Evaluation of Numerical Dissipation Sensitivity of IDDES

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Abstract: IDDES method based on k-ω-SST model was applied to simulate the decaying of homogeneous and isotropic turbulence and tandem cylinders flows. Fourth order Jameson-type central scheme and high order symmetric total variant diminishing schemes with adaptive dissipation were formulated by introducing an adaptive function dependent on the turbulent flow. The numerical dissipation sensitivity is evaluated by changing the threshold of the adaptive function. From the results of DHIT, the large threshold suppresses the cascade of the energy and the small threshold can match the energy cascade well. From the tandem cylinders case, the threshold has great effects on the shear layer instability, the generation of small scale structures, and so on.

Keywords: IDDES, DHIT, Tandem cylinders, adaptive function.

1 Introduction

Detached eddy simulation (DES) was originally developed to simulate the massively separated flows. Due to its high accuracy and efficiency, it was widely used and obtained further improvements. To avoid the separation in the attached boundary layer induced by the locally clustered grids, Spalart proposed a delayed-DDES (DDES). To cure the log-layer mismatch problem, Shur et el. proposed an improved-DDES (IDDES). IDDES combines the advantage of DDES and wall-modeled large eddy simulation (WMLES) and it is applied to simulate the extremely unsteady and massively separated flow past tandem cylinders in this paper.

When DES-type methods are used to resolve the turbulence, the numerical dissipation is required low enough. However, the grids near the wall and in the irrotational region are often not fine enough, the computations always suffer numerical difficulties. Then, the appropriate numerical dissipation is also required. However, the threshold of numerical dissipation has to be evaluated. Furthermore, the effects of the dissipation level on the flow features, such as turbulence energy cascade, shear layer instability, pressure fluctuations, and so on, should be investigated. The evaluation will help us to understand the numerical dissipation characteristics.

2 Numerical methods

The in-house code of UNITs (*U*nseady *N*av*I*er-S*T*okes *s*olver), which is in a cell-centered finite-volume formulation based on multi-block structured grids, is applied to evaluate the numerical dissipation sensitivity. A modified fully implicit LU-SGS with Newton-like sub-iteration in pseudo time is taken as the time marching method when solving the N-S and the turbulence model equations. The approach is a parallel algorithm using domain-decomposition and message-passing-interface

strategies for the platform on PC clusters.
When LES-type methods are applied to resolve the turbulence, high order central schemes are always the suitable choices. In this paper, two high order schemes are used. One is the Jameson-type fourth central scheme only with fourth order artificial viscosity and another is the sixth order symmetric total variant diminishing (STVD) scheme based on Roe scheme through five order WENO interpolation (shortened as S6WENO5).
From our experience, the original Jameson-type central and STVD schemes are often dissipative and they can greatly suppress the generation of small structures. Then, their dissipation should be effectively decrease in the separation region. As analysis before, the numerical dissipation should be large enough near the wall and in the irrotational region where the grid are relatively too coarse to accurately resolve the turbulence.
The inviscid flux of the N-S equation can be written as:

$$F_{i+1/2}=f_{i+1/2}+D_{i+1/2} \tag{1}$$

In equation (1), $f_{i+1/2}$ is the symmetric flux without any dissipation and $D_{i+1/2}$ is the pure dissipation without any dispersive errors.
For the S6WENO5 scheme,

$$f_{i+1/2}=(F_{i-2}-8F_{i-1}+37F_i+37F_{i+1}-8F_{i+2}+F_{i+3})/60 \tag{2}$$

$$D=-\phi\times 0.5\times\left[\left|\tilde{A}_{inv}\right|\left(q^R-q^L\right)\right]_{i+1/2} \tag{3}$$

where q^R and q^L are the original varaibles on the interface.
For the fourth order Jameson central scheme, only the fourth artificial viscosity remained due to low speed flow. The symmetric flux and dissipation are given as:

$$f_{i+1/2}=(-F_{i-1}+7F_i+7F_{i+1}-F_{i+2})/12 \tag{4}$$

$$D^{(4)}_{i+1/2}=-\lambda_{i+1/2}\varepsilon^{(4)}_{i+1/2}\left(q_{i+2}-3q_{i+1}+3q_i-q_{i-1}\right),\ \varepsilon^{(4)}_{i+1/2}=Max(0,\phi\times k^{(4)}) \tag{5}$$

where $k^{(4)}=1/100$; λ is the spectral radius and q are the primary variables.
In equation (3) and (5), ϕ is an adaptive function dependent on the turbulence flow and grid scale. It can be written as:

$$\phi=\phi_{max}\tanh(A^{CH1}) \tag{6}$$

where ϕ_{max} is always taken as one. The definition of ϕ can be found in our previous work. Then, ϕ is equal to zero in the separation regions and equal to one near wall and in the irrotational regions. When it is equal to 0, the S6WENO5 scheme becomes the sixth order central scheme without dissipation and fourth central scheme is a pure central scheme without any artificial viscosity. When it is equal to 1, they return to the original scheme.
As we know, high order purely central scheme always suffers from numerical difficulty, then we should set a threshold of the adaptive function.

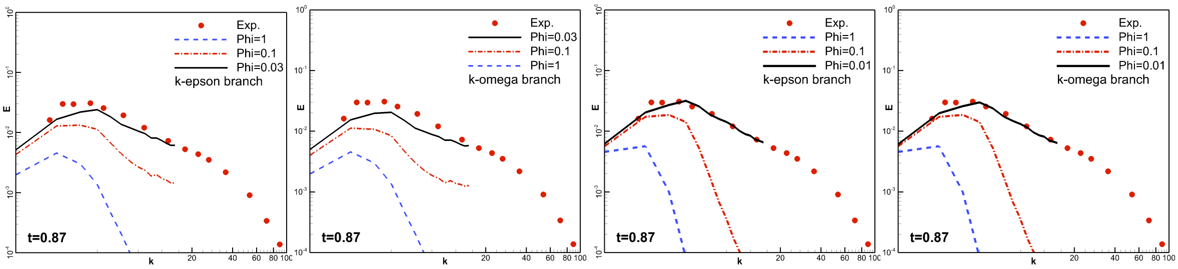
$$\phi=\max(\phi,\phi_{min}) \tag{7}$$

where ϕ_{min} is a constant. It can be taken as 0.01, 0.1, even 1.

3 Partially Results

The resolved turbulence modeling method is the IDDES based on SST model. The constant C_{DES} has been calibrated using UNITs. In this paper, we focus on evaluating the effects of ϕ_{min} on the flow features, such as energy cascade, shear layer instability, pressure fluctuation, and so on.

Case I: DHIT case
DHIT is a typical test case for the resolved turbulence modelling methods. And it is always used to test the dissipative property of computational fluid dynamics (CFD) software and to calibrate the important. Figure 1 present the energy cascade by fourth order Jameson-type central and S6WENO5 with some typical thresholds of ϕ_{min}. For this case, ϕ is a constant and it is equal to ϕ_{min}.



(a) S6WENO5 scheme (b) Central scheme

Figure1: The effects of ϕ_{min} on DHIT (Left: k-ε ; Right: k-ω branch)

Case II: Tandem cylinders

The massively separated flow past tandem cylinders with space of 3.7 diameters was simulated by IDDES coupled with S6WENO6 where ϕ_{min} is equal to 0.1. Figure 2 and 3 present the root mean square of pressure coefficients on the surface and the instantaneous spanwise vorticity between the two cylinders and after the rear one.

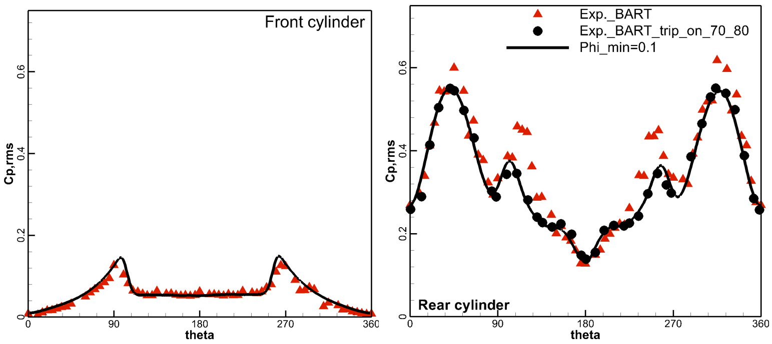


Figure 2 $C_{p,rms}$ on cylinder surface

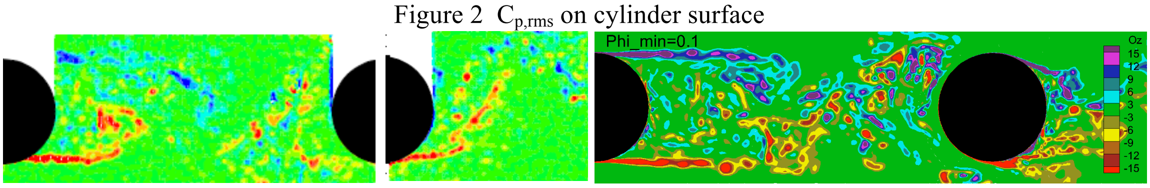


Figure 3 Instantaneous spanwise vorticity (Left: Measurements; Right: S6WENO5 with ϕ_{min}=0.1)

The computations using S6WENO5 scheme with ϕ_{min} of 0.03 and Central scheme with ϕ_{min} of 0.01 are on going. The results and the difference between them will be shown at the conference. The effects of the thresholds of the adaptive function on the flow features will be discussed in the future.

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