URANS & SAS analysis of flow dynamics in a GDI nozzle

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Abstract

URANS and SAS analysis of turbulent flow in a GDI nozzle was carried out. The vortex structures, velocity and pressure distributions predicted based on the two different approaches were compared both for instant and statistical values. FFT analysis was applied to the time series of mass flow rate, the velocity, pressure and turbulence quantities at monitoring points. Only one dominant frequency was predicted by the URANS approach using the SST turbulence model. A clear correlation was found among the frequency of the mass flow rate, pressure and velocity at monitor points and that of vortex shedding from the needle surface. In contrast, SAS predicted multiple frequencies. Though no simple correlation was obtained, the frequency of big event in mass flow time series was found to be linked to the first dominant frequency of the pressure monitors.

Introduction

The quality of spray and mixture formation in engine can be very different from nozzle A to nozzle B even under the same operating conditions. This indicates a strong effect of the in-nozzle flow on spray formation. This work is an effort in pursuing understanding about the link between nozzle internal flow and spray formation. For this purpose, high resolution zoomed spray images in the near nozzle exit were obtained at CORIA in cooperation with Continental Automotive. These spray images suggest that there exists a dominant frequency in the primary breakup process. The simulation work reported here was to look for the physical cause from the in-nozzle flow for this frequency. The experience we made in house and also in literature is that simulation of turbulent cavitating flow in fuel injection nozzle is very sensitive to turbulence and cavitation modeling. Frequency prediction is even a more challenging task, not only sensitive to the modeling, also has high requirements of mesh quality, mesh size, time resolution, and especially needs long simulation time to reach statistical convergence. Here as the first step, we only dealt with the turbulence flow. RANS and scale resolved modeling approaches were applied.

Spray images and Frequency estimation

An example of spray image in the primary breakup zone is displayed in Fig. 1. The distances between neighboring ligament patterns were measured. Taking the average injection velocity as the characteristic velocity, the frequency of primary breakup was estimated. Though the data are in scatter, a main frequency close to 25 kHz was obtained under an injection pressure of 10 bar.

Simulation model and Numerical methods

The nozzle is axis-symmetrical with 3 injection holes. A 120°-sector geometrical model was adopted in simulation and a cyclic period condition was applied at the sector boundaries. (see Fig. 2). Three meshes with about 0.8 M, 1.6 M and 3.0 M hexa cells were prepared for the Best Practice study. Neglecting the cavitation model, a single phase turbulent flow problem of incompressible fluid was considered. The commercial flow solver ANSYS-CFX12.0 was applied to the investigation. RANS simulation using the SST model[1] and scale resolved simulation based on the SST-SAS approach[2] were carried out, respectively. Vortex structure, velocity and pressure distribution from the two approaches were compared each other in terms of instant, time averaged values and the standard deviations. FFT analysis was applied to get frequencies of mass flow rate, velocity, pressure and turbulence quantities at various monitoring points. Correlation or link between the mass flow rate, pressure monitors, and the vortex motion was examined.

Results and Discussion

The vortice visualized by utilizing the 2nd invariant of the velocty gradient tensor Q show rich structures in the sac volume and in injection hole. Compared with the RANS approach, the SAS model produced many fine structures, esp. for the finest mesh (Fig. 3). The time averaged field of velocity and pressure was found to similar between the two approaches, whereas the standard deviations were much higher in SAS. In SST, a single dominant frequency was predicted and a clear correlation between the mass flow frequency and the velocity and pressure at various monitors was identified (Fig.4). In contrast, multiple frequencies were obtained in SAS. The big event frequency of the mass flow fluctuation was found to be correlated to the pressure at the sac volume center.

References

[1] Menter, F.R. , Zonal two equation k-ω turbulence models for aerodynamic flows, AIAA Paper 93-2906 (1993).

[2] Menter, F.R., and Egorov, Y., A scale adaptive simulation model using two-equation models, AIAA Paper 2005-1095 (2006).

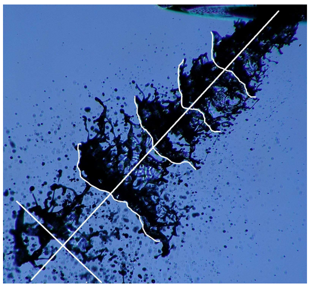

Figure 1. Spray image of primary breakup

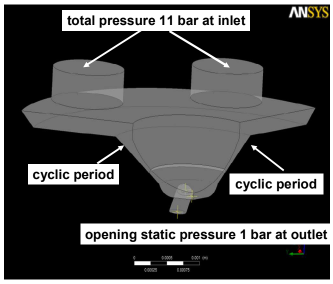

Figure 2. Computation model

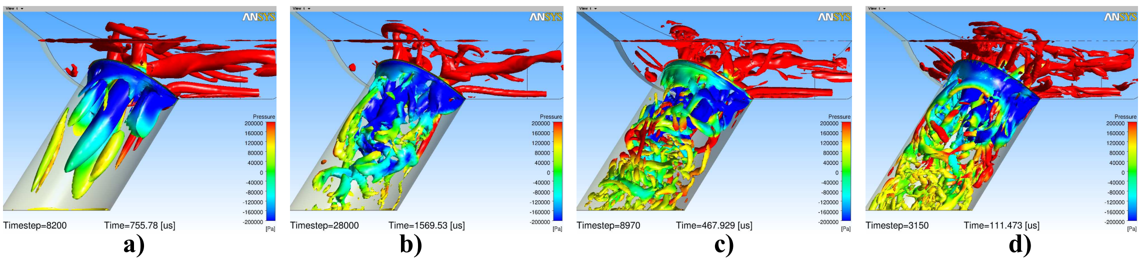

Figure 3. Vortex structures, a) SST, Q = 0.81e11 [1/s2]; b-d) SAS with decreasing mesh sizes, Q = 2.5e12 [1/s2].

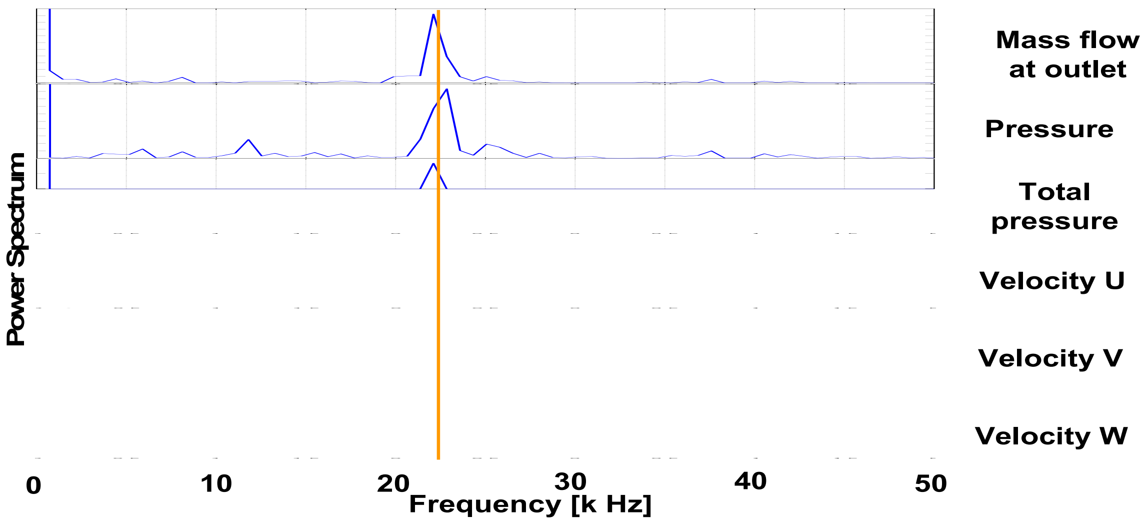

Figure 4. Frequency correlation between mass flow rate and velocity & pressure at injection hole entrance.