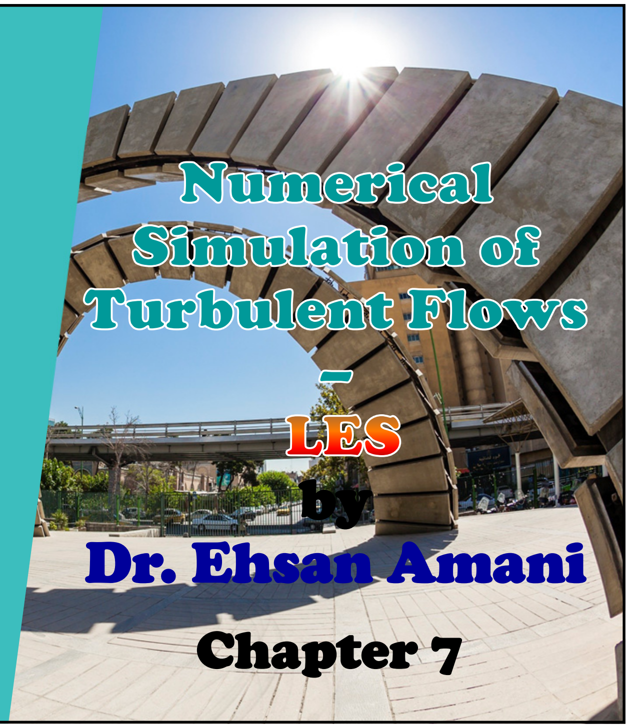


Numerical Simulation of Turbulent Flows – LES

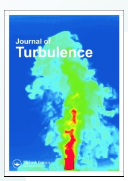
by

Dr. Ehsan Amani

Chapter 7

LES quality criteria

Case study# 1



JOURNAL OF TURBULENCE
https://doi.org/10.1080/14685248.2018.1527033

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A comparative study of turbulence models for non-premixed swirl-stabilized flames

Mohammad Safavi and Ehsan Amani

Mechanical Engineering Department, Amirkabir University of Technology, Tehran, Iran

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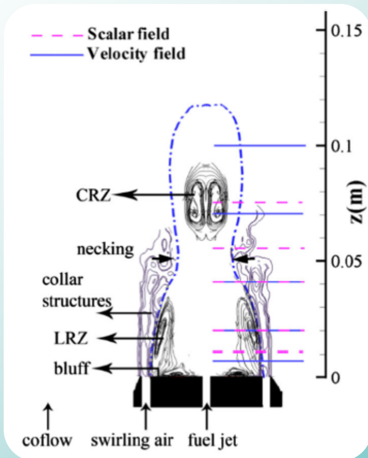
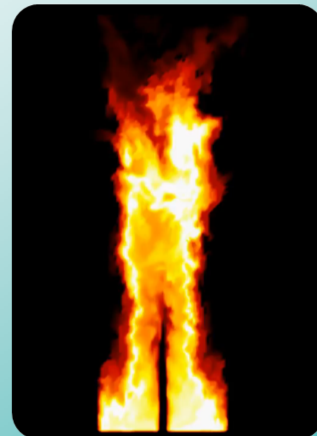
Test case

Sydney swirl burner (SM1)





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Modeling

Turbulence closures

Table 2. Turbulence closures used in this study.

Type	Model	Description
RANS	$k-\varepsilon$	2-equation RNG $k-\varepsilon$
	$k-\omega$	2-equation SST $k-\omega$
	T-SST	4-equation transition SST
	RSM	7-equation stress-ω RSM
Hybrid	SAS	SST $k-\omega$ based SAS
	DES Realizable $k-\varepsilon$	Realizable $k-\varepsilon$ based DES
	DES SST $k-\omega$	SST $k-\omega$ based DES
LES	LES	Germano's dynamic SGS

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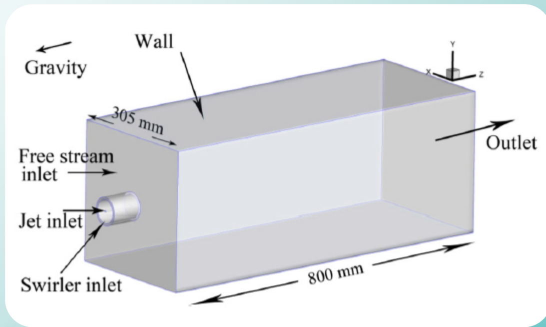
Pre-processing

LES/Hybrid vs. RANS



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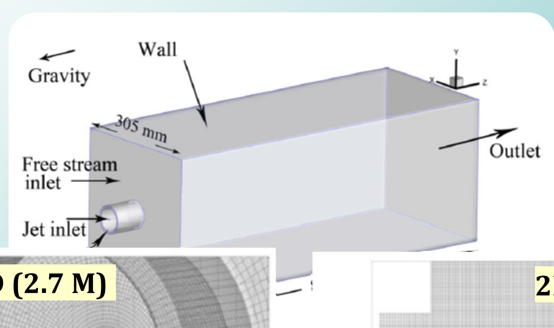
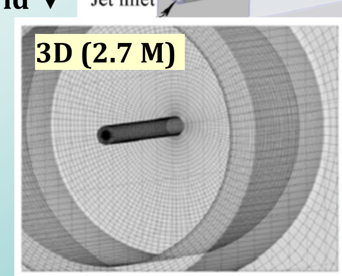
Grid

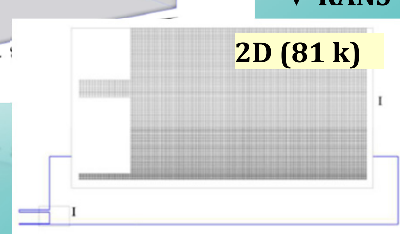
LES/Hybrid vs. RANS



LES/Hybrid ▼



▼ RANS



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Grid

Near-wall region:

- Based on $y^+ < 1$

Core region (Menter 2014):

- Using precursor RANS simulation
- Approximation of integral length scale

$$L = \frac{k^{1.5}}{\varepsilon} = \frac{k^{0.5}}{C_\mu \omega}; C_\mu = 0.09 \qquad \Delta = (V_{\text{cell}})^{1/3}$$

- Based on 80% k_{res} and Kolmogorov spectrum: $\frac{L}{\Delta} > 4.8$
- Plotting contours of and refining where $L/\Delta < 4.8$

	l/l_0	l_0/Δ
$k(l) = 0.1k$ (10%)	6.10	0.33
$k(l) = 0.5k$ (50%)	1.6	1.25
$k(l) = 0.8k$ (80%)	0.42	4.8
$k(l) = 0.9k$ (90%)	0.16	12.5

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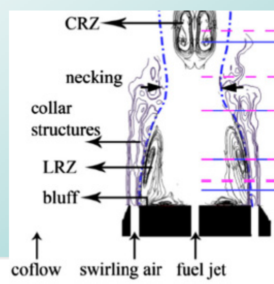
LES quality criteria



Near-wall grid resolution (y^+)

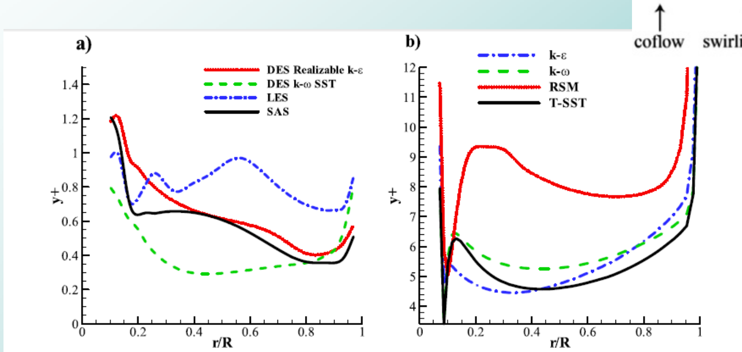


Figure 5. The normalized wall distance, y^+, vs. radial direction at the bluff body wall for (a) 3D LES and hybrid simulations, (b) 2D axisymmetric RANS simulations. $R = 25$ mm is the bluff-body radius.

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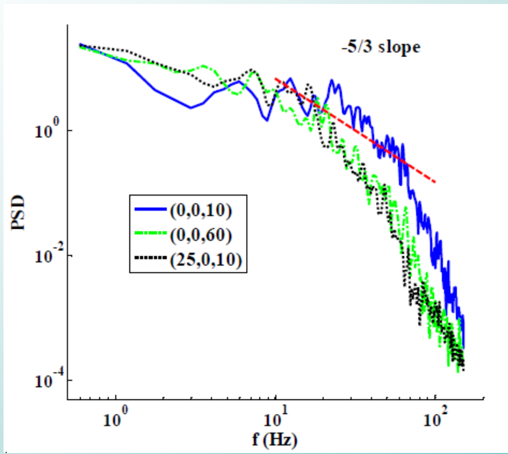
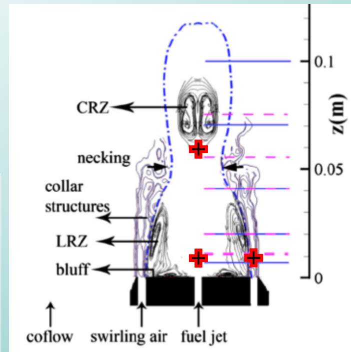
LES quality criteria

Energy spectrum – filter width





◄ The power spectrum density of the velocity versus the frequency at three points (x,y,z): 1) the fuel jet centerline, 2) the centerline within the CRZ, 3) within the swirling shear layer

LES quality criteria

Pope criterion – filter width

$$M = \frac{k_{\text{res}}}{k_{\text{res}} + k_{\text{modeled}}}$$

$$k_{\text{sgs}} = \left(\frac{\mu_{\text{sgs}}}{\rho \Delta C_{\text{DS}}}\right)^2$$

LES quality criteria

Pope criterion – filter width

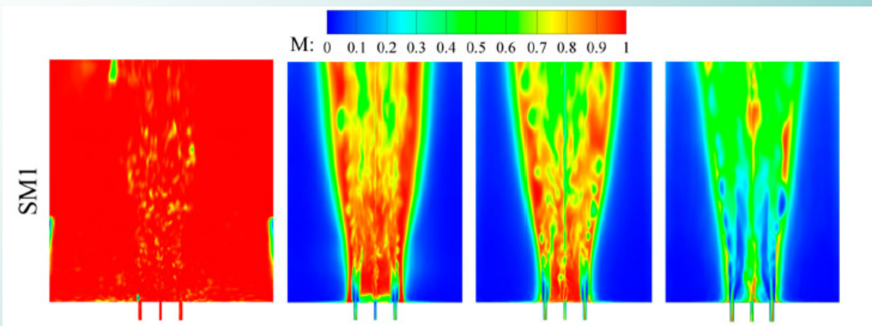


Figure 7. The local resolved-to-total turbulent kinetic energy ratio contours for LES and hybrid simulations of SM1 and SMA2 flames.

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LES quality criteria

Pope criterion – filter width

Table 4. The turbulent kinetic energy ratio, M, for LES and hybrid models.

Case	LES	DES Realizable $k-\varepsilon$	DES SST $k-\omega$	SAS
Non-reactive	0.81	0.73	NA	0.38
SM1	0.84	0.70	0.63	0.44
SMA2	0.81	0.41	0.24	0.21

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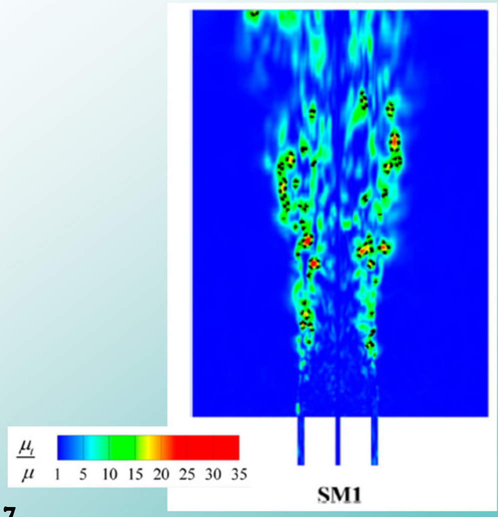
LES quality criteria

Viscosity ratio



◄ The viscosity ratio contours for LES simulations of SM1. The dashed lines indicate the iso-level value of 20.

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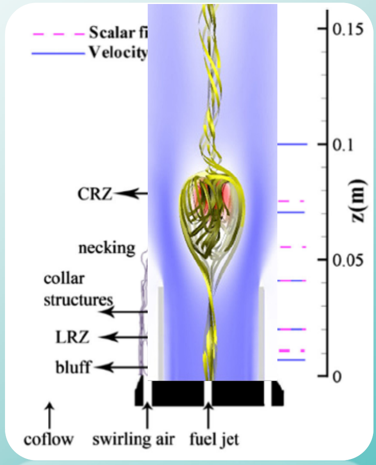
Results

Vortex-Bubble-Breakdown capture



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Results

Vortex-Bubble-Breakdown capture

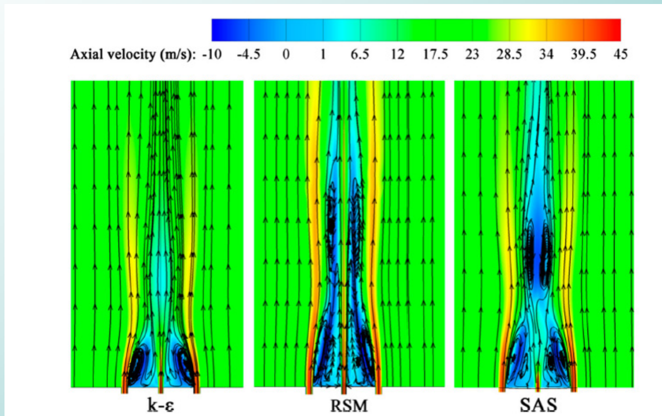

Figure 10. Streamlines and axial velocity contours for $k-\varepsilon$, RSM, and SAS (time-averaged) simulations. Note that $k-\omega$ and T-SST models had the same behavior as $k-\varepsilon$, and LES and DES streamlines were similar to SAS and not shown in this figure.

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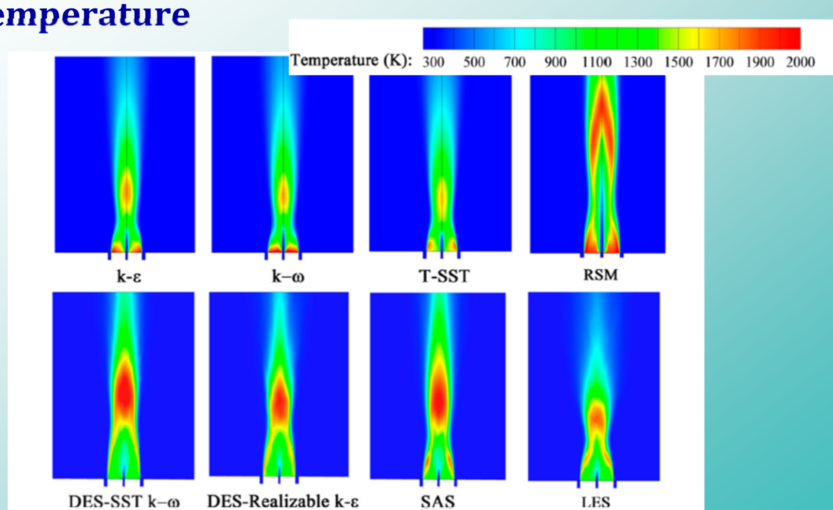
Results

Temperature



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Results

Temperature – unsteady effects

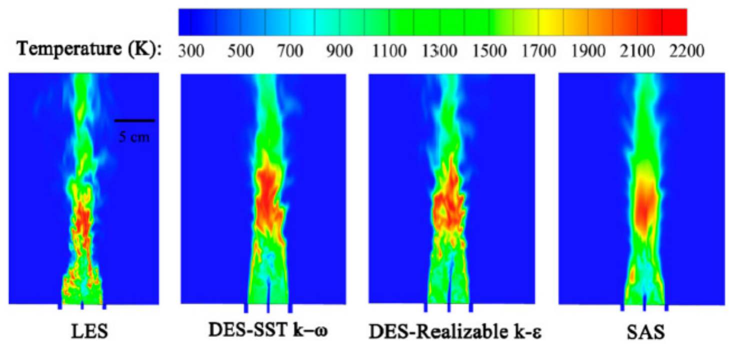

Figure 17. Instantaneous temperature contours on mid-plane for LES, DES, and SAS simulations of SM1 flame.

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