# Evaluation of Detached Eddy Simulation Applicability to Random Hydraulic Load Analysis for Reactor Vessel Internals

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## 1. Introduction

The US NRC Regulatory Guide 1.20 requires the comprehensive vibration assessment program (CVAP) to verify the structural integrity of the reactor vessel internals (RVIs) against flow-induced vibration. The CVAP consists of analysis, measurement, inspection, and evaluation programs [1].

In the conventional analysis, the deterministic hydraulic loads and the random hydraulic loads were predicted by the analytical equations and compensating the correlated random hydraulic function from mock-up test results [2]. Recently, the revised Regulatory Guide 1.20 allows the usage of CFD code and recommends large eddy simulation (LES) for the unsteady simulation of flow turbulence. However, LES is not efficient because many grids and time steps are required to predict the flow turbulence for the reactor vessel internals 3D model.

This paper presents the evaluation results on the applicability of the detached eddy simulation (DES) instead of LES to predict the flow turbulence for the RVIs. Therefore, the flow turbulence in a simple duct was calculated by using DES and LES to evaluate the applicability.

## 2. Methods and Results

The flow-induced vibrations in the reactor vessel are caused by the deterministic and random hydraulic loads. The deterministic hydraulic load is induced by the periodic pressure pulsations of the reactor coolant pump and can be calculated by acoustic wave analysis. The random hydraulic load is induced by the flow turbulence and can be predicted by CFD analysis with turbulence models such as the LES model.

LES solves the Navier Stokes equation without any approximation for a time behavior while RANS solves time averaged Navier Stokes equation. Also, LES provides prediction similar to that of Direct Numerical Simulation (DNS) [3]. However, LES requires a high performance computational environment.

On the other hand, the DES model uses the RANS model in the boundary layer and the LES model in the free shear flow region. The DES model is more efficient than the LES model because the DES model uses fewer grids and time step number than the LES model does. In order to evaluate the applicability of DES instead of LES to predict the random hydraulic function for RVI CVAP, a simple duct was modeled with an obstacle sustaining turbulence and 30 monitoring points, as shown in Fig. 1.

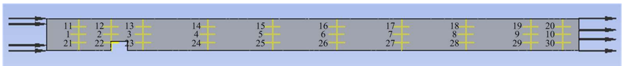

Fig. 1. Schematic of a duct with an obstacle and monitoring points

Test conditions:

- Dimension of the duct: 0.1m x 0.1m x 1.4 m (width x height x length)
- Height of the obstacle: 0.03m
- Fluid: water
- Inlet velocity: 1m/s
- Outlet pressure: 101kPa
- Analysis time: 4.0 second
- Time step: 0.001 second
- Courant number: 0.3 ~ 0.4
- Boundary layer number of DES: 10
  Y + value: < 5
- Boundary layer number of LES: 15
  Y + value: < 5
- Grid number
  - DES: 0.6, 1, 2.4, 4.5 million each
  - LES: 1, 2.4, 4.5 million each
- Grid type: Tetrahedron and prism

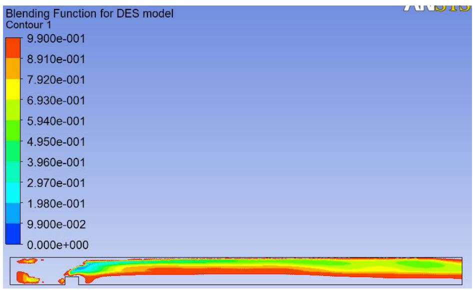


Fig. 2. Distribution of blending function of DES for 1 million grids and a 4.0 second calculation time

Figure 2 shows the distribution of the blending function of the DES model for 1 million grids and a 4.0 second calculation time. It is shown that the flow turbulence in the blended region, which has a blending function between 0 and 1, is calculated appropriately with a blend of the LES and RANS models.

Figure 3 shows the velocity distribution predicted by using the DES model and LES model, respectively, for 2.4 million grids and a 4.0 second calculation time. The flow fluctuation prediction of the DES model is less detailed than that of the LES model because the LES model simulates the flow fluctuation by calculating eddy behavior.

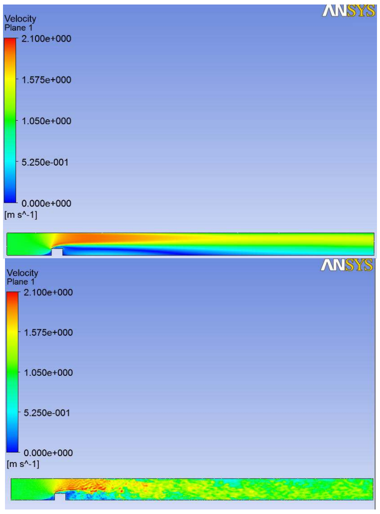


Fig. 3. Velocity distribution of DES (top) and LES (bottom) for 2.4 million grids and a 4.0 second calculation time

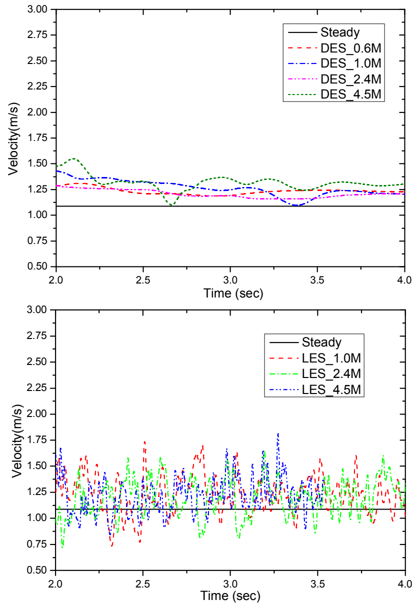


Fig. 4. Flow velocity of DES (top) and LES (bottom) against time for each grid number at point 6

Figure 4 shows the flow velocity of DES and LES against time at point 6. The calculation results during 0 to 2 seconds were discarded because the flow in the duct was not fully developed during 0 to 2 seconds. The calculation results after 2 seconds were used to be analyzed. The straight line in each figure shows the prediction of the RANS model at steady state. The flow fluctuation of the DES model is weaker than that of the LES model. Also, the mean velocity of each turbulence model is approximately 1.25m/s.

Since the power spectral density (PSD) of pressure is used to calculate structural response with the random hydraulic load as inputs, the calculated pressures for the DES model and the LES model in time domain were transformed to PSD in frequency domain as shown in Fig. 5. The flow fluctuation of the DES model between 0 to 100Hz is much weaker than that of the LES model. However, because the PSD trend of the DES model is very similar to that of the LES model, the DES model is deemed a suitable alternative to the LES model to predict the random hydraulic load for structural response analysis.

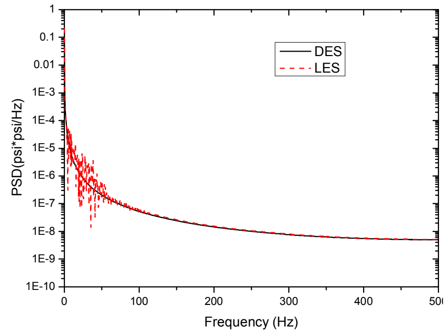


Fig. 5. A PSD diagram of DES and LES for 2.4 million grids at point 6

## 3. Conclusions

In this paper, the applicability of the DES model was evaluated to predict the random hydraulic load for RVI CVAP by comparing DES with LES. Since the PSD trend of the DES model agrees well with that of the LES model, the DES model can be used as a practical alternative to the LES model to predict the random hydraulic load for the RVIs.

In future work, the applicability of the DES model will be further verified through comparing the results calculated by using the DES model with the data measured during the Yonggwang #4 RVI CVAP.

## REFERENCES

[1] U.S. Nuclear Regulatory Commission Regulatory Guide 1.20, Comprehensive Vibration Assessment Program for Reactor Internals during Preoperational and Initial Startup Testing, Revision 3, March 2007.

[2] KEPRI, TM.99NJ13.P2000.243, Report on the Observation and Synthesis about CVAP in KNGR RVI, June 2000.

[3] T. Morii, Hydraulic flow tests of APWR reactor internals for safety analysis, Nuclear Engineering and Design, Vol. 238, p. 469-481, 2008.

[4] P. Nayyar, G. N. Barakos, K. J. Badcock, Numerical study of transonic cavity flows using large-eddy and detached-eddy simulation, The Aeronautical Journal, p. 153-164, 2007.