A FAST PANEL METHOD FOR POTENTIAL FLOWS ABOUT COMPLEX GEOMETRIES

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Abstract

The panel method remains one of the most widespread and commonly used techniques for aerodynamic analysis and design. One of its most appealing properties is that no volumetric grid is required; only the bounding surface must be discretized. Compared to the generation of a good quality volumetric grid, construction of a surface mesh for a complex geometry constitutes a far simpler problem especially since the required geometric information is often already available in the form of CAD files and robust and efficient grid generation techniques for curved surfaces have been developed. Unfortunately, the simplicity afforded in grid generation and economy in the number of panel elements is offset by a quadratic growth in both CPU and storage costs with the number of panels which results from the fact that each panel exerts influence upon every other. This paper describes a novel 'fast panel' implementation which alleviates this computational burden. By combining hierarchical grouping techniques based upon octree structures and formal multipole/Taylor series expansion approximations, both storage and CPU costs are reduced to O(N). An iterative solution procedure is adopted (to minimize storage) in conjunction with the generalized minimum residual (GMRES) method to accelerate convergence. Examples of flows over complex geometries involving more than 10^4 panels are presented and shown to converge within several minutes on a Silicon Graphics Indigo work station.

Nomenclature

A	- panel area
C_{ij}	- influence coefficient defined in Eq.(5b)
${}_nC_r$	- combinatorial, ${}_nC_r = n! / [\, r!\, (n-r)!\,]$
$\{F\}_i$	- the set of panels considered far-field with respect to the group containing panel, i.
G^0_m, $\underline{G}^1_m$	- group multipole coefficients defined in Eqs.(19)
h	- height of observation point normal to panel
M^{2j}_{m-2j}	- m-order Cartesian moment tensor defined in Eq.(14)
$\hat{n}$	- panel normal vector
N	- number of panels
r	- distance, $\|\underline{R}\|$
$\underline{R}$	- position vector with components $\{x,y,z\}^T$
$\underline{u}$	- velocity
$\underline{z}$	- normalized vector, $\underline{\xi}/r$
γ	- panel strength
σ	- smoothing core
$\underline{\xi}$	- position of panel control point relative to its group center
$(\bullet)^T$	- denotes transpose

Introduction

Despite enormous advances in the development of sophisticated grid generation techniques and compressible Euler/Navier-Stokes flow modeling methods, analyses based on incompressible and inviscid potential flow assumptions continue to enjoy widespread use. Foremost among the methods available for solving such flows is the panel method[1-4] where the surface of the body under investigation is discretized into a set of boundary elements or panels. The flow is completely represented by surface distributions of source and dipole singularities, and the objective of a panel algorithm is to deduce these distributions so that zero normal velocities at the surfaces are enforced. The advantages of such a representation are two-fold. First, the need for a volumetric grid is completely dispensed with. For complex 3D geometries the construction of a volumetric grid, even with unstructured mesh generation techniques, remains nontrivial and usually demands extensive user involvement and lengthy set-up time. By contrast, a surface grid is more easily obtained (see for example, Chew[5-6]), particularly since the surface geometry is usually available in the form of CAD files and/or structural FE representations. The second advantage is that a minimal number of variables is employed to characterize the flow. A volumetric discretization requires approximately, $N^{3/2}$ elements (nodes or cells) where N is the number of surface elements. Because of these properties, the panel