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High Speed Internal and External Flow Analysis with Improved Pressure-based Algorithm

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Abstract

In this paper, a pressure-based computational fluid dynamics algorithm for the numerical analysis of internal and external compressible flow is developed. To this end, an improved pressure-based algorithms was developed.

Introduction

Pressure-based algorithm is applied as a major analysis method in most commercial analysis packages, and is widely used in research and industry. In pressure-based CFD, the pressure–velocity coupling algorithm is used to convert a continuity equation to a pressure equation. The Rhie–Chow interpolation scheme is one of the most widely used pressure–velocity coupling methods[1]. The segregated algorithm with Rhie-Chow interpolation scheme is widely used because it is not demanding of computation resources, and is highly efficient for the analysis of an incompressible region with little change in the density.

Especially, the coupled algorithm was yield by combining the pressure–velocity coupled algorithm and the pressure–enthalpy coupled algorithm. In addition, the Kurganov–Tadmor flux splitting scheme, which was studied by Kim[2] and Kraposhin et al. [3], was applied to a developed pressure-based solvers.

In spite of these advantages, there are limitations associated with the application of this analysis algorithm to a compressible flow with large variations in density, the flow inside a combustor with sudden changes in pressure, and the flow of an expanding high-pressure gas. Various studies have been conducted to with the goal of overcoming these limitations.

To confirm the analytical ability of the developed segregated solvers, the hyper tube problems was calculated. A hyper tube system is a cylindrical train that moves at high speed through a pipe with a low density. To confirm the analytical ability of the developed coupled solvers, a variety of Mach number flow problems were performed using the developed solver.

Methods

The Original pressure-velocity & pressure-enthalpy coupled algorithm

- The coupled algorithm in pressure based solver is a way of simultaneously updating the flux on cell faces and the pressure gradient in iterative calculation
- The pressure based coupled solver has than the segregated pressure based solvers but this way is required more computation resources
- To analyze the flow with a large change in density induced by enthalpy in the pressure-velocity coupled algorithm, an internal iterations has to be performed for density convergence

An improved pressure-velocity-enthalpy coupled algorithm

- The two coupled algorithms have some disadvantages to perform analysis the flow with high energy and velocity change as like shock tube and nozzle problem
- To solve this problem, an improved algorithm by combining the above two methods with flux splitting method studied by Kraposhin[3] was developed

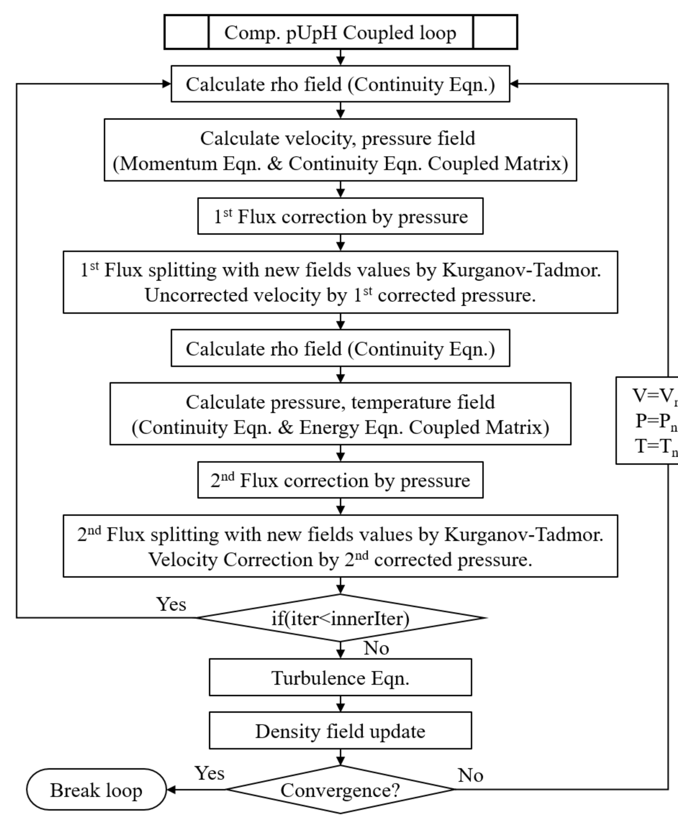

Figure 1. The developed algorithm of coupled numerical analysis.

Results

Some flow cases was employed to verify the developed solver.

1D Shock problems – Coupled Algorithm

- There is 3 shock problem – Sod(Figure 3), Lax(Figure 4), Shu & Osher(Figure 5) cases
- The analyzed results by developed solver are comparatively similar to other in-house and experimental results
- Through the analysis of the these cases, the analytical ability of the developed solver by improved algorithm for the flow with discontinuous flow phenomenon can be verified

High Speed Tube – Segregated Algorithm

- k-ω SST turbulence model
- Inlet condition : mass flux inlet
- Moving wall condition for Tube wall
- Stationary wall condition for capsule wall
- Velocity : M=0.4, 0.5, 0.6, 0.7, 0.8, 0.9
- Chocking phenomena between tube and capsule was confirmed at above M=0.7

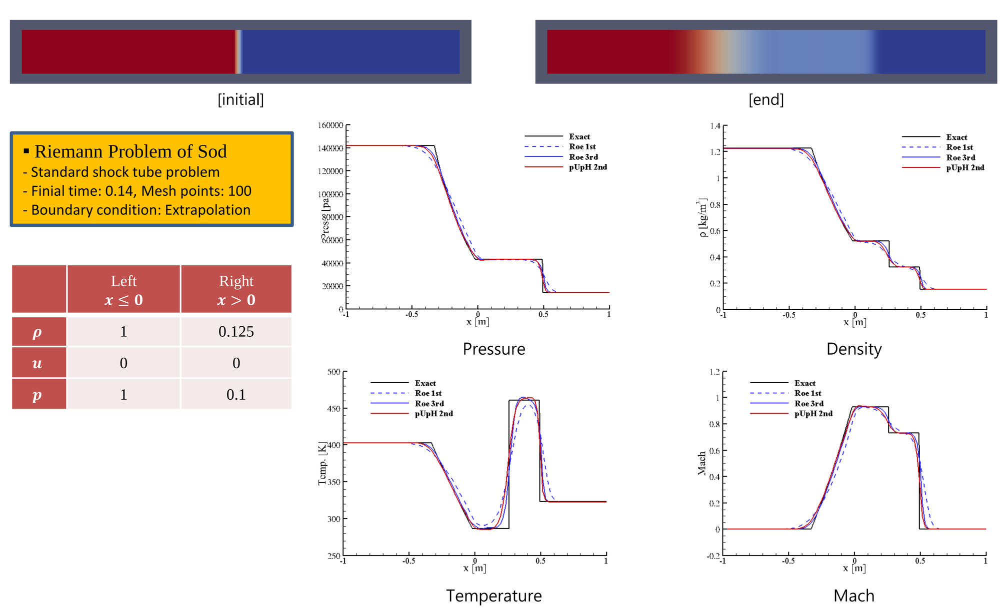

Figure 2. 1D Sod problem conditions and results.

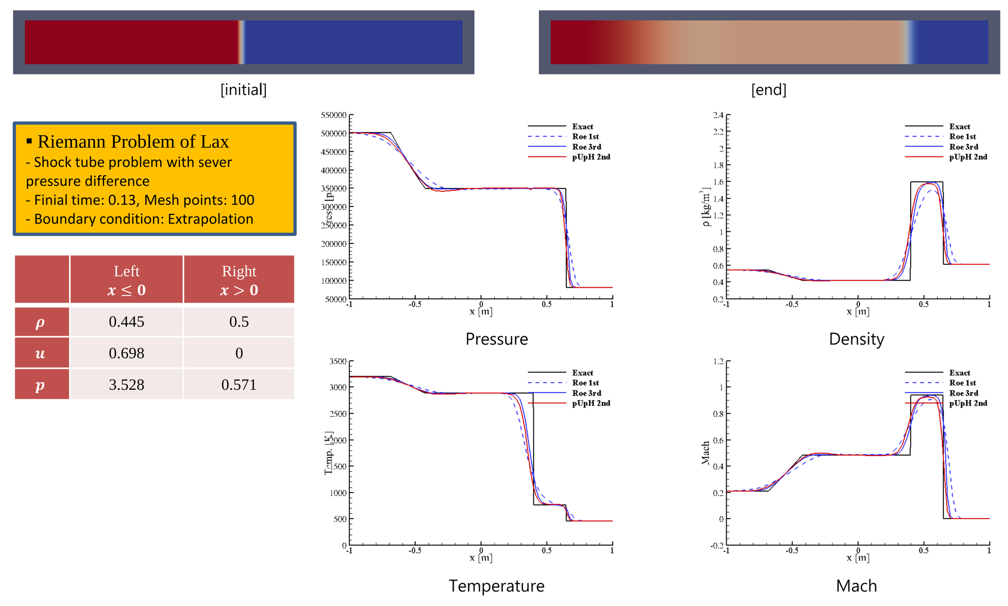

Figure 3. 1D Lax problem conditions and results.

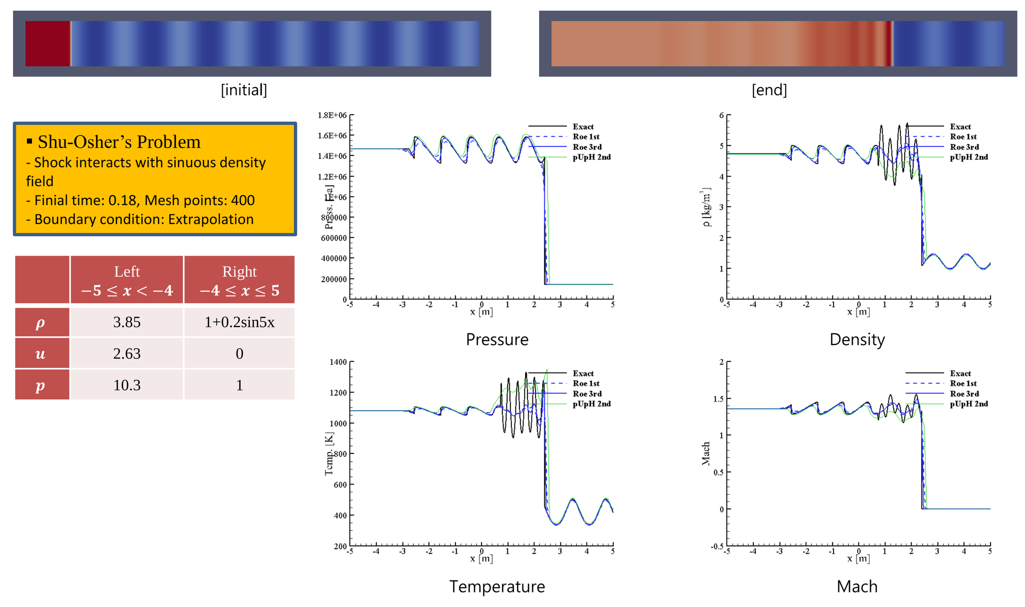

Figure 4. 1D Shu & Osher problem conditions and results.

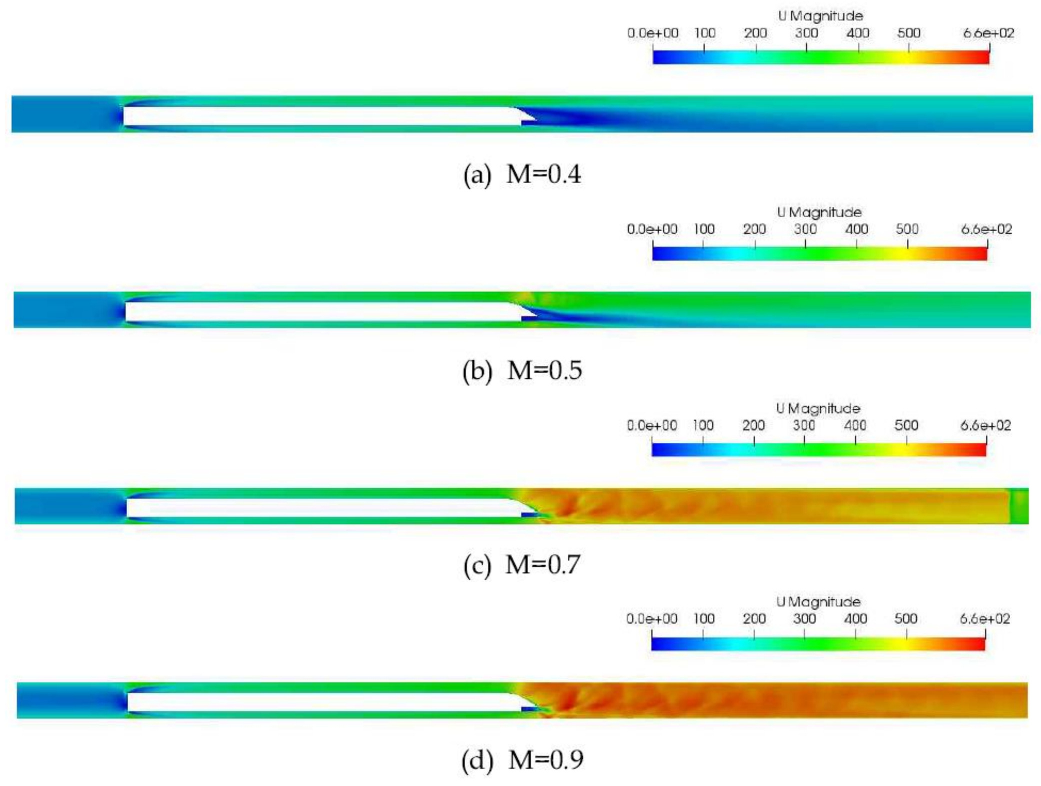

Figure 5. Velocity results at y=0 plane

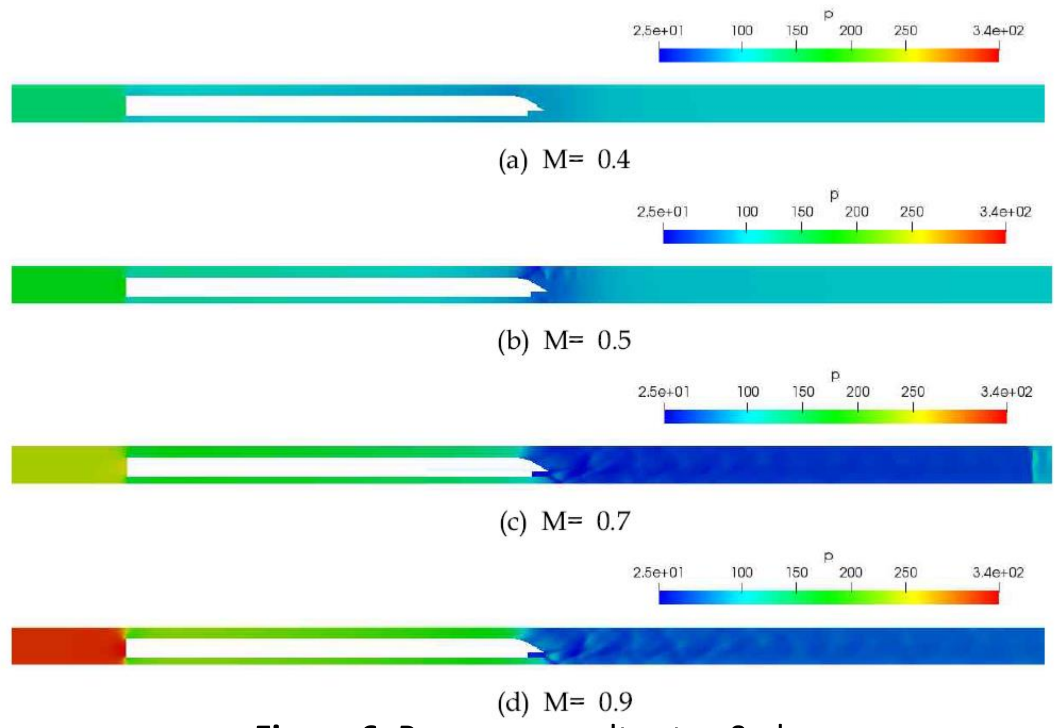

Figure 6. Preesure results at y=0 plane

Conclusions

It was confirmed that the developed coupled solver had the similar analytical ability with that of the other numerical codes through the analysis of the shock wave induced problems in the supersonic flow region.

In order to verify the analytical ability for the high speed internal flow region of the developed segregated solver, the HyperTube problems were analyzed. It is confirmed that the analytical ability of developed solver in the high speed internal flow region such as transonic is sufficient.

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