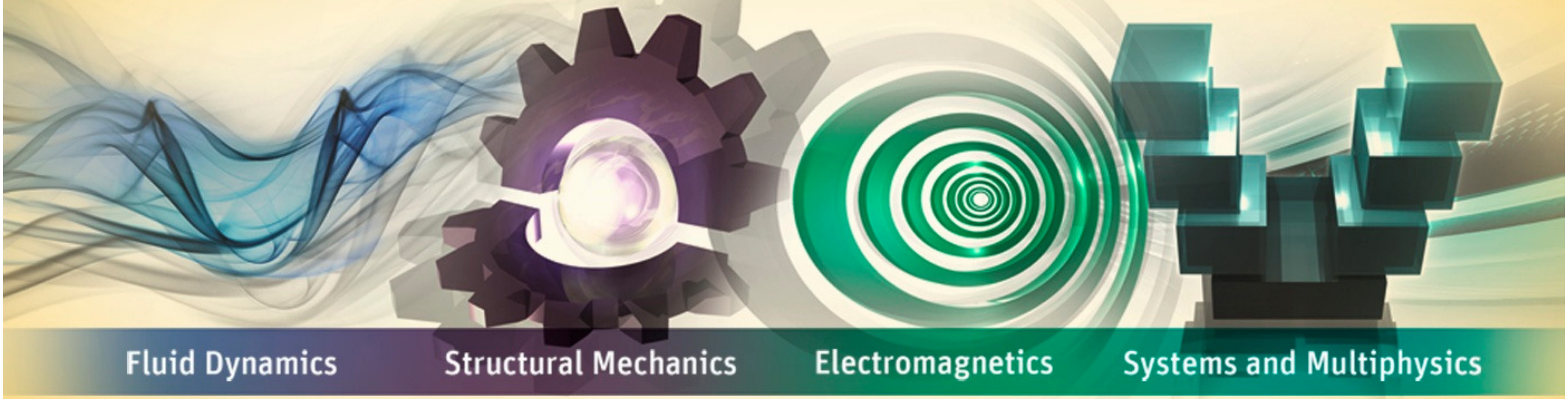
ANSYS

Realize Your Product Promise™

Lecture 9
Best Practice Guidelines

14. 0 Release



Introduction to ANSYS FLUENT

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:

You will learn:

- Four different types of errors
- Strategies for minimizing error
- Issues to consider during mesh creation such as quality and cell type
- Best practices for mesh creation

Learning Objectives:

You will understand the causes of error in the solution and how to build the mesh and perform the simulation in a manner that will minimize errors

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

There are several different factors that combine to affect the overall solution accuracy. In order of magnitude:

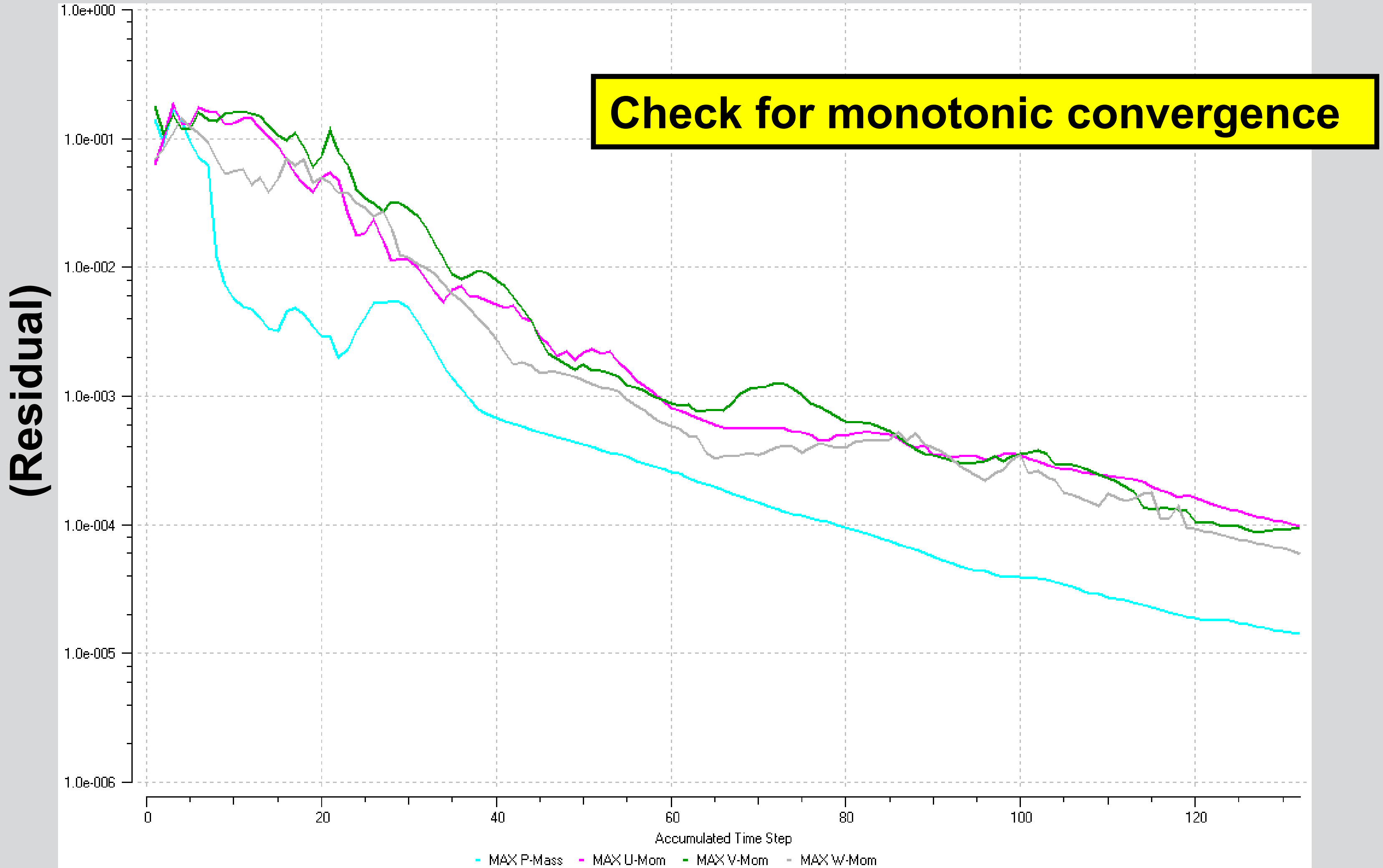
- **Round-off errors**
  - Computer is working to a certain numerical precision
- **Iteration errors**
  - Difference between ‘converged’ solution and solution at iteration ‘n’
- **Solution errors**
  - Difference between converged solution on current grid and ‘exact’ solution of model equations
  - ‘Exact’ solution → Solution on infinitely fine grid
- **Model errors**
  - Difference between ‘exact’ solution of model equations and reality (data or analytic solution)

Round-Off Error

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

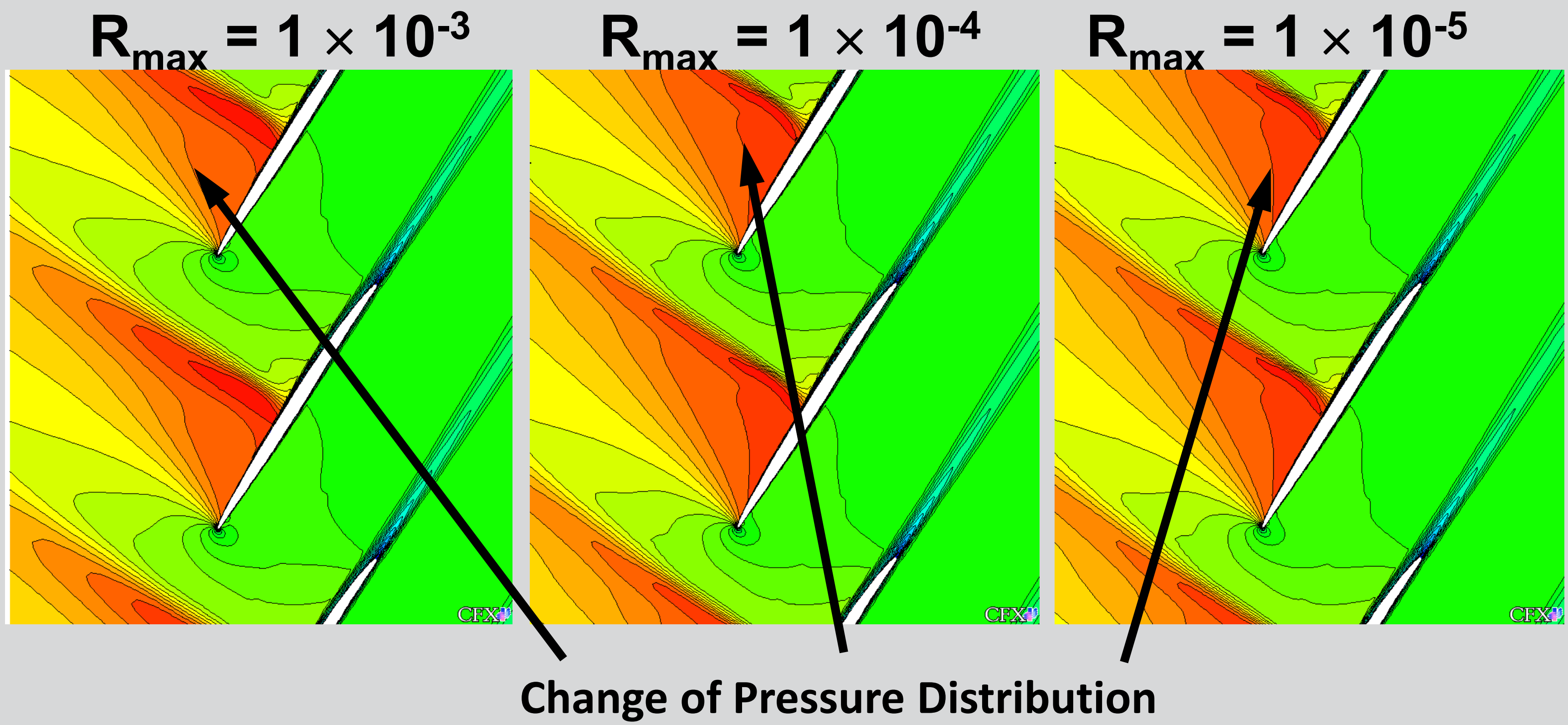
- **Procedure:**
  - Check above criteria
  - Define target variables
  - Calculate with:
    - Single-precision
    - Double-precision
  - Compare target variables

Iteration Error – Example



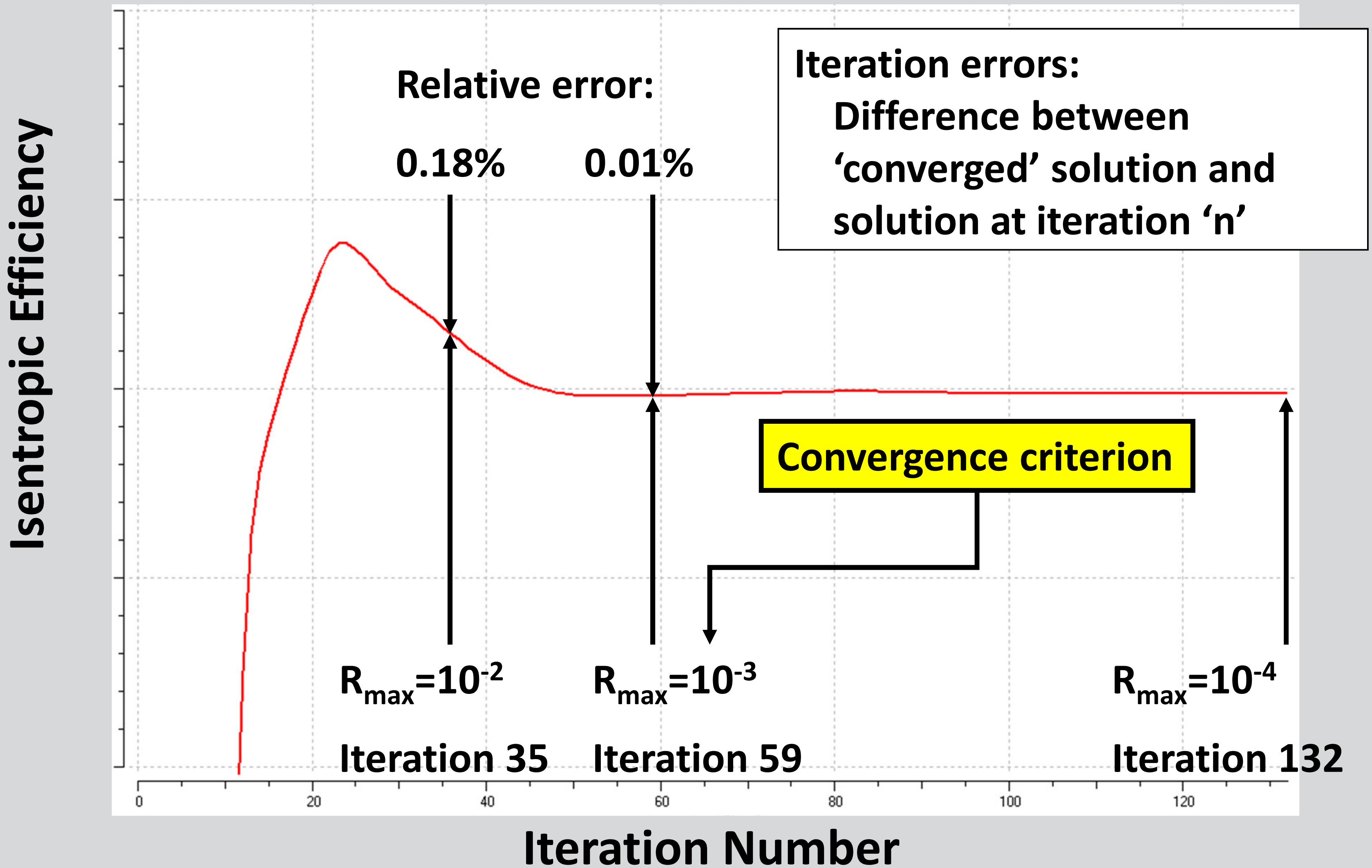
Iteration Error – Example

- **Effect of different Residual limits during convergence:**
  - 2D Compressor cascade
  - 2nd order

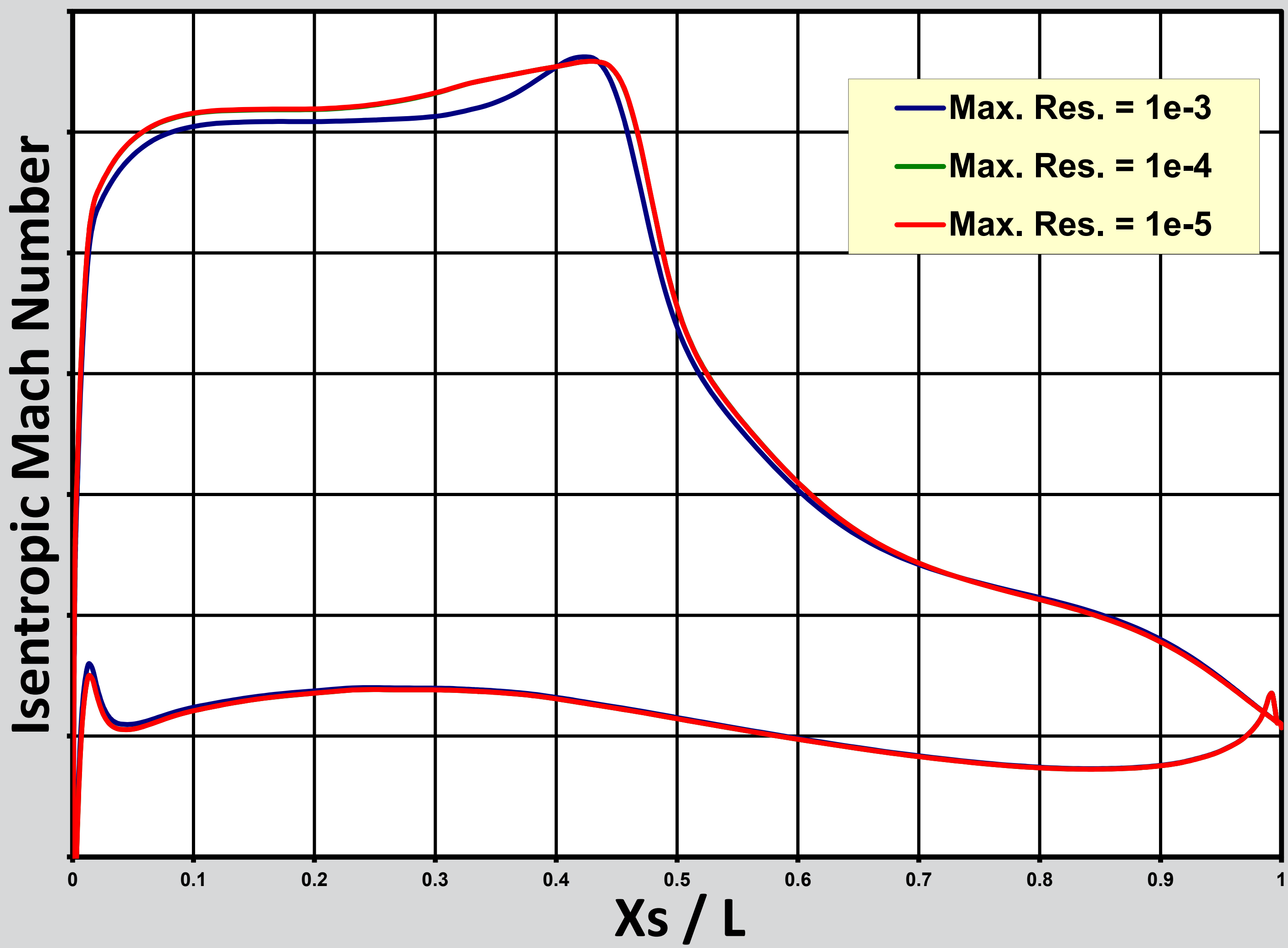


Introduction | Error Types | Best Practices for Meshing | Summary

Iteration Error – Example



Iteration Error – Example



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 <u>discrete</u> methods have solution errors:**
  - Finite volume methods
  - Finite element methods
  - Finite difference methods
  - ...

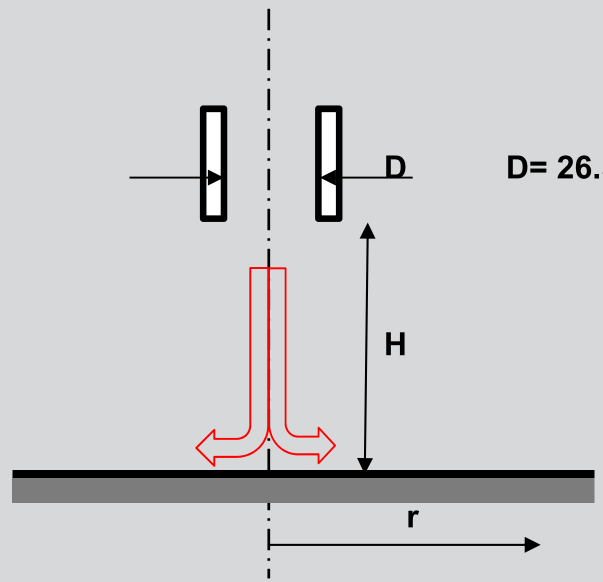
- **Difference between solution on a given grid and “exact‘ solution on an infinitely fine grid**

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

- **Exact solution not available → <u>Discretization error estimation</u>**

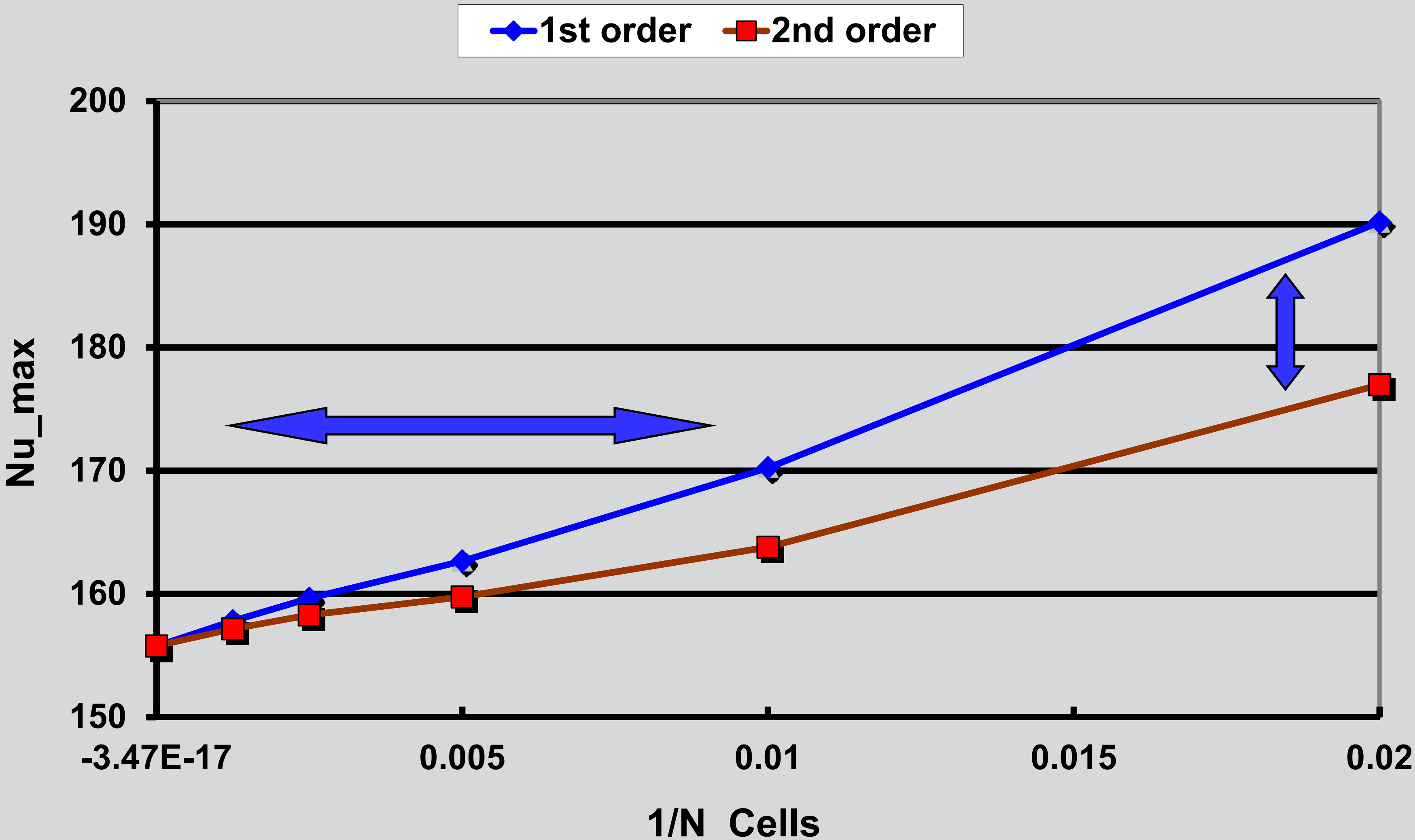
Discretization Error Estimation

- **Impinging jet flow with heat transfer**
- **2-D, axisymmetric**
- **Compared Grids:**
  – 50 × 50 → 800 × 800
- **SST turbulence model**
- **Discretization schemes:**
  – 1st order Upwind
  – 2nd order Upwind



- **Target quantities:**
  – **Heat transfer**
  – **Maximum Nusselt number**

Discretization Error Estimation



Discretization Error Estimation

Grid	Nu		Error	
	1st order	2nd order	1st order	2nd order
50 × 50	190.175	176.981	22.1 %	13.6 %
100 × 100	170.230	163.793	9.3 %	5.1 %
200 × 200	162.664	159.761	4.4 %	2.6 %
400 × 400	159.646	158.296	2.3 %	1.4 %
800 × 800	157.808	157.168	1.1%	0.7 %
∞ × ∞	155.751	155.777		

Discretization Error Estimation

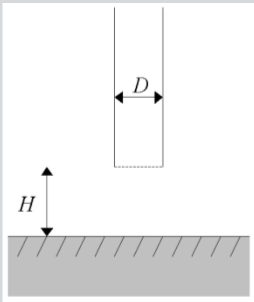
- **Practical alternative**:
  - Compare solutions obtained with different discretization schemes
  - Compare solutions at regional refined meshes

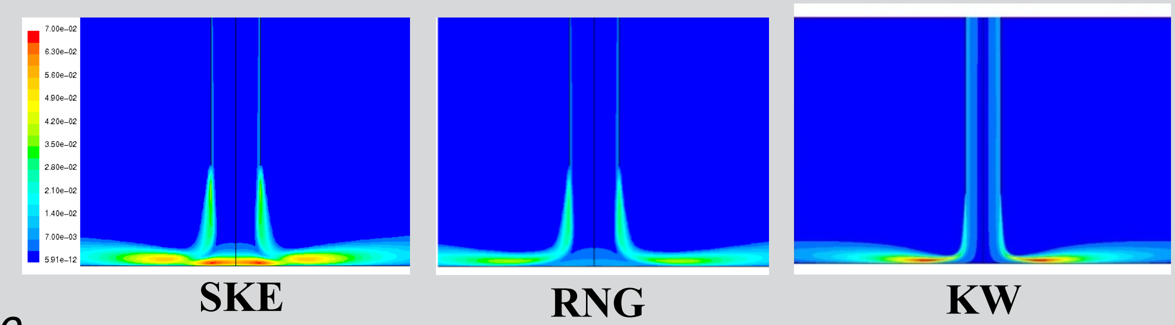
Model Errors

- **Inadequacies of (empirical) mathematical models:**
  - Base equations (Euler vs. RANS, steady-state vs. unsteady-state, …)
  - Turbulence models
  - Combustion models
  - Multiphase flow models
  - …

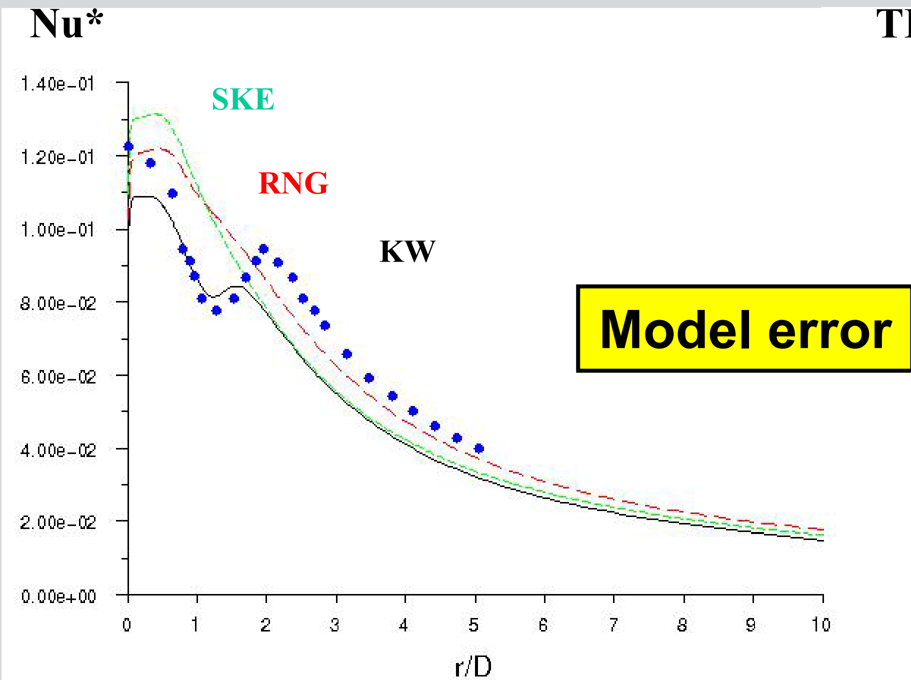
- **Discrepancies between data and calculations remain, even after all numerical errors have become insignificant!**

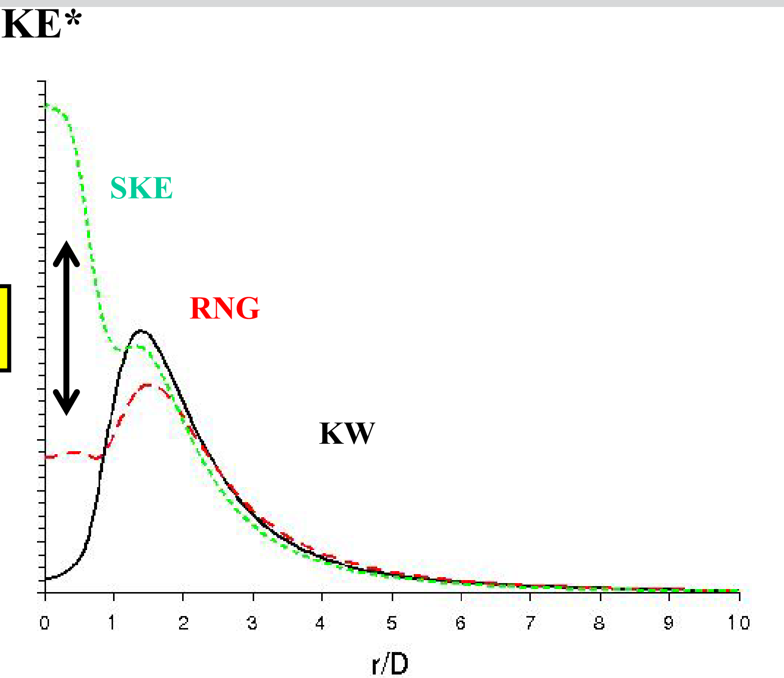
Model Error: Impinging Jet





Results: H/D=2, RE=23 000

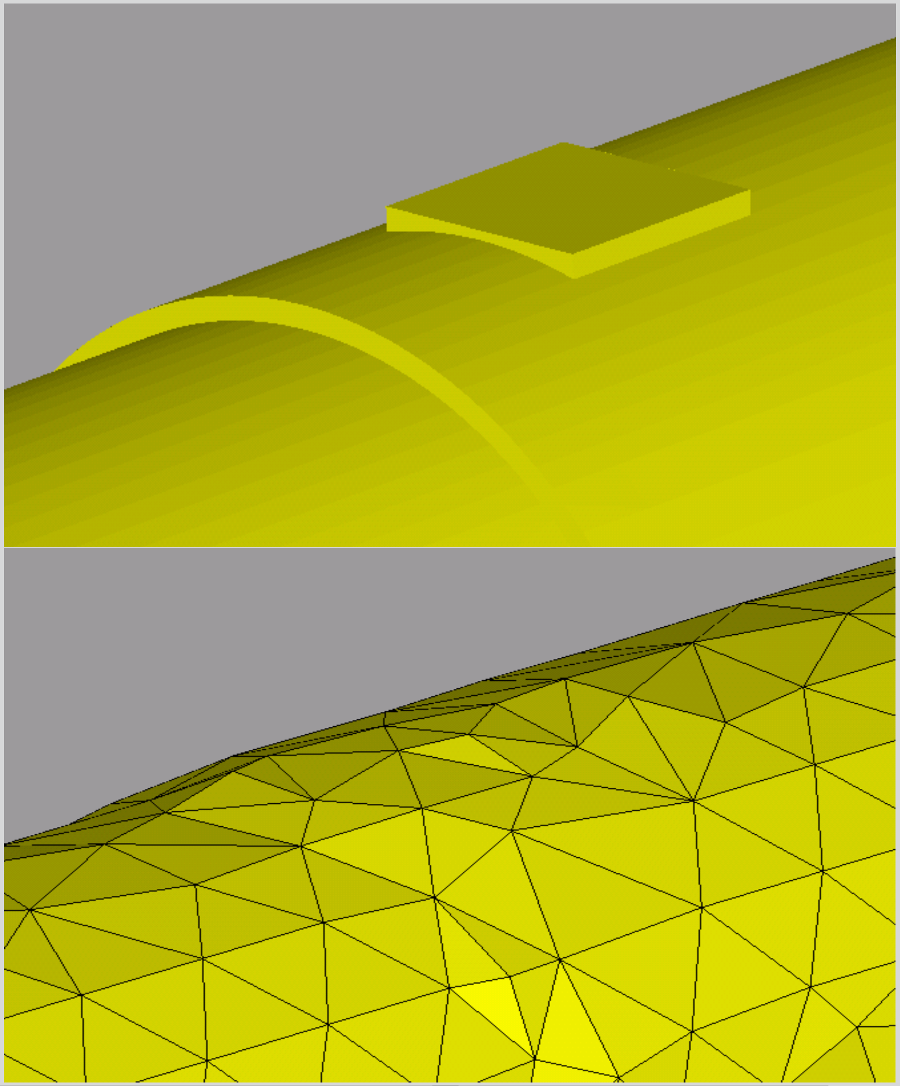




Introduction | Error Types | Best Practices for Meshing | Summary

Systematic Errors

- **Discrepancies remain**
  - **even if numerical and model errors are insignificant**
- **'Systematic errors':**
  - **Approximations of:**
    - Geometry
    - Component vs. machine
    - Boundary conditions
    - Fluid and material properties, …
- **Try to 'understand' application and physics**
- **Document and defend assumptions !**
- **Perform <u>uncertainty analysis</u>**



Meshing Best Practice Guidelines

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

- **Choose the appropriate Meshing strategy**
  - Hex or Tet+Prism or Hybrid (use of non-conformal interfaces)
  - Scalable grid quality (consistent grid quality on mesh refinement)

Meshing Best Practice Guidelines

Choosing your mesh strategy depends on

1.ACCURACY	2. EFFICIENCY	3. EASINESS TO GENERATE
Desired mesh quality What is the maximum skewness and aspect ratio you can tolerate?	**Desired cell count** - Low cell count for resolving overall flow features vs High cell count for greater details	**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
  - Heat transfer
  - Wakes, shock
  - Flow gradients

- **Boundary layers:**
  - Velocity and temperature
  - 10-15 elements
  - Expansion ratios:
    - $\leq 1.2 \ldots 1.3$
  - y+ $\approx$ 1 for heat transfer and transition modeling

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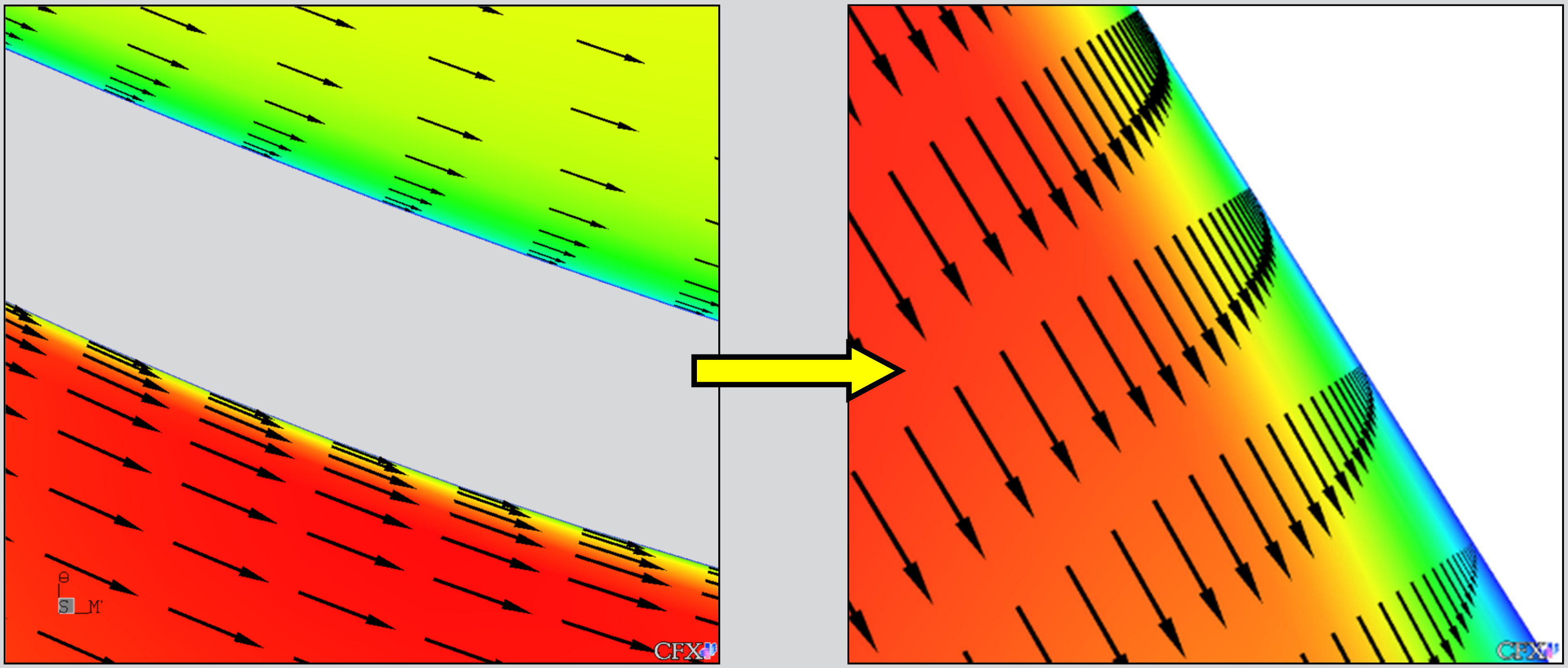
Meshing: Capture Flow Physics

- **Example: Velocity profiles at airfoil**

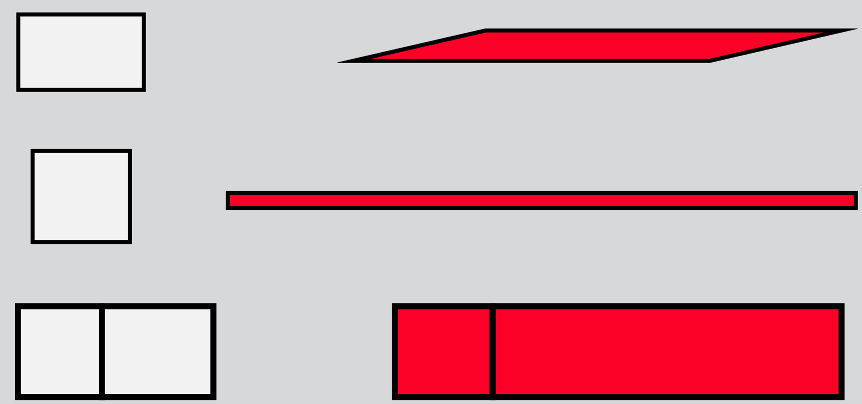
“Bad” **“Good”**



Mesh Quality

- **A good mesh depends on :**
  - **Cell not too distorted**
  - **Cell not too stretched**
  - **Smooth Cells transition**

Good **Not Good**



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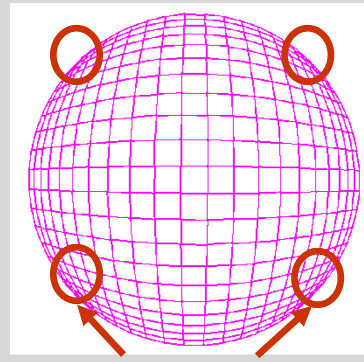
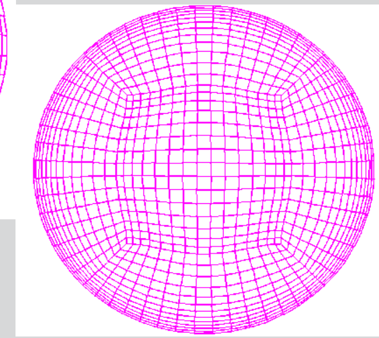
Mesh Quality

- **Grid generation:**
  - Scalable grids
  - Skewness < 0.9 (accuracy, convergence)
  - Aspect ratios < 100
  - Expansion ratios < 1.5 …2
  - Capture physics based on experience (shear layers, shocks)
  - Angle between grid face & flow vector

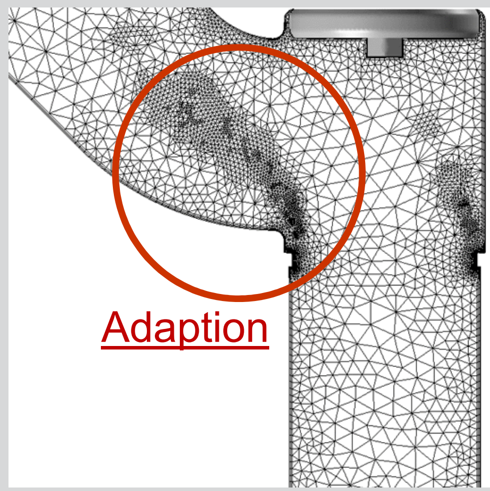
- **Grid refinement:**
  - Manual, based on error estimate
  - Automatic adaptive based on ‘error sensor’



Bad cells

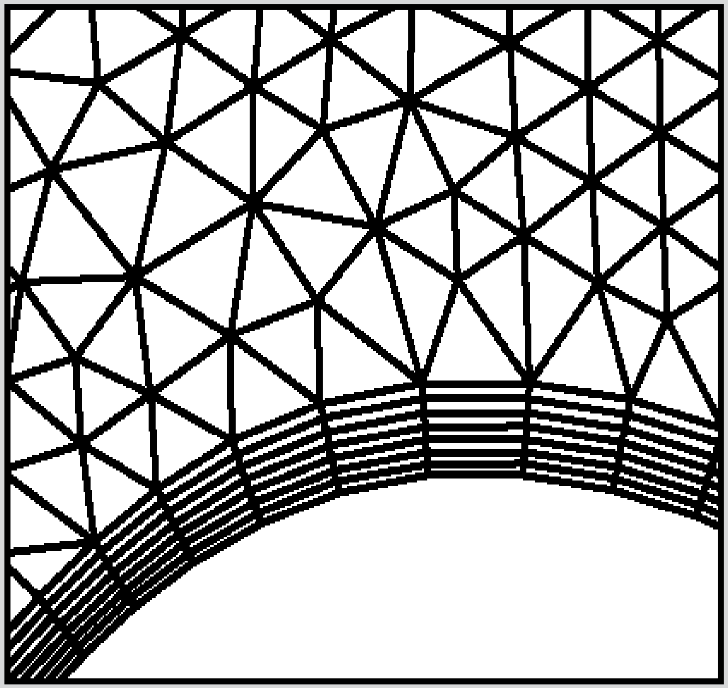


No Bad cells

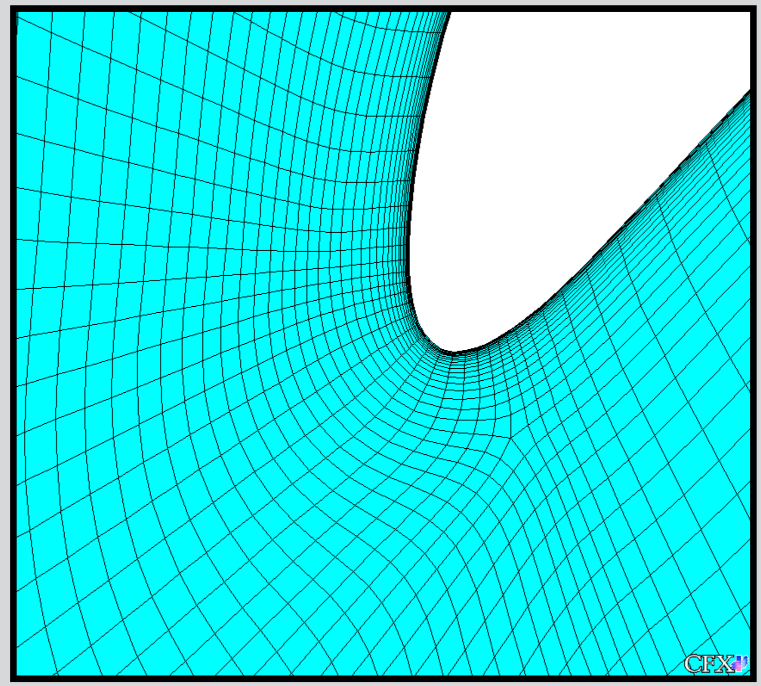


Mesh Quality

- **Avoid sudden changes in mesh density**



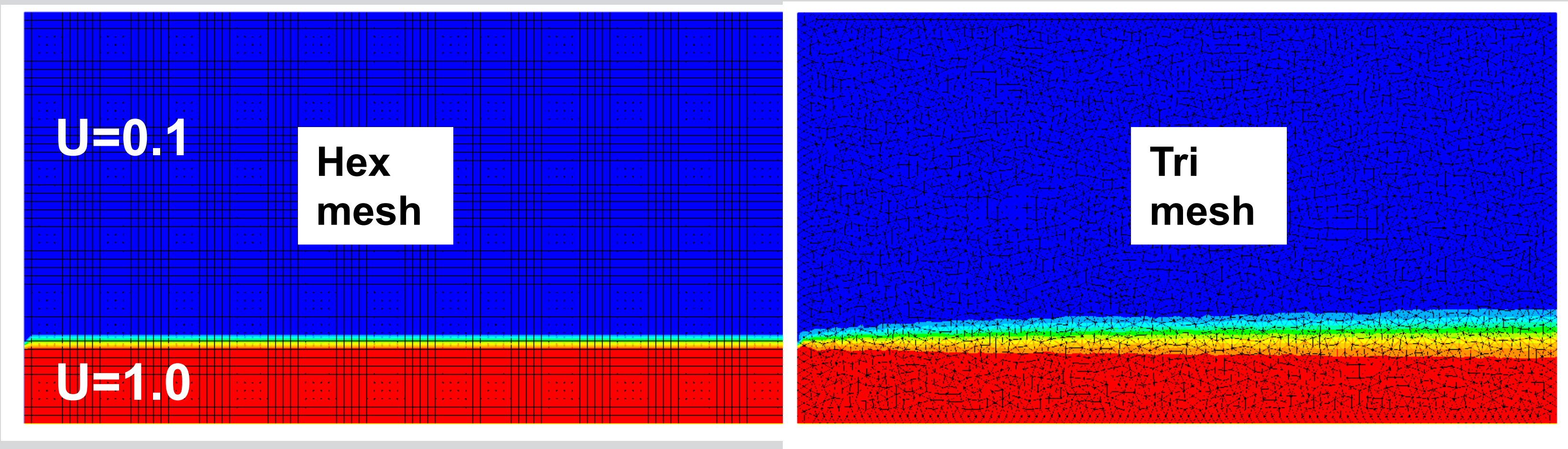
Not good



Good

Hex vs Tet Mesh : Accuracy comparison

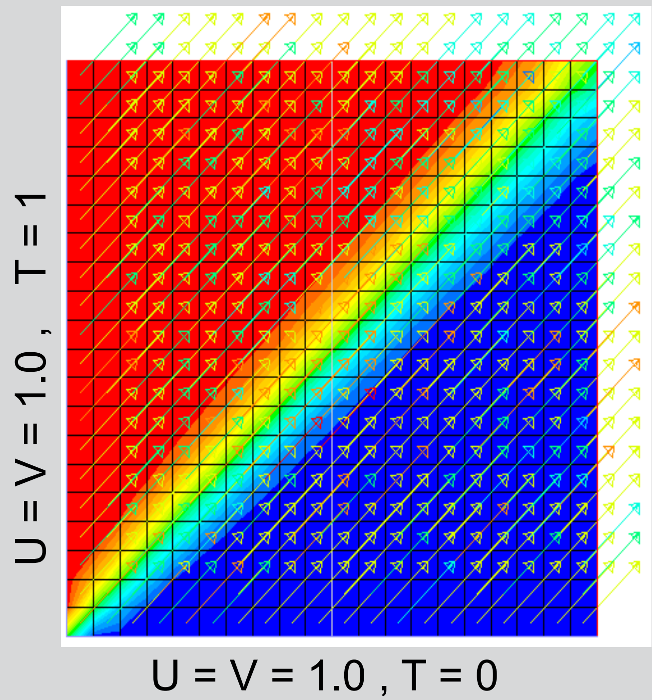
- **Direction of the flow well known**
  ⇨ Quad/Hex aligned with the flow are more accurate than Tri with the same interval size

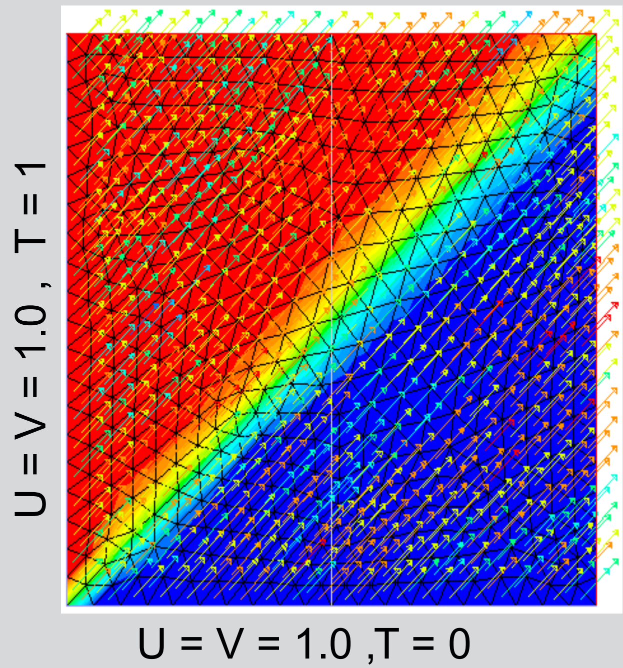


Contours of axial velocity magnitude for an inviscid co-flow jet

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

Introduction | Error Types | **Best Practices for Meshing** | Summary

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?**

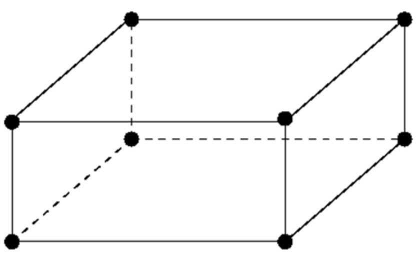
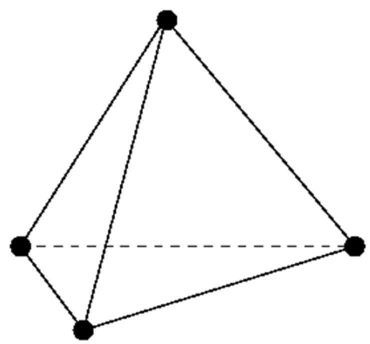
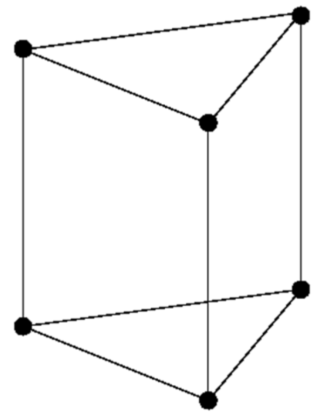
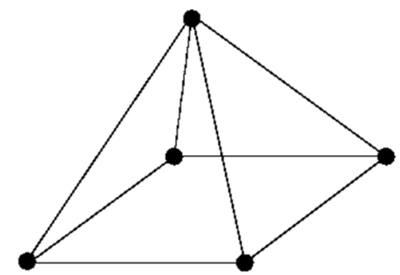
Resources

- **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**

Appendix

Element Types

- **Common 3-D element types:**

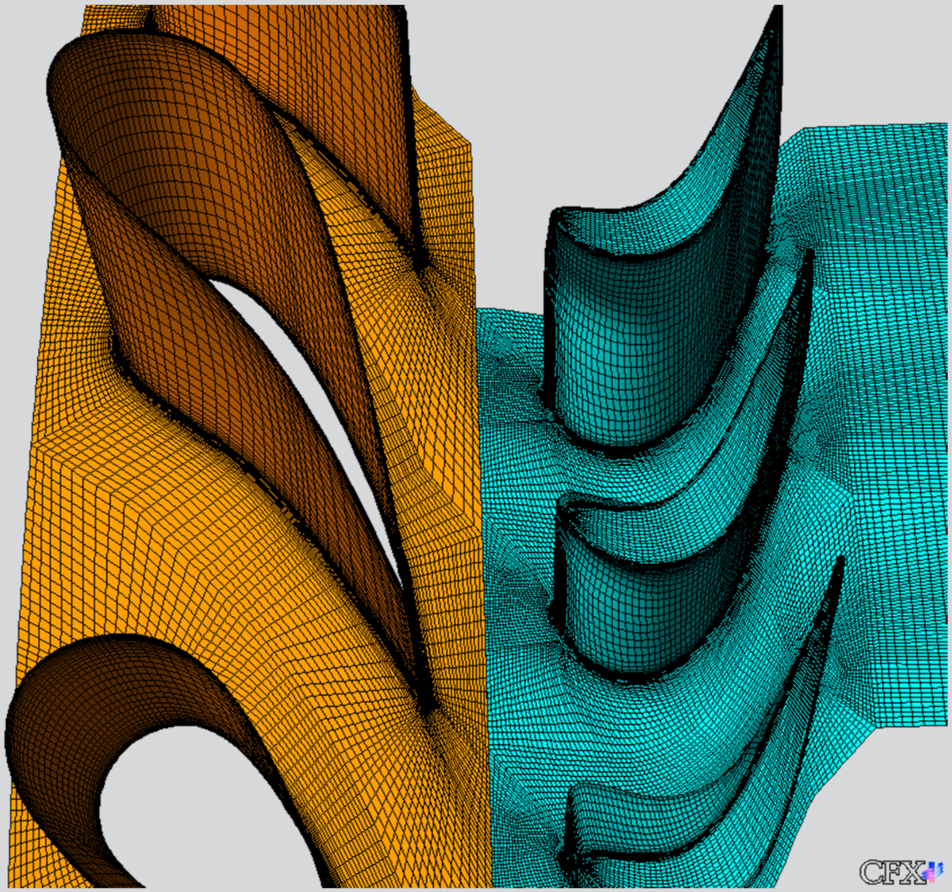
Hexahedron (hex)	Tetrahedron (tet)	Prism	Pyramid
			

- **General polyhedra, …**
- **Difference between control volumes & elements**

Elements: Hex

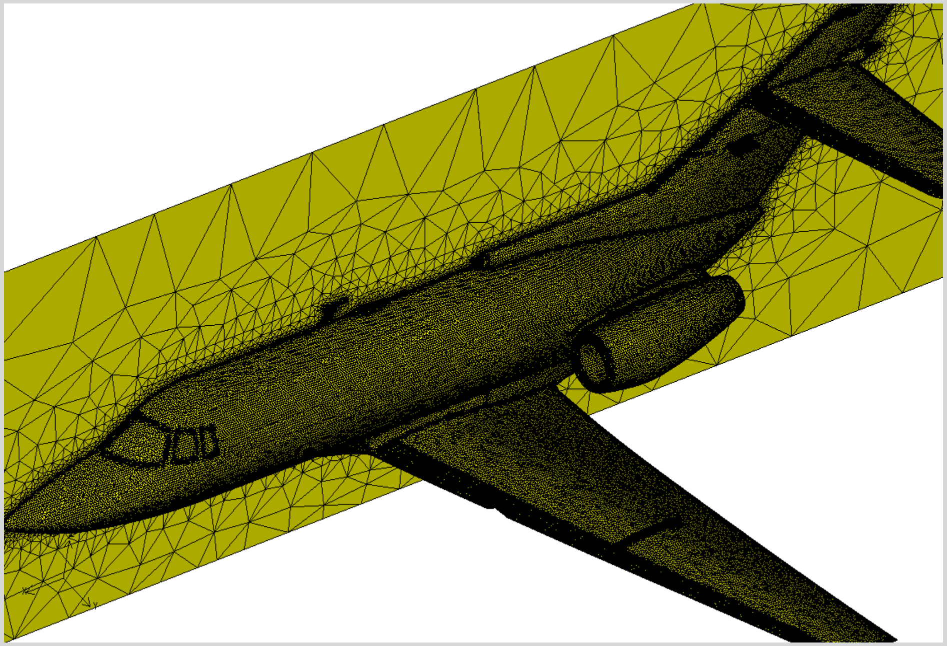
- **Pro:**
  - Good shear layer element
  - Best element wrt. memory & calculation time per element

- **Con:**
  - Degree of automation for grid generation



Elements: Tet

- **Pro:**
  - High degree of automation for grid generation
- **Con:**
  - Memory & calculation time per node ≈ 1.5 × hex
  - Poor shear layer element
  - No streamline orientation
  - Quantity must (and can) make up for quality



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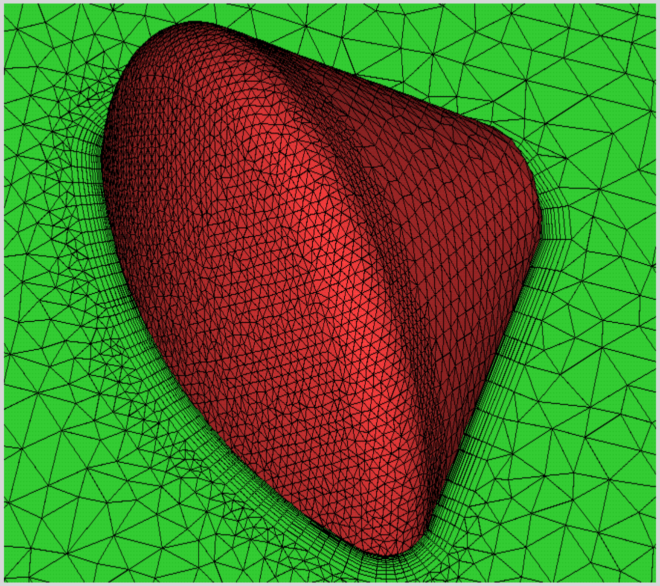
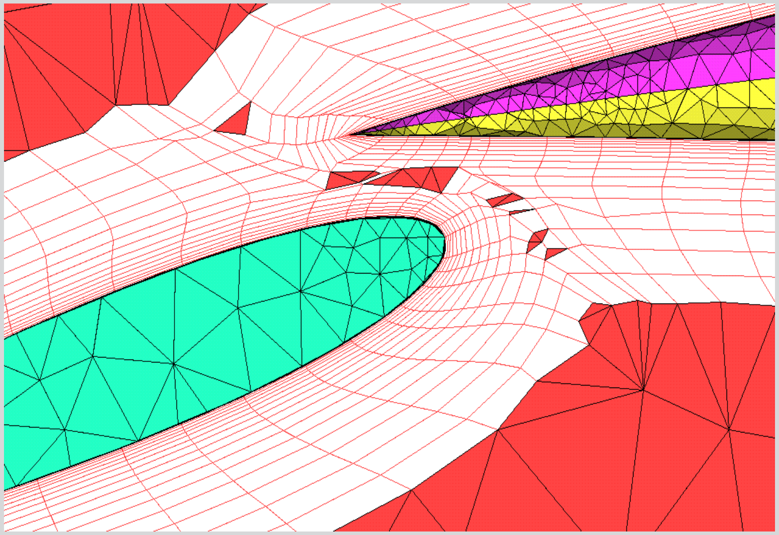
Elements: Prism

- **Pro:**
  - Better shear layer resolution than tet
  - High degree of automation
  - Tet/prism combination

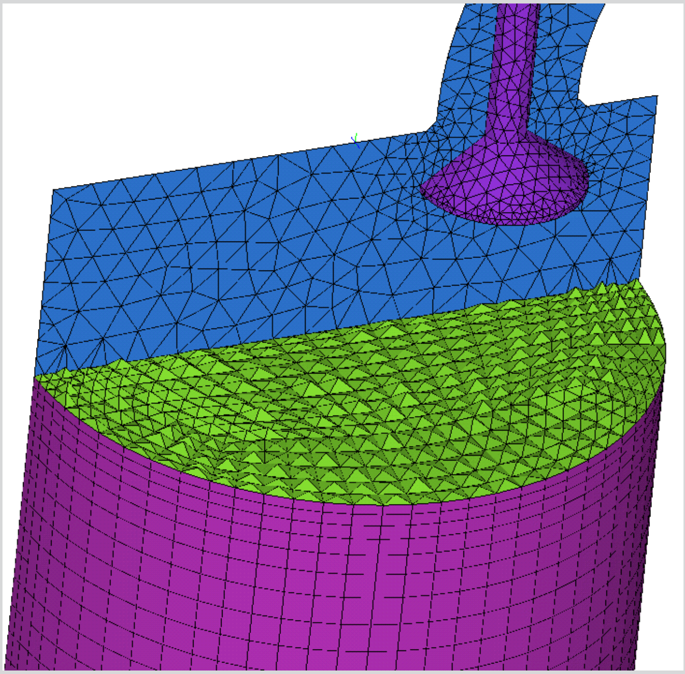
- **Con:**
  - Less efficient than hex
  - Topological difficulties (corners, …) → poor grid quality (angles, …)
  - Manual repair

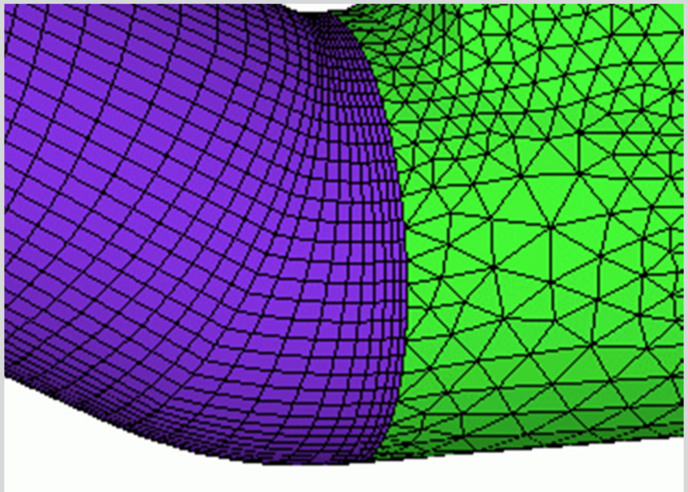




Elements: Pyramid

- **Use in hybrid grids**
- **Transition element between hex and tet**
- **Polyhedral grids**
  - ANSYS Fluent:
    - Generate base types
    - Convert
  - ANSYS CFX builds polyhedrals around vertices





Recommendations

- **1st Option → Hex grid**
  - Best accuracy and numerical efficiency
  - Time and effort manageable?
- **2nd Option → Tet/hex/pyramid grid**
  - Hex near walls & shear layers
  - Developing technology …
- **3rd Option → Tet/prism grid**
  - High degree of automation
  - Quality (prism/tet transition, …)
- **4th Option → Tet grid**
  - Shear layer resolution?

Grid Optimization

- **Truncation errors → source of discretisation errors**
- **Minimize truncation errors → minimize discretisation errors**
- **Truncation error → Difference between 'analog' and 'discrete' representation**

$$\left(\frac{\partial f}{\partial x}\right)_i = \frac{f_{i+1} - f_{i-1}}{2h} + \tau_i$$

$$\tau_i = \frac{h^2}{6}\left(\frac{\partial^3 f}{\partial x^3}\right)_i + \dots$$