CHAPTER 14
GENERATION OF MULTIPLE ELEMENTS THROUGH THE THICKNESS - RESULTS

In this chapter, results are presented to demonstrate the capabilities and utility of the procedures to generate multiple elements through the thickness.

Figure 14.1a shows the initial solid mesh for a simple rectangular plate for which 4 elements have to be introduced through the thickness. The mesh after mesh matching on opposite faces and splitting edges through the thickness is shown in Figure 14.1b. The mesh after swapping is completed is shown in Figure 14.1c. The largest dihedral angle is 150 degrees in the initial mesh and 96 degrees in the final mesh. The initial mesh has 96 elements while the final mesh has 384 elements.

Figure 14.1: Refinement through the thickness for a simple plate. (a) Initial mesh. (b) Mesh after splitting of edges. (c) Mesh after swapping to realign edges. Maximum dihedral angle in final mesh is 96 degrees.
Another illustrative example is shown below in Figure 14.2. The initial mesh is shown in Figure 14.2a and the anisotropically refined mesh is shown in Figure 14.2b. The largest dihedral angle in the initial and final mesh are 144 degrees and 146 degrees respectively.

![Initial mesh](image1)  ![Refined mesh](image2)


Figure 14.2: Refinement through the thickness of a ring. (a) Initial mesh with 145 elements and largest dihedral angle of 144 degrees. (b) The refined mesh with 1179 elements and largest dihedral angle of 146 degrees.

This demonstrates that when the topology and geometry of the model and mesh permit it, the algorithm generates high quality elements while introducing multiple elements through the thickness. Naturally, geometric models of any practical interest and their meshes do not have this perfect structure throughout and some reduction in quality is expected due to constraints in mesh modification procedures.

Figure 14.3 and Figure 14.4 show the initial and refined meshes with close-up views of two models with general topology and no single thickness direction. It can be seen from the figures, that the procedures have correctly captured the local thickness directions in the various sections of the model. In Figure 14.4 the close-up pictures show a transparent view of the initial and final mesh of the base plate verifying that refinement and the structure of the mesh is as desired even in the interior of the model. 99.98% of the elements in the final mesh in Figure 14.3
have large dihedral angles less than 170 degrees. All elements in the final mesh in Figure 14.4 have large dihedral angles less than 161 degrees.

Figure 14.3: Refinement through the thickness for a general model, “asm107”. (a)(i) Initial mesh. (ii)(iii) Close-up views of initial mesh. (b) Refined mesh with 4 elements through the thickness. (ii)(ii) Close-up views of refined mesh. 99.98% of elements in final mesh have large dihedral angles less than 170 degrees.

Figure 14.5 shows a simplified airfoil platform in which the thin sections not very clearly demarked and the sections vary in thickness with the result that the initial mesh (Figure 14.5a) has varying number of elements through the thickness along the length of the platform top. Figure 14.5b shows the refined mesh with a close-up view shown in Figure 14.5b. From the figures it can be seen that the procedures have identified the deficient parts of the mesh well and refined correctly through the thickness. For example the smaller “leg” of the platform initially had two elements through the thickness and two more were added to it. On the other hand the top of the platform is of varying thickness and the initial mesh had one elements in some parts and two in others. The procedures correctly recognize this and
Figure 14.4: Refinement through the thickness for a general model, “asm110”. (a)(i) Initial mesh. (ii) Transparent close-up view of initial mesh of base plate. (b)(i) Refined mesh with four elements through the thickness. (ii) Transparent close-up view of refinement in base plate. 100% of elements in final mesh have large dihedral angles less than 161 degrees.

Refinement has been performed so that there are 4 elements through the thickness throughout. The example also illustrates that not only the conversion of diagonal quads to zigzag works but that the procedure is able to identify the other types of configurations and realign their edges as well.

The various capabilities and features of the procedures to introduce multiple elements through the thickness are also demonstrated in the following example which is a simplified setup for investment casting of an airfoil (Figure 14.6)
Figure 14.5: Refinement through the thickness for airfoil platform. (a) Initial mesh. (b) Refined mesh with 4 elements through the thickness. (c) Close-up view of refined mesh in one of the thin sections.

Finally, the results\textsuperscript{12} of a transient heat conduction analysis with radiative heat transfer in a crucible for crystal growth simulation using a mesh refined by this method are shown in Figure 14.7. The schematic model is shown in Figure 14.7a while shows the mesh with 4 elements introduced through the thickness. The mesh has 32,221 elements compared to an equivalent isotropic mesh, i.e., uniformly refined to have 4 elements through the thickness, which has 317,841 elements, a reduction of an order of magnitude. The temperature distribution near the top of the crucible and through a vertical section (expected to be exponential) are shown in Figures 14.7b,c.

\textsuperscript{12}Courtesy: Hongwei Li, formerly at SCOREC, RPI
Figure 14.6: Refinement through the thickness for model representing the setup for investment casting of an airfoil.
Prescribed periodic transient temperature distribution

Heated by radiation

Insulated

Figure 14.7: Transient heat conduction analysis with radiative heat transfer in crystal growth crucible using a mesh with 4 elements introduced through the thickness. (a) Schematic of problem. (b) Mesh with 4 layers through the thickness. (c) Temperature distribution near the top. (d) Temperature distribution through a vertical section.