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Generating Finite Element Mesh from Parametric Shell Models

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Abstract

Generating finite element mesh for the purpose of determining structural response of shells is not a trivial task. This paper presents a solution to this problem using a combination of basic parametric patch models, mesh to solid intersections and mesh to mesh intersections. First a shell classification and generalization is carried out and then parametric shell patches are defined. At the second level, parametric shell models are defined using parametric patches. The finite element mesh of these parametric models is generated based on specified mesh size and type. The basic parametric models are then combined to create more complex shell forms and structures. The combined mesh of these models is determined by intersecting each parametric model by other overlapping models. This intersection includes the determination of mesh to be removed, the mesh to be retained and mesh to be modified to enforce the compatibility and continuously across and along the intersecting boundaries. The results of each intersection are then carried on to the overlapping parametric models. The mesh intersection is based on volumetric entitles such as cylinder, sphere, prism as well as planes and surfaces. The final mesh can be either in terms of surface elements such as shells or membranes or as line elements such as frame truss or cable elements.

Several examples of mesh generation are given applicable to water tank, reservoirs, shell roofs, fabric structures etc. The basic parametric shells include cylindrical, spherical, hypars, shells or revolution, folded plates, planner canopies etc.

1 Classification of Shell Forms

For developing parametric shell models, it is essential that the shell forms should be classified so that their standardized parametric representation can be developed. The shell forms are classified based on their basic geometric form as well as the method of shell surface generation. The geometric form as the basis for classification is further useful, when combining shell models and computing their intersections. The basic geometric forms considered are plane, prism, cylinder, cone, sphere, and hyperbolic paraboloid.

This also includes patches as parts of Shells based on there basis geometric forms.
The classification based on method of surface generation consists of, straight line generations, shells of revolution, bezier and spline surfaces, canonical surfaces and extruded surfaces.

Table 1 shows a relationship between the basic geometric form and the methods of shell generation for these forms. It can be seen that not all shell forms and generation methods are compatible. However, more than one method of surface generation can be used for a particular shell form.

Table 1: Relationship between basic geometric forms and shell generation methods

	Plane	**Prism**	**Cylinder**	**Cone**	**Sphere**	**Hypar**
Straight Line Generation	✓	✓	✓			✓
Shells of Revolution			✓	✓	✓	
Bezier and Spline			✓	✓	✓	
Canonical			✓	✓	✓	
Extruded	✓	✓	✓			

2 Basic Parametric Shell Patches

2.1 Planar Patch

The parametric models are developed at several levels of complexity. The basic shell models are derived from the geometric classification, using a single geometric entity or part of and entity. The first of these patch is a plate, defined by local L_x, L_y and a global reference plane, defined by a reference line and point.

This simple plate is the basis for several higher level folded plate structures as well as the basic unit for mesh mapping for other forms. The meshing of a planar patch is defined in terms of d_x and d_y parameters. The planar patch, defined in local x, y, z coordinates is placed in global space using 3 points that define the plane as well as the location and orientation of this planar patch.

2.2 Cylindrical Patch

The second basic form is the cylindrical patch, again defined on the local axis and located by a three point reference system. This parametric form is used extensively to generate higher order models. The meshing of a cylindrical patch can either be derived from the mapping of a planar patch or by using direct meshing of the arc and the line in terms of d_θ and d_z.

2.3 Conical Patch

The third basic parametric shell is the conical patch, similar to a cylindrical patch. The main difference is that the conical patch is defined by two radii, one at each end of the patch. For conical patch also the meshing can be done either using the mesh mapping or using direct subdivisions in terms of d_θ and d_z. in the present work direct meshing is used both for the cylindrical and conical patches.

2.4 Spherical Patch

The fourth basic shell form is the spherical patch. This patch is also defined by a local axis system with a radius and four angles. The spherical patch is again a very useful entity for generating more complex shells, and is meshed directly using T_{z1} and T_{z2}.

2.5 Hyperbolic Paraboloid

The next entity is a hyperbolic paraboloid patch. This is basically a rectangular plate meshed on local axis and then mapped on to a three dimensional quadrilateral defined by four ordered points in global space. The hypar can be fitted or mapped on non-rectangular boundary as long as four edges are used for each patch. This hypar patch is an extremely useful entity to generate mesh for arbitrary geometry and as the basis for Bezier and Spline surfaces.

2.6 Revolution Patch

Another basic, yet powerful shell entity is the shell of revolution patch. The patch is defined parametrically as, a curve, revolved about an axis through an angle. The curve is actually represented by a polyline. The other mesh dimension is controlled by the parameter n_θ and the points on the basic curve.

2.7 Super Ellipsoid Patch

Another powerful basic geometric patch for generating the shell model is the super ellipsoids. These surfaces are derived from the general spherical form using additional parameters to modify the spherical equations. By varying these additional parameters, an infinite number of shell surfaces can be generated.

2.8 General Extrusion Patch

The last basic patch is defined as an extrusion patch. Here, an arbitrary curve on a local x-y plane is extruded along a path defined by a set of points in a global space. Different transformation functions can be specified at each point on the extrusion path to modify the basic curve point. The mesh size is based on the number of points on both curves.

3 Higher Level Parametric Forms

The basic parametric shell entities or patches defined above are combined to define higher level shell forms, also in parametric system. This step is the intermediate link between the final shell models and the basic parametric patch. Although the basic patch can be used in some instances to create a particular shell form in its entirety, but most practical shell structures would require the use of higher level parametric forms defined here. These forms are defined in terms of typical structural usage and use appropriate definition of dimensions and parameters.

a) *The Barrel Shell:*

The barrel shell is one of the most commonly used shell structure and is defined here in parametric form. The structure is generated using three cylindrical patches and two planar patches. The patches are defined by using the angles and length on local axis, where as the shell is defined using length, radius, chord, depth, etc. on global axis. Each patch in this structure is generated on local axis and placed on global axis using overall structure parameters. A single mesh size value assures a fully connected valid finite element mesh for the whole structure.

b) *The Spherical Dome:*

The spherical dome is a direct extension of the spherical path. The dome is defined by the diameter, the height and a direction vector. The mesh size is enforced at the diameter level. Partial domes can also be generated using a modified form of the shell of revolution.

c) *The Chimney:*

The basic conical patch is extended to generate the simple chimney structure using two diameters, a height and a direction vector. This form can also be used to create a circular pipe, by setting both diameters equal. This shell is generated from a conical patch but can also be generated by shell of revolution.

d) *The Cooling Tower:*

The typical cooling tower shell is generated using a revolution patch. The curve is specified as an arc, which can be part of parabolic curve defined by three points or generated from a general four point Bezier curve. The required parameters are diameters at various heights and the mesh size.

e) *The Folded Plate:*

Another commonly used category of shell forms is the folded plates. Folded plates of various forms can be generated either by using a series of planar patches, or more easily by using extrusion generation, which is proposed in this research.

The definition of parametric shell can be extended to create a large library of typical structures and nearly 60 such parametric shell have been identified in this research.

4 Combining Shell Models

Finite element mesh for complex or large shell and spatial structures can be generated by dividing the structural form in to sub-models that either lends themselves to one of the parametric models or one of the parametric patches defined above. The mesh for each sub-model or patch is placed in the overall structure. Each of these sub-models or patch is treated as an object. To ensure compatibility and connectivity an object intersection test is then performed. Each object is tested against all other objects. If the bound of two objects intersect or overlap then the mesh of the other object is modified for intersection with current object. This modification is done as follows:

1) The mesh of object-A is tested against the "volume" of the object-B and each mesh element is marked as one of the three tags;
   - Inside object-B
   - On object-B surface
   - Outside object-B
2) The mesh of object-A lying on the object-B surface is sub-divided by the object-B surface and re-meshed in such a way that the new mesh elements are either entirely inside or entirely outside the object-B.
3) Depending on the type of the object-B and additional input from the engineer, either outside mesh or inside mesh, both meshes or none of the mesh is retained.
4) The imprints of the mesh elements on the surface of object-B are also retained for providing further mesh continuity in mesh b.

For the purpose of demonstration the mesh intersection process and its results for some simple objects are shown in Figure 1.

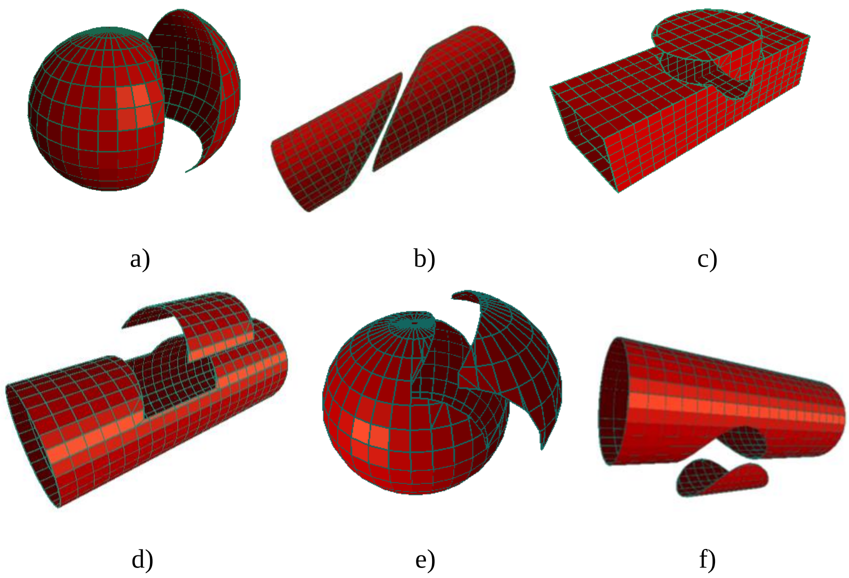

Figure 1: Mesh Intersection results for a) sphere and a plane, b) pipe and a plane, c) tube and a sphere, d) pipe and a pipe e) sphere and a sphere, and f) pipe and a sphere obtained from the present research.

5 Conclusion

A general approach is presented to generate finite element mesh for shell structures using basic parametric patches and forms, and the volumetric intersection techniques. The proposed methodology can be used to develop a library of parametric structures as well as a tool for generating shell models. Part of this research has been used in finite element programs such as SAP2000 (a product and trademark of Computers and Structures, Inc., Berkeley, USA). Work is in progress to develop a more comprehensive shell modeling system.