COMPARISON OF SAS TURBULENCE MODEL TO THE SST K-ω IN NON-PREMIXED COMBUSTION SIMULATION

Jiří Vondál[1] & Jiří Hájek[1]

[1]*Institute of Process and Environmental Engineering, Faculty of Mechanical Engineering, Brno University of Technology, Brno, Czech Republic*

Abstract Scale-Adaptive Simulation (SAS) enhances capabilities of Unsteady Reynolds-Averaged Navier-Stokes (URANS) to capture decay of large eddies in unsteady flows. SAS behaves like a LES in unsteady solutions with lower demand for local grid spacing. Its main effect is in restricting turbulent viscosity and consequently increasing velocity fluctuation. Such a effect is significant for predictions of chemical reactions and mixing when eddy dissipation model is incorporated. The reason is that this model is strongly bounded to the turbulence predictions. In the present paper the effect of SAS procedure is compared to the traditional SST k-ω turbulence model on the case of non-premixed swirling staged natural gas combustion in a confined environment of water cooled combustor. The aim is to provide accurate local wall heat flux predictions in industrial combustors at the end. The ability to predict local wall heat fluxes is highly relevant for engineering purposes as these fluxes are often the main results required by designers of fired heaters, boilers and combustion chambers.

INTRODUCTION

The concept of SAS was derived by Menter from the concept of K-KL model [1]. It adds another scale to the traditional input of the velocity gradient tensor. New additional computed scale is from second derivative of the velocity field which yields to the well known von Karman length scale L_{vK}. This scale allows to better capture dynamic structures in LES-like behavior in unsteady regions while fall-back to the standard RANS mode in steady regions.

The advantage of SAS model over hybrid RANS-LES models (called Detached Eddy Simulation – DES) is in no explicit dependency on grid spatial resolution [2]. Work in this paper was done on the ANSYS Fluent v14.0 which utilizes SST-SAS variant. It differs from the standard one in additional SAS source term Q_{SAS} (see [3]). The other turbulence model utilized was SST modification of k-ω. This model uses blending function for employing k- ω model in the near-wall region and standard k-ε model in the free stream.

The aim of this paper is to provide comparison of the two methods and evaluate its influence on the complex modeling of swirling non-premixed natural gas combustion. There is still broad potential to improve flow prediction in reacting flows which reactions are strongly based on turbulence predictions via Eddy Dissipation Model (EDM) employed together with one step global mechanism.

COMPUTATIONAL SET-UP

Computational domain consists of large-scale combustor with inner diameter 1 m and length 4 m with seven water cooled sections and supply air duct in details described e.g. in [4]. Burner is equipped with axial guide vane swirler acting as a flame holder. Most of the volume of computational domain was meshed by hexahedral cells and only in the vicinity of nozzles were used tetrahedral elements. Total number of grid cells was approximately 1,300,000. Boundary conditions are adopted from measurement and are described in Table 1. The water side wall temperature was identified to be 80 °C and the wall thickness (carbon steel) is 10 mm.

Simulations were run in unsteady mode since combustion in such a complex geometry is physically transient phenomena. Time step (0.002 s) was chosen according the convergence to allow the solver performing from ten to twenty iterations per time step. Two turbulence models were investigated: SST k-ω and SST-SAS. Radiation was modeled by Discrete ordinates model. The new method for Weighted-Sum of Gray Gases Method (WSGGM) absorption coefficient calculation was utilized based on [5]. Discretization scheme was QUICK for density and momentum and first order for others.

Table 1. Operating conditions

		Average	Maximum error estimate [%]
Total thermal duty	[kW]	1119.6	2.2
Natural gas flow rate	[kg/s]	0.02278	2.2
Calculated methane mass flow rate	[kg/s]	0.02232	2.2
Air mass flow rate	[kg/s]	0.436	10.0
Fuel temperature	[°C]	16.83	2.1
Air temperature	[°C]	14.54	1.7
Total extracted heat flux	[kW]	594.1	4.8
Mass flow rate at primary gas stage (calculated)	[kg/s]	5.79E-3	
Mass flow rate at secondary gas stage (calculated)	[kg/s]	1.65E-2	

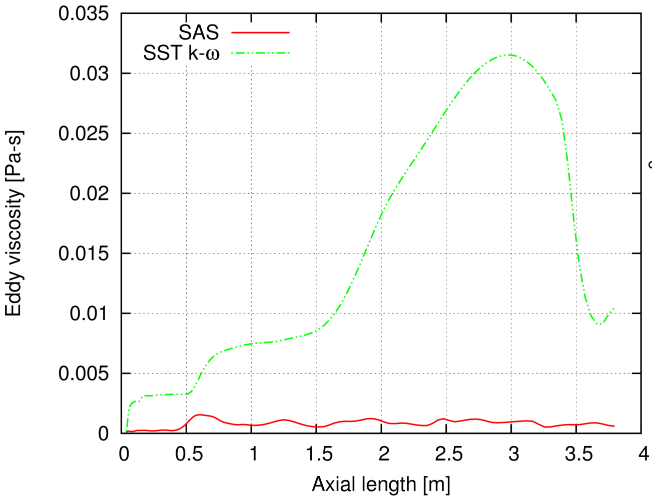

Figure 1. Turbulence eddy viscosity comparison

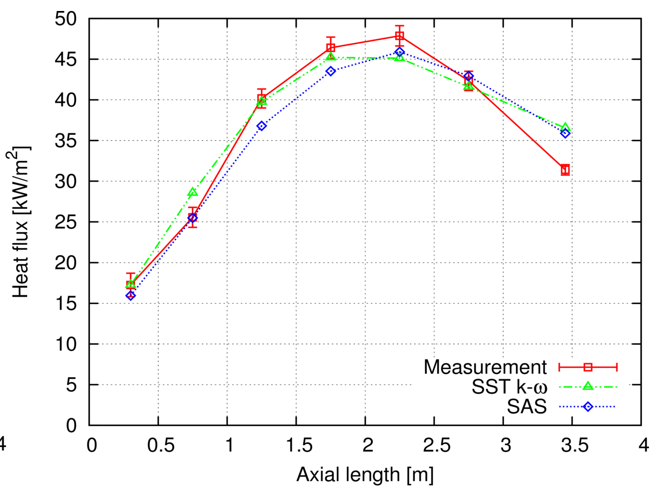

Figure 2. Turbulence model comparison and its effect on predicted local wall heat flux in seven cylindrical sections

CONCLUSIONS

Figure 1 confirms expected behavior of SAS turbulence model which is known to limit turbulent eddy viscosity. Even though this limitation should result in higher velocity fluctuation it actually decreases turbulence kinetic energy. This should affect net rate of production of species due to reactions since it depends among others on turbulent kinetic energy and dissipation rate. However, described effect is weak and there is not a significant change in the heat flux calculations due to other dominant factors e.g. radiation modeling. The overall transferred heat into the wall decreased by less than 3 % and maxim local wall heat transfer reached 11 %.

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