

Product Definition for Additive Manufacturing

Engineering Product Definition and Related Documentation Practices

This is a Draft Standard for Trial Use and comment. This Draft Standard is not an approved consensus standard of ASME nor is it an American National Standard. ASME has approved its issuance and publication as a Draft Standard only. Distribution of this Draft Standard for comment shall not continue beyond 1 year from the date of issuance. The content of this Draft Standard for Trial Use and comment was not approved through ASME's consensus process. Following the 1-year trial and comment period, this Draft Standard, along with comments received, will be submitted to a Consensus Committee or Project Team. The Consensus Committee or Project Team will review and revise this Draft Standard based, in part, upon experience during the trial term and resulting comments. A public review in accordance with established American National Standards Institute (ANSI) procedures is required at the end of the Trial-Use Period and before a Draft Standard for Trial Use is submitted to ANSI for approval as an American National Standard. Thereafter, it is expected that this Draft Standard (including any revisions thereto) will be submitted to ANSI for approval as an American National Standard. Suggestions for revision should be directed to the Secretary, Y14.46 Subcommittee using the following form: <http://go.asme.org/Y14CommentForm>.



Date of Issuance: November 15, 2017

This Draft Standard for Trial Use will be revised following the conclusion of the Trial-Use Period. There will be no written interpretations of the requirements of this Draft Standard for Trial Use issued.

ASME is the registered trademark of The American Society of Mechanical Engineers.

The Standards Committee that approved the Draft Standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate.

ASME does not “approve,” “rate,” or “endorse” any item, construction, proprietary device, or activity.

ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a (draft) standard against liability for infringement of any applicable letters patent, nor assume any such liability. Users of a code or (draft) standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this draft standard.

No part of this document may be reproduced in any form,
in an electronic retrieval system or otherwise,
without the prior written permission of the publisher.

The American Society of Mechanical Engineers
Two Park Avenue, New York, NY 10016-5990

Copyright © 2017 by
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
All rights reserved
Printed in U.S.A.

CONTENTS

Foreword	v
Committee Roster	vi
1 General	1
2 Definitions	3
3 Supplemental Geometry	5
4 Product and Process Definition Requirements	8
5 Product Data Packages (PDP)	28
Nonmandatory Appendices	
A Example AM Notes	31
B Defining Transition Regions	32
C Reference Documents to Test for Conformance	35
Figures	
3-1 Single Coordinate System Related to the Model	5
3-2 Multiple Coordinate Systems	6
3-3 Unit Vector Indicating Build Direction	6
3-4 Unit Vector Indicating Gravity Direction	7
3-5 A Surface Representing a Build Surface	7
4-1 Example of a Theoretical Supplemental Surface Used on a Rectangular Lattice Cuboid	8
4-2 Example of a Theoretical Supplemental Surface Within a Rectangular Lattice Cuboid	9
4-3 Example of a Nonplanar Theoretical Supplemental Surface	9
4-4 Example of a Tolerance Zone Derived From Figure 4-3	10
4-5 Both Bounded Volume and Surface Regions to Indicate Internal and External Surfaces and Volumes	10
4-6 Bounded Volume Region Indicator (VOL1) With a Profile of a Surface Tolerance	11
4-7 Multiple Bounded Volume Region Indicators With Profiles of Surface Tolerances	11
4-8 Bounded Volume Regions Represented by Several Bounded Volume Region Indicators in a Single Part	12
4-9 Bounded Surface Region Indicator Coupled With a Feature Control Frame	12
4-10 Examples of Unit Cell Geometries and Lattice Structures	13
4-11 Lattice Structure With Multiple Bounded Volume Regions	14
4-12 VOL Local Notes That Describe Material Gradient Allocations Shown in Table 4-1	15
4-13 Material Transition Specification Between Bounded Volume Regions With Lattice Fill	16
4-14 Complex Geometries Generated From Topology Optimization	17
4-15 Wrench Produced as a Single Build With Three Parts	18
4-16 Build Direction Indicated Using the Direction Unit Vector	18
4-17 Multiple Build Directions	19
4-18 Planar Build Surface and a Nonplanar Build Surface	19
4-19 Identifying Build Location With Respect to a Specified Build Surface	20

4-20	Coordinate Systems Are Used to Locate Parts Within a Build Envelope	20
4-21	Four Separate Parts Nested Inside One Another on a Build Surface	21
4-22	Free Zone Description With an Offset Dimension	21
4-23	Free Zone Bounding Box Description	22
4-24	Layer Thickness Specification	22
4-25	Specification of a Track Path With Three Contours	23
4-26	Specification of a Track Path Using a Follow Boundary (FB) Modifier	23
4-27	Specification of Track Paths on Different Layers	23
4-28	Examples of Infill and Unit Cells	24
4-29	Example Where Support Structure Location Is Not Specified	25
4-30	Example Where Bounded Surface Region 1 (SURF1) Is Annotated to Indicate a Structure Exclusion Area (SEA)	25
4-31	Example Where SURF1 Is Annotated to Indicate a Structure Limiting Area (SLA) of 20%	26
4-32	Example Where SURF1 Is Annotated to Indicate a Structure Required Area (SRA)	26
4-33	Indication of Geometry Created Inside the Part to Specify Support Structure	27
4-34	Local Notes Identifying Test Coupons	27
B-1	Part With Material Transition Region (Heterogeneous Material Indicator) and Specification of Tolerance	33
B-2	Acceptable Void Fractions for MAT1 and MAT2	33
B-3	Allowable Material Fractions for MAT1 and MAT2	34

Tables

4-1	Material Gradient Values Used in Figure 4-12	15
5-1	Required and Optional Data Packages for AM Products	28
5-2	Required and Optional Elements Within the AM Design DP	28
5-3	Required and Optional Elements Within the AM Build DP	29
5-4	Required and Optional Elements Within the AM Processed DP	29
5-5	Required and Optional Elements Within the End Product DP	29
5-6	Examples of AM Use Cases Using the Codes in ASME Y14.41.1 to Show the Level of Content in an AM Data Package (ADP)	30
5-7	Examples of Metadata Requirements for Model-Based Definition (MBD) Data Sets	30
B-1	Material Gradient Values (Figure 4-12)	32
C-1	Select Reference Documents	35

FOREWORD

General. The Charter of the Y14.46 Subcommittee was approved by the Y14 Standards Committee on October 10, 2014, with the task to develop requirements in geometric dimensioning and tolerancing for additive manufacturing (AM). The goal of the Subcommittee was to create a broadly accepted standard that incorporates, expands, or refines international practices and symbology to enable AM product definition data sets to be created, interpreted, and consumed on a global basis. The Subcommittee worked quickly over the course of 2 years to generate content, collaborate with other standards development organizations to avoid overlap, and review the resulting Draft Standard thoroughly; the Y14 Standards Committee approved this ASME Y14.46 Draft Standard for Trial Use on June 19, 2017. With that said, it is understood that there are many opportunities to continue to improve this Draft Standard, and many of these are currently identified as “forward work” as described in the next paragraph. AM is a large space where industry is thirsty for experienced product definition guidance. The Y14.46 Subcommittee has brought together subject matter experts (SMEs) who have generously volunteered a significant amount of time and resources to this effort over the last 2 years. The Subcommittee believes it prudent to release the Draft Standard as quickly as possible to test the proposed concepts for AM product definition. The Subcommittee welcomes comments and/or proposals for revisions to this Draft Standard; the required method of submittal is under “Submitting Comments and Proposing Revisions” below.

Forward Work Sections. Some subsections are introduced in this Draft Standard because the Subcommittee is aware of the need to address these topics. Work to enhance these sections is ongoing, and feedback from the public is welcome (see “Submitting Comments and Proposing Revisions” below). The following sections and subsections are identified as “forward work”:

4.2.3 Complex Geometry

4.2.4 Design for Assembly

Nonmandatory Appendix C Reference Documents to Test for Conformance

Submitting Comments and Proposing Revisions. Comments and proposals for revision should be directed to the Secretary, Y14.46 Subcommittee using the following form: <http://go.asme.org/Y14CommentForm>. Any proposals for revision should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

The comment form contains instructions on how to submit comments.

Attending Committee Meetings. The Y14 Standards Committee regularly holds meetings and/or telephone conferences that are open to the public. Persons wishing to attend any meeting and/or telephone conference should contact the Secretary of the Y14 Standards Committee. Future Committee meeting dates and locations can be found on the Committee Page at <http://go.asme.org/Y14Committee>.

ASME Y14 COMMITTEE

Engineering Product Definition and Related Documentation Practices

(The following is the roster of the Committee at the time of approval of this Draft Standard for Trial Use.)

STANDARDS COMMITTEE OFFICERS

W. A. Kaba, *Chair*
J. I. Miles, Sr., *Vice Chair*
F. J. Constantino, *Secretary*

STANDARDS COMMITTEE PERSONNEL

A. R. Anderson, Dimensional Dynamics, LLC
F. Bakos, Jr., Frank Bakos Associates
J. V. Burleigh, Consultant
F. J. Constantino, The American Society of Mechanical Engineers
D. O. Coon, Bell Helicopter
R. Courson, SAE International
K. Dobert, Siemens PLM Software, Inc.
S. Hauger, John Deere — MTIC
J. B. Hoskins, The Boeing Co.
J. Houck, Woodward, Inc.
R. C. Jensen, Hexagon Manufacturing Intelligence
W. A. Kaba, Spirit AeroSystems, Inc.

A. Krulikowski, Krulikowski Consulting, LLC
E. McCarthy, Consultant
P. J. McCuistion, Multimac
J. D. Meadows, James D. Meadows & Associates, Inc.
M. E. Meloro, Northrop Grumman Corp.
J. I. Miles, Sr., Dimensional Management
M. A. Murphy, General Motors Co., LLC
H. W. Oakes, U.S. Air Force (SAIC)
M. J. Stahl, Caterpillar, Inc.
B. A. Wilson, Consultant
E. F. Zwettler, Rolls-Royce Corp.
K. E. Wiegandt, *Contributing Member*, Consultant

SUBCOMMITTEE 46 — PRODUCT DEFINITION FOR ADDITIVE MANUFACTURING

J. Herron, *Chair*, Action Engineering, Inc.
P. Witherell, *Vice Chair*, National Institute of Standards and Technology
D. Alonzo, *Secretary*, The American Society of Mechanical Engineers
G. Ameta, Dakota
L. Bergquist, John Deere
C. Brown, Honeywell FM&T
S. Casey, The Boeing Co.
W. Cockrell, Raytheon
K. Delaurentis, U.S. Food and Drug Administration
A. Frey, U.S. Army

R. Lipman, National Institute of Standards and Technology
K. Losoncy, Orbital ATK Space Systems Group
J. Michalowicz, Stryker Orthopedics, Inc.
G. Nair, Lloyd's Register
T. Pilewicz, Rolls-Royce Corp.
S. Ramasamy, Apple
J. Schmelzle, Naval Air Systems Command
J. Sykes, Profile Services
D. Wallace, Youngstown State University
W. Weiss, NASA (IBW)
E. F. Zwettler, *Alternate*, Rolls-Royce Corp.

Y14.46 SUPPORT GROUP

P. Alaniz, Raytheon
C. Canetta, The MITRE Corp.
M. DiPrima, U.S. Food and Drug Administration
J. Houck, Woodward, Inc.
P. Huang, U.S. Navy
E. Kline, Naval Air Systems Command
B. Lucht, SAMPE
E. Morse, University of North Carolina, Charlotte

R. Nascimento, International TechneGroup (ITI)
M. Nielsen, Tech Azul
H. W. Oakes, U.S. Air Force (SAIC)
D. Rockwell, The Boeing Co.
B. Romero, Raytheon
H. Tran, Sandia National Laboratories
J. Van Horn, The Boeing Co.
L. Webster, The MITRE Corp.

PRODUCT DEFINITION FOR ADDITIVE MANUFACTURING

DRAFT STANDARD FOR TRIAL USE

1 GENERAL

1.1 Scope

This Draft Standard, hereafter referred to as “Standard,” covers definitions of terms and features unique to additive manufacturing (AM) technologies with recommendations for their uniform specification in product definition data sets and in related documents. Unless otherwise specified, any reference to features, parts, or processes shall be interpreted as applying to parts or assemblies manufactured using an AM process. Additively manufactured parts or assemblies are referred to as “parts” throughout the Standard. The Standard extends to capturing relevant AM detail from design, manufacturing, and quality engineering.

1.2 ASME Y14 Series Conventions

The conventions in [paras. 1.2.1](#) through [1.2.9](#) are used in this and other ASME Y14 standards.

1.2.1 Mandatory, Recommended, Guidance, and Optional Words

- (a) The word “shall” establishes a requirement.
- (b) The word “will” establishes a declaration of purpose on the part of the design activity.
- (c) The word “should” establishes a recommended practice.
- (d) The word “may” establishes an allowed practice.
- (e) The words “typical,” “example,” and “for reference” and the Latin abbreviation “e.g.” indicate suggestions given for guidance only.
- (f) The word “or” used in conjunction with a requirement or a recommended practice indicates that there are two or more options for complying with the stated requirement or practice.
- (g) The phrase “unless otherwise specified” (UOS) shall be used to indicate a default requirement. The phrase is used when the default is a generally applied requirement and an exception may be provided by another document or requirement.

1.2.2 Cross-Reference of Standards. Cross-reference of standards in text with or without a date following the standard designator shall be interpreted as follows:

- (a) Reference to other ASME Y14 standards in the text without a date following the standard designator indicates that the issue of the standard identified in the References section ([para. 1.5](#)) shall be used to meet the requirement.
- (b) Reference to other ASME Y14 standards in the text with a date following the standard designator indicates that only that edition of the standard shall be used to meet the requirement.

1.2.3 Invocation of Referenced Standards. The following examples define the invocation of a standard when specified in the References section ([para. 1.5](#)) and referenced in the text of this Standard:

- (a) When a referenced standard is cited in the text with no limitations to a specific subject or paragraph(s) of the standard, the entire standard is invoked. For example, “Dimensioning and tolerancing shall be in accordance with ASME Y14.5” is invoking the complete standard because the subject of the standard is dimensioning and tolerancing and no specific subject or paragraph(s) within the standard are invoked.
- (b) When a referenced standard is cited in the text with limitations to a specific subject or paragraph(s) of the standard, only the paragraph(s) on that subject are invoked. For example, “Assign part or identifying numbers in accordance with ASME Y14.100” is invoking only the paragraph(s) on part or identifying numbers because the subject of the standard is engineering drawing practices and part or identifying numbers is a specific subject within the standard.
- (c) When a referenced standard is cited in the text without an invoking statement such as “in accordance with,” the standard is for guidance only. For example, “For gaging principles, see ASME Y14.43” is only for guidance and no portion of the standard is invoked.

1.2.4 Parentheses Following a Definition. When a definition is followed by a standard referenced in parentheses, the standard referenced in parentheses is the source for the definition.

1.2.5 Notes. Notes depicted in this Standard in ALL UPPERCASE letters are intended to reflect actual product definition data. Notes depicted in initial uppercase or in lowercase letters are to be considered supporting data to the contents of this Standard and are not intended for literal entry into product definition data. A statement requiring the addition of a note with the qualifier “such as” is a requirement to add a note, and the content of the note is allowed to vary to suit the application.

1.2.6 Acronyms and Abbreviations. Acronyms and abbreviations are spelled out the first time they are used in this Standard, followed by the acronym or abbreviation in parentheses. The acronym is used thereafter throughout the text.

1.2.7 Units. The International System of Units (SI) is featured in this Standard. It should be understood that U.S. Customary units could equally have been used without prejudice to the principles established.

1.2.8 Figures. The figures in this Standard are intended only as illustrations to aid the user in understanding the practices described in the text. In some cases, figures show a level of detail as needed for emphasis. In other cases, figures are incomplete by intent so as to illustrate a concept or facet thereof. The absence of figure(s) has no bearing on the applicability of the stated requirements or practice. To comply with the requirements of this Standard, actual data sets shall meet the content requirements set forth in the text. To assist the user of this Standard, a list of the paragraph(s) that refer to an illustration appears in the lower right-hand corner of each figure. This list may not be inclusive. The absence of a list is not a reason to assume inapplicability. Some figures are illustrations of models in a three-dimensional (3D) environment. The absence of dimensioning and tolerancing annotations in a view may indicate that the product definition is defined in three dimensions. Dimensions that locate or orient and are not shown are considered basic and shall be queried to determine the intended requirement. When the letter “h” is used in figures for letter heights or for symbol proportions, select the applicable letter height in accordance with ASME Y14.2. Multiview drawings contained within figures are third angle projection.

1.2.9 Precedence of Standards. The following are ASME Y14 standards that are basic engineering drawing standards:

ASME Y14.1, Decimal Inch Drawing Sheet Size and Format
 ASME Y14.1M, Metric Drawing Sheet Size and Format
 ASME Y14.2, Line Conventions and Lettering
 ASME Y14.3, Orthographic and Pictorial Views
 ASME Y14.5, Dimensioning and Tolerancing
 ASME Y14.24, Types and Applications of Engineering Drawings
 ASME Y14.34, Associated Lists
 ASME Y14.35M, Revision of Engineering Drawings and Associated Documents
 ASME Y14.36M, Surface Texture Symbols
 ASME Y14.38, Abbreviations and Acronyms for Use on Drawings and Related Documents
 ASME Y14.41, Digital Product Definition Data Practices
 ASME Y14.100, Engineering Drawing Practices

All other ASME Y14 standards are considered specialty types of standards and contain additional requirements or make exceptions to the basic standards as required to support a process or type of drawing.

1.3 Dimensioning and Tolerancing

The methods of dimensioning and tolerancing shall be in accordance with ASME Y14.5, ASME Y14.41, and this Standard.

1.4 Examples

Where examples are provided, such lists are not exhaustive and other examples could be equally applicable.

1.5 References

The following editions of national and international standards and practices form a part of this Standard to the extent specified herein. A more recent revision may be used, provided there is no conflict with the text of this Standard. In the event of a conflict between the text of this Standard and the references cited herein, the text of this Standard shall take precedence.

ASME B46.1-2009, Surface Texture (Surface Roughness, Waviness, and Lay)

ASME B89.7 series, Measurement Uncertainty
 ASME Y14.2-2014, Line Conventions and Lettering
 ASME Y14.5-2009, Dimensioning and Tolerancing
 ASME Y14.8-2009, Castings, Forgings, and Molded Parts
 ASME Y14.24-2012, Types and Applications of Engineering Drawings
 ASME Y14.36M-1996, Surface Texture Symbols
 ASME Y14.37-2012, Composite Part Drawings
 ASME Y14.41-2012, Digital Product Definition Data Practices
 ASME Y14.41.1, 3D Model Organization Schema
 ASME Y14.100-2013, Engineering Drawing Practices
 Publisher: The American Society of Mechanical Engineers (ASME), Two Park Avenue, New York, NY 10016-5990
 (www.asme.org)

ASTM A1067/A1067M-12a, Standard Specification for Test Coupons for Steel Castings
 ASTM E1316-01, Standard Terminology for Nondestructive Examinations
 ASTM E2339-15, Standard Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE)
 ASTM F2971-13, Standard Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing
 ISO/ASTM 52900:2015, Standard Terminology for Additive Manufacturing — General Principles — Terminology
 ISO/ASTM 52915:2013, Standard Specification for Additive Manufacturing File Format (AMF) Version 1.1
 ISO/ASTM 52921:2013, Standard Terminology for Additive Manufacturing — Coordinate Systems and Test Methodologies
 Publishers: American Society for Testing and Materials (ASTM International), 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959 (www.astm.org)
 International Organization for Standardization (ISO), Central Secretariat, Chemin de Blandonnet 8, Case Postale 401, 1214 Vernier, Geneva, Switzerland (www.iso.org)

MPIF Standard 09, Definition of Terms Used in Powder Metallurgy
 Report on Preliminary Guidelines for Additive Manufacturing in Metallic Materials Property Development and Standardization (MMPDS) Handbook — DRAFT, ARL Penn State, 20 May 2015
 Standard Test Methods for Metal Powders and Powder Metallurgy Products, 2006 edition
 Publisher: Metal Powder Industries Federation (MPIF), 105 College Road East, Princeton, NJ 08540-6692
 (www.mpif.org)

2 DEFINITIONS

The following terms are defined as their use applies in this Standard. Additionally, throughout the Standard, definitions of italicized terms are given in subsections describing their application. Some definitions from ISO/ASTM and ASME standards are reproduced here, and the ownership of those definitions is indicated by the name of the standard after the term being defined.

additive manufacturing process: any process of additive manufacturing (AM), such as those defined by ISO/ASTM 52900.

bounded surface region: a surface subset within a part or on a part surface that is bounded by a set of connected or intersecting edges.

bounded volume region: a volume subset within a part that is bounded by a set of connected or intersecting surfaces.

bounding box (ISO/ASTM 52900¹): orthogonally oriented minimum perimeter cuboid that can span the maximum extents of the points on the surface of a 3D part.

build direction: the direction in which layers are added in an AM process to build a part.

build environment: the conditions in which a part is created.

build location: identification of the location of the build relative to the build platform.

build platform (ISO/ASTM 52900¹): of a machine, base which provides a surface upon which the building of the part/s is started and supported throughout the build process.

¹ Reprinted, with permission, from ISO/ASTM 52900:2015, Standard Terminology for Additive Manufacturing — General Principles — Terminology, copyright © ISO/ASTM International.

build surface (ISO/ASTM 52900¹): area where material is added, normally on the last deposited layer, which becomes the foundation upon which the next layer is formed. Discussion: For the first layer, the build surface is often the build platform.

build volume (ISO/ASTM 52900¹): total usable volume available in the machine for building parts.

complex geometry: combines features that cannot easily be characterized by concise equations or algorithms (e.g., nonlinear, nonrepeating, random, etc.).

coordinate system (ASME Y14.41): a representation of a Cartesian coordinate system in a product definition data set.

datum (ASME Y14.5): a theoretically exact point, axis, line, plane, or combination thereof derived from the theoretical datum feature simulator.

datum feature (ASME Y14.5): a feature that is identified with either a datum feature symbol or a datum target symbol.

end product (end item) (ASME Y14.24): an item, such as an individual part or assembly, in its final or completed state.

free zone: a type of bounded volume region that encloses the entire part and in which other parts cannot be located or intersected.

gradient control: specifies, with tolerance, how physical characteristics are varied spatially (e.g., changes in material composition, color, density, porosity, or unit cell size).

lattice structures (ISO/ASTM 52900¹): three dimensional geometric arrangement composed of connective links between vertices (points) creating a functional structure.

nesting (ISO/ASTM 52900¹): situation when parts are made in one build cycle and are located such that their bounding boxes, arbitrarily oriented or otherwise, will overlap.

part (ASME Y14.100): one item, or two or more items joined together, that is not normally subject to disassembly without destruction or impairment of designed use, e.g., transistor, composition resistor, screw, transformer, and gear.

product data package type: a specific product definition data set that defines a particular stage of manufacturing and conformance to specification.

product definition data (ASME Y14.41): denotes the totality of data elements required to completely define a product. Product definition data includes geometry, topology, relationships, tolerances, attributes, and features necessary to completely define a component part or an assembly of parts for the purpose of design, analysis, manufacture, test, and inspection.

product definition data set (ASME Y14.41): a collection of one or more data files that discloses, directly or by reference, by means of graphic or textual presentations or combinations of both, the physical or functional requirements of an item.

roughness (ASME B46.1): the finer spaced irregularities of the surface texture that usually result from the inherent action of the production process or material condition. These might be characteristic marks left by the processes listed in ASME B46.1, Nonmandatory Appendix B, Figure B-1.

support (ISO/ASTM 52900¹): structure separate from the part geometry that is created in order to provide a base and anchor for the part during the building process.

surface texture (ASME B46.1): the composite of certain deviations that are typical of the real surface. It includes roughness and waviness.

test coupon (ASTM A1067): a test specimen defined by a standard, produced for the purpose of obtaining test results that comply with the requirements of the applicable product standard, sometimes built at the same time as the part for additive manufacturing processes.

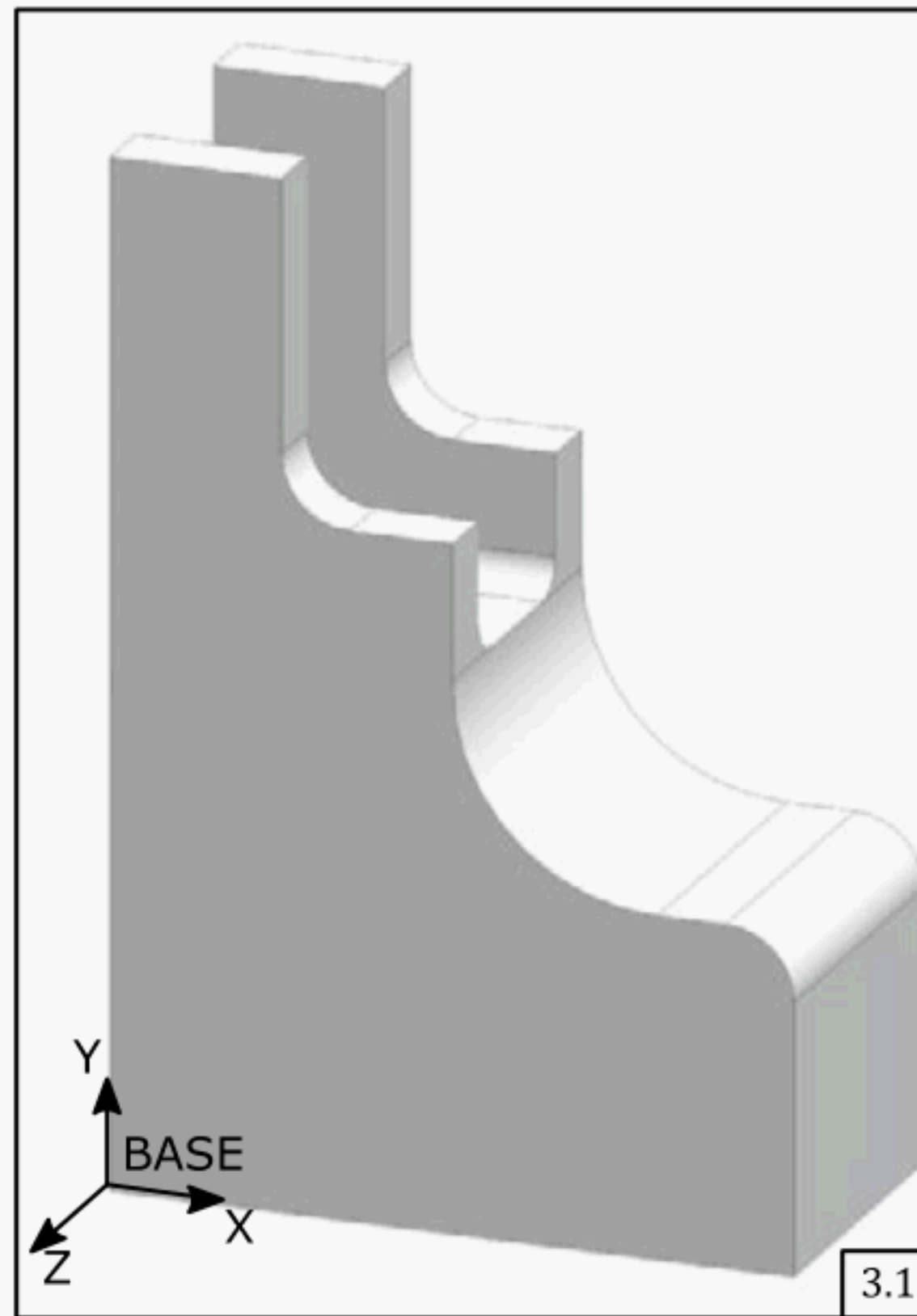
theoretical supplemental surface: supplemental geometry, explicitly defined in the design model and similar to true profile, that may be used to control the form, size, orientation, or location of a functional collection of points, lines, surfaces, or any combination thereof.

track path: the path through space that an AM tool follows on its way to producing the desired geometry of the layer.

transition region: a specific type of bounded region where gradient control applies.

waviness (ASME B46.1): the more widely spaced component of the surface texture. Waviness may be caused by such factors as machine or workpiece deflections, vibration, and chatter. Roughness may be considered as superimposed on a wavy surface.

Other terms related to AM, general product definition practices, and tolerances not defined in this Standard can be found in ASME Y14.5, ASME Y14.41, ISO/ASTM 52900, and ISO/ASTM 52921.

Figure 3-1 Single Coordinate System Related to the Model

3 SUPPLEMENTAL GEOMETRY

Supplemental geometry, such as coordinate systems, unit vectors, and surfaces, may be needed to support product definition data for AM. Datum features are used in this Standard for illustrative purposes. For additional information on datum features, refer to ASME Y14.5 and ASME Y14.41.

3.1 Coordinate System Identification

Coordinate systems shall be identified and labeled per ASME Y14.41. Associativity and representation of the coordinate systems shall be maintained in both native and derivative file formats. Single (see [Figure 3-1](#)) or multiple coordinate systems (see [Figure 3-2](#)) may be used.

NOTE: Alternative coordinate systems may be user defined.

3.2 Unit Vector Identification

If required, a unit vector shall be identified and may be related to a coordinate system or otherwise defined mathematically. Unit vector associativity and representation shall be maintained in both native and derivative file formats.

Examples of unit vectors include the following:

- (a) indication of build direction identified as "B DIR"; see [Figure 3-3](#)
- (b) indication of gravity direction identified as "G DIR"; see [Figure 3-4](#)

3.3 Surface Identification

If required, a surface shall be identified and be represented in native and derivative file formats.

An example of an identified build surface (BSURF) is shown in [Figure 3-5](#). Additional examples of surface identifications can be found in [para. 4.1](#).

Figure 3-2 Multiple Coordinate Systems

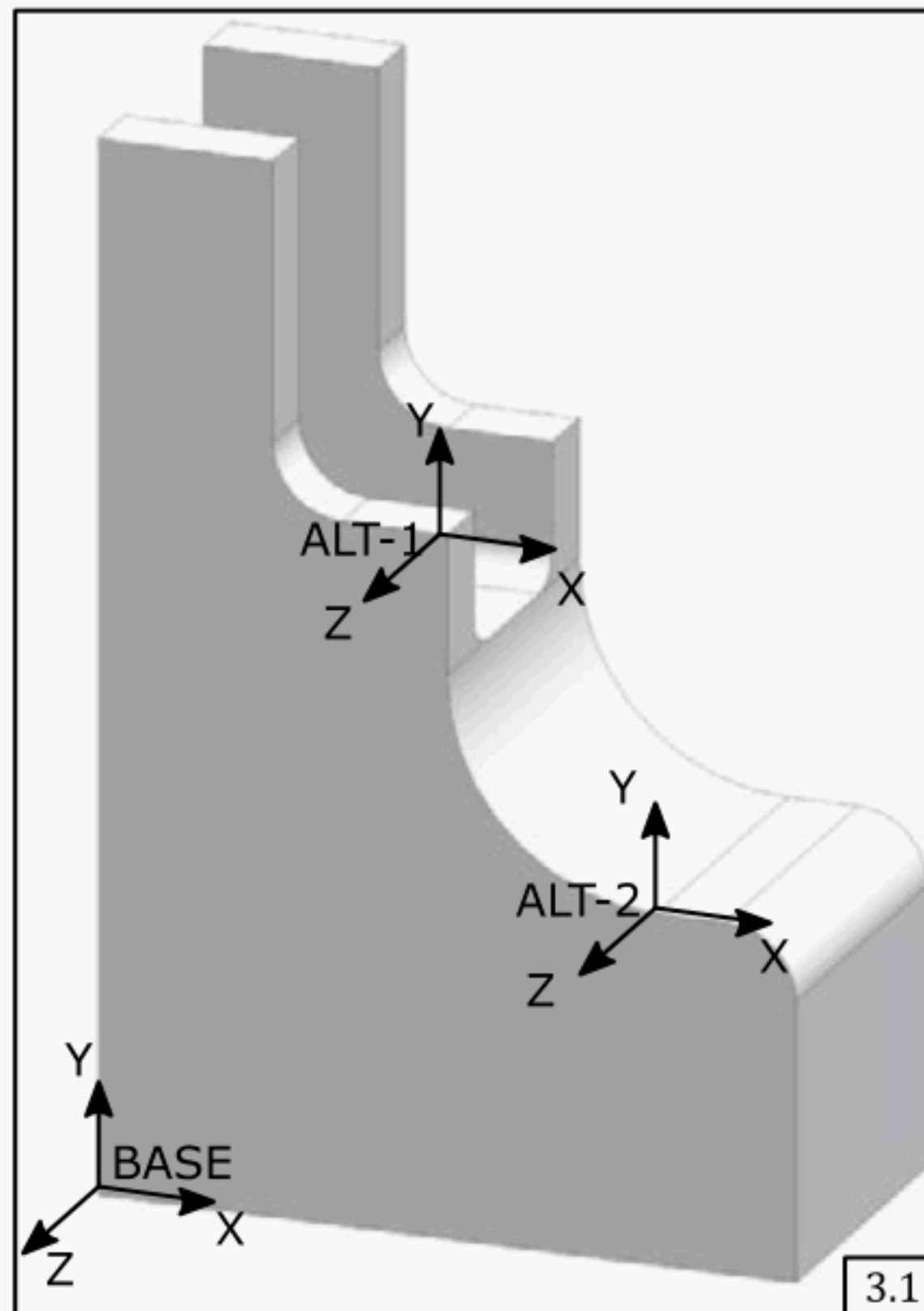


Figure 3-3 Unit Vector Indicating Build Direction

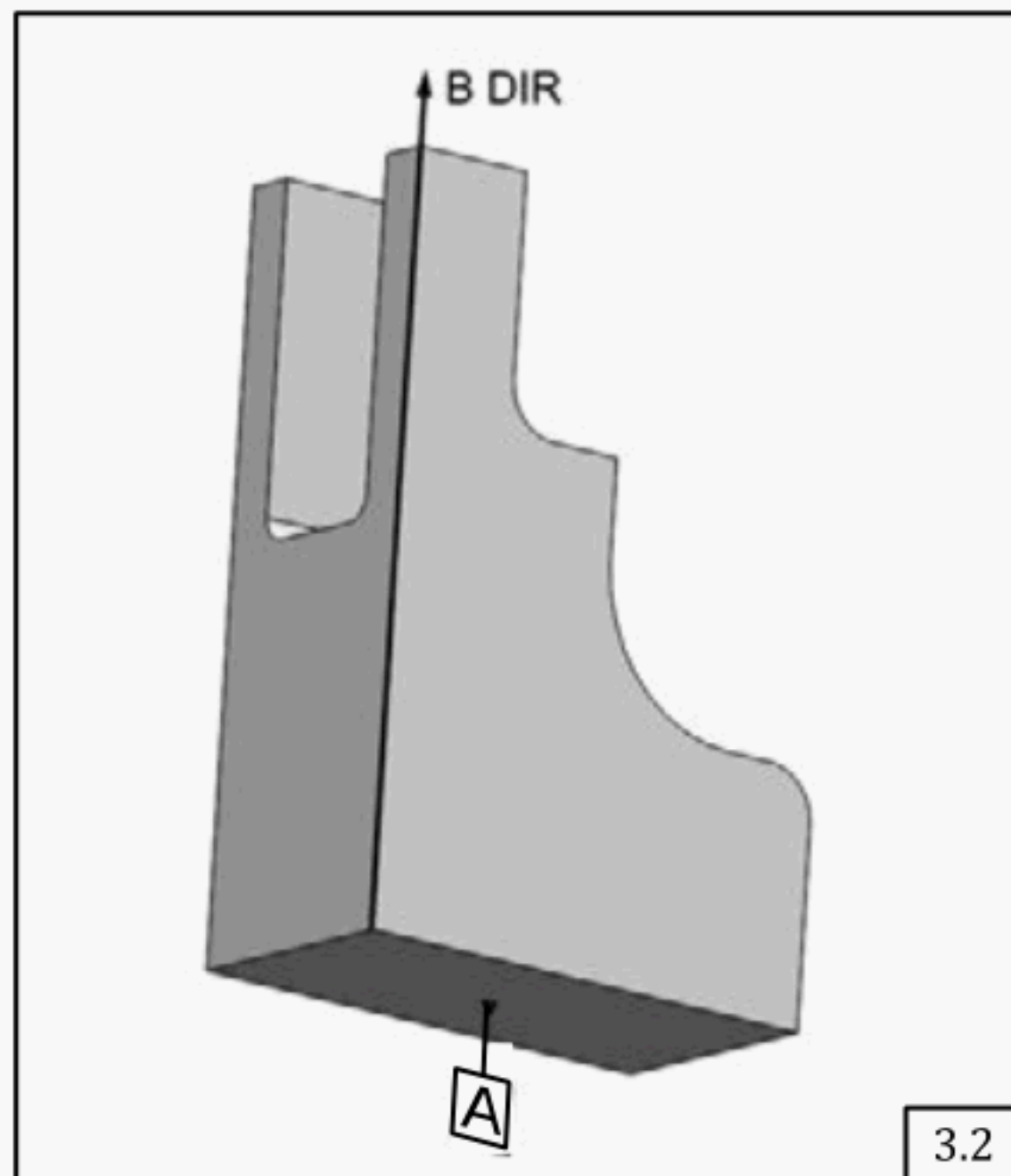


Figure 3-4 Unit Vector Indicating Gravity Direction

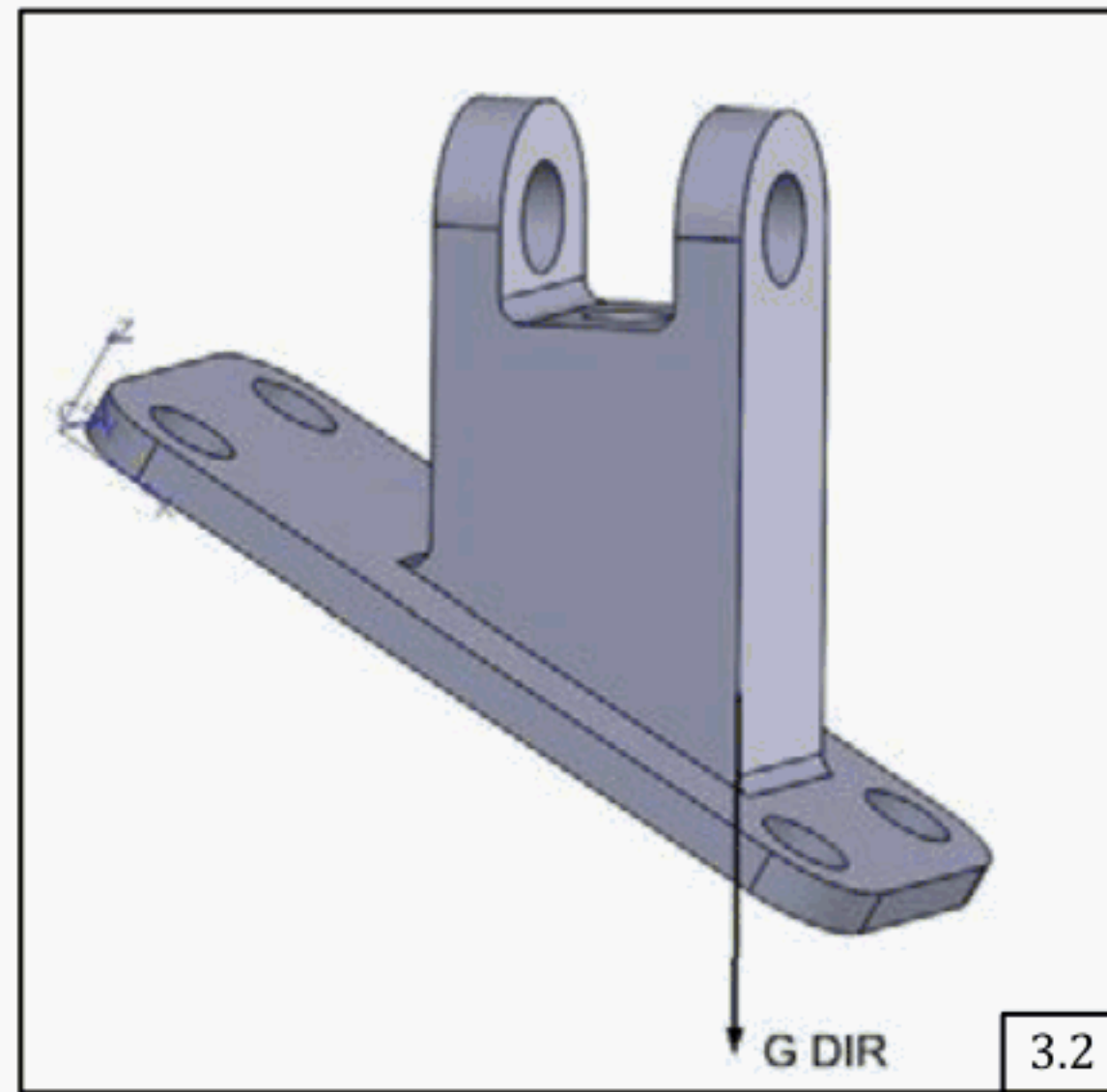


Figure 3-5 A Surface Representing a Build Surface

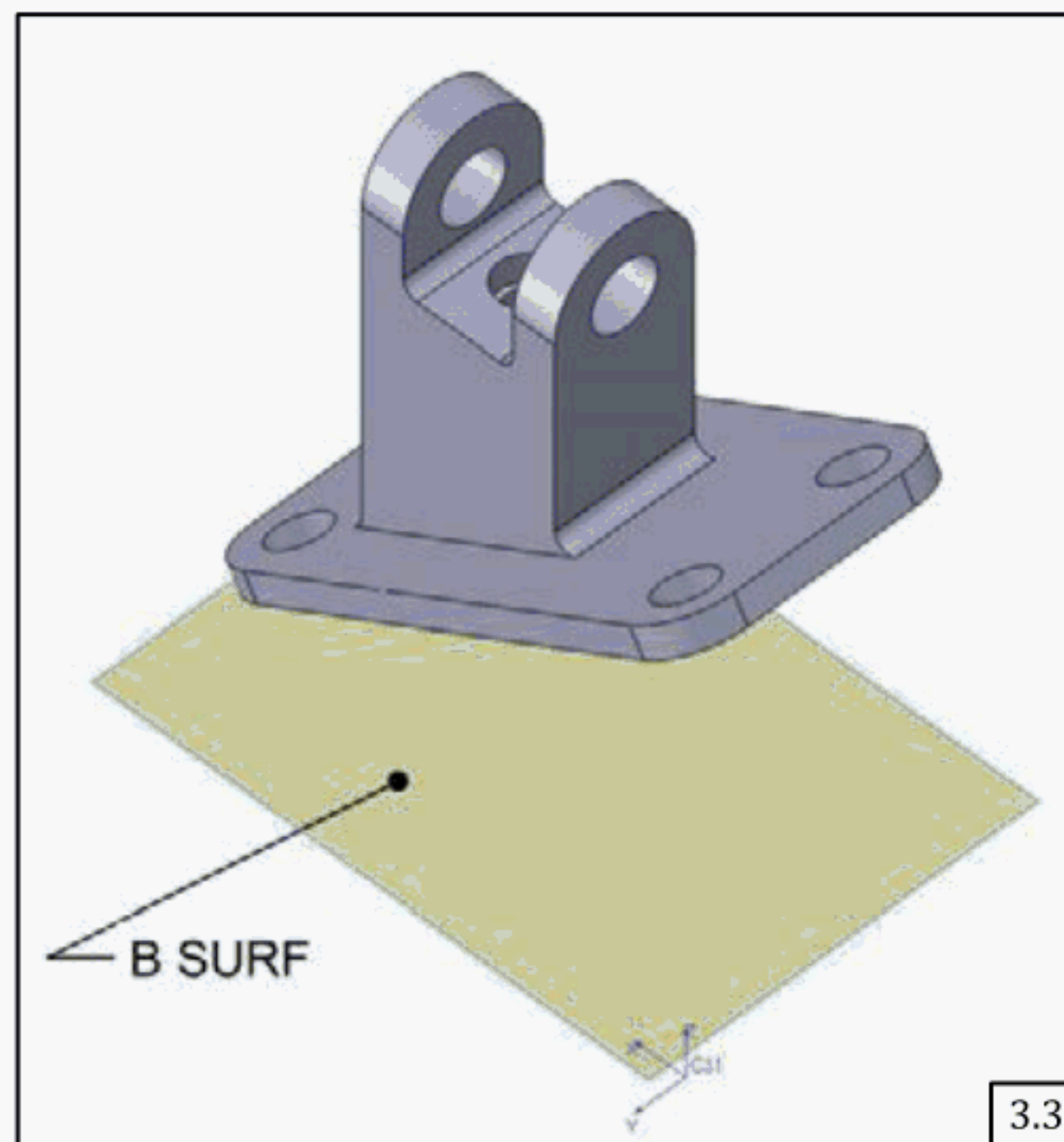
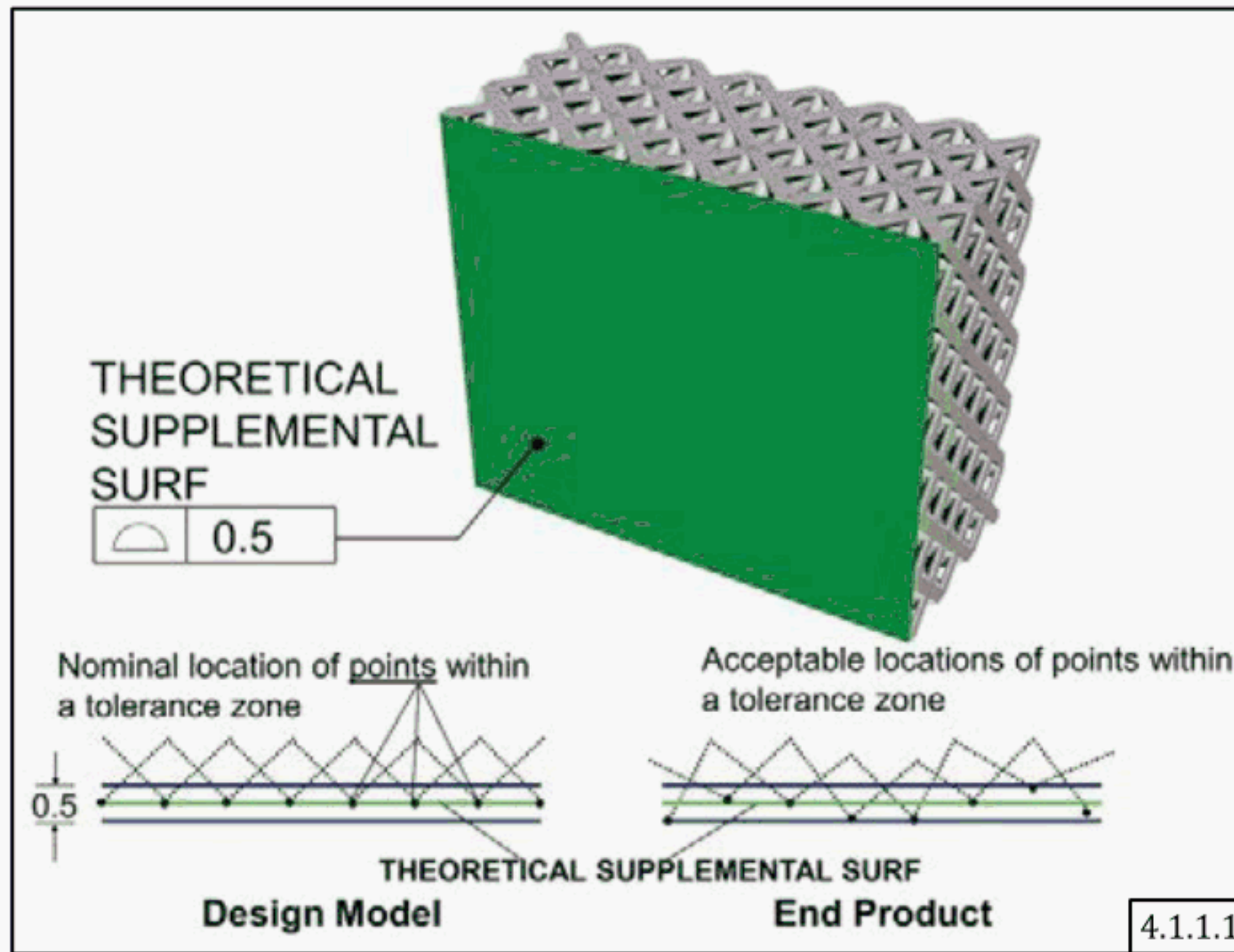


Figure 4-1 Example of a Theoretical Supplemental Surface Used on a Rectangular Lattice Cuboid

4 PRODUCT AND PROCESS DEFINITION REQUIREMENTS

The nature of AM parts is such that a complete product definition may be achieved only by the communication of both design-related and process-related characteristics.

4.1 Geometry Characteristics

4.1.1 Surfaces and Tolerance

4.1.1.1 Defining a Theoretical Supplemental Surface. If required, a theoretical supplemental surface shall be indicated with the words “THEORETICAL SUPPLEMENTAL SURF,” as shown in [Figures 4-1, 4-2, 4-3, and 4-4](#). Any point, line, or surface element within the model that coincides with a theoretical supplemental surface shall be allowed to vary within the applicable geometric tolerance applied to the theoretical supplemental surface.

The purpose of specifying a theoretical supplemental surface is to identify the elements that define the theoretical supplemental surface within a tolerance zone.

4.1.1.2 Defining Surface Texture. Surface texture, where specified, shall be defined using the requirements from ASME B46.1 and ASME Y14.36.

4.1.2 Bounded Regions and Tolerances. Bounded regions may be used to indicate a subset of requirements such as materials, application of geometric tolerances, support structure volumes, allowable attachment areas, and other properties. A bounded region may be represented as a bounded volume region or a bounded surface region.

The bounded region shall be represented as a separate volume or surface region in the specification for the part. See [Figure 4-5](#) for an example of bounded regions representing volume and surface regions in a single part.

4.1.2.1 Bounded Volume Region Identification. If a bounded volume region is required, it shall be indicated by “VOLX” where X is a unique label. The bounded volume region indicator may also be coupled with a feature control frame to specify a geometric tolerance as shown in [Figures 4-6, 4-7, and 4-8](#).

4.1.2.2 Bounded Surface Region Identification. If a bounded surface region is required, it shall be indicated by “SURFX” where X is a unique label. The bounded surface region indicator may also be coupled with a feature control frame to specify a geometric tolerance as shown in [Figure 4-9](#).

Figure 4-2 Example of a Theoretical Supplemental Surface Within a Rectangular Lattice Cuboid

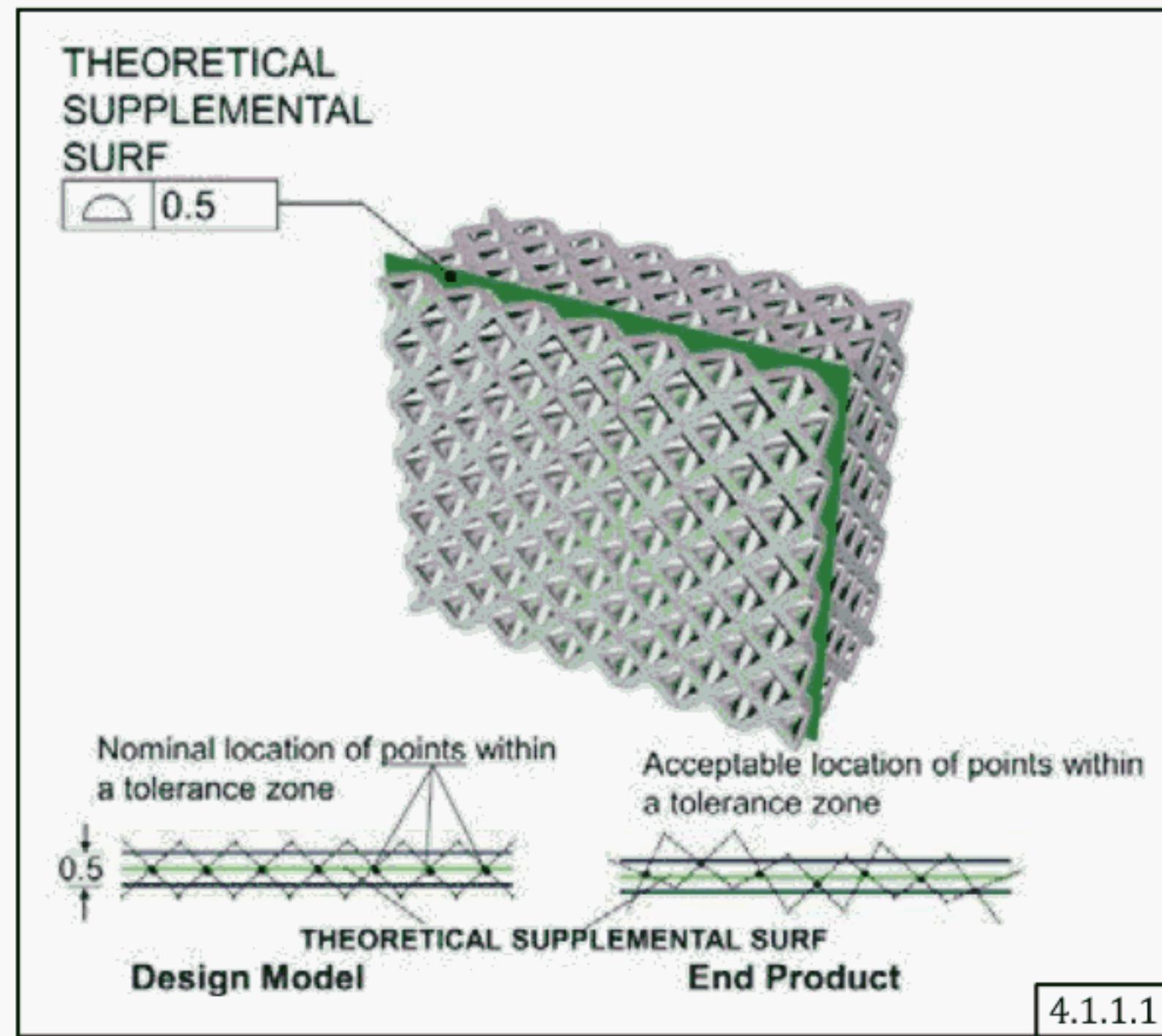


Figure 4-3 Example of a Nonplanar Theoretical Supplemental Surface

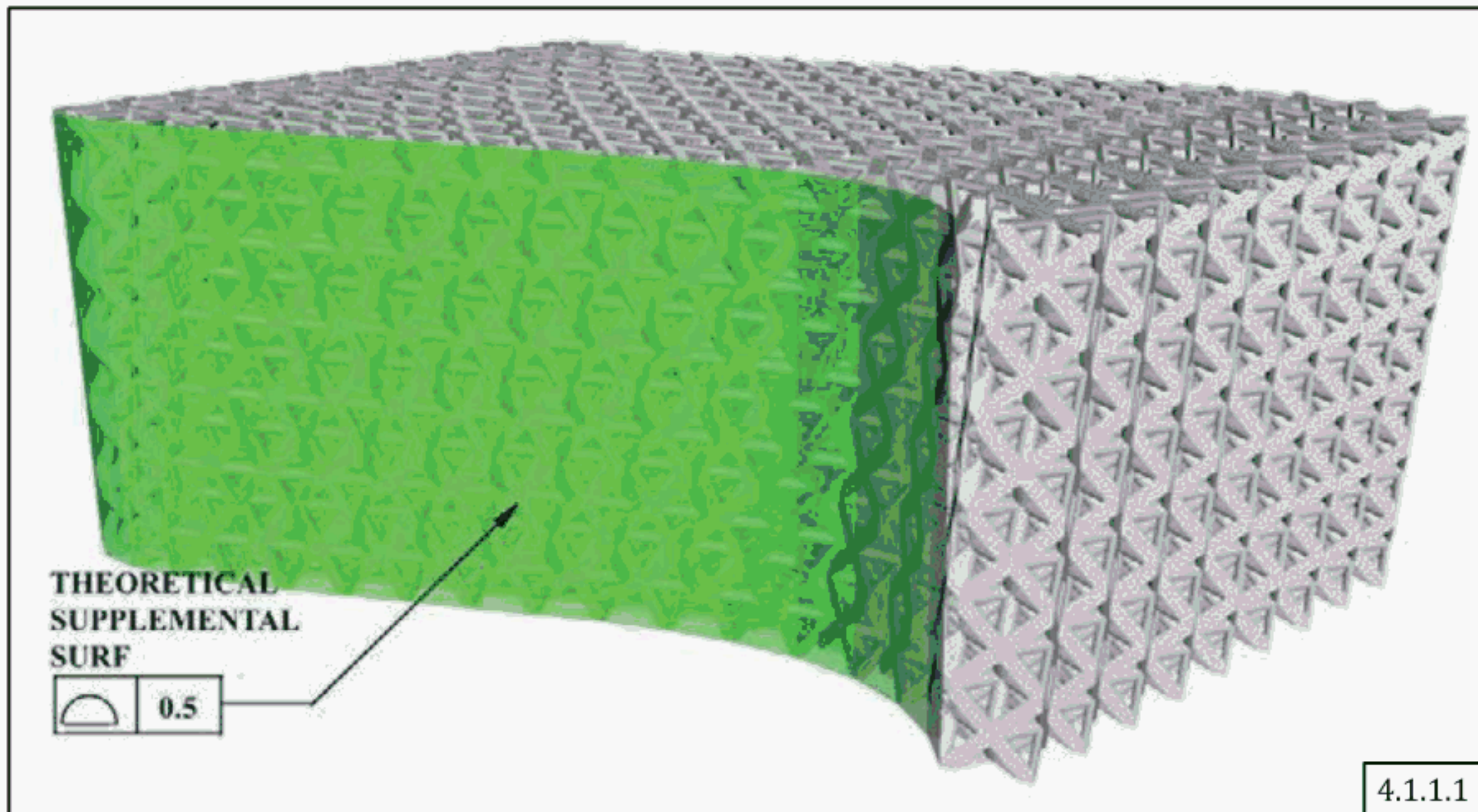


Figure 4-4 Example of a Tolerance Zone Derived From Figure 4-3

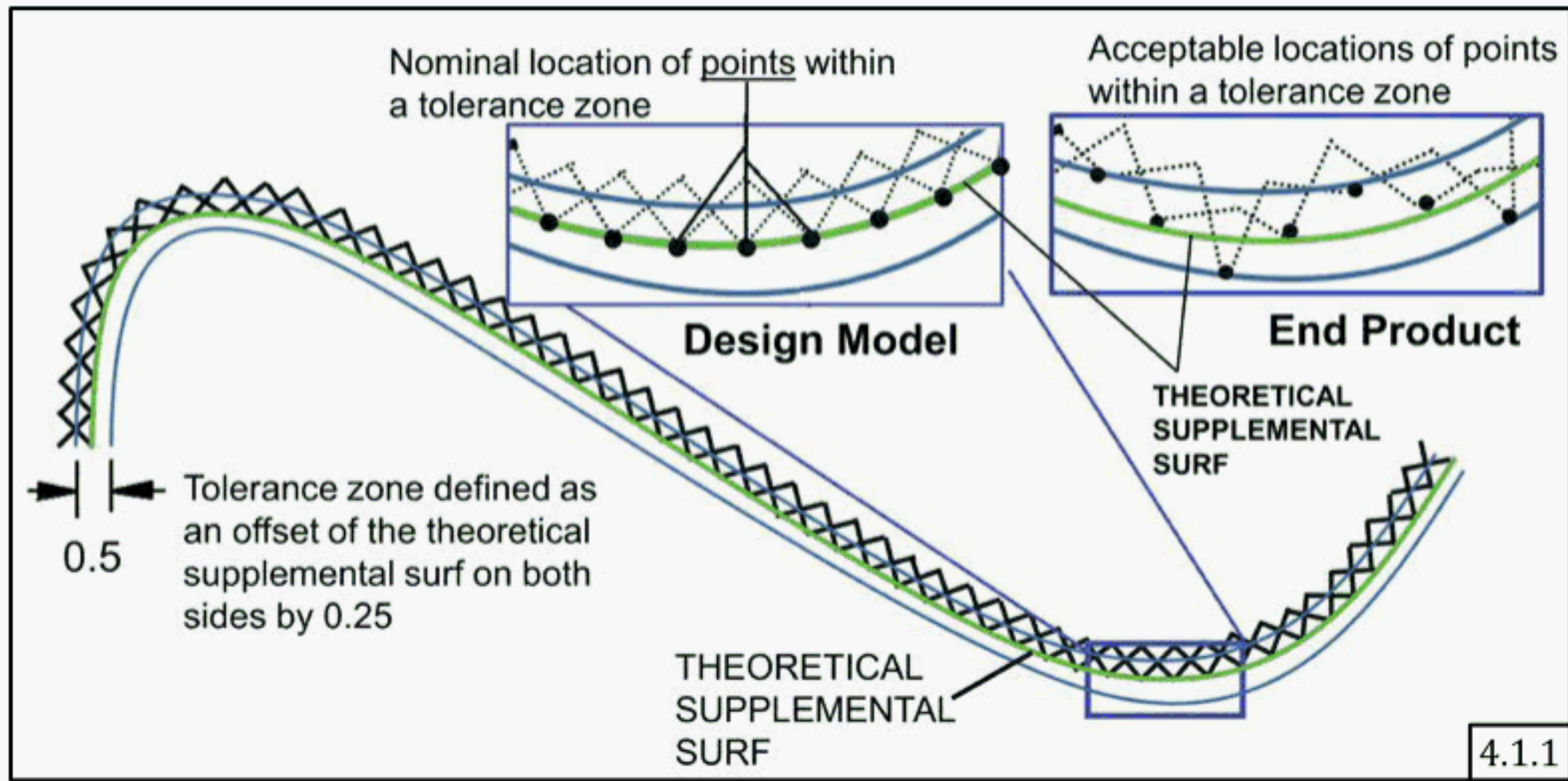


Figure 4-5 Both Bounded Volume and Surface Regions to Indicate Internal and External Surfaces and Volumes

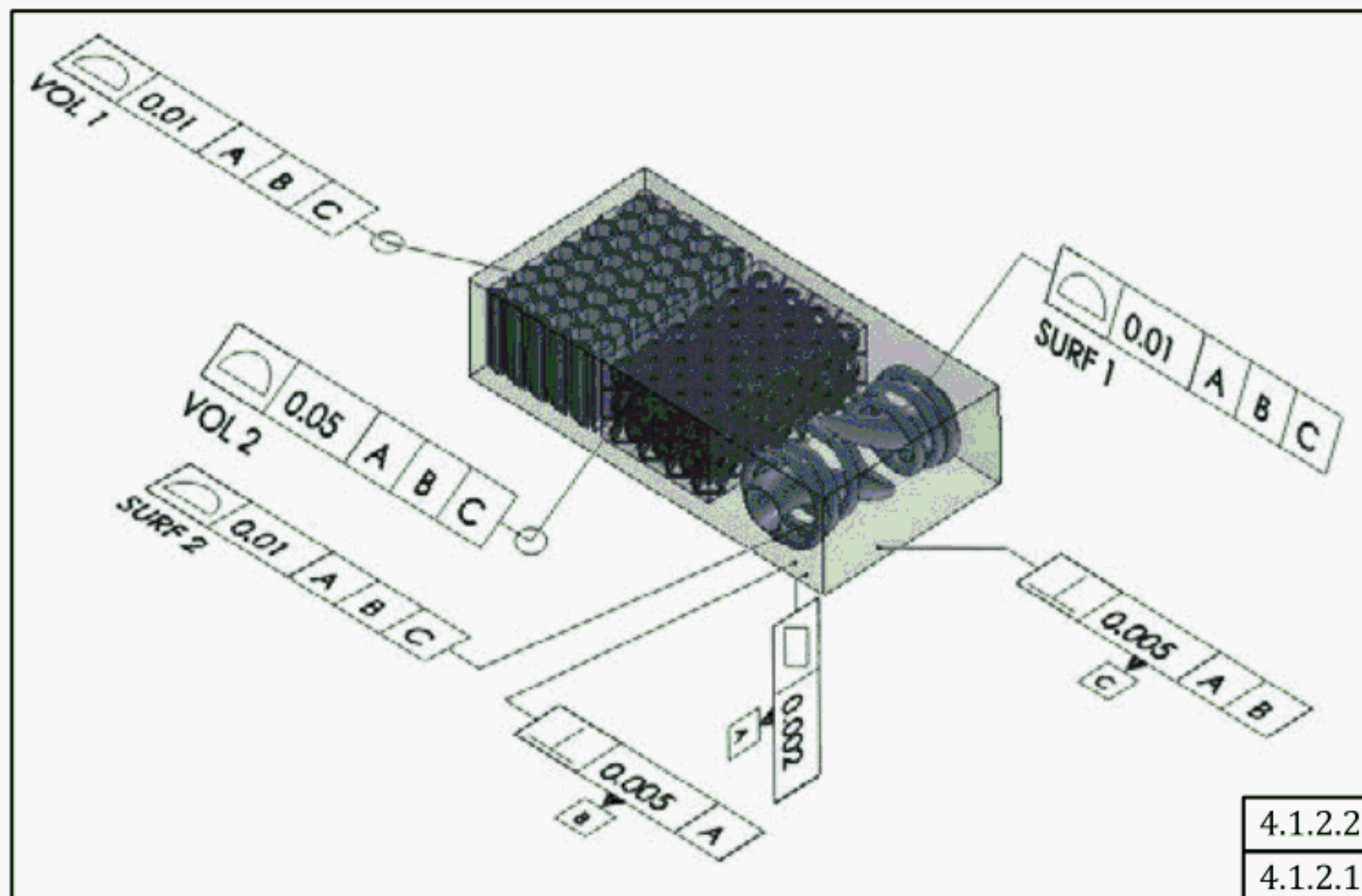


Figure 4-6 Bounded Volume Region Indicator (VOL1) With a Profile of a Surface Tolerance

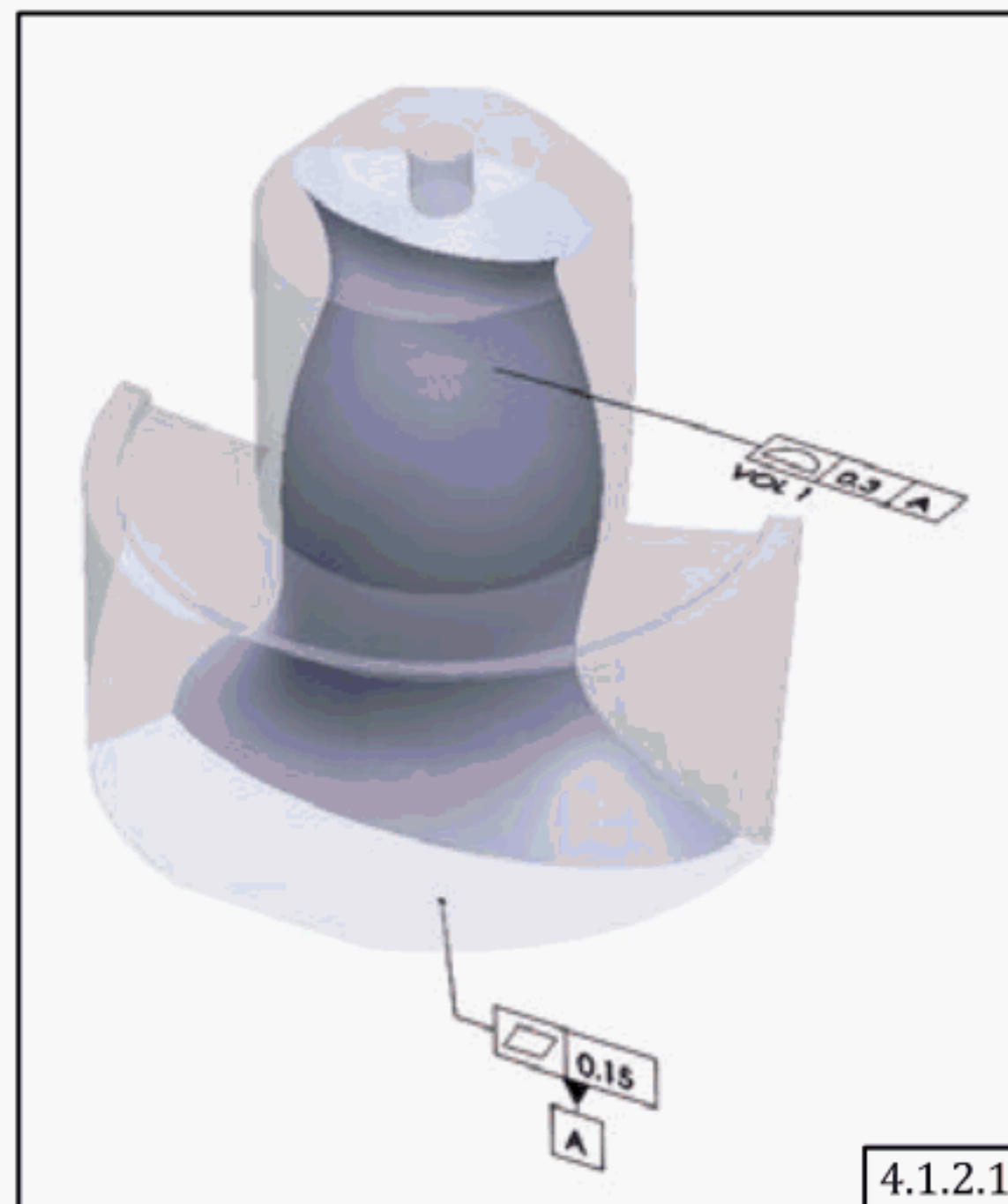


Figure 4-7 Multiple Bounded Volume Region Indicators With Profiles of Surface Tolerances

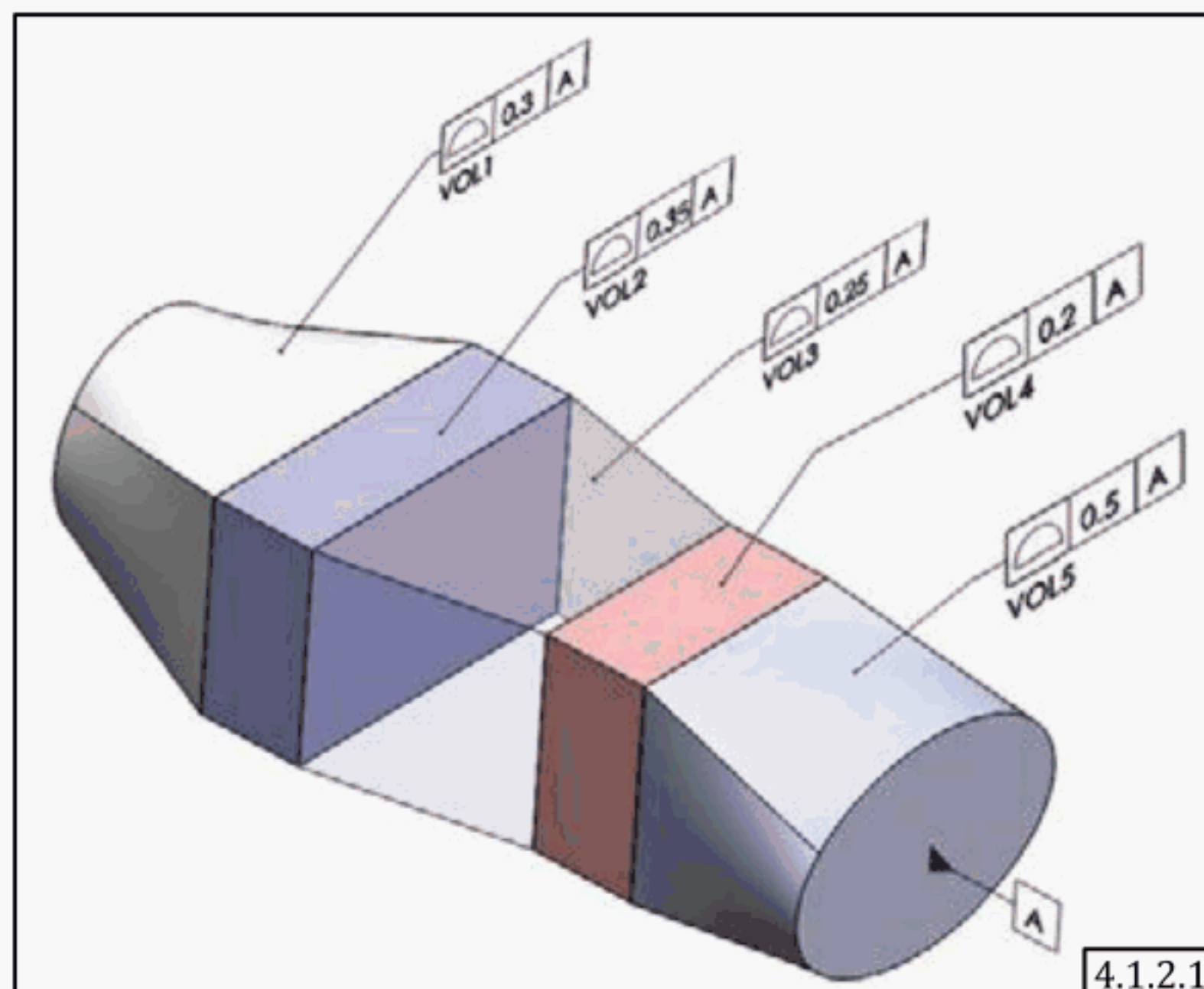


Figure 4-8 Bounded Volume Regions Represented by Several Bounded Volume Region Indicators in a Single Part

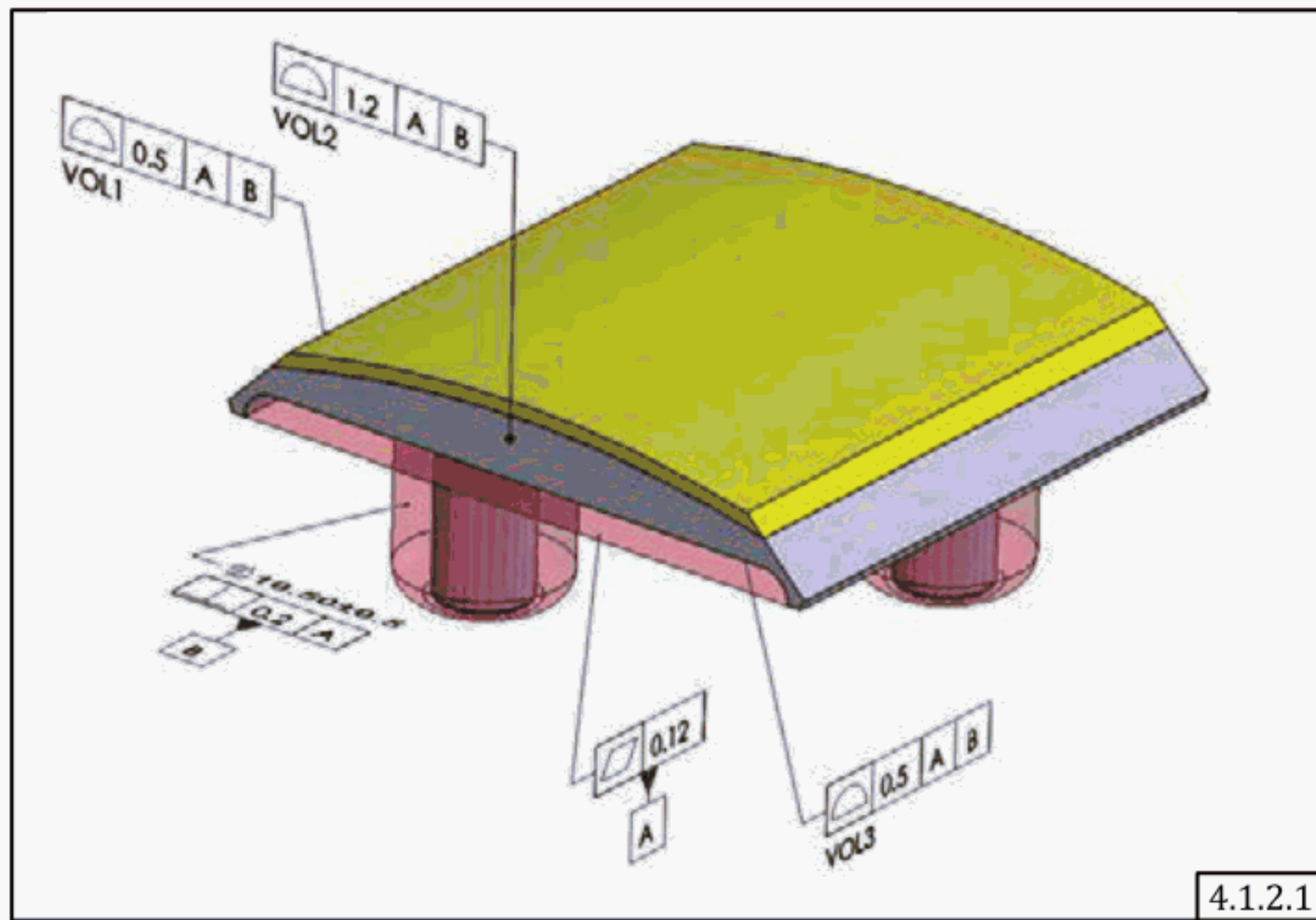
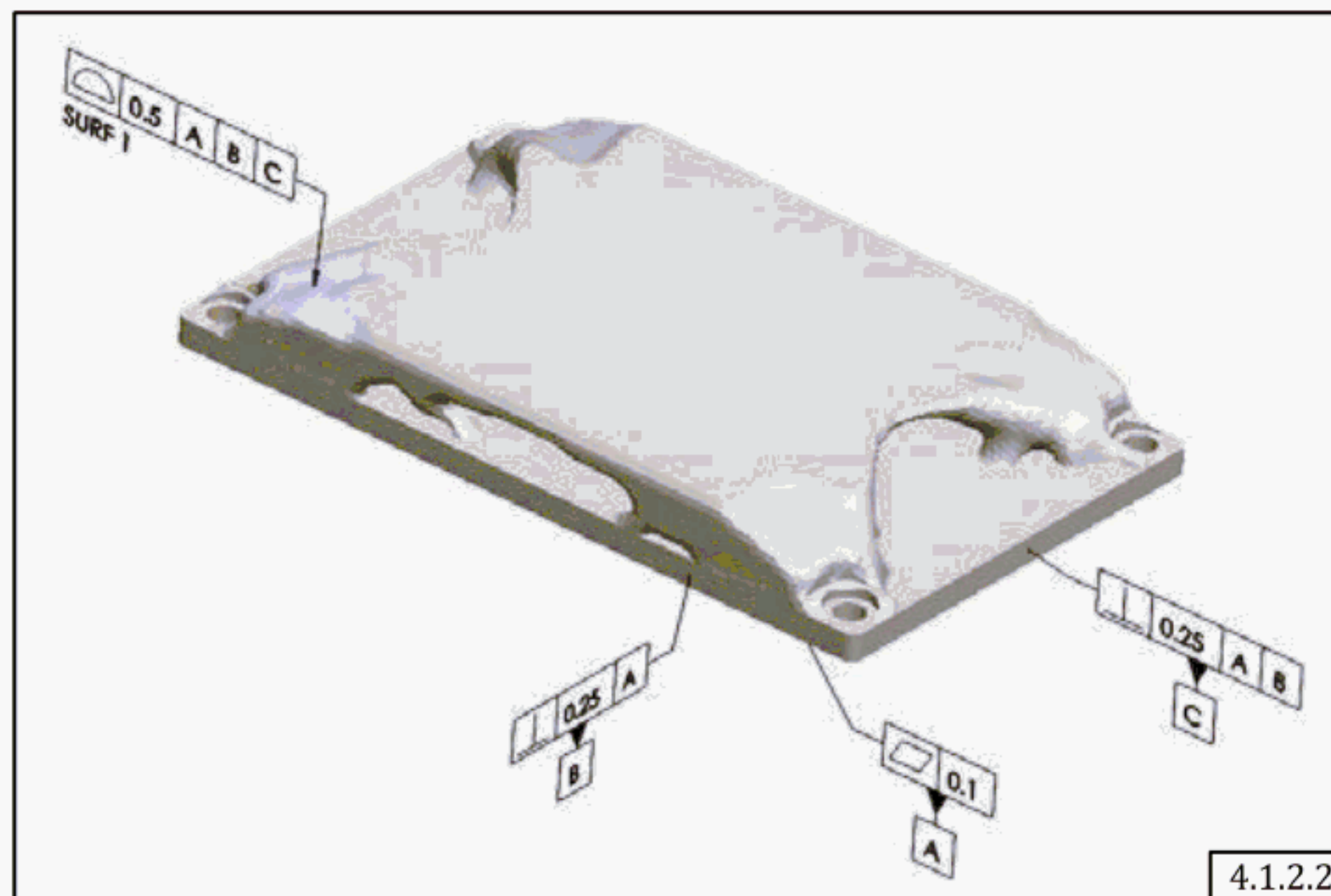
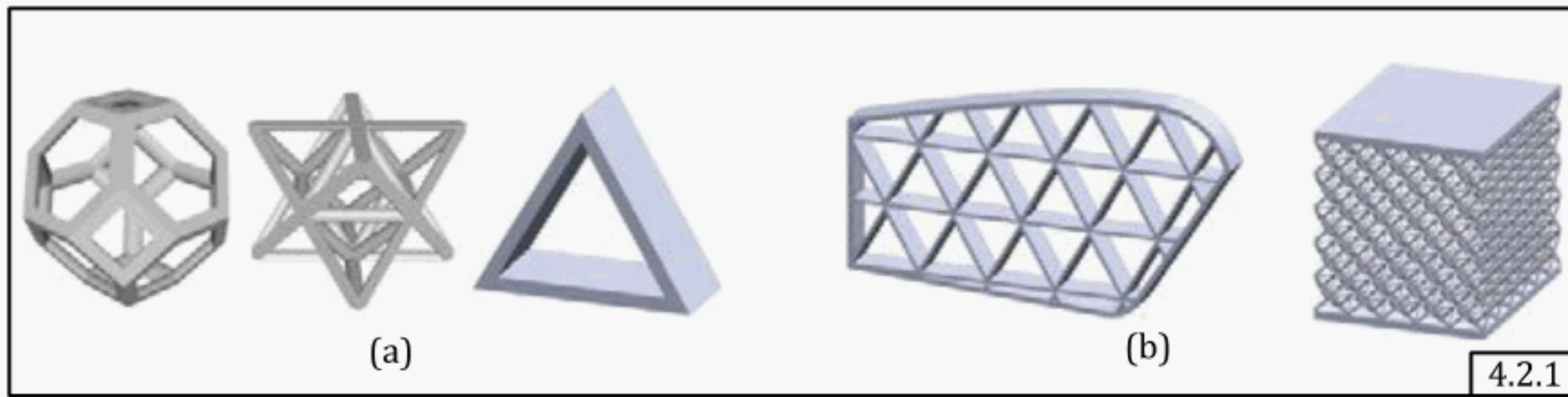


Figure 4-9 Bounded Surface Region Indicator Coupled With a Feature Control Frame



GENERAL NOTE: Feature control frame is indicated with a different color.

Figure 4-10 Examples of Unit Cell Geometries and Lattice Structures

GENERAL NOTE: Illustration (a) shows individual unit cell geometries used in lattice structures. Illustration (b) shows lattice structures formed by repeating unit cells in a pattern.

4.1.2.3 Defining a Transition Region. If a transition region is required, it shall be indicated as a separate bounded region according to [paras. 4.1.2.1](#) and [4.1.2.2](#).

Refer to [para. 4.2.2](#) for the method to describe transitions or gradients.

4.2 Design Characteristics

[Paragraph 4.2](#) addresses practices for communicating design-specific characteristics using the geometry characteristics in [para. 4.1](#). The concepts discussed in this paragraph include lattice structures, gradient control, complex geometries, and design for assembly.

4.2.1 Lattice Structures. A *lattice structure* can be composed of repeated patterns of *unit cells* that are defined as volumetric geometric elements in a defined space. The unit cell pattern can then be repeated to create complex heterogeneous or homogeneous geometric volumes. Examples of unit cells are shown in [Figure 4-10](#).

If the lattice unit cell requires a geometric tolerance control, then an appropriate geometric control may be applied per ASME Y14.5 and [paras. 4.1.1](#) and [4.1.2](#).

[Figure 4-11](#) illustrates abrupt changes in unit cells across five bounded volume regions. Each bounded volume region indicator may have unique tolerances and materials ([para. 4.2.2](#)). A transition region ([para. 4.1.2.3](#)) may be used to indicate how the shape, material, or other characteristic of a unit cell changes from one location in the part to another.

4.2.2 Gradient Control. If a gradient control is required, it shall be indicated with the following:

- (a) bounded volume region notation (see [para. 4.1.2.1](#)), e.g., VOL2. See [Figure 4-12](#).
- (b) equation notation for the mathematical function, e.g., EQ1. See [Figure 4-12](#). See [Nonmandatory Appendix B](#) for an example.
- (c) percentage label indicating tolerance on the variation, e.g., 50% MAT2. See [Figure 4-12](#).

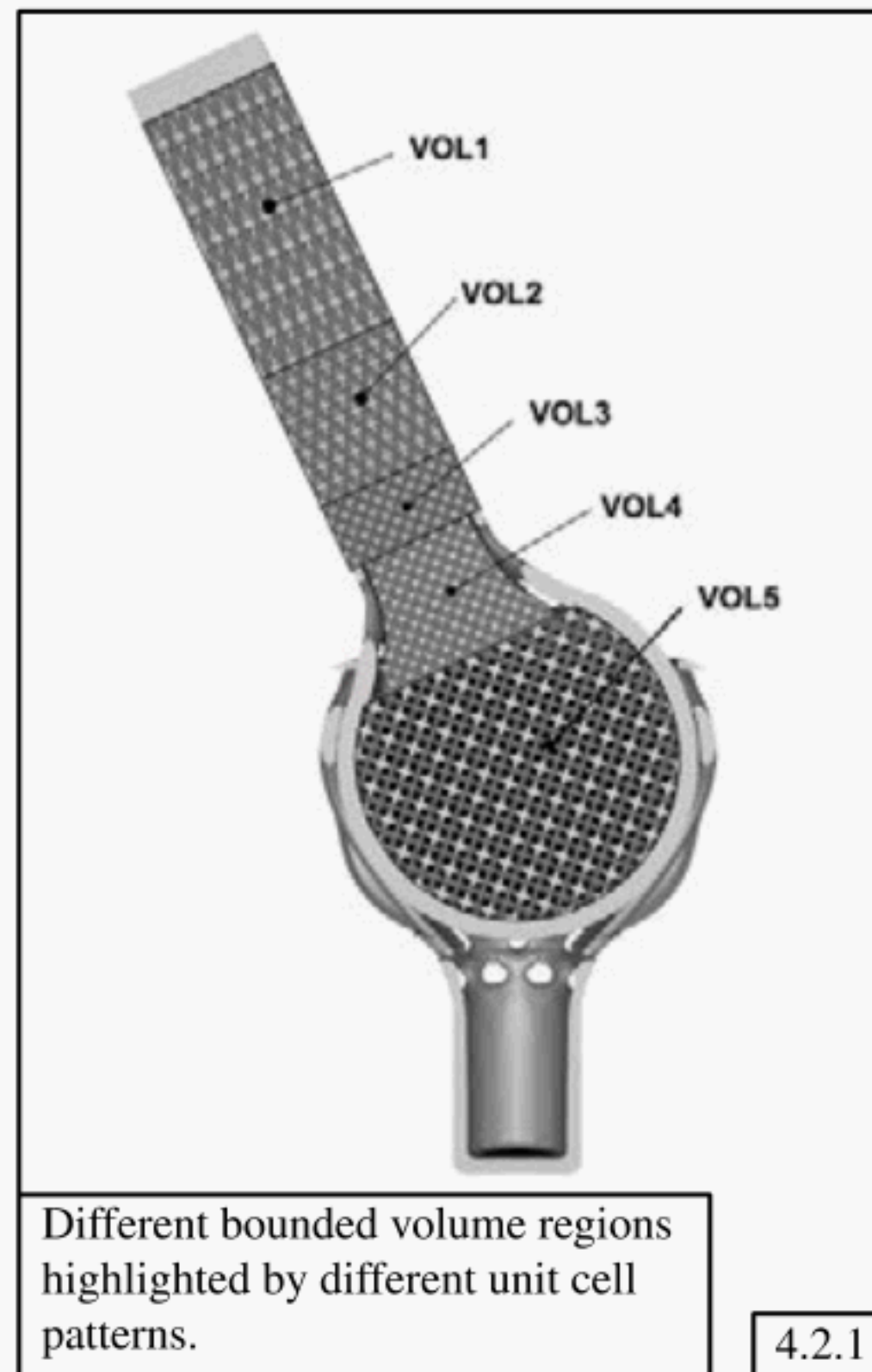
See [Figure 4-12](#) for an example that combines gradient controls and transition regions.

[Table 4-1](#) provides material gradient values for the example part shown in [Figure 4-12](#). This example implements functions to specify a gradient. The tolerances on MAT1 and MAT2 are bilaterally identified in [Table 4-1](#) as $\pm 12.5\%$ and $\pm 25\%$, respectively. At the material boundaries, the tolerance values are unilaterally disposed within the bounded volume regions (e.g., $z = 10$, $z = 25$, or when nominals are either 0% or 100%). See [Nonmandatory Appendix B](#) for a detailed explanation of the example.

NOTE: Voids in a particular unit volume may cause measured material composition to not equal 100%.

[Figure 4-13](#) identifies a gradient control within a part that consists of 5 bounded volume regions. VOL2 is the transition region between material MAT1 in VOL1 and material MAT2 in VOL3.

4.2.3 Complex Geometry. AM facilitates the production of part geometries that are complex. Complex geometry features commonly originate from topology optimization or generative design algorithms. Complex geometry may not conform to existing annotation capabilities. In such cases, complex geometries may be identified using bounded surface regions or bounded volume regions (see [para. 4.1.2](#)). [Figure 4-14](#) provides examples of complex geometries.

Figure 4-11 Lattice Structure With Multiple Bounded Volume Regions

4.2.4 Design for Assembly. AM supports the fabrication of part assemblies that have relative motion between parts and are fabricated in an assembled manner without requiring postbuild assembly. Any applicable geometric requirements (e.g., clearance) shall be identified and toleranced per ASME Y14.5 and this Standard. [Figure 4-15](#) illustrates an example of design for assembly where a wrench is produced in a single AM build yet has individual moving parts. See [para. 4.3.1.3](#) for the concept of nesting that uses a similar product definition.

4.3 Process-Related Characteristics

Specifications related to an AM process may not be separable from the product definition. The following are the most common process-related characteristics needed for AM: part location and orientation, build specification, support structures, and test coupons.

If there are requirements to monitor process-related characteristics during the build process, such as reporting on machine build errors and failures, then those requirements shall be assessed for conformance. See [Nonmandatory Appendix C](#). Postprocessing allowances should be specified as per the ASME Y14 standard relevant to the process. Machining allowances shall be specified in accordance with ASME Y14.36M.

4.3.1 Part Location and Orientation. If a build direction is required, it shall be identified using the model's coordinate system and unit vector (see [Figure 3-3](#)) and shall be consistent with X, Y, Z defined in ISO/ASTM 52921. The unit vector shall be labeled "B DIR" for build direction. See [Figure 4-16](#).

A build direction may be specified as preferred (e.g., manufacturing enhancement) or required (e.g., part tolerances or performance).

Multiple build directions may be specified as shown in [Figure 4-17](#). In such cases, each build direction shall be labeled in a sequence, such as B DIR1, B DIR2, with the sequence of whole numbers starting at 1, and shall have a subscript to identify the coordinate system in which it is defined.

Figure 4-12 VOL Local Notes That Describe Material Gradient Allocations Shown in Table 4-1

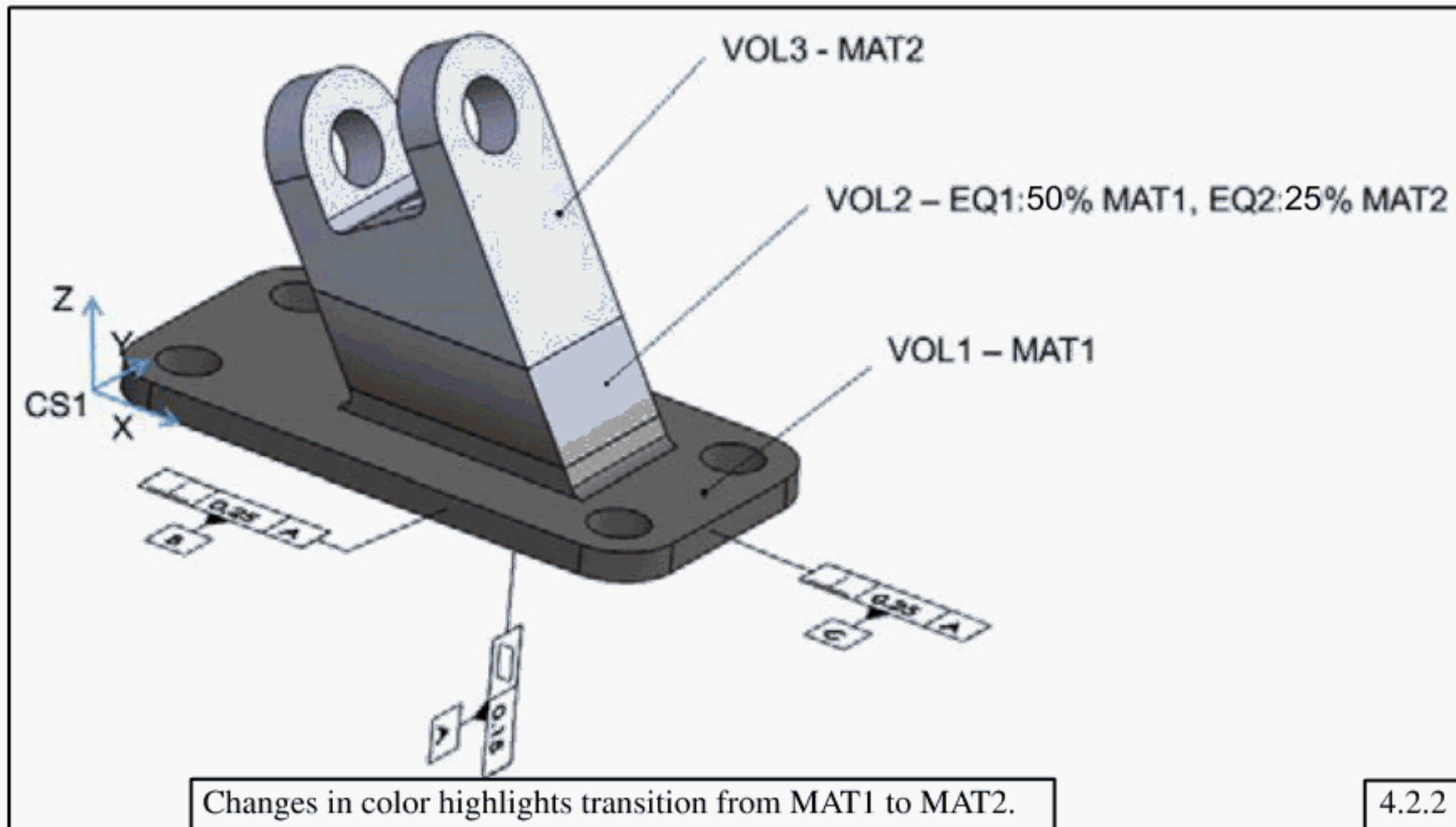


Table 4-1 Material Gradient Values Used in Figure 4-12

Annotation Label	z, mm	Nominal MAT1, $f_1 = 15 - (z - 10)$, %	Nominal MAT2, $f_2 = z - 10$, %	Tolerance on MAT1, %	Tolerance on MAT2, %
VOL1	10	100	0	-12.5	+25
VOL2	15	66	33	± 12.5	± 25
	20	33	66	± 12.5	± 25
VOL3	25	0	100	+12.5	-25

Figure 4-13 Material Transition Specification Between Bounded Volume Regions With Lattice Fill

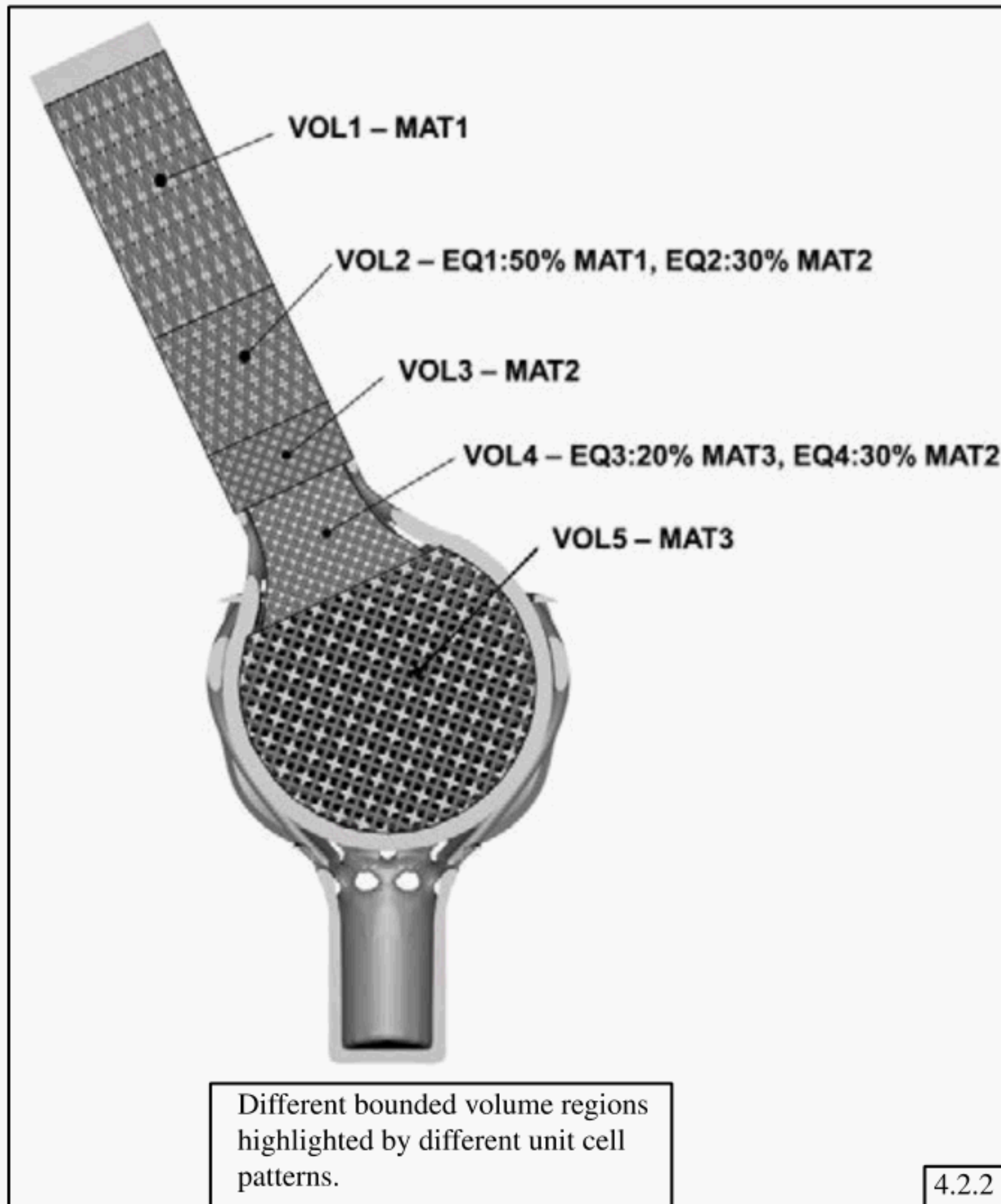


Figure 4-14 Complex Geometries Generated From Topology Optimization



GENERAL NOTE: Changes in color indicate variations in material characteristics.

Figure 4-15 Wrench Produced as a Single Build With Three Parts

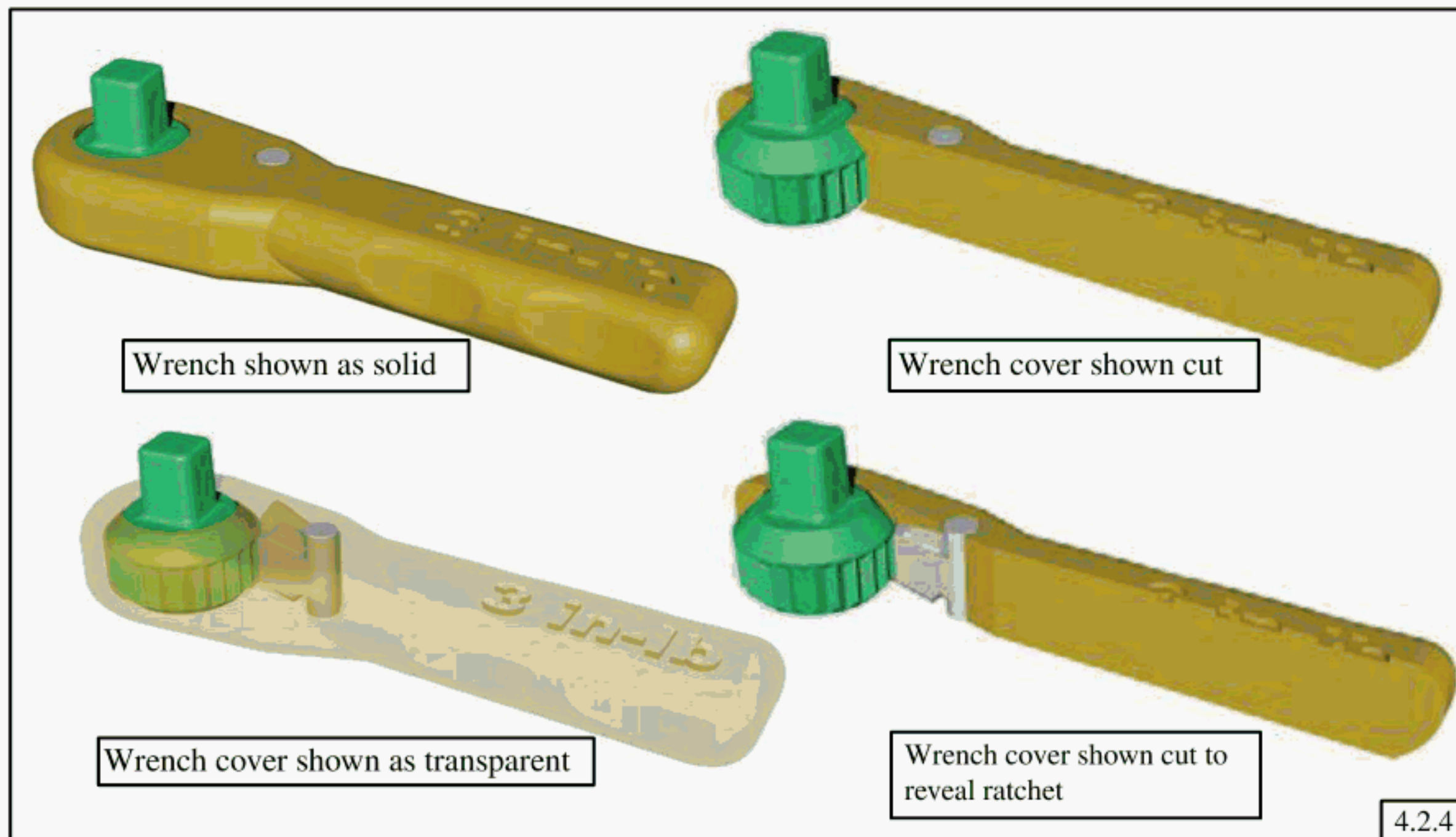


Figure 4-16 Build Direction Indicated Using the Direction Unit Vector

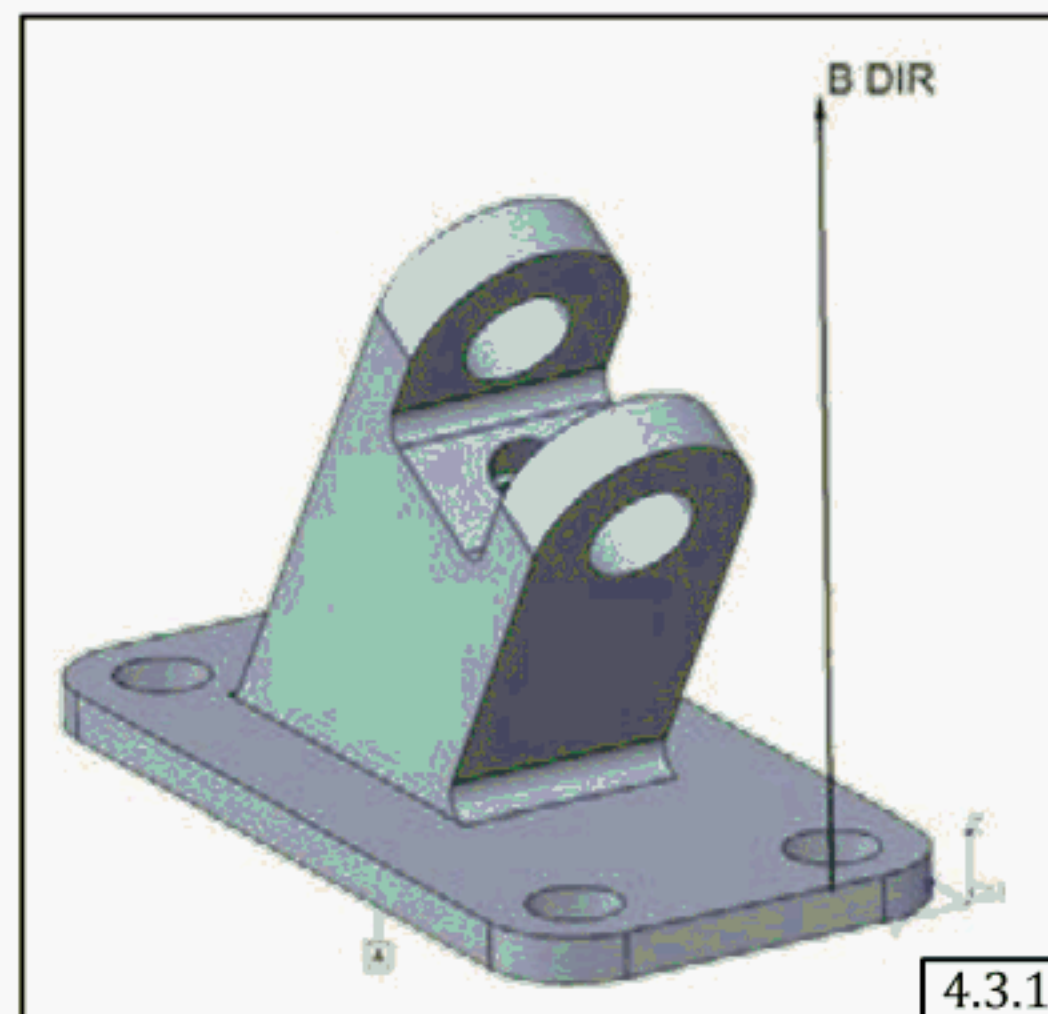
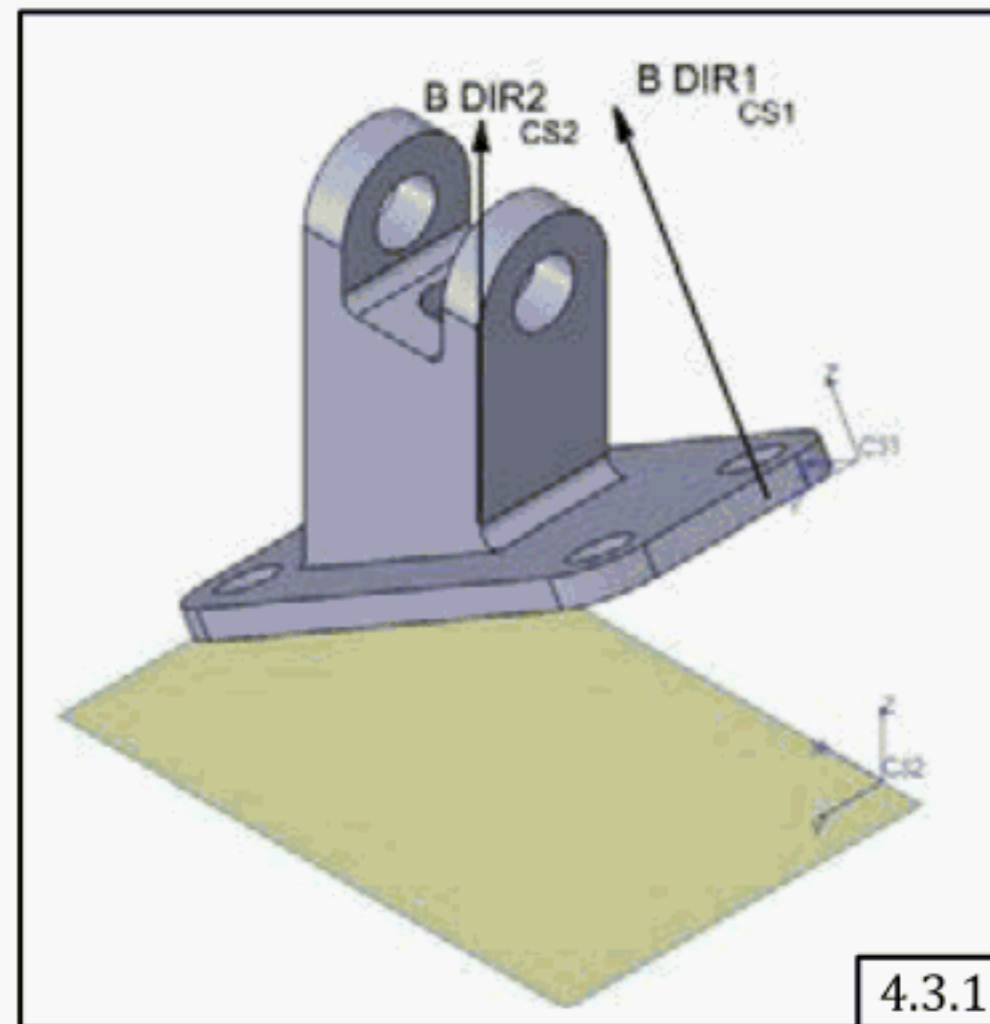


Figure 4-17 Multiple Build Directions

4.3.1.1 Defining the Build Surface. If a build surface definition is required, it shall be defined using a coordinate system that shall be located using basic dimensions and identified relative to the model's coordinate system. The build surface feature shall be indicated as "B SURF," as shown in Figure 4-18. If required, additional build surfaces shall be defined using additional coordinate systems and build surface features.

4.3.1.2 Defining the Part Orientation Relative to the Build Surface. If a part orientation is required, it shall be identified using a coordinate system that shall be located and identified relative to a specified build surface, such as the build platform. The coordinate system shall be identified per para. 3.1. See Figure 4-19.

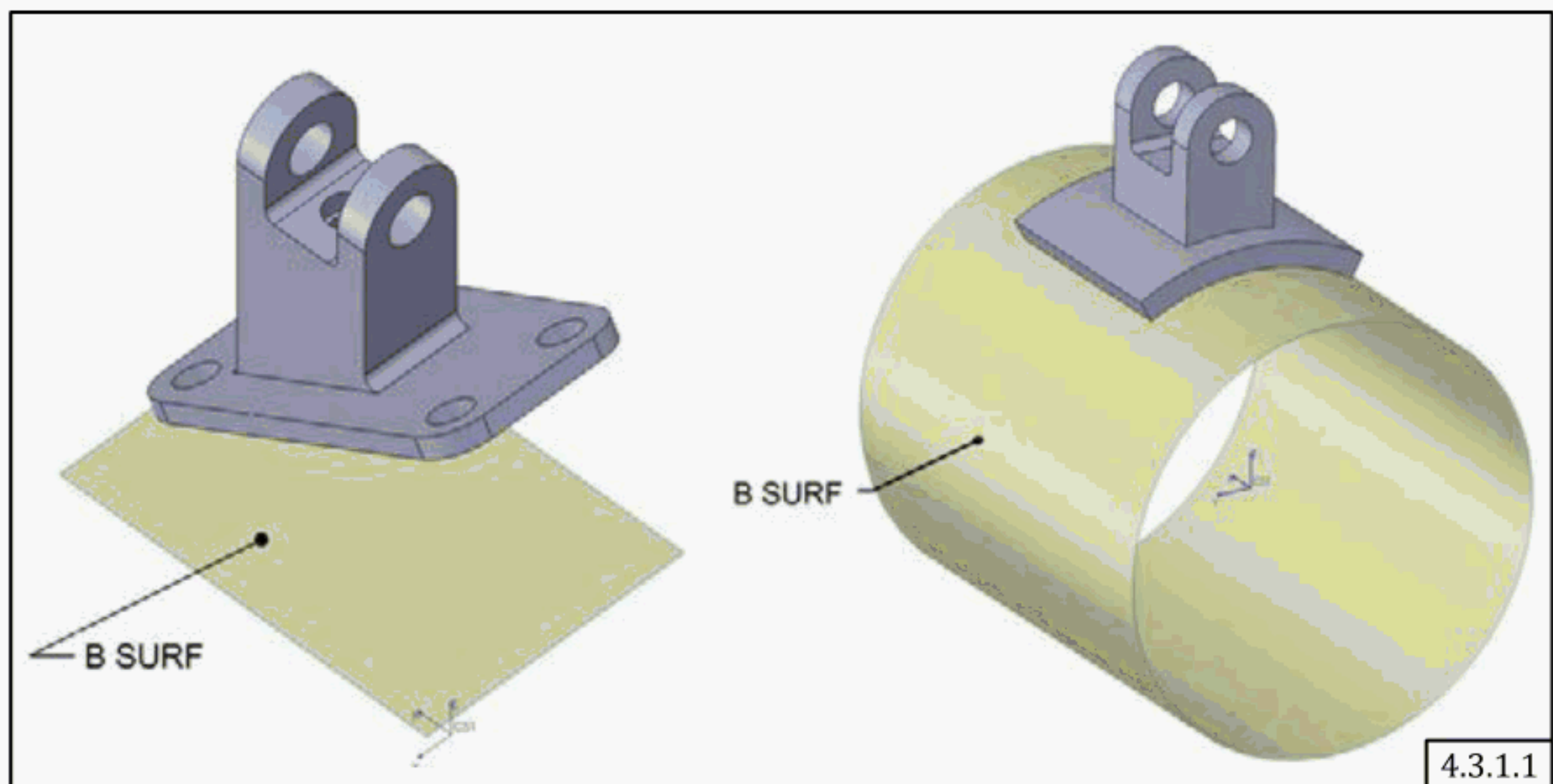
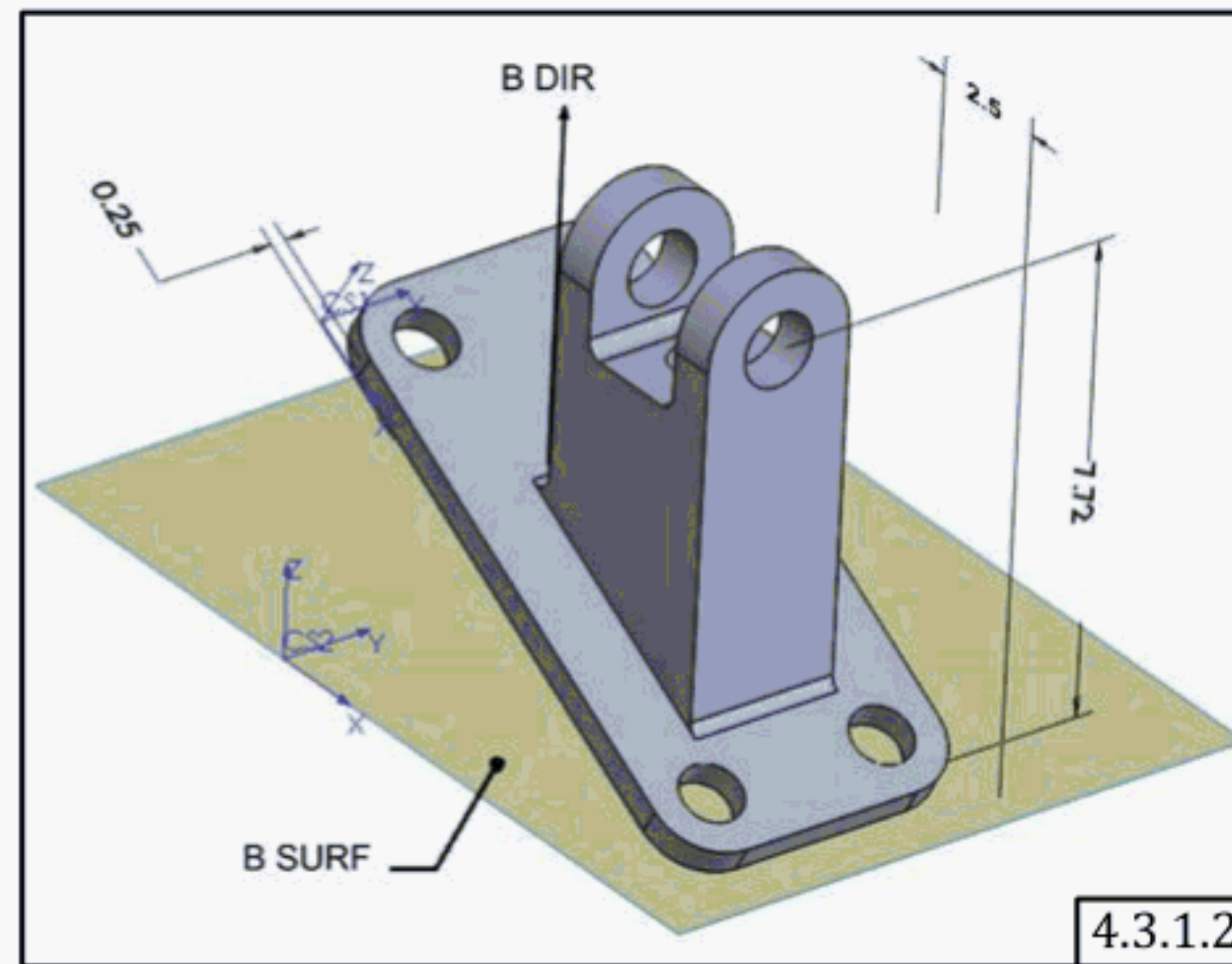
Figure 4-18 Planar Build Surface and a Nonplanar Build Surface

Figure 4-19 Identifying Build Location With Respect to a Specified Build Surface

GENERAL NOTE: An example of a specified build surface is a build platform.

4.3.1.3 Build Location and Nesting. The location of a single part may be specified within a build envelope by identifying a build location. Multiple build locations may be necessary when a simultaneous build of multiple parts, identical or dissimilar, occurs within the same build envelope. See Figures 4-20 and 4-21. This process is known as *nesting* and has product definition requirements similar to design for assembly (para. 4.3.4). Refer to ISO/ASTM 52900 for additional specifications for nesting.

When the specification of a build location is necessary, the build location shall be specified with Cartesian coordinates within a coordinate system. See Figure 4-20.

4.3.1.4 FreeZone. If required, a free zone shall be indicated with “FREE ZONE” followed by the offset dimension. The offset dimension is a uniform boundary, offset normal from the basic part geometry. See Figures 4-22 and 4-23.

A free zone may be applied to the bounding box of an object by indicating “FREE ZONE BOUNDING BOX” followed by the offset dimension. The bounding box shall be associated to the model coordinate system.

If different bounded regions of a part, assembly, or nest require different free zones, then each bounded region shall be specified separately.

4.3.2 Build Specification. It may be necessary to communicate additional information related to process parameters and how the part is processed.

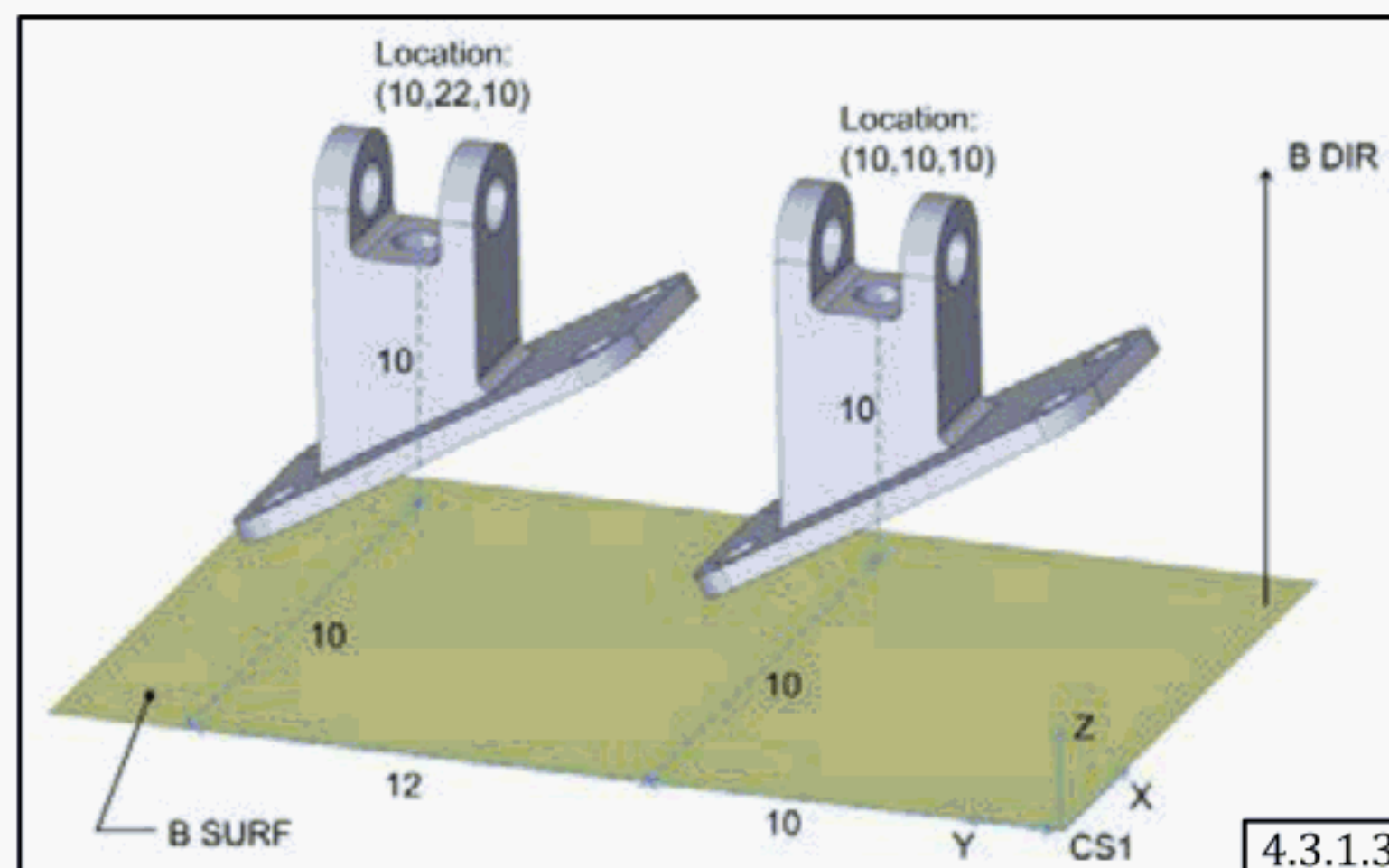
Figure 4-20 Coordinate Systems Are Used to Locate Parts Within a Build Envelope

Figure 4-21 Four Separate Parts Nested Inside One Another on a Build Surface

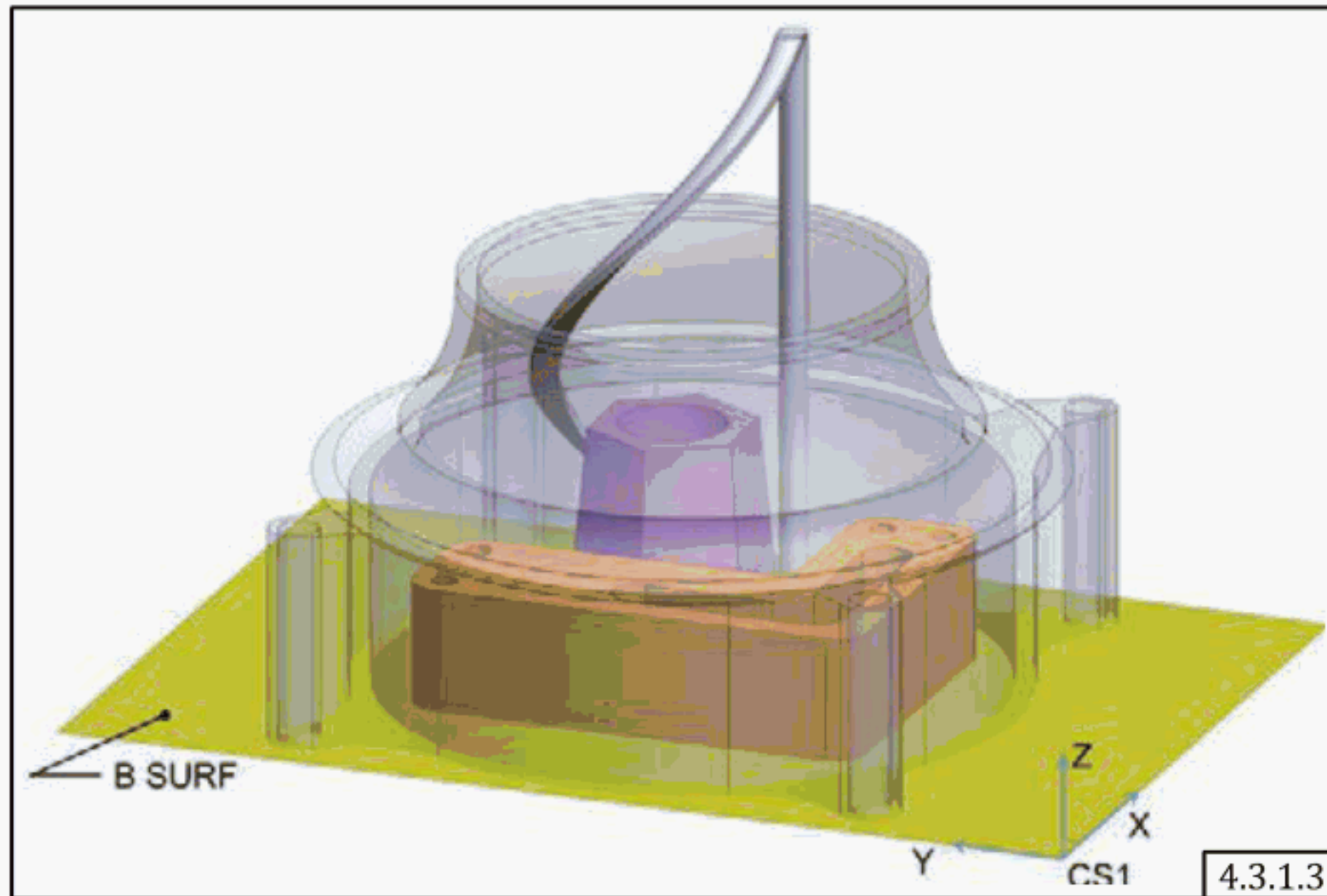


Figure 4-22 Free Zone Description With an Offset Dimension

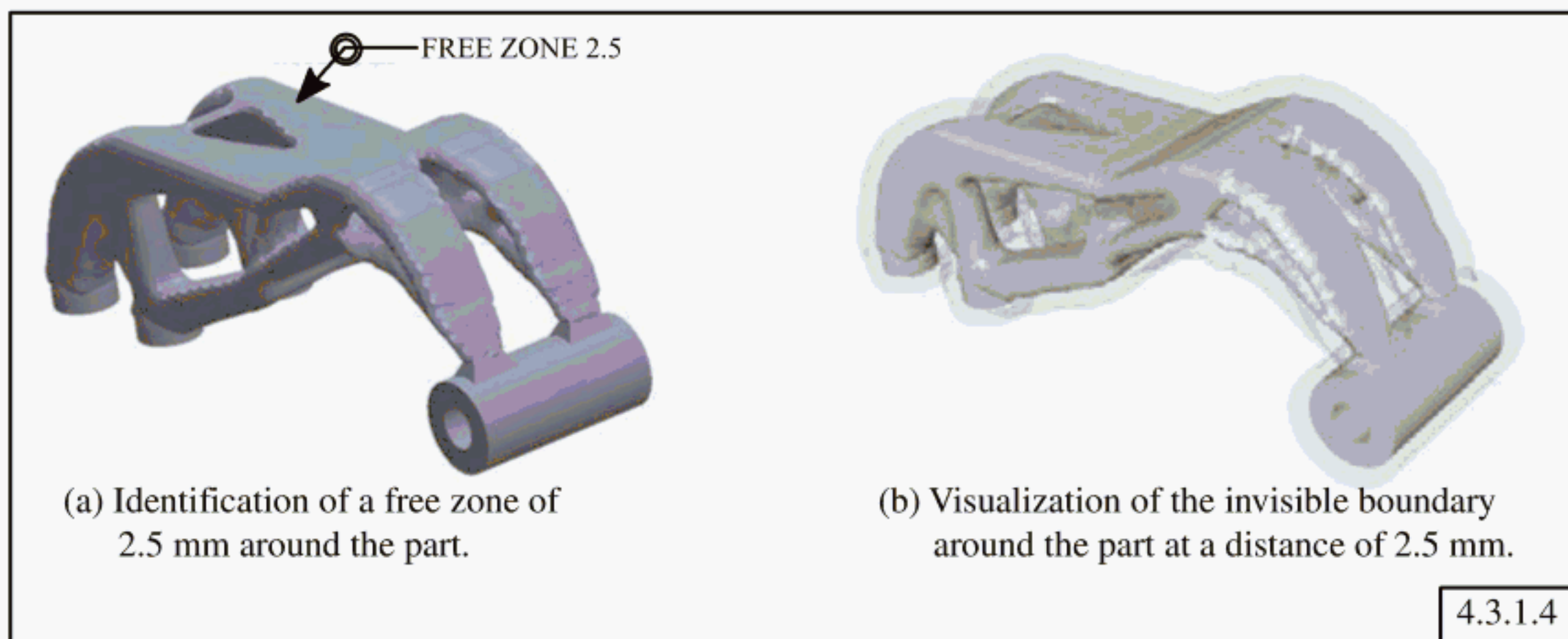
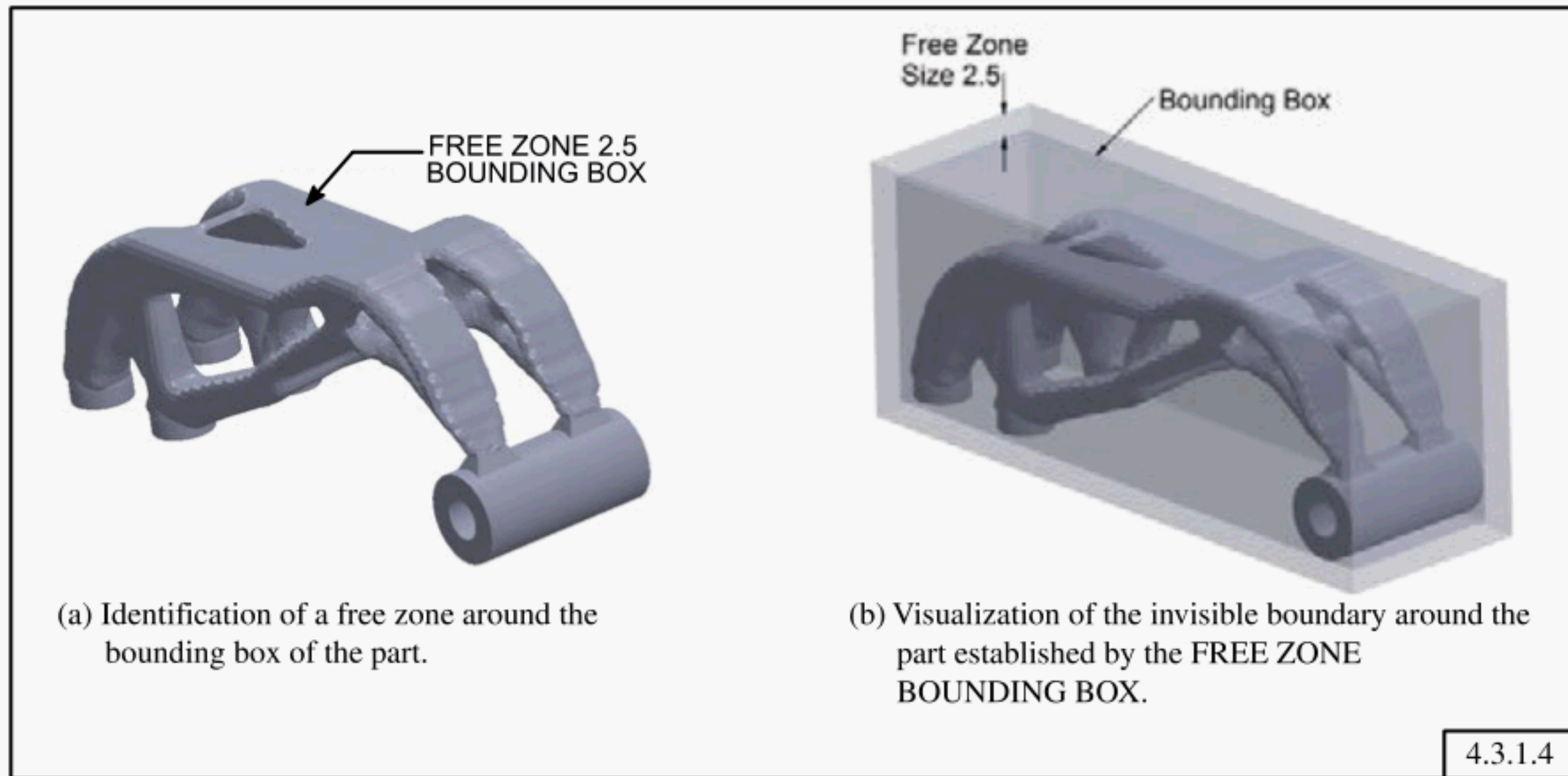


Figure 4-23 Free Zone Bounding Box Description


4.3.2.1 Layer Thickness Specification. If a layer thickness specification is required for a part build, it shall be indicated directly via annotation or indirectly by referencing an associated document. For the direct annotation method, layer thickness shall be indicated with “LAYER THICKNESS,” followed by the limits of acceptable layer thickness values (e.g., 0.03–0.05), as shown in Figure 4-24. If the part has different bounded regions or if the part build uses different layer thicknesses, use the bounded region and transition methods as applicable and as described in para. 4.1.2.

4.3.2.2 Track Path Specification. If required, track path shall be identified with “TRACK” and track path unit vector coordinates, followed by a subscript of the related coordinate system, e.g., CS1. See Figure 4-25. If a follow boundary track path is used, a note shall indicate a track path that follows a boundary contour by identifying “FB” (follow boundary); see Figures 4-25 and 4-26. A number following “FB” shall indicate the number of contours; absence of a number indicates that the entire layer is filled by following the contour. A “TRACK TABLE” annotation (or associated document) may also be included to specify layer numbers whose tracks are specified as unit vector notations. The “TRACK TABLE” concept introduced in Figure 4-27 provides flexibility to specify the contours using a table.

4.3.2.3 Build Environment. The characteristics of the build environment may differ depending on the process used and may include temperature, humidity, and other process conditions that may affect the quality of the build. Specific environment requirements may be communicated as a note.

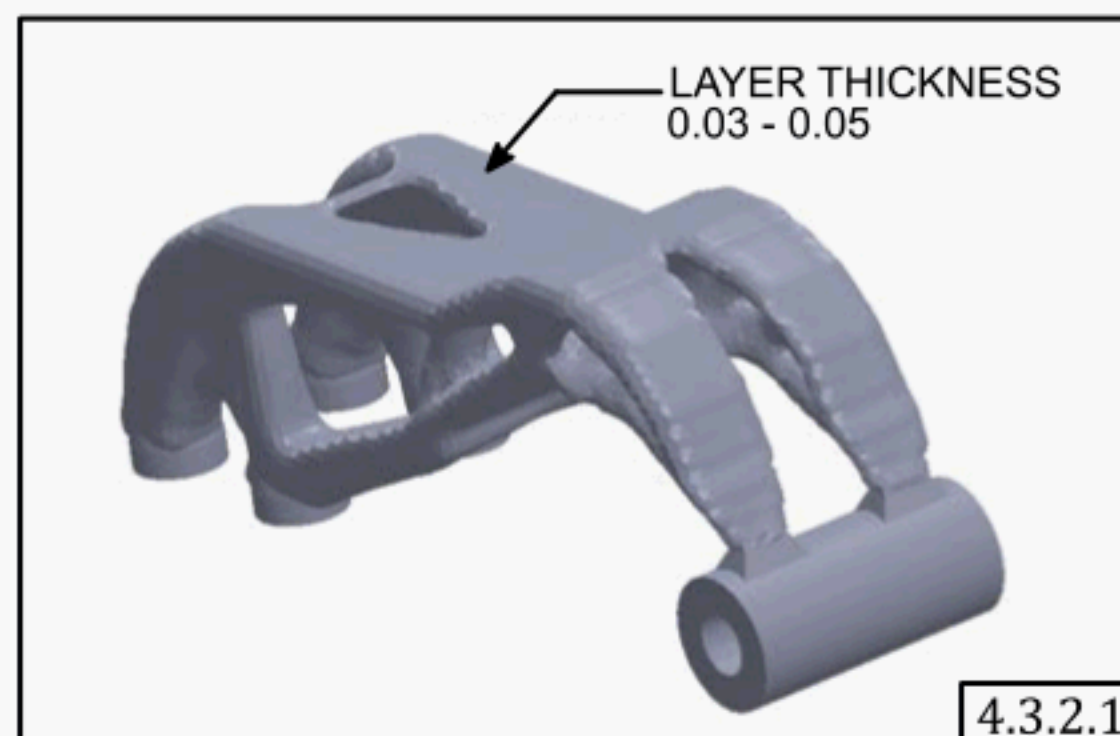
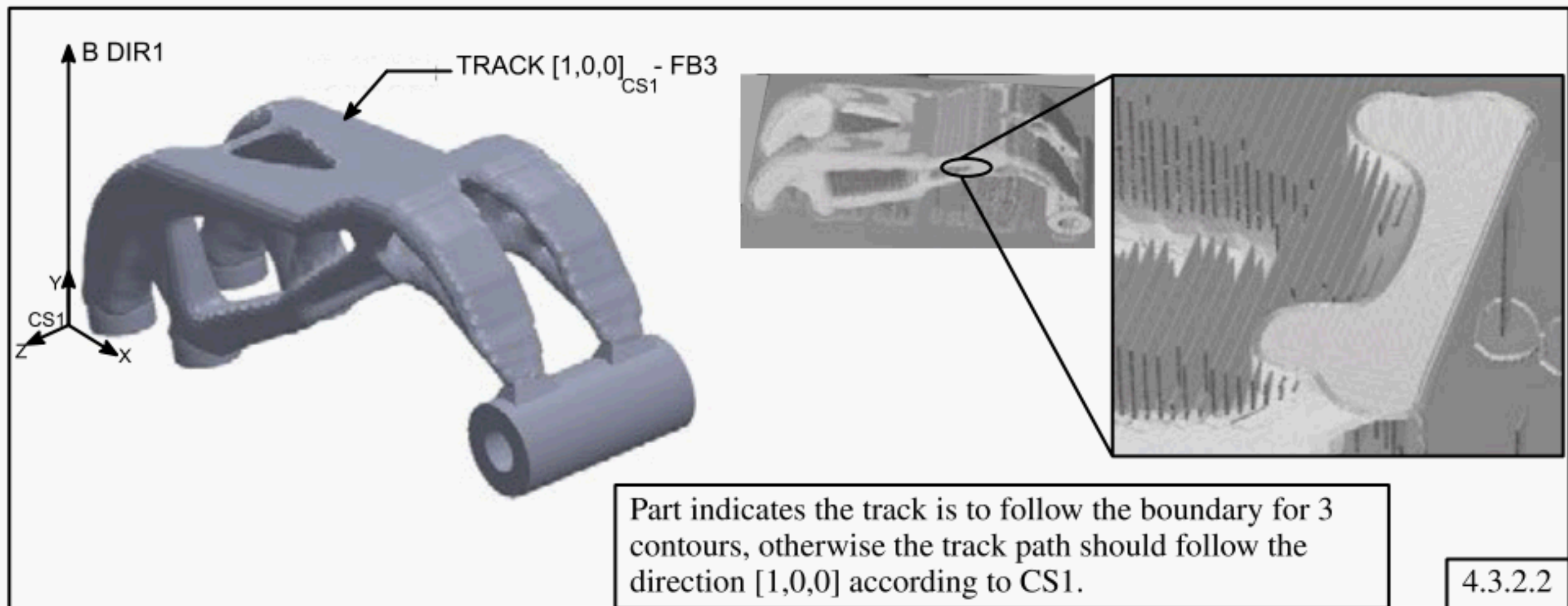
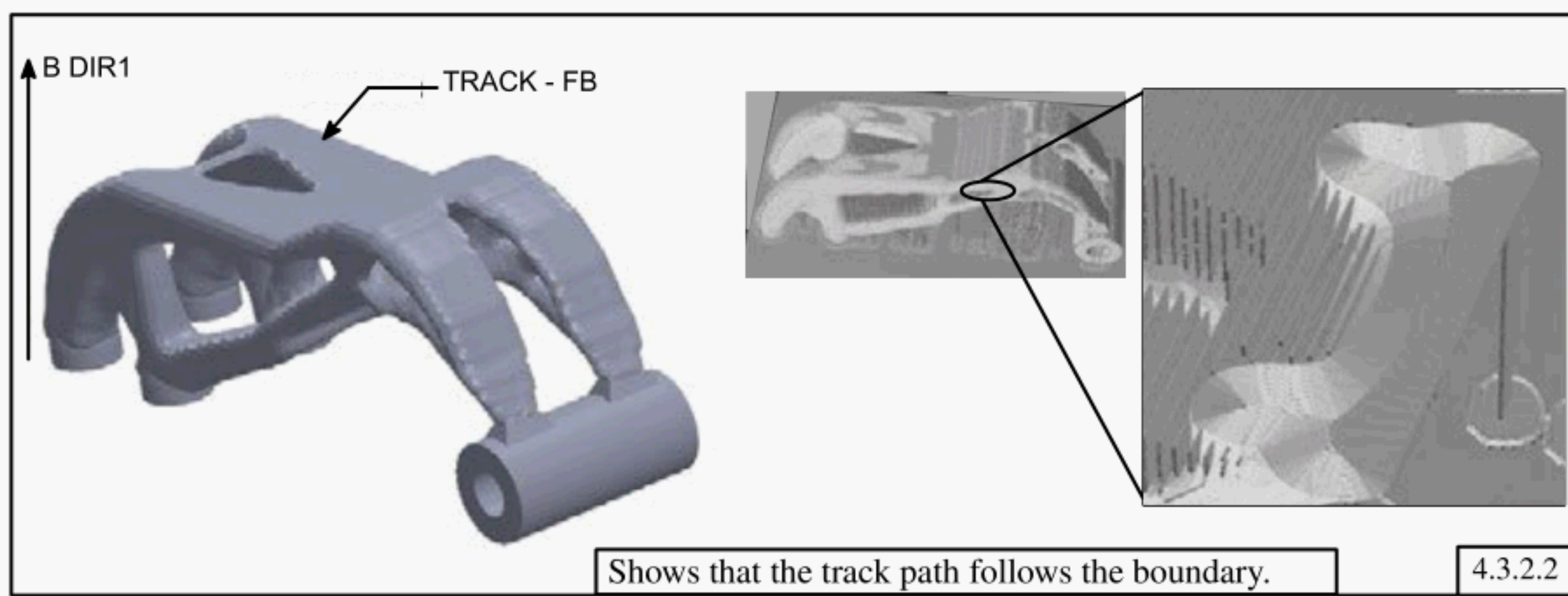
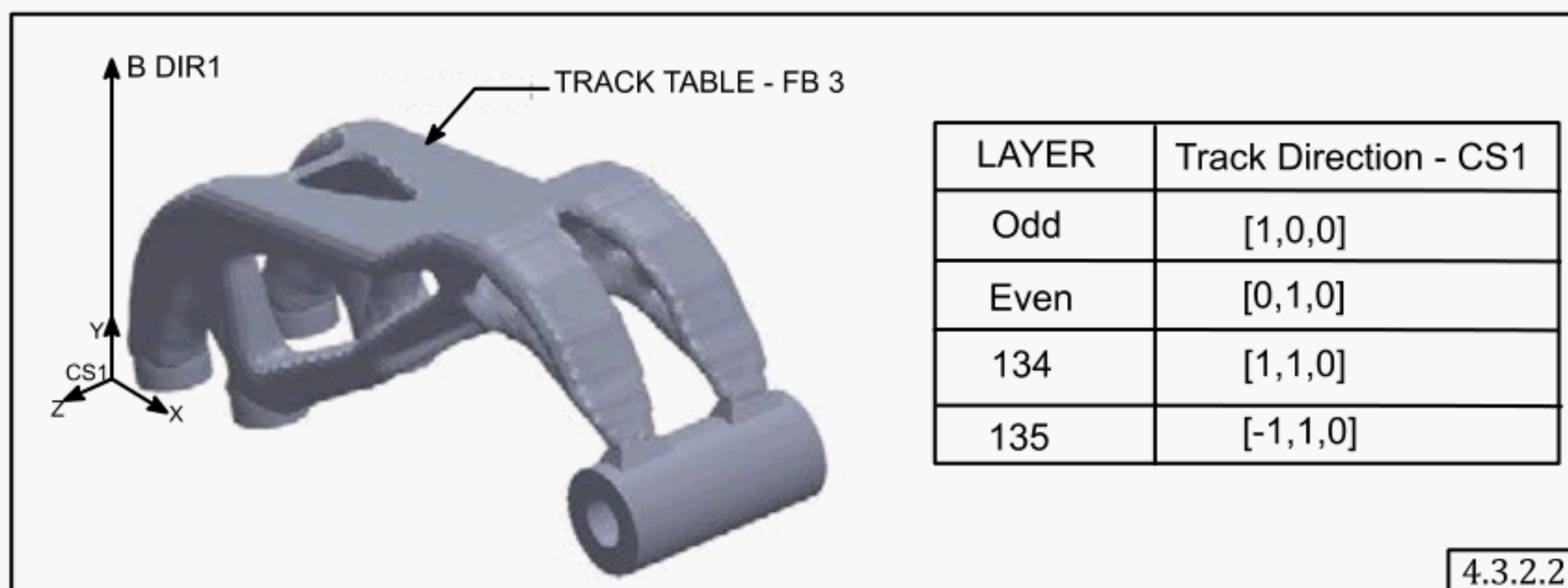
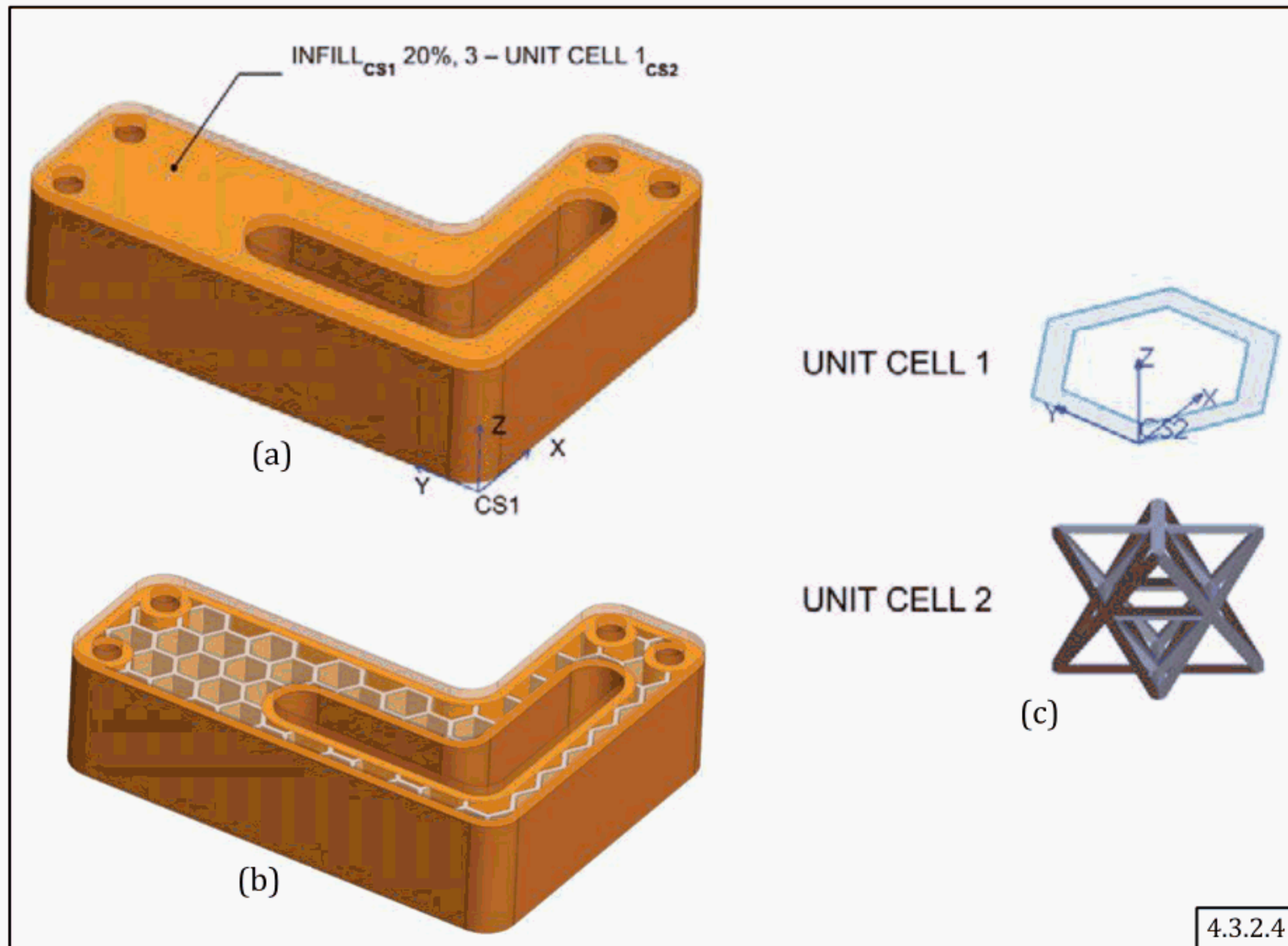
Figure 4-24 Layer Thickness Specification


Figure 4-25 Specification of a Track Path With Three Contours**Figure 4-26 Specification of a Track Path Using a Follow Boundary (FB) Modifier****Figure 4-27 Specification of Track Paths on Different Layers**

GENERAL NOTE: "TRACK TABLE" indicates different track paths on different layers.

Figure 4-28 Examples of Infill and Unit Cells


GENERAL NOTE: Illustration (a) shows a solid model with infill identified in annotation and not modeled. Illustration (b) shows a cross section of a modeled infill geometry. Illustration (c) shows examples of unit cells.

4.3.2.4 Fill Patterns. If required, a fill pattern shall be identified using “INFILL” followed by the percentage of volume to fill, followed by a dimension for the shell thickness (see Figure 4-28). If a specific unit cell is required, it may be included as a feature in the part model or defined in a separate model, and it shall be identified with “UNIT CELL” followed by a number appended to the infill annotation.

Two examples of infill unit cells are shown in Figure 4-28, illustration (c) as a two-dimensional honeycomb and a 3D lattice.

4.3.3 Support Structures. A bounded surface or volume region may be used to specify where to limit or require support structures. Figure 4-29 illustrates a default support structure without any specification.

If necessary, specify locations where support structures attach to nominal geometry.

(a) The following are examples of requirements that may be needed:

- (1) to define the location of support structures
- (2) to limit the surface area interface of support structures
- (3) to define exclusion zones for support structures

(b) Notes may be used to identify the following:

- (1) structure exclusion area (SEA); see Figure 4-30
- (2) structure limiting area (SLA); see Figure 4-31
- (3) structure required area (SRA); see Figure 4-32

NOTE: Figures are for demonstrative purposes only. Support structure geometry in Figures 4-30 through 4-32 is exaggerated to demonstrate concepts.

Figure 4-29 Example Where Support Structure Location Is Not Specified

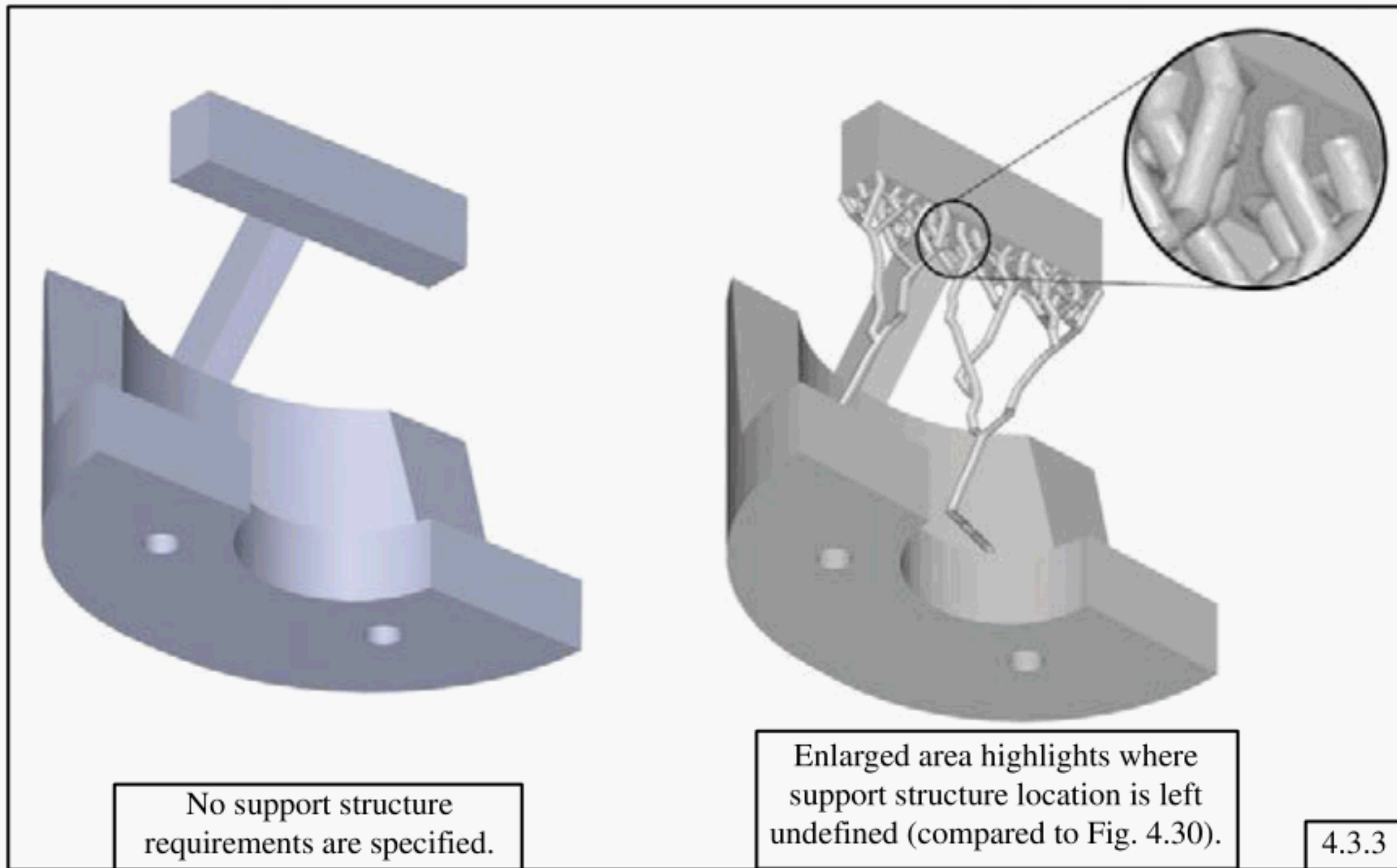


Figure 4-30 Example Where Bounded Surface Region 1 (SURF1) Is Annotated to Indicate a Structure Exclusion Area (SEA)

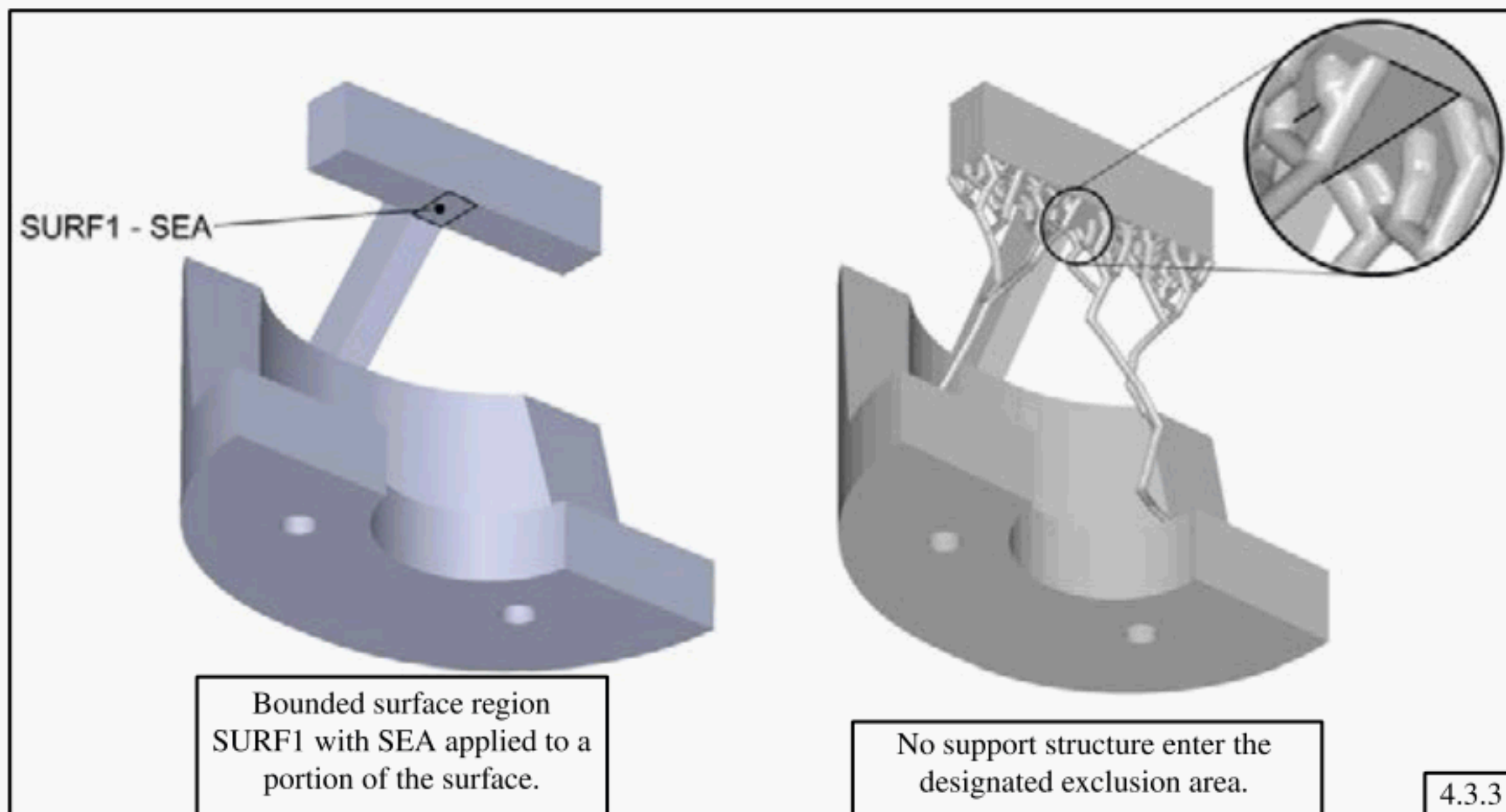
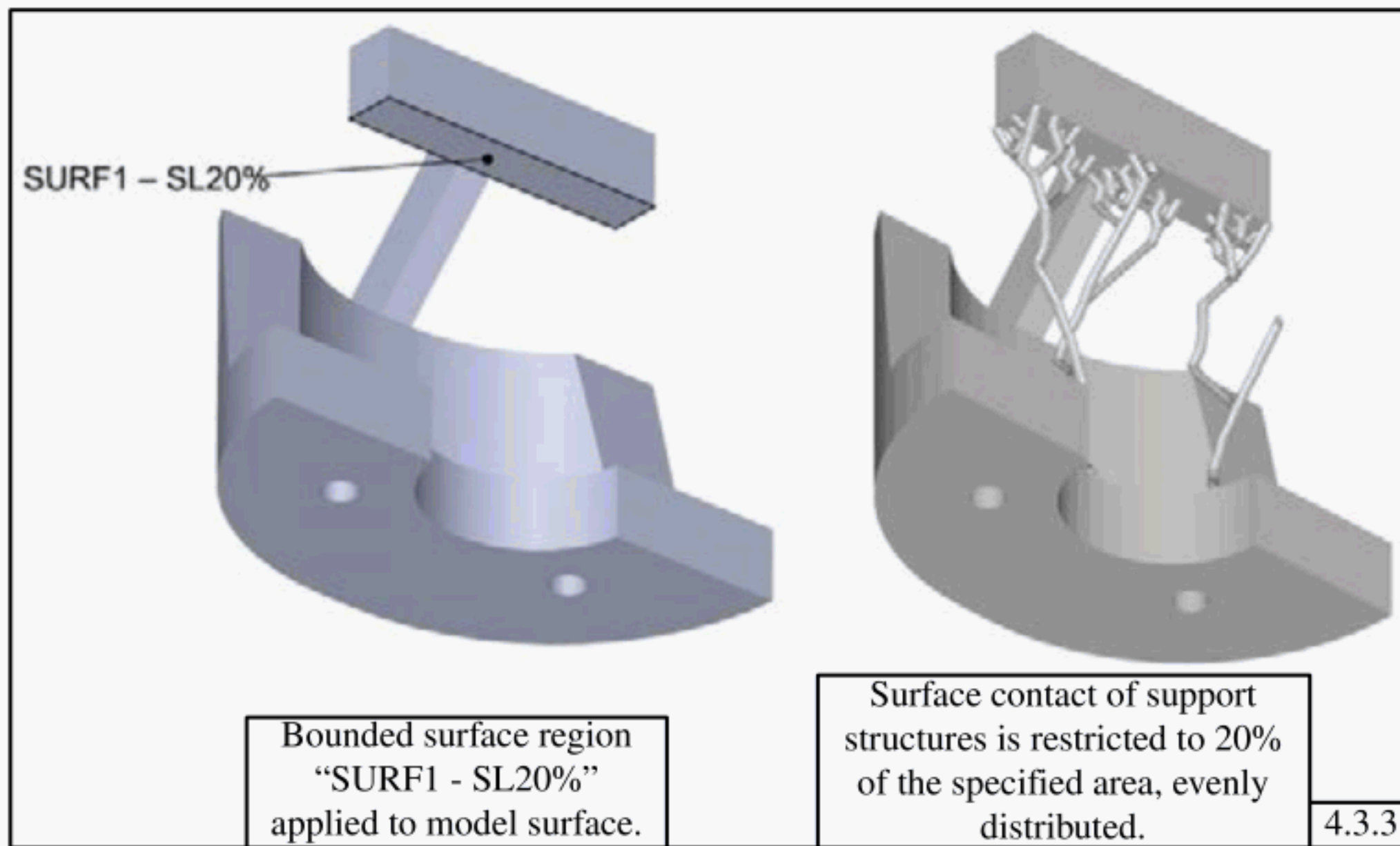


Figure 4-31 Example Where SURF1 Is Annotated to Indicate a Structure Limiting Area (SLA) of 20%

If a note is associated to a feature of size, supports shall connect the identified surface to the feature of size. If the note is not associated to a feature of size, the support shall connect the indicated surface to adjacent surfaces ([Figure 4-32](#)).

If required, support structure geometry shall be included in the model as bounded surface or volume regions. If a profile tolerance is required for support structure geometry, the profile tolerance shall be indicated with “SUPPORT” and a bounded volume region indicator. See [Figure 4-33](#). This may be repeated, as necessary, to indicate support structures outside or inside the part.

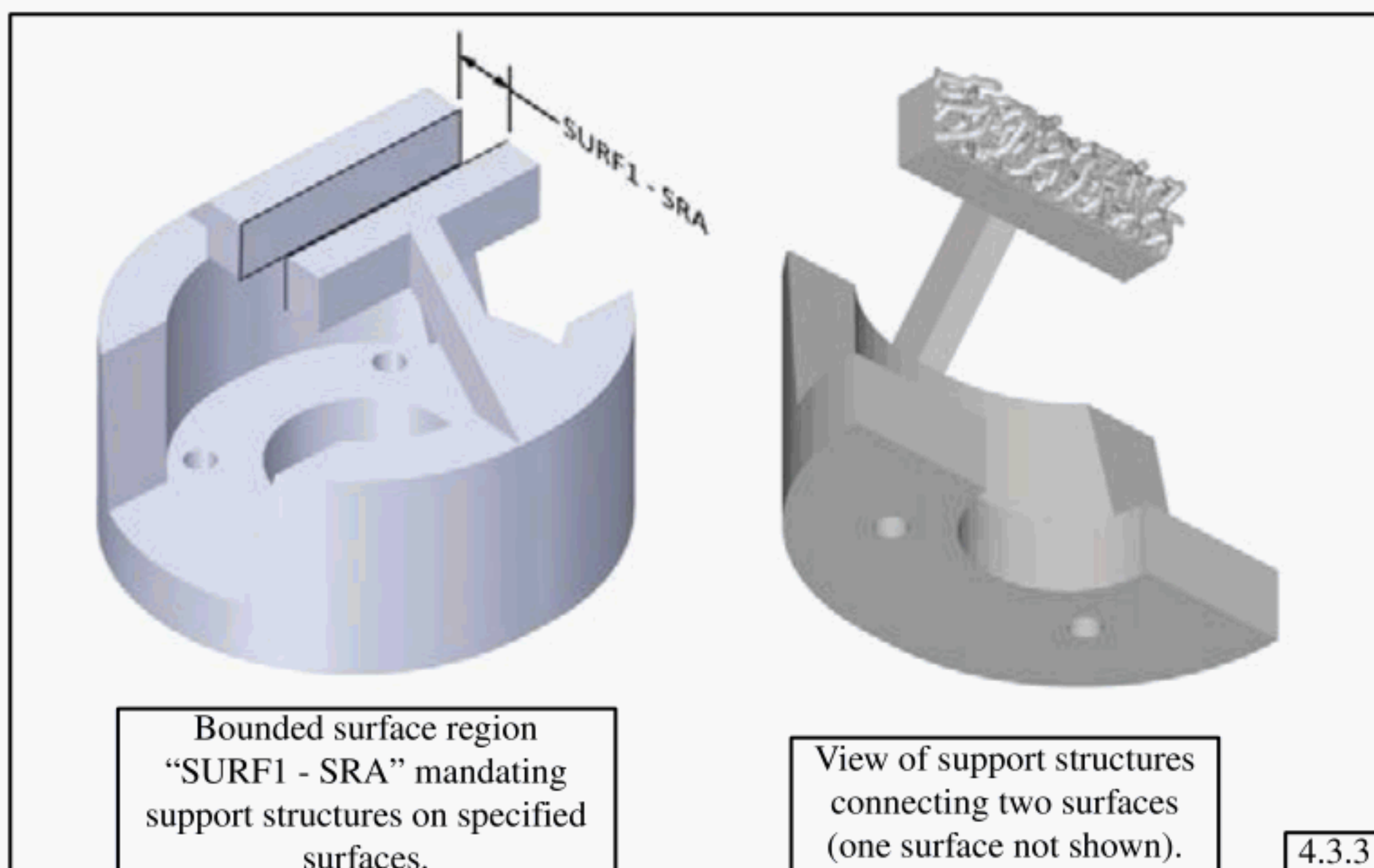
Figure 4-32 Example Where SURF1 Is Annotated to Indicate a Structure Required Area (SRA)

Figure 4-33 Indication of Geometry Created Inside the Part to Specify Support Structure

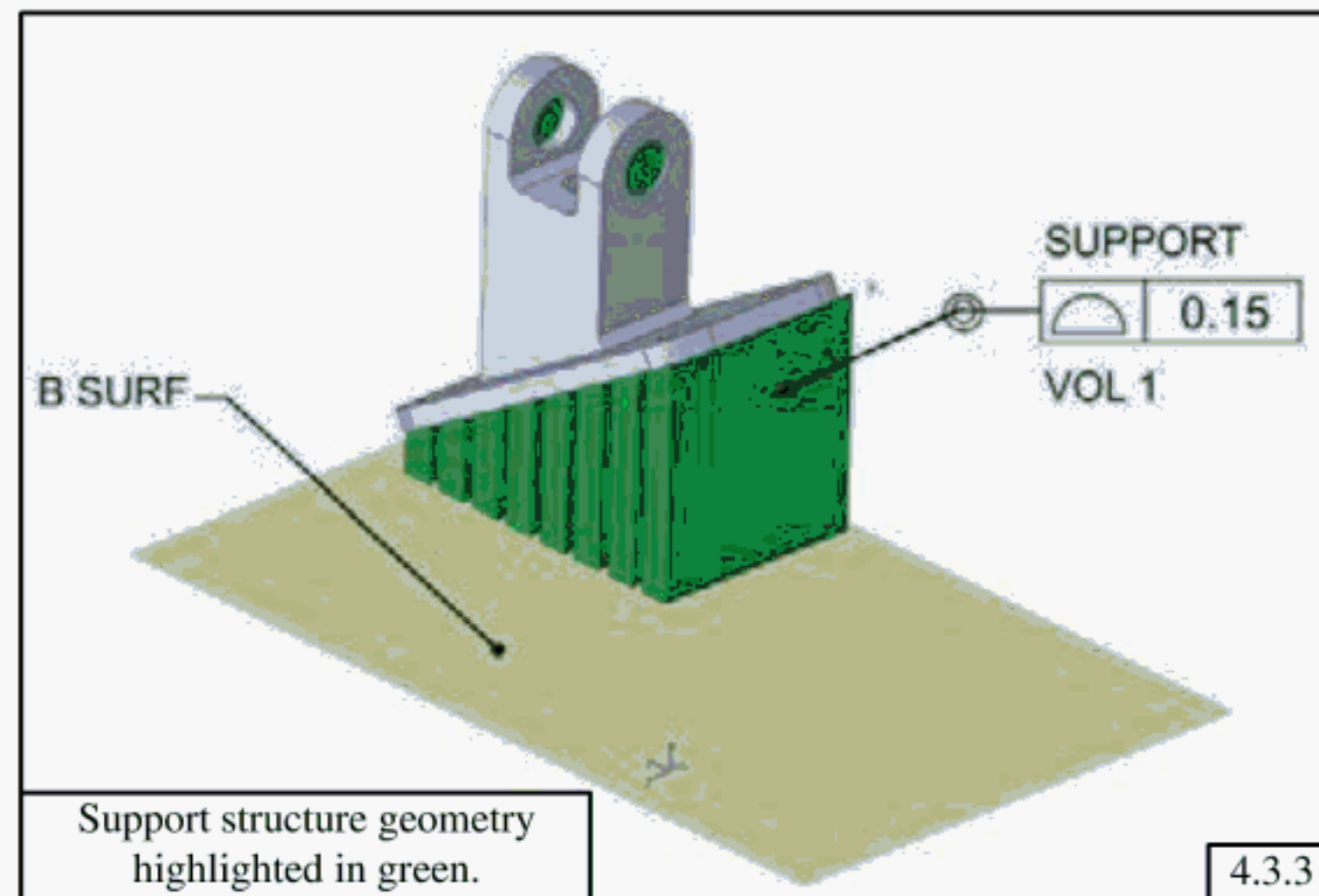
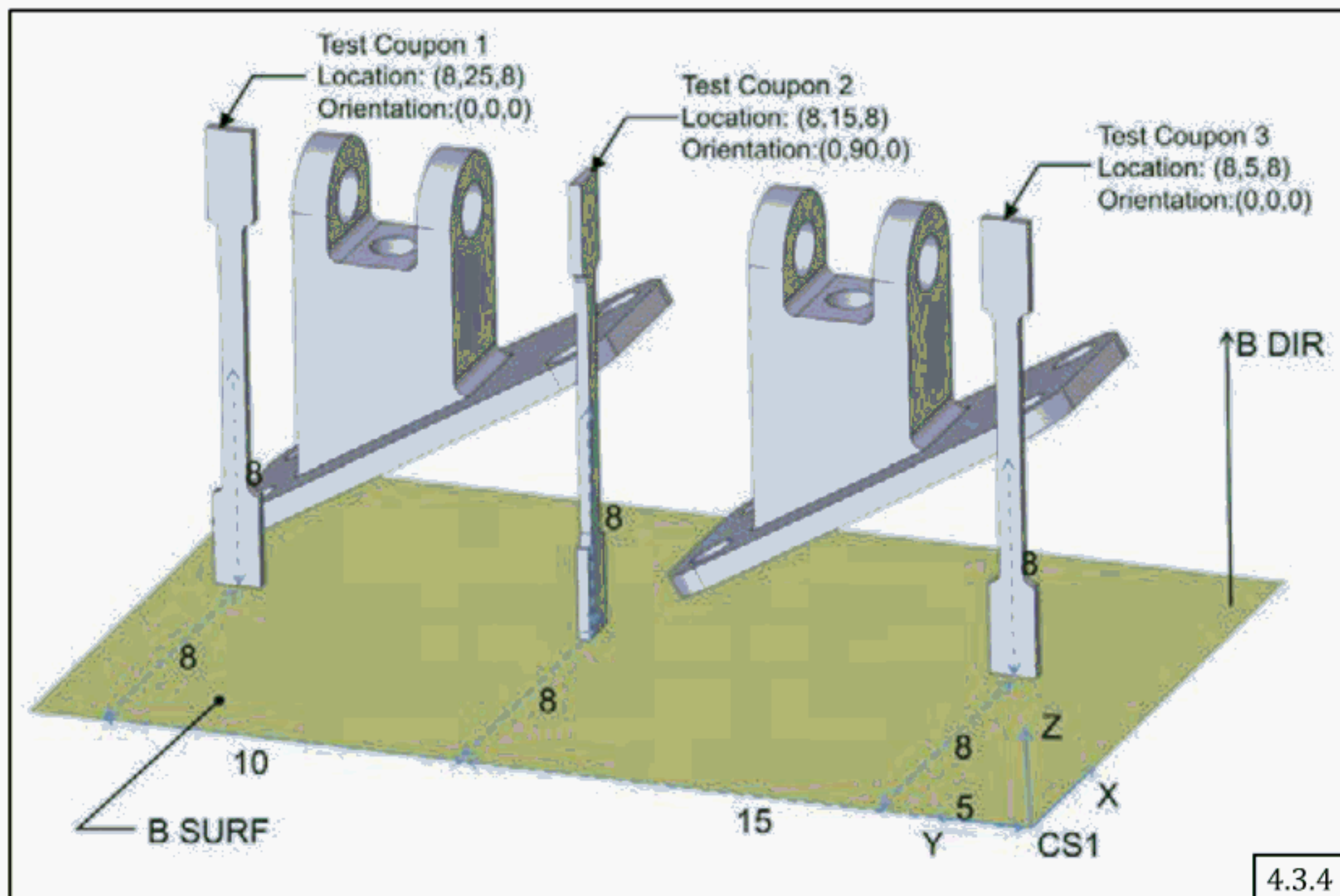


Figure 4-34 Local Notes Identifying Test Coupons



4.3.4 Test Coupons. Test coupons, if specified, shall be identified with “Test Coupon *X*,” where *X* is a unique label. If build layout and build surface are depicted (see Figure 4-34), the build location, orientation, and related tolerance specifications for test coupons shall be indicated as specified in para. 4.3.1.4.

Table 5-1 Required and Optional Data Packages for AM Products

PDP Type	Required/ Optional	Description
AM design	Required	Identifies all requirements for the end product and may also include supplemental geometry as defined in section 3 and geometry characteristics as defined in paras. 4.1 and 4.2 .
AM build	Optional	Identifies all requirements for the printed file geometry and build environment. May also include support structures, supplemental geometry from section 3 , geometry characteristics as defined in paras. 4.1 and 4.2 , and process-related characteristics as defined in para. 4.3 .
AM processed	Optional	Identifies all requirements for completing the part. May include all elements of AM build data package (DP) complemented by additional instructions (e.g., notes) on postprocessing (e.g., machining, coatings, heat treatment, inserts) operations.
AM end product	Optional	Includes evidence of conformance to specification. Refer to Nonmandatory Appendix C for suggestions on collecting data representing the end product.
AM postproduction	Optional	Archive of all data used in the production of the part. May be a combination of some or all of the data packages produced.

5 PRODUCT DATA PACKAGES (PDP)

5.1 General

[Section 5](#) establishes data requirements for manufacturing a part with an AM process. Due to the inherently digital nature of AM processes, this section focuses on model-based requirements (see ASME Y14.100— Classification Codes 3, 4, and 5), as opposed to drawing-centric requirements.

5.2 Product Data Package Types

[Paragraph 5.2](#) establishes data requirements for managing different stages of an AM part. The process intricacies required to define the transition from a product definition data set to a part is like that of forgings and castings in both complexity and postprocessing requirements. As such, managing the AM transition shall be similar to managing transitions established in the applicable standards for casting and forgings. Each transition may be represented as a unique file set with unique formats. These files shall be collected into a PDP type.

[Table 5-1](#) presents examples of constituent PDP types used in AM. At a minimum, one PDP type is required; AM design is described in [Tables 5-1](#) and [5-2](#).

5.3 PDP Type Contents

5.3.1 AM Design Data Package (DP). The AM Design DP content may include the required and optional elements identified in [Table 5-2](#).

5.3.2 AM Build DP. The AM Build DP content may include the required and optional elements identified in [Table 5-3](#).

5.3.3 AM Processed DP. The AM Processed DP content may include the required and optional elements identified in [Table 5-4](#).

Table 5-2 Required and Optional Elements Within the AM Design DP

Data Element	Required/ Optional	Description
Geometry	Required	Represents the final geometric definition, per ASME Y14.41.1, Code G3. May include requirements identified in section 3 and paras. 4.1 and 4.2 .
Annotations	Required	Represents the final dimensions and tolerances required, per ASME Y14.41.1, Code A1, A2, or A3. May include requirements identified in section 3 and paras. 4.1 and 4.2 .
Attributes	Required	Represents information that can be queried in the model per ASME Y14.41. May include requirements identified in section 3 and paras. 4.1 and 4.2 .
Metadata	Required	Represents metadata per ASME Y14.41.1 and Table 5-7 .
Support documentation	Optional	Additional documentation may be required and may be included in the DP. This may include, but is not limited to, analysis requirements and results, material specifications, and build environment requirements.
Additional digital formats	Optional	Additional digital file formats may be needed and are derivatives from the original native file. Examples of additional digital file formats are STL, AMF, STEP, and 3MF.

Table 5-3 Required and Optional Elements Within the AM Build DP

Data Element	Required/ Optional	Description
Geometry	Required	Represents the geometric definition as the model is to be printed, per ASME Y14.41.1, Code G3. May include requirements identified in section 3 and paras. 4.1 and 4.2 .
Annotations	Required	Represents the final dimensions and tolerance required, per ASME Y14.41.1, Code A1, A2, or A3. May include requirements identified in section 3 and paras. 4.1, 4.2, and 4.3 .
Attributes	Required	Represents information that can be queried from the model per ASME Y14.41. May include requirements identified in section 3 and paras. 4.1, 4.2, and 4.3 .
Metadata	Required	Represents metadata per ASME Y14.41.1 and Table 5-7 .
Additional geometry	Optional	Additional DP requirements may be required to represent additional AM build information. May include requirements identified in section 3 and paras. 4.1, 4.2, and 4.3 .
Additional requirements	Optional	Additional requirements may be specified to define the build environment. May include requirements identified in section 3 and paras. 4.1, 4.2, and, particularly, 4.3 .
Additional manufacturing information	Optional	Additional digital file formats may be needed and are derivatives from the original native file. Examples of additional digital file formats include STL, AMF, STEP, 3MF, and manufacturer-specific slice and build files.

Table 5-4 Required and Optional Elements Within the AM Processed DP

Data Element	Required/ Optional	Description
Geometry	Required	Represents the geometric definition as the model is to be printed and postprocessed, per ASME Y14.41.1, Code G3. May include requirements identified in section 3 and paras. 4.1 and 4.2 .
Annotations	Required	Represents the final dimensions and tolerance required, per ASME Y14.41.1, Code A1, A2, or A3. May include requirements identified in section 3 and paras. 4.1 and 4.2 .
Metadata	Required	Represents metadata per ASME Y14.41.1 and Table 5-7 .
Additional geometry	Optional	A variety of geometry representations may be required to represent multiple stages of postprocessing. For example, the AM build part may be processed using traditional machining operations. This geometry may be represented as a model in a variety of file formats.
Additional components and assembly	Optional	Additional components may be added to the part to complete the AM design requirements. An example is adding helical inserts into a part.
Additional procedural instructions	Optional	When processing steps are needed, these shall be included in the data package. These may include, but are not limited to, support structure removal and removal from the build platform, heat treatments, and finishing processes. May include requirements identified in para. 4.3 .
Additional manufacturing information	Optional	A variety of digital files may be produced in order to manufacture the part. An example is the G Code for milling to a final specification.

5.3.4 End Product DP. The End Product DP content may include the required and optional elements identified in [Table 5-5](#).

5.4 Model Schema and Organization

AM product definition data sets shall comply with ASME Y14.41.1 requirements. An example of AM model schema and organization combinations beyond ASME Y14.41.1 examples are described in [Table 5-6](#).

Reference ASME Y14.41.1, para. 6.7, for metadata requirements to be included in the product definition or data package. In addition, metadata elements indicated in [Table 5-7](#) shall also be included.

Table 5-5 Required and Optional Elements Within the End Product DP

Data Element	Required/ Optional	Description
Geometry	Required	Actual 3D geometry, as evaluated to capture the end product. This model may be used to compare to the AM design model for quality validation.
Evidence of conformance to specifications	Optional	Actual measurement results representing the geometry.

Table 5-6 Examples of AM Use Cases Using the Codes in ASME Y14.41.1 to Show the Level of Content in an AM Data Package (ADP)

Use-Case Examples	Categories									
	Maturity State, Level (Code)				Geometry State, Level (Code)			Annotation and Attribute State, Level (Code)		
	Conceptual (M1)	Developmental (M2)	Production (M3)	Postproduction (M4)	None (G1)	Partial (G2)	Full (G3)	None (A1)	Partial (A2)	Full (A3)
Fixturing	...	X	...	...	...	...	X	...	X	...
Production	...	...	X	...	...	...	X	...	...	X
Prototype	...	X	...	...	...	...	X	X	...	...
Visual novelties	X	...	...	...	...	X	...	X	...	...

Table 5-7 Examples of Metadata Requirements for Model-Based Definition (MBD) Data Sets

Element Name	Required/Optional	Data Type	Description	Data Category
DP_Type	Required	String	AM design/ AM build/ AM processed/ End product/ Postproduction	2
AM_Process	Optional	String	Specify AM process per ASTM F42: material extrusion, material jetting, binder jetting, vat photopolymerization, sheet lamination, powder bed fusion, directed energy deposition	3
AM_Joining_Mechanism	Optional	String	Specify joining mechanism: textual input (e.g., binder, laser, electron beam, sinter, melt)	2

NONMANDATORY APPENDIX A

EXAMPLE AM NOTES

A-1 INTRODUCTION

This Appendix is an informative appendix. It contains example notes for an AM part.

A-2 PRODUCT NOTES

INTERPRET PRODUCT DEFINITION IN ACCORDANCE WITH ASME Y14.5-2009, ASME Y14.41-2012, ASME Y14.41.1-201X, AND ASME Y14.46-201X STANDARDS.

DESIGN MODEL MBD051861 IS REQUIRED TO COMPLETE THE PRODUCT DEFINITION.

UNLESS OTHERWISE SPECIFIED, ALL UNTOLERANCED FEATURES SHALL HAVE A PROFILE TOLERANCE OF $\triangle|0.2|A|B|C$.

OBTAIN DIMENSIONS FOR ALL UNDIMENSIONED FEATURES FROM THE MODEL.

ALL VALUES QUERIED OR DERIVED FROM THE MODEL SHALL BE BASIC.

DATUMS Z, Y, X ARE DEFINED FROM CORRESPONDING AM-PROCESS PRODUCT DEFINITION.

MATERIAL ENVELOPE SHALL NOT EXCEED THE BOUNDARY DEFINED BY MECHANICAL ENVELOPE A051861.

A-3 PROCESS NOTES

A PLATFORM OF MINIMUM 3.75MM HEIGHT SHALL BE PRINTED BETWEEN THE BUILD PLATFORM AND THE PART AND CUT OFF AFTER THE ADDITIVE MANUFACTURING PROCESS.

THE PART SHALL BE SANDBLASTED AFTER THE ADDITIVE MANUFACTURING PROCESS AND BEFORE BEING POSTMACHINED.

THREE CYLINDRICAL WITNESS COUPONS SHALL BE PRINTED IN THE SAME BUILD AS EACH PART TO VERIFY MECHANICAL PROPERTIES PER NSC 1234567.

NONMANDATORY APPENDIX B

DEFINING TRANSITION REGIONS

B-1 INTRODUCTION

This Appendix is an informative appendix.

The transition property is indicated with symbol m_i . The transition function is indicated as f_i . At any given location x, y, z within a unit-defined volume of the transition region, the required factor m_i is computed using eq. (1). The unit-defined volume is the volume within which the property is computed. Any given location can be normalized by using all factors m_i and summing to 1; see eq. (2). Furthermore, tolerance on the value of the factor may be specified as t_{mi} and may be computed using formula (3). All computed values may be taken as absolute positive values as deemed necessary. Mathematical functions defined in ISO/ASTM 52915 are also applicable.

The application of this method is illustrated in para. 4.3.2.

$$m_i = \frac{f_i(x, y, z)}{\sum f_i(x, y, z)} \quad (1)$$

where

$$\sum_i^n m_i = 1 \quad (2)$$

$$m_i t_{mi} \quad (3)$$

B-2 MATERIAL GRADIENT DEFINITION

Table B-1 provides an example of material gradient values for the part shown in Figure 4-12. This example implements functions to specify a gradient, which are $f_2 = z - 10$ and $f_1 = 15 - (z - 10)$. These equations may be represented in the part or any derivative model. The tolerance on MAT1 and MAT2 is identified in Table B-1 as $\pm 12.5\%$ and $\pm 25\%$, respectively. The actual value of the material composition in a minimal measurable volume in the part space will equal 100% (including voids). Nominal material compositions are modified by changing the equations computed in the table. The tolerance values are unilaterally disposed within the VOL bounded region at the material boundaries (e.g., $z = 10$, $z = 25$ or when nominals are either 0% or 100%).

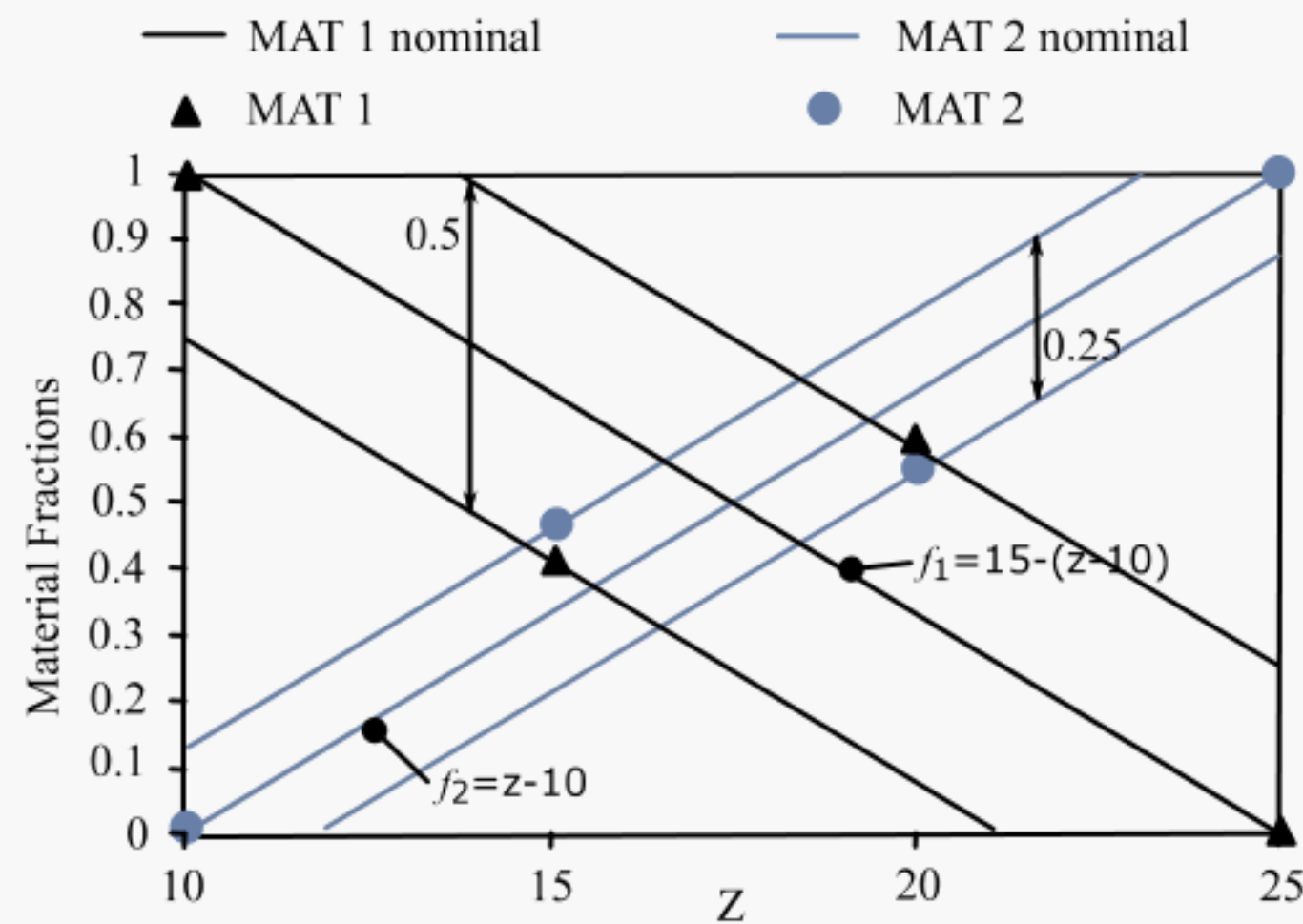
Figure B-1 describes the nominal values of materials along the z -axis with their tolerance zones and a set of allowable values for MAT1 and MAT2. The two lines with small dashes indicate the tolerance zone for each material. For a chosen allowable value of MAT2 (blue circle at a given z -coordinate), a corresponding maximum allowable value of MAT1 is shown in the graph. Although MAT2 values are at their upper/lower allowable limits, MAT1 values do not lie at the upper or lower allowable limits. This is due to different tolerance zones for each material fraction.

Figure B-1 indicates that nominal limits and acceptable material fractions along the z -axis for VOL2 are based on the equations embedded in the part model.

Table B-1 Material Gradient Values (Figure 4-12)

Annotation Label	z , mm	Nominal MAT1, %	Nominal MAT2, %	Tolerance on Fraction of MAT1, %	Tolerance on Fraction of MAT2, %
VOL1	10	100	0	-12.5	+25
VOL2	15	66	33	± 12.5	± 25
	20	33	66	± 12.5	± 25
VOL3	25	0	100	+12.5	-25

Figure B-1 Part With Material Transition Region (Heterogeneous Material Indicator) and Specification of Tolerance

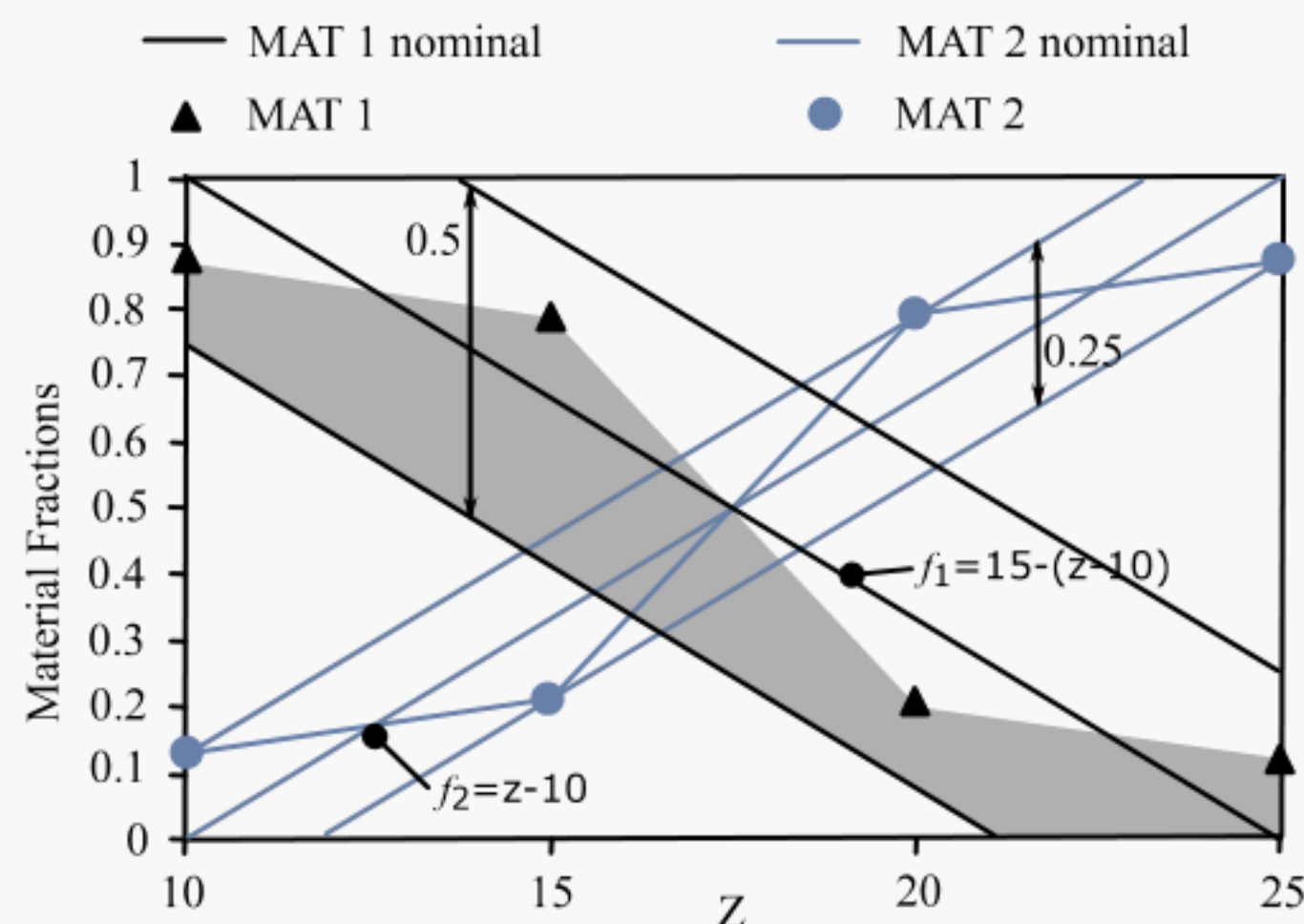


This example also allows for a void fraction. As depicted in [Figure B-2](#), any value of MAT1 in the black area is acceptable, based on the given values of MAT2. When MAT1 fractions are below the top line connecting the black triangles, the material fractions of MAT1 and MAT2 do not add up to 1. In this case, the remainder of the material fraction is allowable void fractions. Similarly, if MAT1 fractions were given as depicted in [Figure B-3](#) with black triangles, the respective maximum allowable fractions for MAT2 are shown with blue circles. All acceptable MAT2 fractions are shown as blue area. When MAT2 fractions are below the top line connecting the blue circles, the material fractions of M1 and M2 do not add up to 1. In this case, the remainder of the material fraction is allowable void fractions.

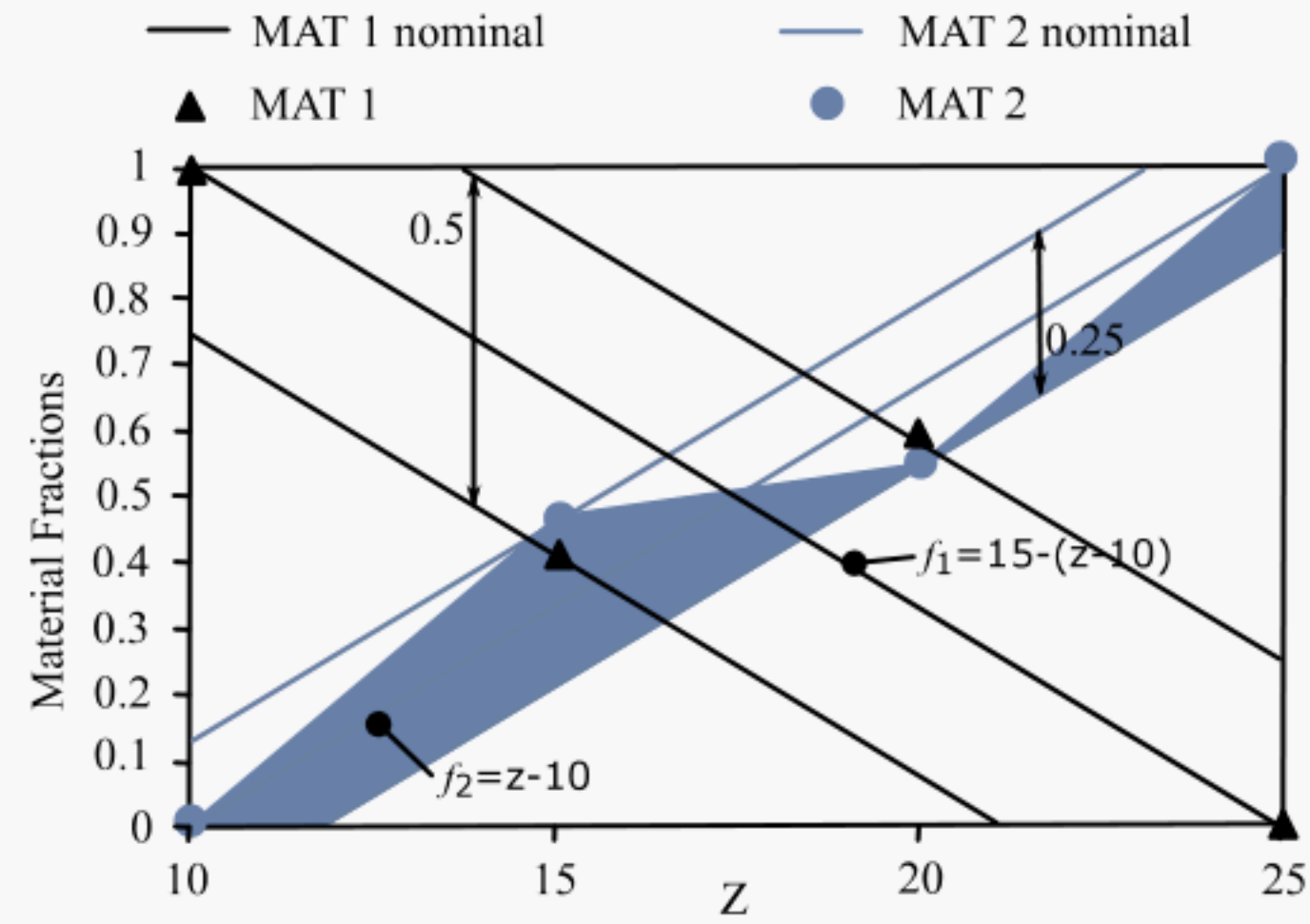
Given material fractions of MAT2, the acceptable material fractions of MAT1 are marked as gray area. Any value of MAT1 below the upper line marked with black triangles leads to acceptable void fractions.

Given material fractions of MAT1, the acceptable material fractions of MAT2 are marked as blue area. Any value of MAT2 below the upper line marked with blue circles leads to acceptable void fractions.

Figure B-2 Acceptable Void Fractions for MAT1 and MAT2



GENERAL NOTE: Gray-shaded area indicates acceptable void fractions.

Figure B-3 Allowable Material Fractions for MAT1 and MAT2

GENERAL NOTE: Blue-shaded area indicates allowable material fractions.

NONMANDATORY APPENDIX C

REFERENCE DOCUMENTS TO TEST FOR CONFORMANCE

C-1 INTRODUCTION

This Appendix is an informative appendix.

C-2 TESTING FOR CONFORMANCE

“Conformance” is the determination, directly or indirectly, of whether a product, process, or system meets relevant standards and fulfills specified requirements. Variations are inherent to all manufacturing processes. To meet functional needs, a designer specifies acceptable limits of these variations.

Options are available when communicating test and conformance decisions for an AM part. A developing checklist of helpful documents that may be used to validate specified properties is provided in [Table C-1](#). Documented validation methods help to confirm that the AM process produced the geometries and properties intended in the product definition.

An AM data package may include additional specifications to supplement dimensional definitions, such as manufacturing process requirements and requirements on attributes of the finished product. See [section 5](#) for AM data package recommendations.

Table C-1 Select Reference Documents

Property of Interest	Documentary Standard	Select Quality Assurance Parameters
Geometric specifications	ASME B46.1, Surface Texture (Surface Roughness, Waviness, and Lay) ASME B89.7.2, Dimensional Measurement Planning ASME Y14.5, Dimensioning and Tolerancing ASME Y14.36M, Surface Texture Symbols	Location, orientation, size, form, texture
Material composition	ASTM A751, Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products ASTM E350, Standard Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron	Chemistry, some implication in compatibility and aging, microstructure
Material performance	ASTM E111, Standard Test Method for Young’s Modulus, Tangent Modulus, and Chord Modulus ASTM E1461, Standard Test Method for Thermal Diffusivity by the Flash Method ASTM E2550, Standard Test Method for Thermal Stability by Thermogravimetry ASTM F2971, Standard Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing	Tensile strength, Young’s modulus, bulk modulus, thermal properties
Process requirements	AIAA S-080, Space Systems — Metallic Pressure Vessels, Pressurized Structures, and Pressure Components AIAA S-110, Space Systems — Structures, Structural Components, and Structural Assemblies AS 9100, Aerospace Quality System Standard ISO/TS 16949, Quality management systems — Particular requirements for the application of ISO 9001:2008 for automotive production and relevant service part organizations	Interrupted builds; implications to performance that are not necessarily directly measurable
Defects	AIAA S-080, Space Systems — Metallic Pressure Vessels, Pressurized Structures, and Pressure Components AIAA S-081, Space Systems — Composite Overwrapped Pressure Vessels AIAA S-110, Space Systems — Structures, Structural Components, and Structural Assemblies ASME BPVC, Boiler and Pressure Vessel Code	Definitions of flaws, inclusions, porosity

ISBN 978-0-7918-7182-9



9 780791 871829



N 1 9 6 1 Q