Scaling (Grid Independence) Test

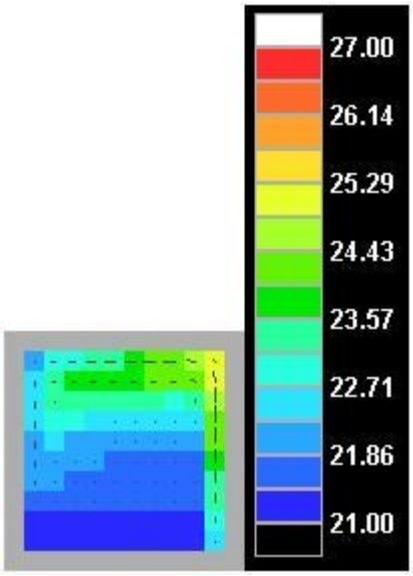
Grid convergence is the term used to describe the improvement of results by using successively smaller cell sizes for the calculations. A calculation should approach the correct answer as the mesh becomes finer, hence the term grid convergence. More details can be found here (http://www.grc.nasa.gov/WWW/wind/valid/tutorial/spatconv.html) and on many other web pages as well as in the literature. The normal CFD technique is to start with a coarse mesh and gradually refine it until the changes observed in the results are smaller than a pre-defined acceptable error. There are two problems with this approach. Firstly, it can be quite difficult with other CFD software to obtain even a single coarse mesh result for some problems (particularly when time is pressing). Secondly refining a mesh by a factor of 2 can lead to an 8 fold increase in problem size so even more time is needed. This is clearly unacceptable for a piece of software intended to be used as an engineering design tool operating to tight production deadlines. These and other issues have added greatly to the perception of CFD as an extremely difficult, time consuming and hence costly methodology.

However, we have developed an algorithm that diverges very little as the cell size is increased making it much easier to obtain the necessary accuracy, even on coarse grids. We have termed this ability to retain consistency across varying cell sizes as ‘grid independence’ or ‘scaling’, as the algorithm is attempting to find the same fundamental solution independent of either grid size or scale factor.

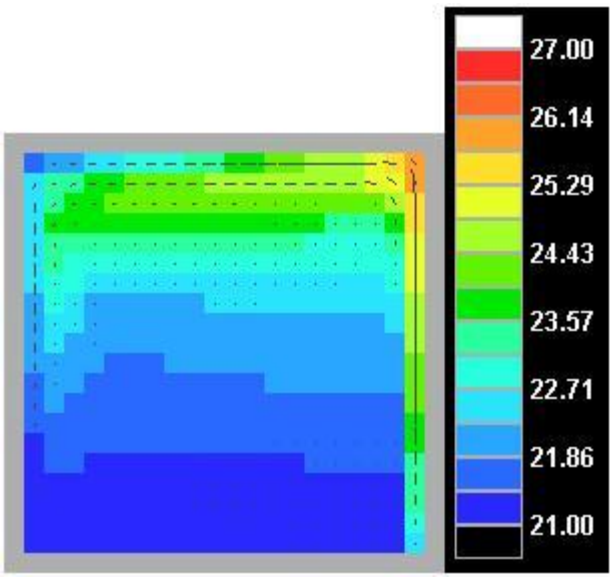
In this section we look at the three runs of the same problem but on very different grids. These show how well the software copes with a changing scale and how very close it is to having grid independence.

The problem considered is a simple 5m x 5m x 5m cube with all 6 surfaces being a simple wall. All the walls are held at 21 ^{o}C except the right wall, which was held at 30 ^{o}C. The three runs were,
coarse, with a cell size of 0.5m giving a mesh of 10 x 10 x 10 or 1000 cells,
medium, with a cell size of 0.25m giving a mesh size of 20 x 20 x 20 or 8000 cells,
fine, with a cell size of 0.1666m giving a mesh size of 30 x 30 x 30 or 27000 cells.

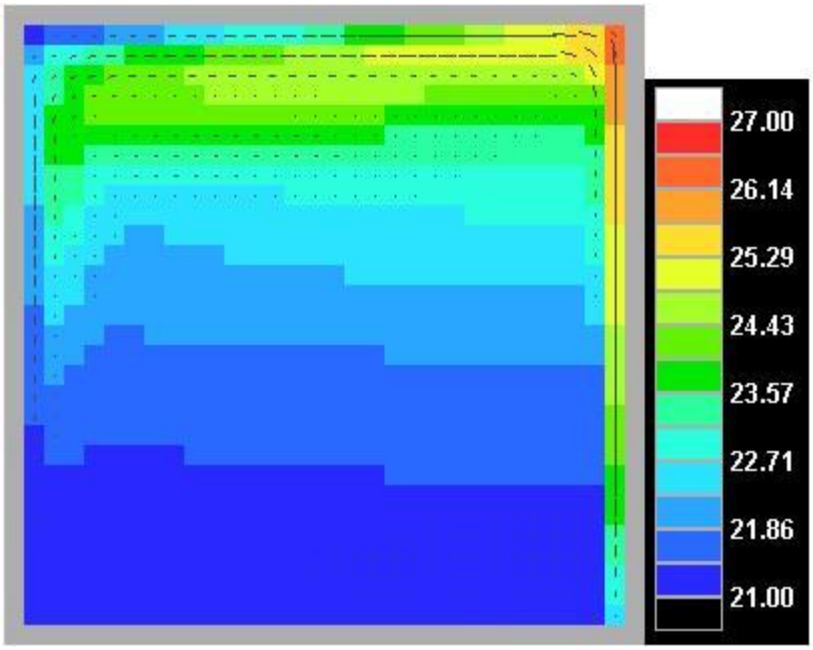
A dynamic simulation was run for each case from quiescent starting conditions until there was no change in temperature or flow fields. The results for the coarse case are shown below. This is a vertical slice taken midway through the cube. The velocity midway up the right hand side for the cell adjacent to the hot wall is 0.077m/s. The run took approximately 8 seconds of elapsed time on an 800MHz Pentium 3 Xeon processor to become steady in a simulated time of 151 minutes.



The results for the medium case are shown below. The velocity midway up the right hand side for the cell adjacent to the hot wall is 0.123m/s. The run took approximately 1 minute 30 seconds of elapsed time on an 800MHz Pentium 3 Xeon processor to become steady in a simulated time of 141 minutes.



The results for the fine case are shown below. The velocity midway up the right hand side for the cell adjacent to the hot wall is 0.161m/s. The run took approximately 7 minutes 30 seconds of elapsed time on an 800MHz Pentium 3 Xeon processor to become steady in a simulated time of 147 minutes.



The three runs show very good agreement considering the extreme variation in size and number of cells. The fine case obviously shows a great deal more detail than the other runs, but even the coarse run has correctly established the main features of the flow and temperature field very well. Using an optical analogy, the fine grid shows a sharper image with its greater resolution, while the coarser runs become unfocused because they are dealing with averaged properties over larger volumes that consequently tend to blur the result.

It is important to remember when studying the images that a single cell from the coarse model actually represents 27 cells from the fine model. That single coarse cell temperature should then represent the average temperature across all 27 fine cells (or more approximately the 9 cells in the single fine slice we have shown). When viewed in this way it can be seen that the coarse simulation has in fact scaled extremely well.

Likewise, the vertical velocities may seem to be changing greatly. However, the single coarse cell with an average velocity of 0.077m/s through its centre is matched by 8 medium case cells. It is not the velocity but the convective flux through the cell face that should be the same to ensure equivalence and energy/momentum conservation. If the faster medium case velocity is averaged with its negligible neighbour (0.123 + 0.0) / 2 = 0.062m/s, this is close to the 0.077m/s of the coarse case and explains the very great overall similarity.