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A New Approach for Uncertainty Analysis of the Numerical Data Using Genetic Algorithm Based on Grid Refinement

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ABSTRACT: A new approach using the genetic algorithms has been presented to estimate the uncertainties in numerical pressure calculation on a 3D wing. The amount of error in this method has been estimated in the form of power series as a function of the element size. The error tensor is expressed as the sum of squares and has been used as the fitness function in the genetic algorithm. The conventional method for error minimization has been differentiation which is replaced by the genetic algorithm in this paper. The error analysis along with a safety factor has been introduced as the uncertainties in numerical calculations. According to the results, refining the grids down to 25% of the initial size, reduced the error by an amount of 50%. The total uncertainty calculated in this paper was 0.03. This value determines a confidence level of 97.6%. The reliability of the results on three baselines higher than 97% approves the high accuracy of the present calculations. The highest and the lowest reliability in the present calculations was 99.16% and 97.6%, respectively.

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1. Introduction

Eca and Hoekstra in 2014, the error was estimated with power series expansions as a function of the typical cell size [1]. These expansions, of which four types were used, were fitted to the data in the least-squares sense. The selection of the best error estimate was based on the standard deviation of the fits. The error estimate was converted into an uncertainty with a safety factor that depends on the observed order of grid convergence and on the standard deviation of the fit. For well-behaved data sets (i.e. monotonic convergence with the expected observed order of grid convergence and no scatter in the data), the method reduced to the well-known Grid Convergence Index.

The lack of any analytical solution for this problem tends to use uncertainty criteria. Here, validation process of numerical work has been done by simulating Onera M6; its wing tunnel database exists. [2]

In this paper, the focus has been on Solution Verification using systematic grid refinement (i.e., a procedure for the estimation of the numerical error/uncertainty of a numerical solution for which the exact solution is unknown, has been offered). Most of the existing methods for uncertainty estimation require data in the so-called “asymptotic range”, that is, data on grids are fine enough to give a single dominant term in a power series expansion of the error. This often means levels of grid refinement which are beyond those normally used in practical applications. [3-8]

Authors have tried to establish an uncertainty estimation procedure that accepts the practical limitations in grid density. Obviously, in the absence of contamination by round-off errors, the confidence in solutions on coarse grids will usually be less than in solutions on fine grids, which must be reflected by an increased level of uncertainty, possibly by choosing a higher factor of safety.

2. The Geometry and Meshing of the Problem

The numerical approach is demonstrated on a 3D wing with twists aerodynamics. The wing considered in this paper includes two sections of the standard NACA series 6 with thicknesses of 15 and 12 percent respectively at the root and tip, as shown in Fig. 1.

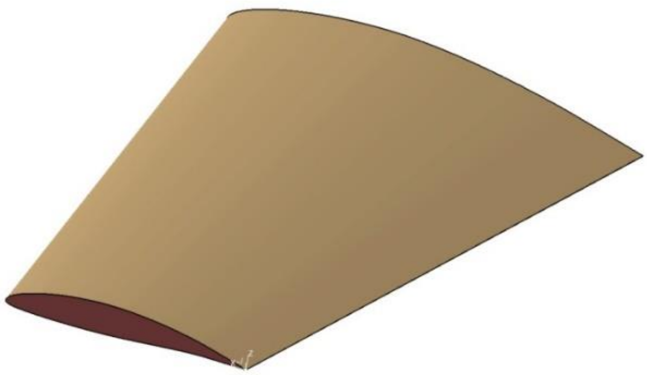

Fig. 1: Half span win geometry

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Figs. 2 and 3 show the individual structured hexahedral grids were generated around half span wing with symmetry boundary included a topology *C* in the smaller domain around the wing and the topology *H* in the farther region, so computational domain blocking has been used.

Their coarse, moderate and fine grids are used to investigate the uncertainty. Totally 4.5 E+6 nods in coarse grids were generated around wing and far field that reached to 27.0 E+6 nods in fine grids. A block with 16 rows in the middle of the wing was created from 0.15 to 0.65 cords.

For the coarse grid, the height of the first layer is 4 mm with growth rate of 1.15, So one can get 64 rows of cells in the fine grid. In all three grids, all cells are similar and the grids have a fixed refinement ratio.

A main contributor to unfavorable data is the lack of geometrical similarity of the grids. While structured grids essentially allow geometrical similarity to be obtained, this is hardly true for unstructured grids. Other sources of scatter in the data are flux limiters, commonly used in the discretization of convective terms, as well as damping functions and switches being part of many present-day turbulence models.

3. Results and Discussion

In airfoils series 6, the variation of the pressure coefficient in the first half of the airfoil (leading edge to half cord) is significant. Thus, the three lines in the positions of 15, 25 and 50 percent are located at the bottom of the base block and perpendicular to the airfoil to check the variation of the pressure coefficient in three grids.

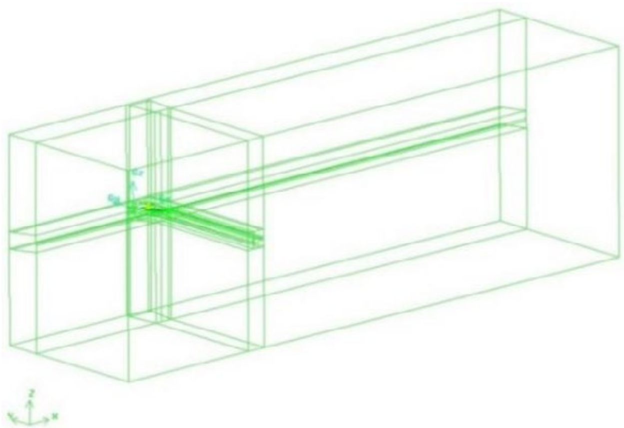

Fig. 2: Blocking of computational region

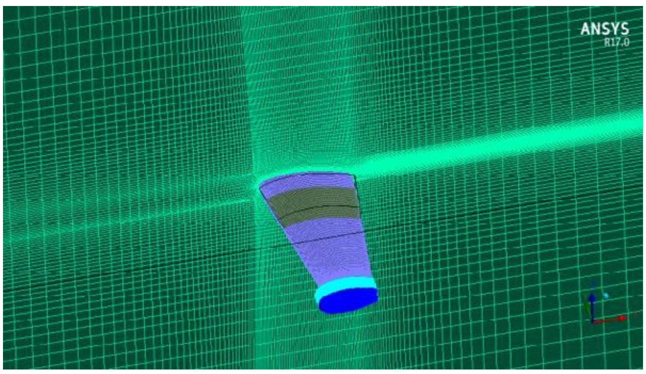

Fig. 3: Structural grid on the wing

The problem could be solved numerically with all three grids. After the complete convergence of the solution, the pressure coefficients were extracted to estimate the numerical error from the base lines. The calculations were carried out with ANSYS-Fluent version 17.0.0. All calculations were performed on a super computer having four 16-core 3.2 GHz processors.

A computational code was expanded to estimate uncertainty by generating a target function, applying a genetic algorithm, calculating semi-exact pressure coefficients and error calculation, and applying the safety factor.

All of the above procedures were used to reach the final goal: an estimate of the uncertainty, that is, an interval that contains the exact solution with 95% coverage. The safety factor was chosen as $Fs = 1.25$ where, the error estimate was considered reliable, else $Fs = 3$.

In traditional methods, the grids must be in the asymptotic range to guarantee that the leading term of the power series expansion (high-order terms are neglected) is sufficient to estimate the error, also it is recommended to use, at least, four grids when some scatter is expected (i.e., for most engineering flow problem). In such conditions, it is possible to do the error estimation in the least-squares sense and standard deviation of the fit.

In this paper, we can reach the uncertainty of the numerical error with high reliability only three grids and no calculation of standard deviation, also higher accuracy is due to calculation of high order term in power series, by applying the optimization method of the genetic algorithm.

4. Conclusions

According to the results, refining the grids down to 25% of the initial size can reduce the error by an amount of 50%. The total uncertainty calculated in this paper was 0.03. This value determines a confidence level of 97.6%. The reliability of the results on three baselines higher than 97% approves the high accuracy of the present calculations. The highest and the lowest reliability in the present calculations are 99.16% and 97.6%, respectively.

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