Numerical schemes for simulations turbulent flows using eddy-resolving models and the OpenFoam software package

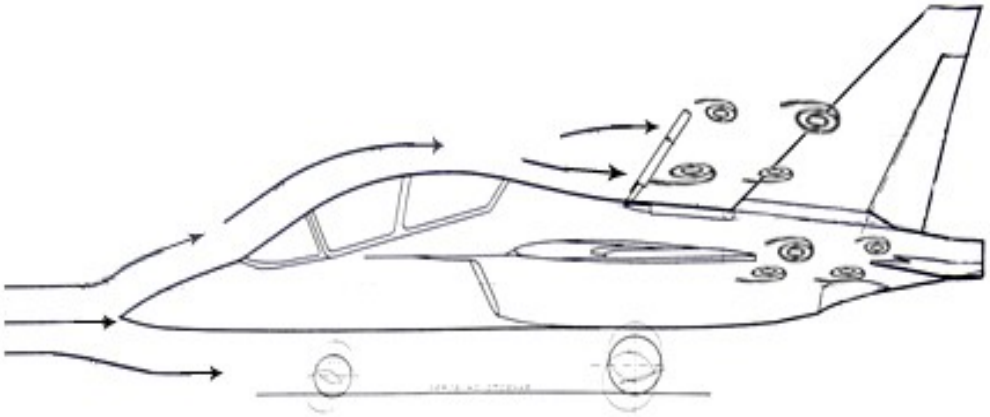
Epikhin A.

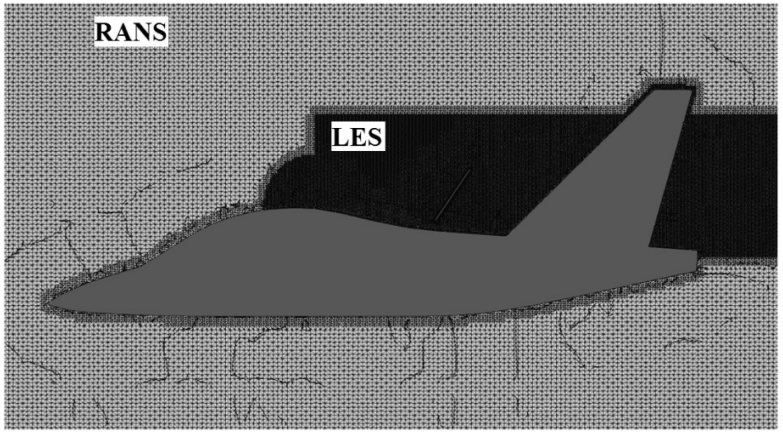
Scientific adviser: doctor of technical science, professor, Kalugin V.

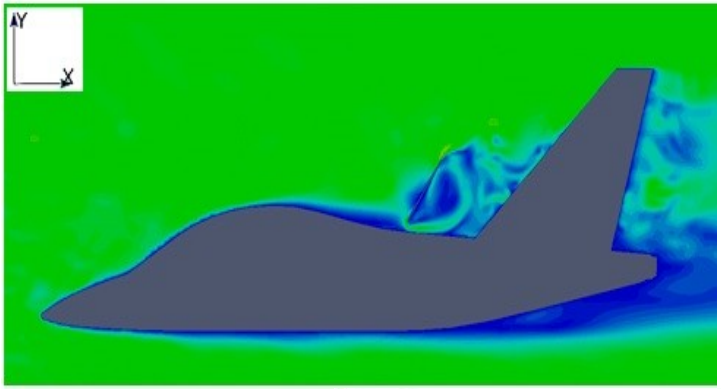
Moscow State Technical University

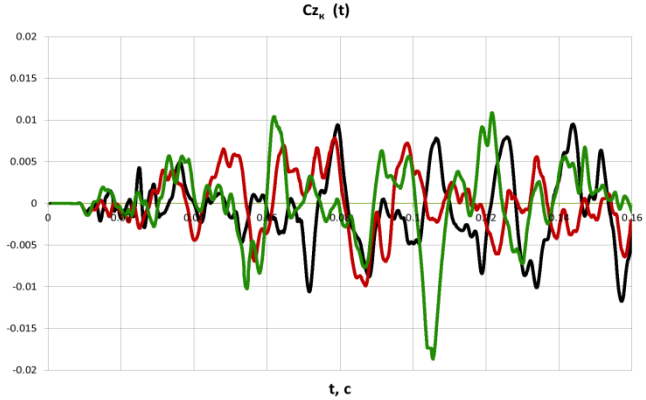
2016

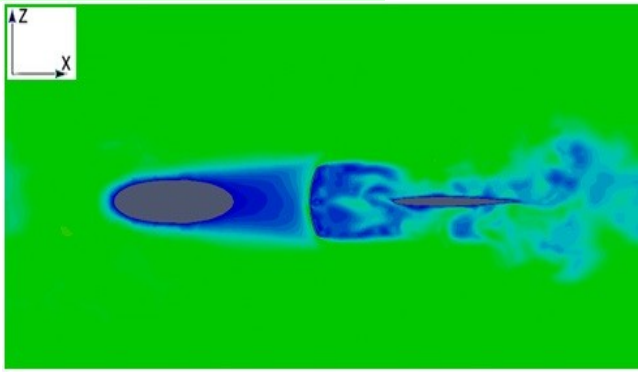
Introduction

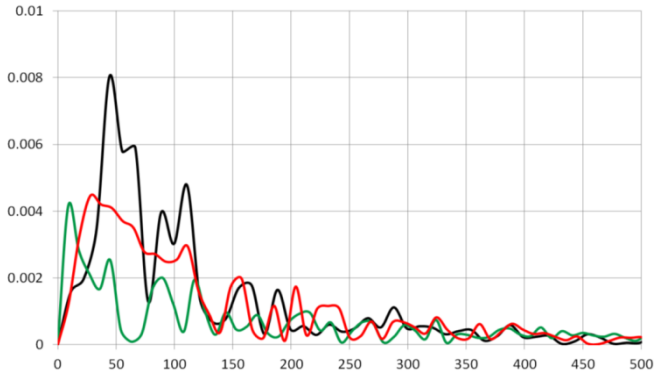






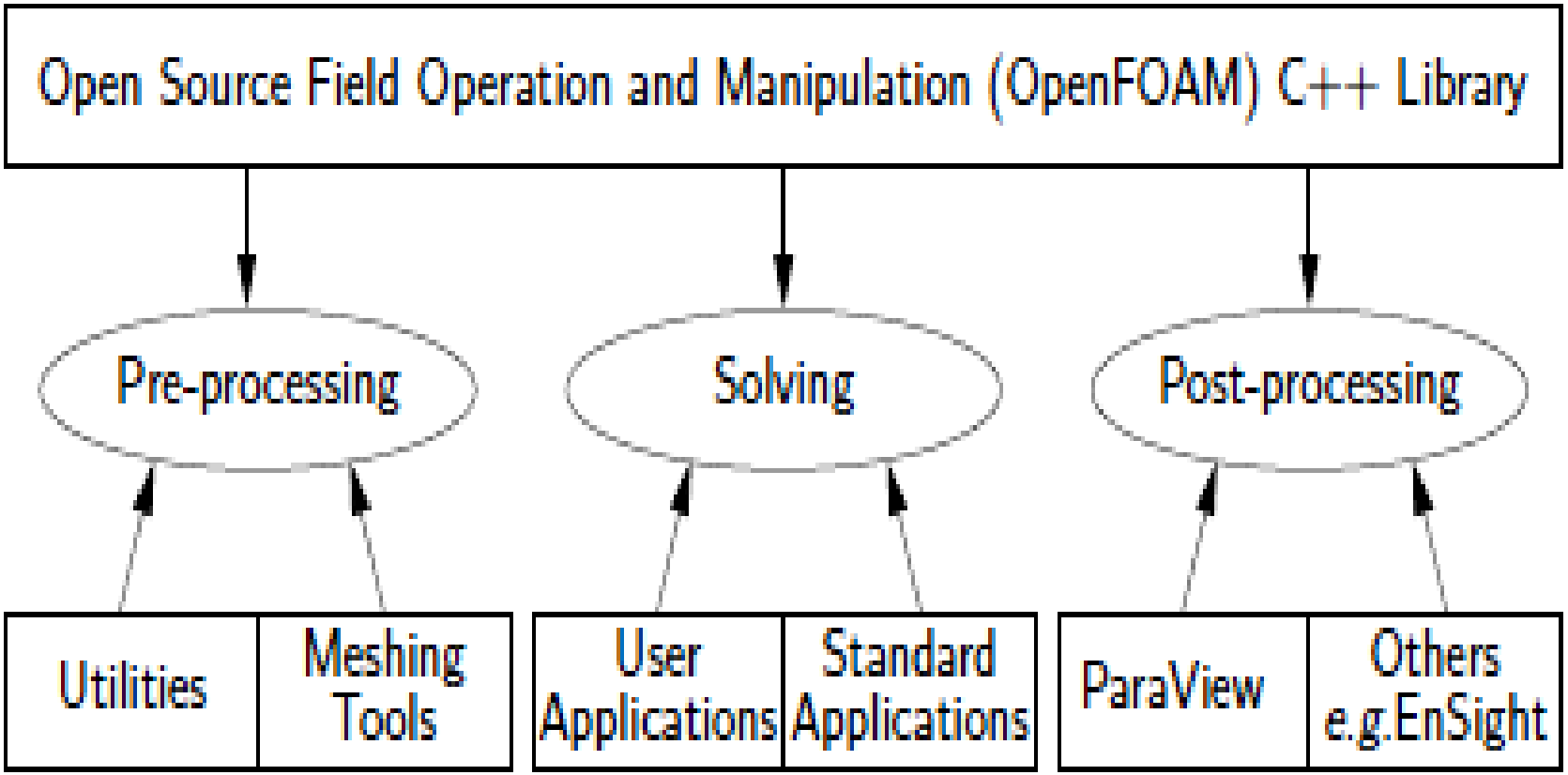




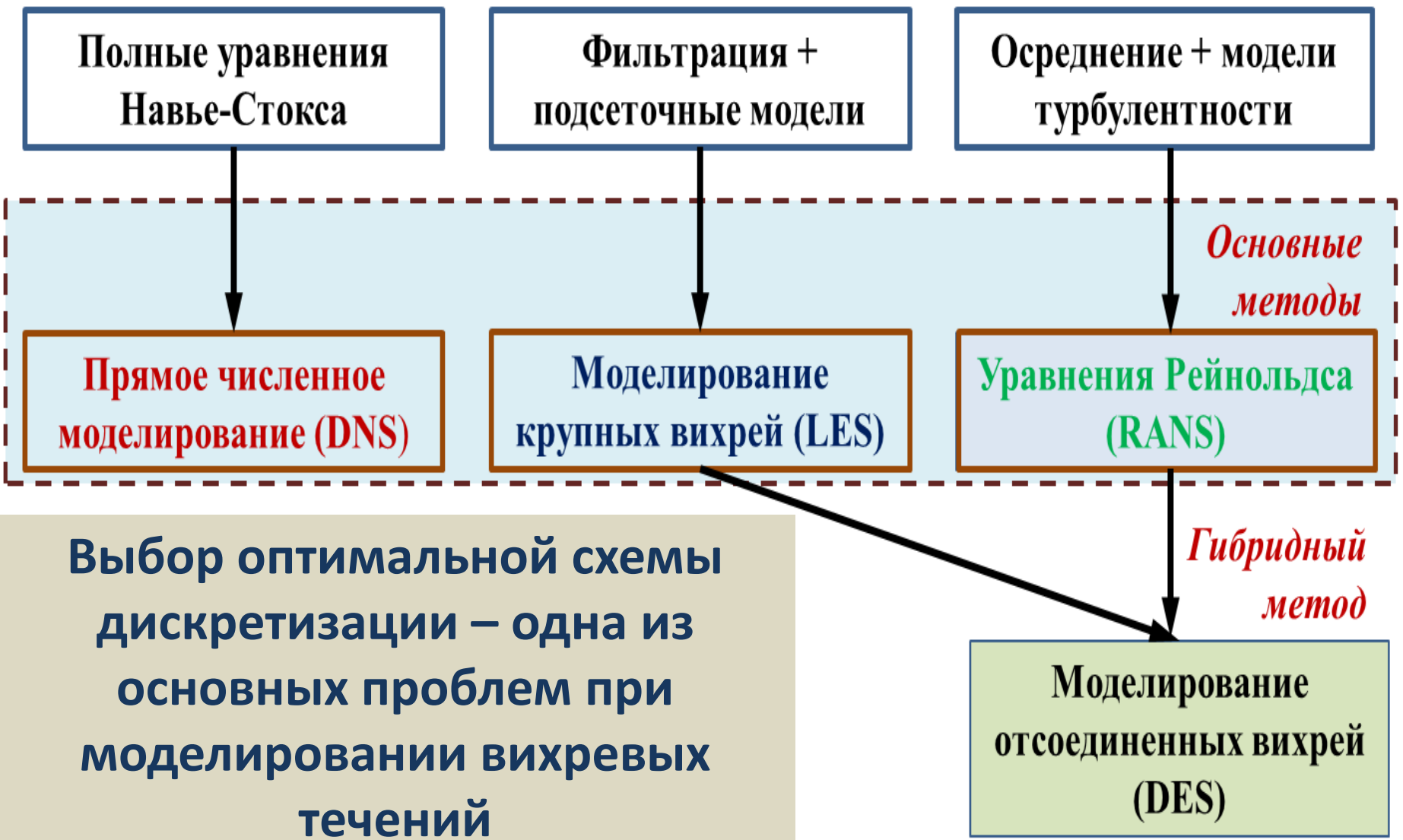


OpenFOAM software package

OpenFOAM is a free, open source CFD software developed primarily by OpenCFD Ltd since 2004. It has a large user base across most areas of engineering and science, from both commercial and academic organisations.



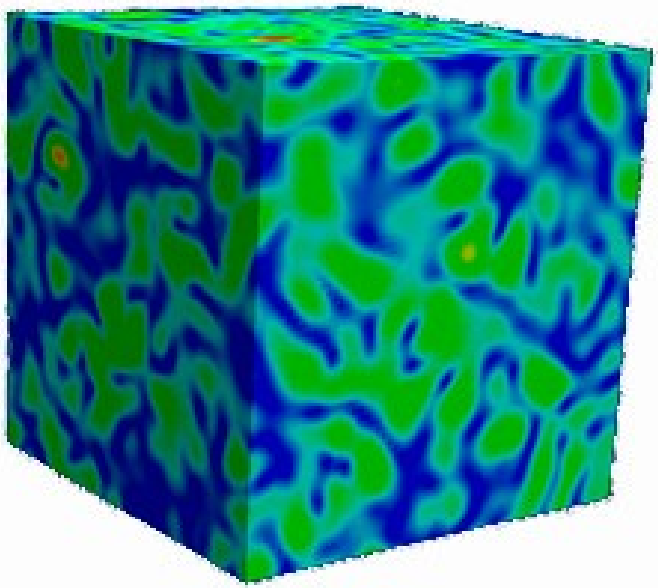
Main approaches for the numerical simulation of turbulent flows



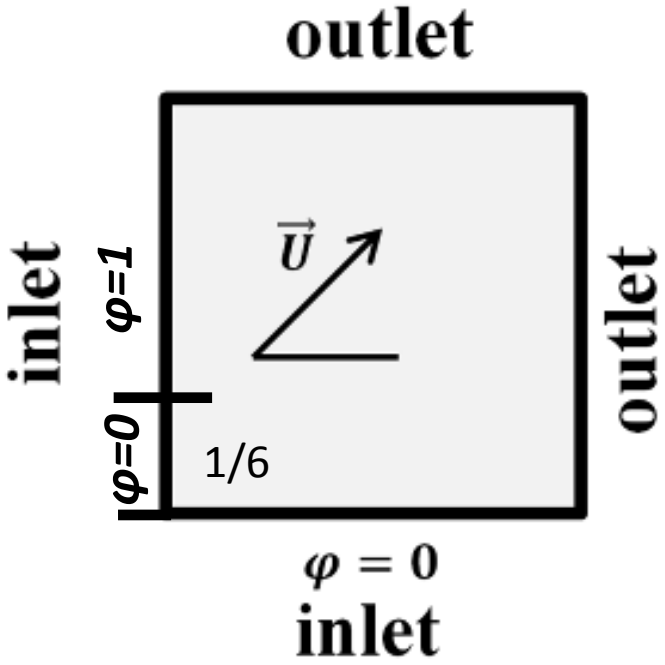
Выбор оптимальной схемы дискретизации – одна из основных проблем при моделировании вихревых течений

Description of test tasks

Decay of Homogeneous Isotropic Turbulence (DIHT)



Scalar transfer (Step profile)



Method:
моделирование крупных вихрей (LES).

Subgrid model:
одного дифференциального уравнения кинетической энергии (**oneEqEddy**); Смагоринского (**Smagorinsky**) с различными константами *Cs.*

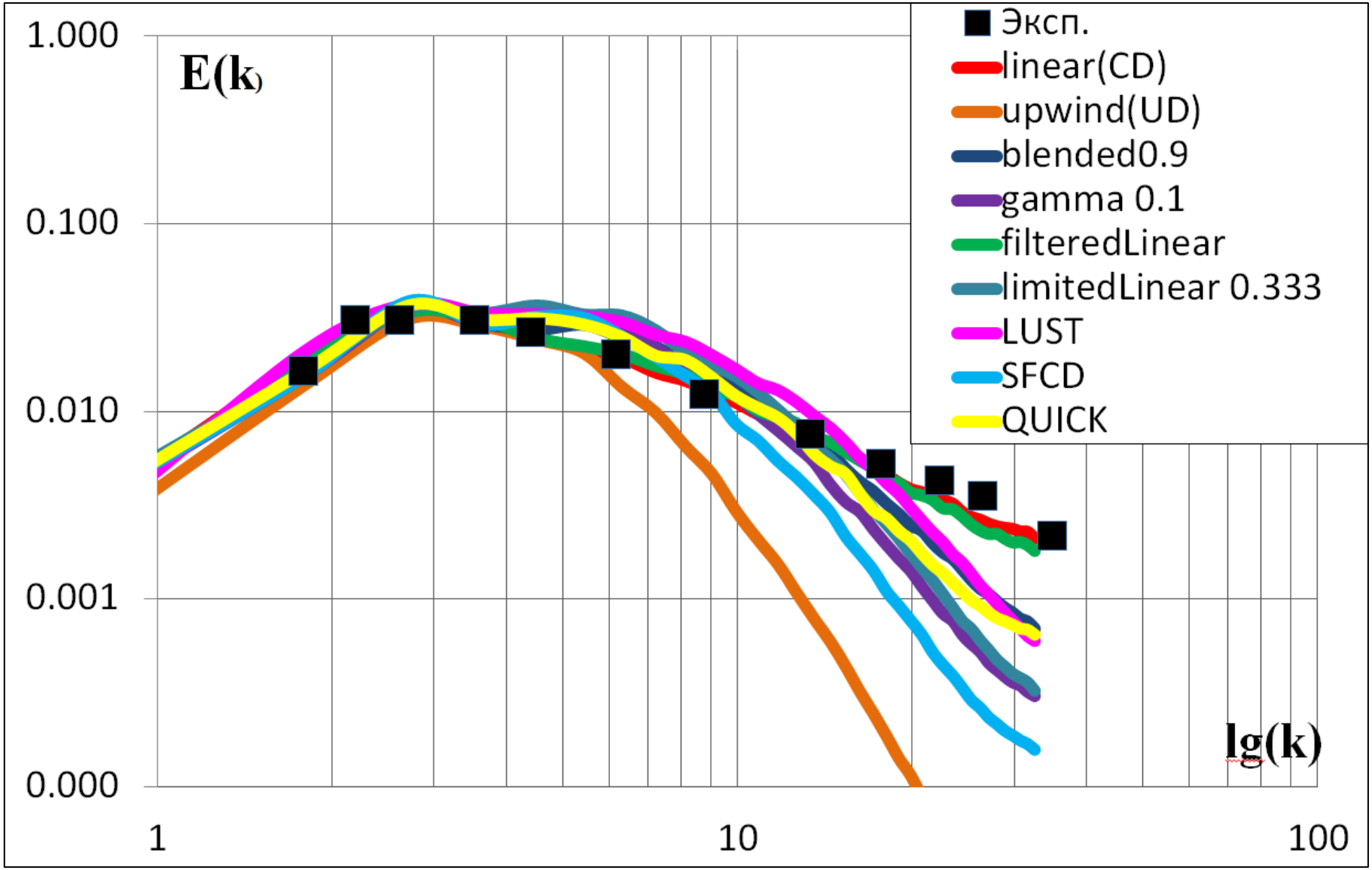
Upwind (UD)	Blended *	SFCD	LimitedLinear * (Sweby limiter)	LUST
Linear (CD)	Gamma *	QUICK	filteredLinear(X) *	Где * - различные варианты параметров схемы

1. Comte-Bellot G., Corrsin S. Simple Eulerian time correlation of full- and narrowband velocity signals in grid-generated “isotropic” turbulence. Journal of Fluid Mechanics, v.48, 1971, pp.273-337.

2. Jasak H., Weller H.G., Gosman A.D. High resolution NVD differencing scheme for arbitrarily unstructured meshes. International journal for numerical methods in fluids, v.31, 1999, pp. 431-449.

Decay of Homogeneous Isotropic Turbulence (DIHT)

Модель одного дифференциального уравнения (OneEqEddy):



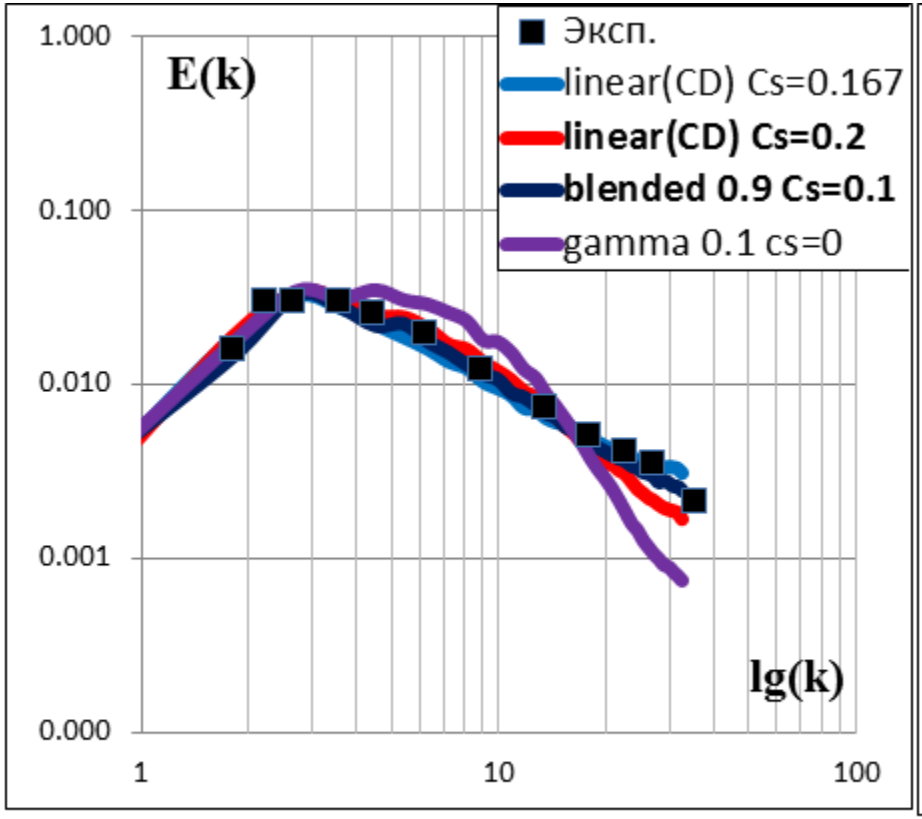
Модель Смагоринского (Smagorinskv model):

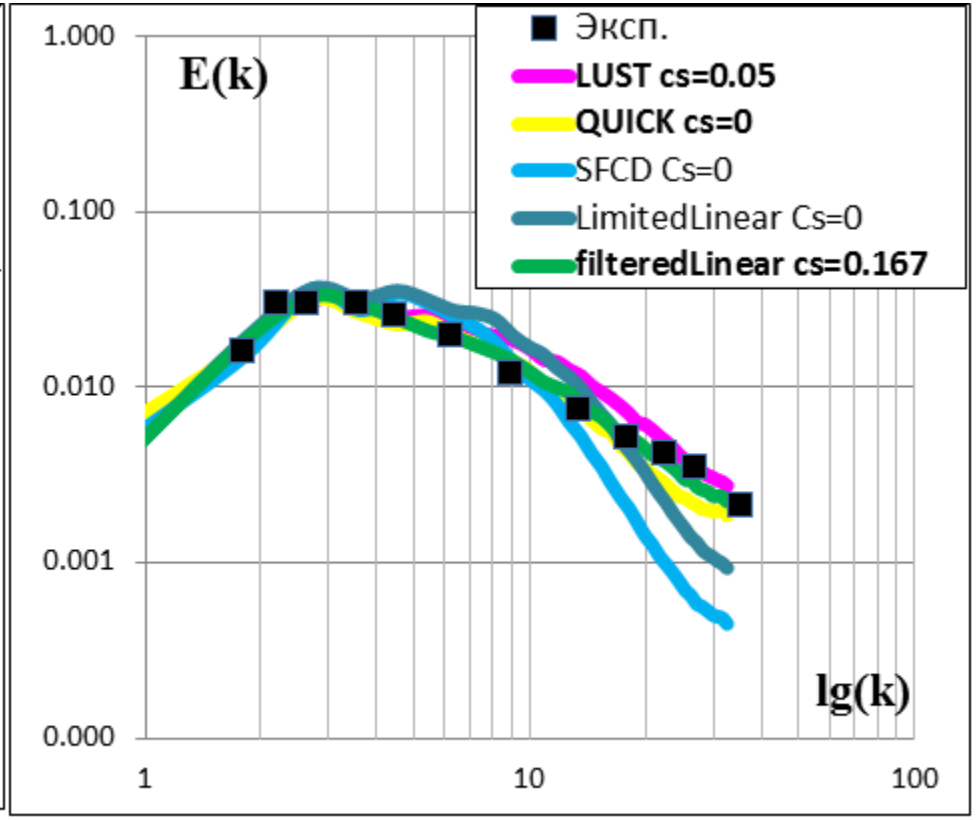
$$\vartheta_{sgs} = (C_s \cdot \Delta)^2 \cdot |\overline{S}| = C_k \cdot \Delta \cdot \sqrt{K} \qquad K = (C_I \cdot \Delta)^2 \cdot |\overline{S}|^2 = \frac{2C_k}{C_\varepsilon} \cdot \Delta^2 \cdot |\overline{S}|^2$$

$$C_s = \sqrt{C_k \cdot \sqrt{\frac{C_k}{C_\varepsilon}}}$$

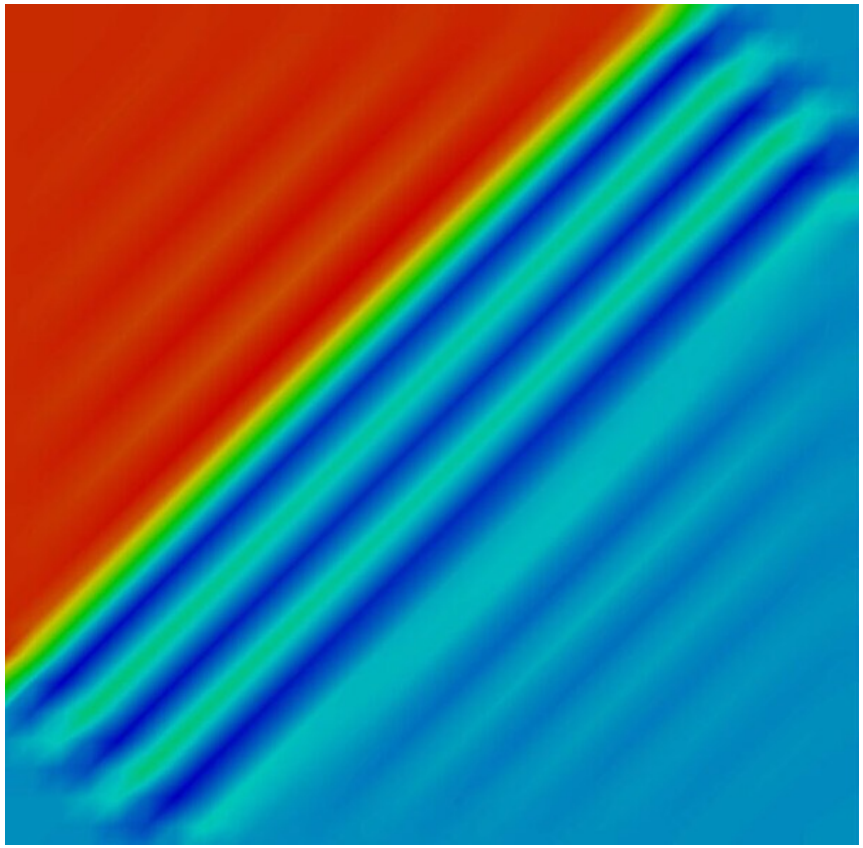
По умолчанию в OpenFOAM :

$$C_k = 0.094;\ C_\varepsilon = 1.05 \Rightarrow\gg\ C_s = 0.167$$

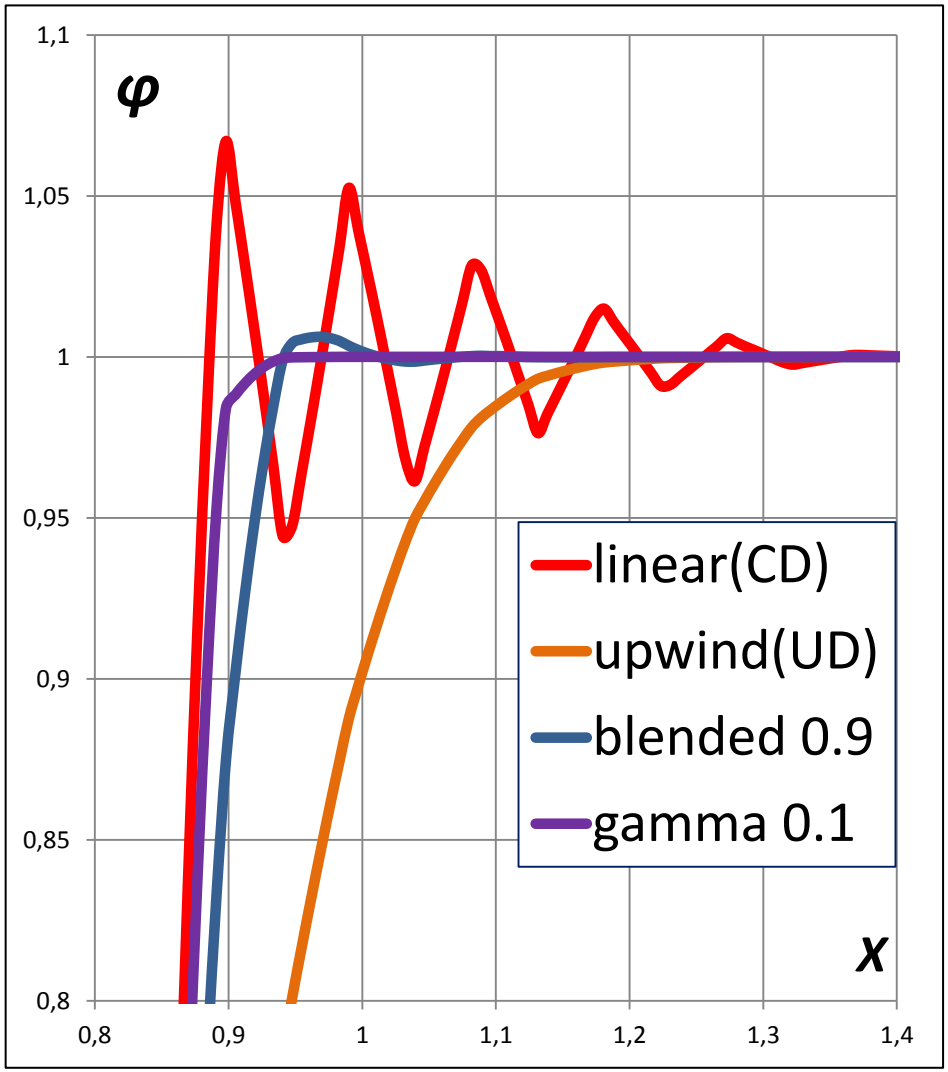




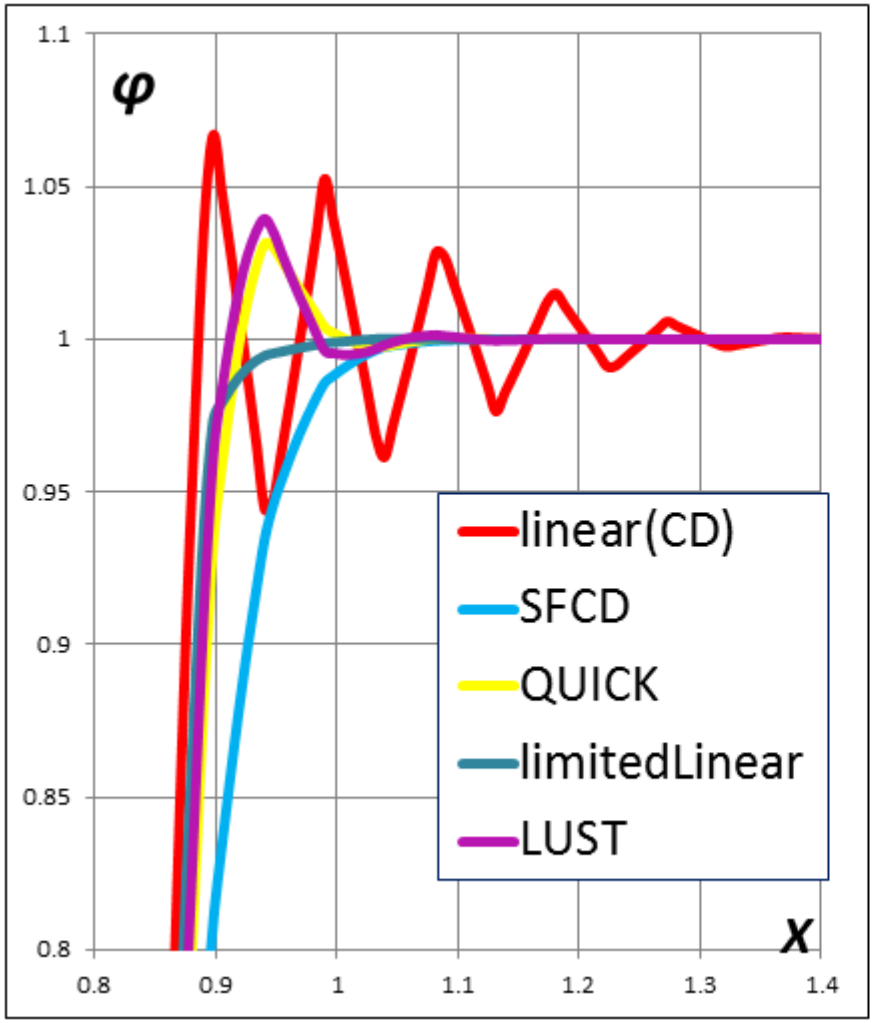
Scalar transfer task

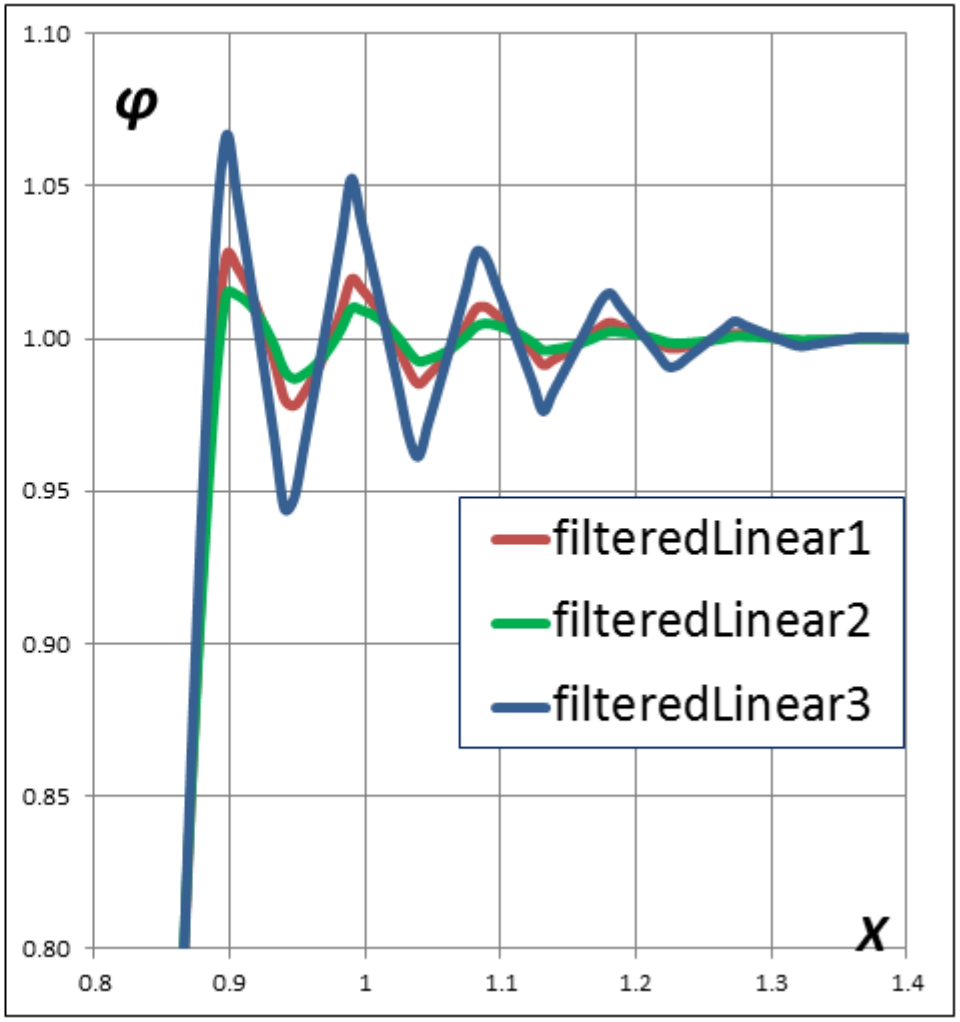


Поле распределения скаляра ϕ при использовании схемы linear (CD)



Convection of a step profile





Противопоточные схемы слишком диссипативны

Схемы на основе центрально разностной схемы 2 порядка - неустойчивы

Modification numerical schemes

Gamma:

$$\begin{cases} \varphi_k \leq 0 \ \cup \varphi_k \geq 1 \ - upwind \\ \gamma \leq \varphi_k < 1 \ - linear\ (CD) \\ 0 < \varphi_k < \gamma \ - blended \end{cases}$$

OpenFOAM

$$\begin{cases} \varphi_k = 1 - \dfrac{\varphi_N - \varphi_P}{2\nabla\varphi_P d} \\ \min\left(\max\left(\dfrac{\varphi_k}{\boldsymbol{\gamma}}, 0\right), 1\right) \end{cases}$$

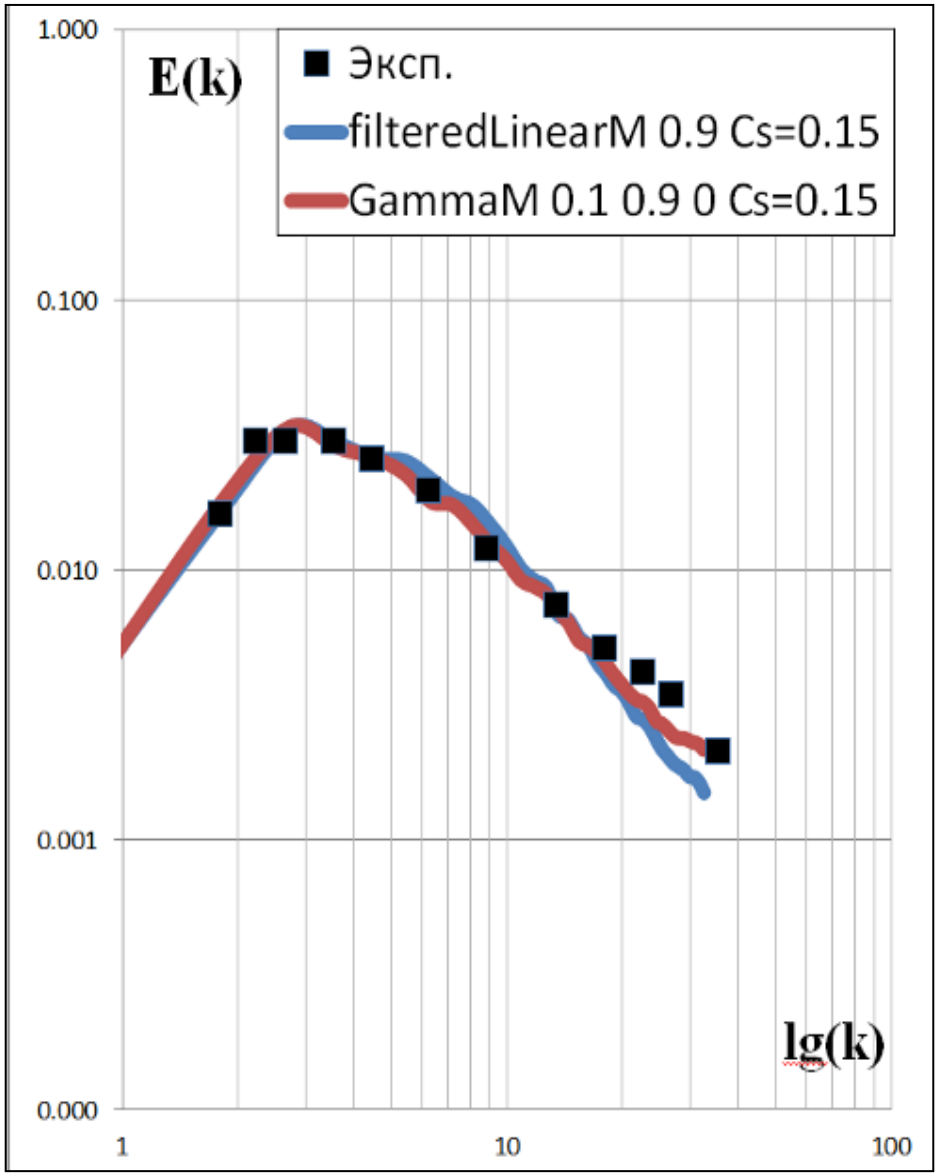
$$\begin{cases} \varphi_k \leq 0 \ - \boldsymbol{\beta}\ (blended) \\ \varphi_k \geq 1 \ - 1\ (linear\ (CD)) \\ \gamma \leq \varphi_k < 1 \ - 1\ (linear\ (CD)) \\ 0 < \varphi_k < \gamma \ - \min\left(\max\left(\dfrac{\varphi_k}{\boldsymbol{\gamma}}, \boldsymbol{\delta}\right), 1\right) - blended \end{cases}$$

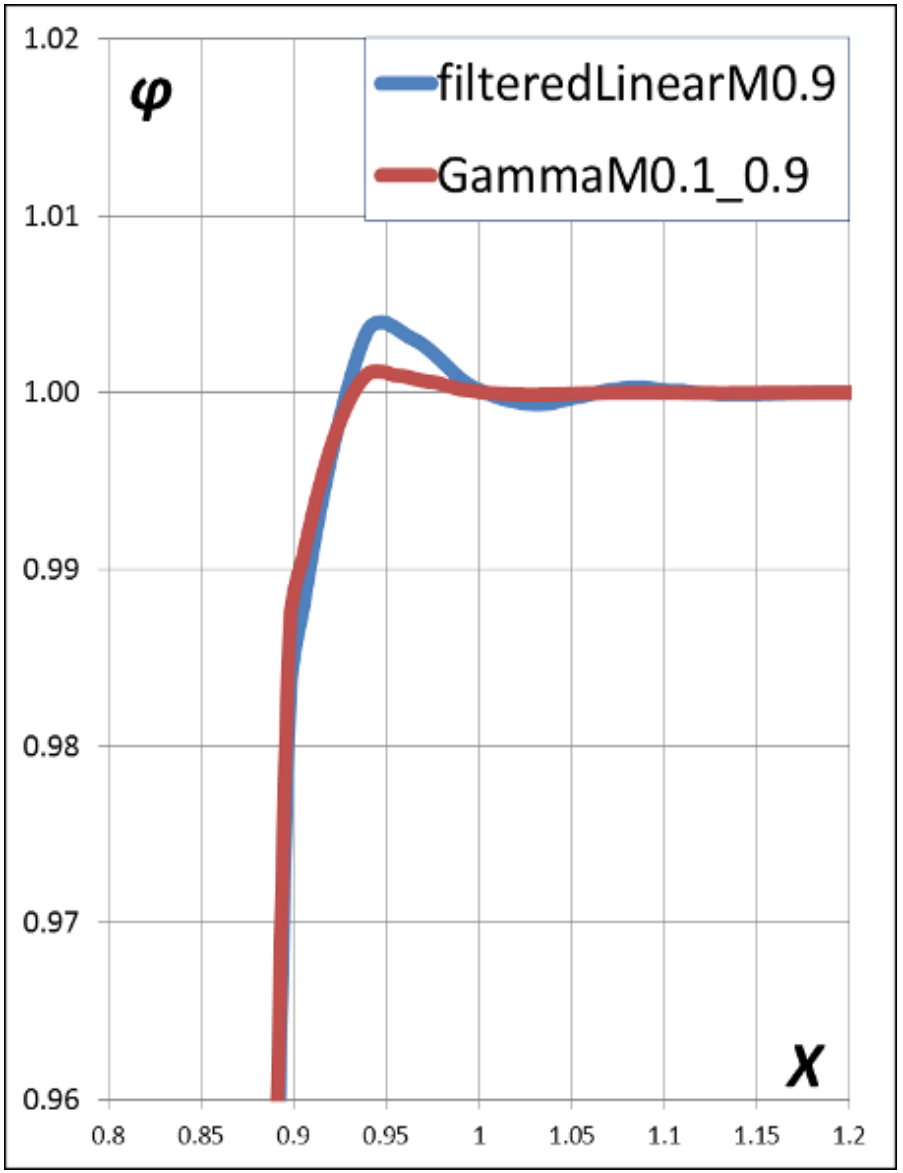
filteredLinear:

$$\begin{cases} limiter = 2 - 0.5\dfrac{\min(mag(\varphi_N - \varphi_P - \nabla\varphi_P d), mag(\varphi_N - \varphi_P - \nabla\varphi_N d))}{max(mag(\varphi_N - \varphi_P - \nabla\varphi_P d), mag(\varphi_N - \varphi_P - \nabla\varphi_N d))} \\ \max(\min(limiter, 1), 0.8) \end{cases}$$

$$\begin{cases} limiter = \mathbf{1} - 0.5\dfrac{\min(mag(\varphi_N - \varphi_P - \nabla\varphi_P d), mag(\varphi_N - \varphi_P - \nabla\varphi_N d))}{max(mag(\varphi_N - \varphi_P - \nabla\varphi_P d), mag(\varphi_N - \varphi_P - \nabla\varphi_N d))} \\ \max(\min(limiter, 1), \boldsymbol{\beta}) \end{cases}$$

Results


E(k)
Эксп.
filteredLinearM 0.9 Cs=0.15
GammaM 0.1 0.9 0 Cs=0.15
1.000
0.100
0.010
0.001
0.000
1
10
100
lg(k)

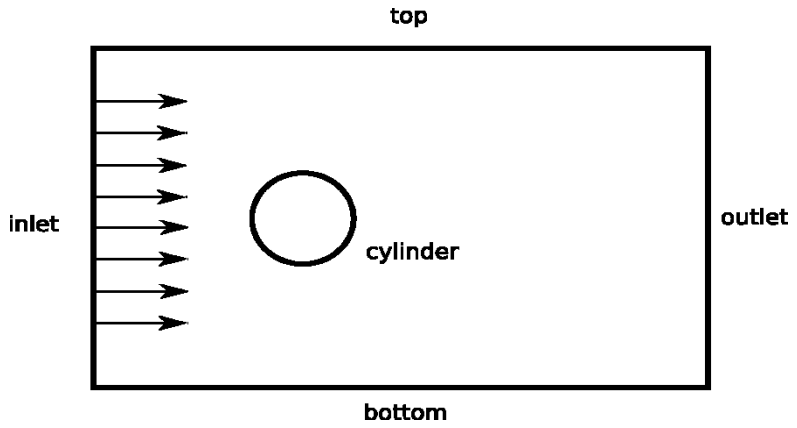

φ
filteredLinearM0.9
GammaM0.1_0.9
1.02
1.01
1.00
0.99
0.98
0.97
0.96
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
X

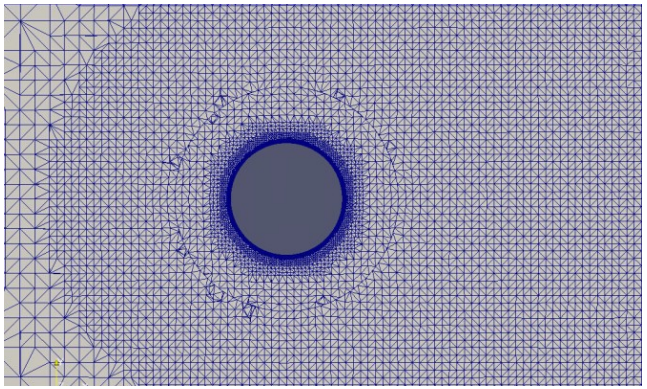
Flowfield around 1 cylinder

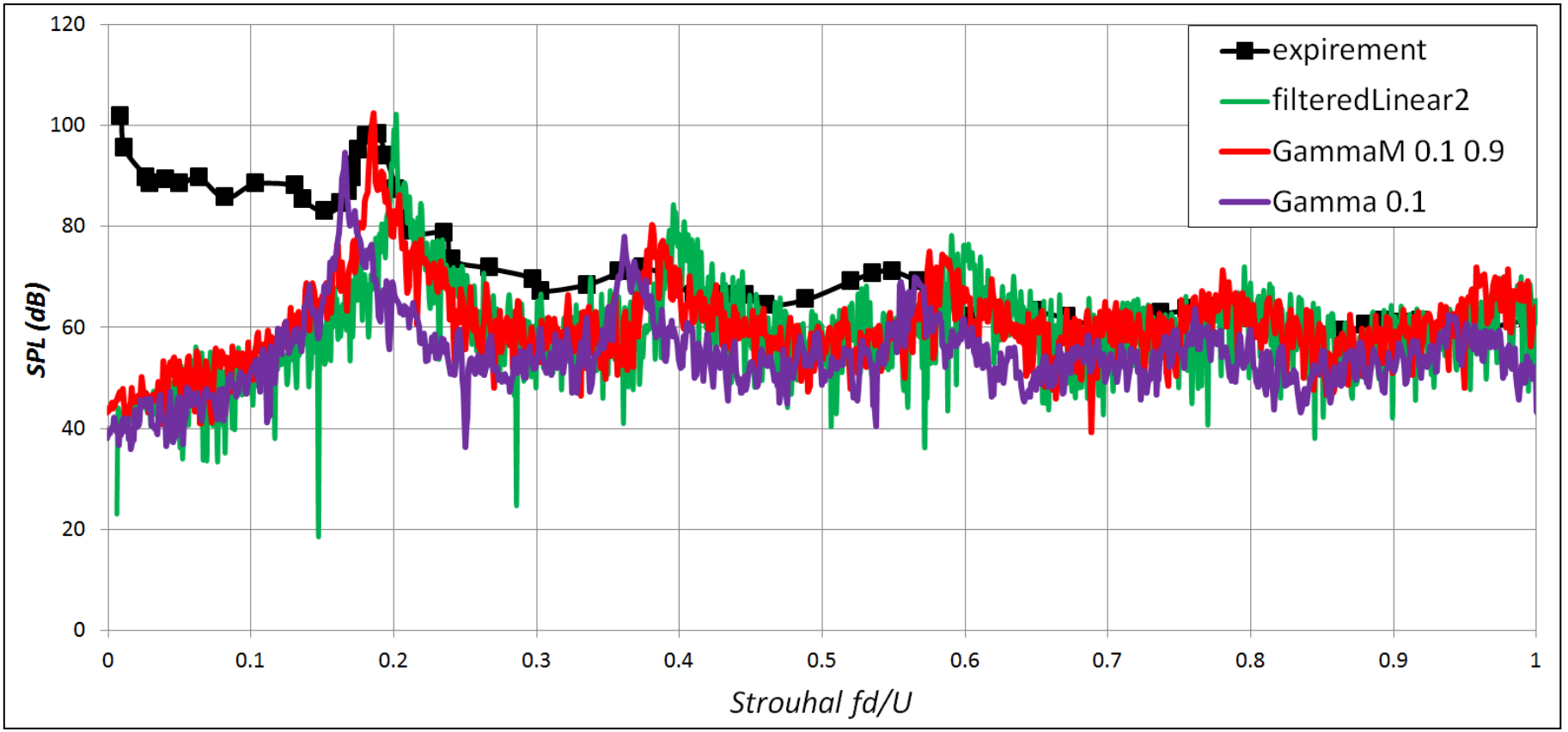
Re = 90000;

D = 0.019 м;

M = 0.2;







Questions?