# CFD Best Practice Guidelines: A process to understand CFD results and establish *Simulation versus Reality*

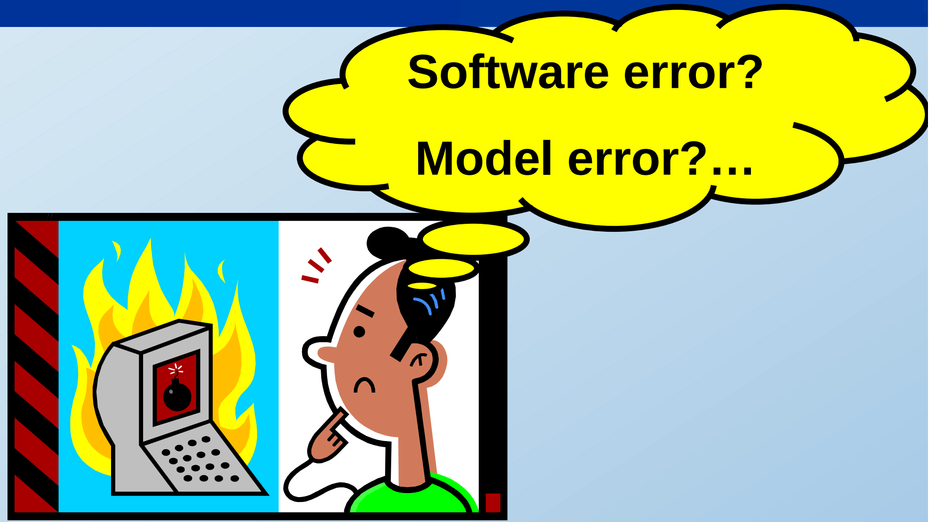
**Judd Kaiser**
**ANSYS Inc.**
**judd.kaiser@ansys.com**

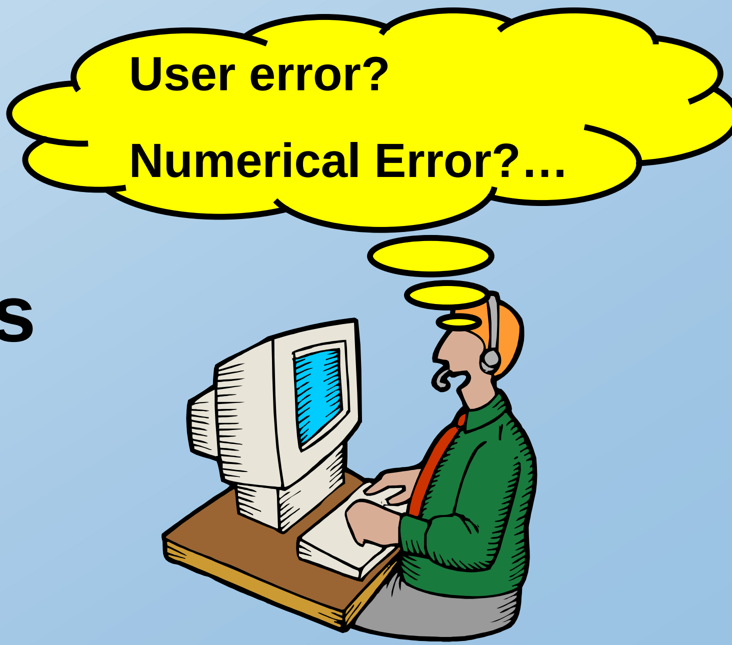
# Overview

- **Definition of sources of error in CFD**
- **Best practice guidelines**
- **Validation example:**
  - **Impinging jet**
- **Demonstration example:**
  - **Cavitation in fuel injection system**

# Sources of Error

- Numerical errors
  - Round-off error
  - Iteration error
  - Solution error
    - Spatial discretization
    - Temporal discretization
- Model errors
- Application uncertainties
- User errors
- Software errors



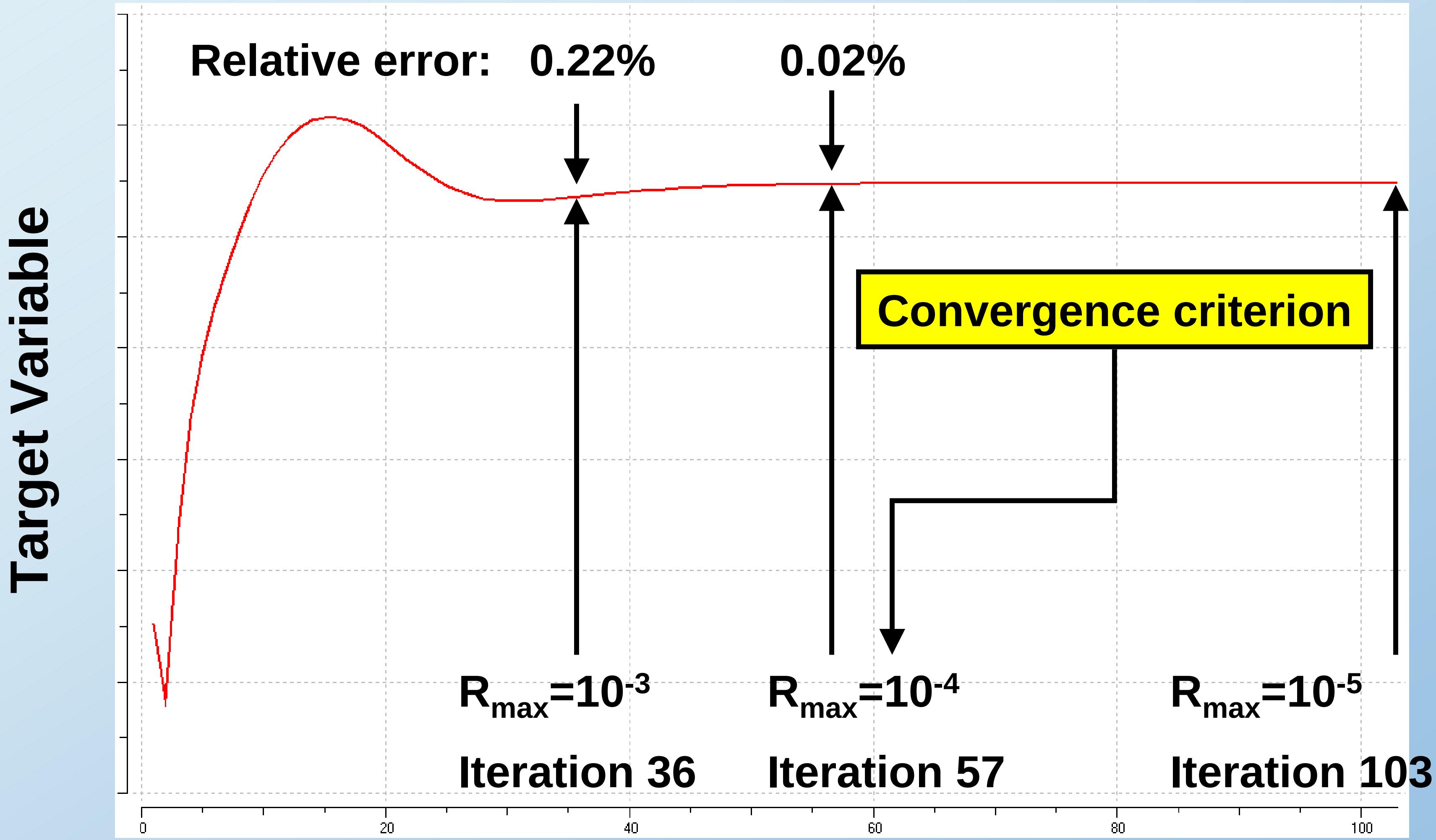
# Numerical: Round-Off Error

- **Error due to machine round-off**
- **Procedure:**
  - **Define target variables**
  - **Calculate with single-precision version**
  - **Calculate with double-precision version**
- **Check:**
  - **Compare target variables**
  - **Grid aspect ratio**
  - **Large differences in length scales**
  - **Large variable range**

# Numerical : Iteration Error

- **Error due to level of convergence**
  - **Differences between current and ‘infinitely converged’ solution, on same mesh**
- **Procedure:**
  - **Define target variables (head rise, efficiency, ...)**
  - **Plot target variables vs convergence**
- **Check:**
  - **Adequate convergence: when target variables become independent of convergence criterion**
  - **For global balances, monotonic convergence**

# Iteration Error

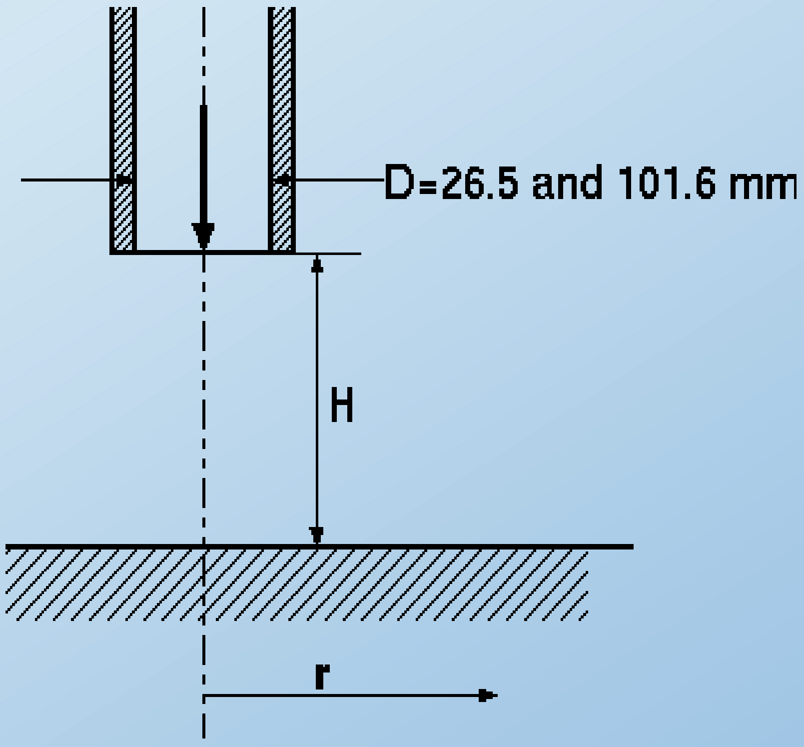


# Quality : Solution Error

- **Error due to mesh resolution**
- **Difference between current and "infinitely fine" mesh**
- **Procedure:**
  - **Minimize by using 2nd order numerics**
  - **1st order numerics: error is ½ when grid nodes x 2**
  - **2nd order numerics: error is ¼ when grid nodes x 2**
- **Check:**
  - **Error indicator: solution differences between two different numerics schemes, same mesh (easy)**
  - **Error level: solution differences between two different meshes, same numerics scheme (hard)**

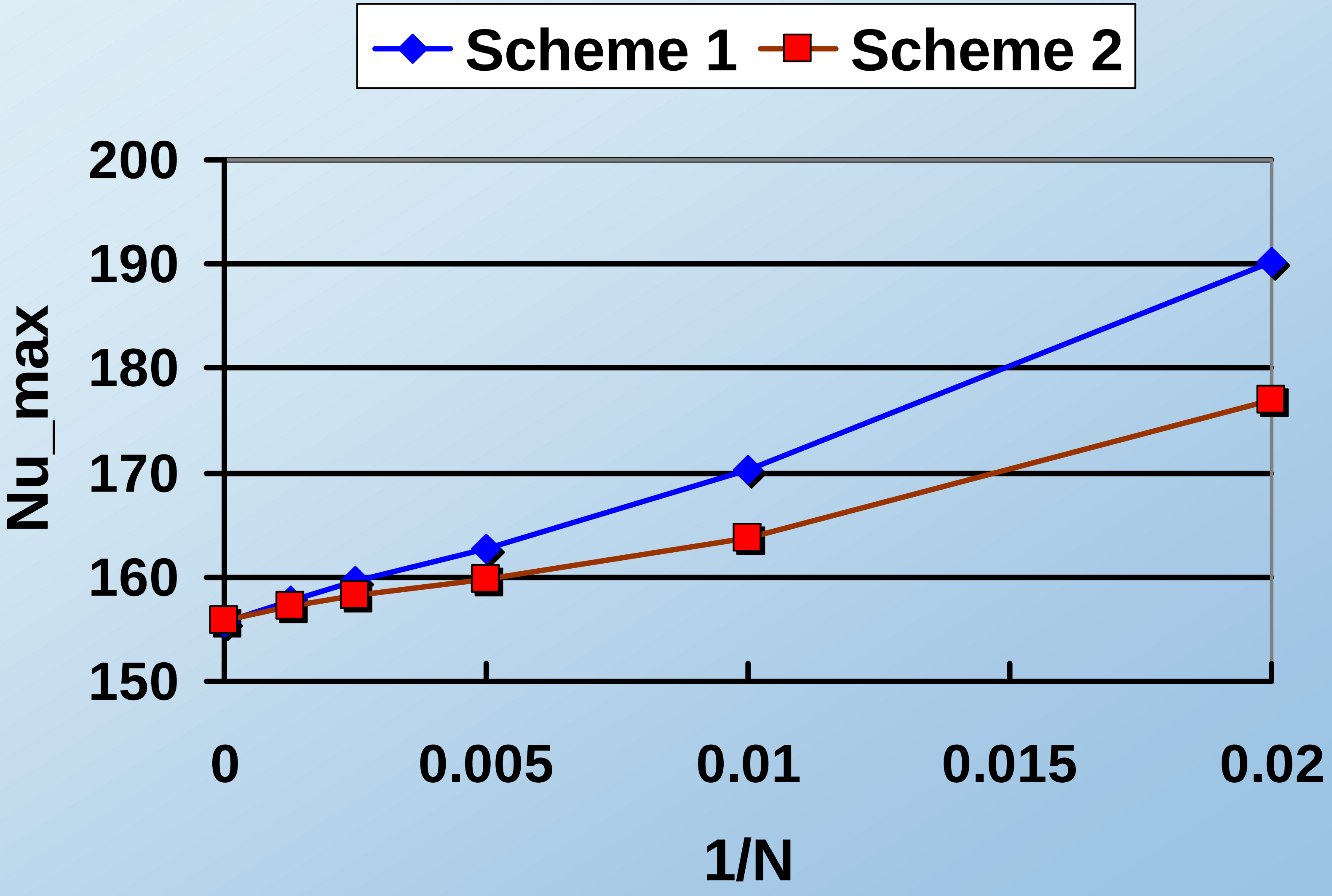
# Test Case VAL01

- Impinging jet flow with heat transfer
- 2-D, axisymmetric
- Grids:
  - 50 × 50 → 800 × 800
- ANSYS CFX
- SST turbulence model
- Discretization schemes:
  - Upwind differencing
  - Upwind differencing + second order correction




- Target quantity:
  - Heat transfer
  - Maximum Nusselt number

# Solution Error Example



# Error Estimation

- **Richardson extrapolation**
  - **Error estimated using:**

$$E = \frac{f_1 - f_2}{\left(r^p - 1\right)}$$

$f_1$: Fine grid solution

$f_2$: Coarse grid solution

r: Refinement ratio

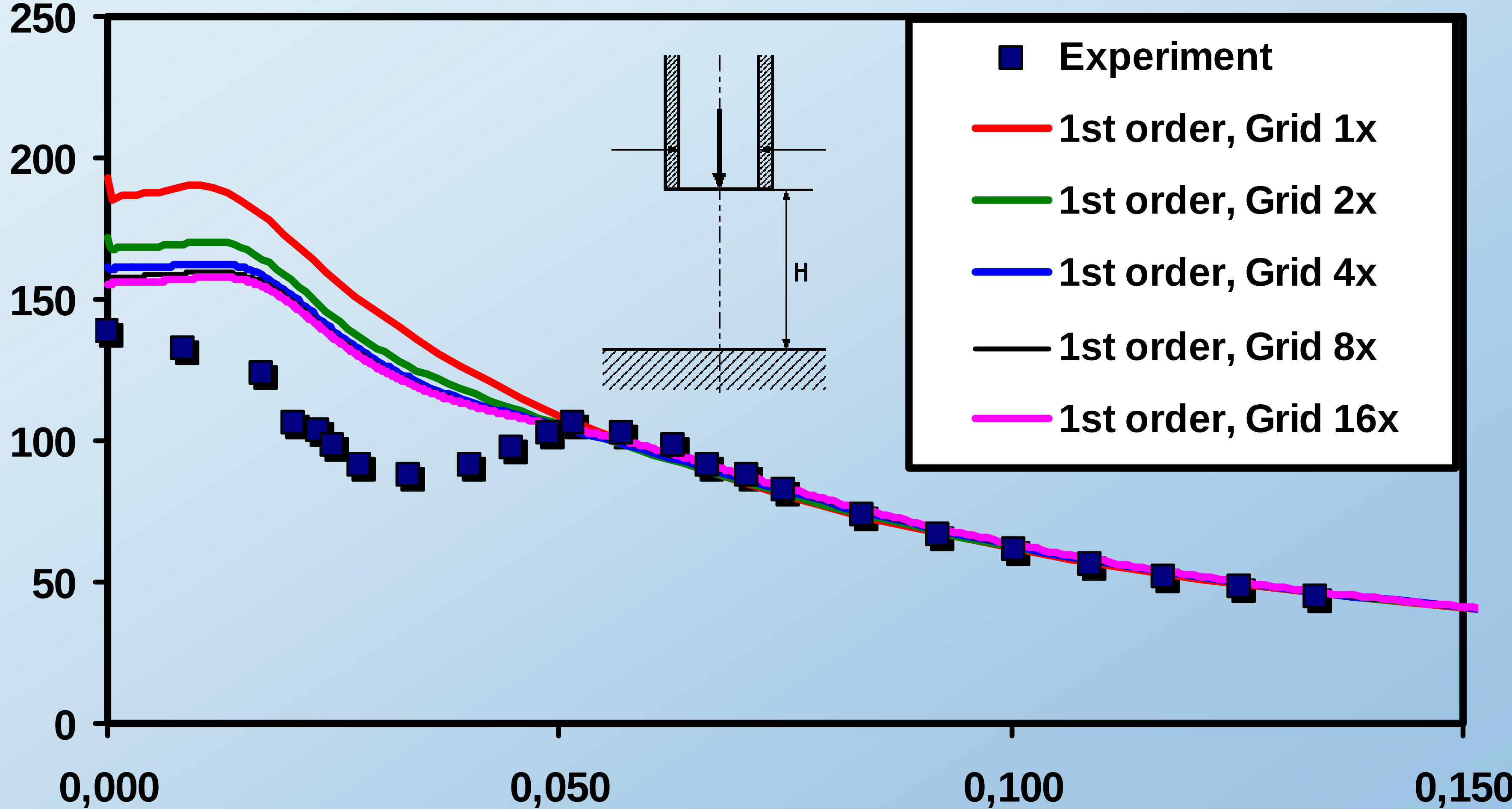
p: Truncation error order

- **Practically:**
  - **Grids must be in the asymptotic range**
  - **Use three different mesh densities to confirm trends**

# Model Errors

- **Model errors remain, even after all numerical errors have become insignificant**
- **Inadequacies of mathematical models:**
  - **Base equations (Euler, RANS, steady, unsteady…)**
  - **Turbulence models**
  - **Multi-phase flow models, …**
- **Difference between good data and calculations**
- **Check only after numerical errors have been quantified**

# Model Error: Example



# Application Uncertainty

- Systematic errors:
  - Approximations of geometry
  - Component vs. machine
  - Approximation of boundary conditions
    - Turbulence quantities
    - Profiles vs. constant values
  - Approximation of unsteady-state flow behaviour
  - Fluid and material properties
  - Setup error
  - Uncertainty in comparison data
- Discrepancies remain, even if numerical and model errors are insignificant

# User Errors

- **Examples:**
  - Geometry oversimplification
  - Poor geometry, mesh generation
  - Incorrect boundary conditions (locations, values)
  - Selection of incorrect models
  - Incorrect solver parameters
  - Acceptance of non-converged solutions
- **Avoidance:**
  - Training, documentation
  - Solve relevant validation cases
  - Process management: adhere to best practice guidelines
  - Increasingly, software automation

# Software errors

- **Examples:**
  - **Coding bugs**
  - **Errors in interface or documentation**
  - **Incorrect support information**
- **Avoidance:**
  - **Automated testing**
  - **Validation and verification cases**
  - **QA guidelines**

# Demonstration example

- **The original presentation included a summary of a CFD study performed by Robert Bosch, involving cavitation in a diesel fuel injector**
- **All images and data were property of Robert Bosch, and have been removed from this presentation**

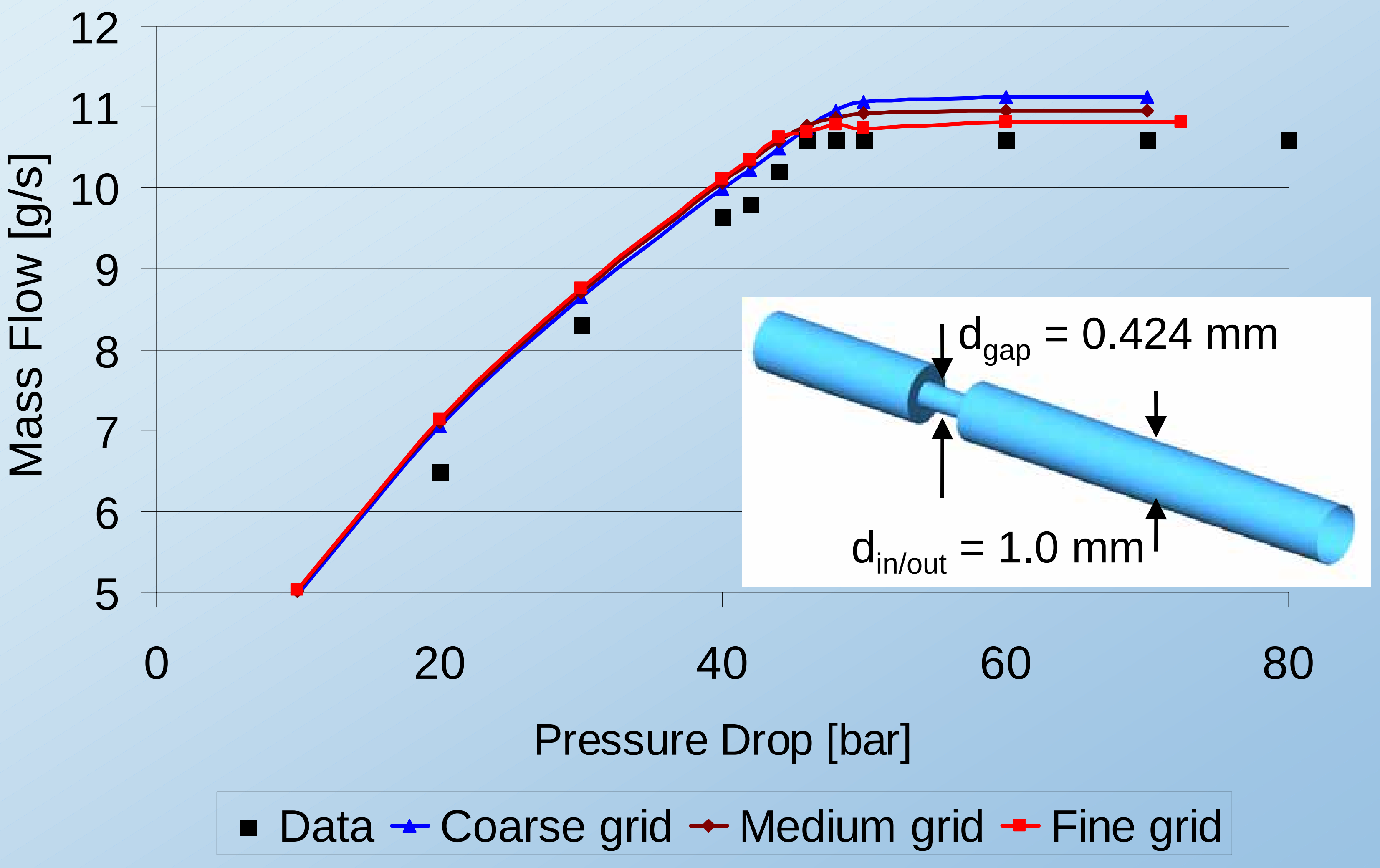
# CFD Simulation

- **Multiphase model**
  - **Homogeneous model**
  - **Cavitation: Rayleigh-Plesset model**
  - **Isothermal**
- **Turbulence model**
  - **SST model with automatic wall treatment**
  - **Detached Eddy Simulation (DES)**

# Simulation Timeline

- **Validation**
- **Throttle Flow**
  - **2-D steady state simulation**
  - **3-D steady state and transient simulation**
  - **3-D DES simulation**

# Validation: Circular Throttle



# Summary of RANS

- **2D steady state: Over-simplification**
- **3-D simulation:**
  - **Steady state: Cavitation inside the throttle**
  - **Transient: Same as steady state**
- **Need to resolve the large scale turbulence**
  - **LES: works well for free shear layer but computationally expensive in the wall layer**
  - **DES model: hybrid of RANS in the near field and LES in the free shear layer**

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- **References:**
  - **Roach, P.J., *Verification and Validation in Computational Science and Engineering,* Hermosa, 1998**
  - **ERCOFTAC Best Practice Guidelines**
    - **www.ercoftac.org**

 