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TESI DI LAUREA

**Assessment of the NEK5000 code for Direct
Numerical Simulations**

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Summary

The present work is included in the frame of the fundamental studies performed worldwide aiming at improving the prediction tools for investigating turbulence phenomena, in order to provide the basis for the assessment of codes and models suitable for the detailed analysis of complex fluid systems, like nuclear reactors.

A critical aspect of the nuclear reactor safety is the fluid-structure interaction, and in particular, the combined effect of a turbulent flow with a thermal mixing, which may lead to local *Thermal Fatigue* phenomena into the structures due to *Thermal Striping*.

The main goal of the present work is to assess the DNS capabilities of the spectral elements code *NEK5000* for the fundamental turbulent flows and their thermal interaction with solid structures. This work is divided into two parts. In the first part, DNS computations are carried out in order to evaluate the performances of the code in predicting the turbulent flow behaviour for simplistic channel flow configurations. Whereas, in the second part, the DNS analyses are further extended for a conjugate heat transfer case, i.e. a planer channel flow along with heated walls. Three different temperature fields are considered.

A wide range of numerical parameters are tested and their influence is studied in order to obtain high quality turbulence statistics both for the velocity and the thermal fields. The obtained results are compared against other well-known DNS databases available in literature. The comparison suggests that *NEK5000* exhibits excellent capabilities to perform high quality DNS computations.

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List of abbreviations

ANL	Argonne National Laboratories
ASME	American Society of Mechanical Engineers
CFD	Computational Fluid Dynamics
CFL	Courant-Friedrichs-Lewy number
DBA	Design Basis Accident
DNS	Direct Numerical Simulation
ECCS	Emergency Core Cooling Systems
FEM	Finite Elements Method
FVM	Finite Volume Method
GFR	Gas-cooled Fast Reactor
GIF	Generation IV International Forum
GLL	Gauss-Lobatto-Legendre points distribution
IAEA	International Atomic Energy Agency
LES	Large Eddy Simulation
LFR	Lead-cooled Fast Reactor
LHS	Left-Hand Side
LWR	Light Water Reactor
MSRF	Molten Salt Fast Reactor
MSR	Molten Salt Reactor
NCBJ	Narodowe Centrum Badań Jadrowych (National Centre for Nuclear Research)
NPP	Nuclear Power Plant
NRS	Nuclear Reactor Safety
NRG	Nuclear Research and Consultancy Group
PDE	Partial Differential Equations
PFM	Probabilistic Fracture Mechanics
PRA	Probabilistic Risk Assessment
PSE	Parabolised Stability Equations
PTS	Pressurized Thermal Shock
PWR	Pressurized Water Reactors
q-DNS	quasi-Direct Numerical Simulation

RANS	Reynolds-Averaged Navier-Stokes
RHS	Right-Hand Side
RPV	Reactor Pressure Vessel
SCWR	Supercritical Water-cooled Reactor
SEM	Spectral Elements Method
SFR	Sodium-cooled Fast Reactor
SGS	Subgrid Scale
TH	Thermal-Hydraulic
TKE	Turbulent Kinetic Energy
URANS	Unsteady RANS
VHTR	Very-High Temperature Reactors
WWER	Water-cooled Water-moderated Energetic Reactor

List of symbols

Latin symbols

c	Generic scalar quantity
c_p	Specific heat capacity at constant pressure
D	Hydraulic diameter
d	Wall thickness in conjugate heat transfer problems
E	Energy distribution
F	External force
G	Ratio of thermal diffusivities
\vec{g}	Gravity acceleration
I	Turbulence intensity
K	Thermal effusivity ratio
k	Turbulent kinetic energy
l	Integral length scale
L_x	Streamwise length of turbulent channel boxes
L_y	Wall-normal width of turbulent channel boxes
L_z	Spanwise length of turbulent channel boxes
N_B	Number of mesh points following Batchelor length scales
N_K	Number of mesh points following Kolmogorov length scales
Pe	Peclet number
Pr	Prandtl number
p	Pressure
q	Specific heat source
Re_T	Reynolds number based on turbulent kinetic energy k
\vec{u}	Velocity field
Sc	Schmidt number
T	Temperature
t	Time
u	Velocity component in the x direction

u_b	Mean bulk velocity
u_τ	Friction velocity at the wall
v	Velocity component in the y direction
w	Velocity component in the z direction
x, y, z	Cartesian coordinate system axes

Greek symbols

α	Thermal diffusivity
α_m	Molecular diffusivity
ε	Dissipation rate of turbulent kinetic energy
η_B	Batchelor length scale
η_K	Kolmogorov length scale
κ	Wave number
λ	Thermal conductivity
λ_κ	Wavelength
μ	Dynamic viscosity
ν	Kinematic viscosity
ρ	Density
$\vec{\tau}$	Viscous stress tensor
$\vec{\tau}_{Re}$	Reynolds stress tensor
τ_K	Kolmogorov time scale
v_K	Kolmogorov velocity scale

Subscripts, superscripts and mathematical operators

\bar{c}	Averaged value of c
$\langle c \rangle$	Averaged value of c
c'	Fluctuation of c in respect to its averaged value
c^+	Non-dimensional value of c
$K(c)$	Kurtosis (or flatness) of c
$S(c)$	Skewness of c
$var[c]$	Variance of c
c_f	Property c for the fluid
c_s	Property c for the solid
∇	Gradient
$\nabla \cdot$	Divergence
∇^2	Laplacian
\sum	Summation