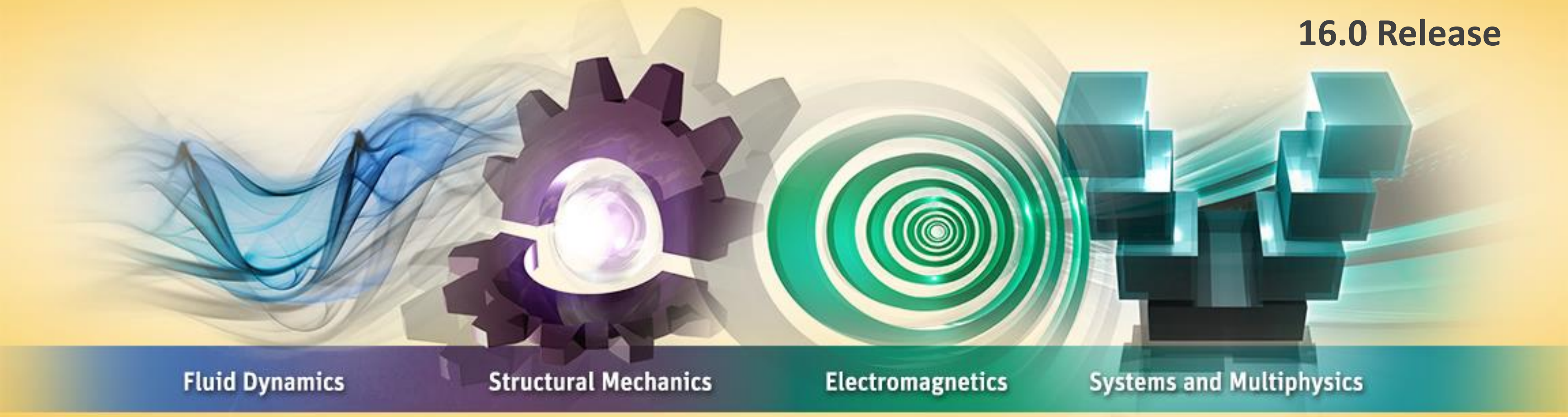
Lecture 12:
Best Practice Guide

16.0 Release



Introduction to ANSYS CFX

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Introduction

- **Lecture Theme:**
  - **The accuracy of CFD results can be affected by different types of errors. By understanding the cause of each different error type, best practices can be developed to minimize them. Meshing plays a significant role in the effort to minimize errors.**
- **Learning Aims:**
  - **Types of errors**
  - **Strategies for minimizing error**
  - **Issues to consider during mesh creation**

Motivation for Quality

- **CFD-Results are used for many different stages of the design process:**
  - **Design & optimization of components and machines**
  - **Safety analyses**
  - **Virtual prototypes**

- **When undertaking a CFD model, consideration should be given to the purpose of the work:**
  - **What will the results be used for?**
  - **What level of accuracy will be needed**?

Different Sources of Error

- Different types of error combine to affect solution accuracy. In order of magnitude:
  - Round-off errors
    - Computer is working to a certain numerical precision
  - Iteration errors
    - Difference between ‘converged’ solution and solution at iteration ‘n’
  - Discretization errors
    - Difference between converged solution on current grid and that on infinitely fine grid
  - Model errors
    - Difference between ‘exact’ solution of model equations and reality
  - Systematic errors
    - Due to approximations/assumptions

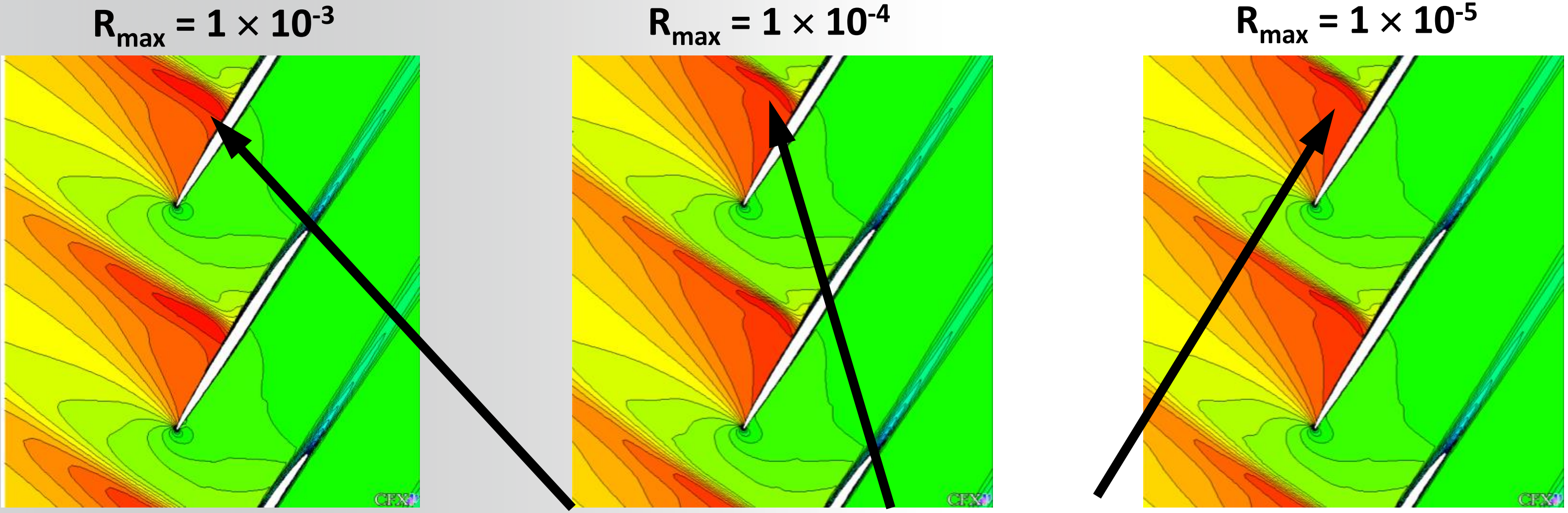
Round-Off Error

- **Inaccuracies caused by machine round-off:**
  - **Large differences in length scales**
  - **Large variable range**
  - **High grid aspect ratios**

- **Procedure:**
  - **Check above criteria**
  - **Define target variables**
  - **Calculate with:**
    - **Single-precision**
    - **Double-precision**
  - **Compare target variables**

Iteration Error – Example

- Iteration errors is the difference between ‘converged’ solution and solution at iteration ‘n’
- Example of a 2D compressor cascade



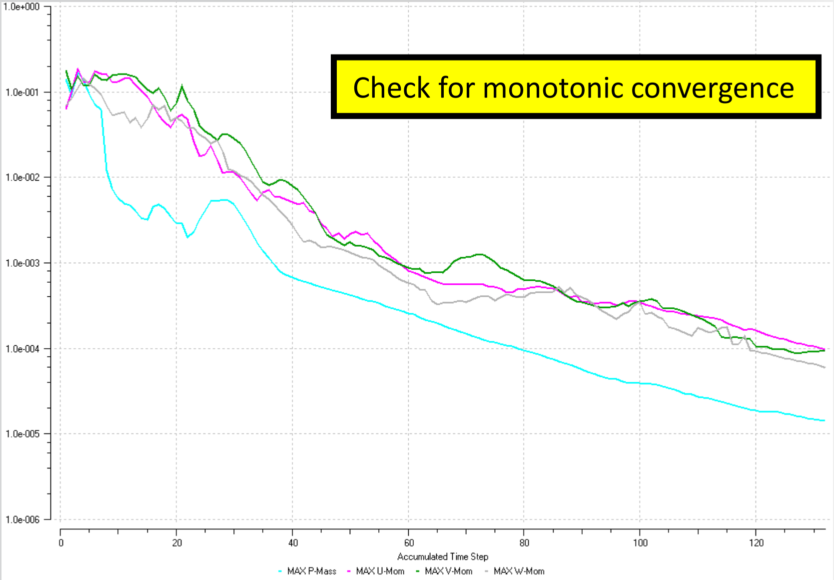
$R_{max} = 1 \times 10^{-3}$

$R_{max} = 1 \times 10^{-4}$

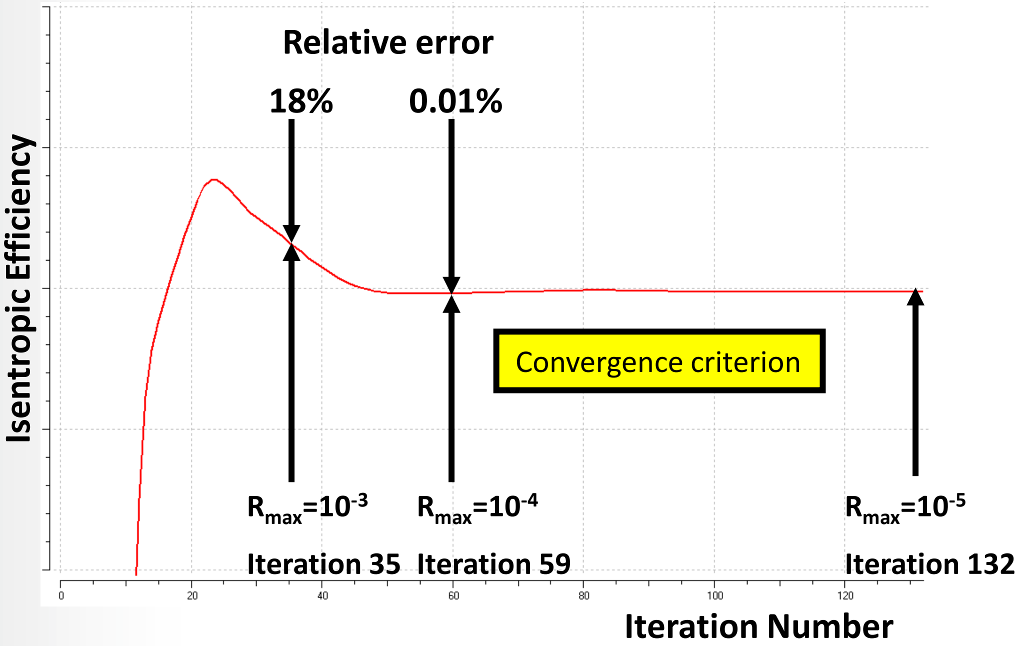
$R_{max} = 1 \times 10^{-5}$

Change of Pressure Distribution

Iteration Error – Example



Check for monotonic convergence



Relative error

18%

0.01%

$R_{max}=10^{-3}$

Iteration 35

$R_{max}=10^{-4}$

Iteration 59

$R_{max}=10^{-5}$

Iteration 132

Convergence criterion

Iteration Error - Best Practice

- **Define target variables:**
  - Head rise
  - Efficiency
  - Mass flow rate…
- **Select convergence criterion (e.g. residual norm)**
- **Plot target variables as a function of convergence criterion**
- **Set convergence criterion such that value of target variable becomes “independent” of convergence criterion**
- **Check for monotonic convergence**
- **Check convergence of global balances**

Discretization Error

- All discrete methods have solution errors:
  - Finite volume methods
  - Finite element methods
  - Finite difference methods...
- Difference between solution on a given grid and “exact” solution on an infinitely fine grid.
  - Exact solution not possible

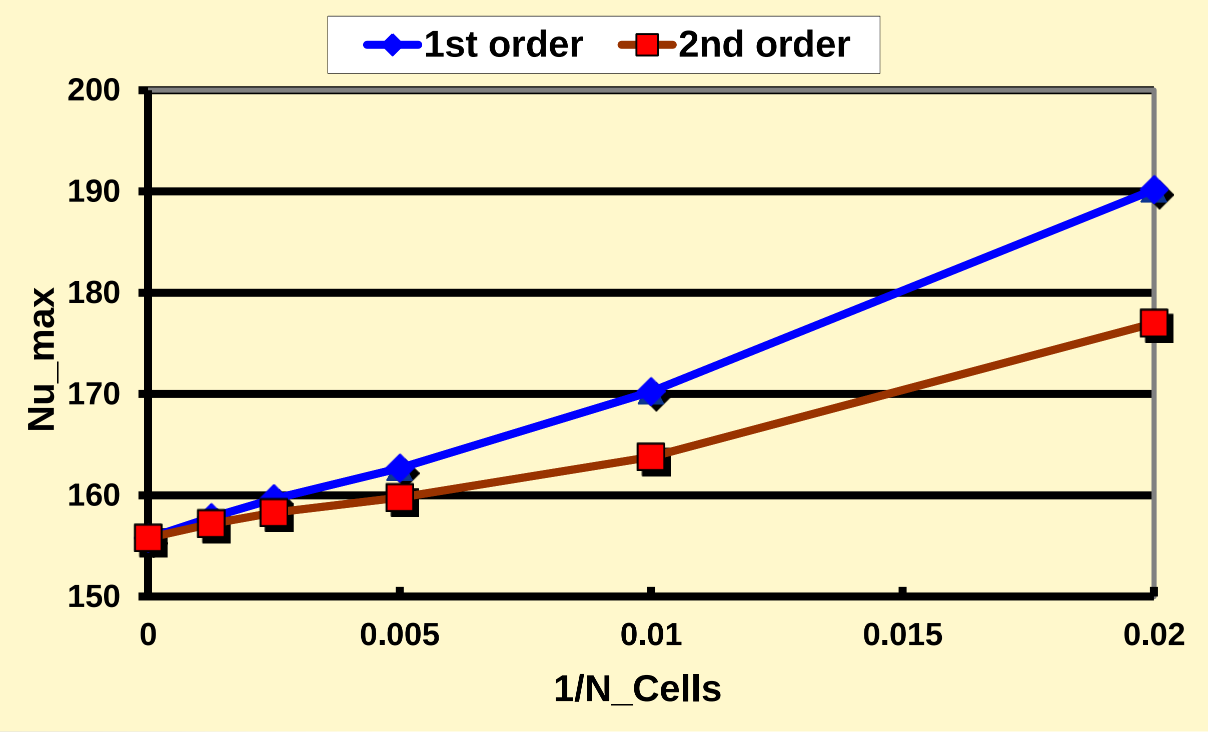
$$\boxed{e_h = f_h - f_{ex}}$$

- Estimation of error
  - Compare solutions obtained with different discretization schemes
  - Compare solutions on meshes of different refinement

Discretization Error Estimation

Impinging jet with heat transfer

- **2-D, axisymmetric**
- **Compared Grids:**
  - 50 × 50 → 800 × 800
- **SST turbulence model**
- **Discretization schemes:**
  - 1^{st} order
  - 2^{nd} order
- **Target quantity**
  - Max Nusselt Number
- **Solution on infinitely fine mesh = 155.8**

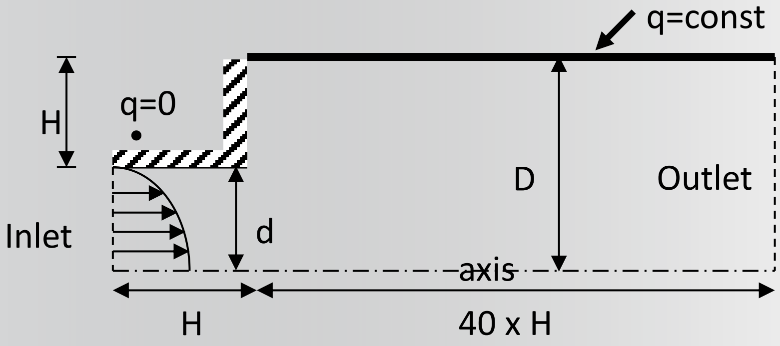


Model Errors

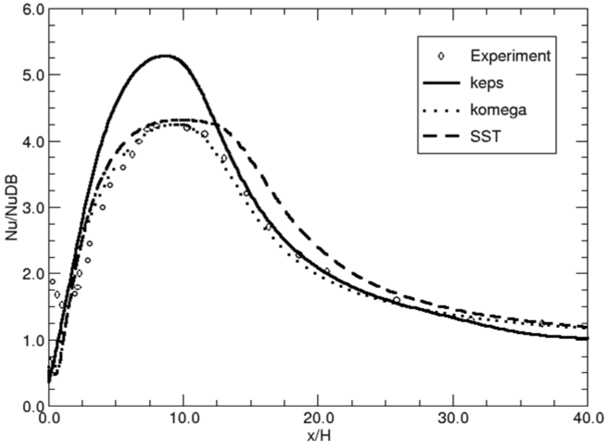
- Inadequacies of (empirical) mathematical models:
  - Base equations (Euler vs. RANS, steady-state vs. unsteady-state, …)
  - Turbulence models
  - Combustion models
  - Multiphase flow models…
- Discrepancies between data and calculations remain, even after all numerical errors have become insignificant

Example: Pipe Expansion with Heat Transfer

- Reynolds Number $Re_D = 40750$
- Fully Developed Turbulent Flow at Inlet
- Experiments by Baughn et al. (1984)

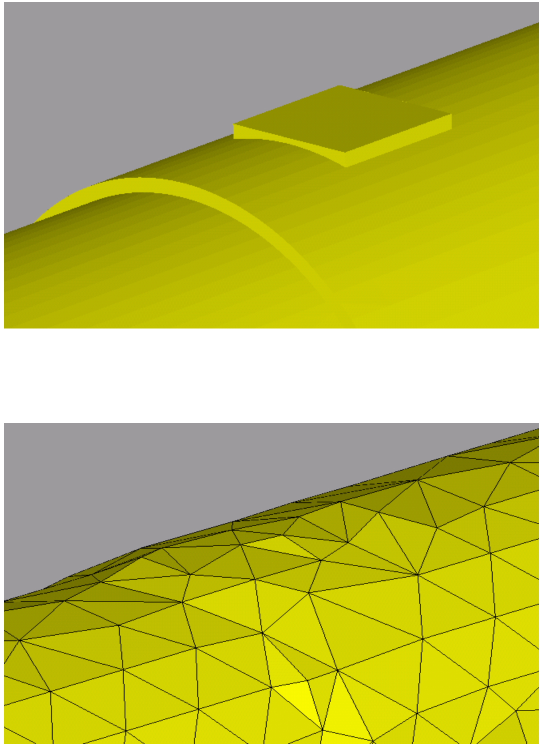


- Plot of dimensionless distance vs. normalised Nu
- Best agreement with SST and k-ω
- Capture flow recirculation zones more accurately



Systematic Errors

- **Discrepancies remain**
  - **even if numerical and model errors are insignificant**
- **Systematic errors due to approximations of:**
  - **Geometry**
  - **Component vs. machine**
  - **Boundary conditions**
  - **Fluid and material properties…**
- **Try to understand application and physics**
- **Document and defend assumptions**
- **Perform uncertainty analysis**



Meshing Best Practice

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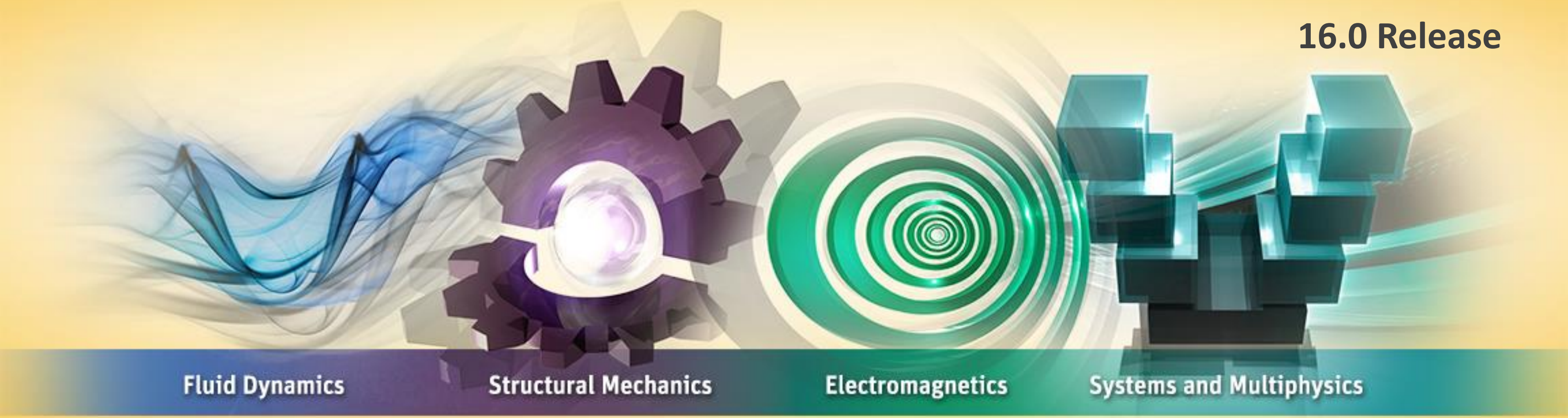

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Meshing Best Practice Guidelines

- **Effects of low mesh quality:**
  - Discretization errors
  - Round-off errors → Poor CFD results
  - Convergence difficulties → Non-reliable CFD results

- **Choose the appropriate Meshing strategy**
  - Hex or Tet+Prism or Hybrid

Meshing Best Practice Guidelines

Choosing your mesh strategy depends on

1.ACCURACY

Desired mesh quality
Minimum orthogonality and maximum aspect ratio that you can tolerate

2. EFFICIENCY

Desired cell count
Low cell count for resolving overall flow features vs High cell count for greater details

3. EASINESS TO GENERATE

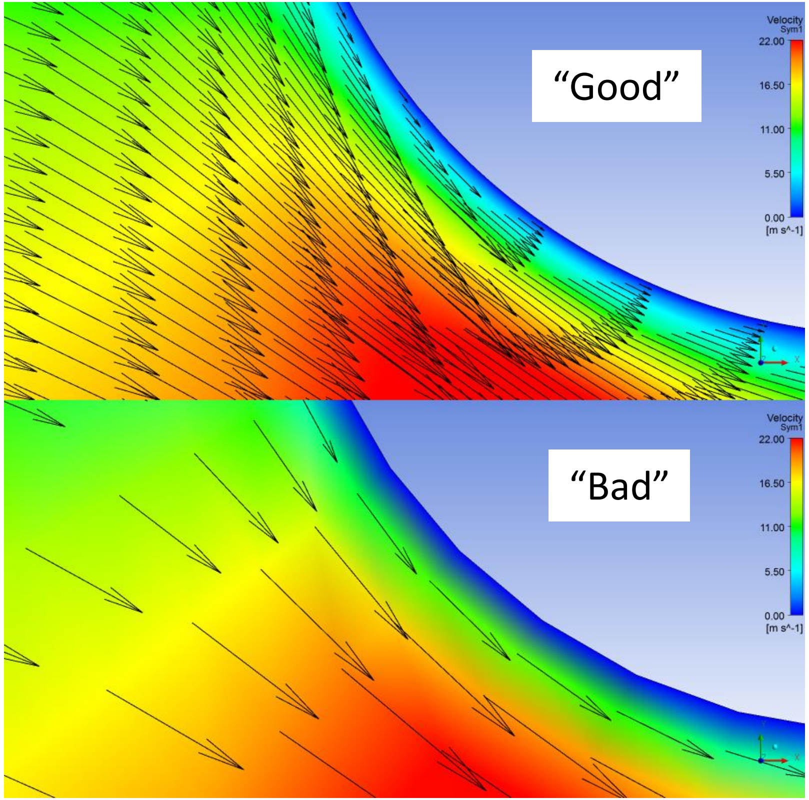
Time available
Faster Tet-dominant mesh vs crafted Hex/hybrid mesh with lower cell count

Goal: Find the best compromise between accuracy, efficiency and easiness to generate

Meshing: Capture Flow Physics

Grid must be able to capture important physics:

- Boundary layers
  - Velocity and temperature
  - 10-15 elements
  - Expansion ratios ≤ 1.2 … 1.3
  - y+ ≈ 1 for heat transfer and transition modeling
- Heat transfer
- Wakes, shock
- Flow gradients

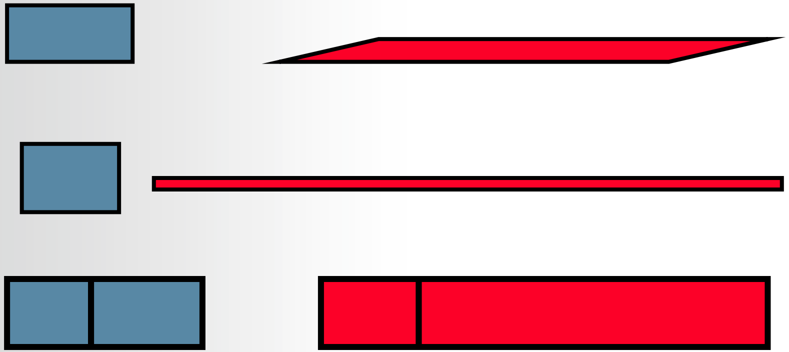


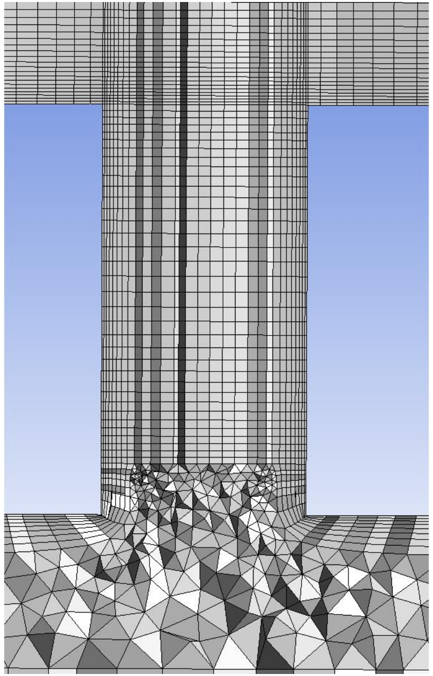
Mesh Quality

Good **Not Good**

A good mesh depends on :

- **Cell not too distorted**
- **Cell not too stretched**
- **Smooth Cells transition**

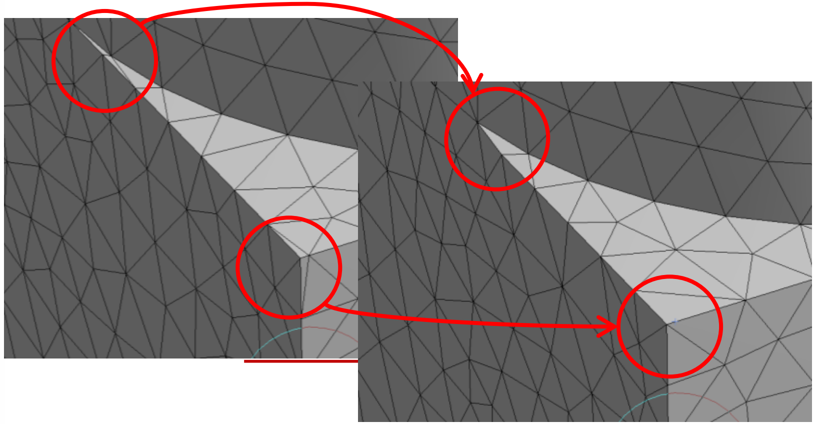




Mesh Quality

Grid generation:

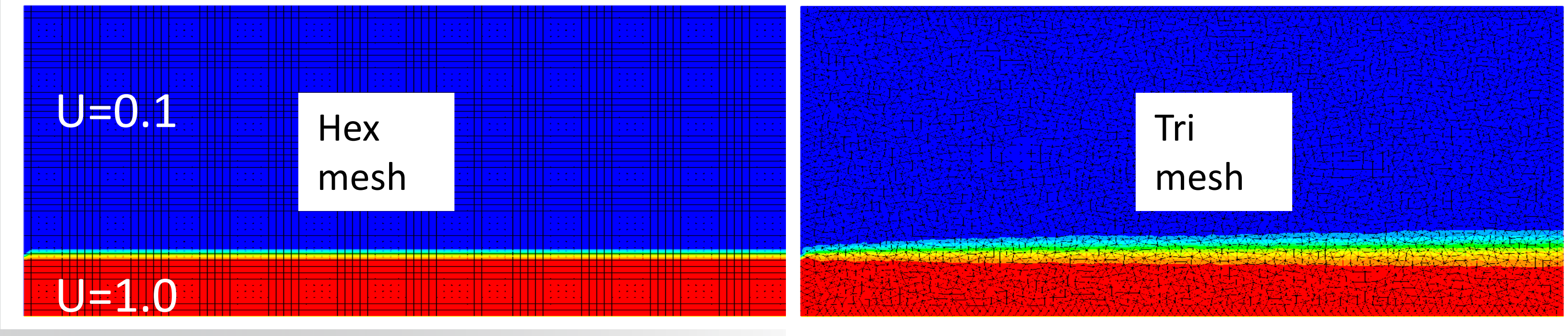
- Orthogonal Quality (ANSYS Meshing) > 0.1 (accuracy, convergence)
- Aspect ratios
  - < 20 to 50 away from boundary
  - Can be much larger in unimportant regions
  - Can be very much larger in well resolved boundary layers, e.g. 10^5 - 10^6
- Expansion ratios < 1.3
- Angle between grid face & flow vector



Hex vs Tet Mesh : Accuracy comparison

- **Direction of the flow well known**

  ⇨ Quad/Hex aligned with the flow are more accurate than Tri with the same interval size

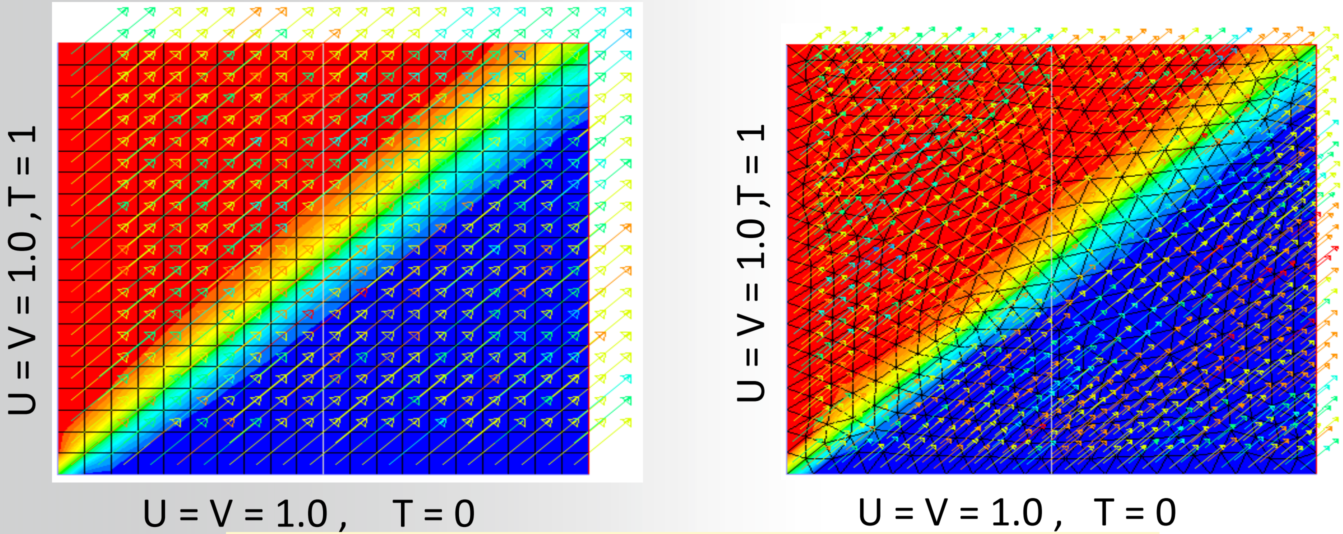


Contours of axial velocity magnitude for an inviscid co-flow jet

Hex vs Tet Mesh : Accuracy comparison

- **For complex flows without dominant flow direction, Quad and Hex meshes lose their advantage**

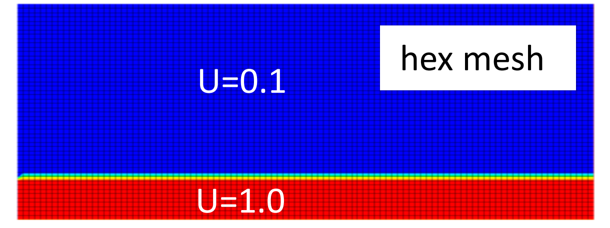
⇨ **Quad & Tri equivalent**

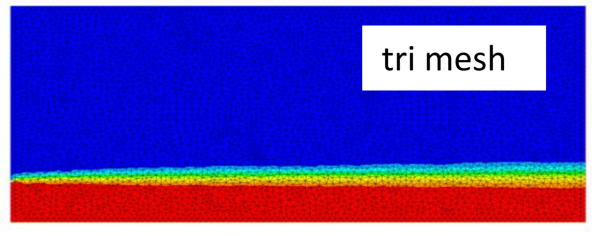


Contours of temperature for inviscid flow

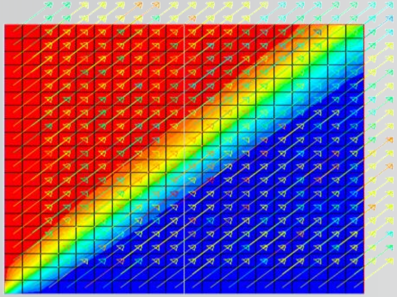
Hex vs Tet Mesh : Accuracy comparison

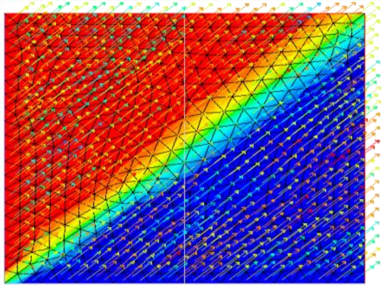
- Where the direction of the flow well known, e.g. in shear layers, tri elements are more prone to numerical diffusion than flow-aligned prism and hex meshes





- For complex flows without dominant flow direction, quad and hex meshes loose their advantage in accuracy





Summary

- **Try to 'understand' application and physics of the application**
- **Distinguish between numerical, model and other errors**
- **Document and defend assumptions**
  - Geometry
  - Boundary conditions
  - Flow regime (laminar, turbulent, steady-state, unsteady-state, …)
  - Model selection (turbulence, …)
- **Sources of systematic error**
  - Approximations
  - Data
- **Accuracy expectations vs. assumptions?**

Resources

- **ERCOFTAC SIG: ‚Quantification of Uncertainty in CFD‘**
- **Roache, P. J., *Verification and Validation in Computational Science and Engineering*, Hermosa Publishers, 1998**
- **ANSYS Best Practice Guidelines**

Workshop 03 Airfoil – Best Practice Study

- **For the simulation of flow round an airfoil, investigate the impact of:**
  - Round-Off errors
  - Iterations errors
  - Discretization errors
  - Modelling errors