

# Dynamic mesh adaption in shockwaves simulations

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**Abstract:** The goal of the article is to compare the accuracy and computational time of the shock wave simulations, using the standard, structured mesh and the dynamic mesh adaption. The coarse and fine mesh will be compared with the dynamically adapted mesh in terms of computational time and accuracy. Based on the results, histograms depicting computational time will be created. The simulation, on which those meshes will be examined will be a simple, two-dimensional oblique shock wave forming over a wedge inclined at 15°, with the Mach number at the domain inlet being equal to 2. The adaption will be based upon the pressure gradient criterion.

**KEYWORDS** SHOCKWAVE, MESH ADAPTION, DYNAMIC MESH ADAPTION

## 1 Introduction

The dynamic mesh adaption methods are a subject worthy of examination, as supersonic air travel is being considered to be reintroduced to commercial air travel [1-4], which rises a necessity to be able to simulate supersonic flow and all of the phenomena related to it efficiently. Dynamic mesh adaption allows for obtaining results which accuracy comparable to results obtained from very fine mesh, while using only a fraction of the mesh element used by the fine meshes and allows for significant reduction of computational expense and time.

## 2 Methods

The geometry for the computational domain was designed in SpaceClaim software, and all of the simulations were conducted in Ansys Fluent 2021 R1, on the Academic license. The geometry generated for the computational domain can be observed in the figure below. Two versions of the mesh, fine and coarse are presented in the figures below.

The coarse mesh serves as a base for dynamic adaption. The procedure of adapting mesh is described in detail in [5].

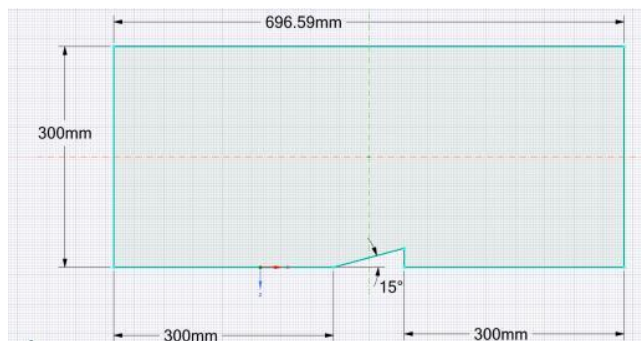


Figure 1: Domain geometry

Mesh details are presented in the table below.

Table 1: Mesh details

	Coarse	Fine
Mesh elements	2251	209096
Mesh nodes	2353	210085

The following assumptions were made regarding the study:

All meshes used in the simulations are quad-dominant meshes;

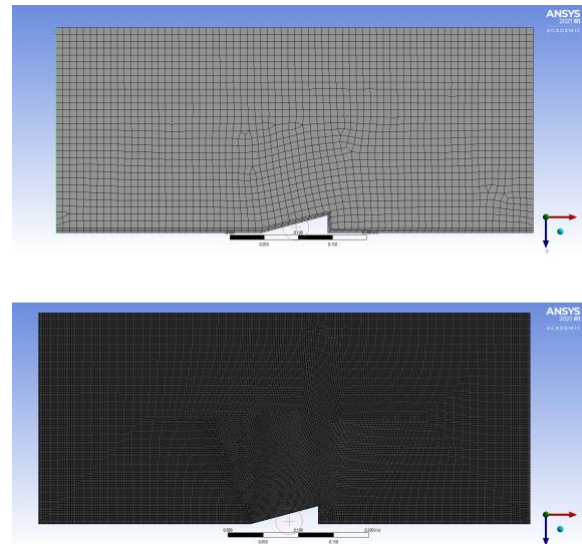


Figure 2: Meshes used for computations

Inflation, consisting of 4 layers, with a growth ratio of 1.1 was applied to all walls;

3rd MUSCL scheme was used for all calculations, to reduce numerical diffusion;

A density-based solver was used for all simulations;

1000 iterations were conducted for each case;

A gradient of pressure was used as a refinement and coarsening criterion, cells with gradient values above 10000 Pa/m are refined, while cells with a value below 10000 Pa/m are coarsened;

Refinement and coarsening levels are equal to 3;

Fluid in the domain is air, and it is assumed to be an ideal gas;

Compressible Aerodynamics Calculator [6] is used as an analytical means of validation of the results, the value compared with the numerical result is the wave angle;

Wave angles are measured based on the Mach number contour.

## 3 Results

After conducting computations results had been obtained, the computational time needed for 1000 iterations is presented in the bar graph below.

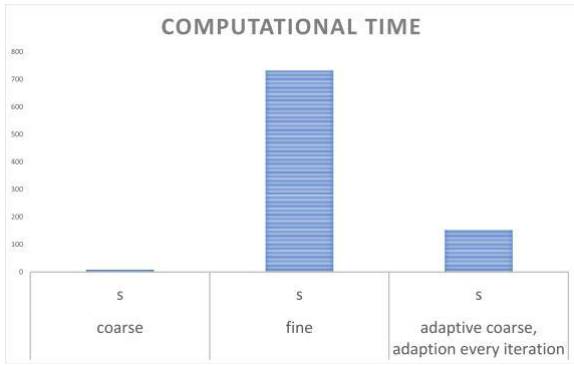


Figure 3: Computational time comparison

The mesh elements and nodes in coarse mesh after adaption had been increased to 6898 elements and 7922 nodes. The graphical representation of the results, in a form of Mach number contours and pressure contours, are presented in the figures below. To validate the results of the numerical computations, the wave angle was calculated by using the  $\Theta - \beta - M$  equation, which is presented below.

$$\tan\theta = 2 \cot\beta \frac{M_1^2 \sin^2\beta - 1}{M_1^2(\gamma + \cos 2\beta) + 2}$$

The equation is solved numerically by bisection, by the Compressible Aerodynamics Calculator [6], to obtain  $\beta$ , which is, in this case, the wave angle. The Mach number contours, needed for the wave angle measurement, are presented in figures 4 and 5. The comparison of the numerical and analytical results is also presented in the following table.

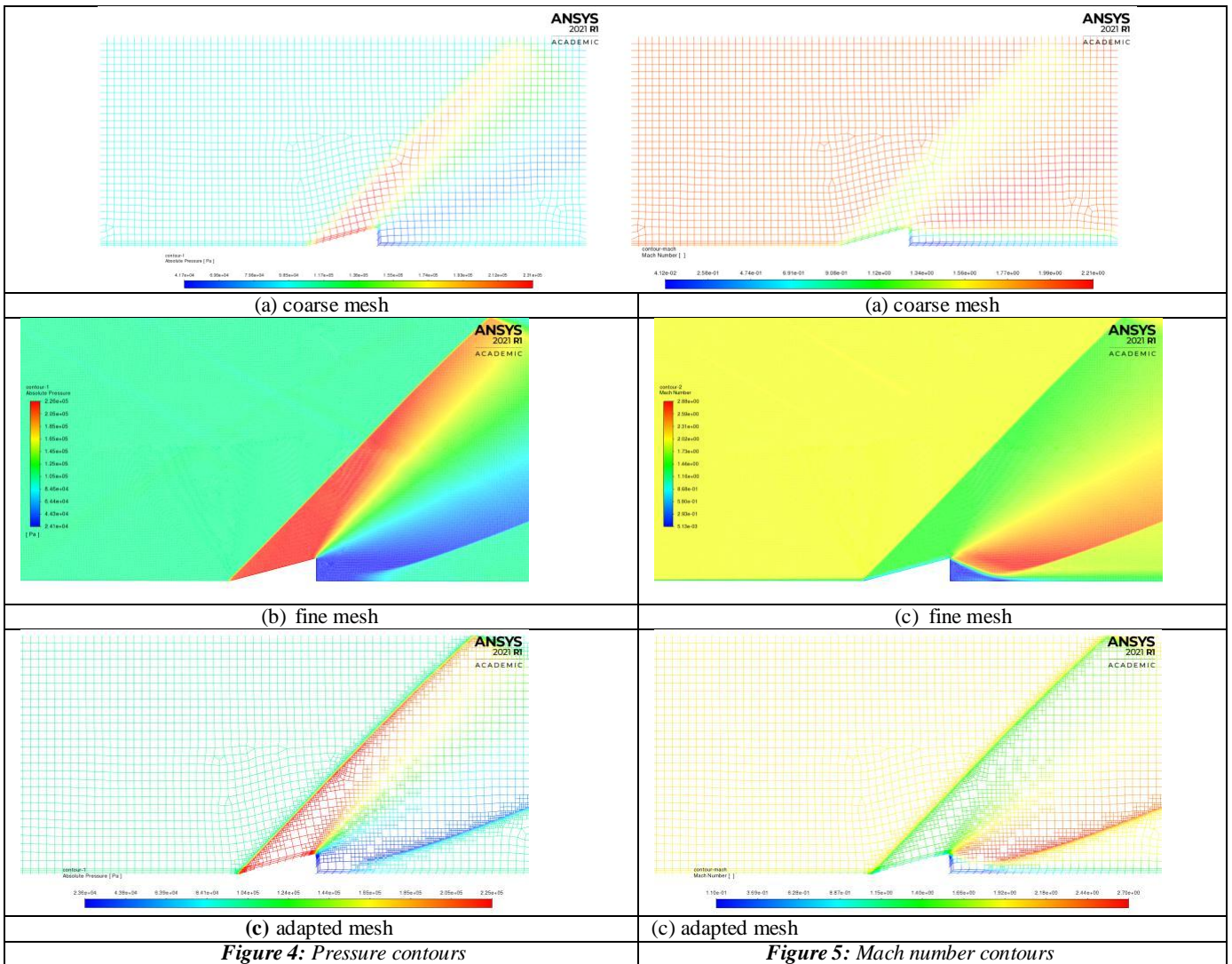


Figure 4: Pressure contours

Figure 5: Mach number contours

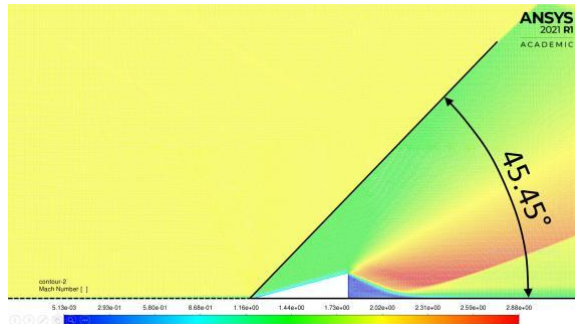
Table 2: Accuracy of the simulations

	coarse	fine	adapted
analytical	45.34	45.34	45.34
numerical	46.74	45.93	45.77
relative error	2.98%	1.27%	0.93%

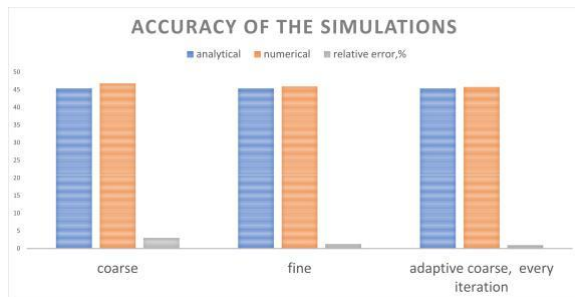
### 4 Conclusions

In the article, the oblique shock angle was examined. Three meshes in total were subjected to the examination, coarse, fine and dynamically adapted coarse mesh. The results obtained had proven the coarse mesh to be inapplicable for the examination of shock angle, due to the significant underestimation of the Mach number, as well as the inability to depict properly the Prandtl-Meyer expansion fan [7], which should have formed behind the wedge, and it is depicted in the fine and adapted cases. It is worth noticing that, the dynamically adapted mesh had led to better accuracy than the fine mesh, which is most likely caused by the

higher local density of the mesh in the area, in which the oblique shock is forming. The expansion fan is depicted more accurately in the fine mesh case, as it does not have as high a gradient of pressure as the oblique shockwave. The measurement method used for measuring the wave angle is depicted in figure 6, it is important to take the accuracy of the wave angle measurement into account, as it generates a possibility for the measurement error to occur. The approach, which would allow reducing the measurement error, is to measure the angle multiple times to be able to obtain the standard deviation value.



**Figure 6:** Measurement of the wave angle in the refined mesh case



**Figure 7:** Accuracy of the simulations

The adaptive mesh refinement shows a potential to reduce the computation time of the numerical simulations, without compromising on the accuracy and precision of the computations. It is worth noticing, that the method does not apply exclusively to the shockwaves, it might be used to simulate mixing in multiphase flow, with the volume fraction being a refinement criterion.

## References

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