International Communications in Heat and Mass Transfer 54 (2014) 103–114

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

A new two-dimensional hybrid grid generation method based on improved hole cutting ☆

Yu Zhao, Bo Yu *, Guojun Yu

National Engineering Laboratory for Pipeline Safety, Beijing Key Laboratory of Urban Oil and Gas Distribution Technology, China University of Petroleum, Beijing 102249, People's Republic of China

ARTICLE INFO

Available online 26 March 2014

Keywords:
Grid generation
Hybrid grid
Improved hole cutting

ABSTRACT

A new hybrid grid generation method for a two-dimensional computational domain is proposed in this paper. Based on the past research in this field, this new proposed method aims to generate high-quality hybrid mesh which is structured-grid (quadrilateral grid) dominated with unstructured grids (triangular grid) in a relatively small region. It is capable of preserving the advantageous features of both structured and unstructured grids and minimizing their shortcomings by improving several crucial aspects of previous algorithms. Through creating the structured part of the hybrid grids in a more flexible way and introducing some improvements to the vital procedure, so-called "hole cutting", the present method could generate hybrid grids of desirable quality automatically and quickly without forming overlapped grids during the process. In this paper, the new method is described in detail and several grid generation examples are shown to evaluate the capability of this new method and illustrate its promising features.

1. Introduction

The efficient generation of high-quality computational grids is no doubt the essential premise of numerical simulation where the size, shape and number of grids greatly influence the accuracy and cost of final numerical results [1]. Compared with incredible progresses and broad applications of computational fluid dynamics (CFD), the speed and quality of grid generation have gradually become a serious bottleneck for further development of CFD, especially when the computational domain contains irregular and multi-connected complex components which are commonly involved in practical engineering problems. Thus, simplifying the process of grid generation, reducing the required human efforts and improving the adaptability of grids to complicated geometries are still in the challenging field and of course, have very important significance [2].

During the past decades, the two main streams of computational grid generation, both the structured and unstructured grid algorithms, have been extensively developed and successfully applied in different fields with their advantageous properties. However, the limitations or drawbacks of both algorithms have also caused wide attention among researchers.

On the one hand, structured grid is the earliest presented grid type and is always the first choice for the discretization of regular computational domain since it has a simple and straightforward generation process, together with the rapid formation. In most cases of viscous flow, structured grid algorithm can easily yield an accurate and efficient solution in subsequent numerical simulation by generating highly stretched grids to encompass the viscous regions of computational domain. Nevertheless, for irregular and complex geometric configurations, it is usually quite difficult to generate structured grids without employing large amount of human efforts because of the restricted arrangement and order. To deal with such situations in which complex geometry imposes considerable constraints in creating grids, composite structured grid algorithms are proposed and developed to expand the application range of structured grid. The Chimera algorithm [3,4] and other similar ones [5], using overlapped grids to adapt to complex geometries or flow features, firstly decompose the original domain into several separated subdomains, then structured grids are generated for each of these subdomains respectively and independently. Even though overlapped regions are inevitable during the process, when it comes to actual computation later on, carefully controlled interpolation schemes are taken to achieve the communications of solution data among these subdomains. In addition, overlapping scheme used in these composite algorithms guarantees the satisfactory quality of structured grids more easily even for complex geometries, thus they have been widely used for complicated viscous flows [6,7] and for flows over objects in relative motion [8,9] as well. In fact, the essentially nonconservative interpolations to update variables in the overlapped regions, without strict

☆ Communicated by W.J. Minkowycz.

* Corresponding author.
E-mail address: yubobox@vip.163.com (B. Yu).

http://dx.doi.org/10.1016/j.icheatmasstransfer.2014.03.015

Nomenclature

d	Distance (m)
i	Cartesian subscript in the horizontal direction
j	Cartesian subscript in the vertical direction
n	Grid number
x	Coordinate in the horizontal direction (m)
y	Coordinate in the vertical direction (m)

Subscripts

min	minimum
max	maximum

satisfaction of the governing equations, may result in incorrect solutions [10,11], especially near the solid boundaries, due to the large gradients of the flow variables in these regions [11,12].

On the other hand, different from structured grid, unstructured grid algorithm is more suitable for discretization of irregular and complex geometries because of its topological flexibility and easier control of size transition between generated grids [13]. Since the 1980s, unstructured grid algorithms, such as the Advancing Front Method, Delaunay Method and so forth, along with the Finite Volume Method have obtained rapid developments and applications in the numerical calculation field. However, the choices of efficient flow and heat transfer solvers for unstructured grids are often limited due to the disordered relationships between adjacent grids. Besides that, coefficient matrices of governing equations defined on unstructured grids also bring about difficulties in guaranteeing that a matrix is diagonally dominant, which would definitely affect the convergence rate of subsequent computation. Also it needs more unstructured grids than structured grids to fill the same computational domain especially the boundary layer regions of viscous flows, thus leading to unnecessary calculating time and memory consumption during the whole process [14].

Generally speaking, composite structured grid algorithms are considered to be more flexible to employ efficient and high-precision numerical solvers but sometimes there would be interpolation errors in the regions with fringe points. On the other hand, unstructured grid methods are thought to be fairly versatile and suitable to deal with geologically complex problems but not quite satisfactory to resolve viscous flows. Fortunately, these two kinds of algorithms complement each other with their strengths and a hybrid grid generation method taking advantage of both structured and unstructured grids would be truly attractive and fruitful. Hence, in the 1990s, some hybrid grid methods have already appeared in the literatures [15–18] and have been applied broadly for complicated flow calculations [19–23] and mesh adaption researches [24–26]. These methods could generate structured grids for separated subdomains respectively, especially near the heat transfer or flow boundaries where the gradients of variables might be very sharp and then need to use unstructured grids to connect different parts of structured grids seamlessly. At present, there are two primary categories of methods in generating hybrid grid: one contains predominant unstructured grids with the boundary layer regions encompassed by structured grids [15,17], while the other is structured-grid dominated with unstructured grids in a relatively small region [16,18]. In spite of the fact that the first category of the hybrid grid generation method makes full use of the adaptable advantages of unstructured grid, its drawbacks, such as large consumption of computer memory and long calculating time, are apparent and its practical performance is limited. On the contrary, the second category of the method has more potential for further applications since it maximizes the advantages of composite structured grid and adopts the strengths of unstructured grid while minimizing its weaknesses.

In the following text, the new method proposed in this paper is presented as follows. In Section 2, the basic procedures and limitations of previous hybrid grid generation methods are briefly outlined. Then the new method is detailed in Section 3. The main improvements of structured grid generation and hole cutting are given in Subsection 3.1 and Subsection 3.2 respectively. Finally, in Section 4 a program derived from the present method generates hybrid grids for several typical computational domains to assess the performance of this method and further illustrate its desirable features.

2. Overview of hybrid grid generation

Almost every hybrid grid generation method consists of several principal parts, and here taking the DRAGON grid method (Direct Replacement of Arbitrary Grid Over-lapping by Nonstructured grid) [27, 28] as an example, the main process and critical procedures (as shown in Fig. 1) involved in the second category of the hybrid grid generation method are briefly illustrated as follows.

(1) Decomposition and structured grid generation: Given the initial geometric information of the computational domain, the hybrid grid generation method firstly decomposes the original domain into several subdomains which have a relatively simple configuration and are independent from each other. Then structured grids would be generated for each of these subdomains respectively.
(2) Hole cutting for overlapped regions: After the generations of structured grids for all subdomains, hole bodies are formed by eliminating the overlapped grids. This procedure is repeated until no region is covered with multi-layer grids.
(3) Formation of boundaries for unstructured grid generation: When the hole bodies are created, specific nodes on the internal or external hole boundaries are picked out and connected to form the initial boundaries for subsequent unstructured grid generation.
(4) Unstructured grid generation and optimization: Starting from the new boundaries, unstructured grids are generated to fill the hole bodies by proper methods until all the hole bodies are fully paved by unstructured grids. Then optimization measures are carried out to further increase the quality of the entire hybrid grids.

The hybrid grid generation methods naturally combine the advantageous features of structured grid and unstructured grid to meet the demands of modern numerical simulation development. But through deeper research and analysis, the existing hybrid grid generation methods are found to rely mainly on composite structured grid algorithms, like Chimera, to achieve domain decomposition and structured grid generation. Besides that, the existing hole cutting algorithms in hybrid grid generation methods are usually carried out after the decomposition and all structured grid generations are finished. This would introduce unnecessary computation quantity and increase the possibility

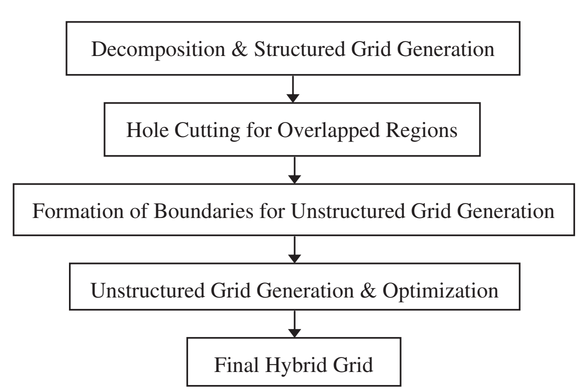

Fig. 1. Main process and critical procedures of hybrid grid generation method.