spike, but it is suspected that it is numerical in nature. It should also be noted that a spike did not occur in the mass flow profile shown in Fig. 5.12, although the mass flow is directly proportional to the void fraction. This anomaly was not investigated further since it was felt to be an item of relatively low priority.

5.3 Numerical Accuracy Considerations

Another objective of an analysis of the code results is to establish the accuracy of the numerical algorithm. Two methods, aside from comparison with experimental data and qualitative comparison with physical intuition, are used to check numerical results. The first is a check of satisfaction of the conservation equations over the entire duct. The second is a check that the results are independent of the fineness of the computational grid used.

Satisfaction of global conservation requirements is required when the discretization method used inherently ensures such an outcome, as this one does. However, since the code employs several iteration loops which must be closed to achieve convergence, global satisfaction requirements are no better than the error criteria used in these loops. It can, however, be shown that as the error criteria are tightened, so are the errors in the global conservation equations. Table 5.2 shows such a result for the case described above. Shown are the error criteria for iteration loops in the main program and beside it is the error in the global conservation of x-momentum and continuity. The coarsest of these error criteria was used for the results presented here since the results with this case are indistinguishable from results for the tighter criteria and because this allows much faster computer run time.

Grid independence was also checked by running the code for a series of increasingly fine grids. If the finest grid used is considered to be the exact, grid independent solution, and

the average error between it and the coarser grids are examined (Fig. 5.14), it seems as if the 100 by 40 grid size (# of radial cells = 100, # of axial cells = 40) has a sufficiently small error to be considered grid independent, at less than one percent. The 100 by 40 grid size was thus used in the presentation of most of the results shown here. Although not shown, it can also be visually verified using velocity or void fraction profiles that using a finer grid than this one is simply a waste of computer time.

Although the code is believed to be numerically accurate and give, within its limitations, physically realistic results, it has significant difficulty reaching convergence in several practical cases. Adjustments to the error tolerances mentioned above, underrelaxation factors, and values of the turbulent boundary layer thicknesses aided in achieving convergence. In several cases convergence was never achieved. A potential user of the code should be warned that some work is still required to increase its robustness.

For cases that did converge, approximately 20 minutes of computer run time was required on a 100 by 40 grid using the coarsest of the error criteria shown in Table 5.2. The computer used was a Pentium 166 with 32 MB RAM.

Table 5.2 - Program Error Criteria with Global Momentum/Continuity	
Error Criteria	Resulting Global Error
FLOWERR=1E-8 (error in cont. phase flowrate based on guessed dp/dx)	MOMERR1=2.518E-2
CONERR=1E-6 (error between guessed and calc. cont. phase velocities)	MOMERR2=3.47E-3
GLOBX1MOMERR=1E-6 (global mom. error from guessed wall shear)	FLOWERR1=3.927E-2
ERRORVEL2=1E-6 (error between guess and calc. second phase velocities)	FLOWERR2=2.02E-16
UDIFF=1E-6 (same for disc. phase velocities used in cont. phase loop)	
ERRALPHA=1E-4 (error between guessed and calc. void fraction)	
FLOWERR=1E-10	MOMERR1=4.959E-4
CONERR=1E-8	MOMERR2=9.725E-5
GLOBX1MOMERR=1E-8	FLOWERR1=7.712E-4
ERRORVEL2=1E-8	FLOWERR2=0.0
UDIFF=1E-8	
ERRALPHA=1E-6	
FLOWERR=1E-15	MOMERR1=1.553E-9
CONERR=1E-13	MOMERR2=4.003E-10
GLOBX1MOMERR=1E-13	FLOWERR1=3.711E-8
ERRORVEL2=1E-13	FLOWERR2=0.0
UDIFF=1E-13	
ERRALPHA=1E-10	

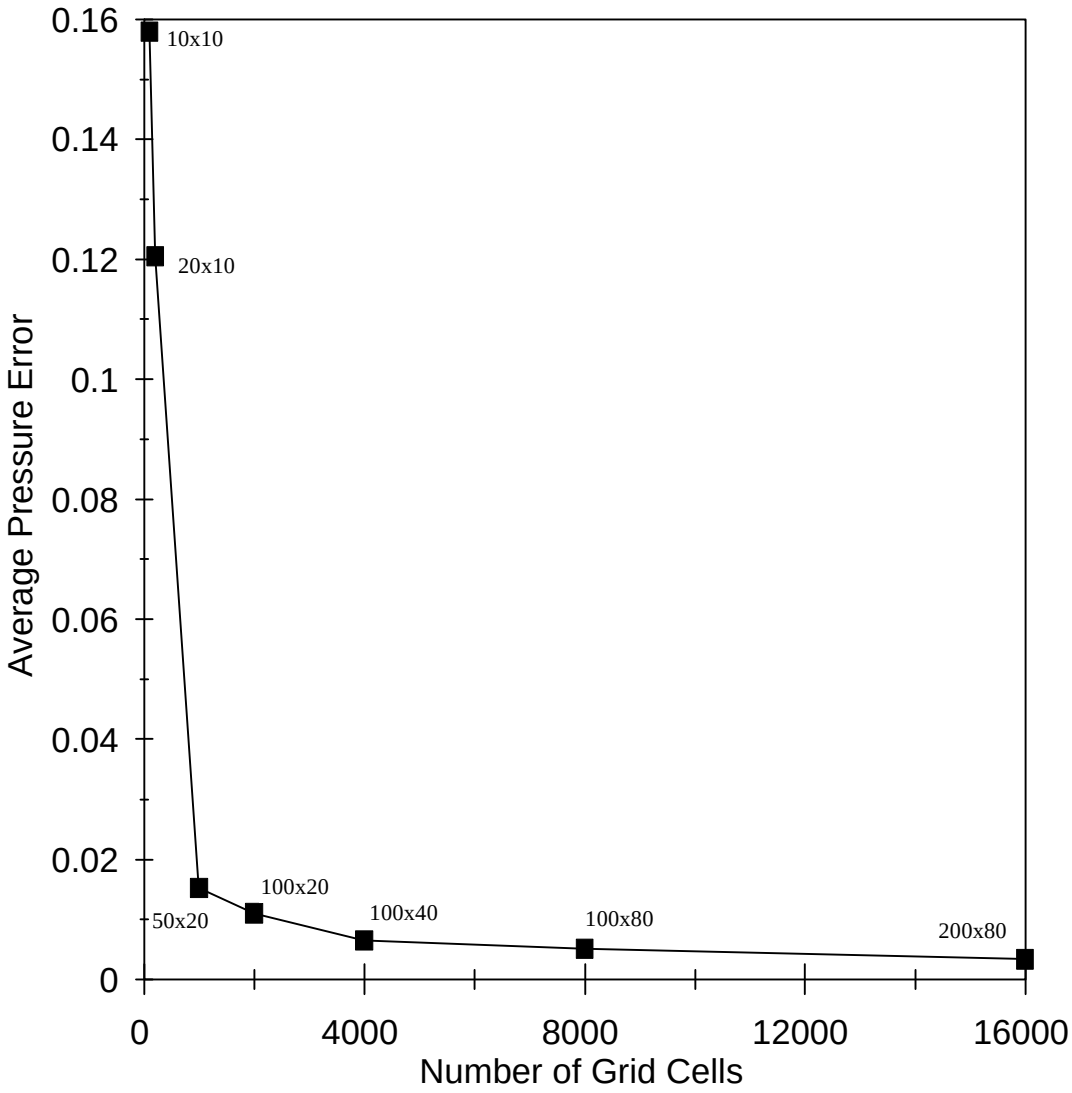

Figure 5.14 - Error Variation with Grid Refinement

(Zero Error Taken as 200x160 Grid)