COMPARISON OF NUMERIC AND EXACT SOLUTION OF PRESSURE FAR FLOWFIELD

Peter GASPAROVIC*, Peter SZABO
Letecka fakulta, Technicka univerzita v Kosiciach, Rampova 7, 04121 Kosice, Slovak Republic
**Corresponding author.* E-mail: peter.gasparovic@tuke.sk

Summary. The article compares three solutions of pressure flowfield of inviscid fluid in far field of streamlined object. Exact solution is derived from potential flow, the first numerical solution is based on panel method of PANAIR, and the second solution is based on finite volume method in system ANSYS FLUENT.

Keywords: inviscid flow; panel method; finite volume method; computational fluid mechanics

NOMENCLATURE

p	pressure (Pa),
ρ	fluid density (kg/m3),
v	stream velocity (m/s),
Cp	pressure coefficient (1), Cp=p/(1/2 ρ v2).

1. INTRODUCTION

The design of accurate static pressure probes, calibration of the working section of a wind tunnel and preparation of experiments depends on precise modeling of a pressure field in the flow. For example, the design and analysis of the static probes in [1], [2], [3], [4] requires accurate prediction of the surface pressure. The aim of this article is to compare two numerical methods in their ability to reach similar accuracy of the results of inviscid flow. The first numerical method, specifically system Ansys Fluent, is based on Finite Volume Method (FVM), which belongs to the class of methods called Computational Fluid Dynamics (CFD). Detailed investigation on solver settings of Fluent was presented in previous article [5], and investigation of influence of various mesh properties on accurate predictions of subtle pressure differences in the flow by FVM was presented in the following article [6]. In this article, only conclusions on FVM mesh use will be presented. The rest is devoted to investigation of various surface paneling on accuracy of the second numerical method, system Panair, which belongs to so called panel methods.

2. MODEL OF THE FLOW

The simple inviscid flow past the sphere is investigated, because most low speed probes contain spherical surfaces, which are the main source of pressure disturbances. Inviscid flow past the sphere is one of the few cases where the exact solution is known and this allows us directly estimate the accuracy of Computational Fluid Dynamics (CFD) prediction by comparison with exact analytical solution.

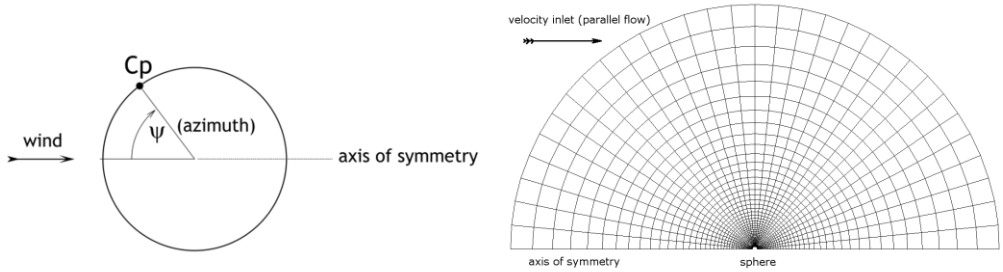

Figure 1 The model and its 2D numerical mesh.

3. STANDARD NUMERICAL MESH OF FVM SOLVER FLUENT

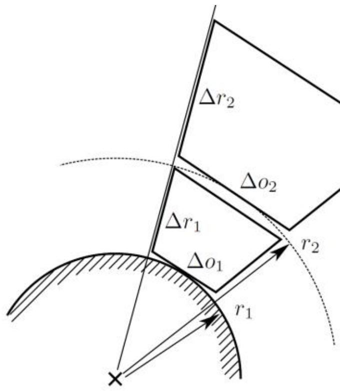

Figure 2 Notation used in deriving parameters of standard numerical mesh

The numerical mesh has quadrilateral cells with with angles approaching 90° and aspect ratio equal to 1.

4. EXACT ANALYTICAL SOLUTION

Exact solution of the inviscid flow past sphere is known and can be described as a function of polar coordinates r (radius) and Ψ (azimuth). Distribution of pressure coeficient on three curves is investigated – on a contour, on a radial line upwind and on a radial line sidewise. For unit diameter of the sphere the distributions are:

$$C_p = 1 - \tfrac{9}{4}\sin^2\Psi \qquad (contour) \tag{1}$$

$$C_p = 1 - \left(1 - \frac{1}{8r^3}\right)^2 \qquad (upwind) \tag{2}$$

$$C_p = 1 - \left(1 + \frac{1}{16r^3}\right)^2 \qquad (sidewise) \tag{3}$$

Exact value of pressure coefficient at impact point is 1.0 (i.e. maximum) and exact value at 90° azimuth is -1.25 (i.e. minimum of pressure in whole flowfield).

5. MESH PARAMETERS INFLUENCING FVM ACCURACY

The radius of mesh domain of 100 sphere diameters is the largest radius used. The first 30% of the radius is accurate and only in outer 70% of the domain the accuracy deficiency is observable.

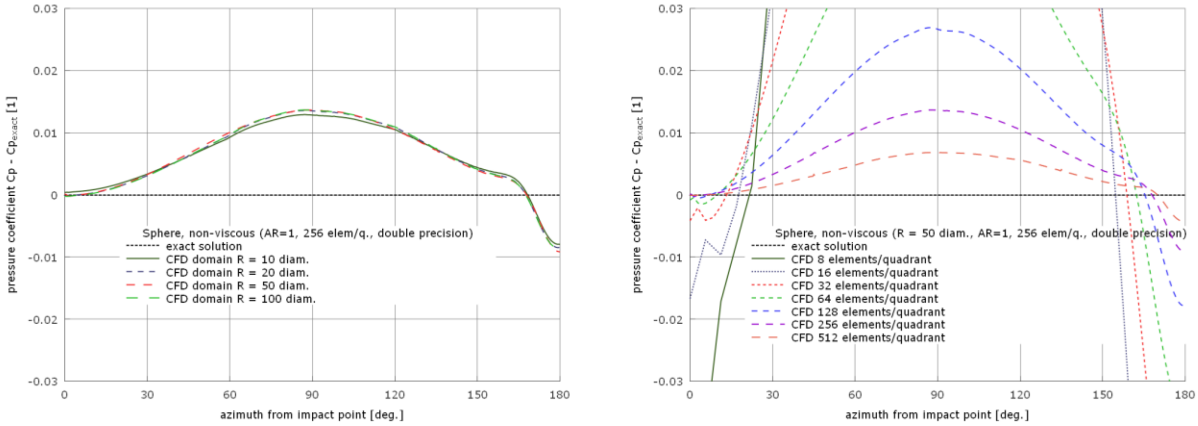

Figure 3 Influence of mesh diameter and global mesh density on pressure distribution along contour.

6. INVESTIGATION OF MESH INFLUENCE ON PANEL METHOD ACCURACY

Four various meshes were investigated. The first meshes are axisymmetrical. The first mesh "quarter" utilizes rotational symmetry, permitting use of only section of quarter size instead of full mesh. The results on full mesh would be the same as on "quarter" mesh, therefore it was omitted. The second mesh is "full axial symmetric" rotated perpendicularly to the direction of the flow. The third mesh "full cubic" uses tiled surface topology in the shape of cube and edges of the panels located on XY plane, which is used for the sampling of surface pressure. The last "full cubic" mesh has panels located on XY plane by their centroids. See figure 4.

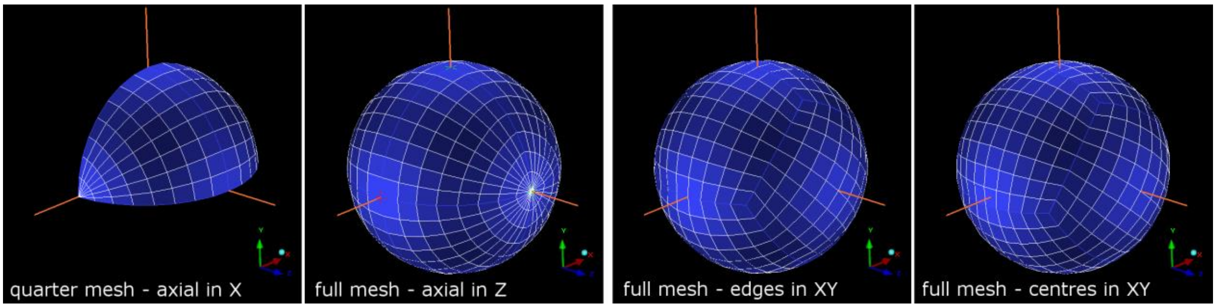

Figure 4 Four types of surface panel meshes investigated.

In addition to the mesh types also the mesh density was varied. Mesh types are compared at fixed density and mesh densities are compared for one type of mesh – "quarter" mesh. Mesh density is described by number of elements per quadrant of circular contour. Accuracy is evaluated on pressure distribution in line directed against wind (x-direction) (see figure 5) and on pressure distribution along contour created by intersection of mesh surface with XY-plane (figure 6). The distance along contour is measured by angle called "azimuth" (see figure 1).

It can be seen that the most suitable mesh is the last – "full mesh – centers in XY". The worst mesh is the full axial mesh oriented perpendicularly with the flow – it causes big error in stagnation point pressure. The quarter mesh is acceptable, because it is economical compromise in terms of computational cost, and the required accuracy can be effectively achieved by higher mesh density.

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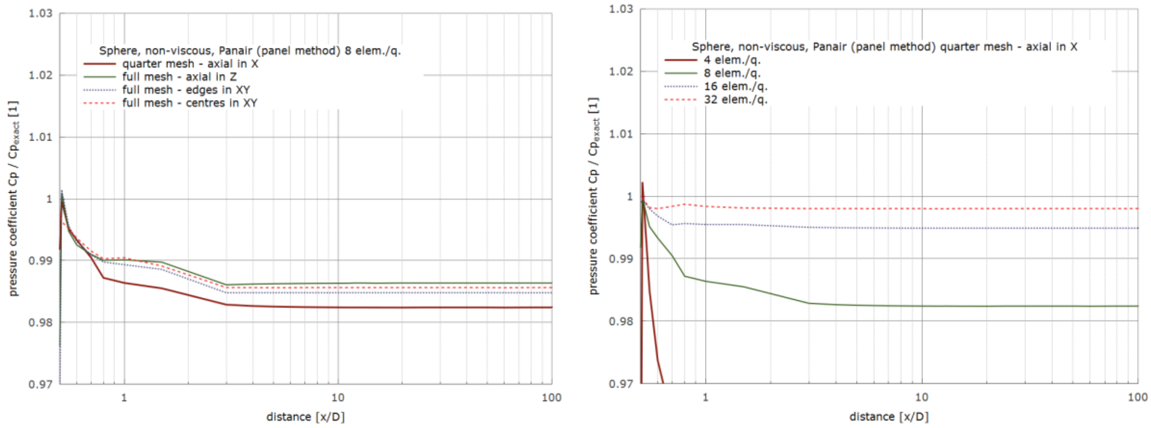

Figure 5 Influence of mesh types and mesh density on pressure ratio in the x-direction.

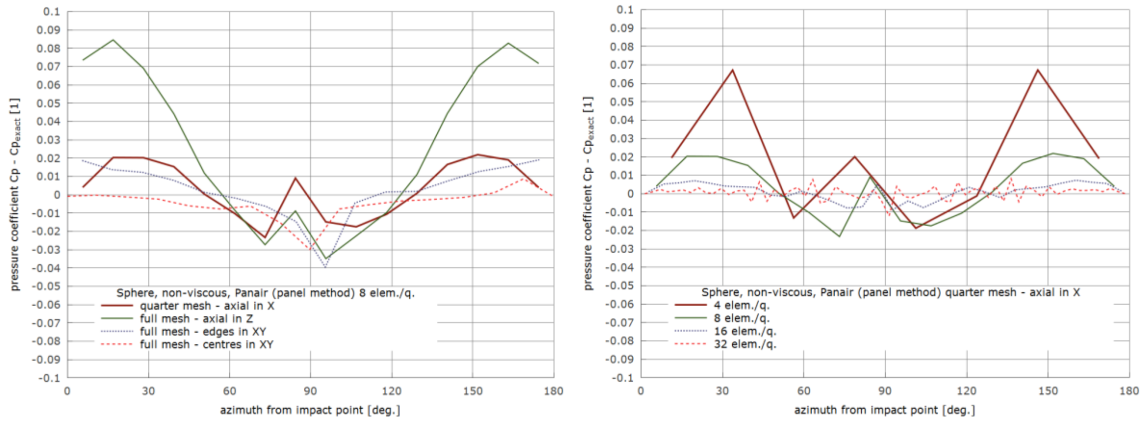

Figure 6 Influence of mesh types and mesh density on absolute error along contour.

7. COMPARISON OF THE FVM AND PANEL METHOD

The mesh for FVM and the mesh for panel method was chosen such way as to achieve similar accuracy – set by 1% acceptable error. The required FVM mesh has 512 element per quadrant and the panel method mesh has 16 elements per quadrant.

The pressure ratio along contour has relatively extreme values, but it is normal, because it is caused be near zero value of the exact pressure which the numerical results are compared. In such location the absolute error graph is more suitable.

The FVM results are smoother than the panel method results, and also accuracy in front of stagnation point is better. However the accuracy in the far field requires three times larger radius of the domain which is computationally expensive and the decision must be made apriori. On the other hand calculation of far field pressure in the case of panel method is very cheap and quick and bring no requirement on mesh, so the decision can be made aposteriori (after the mesh was created).

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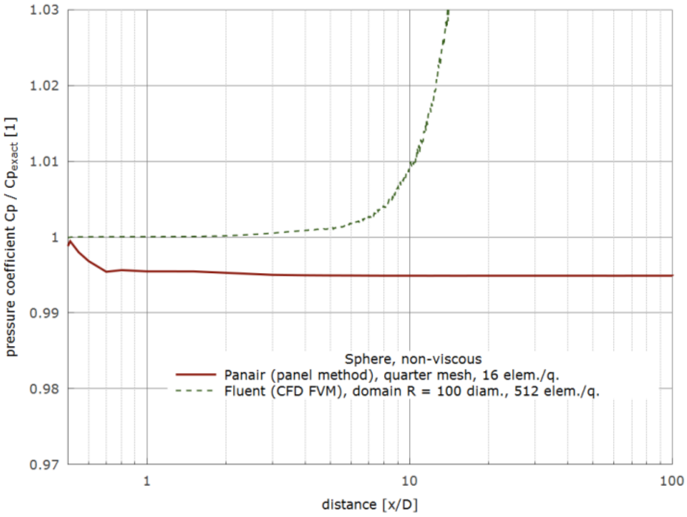

Figure 7 Comparison of FVM and panel method on pressure ratio in the x-direction.

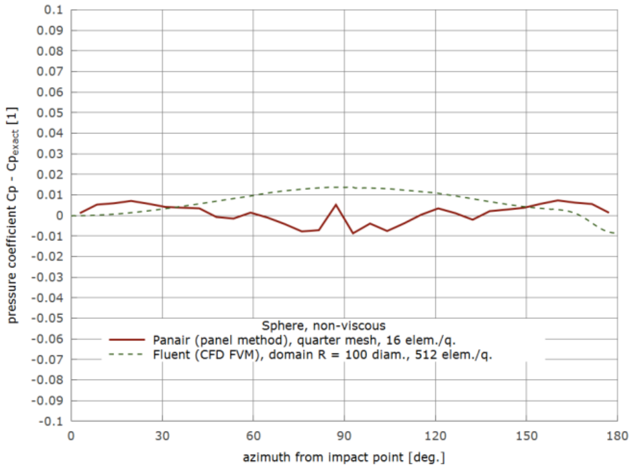

Figure 8 Comparison of FVM and panel method on absolute error along contour.

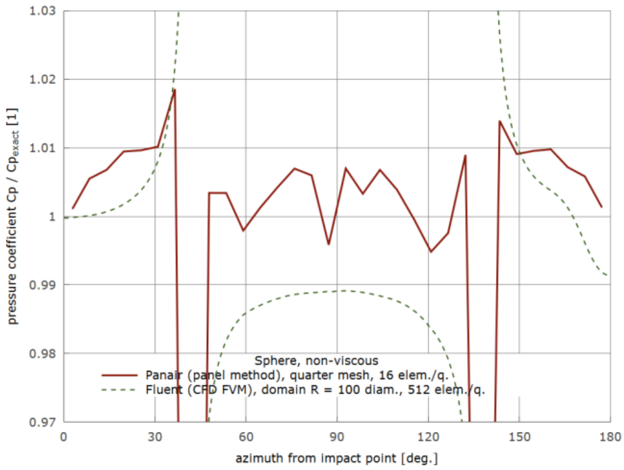

Figure 9 Comparison of FVM and panel method on pressure ratio along contour.

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