacements. Options to control how they are viewed are on the Options tab.

Table 1 shows the icons used for constrained degrees-of-freedom (DOF). Different types of icons can be combined for the appropriate DOF.

**Table 1: Icons for constrained DOF**

<table>
<thead>
<tr>
<th>Degree-of-freedom</th>
<th>Icon</th>
</tr>
</thead>
<tbody>
<tr>
<td>All six DOF</td>
<td>Gray box</td>
</tr>
<tr>
<td>All three translation DOF</td>
<td>Gray pyramid</td>
</tr>
<tr>
<td>All three rotation DOF</td>
<td>Gray sphere</td>
</tr>
<tr>
<td>Single translation DOF</td>
<td>Red (x), green (y), or blue (z) line along the constrained translation DOF axis</td>
</tr>
<tr>
<td>Single rotation DOF</td>
<td>Red (x), green (y), or blue (z) circle around the constrained rotation DOF axis</td>
</tr>
</tbody>
</table>
Figure 33 shows some of the nodal boundary conditions for the FEM in Figure 32. All rotation (gray spheres) and Z translation (blue vertical lines) DOF are constrained for all nodes. Nodes along the X and Y axis are constrained in Y (green lines) and X (red lines) DOF, respectively.

![Figure 33: AP209 nodal boundary conditions](image)

Figure 34 shows nodal load vectors that are colored and scaled by the magnitude of the load. The vectors can also be shown with constant length. In this example there is only one load case. The color scale shows the value of the loads.

![Figure 34: AP209 nodal load vectors](image)
Figure 35 shows nodal displacement vectors that are colored and scaled by the magnitude of the displacement. The color scale shows the value of the displacements. The finite element mesh is not displaced.

Figure 35: AP209 displacement vectors

Figure 36 shows the displacements for one of ten mode shapes of a connecting rod.

Figure 36: AP209 mode shape displacements
4.5 Augmented Reality

The viewer can save an X3D file [33] with the option on the Spreadsheet tab. Figure 37 shows an augmented reality application\(^5\) to visualize model-based product definitions that uses the saved X3D file [31].

\[\text{Figure 37: Augmented reality application of SFA output}\]

### 5 Spreadsheets

Typical STEP file viewers show a 3D view of the part or model represented by the STEP file. The viewers usually have a high-level hierarchical display of the assembly structure in the STEP file where you can drill down to individual attributes of parts. However, there is no way to view all of the actual STEP entities and their attributes at once.

SFA provides this capability by creating a spreadsheet from the STEP file. The spreadsheet generated by SFA contains several worksheets. There are Summary and Header worksheets, along with a worksheet for each entity type that was processed from the STEP file. Links to sample worksheets are in the Examples menu.

#### 5.1 Summary Worksheet

A Summary worksheet is shown in Figure 38. Rows 1-7 contain basic information about the STEP file including a link to documentation for the schema used in the file. Starting with row 10, each row in column A is the name of an entity processed from the STEP file. The entity names are linked to their corresponding worksheet. Column B is the number of each entity type.

![Figure 38: Summary worksheet](image-url)
At the bottom of the spreadsheet are tabs for the Summary, Header, and many entity worksheets. Entities in column A and in the worksheet, tabs are grouped, ordered, and colored according to the categories of entities in the Process section of the Options tab. Selecting a tab, using the links in column A, or using the Control-PageUp and Control-PageDown keys will switch to a different worksheet.

5.2 Header Worksheet

A Header worksheet is shown in Figure 39. Rows 3-11 contain the information in a STEP file header section. Rows 1 and 2 are the STEP file name and directory.

![Figure 39: Header worksheet](image)

5.3 Entity Worksheets

An entity worksheet is generated for each entity type shown on the Summary worksheet above. The following example relates entities in a STEP file to the resulting worksheet generated by SFA. Six datum_system entities from a STEP file are shown in Figure 40. The entity ID is the number before the equal sign. Values between the outermost parentheses are attribute values that are separated by commas. There are several different types of attributes including strings delimited by quote marks, references to other entity IDs (numbers preceded by #), boolean values (.T.), and null values ($).  

![Figure 40: datum_system entities](image)

The resulting datum_system entity worksheet is shown in Figure 41. Row 1 contains the name of the entity and the number of entities. It is also a link back to the Summary worksheet. Row 3 is the names of the entity attributes. Column A is the entity ID.
Starting with row 4, each row contains the attribute values for an entity. Column B is the text string for the name attribute. Column C is the description attribute which is blank as indicated by the dollar sign above. Column D is the of_shape attribute where, in this example, all of the values for the entities are product_definition_shape 56. This means that the of_shape attribute is a reference to the product_definition_shape entity with an ID of 56 as shown above. In column F, the constituents attribute refers to either single or multiple datum_reference_compartment entities. The number in parentheses is the number of entity references and the numbers after the entity name are the entity IDs that are referenced.

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Description</th>
<th>of_shape</th>
<th>Product Definition</th>
<th>Constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>37106</td>
<td>Perpendicularity 1</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
<td>(1) datum_reference_compartment 37101</td>
<td></td>
</tr>
<tr>
<td>42046</td>
<td>Position.1</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
<td>(2) datum_reference_compartment 42038 42041</td>
<td></td>
</tr>
<tr>
<td>51481</td>
<td>Position.3</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
<td>(3) datum_reference_compartment 51466 51471 51476</td>
<td></td>
</tr>
<tr>
<td>53696</td>
<td>Position.4</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
<td>(3) datum_reference_compartment 53681 53686 53691</td>
<td></td>
</tr>
<tr>
<td>70901</td>
<td>Position Surface Profile.2</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
<td>(3) datum_reference_compartment 70786 70791 70796</td>
<td></td>
</tr>
<tr>
<td>84089</td>
<td>Perpendicularity 2</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
<td>(1) datum_reference_compartment 84085</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 41: Entity worksheet (datum_system)**

In the draughting_model entity worksheet, shown in Figure 42, cells C4 and C6 refer to multiple entity types. Cell C5 refers to multiple styled_item entities, however, the entity IDs are not shown because there are too many entity IDs to fit in one worksheet cell.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>draughting_model</td>
<td>(3)</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>ID</td>
<td>name</td>
</tr>
<tr>
<td>4</td>
<td>31471</td>
<td>(2) annotation_plane 29651 31466</td>
</tr>
<tr>
<td>5</td>
<td>31941</td>
<td>(93) styled_item</td>
</tr>
<tr>
<td>6</td>
<td>32031</td>
<td>detail view (1) axis2_placement_3d 36</td>
</tr>
</tbody>
</table>

**Figure 42: Entity worksheet (draughting_model)**
5.4 Skipped Attributes

Sometimes SFA skips some specific types of entity attributes due to limitations of the IFCsvr toolkit. A message about skipping an entity attribute will be shown in the Status tab and question marks are shown in the worksheet. Figure 43 shows question marks (???) in column E where the control_points_list attributes were skipped.

![Figure 43: Entity worksheet (b_spline_surface_with_knots)](image)

5.5 Options

There are several options that affect how information is shown in a spreadsheet.

5.5.1 Maximum Rows

The maximum rows option in the Spreadsheet tab limits the maximum numbers of rows in any spreadsheet or CSV file to the selected value. This reduces the size of the spreadsheet and speed processing of the STEP file. Figure 44 shows that only the first 100 of 43681 rows for the cartesian_point entities are written to the worksheet. Syntax errors (Sec.6.5) related to reports might be missed if some entities are not processed due smaller values for maximum rows.

![Figure 44: Maximum rows example](image)

5.5.2 Text Strings and Numbers

Text strings in STEP files might use non-English characters or symbols. Some examples are accented characters in European languages (for example é), and Asian languages that use different characters sets such as Cyrillic or Chinese. Text strings with non-English characters or symbols are usually found on descriptive measure or product related STEP entities with name, description, or id attributes.
According to ISO 10303 Part 21 section 6.4.3 [5], Unicode can be used for non-English characters and symbols with the control directives \X\ and \X2\. For example, \X\E9 or \X2\00E9\X0\ is used for the accented character é. Unicode characters, such as E9, are defined by the Unicode standard\(^6\). Some CAD software does not support these control directives when exporting or importing a STEP file.

For a spreadsheet, the \X\ and \S\ control directives are supported by default. Use the option on the Spreadsheets tab to support non-English characters using the \X2\ control directive. In some cases, the option will be automatically selected based on the file schema or size. There is a warning message if \X2\ is detected in the STEP file and the option is not selected. In this case the \X2\ characters are ignored and will be missing in the spreadsheet. Figure 45 shows an example of how Unicode text strings appear in the spreadsheet.

![Figure 45: Entity worksheet with Unicode characters](image)

For the viewer, all control directives are supported for part and assembly names.

Non-English characters that do not use the Unicode control directives are supported depending the STEP file encoding, e.g., UTF-8 or ANSI. Use the Notepad++ text editor to convert the file to UTF-8 encoding. Some non-English characters might cause the software to crash or prevent a view from being generated. The Syntax Checker (Sec. 7) identifies non-English characters as 'illegal characters'.

Numbers in a STEP file use a period '.' as the decimal separator. Some non-English language versions of Excel use a comma ',' as a decimal separator. This might cause some real numbers to be formatted as a date in a spreadsheet. For example, the number 1.5 might appear as 1-Mai.

\(^6\) [https://www.unicode.org/charts](https://www.unicode.org/charts)
To change the formatting in Excel, go to the Excel File menu > Options > Advanced. Uncheck 'Use system separators' and change 'Decimal separator' to a period . and 'Thousands separator' to a comma ,. Note that this change applies to all Excel spreadsheets on your computer. Change the separators back to their original values when finished. You can always check the STEP file to see the actual value of the number.

5.5.3 Tables
Figure 46 shows the shape_aspect worksheet with the option for generating tables selected. With this option, pull-down menus (selector on the right of each cell in row 3) are shown with the column headers in row 3 that access functions to sort and filter the rows. The table is sorted by the name attribute in column B. This is evident by the non-numerical ordering of the entity IDs in column A. The worksheet containing validation properties (Sec. 6.3) is always sorted.

![Figure 46: Entity worksheet (shape_aspect) with tables for sorting](image)

5.5.4 Number Format
By default, when a single real number is written to a worksheet cell, Excel might round the number. Figure 47, on the left, shows values of radius in column D that are rounded. Using the Number Format option in the Spreadsheet tab to not round real numbers, results in the radius column is shown with full precision in the worksheet on the right. The non-rounded real numbers are the actual values that appear in a STEP file. The non-rounded real numbers are indicated by the small green triangle in the upper left corner of a cell. The non-rounded real numbers are also left justified as opposed to the rounded real numbers that are right justified. Real numbers that appear in pairs or triplets, such as cartesian points, are never rounded.

![Figure 47: Rounding numbers example](image)
5.6 Anchor Section

ISO 10303 Part 21 Edition 3 [27] is a new version of Part 21 that supports anchor, reference, and signature sections in a STEP file. The anchor section can be used to assign a globally unique ID (GUID) to a specific entity. Figure 48 shows the ANCHOR section in a STEP file which appears after the HEADER section and before the DATA section.

```
ANCHOR;
<6db46031-4fab-4838-824b-91cea43922e4>#10; /* product_definition */
<3c9773de-5015-4c05-86b4-0e35a5bf96f>#17076; /* dimensional_size */
<305dc4d8-6cd4-4e44-89c7-9ad5476774cb>#17090; /* cylindricity_tolerance */
<09c07753-38cf-4928-928f-4acd0e636247>#17095; /* datum */
<f1ab2591-7e1b-4898-90c4-a60ff7916774>#17099; /* datum */
<9416b6d8-44ef-4f0e-8b50-4d24a50d0e>#17103; /* perpendicularity_tolerance */
<28710d0e-9f87-4349-aab0-7832e53fa25a>#17105; /* datum */
ENDSEC;
```

Figure 48: ANCHOR section in a STEP file

Figure 49 shows the ANCHOR section worksheet corresponding to the STEP file above.

Figure 49: ANCHOR section worksheet

Figure 50 shows the ANCHOR IDs associated with the three datum entities. ANCHOR IDs are also reported on the PMI Representation Summary worksheet (Sec. 6.1.6). GUIDs can also be assigned to entities with the id_attribute entity.

Figure 50: ANCHOR ID reported on datum worksheet
6 Analysis Reports

The analysis reports check the STEP file against recommended practices are defined by the CAx Interoperability Forum (CAx-IF) [26, 28]. The objective of the CAx-IF is to advance CAx (mainly Computer-Aided Design, Engineering, and Manufacturing) software system translator development and to ensure that user requirements for interoperability are satisfied. Three different reports can be created.

1. PMI Representation (Semantic PMI) described in Sec. 6.1
2. PMI Presentation (Graphical PMI) described in Sec. 6.2
3. Validation Properties described in Sec. 6.3

Product and manufacturing information (PMI) are annotations and attributes that define product geometry and product specifications [34]. PMI includes 3D annotations to specify Geometric Dimensioning and Tolerancing (GD&T), as well as non-geometric data such as surface texture specifications, finish requirements, process notes, material specifications, and welding symbols. GD&T is a symbolic language used to communicate tolerances on manufactured parts. The industry standards for presentation of GD&T in axonometric views in 3D space are ASME Y14.41-2003 [35] and ISO 16792:2006 [36]. Some common tolerances include dimensional tolerances on length and diameter, and geometric tolerances on flatness, position, surface profile, and circular runout.

Figure 51 shows NIST test case CTC 37 with typical feature control frames (FCF) with PMI annotations including dimensions, geometric and dimensional tolerances, and datum features. Most of these types of annotations are processed by SFA.

---

7 https://s3.amazonaws.com/nist-el/mfg_digitalthread/nist_ctc_03_asme1_rc.pdf
Figure 51: NIST test case CTC 3

Figure 52 shows the summary worksheet, similar to Figure 38, with entities highlighted that have information related to PMI Representation and PMI Presentation. Rows 11-14 are entities related to the datum reference frame. Row 15 is the dimensional_characteristic_representation entity which is associated with all dimensional tolerances. Rows 10 and 19-29 are entities related to geometric tolerances. Row 30 is the annotation_curve_occurrence entity which is associated with PMI presentation. The entity name in parentheses in cell A19 is for a complex entity (flatness_tolerance)(geometric_tolerance_with_defined_unit_area). The cells colored gray indicate that there are errors or warnings associated with at least one entity instance of the entity type. All of the worksheets for the highlighted entities will have additional columns with PMI information related to that type of entity.
Figure 52: Summary worksheet with entities highlighted for PMI

6.1 PMI Representation (Semantic PMI)

PMI representation (also known as semantic PMI) includes all information necessary to represent GD&T without any graphical presentation elements. PMI representation is associated with CAD model geometry and is computer-interpretable to facilitate automated consumption by downstream applications for manufacturing, measurement, inspection, and others. PMI representation does not contain any information regarding its visual appearance although an importing CAD system can attempt to recreate the visual presentation of the annotation. The CAX-IF defines recommended practices for PMI representation [37]. Syntax errors related to nonconformance to the recommended practices are highlighted in red in the Status tab and in the relevant entity worksheets (Sec. 6.5).
6.1.1 Visual Presentation of PMI Representation

Sections 6.1.2 through 6.1.4 show three examples of how PMI representation is reported. The report includes a visual presentation of the semantic PMI information that can be used for visual verification of that information. The visual presentation is based only on the semantic PMI and not on the graphical PMI. The visual presentation should correspond to the expected PMI annotations similar to those on Figure 51. If the visual presentation does not look right, then the semantic PMI information might be wrong. The visual presentation is limited by the characters and symbols available in the spreadsheet. Section 6.6.1 has examples of problems with the visual presentation of the PMI representation.

6.1.2 Datum Reference Frame

The following figures show how a datum reference frame is modeled in a STEP file. Figure 53 shows the datum worksheet that defines the datum labels in column F.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Datum</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Id</td>
<td>Name</td>
<td>Description</td>
<td>Of_shape</td>
<td>Product_Definitional</td>
</tr>
<tr>
<td>3</td>
<td>36203</td>
<td>Simple Datum.2</td>
<td>Simple Datum.2</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
</tr>
<tr>
<td>4</td>
<td>40338</td>
<td>Simple Datum.3</td>
<td>Simple Datum.3</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
</tr>
<tr>
<td>5</td>
<td>70983</td>
<td>Simple Datum.5</td>
<td>Simple Datum.5</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
</tr>
<tr>
<td>6</td>
<td>37096</td>
<td>Simple Datum.1</td>
<td>Simple Datum.1</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
</tr>
<tr>
<td>7</td>
<td>53676</td>
<td>Simple Datum.4</td>
<td>Simple Datum.4</td>
<td>product_definition_shape 56</td>
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</tr>
<tr>
<td>8</td>
<td>854273</td>
<td>Simple Datum.6</td>
<td>Simple Datum.6</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
</tr>
</tbody>
</table>

**Figure 53: Entity worksheet (datum)**

Figure 54 shows the datum_reference_compartment worksheet with information for the compartments of a datum reference frame. The compartments are constructed from the base attribute that refers to the datum entity above and the modifiers attribute. The visual presentation of the compartments is shown in column H. The parenthetic notation in cell H3 specifies the section number in the CAx-IF recommended practice for PMI representation related to that information [37].

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Datum_reference_compartment (26)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Id</td>
<td>Name</td>
<td>Description</td>
<td>Of_shape</td>
<td>Product_Definitional</td>
<td>Base</td>
<td>Modifiers</td>
</tr>
<tr>
<td>3</td>
<td>57101</td>
<td>Perpendicularity.1</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
<td>datum 17096</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>42036</td>
<td>Position.1</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
<td>datum 17096</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>42041</td>
<td>Position.1</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
<td>datum 17241</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>51496</td>
<td>Position.2</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
<td>datum 17096</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>51471</td>
<td>Position.3</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
<td>datum 16204 maximum_material_requirement</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>51476</td>
<td>Position.1</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
<td>datum 16204 maximum_material_requirement</td>
<td>B</td>
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</tr>
<tr>
<td>9</td>
<td>53681</td>
<td>Position.4</td>
<td>product_definition_shape 56</td>
<td>TRUE</td>
<td>datum 35676</td>
<td>D</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 54: Entity worksheet (datum_reference_compartment)**
Figure 55 shows the datum_system worksheet with information to combine the datum reference compartments, defined by the constituents attribute, to create a datum reference frame. The visual presentation of the datum reference frames is shown in column G.

### Figure 55: Datum reference frame example

#### 6.1.3 Dimensional Tolerance

The following example shows how a dimensional tolerance is modeled in a STEP file. Figure 56 and Figure 57 show the dimensional_characteristic_representation worksheet where information related to dimensional tolerances is reported.

- Column B is the type of dimension, either dimensional_size or dimensional_location.
- Column C is a reference to shape_dimension_representation which refers to information for the dimension name and value.
- Column D shows the visual presentation of the dimensional tolerances that correspond to the PMI annotations in Figure 51.
- Column E shows the name attribute of the entity type shown in column B.
- Column F shows the dimension (length value) associated with the shape_dimension_representation entity in column C.
- Column G shows the name of the length value in column F.
- Column H shows the plus-minus bounds associated with the dimensional tolerance. The bounds are defined by plus_minus_tolerance entities.
- Column I shows the geometric entities associated with the dimensional tolerances. In this case, the association is through shape_aspect entities which refer to advanced_face entities. The geometry entities cylindrical_surface and plane are referred to by the advanced_face attribute face_geometry.
- Section 6.1.5 explains how associated geometry is important to relate dimensional tolerances with geometric tolerances and datum features.
- More columns may show other attributes of dimensional tolerances.

The parenthetic notation in row 3 specifies the section number in the CAx-IF recommended practice for PMI representation related to that piece of information. For example, recommended practice sections 5.1.1 (column E) and 5.2.1 (column G) specify allowable attribute values shown in those columns.
<table>
<thead>
<tr>
<th>ID</th>
<th>dimension</th>
<th>representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>35831</td>
<td>dimensional_size35861</td>
<td>shape_dimension_representation35826</td>
</tr>
<tr>
<td>40201</td>
<td>dimensional_size40171</td>
<td>shape_dimension_representation40196</td>
</tr>
<tr>
<td>45336</td>
<td>dimensional_size45306</td>
<td>shape_dimension_representation45331</td>
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<tr>
<td>48741</td>
<td>dimensional_size48711</td>
<td>shape_dimension_representation48735</td>
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<td>dimensional_size60511</td>
<td>shape_dimension_representation60536</td>
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<td>dimensional_size64856</td>
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</tr>
<tr>
<td>67011</td>
<td>dimensional_size66581</td>
<td>shape_dimension_representation67006</td>
</tr>
<tr>
<td>69441</td>
<td>dimensional_location69411</td>
<td>shape_dimension_representation69436</td>
</tr>
<tr>
<td>80071</td>
<td>dimensional_location80041</td>
<td>shape_dimension_representation80066</td>
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<td>83161</td>
<td>dimensional_size83151</td>
<td>shape_dimension_representation83176</td>
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</tbody>
</table>

Figure 56: Dimensional tolerance example (columns A-C)
The visual presentation in Figure 57 can be used to do a semantic analysis of the PMI representation information. The dimension ‘0.75’ in cell D11 appears as a reference dimension ‘(.750)’ in Figure 51. In this case, the STEP file is missing the dimension modifier for a reference dimension. The visual presentation of the dimension shows that parentheses for a reference dimension are missing.

The feature count for a repetitive dimension, e.g., ‘4X’ and ‘2X’, in cells D6 and D7, respectively, are derived from the number of geometric surfaces in the associated geometry in column I. In this example, the feature count is half the number of cylindrical_surface entities in cells I6 and I7. This assumes that a cylindrical hole is modeled with two half cylindrical surfaces.

<table>
<thead>
<tr>
<th></th>
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<th>Dimensional Tolerance (Sec. 5.1.1, 5.1.5)</th>
<th>Dimension name (Sec. 5.1.1, 5.1.5)</th>
<th>length/angle (Sec. 5.2.1)</th>
<th>length/angle name (Sec. 5.2.1)</th>
<th>plus minus bounds (Sec. 5.2.3)</th>
<th>Associated Geometry (Sec. 5.1.1, 5.1.5)</th>
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<td>0.438 ± 0.005</td>
<td>diameter</td>
<td>0.438</td>
<td>nominal value</td>
<td>-0.005 0.005</td>
<td>(2) cylindrical_surface 22561 23771</td>
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<td>40201</td>
<td>0.438 ± 0.005</td>
<td>diameter</td>
<td>0.438</td>
<td>nominal value</td>
<td>-0.005 0.005</td>
<td>(2) cylindrical_surface 23851 23941</td>
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<td>(1) composite_group_shape_aspect 40196</td>
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<td>45336</td>
<td>0.625 ± 0.005</td>
<td>diameter</td>
<td>0.625</td>
<td>nominal value</td>
<td>-0.005 0.005</td>
<td>(8) cylindrical_surface 10716 10826 10996 11056 11216 11226 11336</td>
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<td>48741</td>
<td>0.438 ± 0.005</td>
<td>diameter</td>
<td>0.438</td>
<td>nominal value</td>
<td>-0.005 0.005</td>
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<td>0.09 ± 0.01</td>
<td>diameter</td>
<td>0.09</td>
<td>nominal value</td>
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<td>0.75</td>
<td>nominal value</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td>(2) shape_aspect 69380 69398</td>
</tr>
<tr>
<td>11</td>
<td>80071</td>
<td>0.82 ± 0.05</td>
<td>linear distance</td>
<td>0.82</td>
<td>nominal value</td>
<td>-0.09 0.09</td>
<td>(2) plane 12212 12394</td>
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<td></td>
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<td></td>
<td>(2) advanced_face 11711 14501</td>
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<td></td>
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<tr>
<td>12</td>
<td>81310</td>
<td>0.065 ± 0.003</td>
<td>diameter</td>
<td>0.065</td>
<td>nominal value</td>
<td>-0.003 0.003</td>
<td>(2) cylindricalsurface 25566 2666</td>
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<td></td>
<td></td>
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<td></td>
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<td>(1) composite_group_shape_aspect 83116</td>
</tr>
</tbody>
</table>

Figure 57: Dimensional tolerance example (columns A, D-I)

### 6.1.3.1 Rounding

The number of decimal places for dimension and geometric tolerance values can be specified in the STEP file. If specified, the value is always truncated. However, using the ‘Round dimensions and geometric tolerances’ option the values can be rounded instead. For example, the value 0.5625 could be truncated to 0.562, however, rounding will show 0.563. Rounding values might result in a better match to graphical PMI shown by the viewer or expected PMI in the NIST models (Sec. 6.6). This option is different than the Number Format option (Sec. 5.5.4).
6.1.4 Geometric Tolerances

The following examples show how geometric tolerances are modeled in a STEP file. Figure 58 and Figure 59 show the flatness_tolerance worksheet with the reconstructed visual presentation for the flatness tolerance.

- Column D is the magnitude of the flatness tolerance zone which is a reference to a length_measure_with_unit. As a convenience, the value of the length measure “0.005” is also shown.
- Column E is a reference to the tolerated_shape_aspect.
- Columns F and G define the unit-basis size and type for the flatness tolerance. Another unit-basis parameter in column H is not shown.
- Column I shows the visual presentation of the FCF for the flatness tolerance with the corresponding unit-basis and datum feature. It corresponds to the PMI annotations in Figure 51.
- Column J is the datum feature associated with the flatness tolerance.
- Column K shows the tolerated geometry associated with the flatness tolerance derived from the tolerated_shape_aspect attribute in column E. The advanced_face entity references the plane entity.
- Section 6.1.5 explains how tolerated geometry is important to relate geometric tolerances with dimensional tolerances and datum features.

The reconstructed visual presentation of the PMI representation is limited by the character set available in the spreadsheet. The flatness tolerance symbol (parallelogram) appears somewhat small and misshapen. The lines for the compartments of the feature control frame are not shown. The combination of the inverted triangle, vertical line, and ‘E’ in brackets represents the reference to datum feature ‘E’.

![Figure 58: Flatness tolerance example (columns A-H)](image)

![Figure 59: Flatness tolerance example (columns I-K)](image)
Figure 60 and Figure 61 show the position_tolerance worksheet with the reconstructed visual presentations of two position tolerances.

- Column D is the magnitude of the position tolerance zone. As a convenience, the value of the length measure “0.005” is also shown.
- Column E is a reference to the tolerated shape_aspect.
- Column F is a reference to the associated datum reference frame.
- Column G is the modifier applied to the tolerance zone.
- Column H shows the visual presentation of the position tolerances with their associated dimensions. An association between a geometric tolerance and dimension (or datum) is shown if each has the identical cylindrical_surface entities in the geometric tolerance Toleranced Geometry (Figure 61, Column J) and dimension Associated Geometry (Figure 57, cells 16 and 17).
- Column I shows the FCF of the dimensional tolerance, defined in Figure 57, associated with the position tolerance. The dimensional_size entities are referred to in column B of Figure 56.
- Column J shows the geometry, defined by the tolerated_shape_aspect attribute in column E, associated with the position tolerance.
- Section 6.1.5 explains how toleranced geometry is important to relate geometric tolerances with dimensional tolerances and datum features.

![Figure 60: Position tolerance example (columns A-G)](image)

![Figure 61: Position tolerance example (columns H-J)](image)
### 6.1.5 Associated and Toleranced Geometry

The previous examples for dimensional and geometric tolerances show columns for associated and tolerated geometry. The relationship between the geometries is important to understand how the visual presentation of the feature controls frames (FCF) in Figure 59 and Figure 61 are constructed. Figure 62 shows one of the position tolerances from Figure 51 where the FCF contains a position tolerance, hole dimension, and datum feature.

![Figure 62: Position tolerance feature control frame](image)

Cell G4 in Figure 63 shows the visual presentation of the FCF based on the position tolerance, dimension tolerance, and datum feature. The key to the visual presentation is that all three components of the FCF refer to the same geometric entities. The tolerated geometry for the position tolerance in cell J4 should be read from bottom to top. The composite_group_shape_aspect (CGSA) entity is from the tolerated_shape_aspect attribute on the position_tolerance entity. CGSA refers to two shape_aspect entities. Those two entities each refer to a single advanced_face entity which each refer to a cylindrical_surface entity. The two cylindrical_surface entities (#23831, #23941), highlighted in red, are the two half cylinders for the surfaces of the hole. Sometimes there is only one cylindrical_surface for a hole as described in Sec. 6.1.5.

<table>
<thead>
<tr>
<th>A</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>geometric_tolerance with datum reference</td>
<td>position</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>See</td>
<td>GD&amp;T</td>
<td>Dimensional Tolerance</td>
<td>Datum Feature</td>
</tr>
<tr>
<td>3</td>
<td>ID</td>
<td>Annotation</td>
<td>(Sec. 6.2)</td>
<td>(Sec. 6.5)</td>
</tr>
</tbody>
</table>
|   | 42056 | 0.438 ± .005      | dimensional_size 40171 | datum_feature 40517 | cylindrical_surface
|   | | | | | #23831, #23941 |
|   | 4 | | | | advanced_face 23916 23976 |
|   | | | | | shape_aspect 42006 42021 |
|   | | | | | composite_group_shape_aspect 42001 |

![Figure 63: Toleranced geometry for position tolerance](image)
Cell K5 in Figure 64 shows the associated geometry for the dimension tolerance in cell D5. Although the CGSA and shape_aspect entities are different than those in cell J4 of Figure 63, the advanced_face and cylindrical_surface (#23831, #23941) entities are identical. Therefore, the position and dimension tolerance are both associated with the same hole geometry. The associated geometry for dimensions is found through the applies_to attribute on dimensional_size and the relating_shape_aspect and related_shape_aspect attributes on dimensional_location.

Figure 64: Associated geometry for dimensional tolerance

Cell G5 in Figure 65 shows the associated geometry for datum feature ‘C’. In this case, the datum_feature entity refers directly to the advanced_face entities. Therefore, the datum feature is also associated with the same hole as the position and dimension tolerance. The datum feature is also directly associated with the position tolerance because the position_tolerance entity is a complex entity with geometric_tolerance_with_datum_reference that refers directly to the datum feature.

Figure 65: Associated geometry for datum feature

If an expected association between a geometric tolerance and a dimension or datum is not reported, then the associated geometry and tolerated geometry for each tolerance, dimension, and datum should be checked. A common problem is a position tolerance for a hole being associated with the surfaces of the hole cylinder and the corresponding hole diameter dimension only being associated with the circular edge of the hole and the hole surfaces.

In Figure 51 datum feature ‘E’ is associated with a surface profile tolerance. Datum feature ‘E’ is the surface of the tab. However, in Figure 69, datum feature ‘E’ is associated with two geometric tolerances shown in cells C21 and C28. Semantically both are correct since both tolerances refer to the same surface. There is no semantic information in the STEP file to specify which tolerance the datum feature is presented with.
6.1.5.1 Multiple Dimensions
In some cases, multiple dimensions might be associated with the same geometric entities. Figure 66 shows the warning message when multiple dimensions are detected. Cells D9 and D10 in Figure 67 show the multiple dimensions. In this example, there are two diameter dimensions with and without a tolerance value. Cells K9 and K10 in Figure 68 show the associated geometry for each dimension where they are both associated with the same cylindrical_surface entities (#10546, #10656). Multiple dimensions might also be reported for holes that have a counterbore, countersink, and depth.

Figure 66: Warning message for multiple dimensions

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>dimensional characteristic representation (10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>See C2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ID</td>
<td>Dimensional</td>
<td>dimension name</td>
<td>length/angle</td>
<td>length/angle name plus minus bounds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>-------------</td>
<td>----------------</td>
<td>-------------</td>
<td>-----------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>64886</td>
<td>01.500 ± .005</td>
<td>diameter</td>
<td>1.5</td>
<td>nominal value</td>
<td>-0.005 0.005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>67011</td>
<td>01.5</td>
<td>diameter</td>
<td>1.5</td>
<td>nominal value</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 67: Multiple dimensions example (columns D-H)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMI Representation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Associated Geometry (Sec. 5.1.1, 5.1.5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ID</td>
<td>PMI Representative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) cylindrical_surface 10546 10656</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>(2) advanced_face 10531 10691</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) shape_aspect 64826 64841</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) composite_group_shape_aspect 64821</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(2) advanced_face 10531 10691</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>(2) shape_aspect 66951 66956</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>(1) composite_group_shape_aspect 66946</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Multiple dimensions are associated with the same geometry. The identical information in this cell should appear in another Associated Geometry cell above.

Figure 68: Multiple dimensions example (column K)
6.1.6 PMI Representation Summary

As a convenience, all of the visual presentations of the datum reference frames, dimensional tolerances, and geometric tolerances are collected on the PMI Representation Summary worksheet shown in Figure 69. The annotations in column C are collected from column G in Figure 55, column D in Figure 57, column I in Figure 59, and column H in Figure 61. The annotations in column C correspond to the annotations shown in Figure 51.

![Figure 69: PMI Representation Summary worksheet](image)

If a STEP file that was generated from a NIST CAD model from the MBE PMI Validation and Conformance Testing Project [38] is processed and the file can be recognized as having been generated from one of the CAD models, then the PMI Representation Summary worksheet is color-coded by the expected PMI annotations (Sec. 6.6.1).
6.1.7 PMI Representation Coverage Analysis

Coverage analysis counts the number of occurrences of a PMI element in a STEP file. Figure 70 shows the worksheet that is generated for coverage analysis of PMI Representation. Column A in rows 4 through 26 contain different types of PMI elements related to geometric and dimensional tolerances. Tolerances and modifiers show their associated symbol. The numbers in parentheses refer to the sections in the CAx-IF recommended practice for the representation of PMI [37] where there is implementation guidance for that type of PMI element.

Column B contains the number of occurrences of that type of PMI element in the file. Comparing the count to the number of expected PMI elements is a way to verify the PMI in the STEP file and resolve and modeling issues. If a STEP file that was generated from a NIST CAD model is processed, then the PMI Representation Coverage worksheet is color-coded by the expected number of PMI elements (Sec. 6.6.2).

Figure 70: PMI Representation Coverage worksheet
Table 2 shows the complete list of PMI Elements that can appear in column A above. Tolerances and modifiers show their associated symbol. The numbers in parentheses refer to the sections in the CAX-IF recommended practice for the representation of PMI.

### Table 2: All PMI Elements for PMI Representation Coverage

<table>
<thead>
<tr>
<th>PMI Element</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>angularity_tolerance</td>
<td>Measure qualified</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>circular_runout_tolerance</td>
<td>Linear distance inner/outer (5.1.1)</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>coaxiality_tolerance</td>
<td>Derived feature (6.9.5)</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>concentricity_tolerance</td>
<td>Derived feature (6.9.5)</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>cylindricity_tolerance</td>
<td>Derived feature (6.9.5)</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>flatness_tolerance</td>
<td>Derived feature (6.9.5)</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>line_profile_tolerance</td>
<td>Derived feature (6.9.5)</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>parallelism_tolerance</td>
<td>Derived feature (6.9.5)</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>perpendicularity_tolerance</td>
<td>Derived feature (6.9.5)</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>position_tolerance</td>
<td>Derived feature (6.9.5)</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>roundness_tolerance</td>
<td>Derived feature (6.9.5)</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>straightness_tolerance</td>
<td>Derived feature (6.9.5)</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>surface_profile_tolerance</td>
<td>Derived feature (6.9.5)</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>symmetry_tolerance</td>
<td>Derived feature (6.9.5)</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>total_runout_tolerance</td>
<td>Derived feature (6.9.5)</td>
<td>(5.9.5)</td>
</tr>
<tr>
<td>tolerance zone diameter (6.9.2)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(5.9.2)</td>
</tr>
<tr>
<td>tolerance zone within a cylinder (6.9.2)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(5.9.2)</td>
</tr>
<tr>
<td>tolerance zone spherical diameter (6.9.2)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(5.9.2)</td>
</tr>
<tr>
<td>all_over &lt; (6.3)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(6.3)</td>
</tr>
<tr>
<td>all_grand &lt; (6.4.2)</td>
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</tr>
<tr>
<td>between &lt; (6.4.3)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(6.4.3)</td>
</tr>
<tr>
<td>affected plane tolerance zone (6.2.2.1)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(6.2.2.1)</td>
</tr>
<tr>
<td>projected &lt; (6.9.2)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(6.9.2)</td>
</tr>
<tr>
<td>non-uniform tolerance zone (6.9.2.3)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(6.9.2.3)</td>
</tr>
<tr>
<td>equality/disposed &lt; or &gt; (6.9.4)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(6.9.4)</td>
</tr>
<tr>
<td>tolerance with max value (6.9.5)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(6.9.5)</td>
</tr>
<tr>
<td>unit-basis tolerance (6.9.6)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(6.9.6)</td>
</tr>
<tr>
<td>composite tolerance (6.9.9)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(6.9.9)</td>
</tr>
<tr>
<td>intersection/orientation plane indicator</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(6.9.9)</td>
</tr>
<tr>
<td>dimensions (locationsize)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(5.1.1)</td>
</tr>
<tr>
<td>dimensional dimension (5.1.1)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(5.1.1)</td>
</tr>
<tr>
<td>angular dimension (5.1.2)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(5.1.2)</td>
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<td>angular size (5.1.6)</td>
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<td>directed dimension &lt; (5.1.1)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(5.1.1)</td>
</tr>
<tr>
<td>oriented dimensional location (5.1.3)</td>
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<td>(5.1.3)</td>
</tr>
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</tr>
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<td>location with path (5.1.7)</td>
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<td>(5.1.7)</td>
</tr>
<tr>
<td>repetitive dimensions 'X' (5.1.1, User Guide 5.1.5)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(5.1.5)</td>
</tr>
<tr>
<td>dimension association to geometric tolerance (5.1)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(5.1)</td>
</tr>
<tr>
<td>bilateral tolerance (5.2.3)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(5.2.3)</td>
</tr>
<tr>
<td>non-bilateral tolerance (5.2.3)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(5.2.3)</td>
</tr>
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<td>(5.2.4)</td>
</tr>
<tr>
<td>limits and fits (5.2.5)</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(5.2.5)</td>
</tr>
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<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(6.5.1)</td>
</tr>
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<td>spherical diameter [5.1.5]</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(5.1.5)</td>
</tr>
<tr>
<td>spherical radius [5.1.5]</td>
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<td>(5.1.5)</td>
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<td>curved distance [5.1.1]</td>
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<td>(5.1.1)</td>
</tr>
<tr>
<td>linear distance [5.1.1]</td>
<td>Datum feature association to geometric tolerance (6.1)</td>
<td>(5.1.1)</td>
</tr>
</tbody>
</table>
6.2 PMI Presentation (Graphical PMI)

PMI presentation (also known as graphical PMI) presents GD&T annotations as a visual representation of geometric elements such as lines and arcs as part of the CAD model, i.e., how the annotation is drawn on the model. PMI presentation is not intended to be computer-interpretable and does not carry any semantic representation information although it can be linked to its corresponding semantic representation. The CAx-IF defines recommended practices for PMI presentation [37]. Syntax errors related to nonconformance to the recommended practices are highlighted in red in the Status tab and in the relevant entity worksheets (Sec. 6.5).

Figure 71 through Figure 73 show how PMI presentation is reported in the spreadsheet. The report for PMI presentation only contains information about the graphical elements (points, lines, colors) needed to draw PMI annotations. PMI presentation information is always reported on the annotation_curve_occurrence (as in this example), tessellated_annotation_occurrence, or annotation_occurrence worksheets.

- Columns B, C, and D show the entity attributes.
- Column E shows the name attribute of the geometric_curve_set in column D.
- Column F shows the element attributes of the geometric_curve_set. In this case, the elements refer to polyline entities.
- Column G shows the curve_style associated with the presentation_style_assignment in column C.
- Column H shows the color associated with the curve_style in column G.
- Column I shows the annotation plane associated with the annotation.
- Column J shows the geometry that the annotation is attached to. If associated geometry is missing, then there is no cross-highlighting between the annotation and geometry.
- Column K shows the associated PMI representation entities.
- Not shown are columns for PMI presentation validation properties and Saved Views.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>annotation_curve_occurrence</td>
<td>Linear Size.1</td>
<td>(1) presentation_style_assignment 35731</td>
<td>geometric_curve_set 35728</td>
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<tr>
<td></td>
<td>Simple Datum.2</td>
<td>(1) presentation_style_assignment 36191</td>
<td>geometric_curve_set 36186</td>
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<tr>
<td></td>
<td>Perpendicularity.1</td>
<td>(1) presentation_style_assignment 37051</td>
<td>geometric_curve_set 37046</td>
</tr>
<tr>
<td></td>
<td>Linear Size.2</td>
<td>(1) presentation_style_assignment 40126</td>
<td>geometric_curve_set 40121</td>
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<td></td>
<td>Simple Datum.3</td>
<td>(1) presentation_style_assignment 40506</td>
<td>geometric_curve_set 40501</td>
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</tbody>
</table>

Figure 71: PMI presentation example (columns A-D)
### Figure 72: PMI presentation example (columns E-H)

<table>
<thead>
<tr>
<th></th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>name</td>
<td>elements</td>
<td>presentation style</td>
<td>color</td>
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<td></td>
<td>(Sec. 8.4)</td>
<td>(Sec. 8.1.1)</td>
<td>(Sec. 8.5)</td>
<td>(Sec. 8.5)</td>
</tr>
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<td>draughting_pre_defined_colour 35734</td>
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<td></td>
<td>33361 33656 33726 33896 33986 34016 34106 34196 34226 34316</td>
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<td></td>
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</tr>
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<td>5</td>
<td>datum</td>
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<td>draughting_pre_defined_colour 36194</td>
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<td>draughting_pre_defined_colour 37054</td>
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<td>36841 36906 36936 36961 37011 37041</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
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<td>(35) polyline 37756 38011 38121 38261 38381 38411 38501 38521 38621 38712</td>
<td>curve_style 40127</td>
<td>draughting_pre_defined_colour 40129</td>
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<td></td>
<td></td>
<td>39731 39821 40021 40046 40071 40085 40101 40116</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>datum</td>
<td>(4) polyline 40426 40456 40471 40496</td>
<td>curve_style 40507</td>
<td>draughting_pre_defined_colour 40509</td>
</tr>
</tbody>
</table>

### Figure 73: PMI presentation example (columns I-K)

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>J</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>plane</td>
<td>Associated Geometry</td>
<td>Associated Representation</td>
</tr>
<tr>
<td></td>
<td>(Sec. 9.1)</td>
<td>(Sec. 9.3.1)</td>
<td>(Sec. 7.3)</td>
</tr>
<tr>
<td>4</td>
<td>annotation_plane 69451 (ProjView.1)</td>
<td>(2) cylindrical_surface 23661 23771</td>
<td>dimensional_size 35801</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) advanced_face 23745 23806</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) shape_aspect 35771 35786</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) composite_group_shape_aspect 35766</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>annotation_plane 69451 (ProjView.1)</td>
<td>(2) cylindrical_surface 23661 23771</td>
<td>datum_feature 36202</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) advanced_face 23745 23806</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) datum_feature 36202</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>annotation_plane 69451 (ProjView.1)</td>
<td>(2) cylindrical_surface 23661 23771</td>
<td>perpendicularity_tolerance 37116</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) advanced_face 23745 23806</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) shape_aspect 37066 37081</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) composite_group_shape_aspect 37061</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>annotation_plane 69451 (ProjView.1)</td>
<td>(2) cylindrical_surface 23831 23941</td>
<td>dimensional_size 40171</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) advanced_face 23916 23976</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) shape_aspect 40141 40156</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) composite_group_shape_aspect 40136</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>annotation_plane 69451 (ProjView.1)</td>
<td>(2) cylindrical_surface 23831 23941</td>
<td>datum_feature 40517</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) advanced_face 23916 23976</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) datum_feature 40517</td>
<td></td>
</tr>
</tbody>
</table>
### 6.2.1 PMI Presentation Coverage Analysis

Coverage analysis counts the number of occurrences of a PMI element in a STEP file. Figure 74 shows the worksheet that is generated for coverage analysis of PMI presentation. Rows 4 through 35 of column A contain the recommended names [37] that can be associated with a PMI annotation. The names correspond to the values in column E in Figure 72. There is no semantic meaning associated with the names. PMI presentation assumes a semantic meaning through its association with PMI representation as shown in column K of Figure 73.

![PMI Presentation Coverage worksheet](image-url)

**Figure 74: PMI Presentation Coverage worksheet**
6.3 Validation Properties

Validation properties are an important tool to verify the information in a STEP file. The properties include geometric, PMI, assembly, annotation, attribute, and tessellated validation properties. For example, geometric validation properties are characteristics of solid and surface models, such as area, volume, and centroid. Geometric validation properties could be written to a STEP file when it is exported from a CAD system. When the STEP file is imported to a receiving CAD system, that system can compute the same validation properties and compare them to the values from the originating system in the STEP file. If the computed validation properties are within an agreed tolerance to the original validation properties, then the exchange of geometric information has been validated. The CAx-IF defines recommended practices for validation properties [39]. Syntax errors related to nonconformance to the recommended practices are highlighted in red in the Status tab and in the relevant entity worksheets (Sec. 6.5).

Figure 75 and Figure 76 show a validation properties report. The report always appears on the `property_definition` worksheet. The rows can be sorted by any of the column attributes. The validation properties are shown in the yellow and green columns E, G, I, K, and M. Row 3 contains the names of the type of value in those columns. Properties not colored yellow and green are not validation properties as defined by the recommended practice. The values in cells I7, I10, and I16 are cartesian coordinates. Empty cells E13 and E14 show that values for those attributes were not specified in the STEP file. If no values for units and exponent appear in rows K and M, then none are required based on the type of value in row I.

The hidden columns F, H, J, L, and N can be shown by clicking on the plus (+) signs above the columns or the “2” in the upper left corner. Those columns contain the entity attribute name and ID for the corresponding validation property value in the column to the left. Opening the hidden columns shows where the validation property values come from in the STEP file. The hidden columns F, H, and J are shown in Figure 77. Columns L, M, and N are not shown. For example, the value in cell G4 “surface area measure” comes from the `measure_representation_item` name attribute of entity ID 393. The expanded columns can be hidden again by clicking on the minus (-) signs above the columns or the “1” in the upper left corner.

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>ID</td>
<td>name</td>
<td>description</td>
<td>definition</td>
</tr>
<tr>
<td>4</td>
<td>388</td>
<td>shape for solid data with which properties are associated</td>
<td>shape_aspect 384</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>389</td>
<td>geometric validation property</td>
<td>area of C1_SOLID</td>
<td>shape_aspect 384</td>
</tr>
<tr>
<td>6</td>
<td>401</td>
<td>geometric validation property</td>
<td>volume of C1_SOLID</td>
<td>shape_aspect 384</td>
</tr>
<tr>
<td>7</td>
<td>407</td>
<td>geometric validation property</td>
<td>centroid of C1_SOLID</td>
<td>shape_aspect 384</td>
</tr>
<tr>
<td>8</td>
<td>416</td>
<td>geometric validation property</td>
<td>area of C1_SOLID</td>
<td>product_definition_shape 383</td>
</tr>
<tr>
<td>9</td>
<td>425</td>
<td>geometric validation property</td>
<td>volume of C1_SOLID</td>
<td>product_definition_shape 383</td>
</tr>
<tr>
<td>10</td>
<td>428</td>
<td>geometric validation property</td>
<td>centroid of C1_SOLID</td>
<td>product_definition_shape 383</td>
</tr>
<tr>
<td>11</td>
<td>482</td>
<td>volume validation property</td>
<td>number of views of C1_SOLID</td>
<td>product_definition_shape 382</td>
</tr>
<tr>
<td>12</td>
<td>490</td>
<td>volume validation property</td>
<td>number of annotations of Default</td>
<td>(characterized_object) (draughting_model) 434</td>
</tr>
<tr>
<td>13</td>
<td>493</td>
<td>DESCRIPTION</td>
<td>user defined attribute</td>
<td>product_definition 382</td>
</tr>
<tr>
<td>14</td>
<td>493</td>
<td>MODELED BY</td>
<td>user defined attribute</td>
<td>product_definition 382</td>
</tr>
<tr>
<td>15</td>
<td>502</td>
<td>attribute validation property</td>
<td>part user attributes of C1_SOLID</td>
<td>product_definition_shape 383</td>
</tr>
<tr>
<td>16</td>
<td>513</td>
<td>geometric validation property</td>
<td>centroid of C1_SOLID</td>
<td>product_definition_shape 513</td>
</tr>
</tbody>
</table>

Figure 75: Validation properties example (columns A-D)
Validation properties are also reported on their associated annotation, dimension, geometric tolerance, and shape aspect entities. The report includes the validation property name and names of the properties. Some properties are reported only if the analysis for semantic PMI is selected. Other properties and user-defined attributes are also reported.

6.3.1 Semantic Text

Another type of validation property is known as semantic text where explicit text strings in the STEP file can be associated with part surfaces similar to semantic PMI. Figure 51 shows text strings SWITCH MOUNTING LOCATIONS and 2 COPLANAR SURFACES as graphical PMI. The semantic text will appear in the spreadsheet on shape_aspect and other related entities. A message in the Status tab will indicate when semantic text is added to entities.
### 6.4 Inverse Relationships

In a STEP schema, an entity attribute whose value consists of entity references, in which the referenced entity has attributes referring to the referencing attribute’s entity is called an inverse attribute. This establishes an inverse relationship [40] that is explicitly defined in a STEP schema.

Figure 78 is an entity worksheet for shape_aspect_relationship that shows the entity relationships established between the attribute values for relating_shape_aspect and related_shape_aspect in columns D and E.

![Figure 78: Entity worksheet (shape_aspect_relationship)](image)

Figure 79 and Figure 80 show how inverse relationships are shown on the datum entity based on shape_aspect_relationship shown above. Column G shows the relationship between datum and other entities. Column H, with the ‘Used In’ header, shows where datum is referred to from other entity attributes although not by an inverse relationship established by a STEP schema. The tooltip in the Options tab for the Inverse Relationships selection shows the list of entities for which some attributes with Inverse and Used In relationships that are reported.

![Figure 79: Inverse Relationships and Used In example (columns A-F)](image)
6.5 Syntax Errors

Syntax errors, related to nonconformance to a CAx-IF recommended practice, are highlighted in red in the Status tab and on the relevant entity worksheets. Figure 81 shows a syntax error displayed in the Status tab associated with an annotation_curve_occurrence entity while generating the PMI Presentation report. The second line of the syntax error refers to specific sections, figures, or tables in the relevant recommended practice that provides the guidance for the correct implementation of that information. Figure 82 shows a warning message highlighted in yellow related to dimensional_characteristic_representation.
Entity types that have any syntax or warning messages are highlighted in gray on the Summary worksheet as shown in Figure 83. The red triangle in the upper left corner of a cell indicates that there is a comment shown in the yellow box. Entities with errors are also highlighted in red in the Status tab with the messages about Formatting Worksheets.

![Figure 83: Entities with errors or warnings highlighted on Summary worksheet](image-url)

- There are Errors or Warnings for at least one entity of this type. See Help > Analyze > Syntax Errors.
Figure 84 shows the (characterized_representation)(draughting_model) worksheet where the syntax errors from Figure 81 are highlighted in cells C4 and C5. The comment is same text displayed in the Status tab in Figure 81. Although the syntax error was detected when processing annotation_curve_occurrence entities, the actual error is related to the items attribute on the (characterized_representation)(draughting_model) entity.

![Figure 84: Syntax error on (characterized_representation)(draughting_model)](image1.png)

Figure 85 shows the dimensional_characteristic_representation worksheet where the warning message from Figure 82 is shown with a comment for the cell in column L. The comment means that the associated geometry for this hole diameter is an edge curve when a hole diameter would usually be associated with cylindrical surfaces.

![Figure 85: Warning message on dimensional_characteristic_representation](image2.png)
There are also some other explanatory comments for the headings in row 3 on several types of worksheets as shown in Figure 86.

<table>
<thead>
<tr>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensional Tolerance</td>
<td></td>
<td><strong>See Help &gt; User's Guide (section 5.1.3) for an explanation of how the dimensions below are constructed. ***** Dimension units: INCH ***** Repetitive dimensions (e.g., 4X) might be shown for diameters and radii. They are computed based on the number of cylindrical, spherical, and toroidal surfaces associated with a dimension (see Associated Geometry column to the right) and, depending on the CAD system, might be off by a factor of two, have the wrong value, or be missing. ***** See the PMI Representation Summary worksheet to see how the Dimensional Tolerance below compares to the expected PMI.</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.000 ± .008 &lt;ST&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[1.250]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[1.250]</td>
<td>linear distance</td>
<td>1.25</td>
<td>nominal value</td>
<td></td>
<td>NR2 1.3</td>
</tr>
<tr>
<td>Ø10.000 ± .001</td>
<td>diameter</td>
<td>10.0</td>
<td>nominal value</td>
<td>-.001 0.001</td>
<td>NR2 2.3</td>
</tr>
<tr>
<td>[2.000]</td>
<td>linear distance</td>
<td>2.0</td>
<td>nominal value</td>
<td></td>
<td>NR2 1.3</td>
</tr>
<tr>
<td>[2.000]</td>
<td>linear distance</td>
<td>2.0</td>
<td>nominal value</td>
<td></td>
<td>NR2 1.3</td>
</tr>
</tbody>
</table>

**Figure 86: Cell comment for dimensional tolerances**
6.6 Color-coding Results for NIST CAD Models

If a STEP file is processed that was generated from a NIST CAD model from the MBE PMI Validation and Conformance Testing Project [38] and the file can be recognized as having been generated from one of the CAD models, then the PMI Representation Summary and PMI Representation Coverage worksheets are color-coded by the expected PMI annotations.

6.6.1 Representation Summary

The PMI Representation Summary worksheet is color-coded by the expected PMI annotations in a NIST test case drawing. Figure 87 is a color-coded worksheet for a STEP AP242 file generated from CAD model based on NIST test case CTC 5. A similar worksheet based on NIST test case CTC 3, without color-coding, is shown in Figure 69.

The color-coding is determined by comparing the expected PMI annotations for a NIST test case, that are stored in SFA, with the PMI Representation generated by SFA in column C. The comparison has nothing to do with the graphic PMI in the STEP AP242 file, only the semantic PMI.

The legend at the bottom of column C describes the color-coding.

- Green is an exact match to an expected PMI annotation in the NIST test case drawing.
- Cyan is a partial match.
- Yellow is a possible match.
- Red is no match.

For partial and possible matches, the best match to expected Similar PMI is shown in column D. At the bottom of column C are the expected Missing PMI annotations not found in the STEP file. The red triangles in the upper right corners of cells C3 and D3 indicate that there is a cell comment that explains the meaning of the cells in columns C and D.

In this example, cell C14 is missing the diameter symbol for a hole dimension. This means that the dimensional_characteristic_representation entity (#906) refers to a dimensional_location entity instead of a dimensional_size entity. Dimensional_size should almost always be used for hole diameters. Cell D14 shows the expected Similar PMI, from the NIST test case drawing for the hole diameter, that includes the diameter symbol.

Cell C15 is colored red because the reference dimension value ‘(2.500)’ found in the STEP file does not appear in the NIST test case drawing. Conversely, the missing PMI in cells C33 and C34 show that those two basic dimensions are found in the NIST test case drawing but not in the STEP file.

The shape of the placed datum targets in cells C18 and C19 are incorrect. This means that the description attributes on the placed_datum_target_feature entities (#1103, #1104) are ‘point’ instead of ‘rectangle’.

---

8 https://s3.amazonaws.com/nist-el/mfg_digitalthread/nist_ctc_05_asme1_rd.pdf
There are several problems with the `total_runout_tolerance` in cell C22. Because there are more problems it is colored yellow as a possible match. The magnitude of the tolerance zone is ‘.001’ instead of ‘.002’.

Figure 87: Color-coded PMI Representation Summary worksheet for CTC 5
The feature control frame (FCF) for the similar PMI in cell D22 shows that there is a dimension tolerance and datum feature associated with the geometric tolerance. Figure 88, from NIST test case drawing for CTC 5, shows a large inner diameter surface with the total runout tolerance. That surface also has a diameter dimension that is defined as datum feature ‘B’. Semantically, those three PMI elements all refer to the same large inner diameter surface in the test case drawing. Therefore, the similar PMI in cell D22 is also a correct visual presentation of the FCF for the PMI annotation. Cell C22 is missing the diameter dimension and datum feature because the geometric tolerance is not associated with the same geometric surfaces as the diameter dimension and datum feature. This can be confirmed by checking the tolerated or associated geometry for the total_runout_tolerance, the dimensional_characteristic_representation, and datum_feature. The geometric tolerance must have the exact same tolerated or associated geometry to be able to show the FCF in cell C22 as it appears in cell D22. The association of tolerated and associated geometry is described in Sec. 6.1.5.

![Figure 88: Feature from NIST CTC 5](image)

The roundness_tolerance in cell C20 has the exact same associated geometry as datum feature ‘A’. Therefore, the FCF appears correct and is colored green.

Trailing and leading zeros are ignored when matching a PMI annotation to the expected PMI. Matches also only consider the current capabilities of PMI in STEP AP242 and CAX-IF Recommended Practices. For example, PMI annotation symbols for counterbore, countersink, and depth are ignored although they might appear in the corresponding CAD model.

Some causes of partial and possible matches are:

- missing associations of a geometric tolerance with a datum feature or dimension
- missing diameter and radius symbols
- wrong feature counts for repetitive dimensions
- wrong dimension or tolerance zone values
- missing or wrong values for dimension tolerances
- missing or wrong datum reference frames
- missing datum features
- missing or incorrect modifiers for dimensions, tolerance zones, and datum reference frames
- missing composite tolerances
6.6.2 Representation Coverage Analysis

The PMI Representation Coverage worksheet is color-coded by the expected number of PMI elements for a NIST test case. The expected number of PMI elements was determined by manually counting them in each test case drawing, similar to Figure 51, for the NIST test cases. The color-coded worksheet is shown in Figure 89. A similar worksheet without color-coding is shown in Figure 70.

If more or less than the expected number of PMI elements was found, then the first value of two is the number found and the second is the expected number. For example, ‘2/3’ means that two PMI elements were found when three were expected. Counting of some modifiers, e.g., maximum material condition in row 24, does not differentiate whether the modifier appears in the tolerance zone definition or datum reference frame.

A legend describing the colors is in column D of Figure 89.

- A green cell is a match to the expected number of PMI elements.
- Cyan means that more were found than expected, e.g., ‘4/3’.
- Yellow, yellow-green, and orange mean that less were found than expected, e.g., ‘2/3’.
- Red means that no instances of an expected PMI element were found, e.g., ‘0/3’
- Magenta means that PMI elements were found when none were expected, e.g., ‘1/0’

In this example, there is one extra dimensional location (cell B13). This is also apparent from cell B11 which counts that total number of dimensions in cells B12 and B13. Cell B24 shows that the saved view is missing.

A cell color other than green might mean that a CAD system or translator

- did not or cannot correctly create in the CAD model, a PMI element defined in a NIST test case,
- did not follow CAx-IF Recommended Practices for PMI [37],
- has not implemented exporting a PMI element to a STEP file, or
- mapped an internal PMI element to the wrong STEP PMI element.

Some of the NIST test cases have complex PMI annotations that are not commonly used. There might be ambiguities in counting the number of PMI elements.

6.6.2.1 Color-coding Expected PMI

From the PMI Representation Summary results in Figure 87, color-coded percentages of exact, partial, and possible matches to Expected PMI and missing PMI is shown in a table below the PMI Representation Coverage Analysis in Figure 89 in rows 29 through 35. The Total PMI on which the percentages are based on is also shown. Coverage Analysis is only based on individual PMI elements. The PMI Representation Summary is based on the entire PMI feature control frame and provides a better understanding of the PMI. The Coverage Analysis might show that there is an exact match for all of the PMI elements, however, the Representation Summary might show less than exact matches.

For example, if a STEP file has the correct number of dimensions, the dimension PMI elements will be colored green. This does not mean that the dimension values are correct. Those incorrect dimension values are not reflected in the PMI Coverage Analysis. Incorrect values would show up as partial or possible matches in Figure 87. Those partial or possible matches would show up in the second table in Figure 89.
### Figure 89: Color-coded PMI Representation Coverage worksheet

<table>
<thead>
<tr>
<th>PMI Element</th>
<th>Count</th>
<th>Values as Compared to NIST Test Case Drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>angularity_tolerance △</td>
<td>1</td>
<td>See Help &gt; Analyze &gt; NIST CAD Models</td>
</tr>
<tr>
<td>flatness_tolerance □</td>
<td>1</td>
<td>More than expected</td>
</tr>
<tr>
<td>perpendicularity_tolerance ⊥</td>
<td>2</td>
<td>Exact match</td>
</tr>
<tr>
<td>position_tolerance ⊙</td>
<td>6</td>
<td>Less than expected (upper third)</td>
</tr>
<tr>
<td>surface_profile_tolerance ⊥</td>
<td>3</td>
<td>Less than expected (middle third)</td>
</tr>
<tr>
<td>tolerance zone diameter (6.9.2)</td>
<td>7</td>
<td>Less than expected (lower third)</td>
</tr>
<tr>
<td>unit-basis tolerance (6.9.6)</td>
<td>1</td>
<td>None (0/n)</td>
</tr>
<tr>
<td>dimensions (location=size)</td>
<td>10/9</td>
<td>Unexpected (n/0)</td>
</tr>
<tr>
<td>dimensional location (5.1.1)</td>
<td>2</td>
<td>Not checked</td>
</tr>
<tr>
<td>dimensional size (5.1.5)</td>
<td>8/7</td>
<td></td>
</tr>
<tr>
<td>directed dimension (5.1.1)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>repetitive dimensions 'NX' (5.1, User Guide 6.1.3)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>dimension association to geometric tolerance (5.1)</td>
<td>8/7</td>
<td></td>
</tr>
<tr>
<td>bilateral tolerance (5.2.3)</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>diameter Ø (5.1.5)</td>
<td>8/7</td>
<td></td>
</tr>
<tr>
<td>linear distance (5.1.1)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>reference dimension (5.3)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>datum (6.5)</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>datum system (6.9.7)</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>datum feature association to geometric tolerance (6.1)</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>maximum material requirement (M) (6.9.3 or 6.9.7)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>saved views (9.4)</td>
<td>0/1</td>
<td></td>
</tr>
</tbody>
</table>

Section numbers above refer to the CAx-IF Recommended Practice for Representation and Presentation of PMI (AP242)

### Expected PMI

<table>
<thead>
<tr>
<th>Expected PMI</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exact match</td>
<td>96</td>
</tr>
<tr>
<td>Partial match</td>
<td>4</td>
</tr>
<tr>
<td>Possible match</td>
<td>0</td>
</tr>
<tr>
<td>Missing match</td>
<td>0</td>
</tr>
<tr>
<td>No match</td>
<td>4</td>
</tr>
<tr>
<td>Total PMI</td>
<td>28</td>
</tr>
</tbody>
</table>
7 Syntax Checker

The Syntax Checker checks for basic syntax errors and warnings in the STEP file related to missing or extra attributes, incompatible and unresolved entity references, select value types, illegal and unexpected characters, and other problems with entity attributes. Some errors might prevent SFA and other software from processing a STEP file.

There should not be any of these types of syntax errors in a STEP file. Errors should be fixed to ensure that the STEP file conforms to the STEP schema and can interoperate with other software. There are other validation rules defined by STEP schemas (where, uniqueness, and global rules, inverses, derived attributes, and aggregates) that are not checked. Conforming to the validation rules is also important for interoperability with STEP files.

The Syntax Checker can be run with function key F8 or when a Spreadsheet or View is generated. The Status tab might be grayed out when the Syntax Checker is running. The Syntax Checker works with any supported STEP schema.

Syntax checker results appear in the Status tab. If the Log File option is selected, the results are also written to a log file myfile-sfa-err.log. The syntax checker errors and warnings are not reported in the spreadsheet.

The Syntax Checker can also be run from the command-line version (Sec. 9) with the command line argument `syntax`. For example: `sfa-cl.exe myfile.stp syntax`

Syntax Checker errors and warnings are unrelated to those reported when CAx-IF Recommended Practices are checked with one of the Analyze options as described in Sec. 6.5.

Figure 90 is an example of syntax checking results. The number in parentheses is the line number in the STEP file where the error or warning was detected.

```
Syntax Checker results for: C:/Users/test/Documents/syntax-err.stp
Generated by the NIST STEP File Analyzer and Viewer

syntax-err(13497): error: Reference to #4410 is geometric_curve_set, not compatible with representation.
syntax-err(14027): error: Reference to #4451 is geometric_curve_set, not compatible with representation.
syntax-err(20059): warning: Illegal control directive in string.
syntax-err(20060): error: Expecting ',', found _3D in instead.
syntax-err(20060): warning: Illegal character ' ' in enum.
syntax-err(20060): warning: Illegal hyphens in keyword BS7752-1.
syntax-err(20060): warning: Unexpected character '{'.
syntax-err(20060): warning: Unexpected character '}'

syntax-err(22073): error: Reference to #4451 is geometric_curve_set, not compatible with representation.
syntax-err(22076): error: Reference to #4451 is geometric_curve_set, not compatible with representation.
syntax-err(68577): error: Reference to #67531 is axis2_placement_3d, not compatible with representation_map.
syntax-err(68577): error: Reference to #67533 is representation_map, not compatible with representation_item.
syntax-err(68579): error: Reference to #4191 is geometric_curve_set, not compatible with representation.
syntax-err(68580): error: Reference to #67531 is axis2_placement_3d, not compatible with representation_map.
syntax-err(68580): error: Reference to #67536 is representation_map, not compatible with representation_item.
syntax-err: warning: Unresolved reference to Instance #19750.
syntax-err: warning: Unresolved reference to Instance #19751.
syntax-err: warning: Unresolved reference to Instance #19752.
syntax-err: warning: Unresolved reference to Instance #19753.
syntax-err: warning: Lowercase letters used in keywords. (8 occurrences)
```

Figure 90: Syntax Checker results
8 Multiple STEP Files

Processing multiple STEP files at once is an easy way to process many STEP files with only a few mouse clicks and to compare entity usage and coverage of PMI representation and presentation across multiple STEP files.

There are two ways you can select multiple STEP files. The first is to use the Open Multiple STEP Files in a Directory option from the File menu as shown in Figure 4. You can select a directory in which all STEP files in that directory will be processed. Subdirectories of the selected directory can also be searched. The other way is to select multiple individual STEP files when using the Open STEP File(s) option from the File menu. Multiple STEP files can be selected in the Open STEP File(s) dialog by holding down the control or shift key when selecting files.

8.1 Summary Worksheet

When processing multiple STEP files, a second spreadsheet is generated in addition to the individual spreadsheets for each STEP file. The second spreadsheet contains a summary worksheet of the entities found in the multiple files and possible coverage worksheets for PMI representation and presentation as shown in Figure 91. In this example five STEP files were processed. Starting after row 9, column A lists all of the entity types in all five files. All of the entities (rows) are not shown. The entities in column A are grouped and colored according to the categories of entities in the Process section of the Options tab. Columns B through F contain the entity counts for each of the five STEP files. Column G is the total entity count for all of the files and column H is the total number of files that an entity appears in.

Row 1 is the top-level directory where all of the STEP files are located. Row 3 contains links to the individual spreadsheets. Row 4 contains the name of the STEP file and a link to it. The file name can also contain the file’s subdirectory. Clicking on the STEP file link will show it in whatever program is set to open STEP files (.stp file extension) on your computer. The links in rows 3 and 4 can be turned off in the Spreadsheet tab with the selections for Excel Options. Rows 5 through 9 contain, respectively, the file timestamp, software that generated the STEP file (blank in this example), the STEP AP from the file, the size of the STEP file, and the number of entities in the STEP file.

The gray cell B34 with the comment indicates that there is at least one perpendicularity_tolerance entity that has an error or warning (Sec. 6.5).
Figure 91: File Summary worksheet, multiple files (rows 31-56)

8.2 Coverage Analysis Worksheets

If PMI representation or presentation is found in the STEP file, then coverage analysis worksheets are generated.
8.2.1 PMI Representation Coverage Analysis

Figure 92 and Figure 93 show the worksheet that is generated for coverage analysis of PMI representation. The information on the worksheet is the same as described in Sec. 6.1.7. Columns B through F refer to five STEP files and contain the number of occurrences of that PMI element. Column G counts the total number of occurrences for all STEP files that contain that type of PMI element. In this example the cells are color-coded, as described in Sec. 6.6, because all five STEP files were generated from the NIST CAD models.

![PMI Representation Coverage worksheet, multiple files (rows 1-34)](image_url)
<table>
<thead>
<tr>
<th></th>
<th>PMI Representation Coverage worksheet, multiple files (rows 35-62)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>diameter Ø (5.1.5)</td>
</tr>
<tr>
<td>36</td>
<td>linear distance (5.1.1)</td>
</tr>
<tr>
<td>37</td>
<td>curve length (5.1.5)</td>
</tr>
<tr>
<td>38</td>
<td>dimension basic (5.3)</td>
</tr>
<tr>
<td>39</td>
<td>reference dimension (5.3)</td>
</tr>
<tr>
<td>40</td>
<td>datum (6.5)</td>
</tr>
<tr>
<td>41</td>
<td>datum system (6.9.7)</td>
</tr>
<tr>
<td>42</td>
<td>multiple datum features (6.9.8)</td>
</tr>
<tr>
<td>43</td>
<td>datum feature association to geometric tolerance (6.1)</td>
</tr>
<tr>
<td>44</td>
<td>all datum targets</td>
</tr>
<tr>
<td>45</td>
<td>point datum target (6.6.1)</td>
</tr>
<tr>
<td>46</td>
<td>rectangle datum target (6.6.1)</td>
</tr>
<tr>
<td>47</td>
<td>circle datum target (6.6.1)</td>
</tr>
<tr>
<td>48</td>
<td>least material requirement (6.9.3 or 6.9.7)</td>
</tr>
<tr>
<td>49</td>
<td>maximum material requirement (6.9.3 or 6.9.7)</td>
</tr>
<tr>
<td>50</td>
<td>statistical dimension &lt;ST&gt; (5.3)</td>
</tr>
<tr>
<td>51</td>
<td>saved views (9.4)</td>
</tr>
<tr>
<td>52</td>
<td>ISO modeling standard (4, Fig. 2)</td>
</tr>
<tr>
<td>53</td>
<td><strong>Section numbers above refer to the CAx-IF Recommended Practice for Representation and</strong></td>
</tr>
<tr>
<td>54</td>
<td><strong>Expected PMI</strong></td>
</tr>
<tr>
<td>55</td>
<td>Exact match</td>
</tr>
<tr>
<td>56</td>
<td>Partial match</td>
</tr>
<tr>
<td>57</td>
<td>Possible match</td>
</tr>
<tr>
<td>58</td>
<td>Missing match</td>
</tr>
<tr>
<td>59</td>
<td>No match</td>
</tr>
<tr>
<td>60</td>
<td>Total PMI</td>
</tr>
</tbody>
</table>
### 8.2.2 PMI Presentation Coverage Analysis

Figure 94 shows the worksheet that is generated for coverage analysis of PMI presentation. The information in the worksheet is the same as described in Sec. 6.2.1. Columns B through F refer to five STEP files and contain the number of occurrences of that PMI presentation name. Column G counts the total number of occurrences for all STEP files that contain that name.

![PMI Presentation Coverage worksheet, multiple files](image_url)

Figure 94: PMI Presentation Coverage worksheet, multiple files
9 Command-line Version

A command-line (console) version of SFA is available (sfa-cl.exe) that can be run from a Windows command prompt. SFA can also be accessed by or embedded in other programs. The command-line version will use the options that were last used in the GUI version of SFA. Figure 95 shows the options available for the command-line version.

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**Figure 95: Command-line version options**

To facilitate running the command-line version, the PATH environment variable can be set to include the directory where the command-line executables are located. A batch file can also be created to run the command-line executable. If the STEP file is not located in the same directory as the command-line executable, then the STEP file name should also include the directory pathname for the file. When the command-line version is run, feedback is provided that is similar to what is shown in the Status tab as shown in Figure 96. Error and warning messages are preceded with asterisks (*) and highlighted with a different font and background color.
**Figure 96: Command-line version output**
10 References

All websites were successfully accessed in October 2021.


