4.49 Manifold Solid B-Rep Object Entity (Type 186) ‡

‡The Manifold Solid B-Rep Object Entity has not been tested. See Section 1.9.

A manifold solid is a bounded, closed, and finite volume V in three dimensional Euclidean space, $R3$. V is restricted to be the closure of the interior of V which shall be arcwise connected. There is no restriction on the number of voids within V or on the genus of the boundary surfaces. Discussion of the manifold solid from a graph theoretic view is contained in Appendix I.

The Manifold Solid B-Rep Object (MSBO) defines a manifold solid by enumerating its boundary. This boundary may be decomposed into its maximal connected components called closed shells. Each shell is composed of faces which have underlying surface geometry. The faces are bounded by loops of edges having underlying curve geometry. The edges are bounded by vertices whose underlying geometry is the point. Implicit in the representation is a concept of oriented uses of topological entities by containing entities. This allows the referencing entity to reverse the natural orientation of the referenced entity. The natural orientation is derived from the underlying geometry. Figure 58 illustrates the hierarchical nature of this representation.

The vertex represents a location. The geometry underlying a vertex is a point in $R3$.

An edge connects two vertices. It is bounded by two vertices (V_1 and V_2). It does not contain its bounds. The start and terminate vertices do not have to be distinct. Edges do not intersect except at their boundaries (*i.e.,* vertices). The geometry underlying an edge is some portion of a curve in $R3$. The edge has a natural orientation in the same direction as its underlying curve in $R3$. Thus the edge is traced from start vertex to terminate vertex as the underlying curve is traced in the
ECO713 direction of increasing parameter value. Each edge shall be used exactly twice in a MSBO. Refer to the shell discussion below for further details.

The loop is a path of oriented edges and vertices having the same start and terminate vertex. Typically, a loop represents a connected collection of face boundaries, seams, and poles of a single face (refer to Figures in Appendix I). Its underlying geometry is a connected curve or a single point in $R3$. The loop is represented as an ordered list of oriented edges, edge-uses ($EU_i, i = 1, n$), which has the following properties:

- The terminal vertex of EU_i is the initial vertex of $EU_{i+1}, i = 1, n-1$.
- The loop is closed. This implies that the terminal vertex of EU_n is the same as the initial vertex of EU_1.
- The orientation of the loop is defined to be the same as its constituent edge-uses which reference edges. Therefore the direction of the loop at an edge-use which references a vertex, A, can be taken from any edge-use having an underlying edge which has A as either its start or terminate vertex.

The edge-use is an instancing of an edge or vertex into a loop. It consists of either an edge, an orientation, and optional parameter space curves (see the definitions of associated parameter space and collections in the Boundary Entity (Type 141)), or (in the case of a pole) a vertex and an optional parameter space curve.

If the edge-use references an edge, then the orientation describes whether the direction of this use of the edge is in agreement with the natural orientation of the edge. If the orientation of the edge-use is in agreement with the edge, then the use is directed from the start vertex to the terminate vertex of the edge. If the orientation is not in agreement, then the use of the edge is directed from the terminate vertex to the start vertex. At any point the direction of an edge-use is called its topological tangent vector, T. See the face discussion to determine how to set the orientation. If the edge-use references a vertex, then no orientation is defined.

The face is a bound (partial) of an arcwise connected open subset of $R3$ and has finite area. It has an underlying surface, S, and is bounded by at least one loop. If more than one loop bounds a face, then the loops shall be disjoint. The cross product, $N \times T$, where N is in the same direction as the normal to S and T is the topological tangent vector of an edge-use in a loop bounding the face, points toward the material of the face. Note that this determines the edge-use orientation.

The MSBO shall point to one or more closed shells. The closed shell is represented as a set of edge-connected oriented uses of faces (face-uses). The closed shell divides $R3$ into two arcwise-connected open subsets (parts). The normal of the shell is in the same direction as the normal of its face-uses. The normal of each face-use of the closed shell points toward the same part of $R3$. The normal of the face-use is assumed to be in the direction of the normal of the underlying surface of the face unless the face-use orientation indicates it needs to be reversed. The faces used by the shell are connected to each other only via edges. Each edge shall be used exactly twice in the closed shell. If the ECO713 orientation flags of the faces using the edge are identical, each edge is used once in each orientation. If the orientation flags are not identical, one of the two edge orientations shall not be used and the other shall be used twice.

The MSBO describes the boundaries of the solid via oriented uses of shells (shell-use). It is the orientation of the use of the shells which define the volume of $R3$ the MSBO is describing. The orientation of the shell-use is determined by the shell-use normal which is either in the same or opposite direction as the shell normal. By convention, the direction of the shell-use normal points away from the part of $R3$ being described. One shell, the outer, shall completely enclose all the other shells and only the outer shell shall enclose a shell.

The geometric entities that may be used in a MSBO consist of the point, curve, and surface. The point data is embedded in the Vertex Entity for reasons of data compaction. The entities that may be used for a curve are restricted to the subset identified for Form 1 of the Edge Entity. The subset of surface entities that may be used is identified in Form 1 of the Face Entity. To avoid processing difficulties, the use of nested constructs is discouraged. For example, allowing the Edge to point at a Composite Curve which uses an Offset Curve as one of its components is not recommended.

The geometric surface definition used to specify the geometry of a face shall be a 2-manifold which is arcwise connected, oriented, bounded, non-self-intersecting, and has no handles within the region underlying the face. The surfaces can be represented implicitly, $F(x, y, z) = 0$, or parametrically, $S(u, v)$. In the implicit representation the direction of the surface normal (orientation) is defined by the gradient of $F(x, y, z)$. If the surface is represented parametrically, the surface normal (orientation) is given by the cross product of the partial derivatives (in the order stated) with respect to u and v.

The model space ($R3$) curves underlying the edges are assumed to be parametrically represented, have a unique non-zero tangent vector at each point, lie on the two (2) intersecting surfaces, and be non-self intersecting on the open segment underlying the edge.

Note that, due to seams and poles, the representation of the pre-image of the curve, C, in the parameter space of the surfaces, S_1 and S_2, can consist of ordered lists of curves, ${C_1}_i^*, i = 1, n$ for surface S_1 and ${C_2}_j^*, j = 1, m$ for surface S_2. The C_{1i} given by the composition $(S_1 \circ {C_1}_i^*, i = 1, n)$ and the C_{2j} given by the composition $(S_2 \circ {C_2}_j^*, j = 1, n)$ form composite curves in $R3$ which are coincident with the curve C.

The optional parameter space curves, $C_i^*, i = 1, n$, referenced by an edge-use are in the parameter space defined by the surface underlying the face bounded by the loop containing the referencing edge-use. These curves are assumed to be ordered in the list and oriented such that as the parameter goes from its initial to its final value for each parameter space curve the composition $(S \circ C_i^*, i = 1, n)$

produces a composite curve, $C_i, i = 1, n$, which is coincident with the curve underlying the edge. The orientation of $C_i, i = 1, n$ is in agreement with the orientation of the edge-use.

See Appendix I for examples that illustrate the general model for any entity modeling of a Cylinder, Sphere, and Torus.

The following is a summary of the major constraints on the topological and geometrical entities that may be used in representing the MSBO:

- The MSBO shall contain exactly one outer shell
- The volume described by the MSBO shall be arcwise connected. This implies that voids inside the outer shell shall not be contained in another void.
- The shells of an object shall be disjoint.
- The direction of the normals of the face-uses of a shell, reversed if the shell orientation flag is false, shall point away from the portion of $R3$ that is in the volume being communicated by the MSBO.
- The shells of an object shall be closed shells.
- The face interiors, edge interiors, and vertices shall not intersect.
- Only the MSBO and the $R3$ curve and surface entities shall have a transform.

The following topological entities may be used in representing the MSBO:

Manifold Solid B-Rep Object (MSBO) Entity (Type 186, Form 0) Identifies the shell-uses (shell + orientation) which make up the MSBO.

Closed Shell Entity (Type 514, Form 1) defines a boundary for a region of $R3$ by identifying and orienting the use of faces.

Face Entity (Type 510, Form 1) implements the topological concept of a portion of a boundary of $R3$. The underlying surface is required.

Loop Entity (Type 508, Form 1) identifies and orients the use of edges as bounds (partial) of faces. It also establishes the optional association of parameter space geometry.

Edge List Entity (Type 504, Form 1) models an edge or a list of edges. Each edge referenced in a MSBO shall be modeled in only one Edge List Entity. Thus all references to a specific edge shall use the same Edge List Entity and list index. The underlying curve geometry in $R3$ is required.

Vertex List Entity (Type 502, Form 1) models a vertex or a list of vertices. Each vertex referenced in a MSBO shall be modeled in only one Vertex List Entity. Thus all references to a specific vertex shall use the same Vertex List Entity and list index.

Figure 58 illustrates the hierarchical nature of a MSBO. Figure 59 illustrates the construction of a MSBO.

4.49 MANIFOLD SOLID B-REP OBJECT ENTITY (TYPE 186) ‡

Directory Entry

Number and Name	Value
(1) Entity Type Number	186
(3) Structure	$< n.a. >$
(4) Line Font Pattern	$\#, \Rightarrow$
(5) Level	$\#, \Rightarrow$
(6) View	$0, \Rightarrow$
(7) Transformation Matrix	$0, \Rightarrow$
(8) Label Display Assoc.	$0, \Rightarrow$
(9a) Blank Status	??
(9b) Subord. Ent. Switch	??
(9c) Entity Use Flag	??
(9d) Hierarchy	??
(12) Line Weight Number	#
(13) Color Number	$\#, \Rightarrow$
(15) Form Number	0

ECO706

Parameter Data

Index	Name	Type	Description
1	SHELL	Pointer	Pointer to the DE of the shell
2	SOF	Logical	Orientation flag of shell with respect to its underlying faces (True = agrees)
3	N	Integer	Number of void shells, or zero
4	VOID(1)	Pointer	Pointer to the DE of the first void shell
5	VOF(1)	Logical	Orientation flag of first void shell
⋮	⋮	⋮	
2+2*N	VOID(N)	Pointer	Pointer to the DE of the last void shell
3+2*N	VOF(N)	Logical	Orientation flag of last void shell

Additional pointers as required (see Section 2.2.4.5.2).