Advanced Unsteady Turbulence Models in ANSYS CFD

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Motivation for UTM: A Survey of the Models and Their Development

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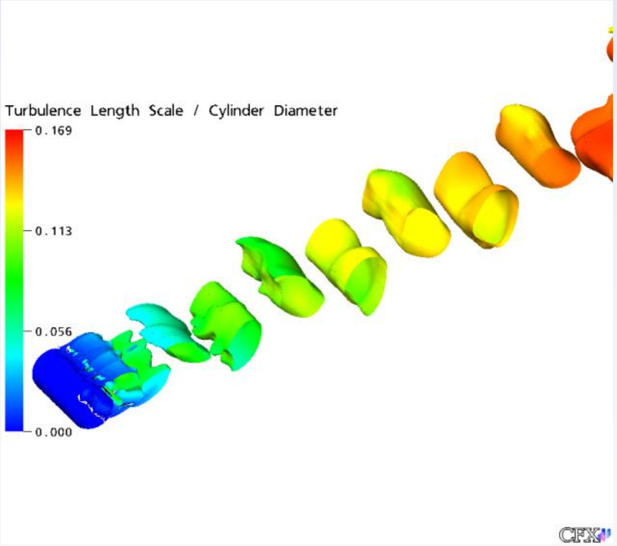
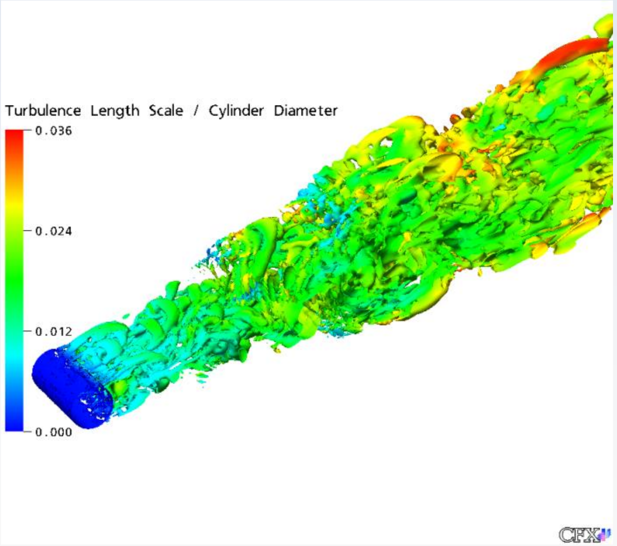
Applications Requiring Unsteady Turbulence Models (UTM)

- **Some applications need explicit computation of unsteady fields**
  - Bluff body aerodynamics
  - Aerodynamically generated noise (sound)
  - Fluid-structure interaction
  - Combustion Processes and Combustion instabilities
- **URANS with good turbulence models can occasionally predict vortex shedding, i.e. largest unsteady scales**
  - URANS often falls short of capturing the remaining large scales

URANS with SST k-w model



Scale-Resolving Simulation



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Spectrum of Models Available

- **ANSYS CFD offers a hierarchy of UT Models**
  - – URANS
  - – Scale Adaptive Simulation
    - Available in ANSYS CFX
    - Beta in ANSYS FLUENT 12.1 – Fully available in R13
  - – Detached Eddy Simulation
    - Available in ANSYS CFX and ANSYS FLUENT
  - – Zonal RANS-LES models
    - Available in ANSYS CFX and ANSYS FLUENT R13
  - – Large Eddy Simulation
    - Available in ANSYS CFX and ANSYS FLUENT
  - – Direct Numerical Simulation
    - Restricted to Low Re flows (no models needed)

Industrial Applications

R&D

Research

Increased grid requirement and computational cost

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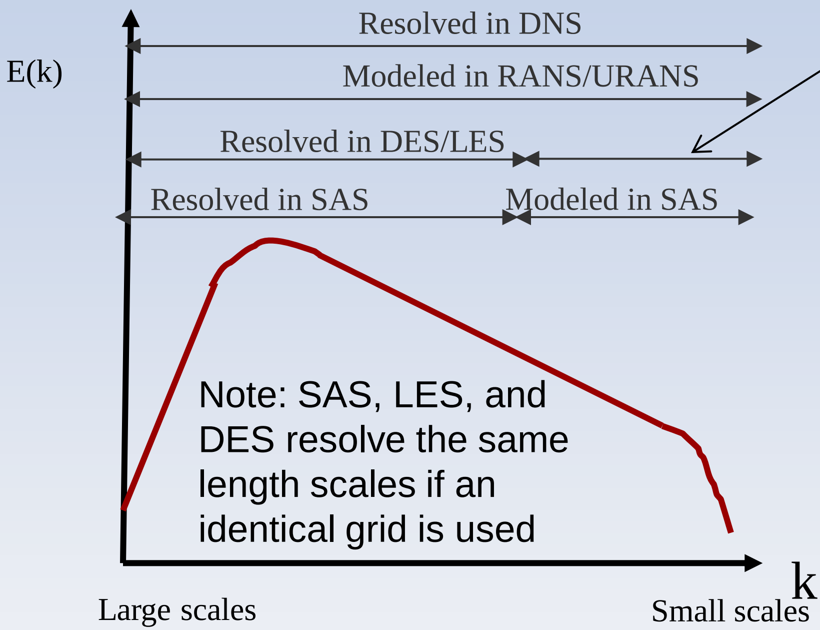
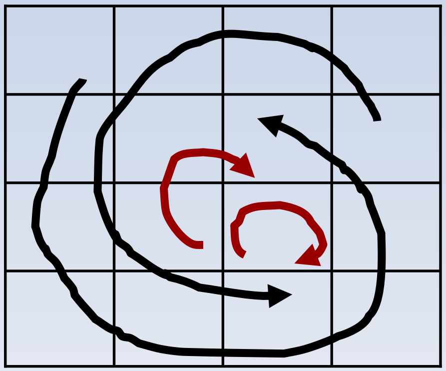
Space and Time Resolution of Different Turbulence Models

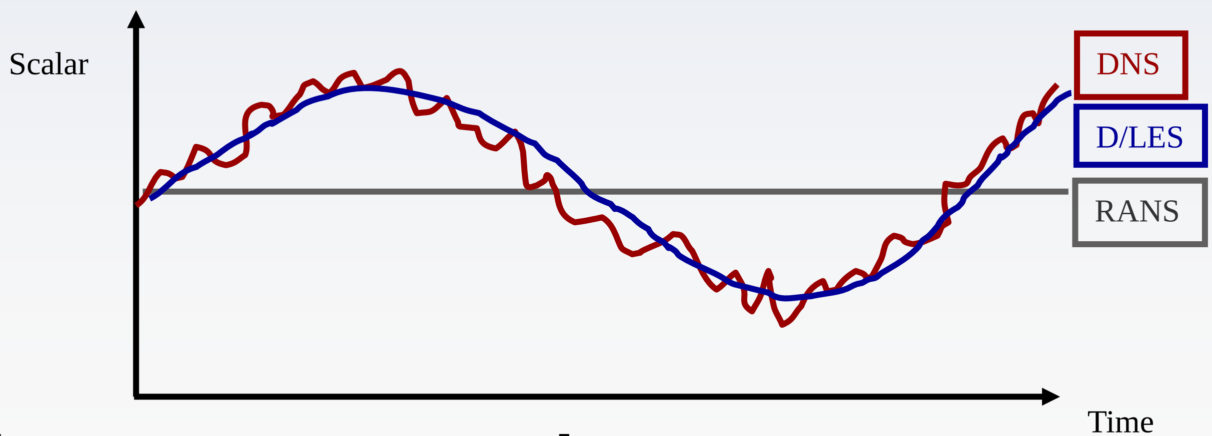
Turbulent Flows = large range of length and time scales





For High Reynolds flows, all eddies can not be resolved

– **Large eddies** (geometry specific behavior) can be resolved
– **Small eddies** can be modeled ('universal' behavior)



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Eddy Viscosity Model (EVM) Concept

- Averaged Navier-Stokes (RANS/LES) Equations with Eddy Viscosity:

$$\frac{\partial(\overline{U}_i)}{\partial t}+\frac{\partial(\overline{U}_j\overline{U}_i)}{\partial x_j}=-\frac{1}{\rho}\frac{\partial\overline{P}}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\left(\nu+\nu_t\right)\left(\frac{\partial\overline{U}_i}{\partial x_j}+\frac{\partial\overline{U}_j}{\partial x_i}\right)\right]$$

- **Formally (U)RANS and LES equations are derived differently:**
  - **(U)RANS – Reynolds averaging**
  - **LES – Filtering of equations in space**
- **The effective difference between (U)RANS and LES is the size of the eddy viscosity**
- **Practically the equations are modeled the same way – using EVM**
- **Only for this reason are “hybrid” models (DES etc.) possible**

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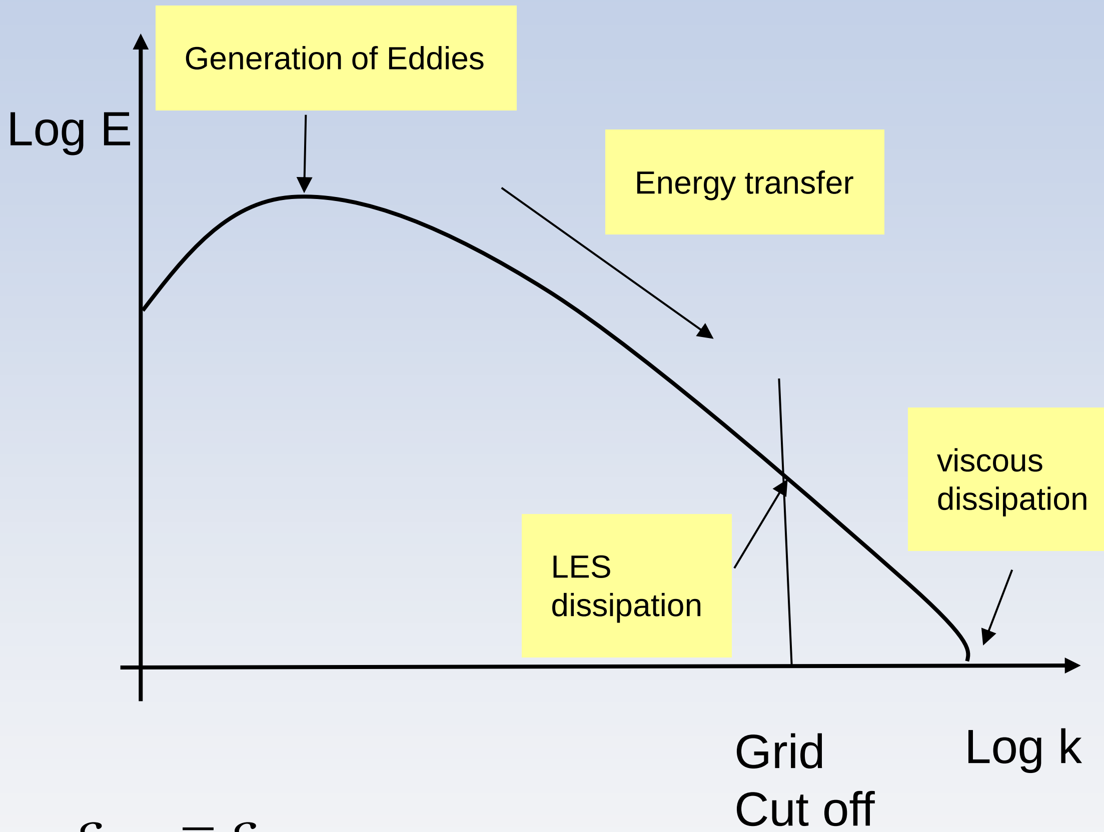
Effect of LES Model

- **Role of LES model:**
  - **Eddies cannot be resolved down to the molecular dissipation limit**
  - **Dissipation of turbulent kinetic energy at grid-resolution limit requires eddy viscosity**
  - **Arguably the only function that LES models perform**
  - **This means that all relevant scales have to be resolved properly**



$$\varepsilon_{LES} = \varepsilon_{DNS}$$

$$\varepsilon_{DNS} = \nu \frac{\partial u_i}{\partial x_j} \frac{\partial u_i}{\partial x_j} \qquad \varepsilon_{LES} = \nu_t^{LES} \frac{\partial \hat{u}_i}{\partial x_j} \frac{\partial \hat{u}_i}{\partial x_j} \qquad \frac{\nu_{LES}}{\nu} = \frac{\partial u_i / \partial x_j \cdot \partial u_i / \partial x_j}{\partial \hat{u}_i / \partial x_j \cdot \partial \hat{u}_i / \partial x_j} >> 1$$

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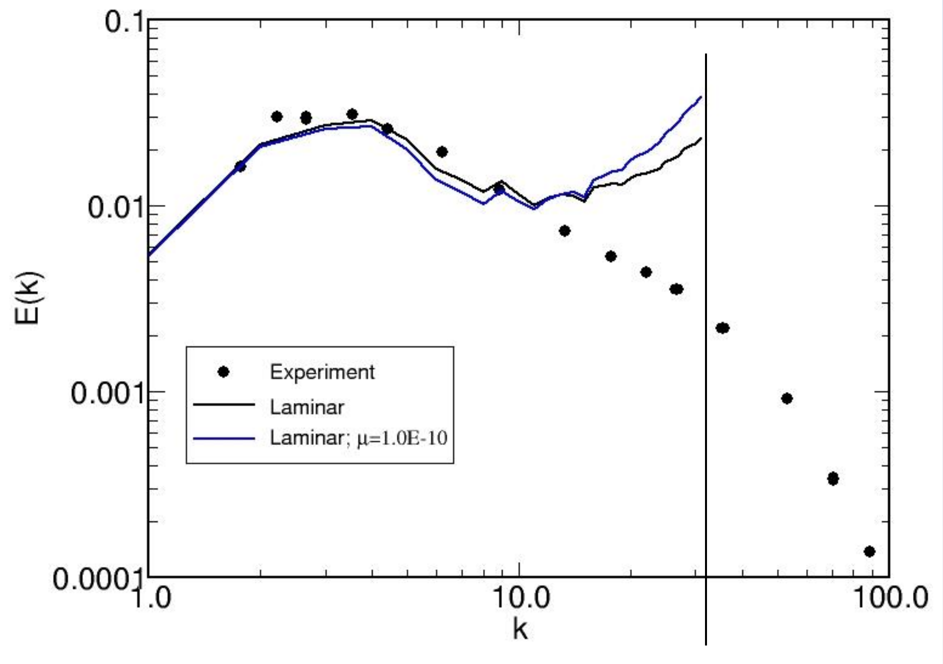
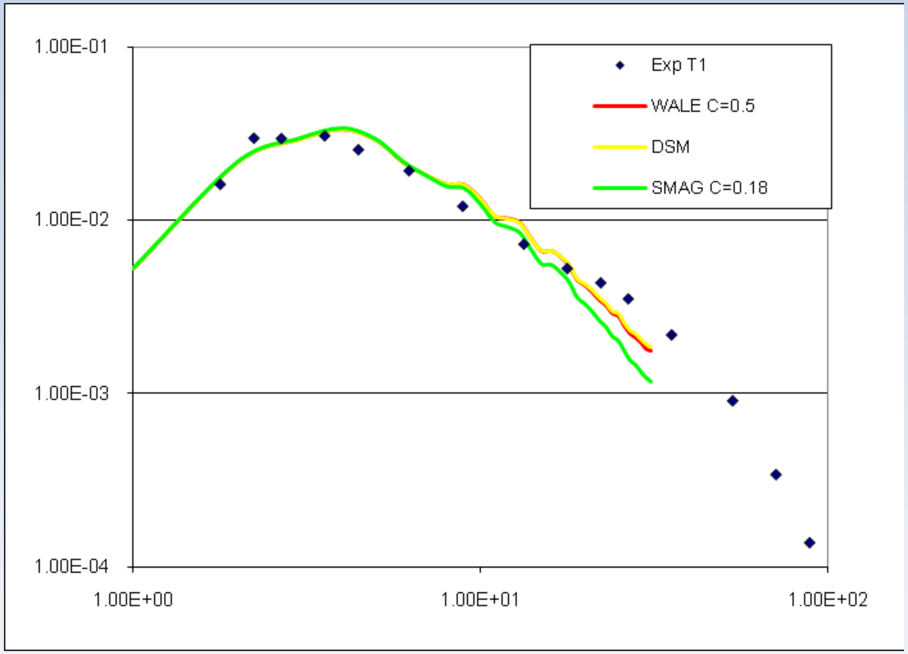
Decaying Isotropic Turbulence

No LES Model



With LES Model



Grid size cutoff

- **Without LES model energy is accumulated at small scales (large wave number *k*)**
- **With LES models, energy is dissipated at grid resolution limit**

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LES Concept

	RANS	LES
Large Eddies	Modeled	Resolved
Small Eddies	Modeled	Dissiipation Modeled
Filtering	Time	Space
Length Scale	Integral length scales	Grid size
K	Turbulent Kinetic Energy	SUBGRID Turbulent Kinetic Energy

ANSYS CFD offers several eddy viscosity sub-grid scale models

- Smagorinsky-Lilly model
- Wall-Adapting Local Eddy-Viscosity (WALE) model
- Dynamic Smagorinsky-Lilly model
- Dynamic Kinetic Energy Transport model

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Description of the LES Models

- **Smagorinsky-Lilly Model**
  – Simple algebraic (0-equation) model
  – Model relies on a local equilibrium of the sub-grid scales
  – Difficulty with transitional (laminar) flows
  – An *ad hoc* damping is needed in near-wall region
- **Wall-Adapting Local Eddy-Viscosity (WALE) model**
  – Algebraic (0-equation) model **–** retains the simplicity of Smagorinsky's model
  – Wall damping effects are accounted for without using the damping function explicitly
- **Dynamic Smagorinsky-Lilly Model**
  – Based on the similarity concept and Germano's identity
  – Assumes local equilibrium of sub-grid scales, scale similarity between the smallest resolved scales and the sub-grid scales
  – The model parameter C_s is automatically adjusted using the resolved velocity field
- **Dynamic Kinetic Energy Transport**
  – Transport equation for sub-grid scale kinetic energy allows for history and non-equilibrium effects
  – Like the dynamic Sgamorinsky's model, the model constants (C_k, C_ε) are automatically adjusted on-the-fly using the resolved velocity field

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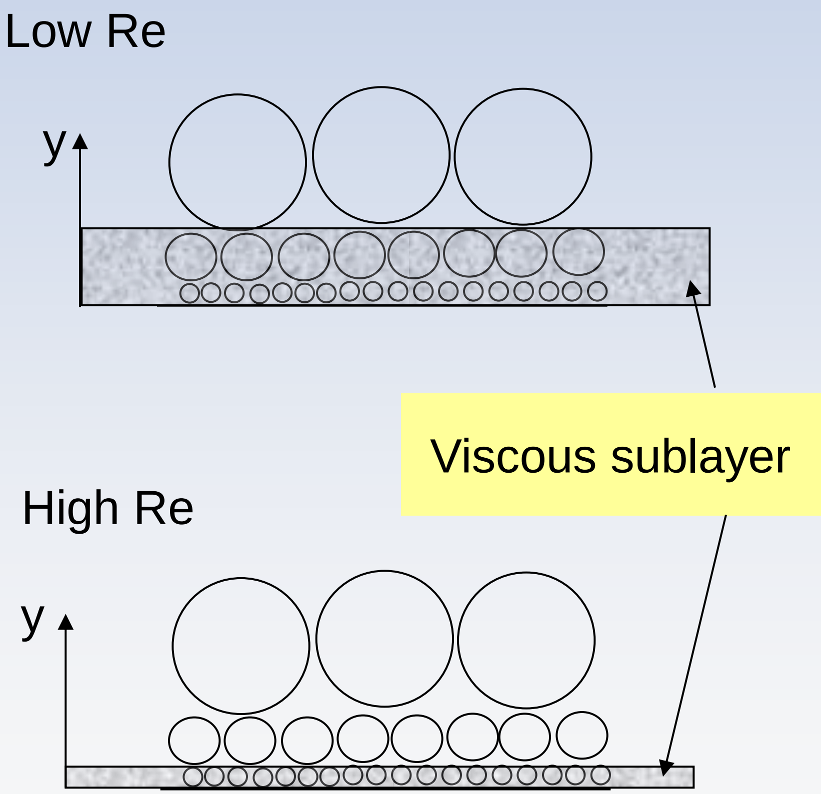
LES Problem: Near Wall Scaling

- Turbulent length scale is independent of Re number
- However thickness of viscous sub layer decreases with increasing Re number
- Turbulent structures inside sublayer are damped out
- Smaller turbulence structures near the wall get “exposed” as Re increases
- Solution is to model small near wall structures with RANS and only resolve larger structures – less dependent on Re number

$$L_t = \kappa y$$



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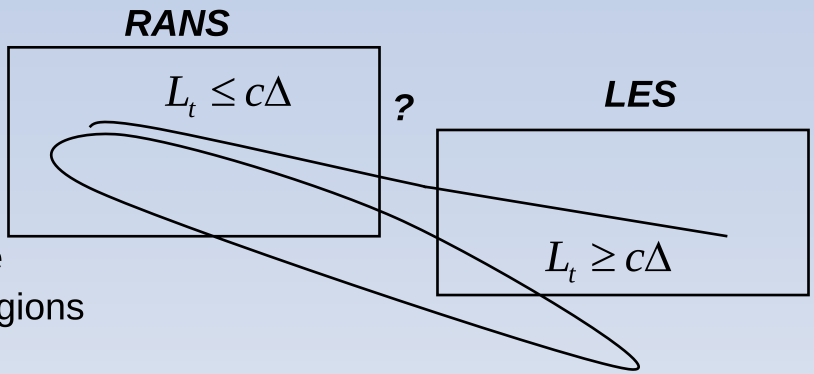
Hybrid Models: Detached Eddy Simulation (DES)



- **Hybrid Model:**
  - RANS equations in boundary layer
  - LES „ detached “ regions
- **Switch of model**
  - Based on ratio of turbulent length-scale to grid size
  - Different numerical treatment in RANS and LES regions

- **k-equation RANS**

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho \bar{U}_j k)}{\partial x_j} = P_k - \rho \frac{k^{3/2}}{L_t} + \frac{\partial}{\partial x_j}\left[(\mu + \frac{\mu_t}{\tilde{\sigma}_\kappa})\frac{\partial k}{\partial x_j}\right] \qquad L_t = \frac{\sqrt{k}}{\beta^* \omega}$$

- **k-equation LES**

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho \bar{U}_j k)}{\partial x_j} = P_k - \rho \frac{k^{3/2}}{C_{DES}\Delta} + \frac{\partial}{\partial x_j}\left[(\mu + \frac{\mu_t}{\tilde{\sigma}_\kappa})\frac{\partial k}{\partial x_j}\right] \qquad \Delta = \max(\Delta x, \Delta y, \Delta z)$$

- **k-equation DES**

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho \bar{U}_j k)}{\partial x_j} = P_k - \rho \frac{k^{3/2}}{\min\left(L_t; C_{DES}\Delta\right)} + \frac{\partial}{\partial x_j}\left[(\mu + \frac{\mu_t}{\tilde{\sigma}_\kappa})\frac{\partial k}{\partial x_j}\right]$$

- **Overcomes threshold limit of LES**
- **Cost: Strong grid sensitivity in RANS region**

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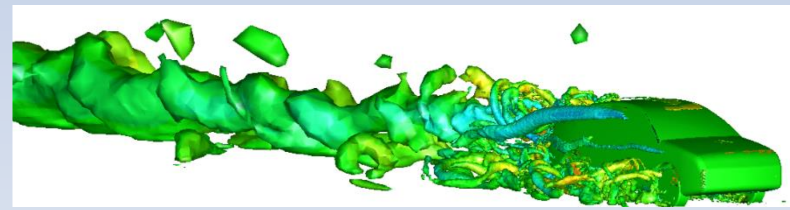
DES for SST – Delayed DES (DDES)

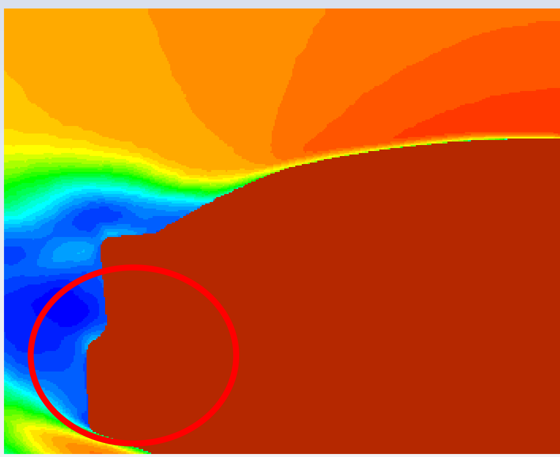
DES function used for SST model to shield boundary layer from DES impact

$$F_{DES-CFX} = \max\left(\frac{L_t}{C_{DES}\Delta}\cdot\left(1-F_{SST}\right), 1\right); \quad F_{SST} = 0, F_1 \text{ or } F_2 \qquad \Delta = \max(\Delta x, \Delta y, \Delta z)$$

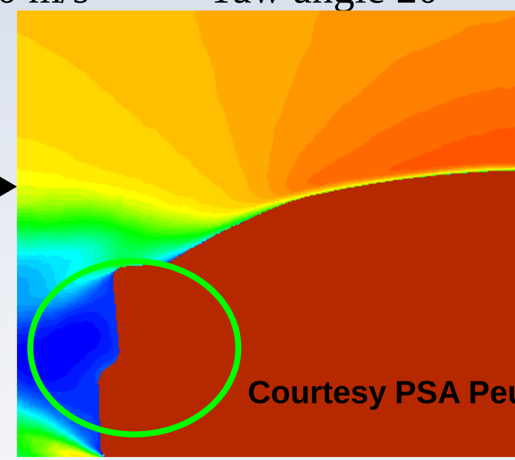
Model	Exp.	DDES	DES	LES
Drag (SCx)	0.70	0.71	0.75	0.69



U=40 m/s Yaw angle 20° $Re_H \sim 10^6$



DES ← → DDES



Courtesy PSA Peugeot Citroën

- **Grid induced separation on genetic car using DES**
- **Only DDES should be used in industrial flows**
- **The DDES function proposed by Spalart for the Spalart-Allmaras model provides insufficient shielding (there can still be Grid-Induced Separation GIS). The F2 SST function is safest**

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Standard Delayed DES (DDES)

- **DDES and IDDES formulations published by Spalart et al. are not safe in terms of preventing Grid-Induced Separation (GIS).**

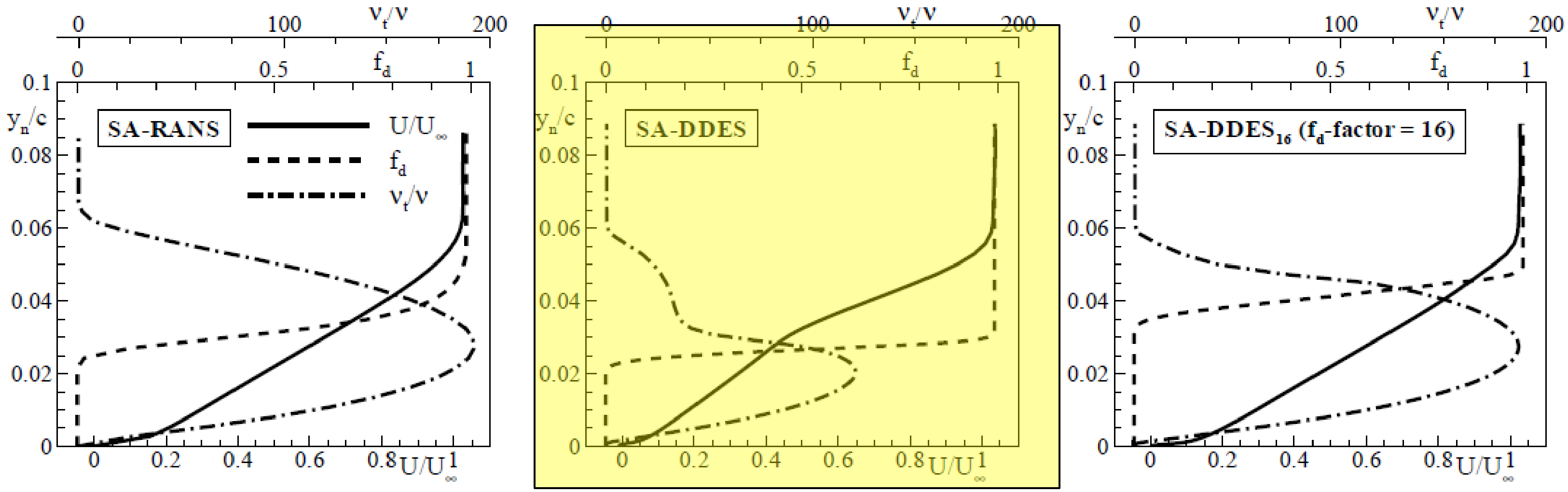

Figure 10. Profiles of streamwise velocity, delay function f_d and eddy viscosity at $x/c = 0.9$ of the HGR-01 airfoil at $\alpha = 12^\circ$ computed with SA-RANS (left), SA-DDES (middle) and modified SA-DDES$_{16}$ (right).

- **To avoid GIS one needs: with δ being the boundary layer thickness**

$$\Delta_{max} > \delta$$

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A Comparison of Detached-Eddy Simulation and Reynolds-Stress Modelling Applied to the Flow over a Backward-Facing Step and an Airfoil at Stall

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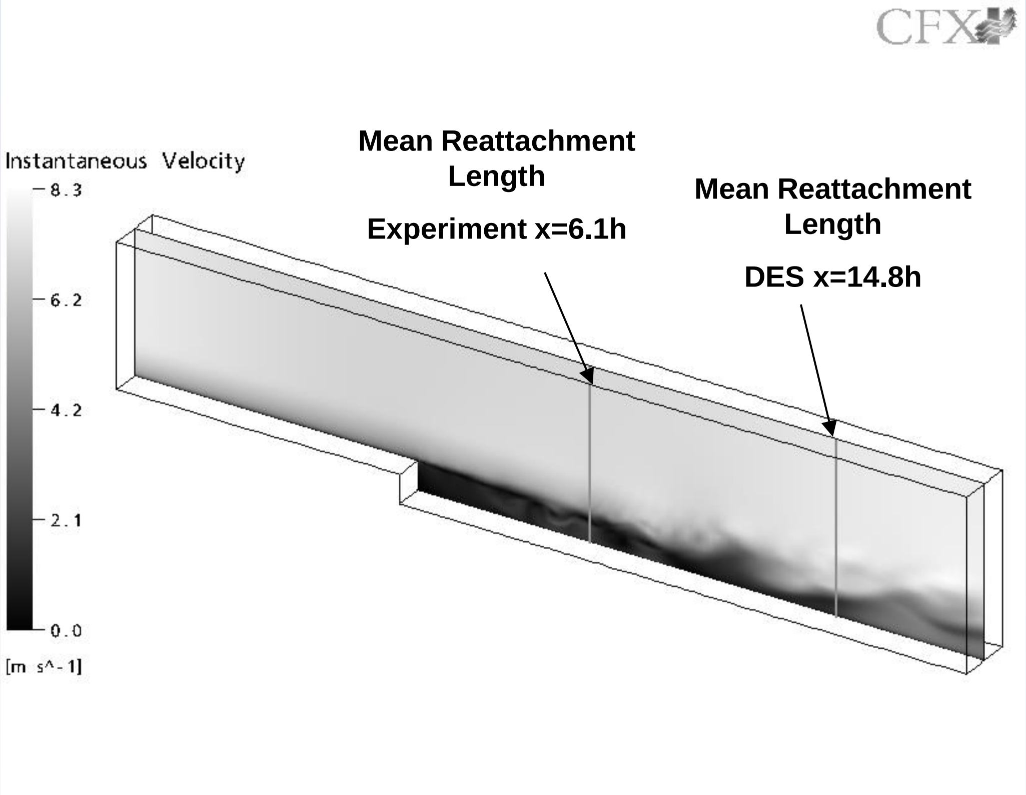
DES Problem: “Grey Areas”

- **“Grey Area” where model has not fully switched between RANS and LES mode**
  - Grid resolution to low
  - Instability too weak
- **Balance of resolved and unresolved portions of the flow is not achieved – loss of turbulent kinetic energy**
- **Undefined model**
- **Further mesh refinement required**



Courtesy: Herr Sohm – BMW AG

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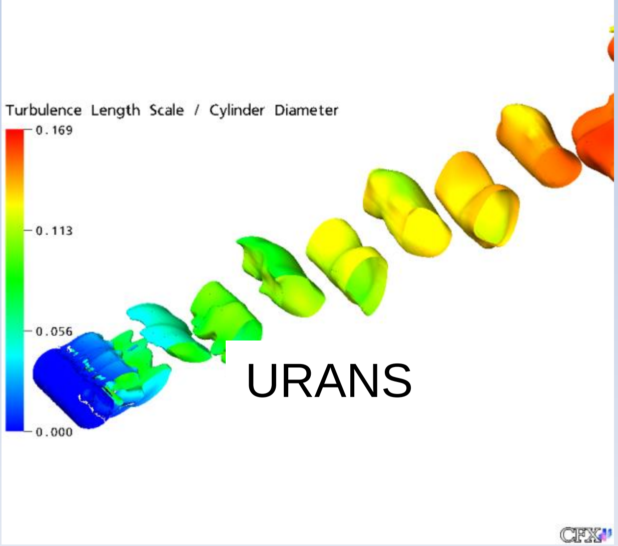
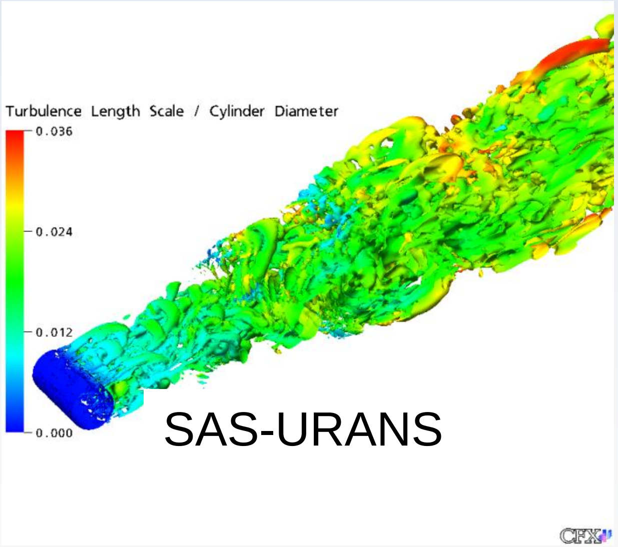
SAS:
Alternative to DES Method

- **URANS (Unsteady Reynolds averaged Navier Stokes) Methods**
  – URANS gives unphysical single mode unsteady behavior
  – Some improvement relative to steady state (RANS) but often not sufficient to capture main effects
  – Reduction of time step and refinement of mesh do not benefit the simulation

- **SAS (Scale-Adaptive Simulation) Method**
  – Extends URANS to many technical flows
  – Provides “LES”-content in unsteady regions
  – Produces information on turbulent spectrum
  – Can be used as basis for acoustics simulations





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Source Terms Equilibrium – k-ω Model

Only one Scale in Sources (S~1/T)

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho U_j k)}{\partial x_j}=\boxed{\mu_t\left(S^2-c_\mu\omega^2\right)}+\frac{\partial}{\partial x_j}\left(\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right)$$

$$\frac{\partial(\rho\omega)}{\partial t}+\frac{\partial(\rho U_j \omega)}{\partial x_j}=\boxed{\rho\left(c_{\omega1}S^2-c_{\omega2}\omega^2\right)}+\frac{\partial}{\partial x_j}\left(\frac{\mu_t}{\sigma_\omega}\frac{\partial \omega}{\partial x_j}\right)$$

Input S → Turbulence Model → Output k

Output ω

One input scale – two output scales?

Source terms actually do not contain information on two independent scales

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Determination of *L* in *k*-ω Model

k-equation:

$$\frac{\partial(k)}{\partial t}+\frac{\partial(U_k k)}{\partial x_k}=\frac{k}{\omega}(S^2-c_\mu\omega^2)+\frac{\partial}{\partial y}\left[\frac{k}{\omega}\frac{\partial k}{\partial y}\right]$$

- **Diffusion term carries information on shear-layer thickness δ**
- **Turbulent length scale proportional to shear layer thickness**
- **Finite thickness layer required**
- **Computed length scale independent of details inside turbulent layer**
- **No scale-resolution, as L_t always large and dissipative**

$$0=\frac{k}{\omega}(S^2-c_\mu\omega^2)+c\frac{1}{\delta}\left[\frac{k}{\omega}\frac{k}{\delta}\right]$$

$\omega \sim S$ **from ω-equation**

$$0=cS^2+\tilde{c}\frac{k}{\delta^2} \qquad k\sim S^2\delta^2$$

$$L_t\sim\frac{\sqrt{k}}{\omega}\sim\frac{\sqrt{S^2\delta^2}}{S}\sim\delta$$

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Rotta's Length Scale Equation

- **To avoid the problem that the ε (ω) equation is an equation for the smallest scales, an equation for the large (integral) scales is needed**
- **This requires first a mathematical definition of an integral length scale, *L***
- **Based on that definition of *L*, an exact transport equation can be derived from the Navier-Stokes equations**
- **Requirements:**
  - **Standard RANS behaviour in steady regimes (boundary layers)**
  - **Avoid "single-mode" solution of standard URANS methods**
  - **Allow break-down of large structures into turbulent spectrum in unsteady regimes**
  - **Grid resolution does not impact RANS formulation**

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New 2-Equation Model (KSKL)

$$\frac{\partial(k)}{\partial t}+\frac{\partial(U_j k)}{\partial x_j}=P_k-c_\mu^{3/4}\frac{k^{3/2}}{L}+\frac{\partial}{\partial x_j}\left(\frac{\nu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right)$$

$$\frac{\partial\Phi}{\partial t}+\frac{\partial(U_j\Phi)}{\partial x_j}=\frac{\Phi}{k}\left(\zeta_1 P_k-\boxed{\zeta_2\frac{1}{\kappa^2}L^2\nu_t\left(U''\right)^2}\right)-\zeta_3\cdot k+\frac{\partial}{\partial y}\left[\frac{\nu_t}{\sigma_\Phi}\frac{\partial\Phi}{\partial y}\right]$$

- With:

$$\Phi=\sqrt{k}L \qquad \nu_t=c_\mu^{1/4}\Phi \qquad |U'|=\sqrt{\frac{\partial U_i}{\partial x_j}\frac{\partial U_i}{\partial x_j}}; \quad |U''|=\sqrt{\frac{\partial^2 U_i}{\partial x_j\partial x_j}\frac{\partial^2 U_i}{\partial x_k\partial x_k}}; \quad L_{\nu K}=\kappa\left|\frac{U'}{U''}\right|$$

v. Karman length-scale as natural length-scale:

$$L\sim\kappa\left|\frac{\partial U/\partial y}{\partial^2 U/\partial y^2}\right|=L_{\nu K}$$

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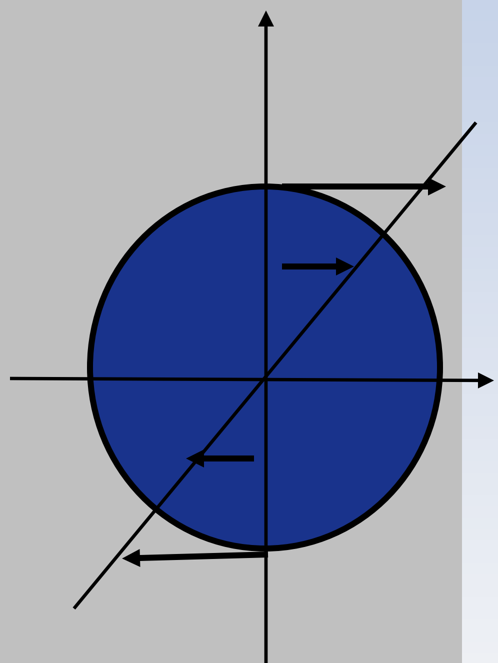
Limitation of Growth by U”

Homogenous Shear

$$\frac{dU}{dy} = const.$$

$$\omega \sim \frac{dU}{dy}$$

$$L \to \infty$$



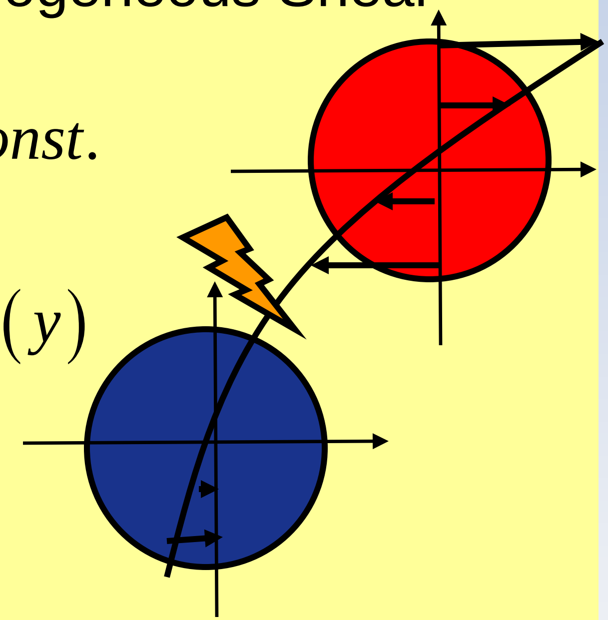
Eddies grow to infinity

Inhomogeneous Shear

$$\frac{dU}{dy} \neq const.$$

$$\omega \sim \frac{dU}{dy}(y)$$

$$L \to L_{vK}$$



Eddy growth limited by LvK.

For non-homogenous shear, two eddies at different locations have different turn over frequencies as the driving force S is different. They can therefore not grow or merge, as one eddy cannot have two different turnover frequencies.

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Transformation of SAS Terms to SST Model

- Transformation: $$\Phi = \frac{1}{c_\mu^{1/4}} \frac{k}{\omega}$$

$$\frac{D\omega}{Dt} = \frac{1}{c_\mu^{1/4}} \frac{D}{Dt}\left(\frac{k}{\Phi}\right) = \frac{1}{c_\mu^{1/4}}\left(\frac{1}{\Phi}\frac{Dk}{Dt} - \frac{k}{\Phi^2}\frac{D\Phi}{Dt}\right) = \frac{\omega}{k}\frac{Dk}{Dt} - \frac{\omega}{\Phi}\frac{D\Phi}{Dt}$$

$$\downarrow$$

$$\frac{\partial \rho\omega}{\partial t} + \frac{\partial U_j \rho\omega}{\partial x_j} = \underbrace{\alpha\rho S^2 - \beta\rho\omega^2 + \frac{\partial}{\partial x_j}\left(\frac{\mu_t}{\sigma_\omega}\frac{\partial \omega}{\partial x_j}\right)}_{\text{Wilcox Model}} + \underbrace{\frac{2\rho}{\sigma_\Phi}\left(\frac{1}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j} - \frac{k}{\omega^2}\frac{\partial \omega}{\partial x_j}\frac{\partial \omega}{\partial x_j}\right)}_{\text{BSL (SST) Model}} + \underbrace{\tilde{\zeta}_2 \kappa\rho S^2\left(\frac{L}{L_{vK}}\right)^2}_{\text{New}}$$

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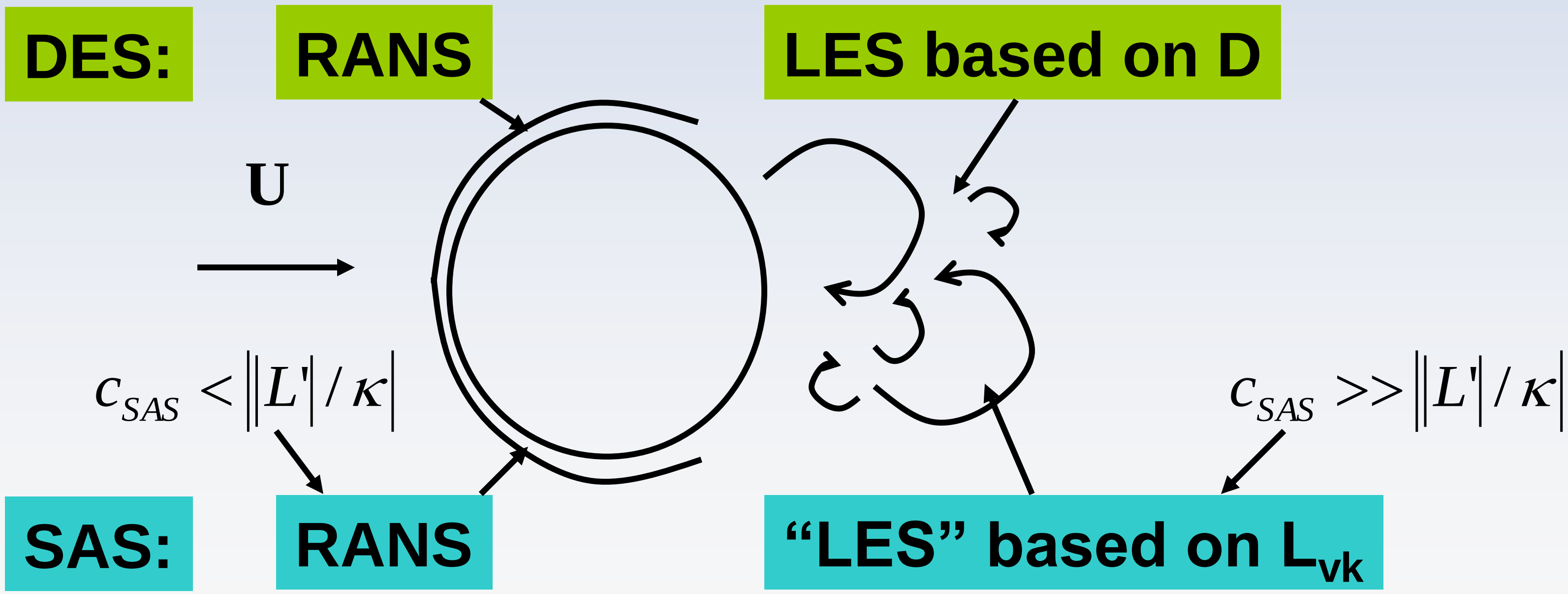
SAS & DES

- SAS model behaves similar to DES model without explicit grid information required
- Avoids one of the main problems of DES – Grid induced separation due to interference of DES limiter with RANS model



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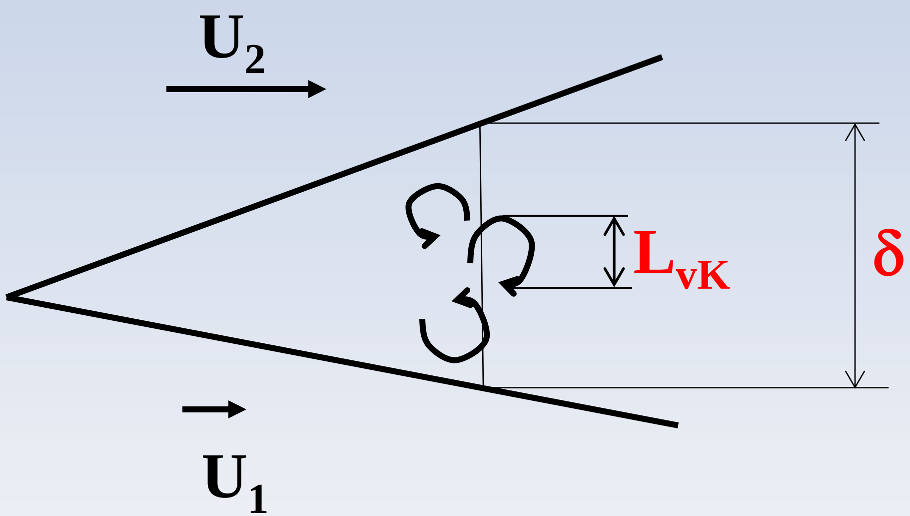
URANS Performance - SAS

Example: Mixing Layer with resolved scales (URANS)



Standard 2-Eq. Models:

$$L \sim \delta$$

Current Model

$$L \sim L_{vK}$$

- **New model adjusts to resolved scales – smaller ν_t than for standard 2-equation models**
- **This is Scale-Adaptive Simulation (SAS) capability**
- **May become steady for attached or mildly separated boundary layers and undisturbed channel/pipe flows**

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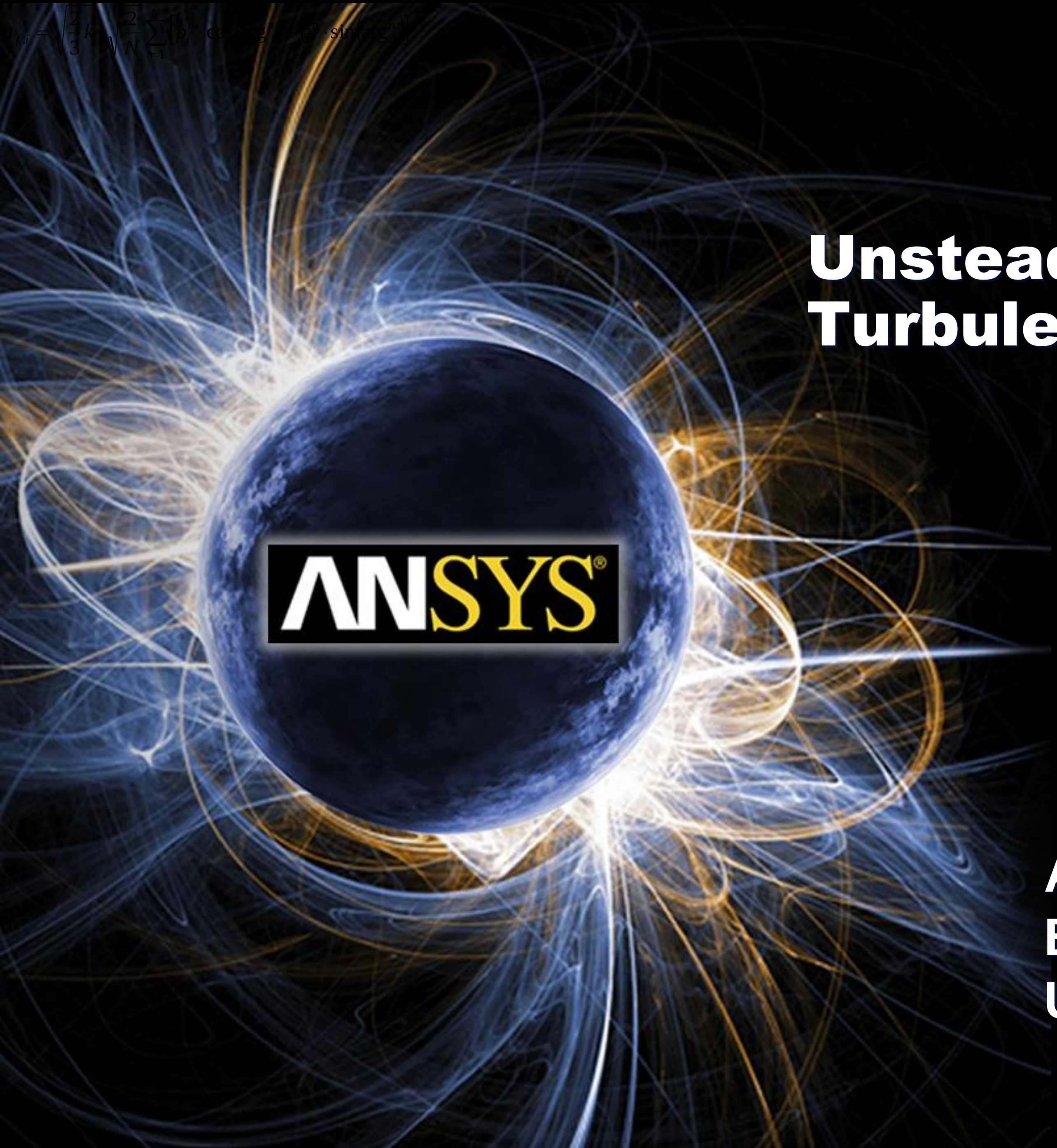

Unsteady Turbulence Models

Application and Best Practices for UTM

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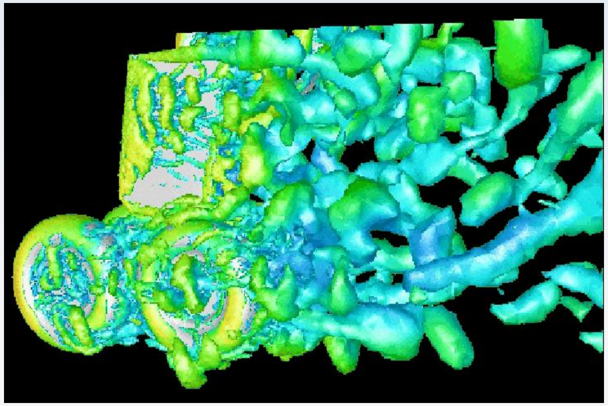
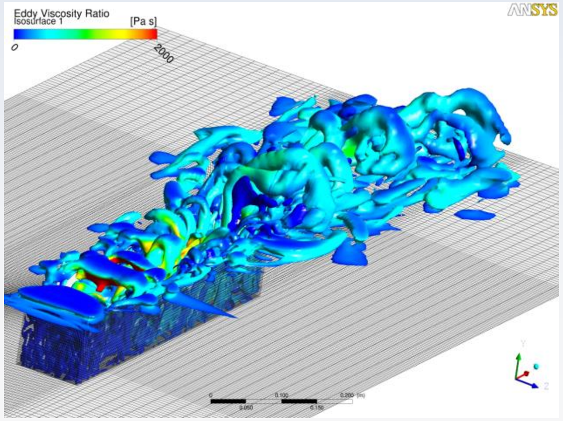
Simulation and Post-Processing General Approach

- **Initial conditions from RANS Simulation**
- **Conversion from RANS to developed unsteady flow field**
  - Monitor points used to established if the unsteady flow motion is fully developed
- **Statistical data extracted over 10-20 (often more) typical flow cycle (check symmetry of averaged quantities)**
  - Time averaged results
  - RMS data





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UT Models comparison Chart

	SAS	DDES	LES
Wall Resolution (y^+)	1	1	1-20*
Stream-wise Resolution (x^+)	-	-	40
Span-wise Resolution (z^+)	-	-	20
Time Step (CFL)	10	1	1
External Flows	YES	YES	YES
Confined Flows (boundary layer driven turbulence)	NO	NO	YES
Confined Flows with large sources of Turbulence (jets, jets in crossflow)	YES	YES	YES
Inlet Boundary Conditions	RANS	RANS	LES Specific

(*) LES wall function is available in ANSYS FLUENT via the TUI

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Best Practices: LES

- **Simulation of the full 3-D geometry is recommended**
  - Avoid sector simulation in an axi-symmetric problem
- **SGS modeling**
  - WALE model is good starting points
  - Dynamic TKE model can potentially benefit highly non-equilibrium flows and reacting flows
  - Consider Wall Functions or DES for external high-Re wall-bounded flows with large flow separation
- **Mesh resolution**
  - HEX meshes are preferred over TET meshes
    - Lower numerical dissipation
    - Lower cell count
  - Mesh stretching limited to maximum 3-5%
  - Non conformal interfaces are not recommended
- **In ANSYS FLUENT, specific LES boundary conditions are available**

See best practice (KR 527) for ANSYS FLUENT

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Best Practices: DDES

- **Useful to relax the strong LES mesh constraints close to the wall**
  - LES Mesh constraints relaxed parallel to wall, i.e. in stream- and span-wise directions
  - A relatively fine RANS mesh is recommended normal to the wall to accurately capture flow separation
- **RANS/LES interface depends on the mesh**
  - Boundary layer mesh requirements identical to high-quality RANS
  - All the boundary layer should be covered by RANS
  - Production mechanisms far from wall must be correctly resolved with LES
  - Need to check the RANS/LES interface a posteriori
  - In case less stringent shielding functions than F2-SST (F1, DDES, IDDES) are used the maximum edge length of boundary layer cell needs to be larger than the BL thickness.
- **Mesh Resolution**
  - LES recommendations away from the wall region
- **Other Tips**
  - DES should be applied in its DDES variant using the in the SST model the F2 shielding function to avoid Grid Induced Separation

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Best Practices: SAS

- **Useful in relaxing the strong LES mesh constraints close to the wall, eliminates grey areas that occur with DES**
  - LES Mesh constraints relaxed parallel to wall, i.e. in stream- and span-wise directions
  - Still a relatively fine mesh (RANS/SST quality is required normal to the wall where flow is boundary layer dominated)
- **RANS/LES interface depends on the flow**
  - Boundary layer mesh requirements identical to high-quality RANS
  - All the boundary layer will be covered by RANS
  - Time step should be chosen to maximize resolution of turbulent structures
  - In unsteady regions use CFL ~1
- **Mesh Resolution**
  - LES recommendations away from the wall region, but for coarser grids, the model covers the un-resolved portion with URANS.

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Best Practices: Free Mixing Layer (SAS, DES, LES)

- Compute RANS solution first
- Calculate R (Δ_{max} is maximum edge length of cell – available in ANSYS CFD-Post R13)
- Based on RANS solution
- A value of $R_l=5$ is the lowest limit and a ratio of $R_l=10$ should be aspired
- $R_l=10$ should result in ~20 cells across the mixing layer
- This is a very rough estimate, which is likely problem dependent (e.g. different for jets).
- SAS can cover partly under-resolved regions with URANS
- Use CFL=1 time step

$$L_t = \frac{k^{3/2}}{\varepsilon} = \frac{k^{1/2}}{0.09\omega},$$

$$R_l = \frac{L_t}{\Delta_{\max}}$$

$$R_l > 5-10$$

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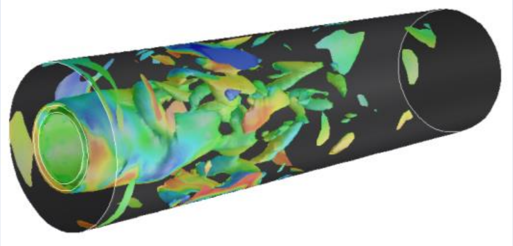
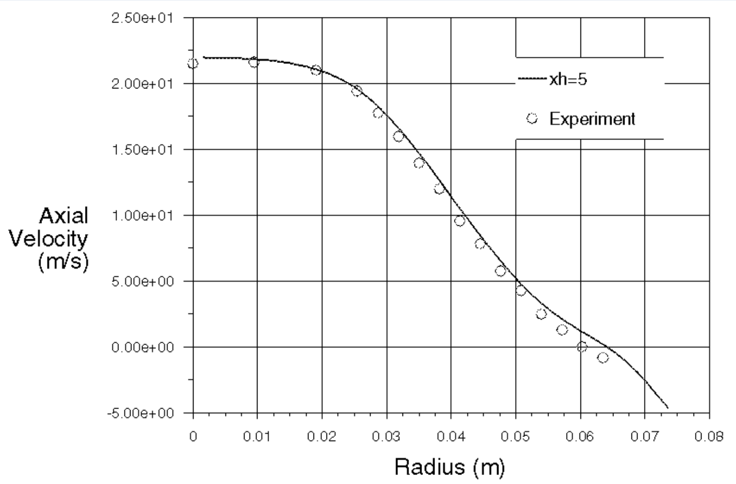
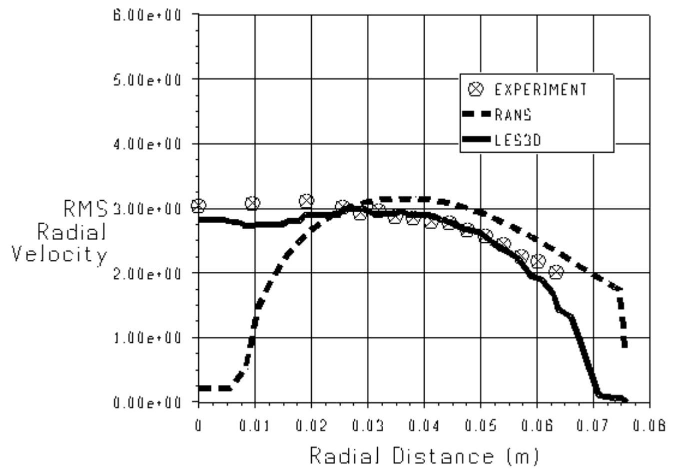
LES Example - Dump Combustor

- **A 3-D model of a lean premixed combustor studied by Gould (1987) at Purdue University**
- **Non-reacting (cold) flow was simulated with a 170K cell hexahedral mesh using second-order temporal and spatial discretization schemes**



Iso-surface of instantaneous vorticity magnitude colored by velocity angle





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Example DDES Modeling Process (Boeing)

Courtesy The Boeing Company

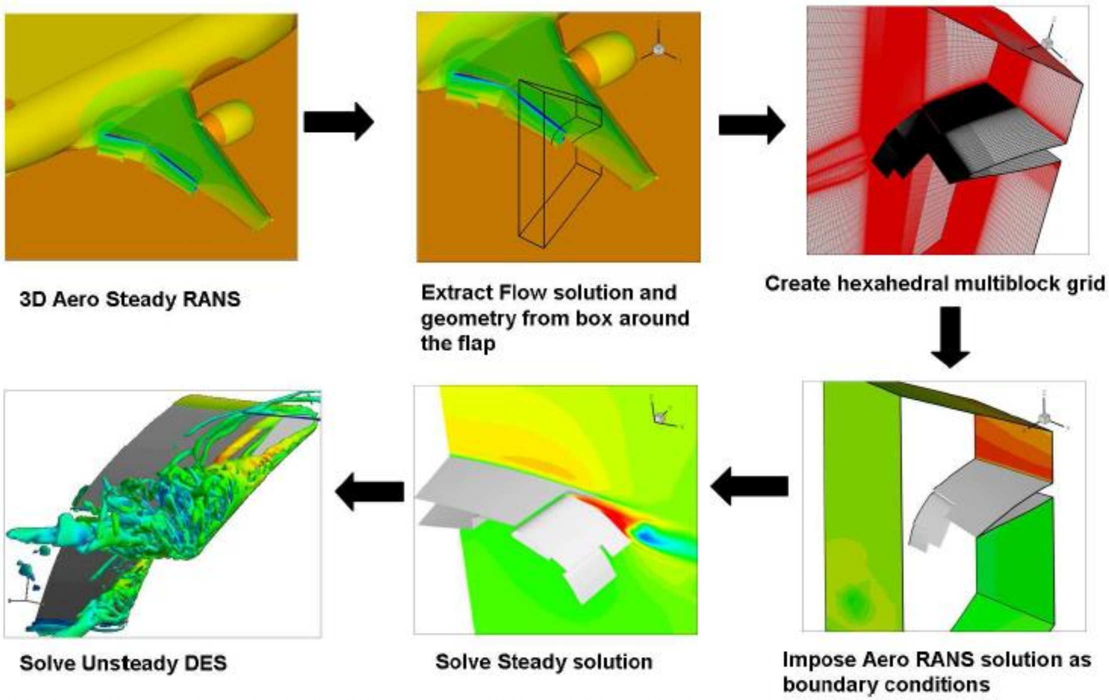

Figure 4: Process for running a local DES around the flap edge based on the full 3D steady RANS solution around an airplane.

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ETMM7 - ***R.B. Langtry, J.V. Larssen and P.R. Spalart***

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Example DES Modeling Process (Boeing)

- ANSYS FLUENT 6.3
- 300 time steps with 7 inner iterations to converge by 2 orders each time step
- 2nd order bounded central diffeence scheme
- Grid: 14 million nodes
- CPU: 20 nodes (40 CPUs) require ~1,5 weeks.

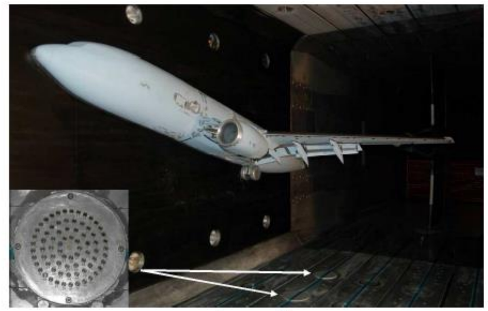

Figure 3: Boeing wind tunnel test using an Acoustic Phased Array mounted on the tunnel wall (Reproduced from Stoker et al., 2008).

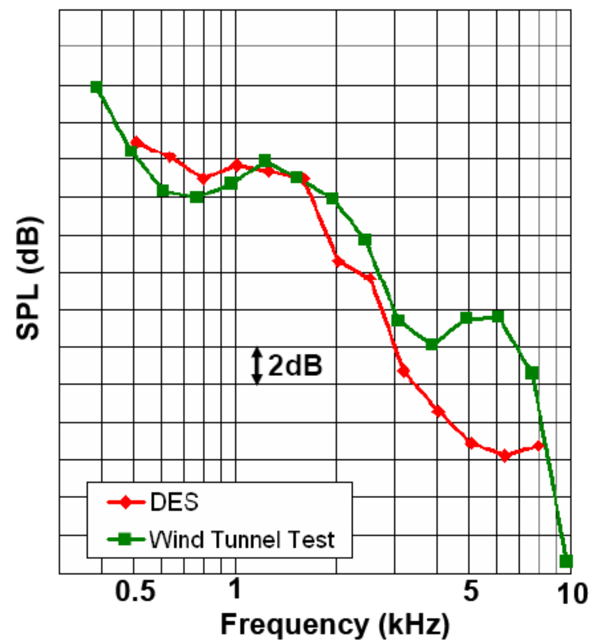

Figure 9: Relative Sound Pressure Level (SPL) vs Frequency measured in a wind tunnel test and predicted by DES for the flap edge.

ETMM7 - ***R.B. Langtry, J.V. Larssen and P.R. Spalart***

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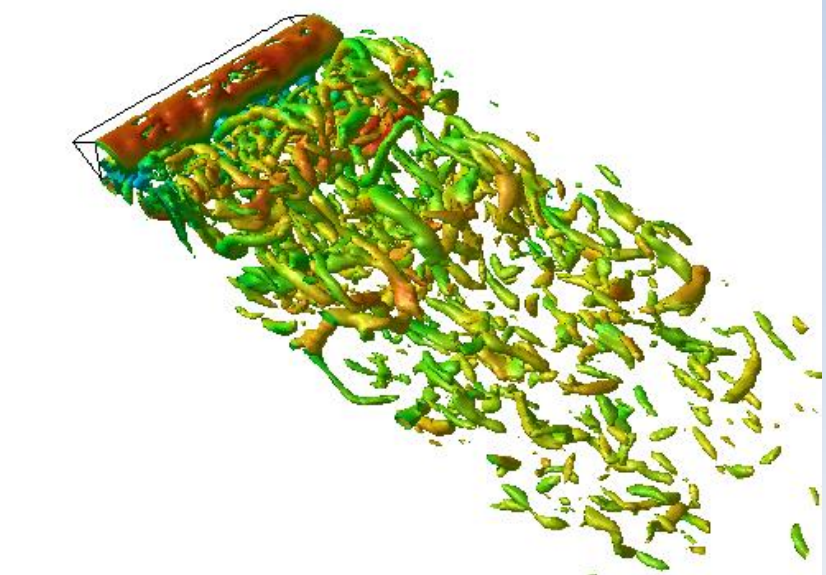
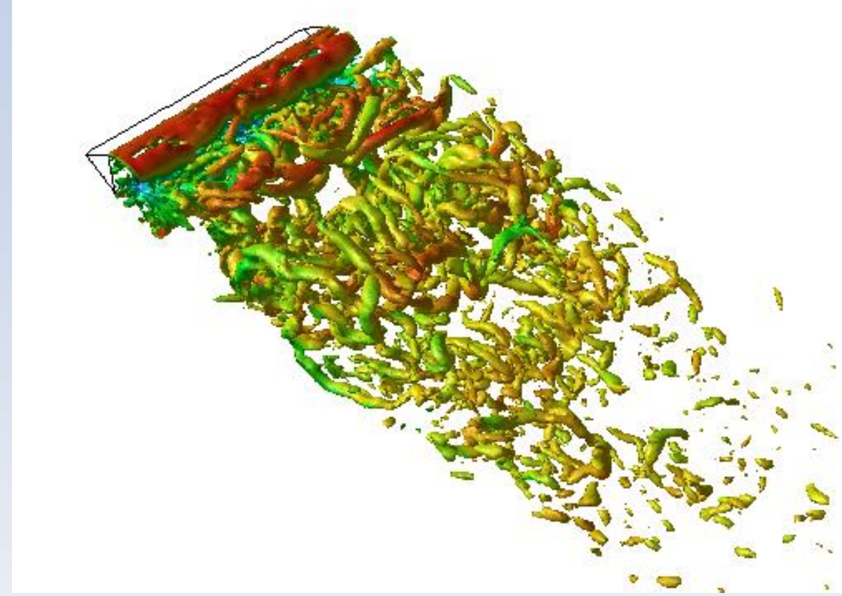
Courtesy The Boeing Company

VOLVO Cold case – Q (1e06) criterion





- Comparison BCD and CD for Triangular Cylinder
  - Near wake is most unstable region
    - differences are small
  - Far wake – decaying turbulence
    - larger differences
    - smaller scales are damped
  - Does this affect averaged velocity profiles?

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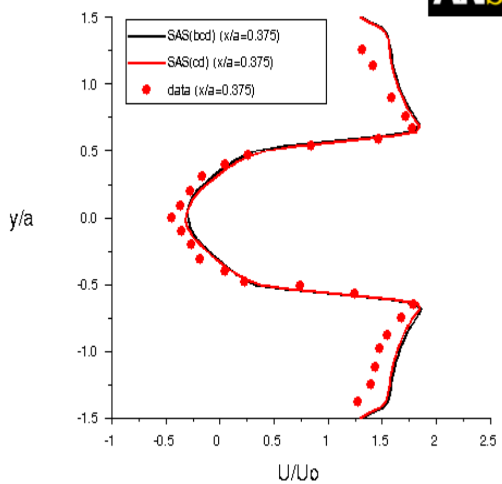
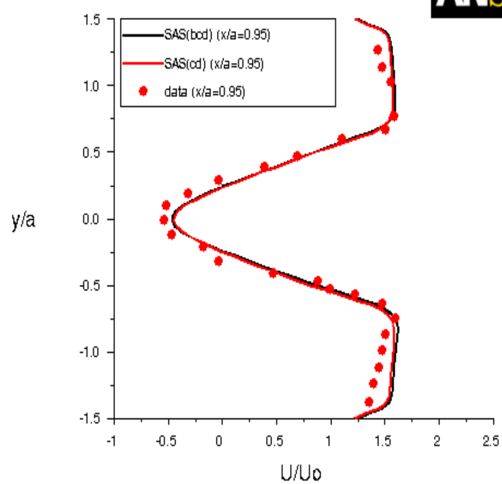
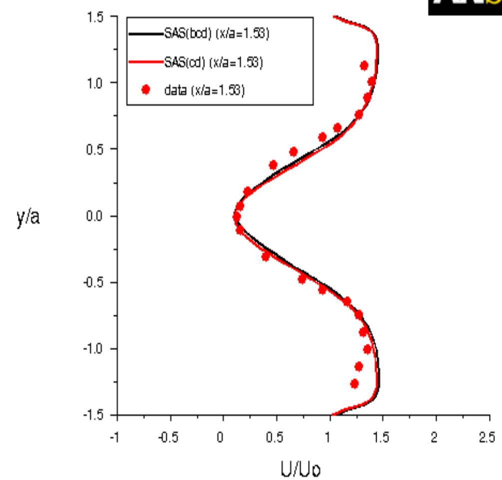
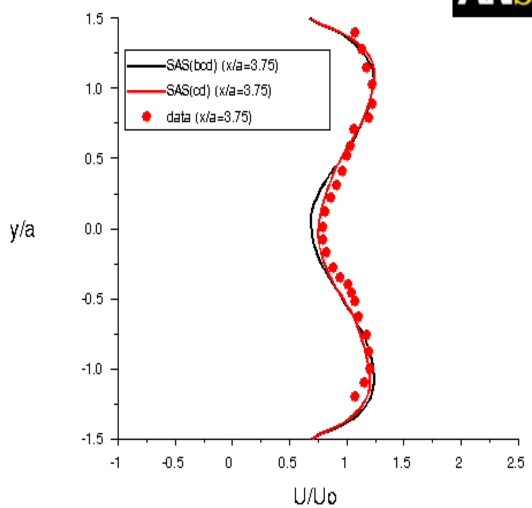
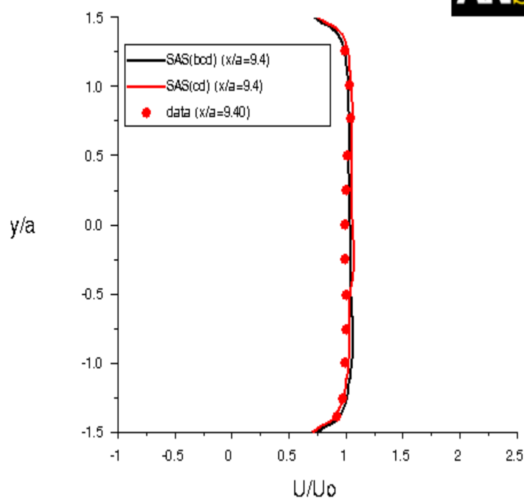
VOLVO Cold Case







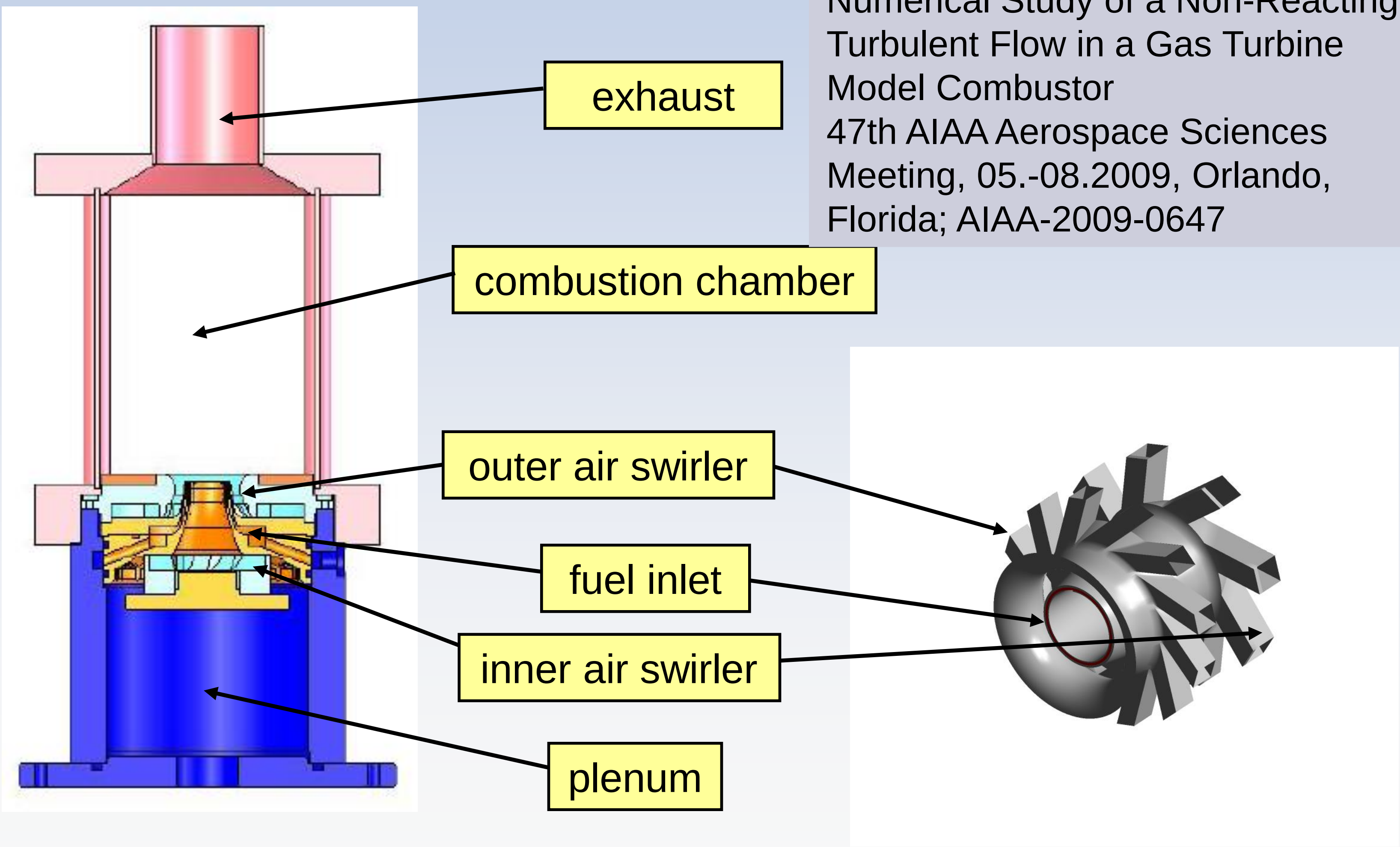




Time-averaged U-velocity

DLR – Swirl Burner Design

A. Widenhorn, B. Noll, M. Aigner
Numerical Study of a Non-Reacting Turbulent Flow in a Gas Turbine Model Combustor
47th AIAA Aerospace Sciences Meeting, 05.-08.2009, Orlando, Florida; AIAA-2009-0647



Courtesy DLR Stuttgart – Axel Widenhorn

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DLR – Swirl Burner (35kW non-reacting) Numerical Setup

- **CFD Code:** ANSYS CFX 11.0
- **Computational grid:** Combined Hexa- & Tet mesh; 1.9 million grid points
- **Turbulence model:** SAS (Hybrid LES/RANS)
- **Time Step:** Δt=1e-5s
- **Total time:** t=0.23s; t=0.065s (start up); t=0.165s (averaging)
- **Computational Power:** AMD Opteron 64Bit; Linux; 20 Processors

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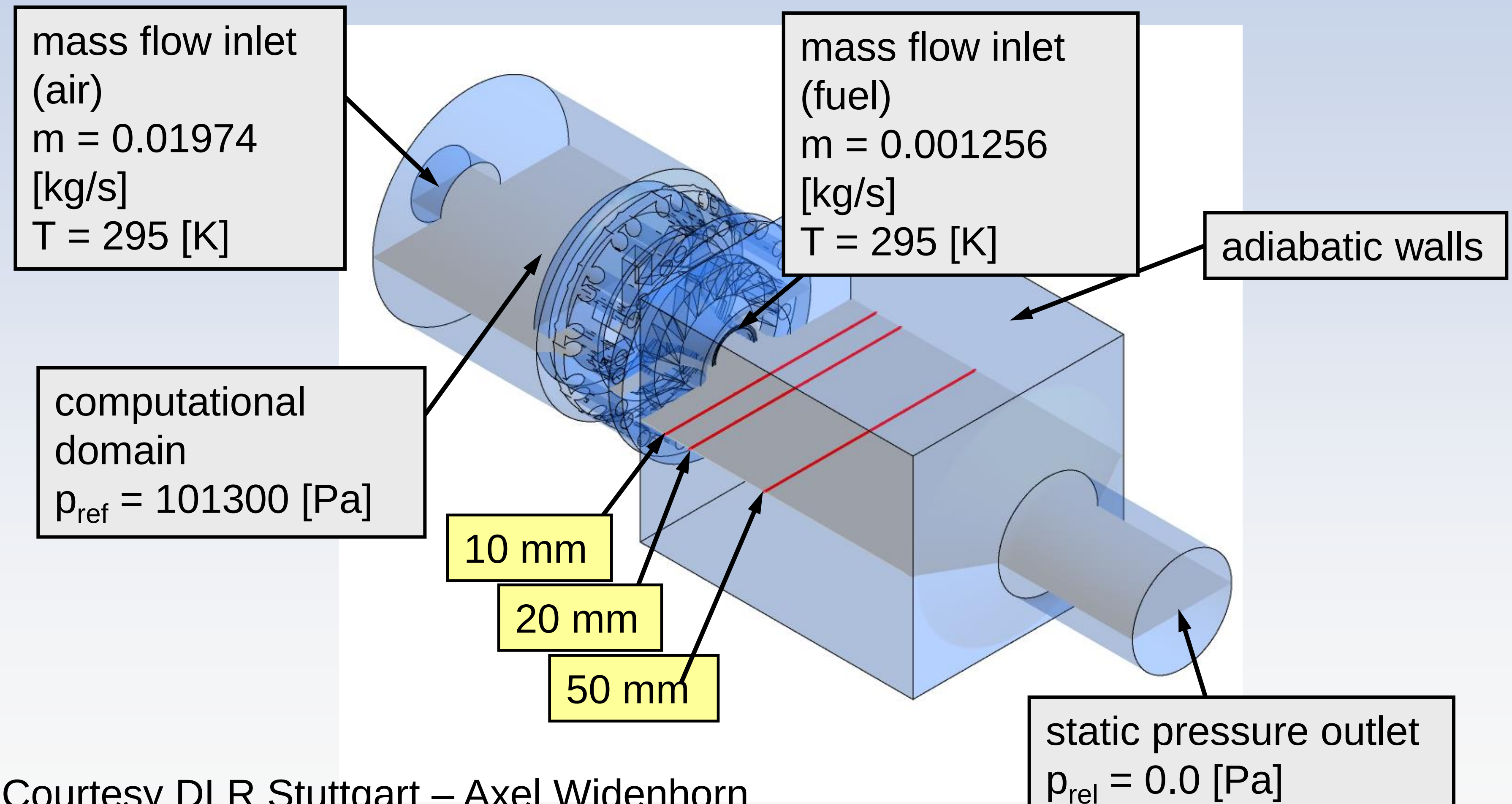
DLR – Swirl Burner (35kW non-reacting)
Boundary Conditions



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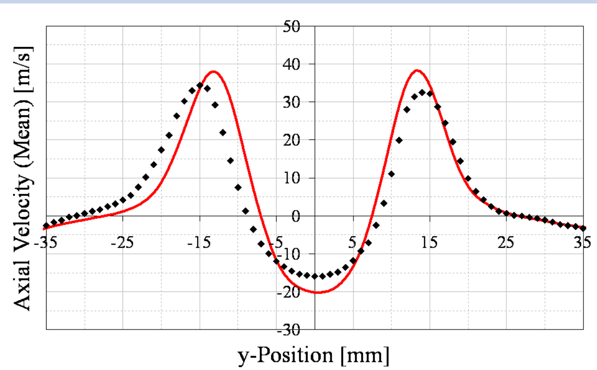
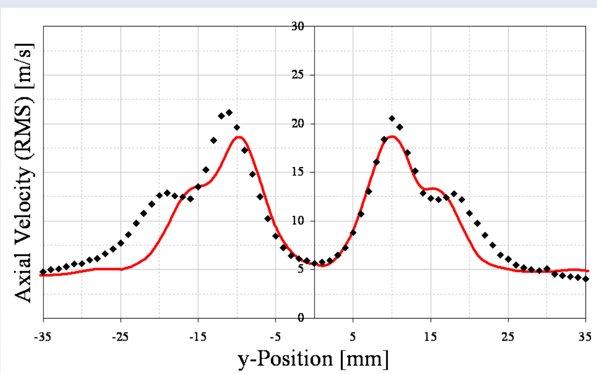
DLR – Swirl Burner (35kW non-reacting) Time-Averaged Axial Velocity Profiles (Mean & RMS) – SAS Model

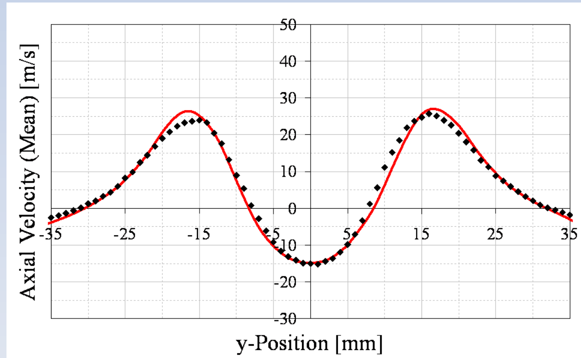
ANSYS®

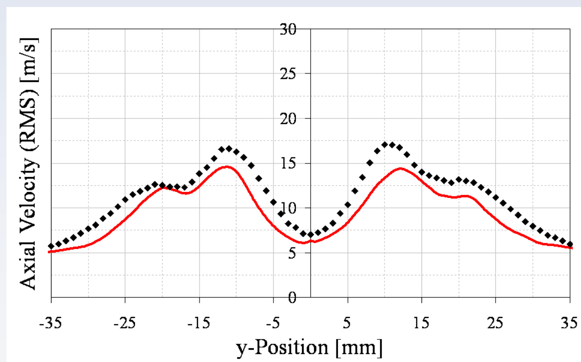
Axial Velocity; h=10mm



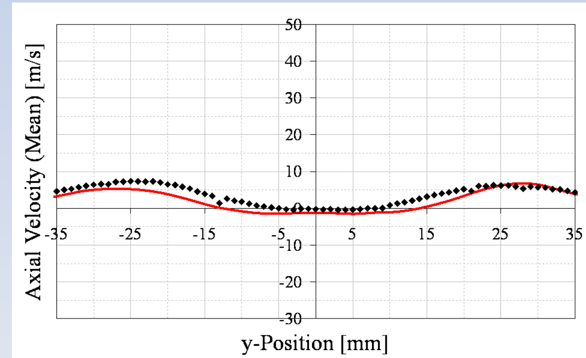


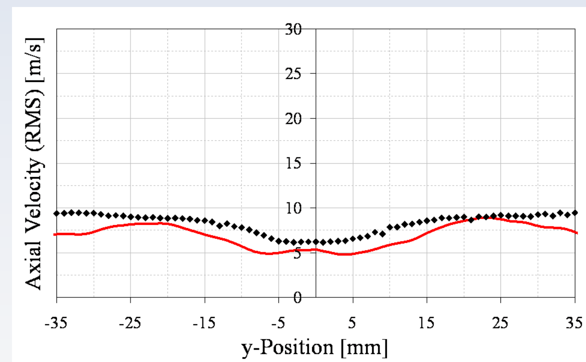
Axial Velocity; h=20mm





Axial Velocity; h=50mm





◆ LDA Measurement — SAS Turbulence Model

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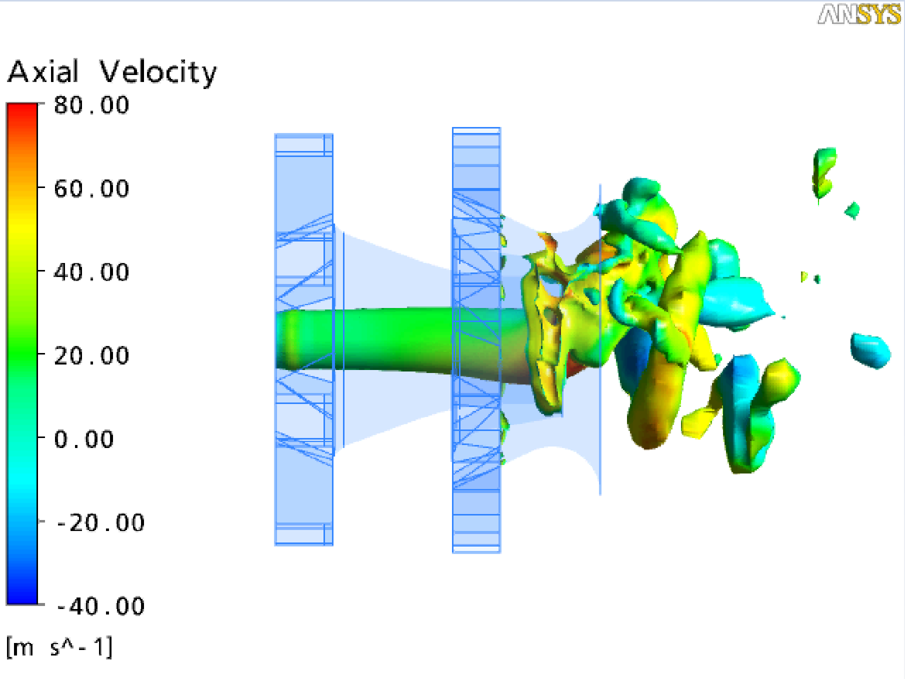
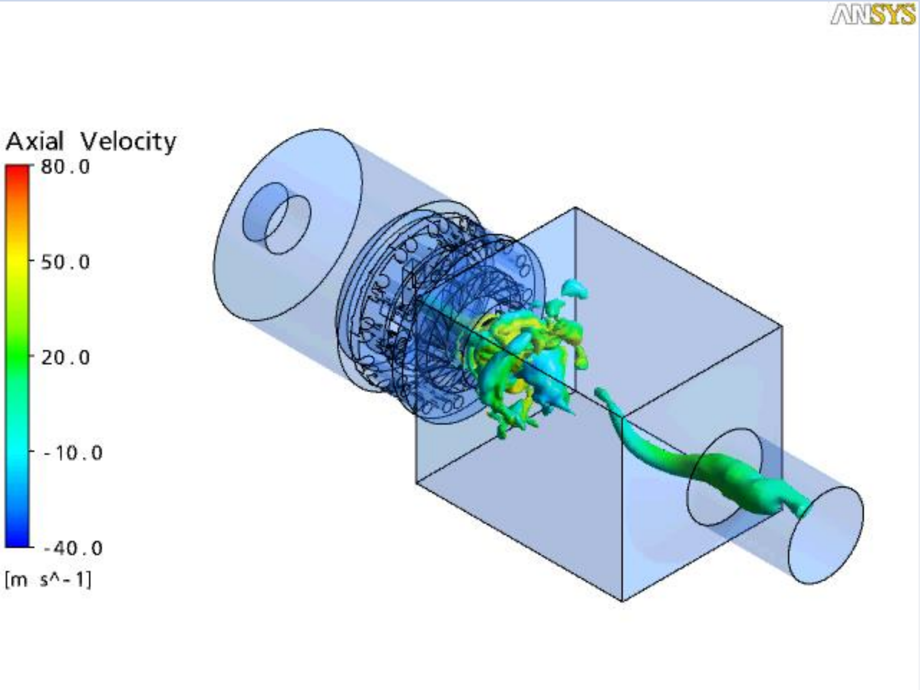
DLR – Swirl Burner (35kW non-reacting) Instantaneous Velocity Field & Coherent Structures – SAS Model

Precessing Vortex Core (PVC)

Tornado-like Vortex Core





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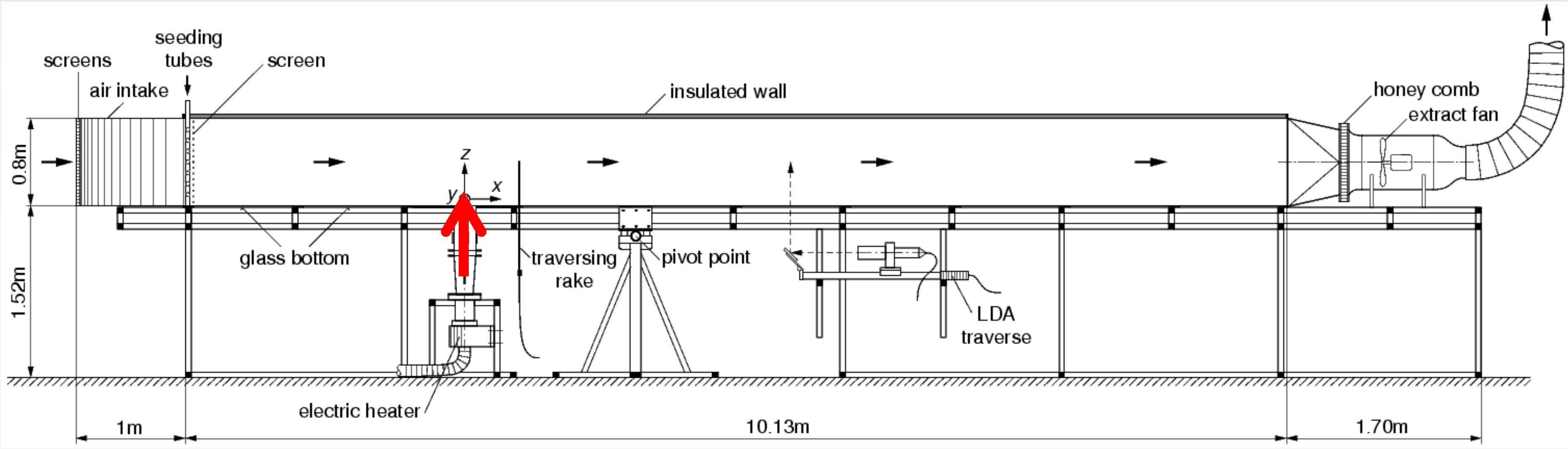
3D Transient Flows: SAS

- **Hot buoyant jet in cross flow in a channel (ETH)**
  - Study of mixed convection during fires in confined spaces
  - Long square channel 0.8m×0.8m
  - Ventilation: 0.73 m/s at room temperature
  - Jet: ∅ 0.2 m, injected with 2.8 m/s at 500°C



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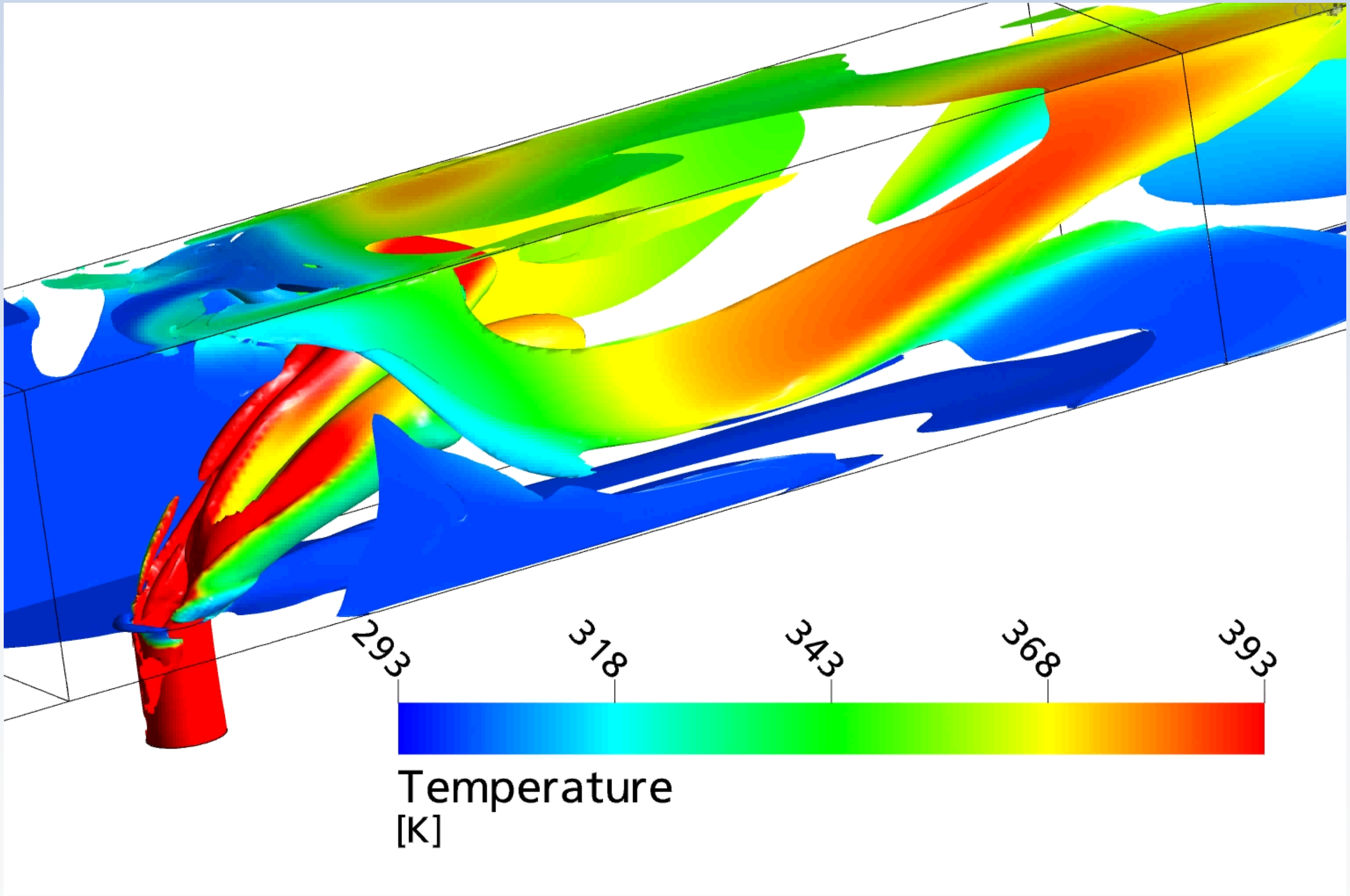
3D Transient Flows: SAS

- **Hot buoyant jet in cross flow in a channel:**
  - Development of the SAS solution from the RANS initialisation



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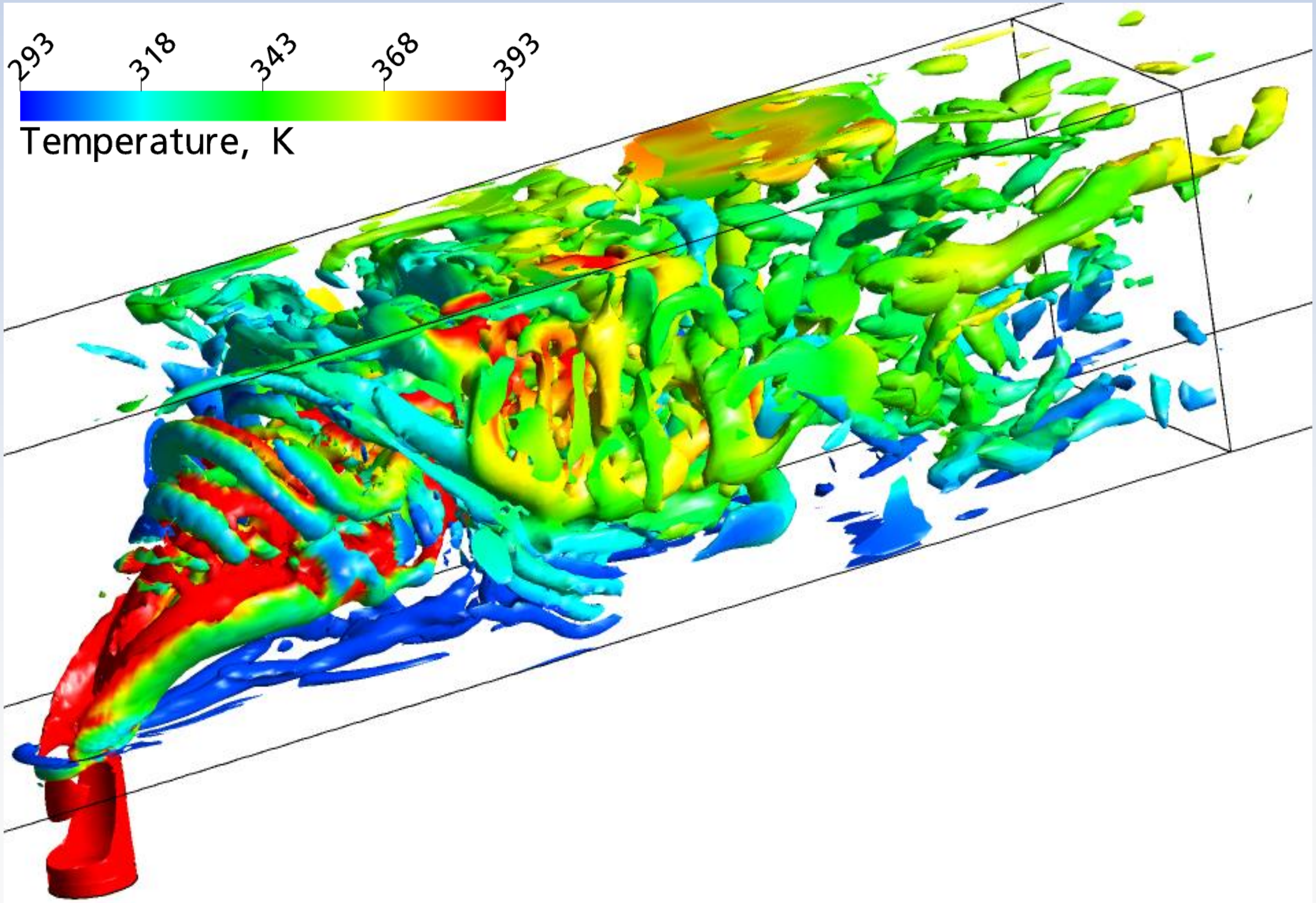
3D Transient Flows: SAS

- **Hot buoyant jet in cross flow in a channel (ETH)**



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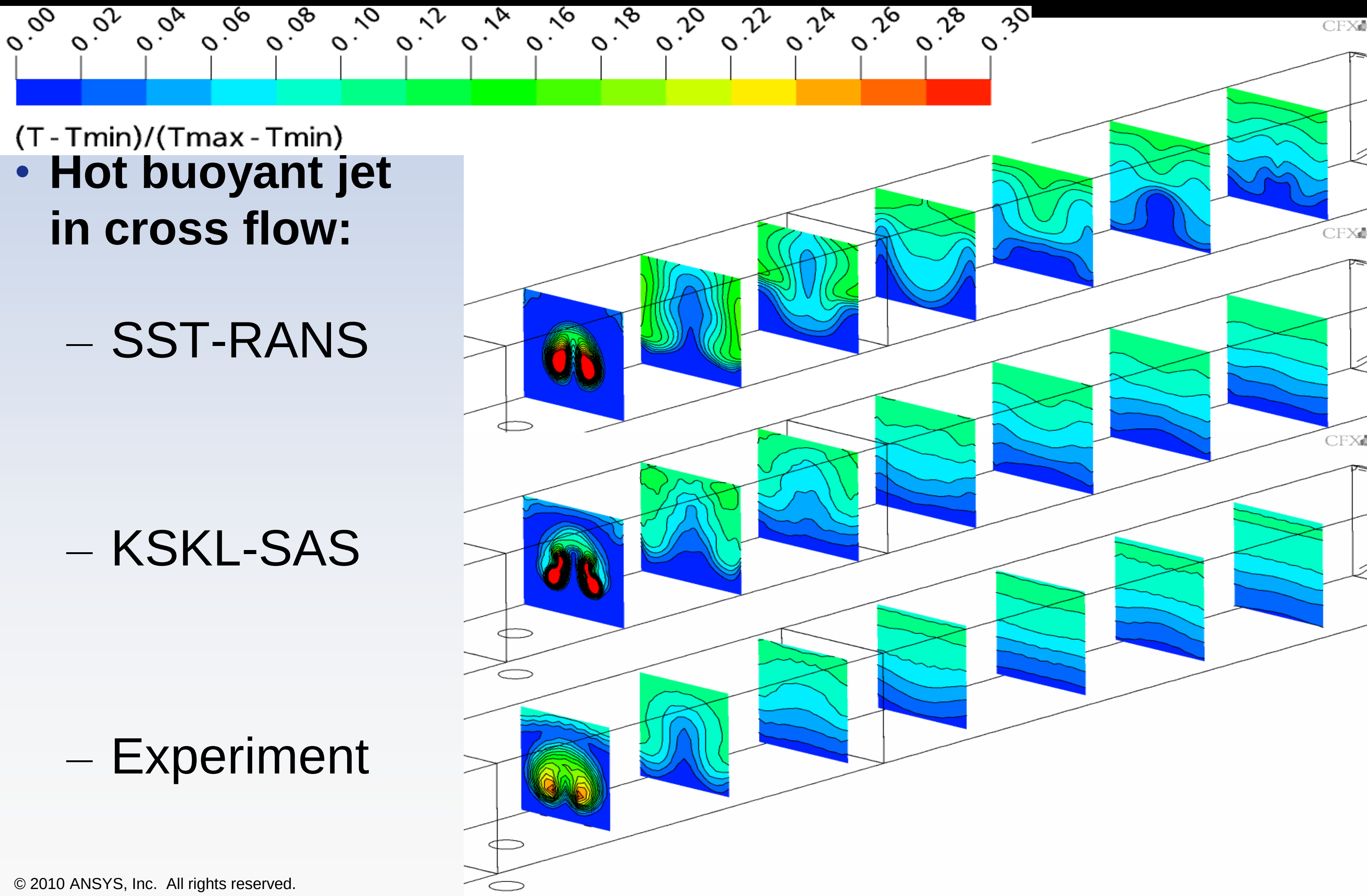
3D Transient Flows: SAS



- **Hot buoyant jet in cross flow:**
  - SST-RANS
  - KSKL-SAS
  - Experiment

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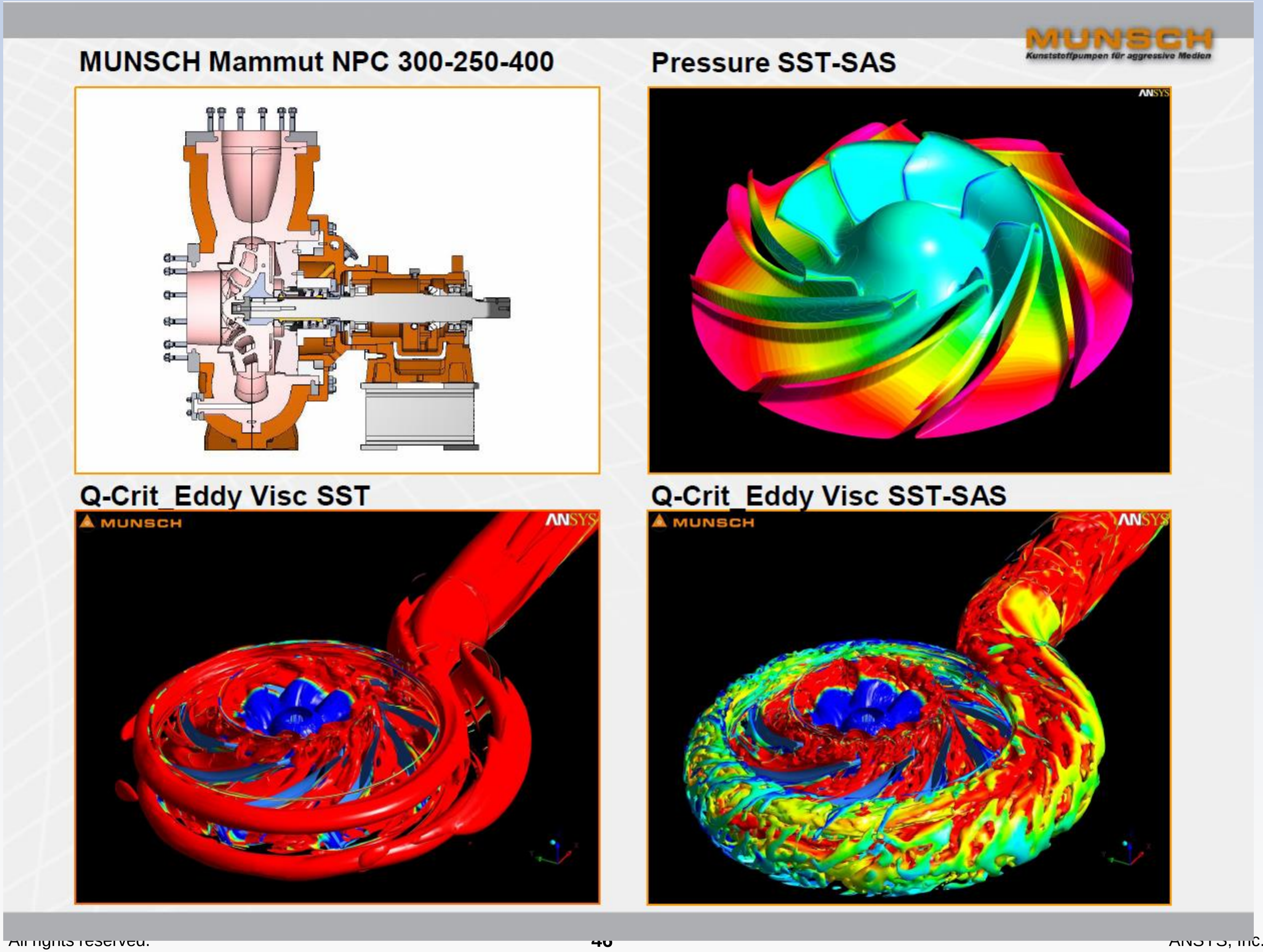
Munsch Pump – SAS Example



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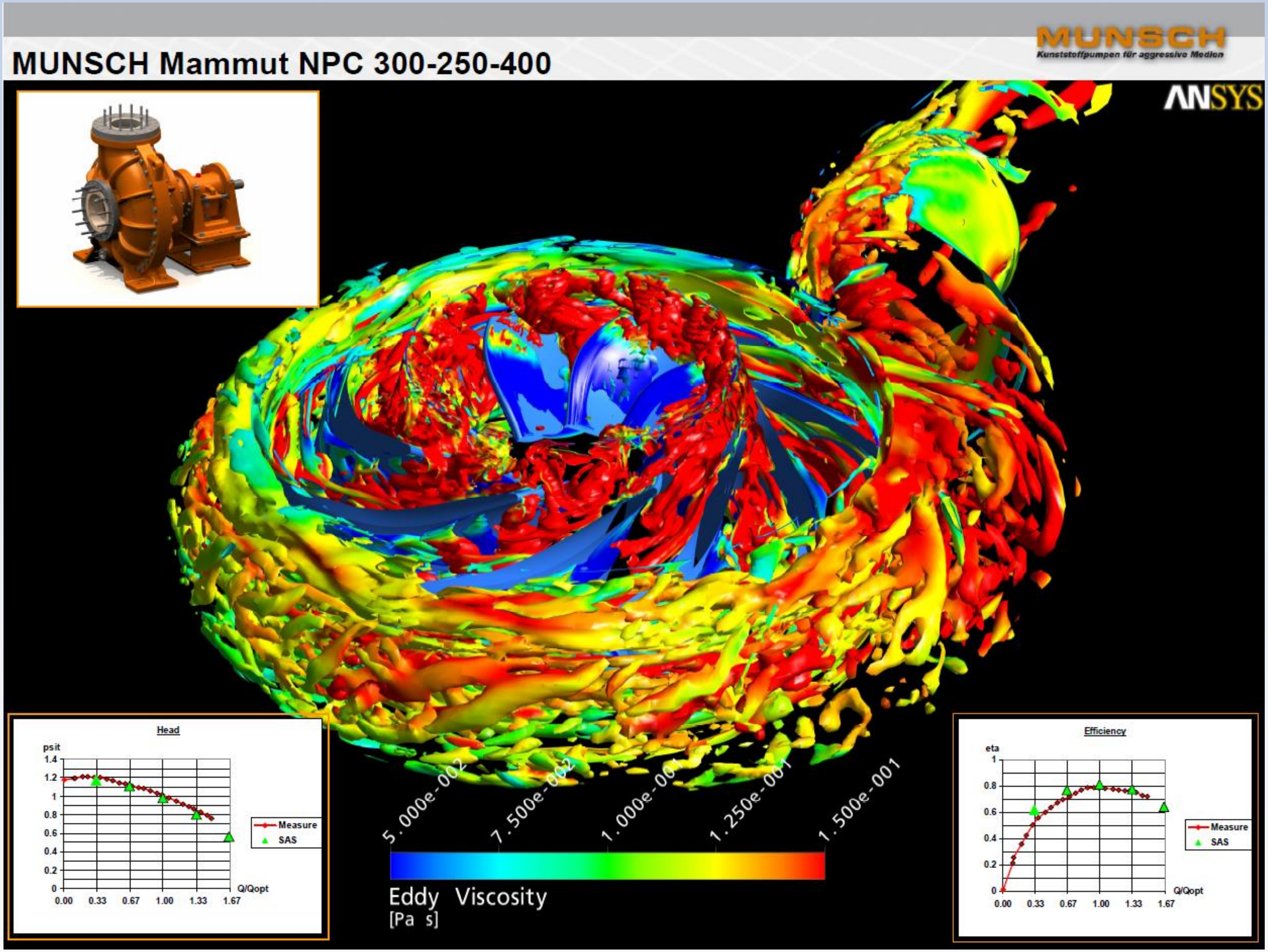
Munsch Pump – SAS Example



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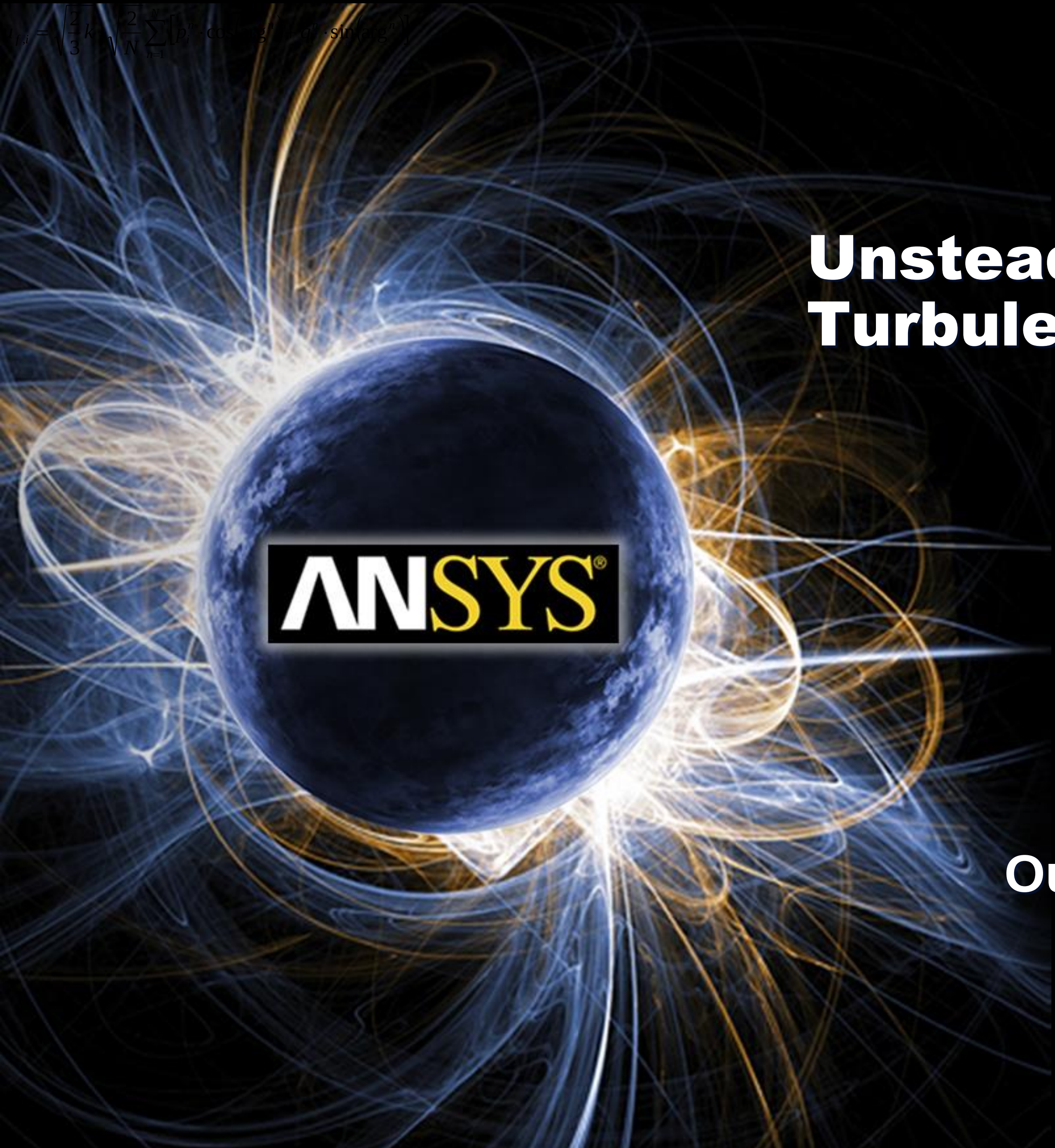

Unsteady Turbulence Models

Outlook Release 13

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Zonal Modelling – Release R13

- There are applications, where the unsteadiness is not generated by a sufficiently large flow instability and both SAS and DDES will not provide any or sufficient scale resolution
- Examples:
  - Mildly swirling flows
  - Turbulence originating from wall boundary layers
  - Channel, pipe flows etc.
- Zonal models allow the definition of separate RANS and LES regions. At the RANS-LES interface synthetic turbulence will be generated.
- ANSYS Fluent R13 – Embedded LES (E-LES)
- ANSYS CFX R13 – Forced LES (F-LES)

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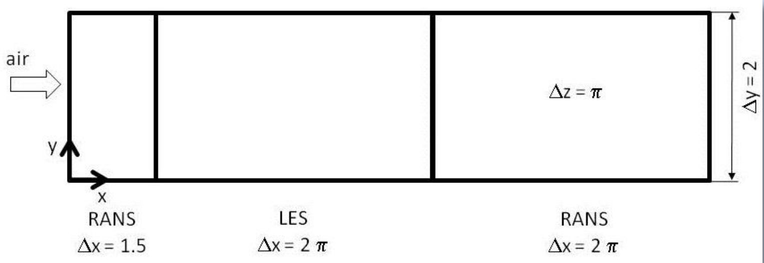
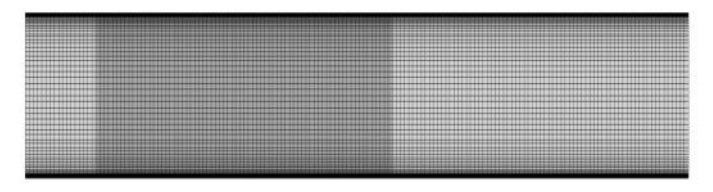
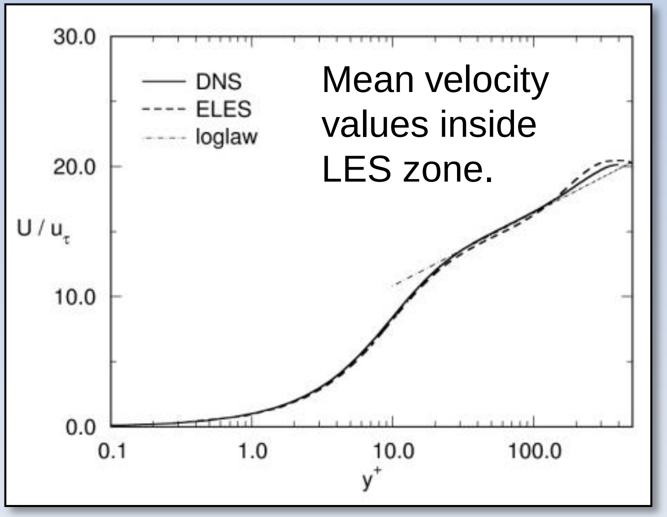
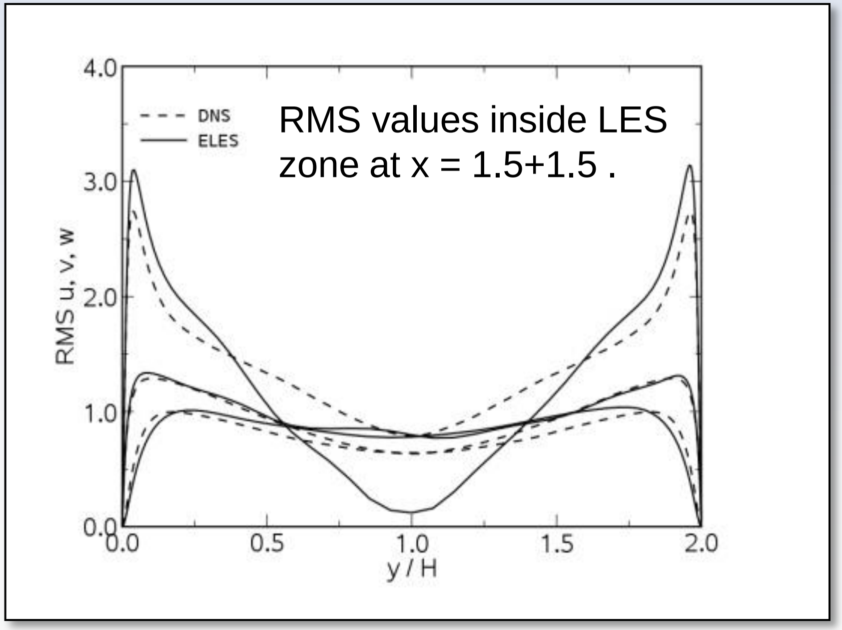
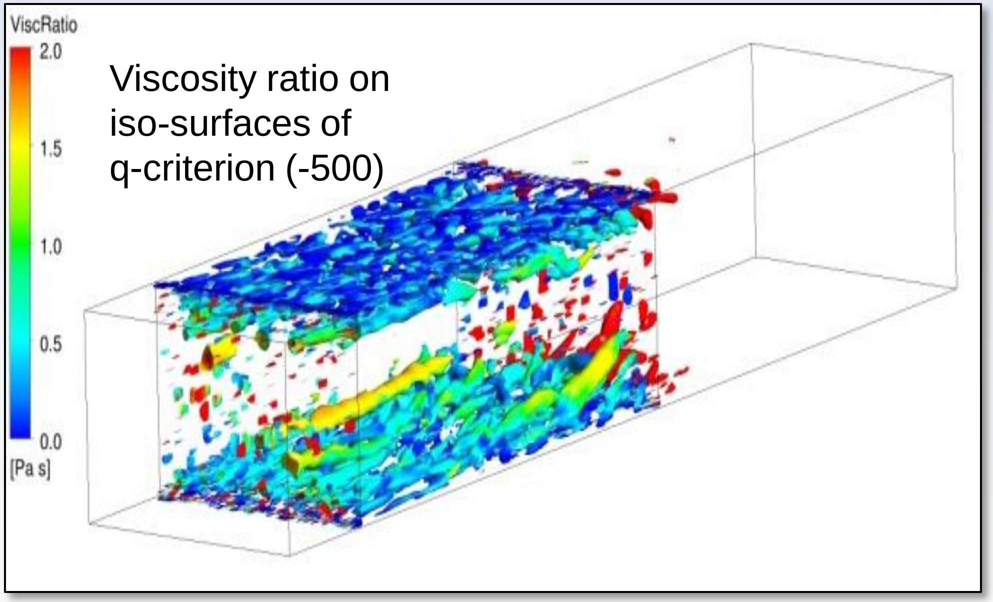
E-LES: Fully developed channel flow, Re=395 (ANSYS-Fluent)











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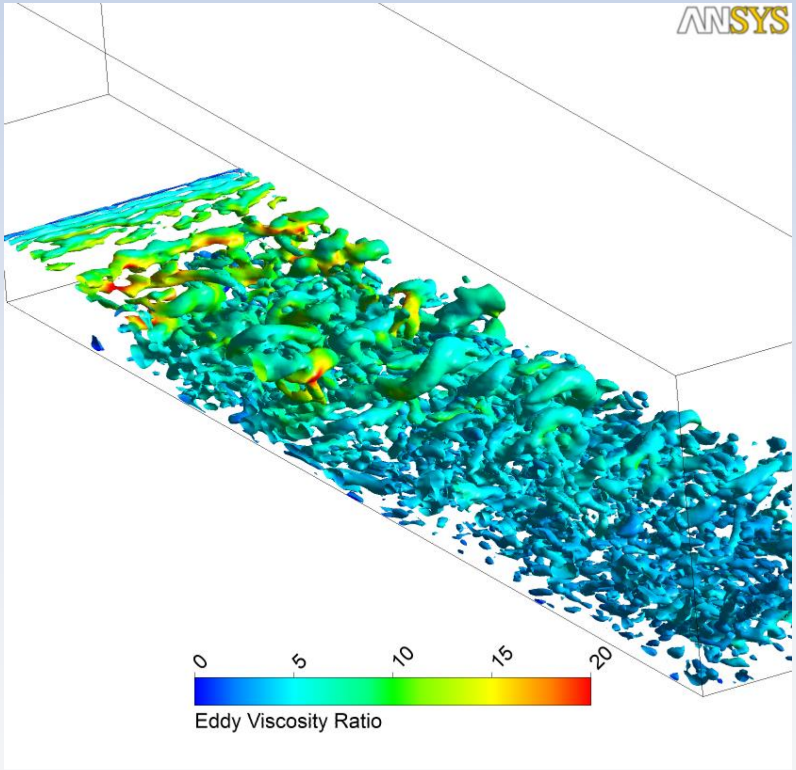
F-LES: Fully developed channel flow, Re=395 (ANSYS-CFX)

- **Forcing applied downstream of the step**
- **3D turbulent structures develop past step**
- **Turbulence becomes quickly anisotropic even though RFG is producing isotropic structures**
- **Effect comes from inherent flow instability in mixing layer past the step**



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Conclusions

- **Scale-Resolving simulations are the future of CFD in many areas**
- **The switch from RANS to LES is in most industrial cases not possible in the foreseeable future – especially wall-bounded flows pose severe problems**
- **A wide range of “hybrid” RANS-LES formulations are currently explored and some applied to industrial flows**
- **From Release 13 zonal models (explicit switch between models at pre-defined interface) will become available to industrial users**
- **Often great care is required to apply and analyze the models**

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Upcoming ANSYS Events

ANSYS Regional Conferences

Scheduled for 2010

- September 9 and 10, 2010 – Washington, D.C.
- September 13 and 14, 2010 – Houston, TX
- September 14 and 15, 2010 – Santa Clara, CA
- September 16, 2010 – Detroit, MI
- September 20, 2010 – Toronto, Ontario
- October 4, 2010 – Irvine, CA

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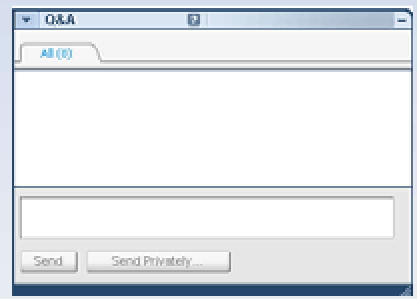
Ask the Expert – ANSYS DesignModeler to Create FE Efficient Mechanical Solid Models from CAD Geometry

To Ask a Question:

Click on the Q&A tab in the WebEx Toolbar



Webinar Recording:

Available in one week's time in the ANSYS Demo Room at www.ansys.com/demoroom

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