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Design Of An Anisokinetic Probe For Sampling Radioactive Particles From Ducts Of Nuclear Facilities

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Introduction: The International Standard ISO 2889 focuses on monitoring the activity concentrations and activity releases of radioactive substances in air in ducts and stacks of nuclear facilities and sets the performance criteria and recommendations required for obtaining valid measurements. The recommendations are aimed at sampling that is conducted for worker and environmental protection, regulatory compliance and system control. It also provides performance-based criteria for the design and use of air-sampling equipment, including probes: in particular the transmission ratio (ratio of the aerosol particle concentration at the nozzle outlet C_{pout} to that in the free stream C_0) must be within the range of 0,80 to 1,30 for an aerosol with a particle aerodynamic equivalent diameter AED of 10 µm.

The aim of this study is to design a new concept of shrouded probe that meets the ISO 2889 requirements and it is suitable for small-ducts installation (not standard dimensions). In order to reduce the construction costs they have been considered standard stainless steel welding fittings manufactured according to ASME/ANSI specifications.

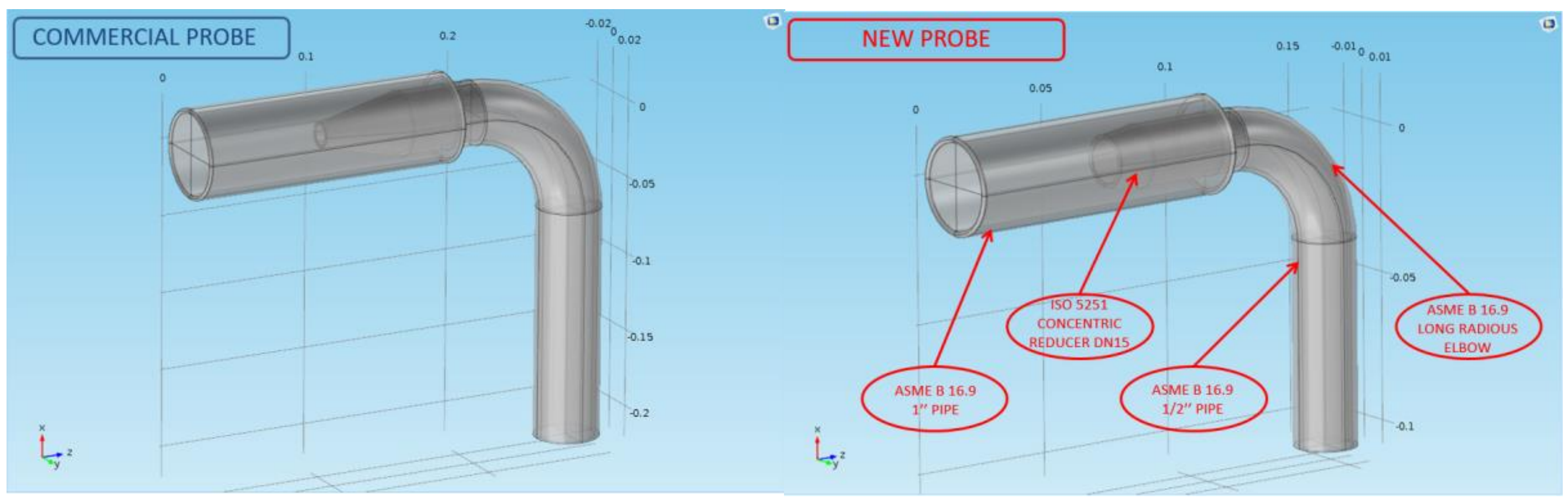

Figure 1. Geometry of commercial (left) and new concept shrouded probe (right)

Computational Methods: With the numerical simulations they have been firstly validated the capabilities of the numerical model to reproduce the available experimental data for a commercial shrouded probe and secondly they have been investigated the performances of the new concept design. The 3D simulations have been performed with Comsol Multiphysics 5.1 – Heat Transfer and Particle Tracing Modules and they are based on the following steps: 1) stationary fluid flow study (single phase incompressible turbulent k-ε closure model); 2) time dependent particle transport study (using the air velocity field obtained in the first study). The particle transport simulation is based on the "sparse flow"

$$\tau = \frac{C_{pout}}{C_0} = \left(\frac{N_{prout}}{N_0}\right)\left(\frac{U_0}{U_{pr}}\right)\left(\frac{A_0}{A_{pr}}\right)$$

C_{pout} particle concentration at the nozzle outlet
C_0 particle free stream concentration
N_{prout} particle that reached the sampling section
N_0 uniformly distributed in area A_0
U_0 free stream velocity
U_{pr} mean velocity at the probe inlet
A_{pr} cross sectional area of the probe inlet
A_0 particle section inlet

$$\nabla \cdot \boldsymbol{u} = 0$$

$$\rho \frac{\partial \boldsymbol{u}}{\partial t} + \rho(\boldsymbol{u} \cdot \nabla)\boldsymbol{u} = \nabla \cdot [-p\boldsymbol{I} + \boldsymbol{\tau}]$$

$$\frac{d}{dt}(m_p \boldsymbol{v}) = \left(\frac{1}{\tau_p}\right) m_p(\boldsymbol{u}' - \boldsymbol{v}) + m_p \boldsymbol{g} \frac{(\rho_p - \rho)}{\rho_p} + \boldsymbol{F_{brow}}$$

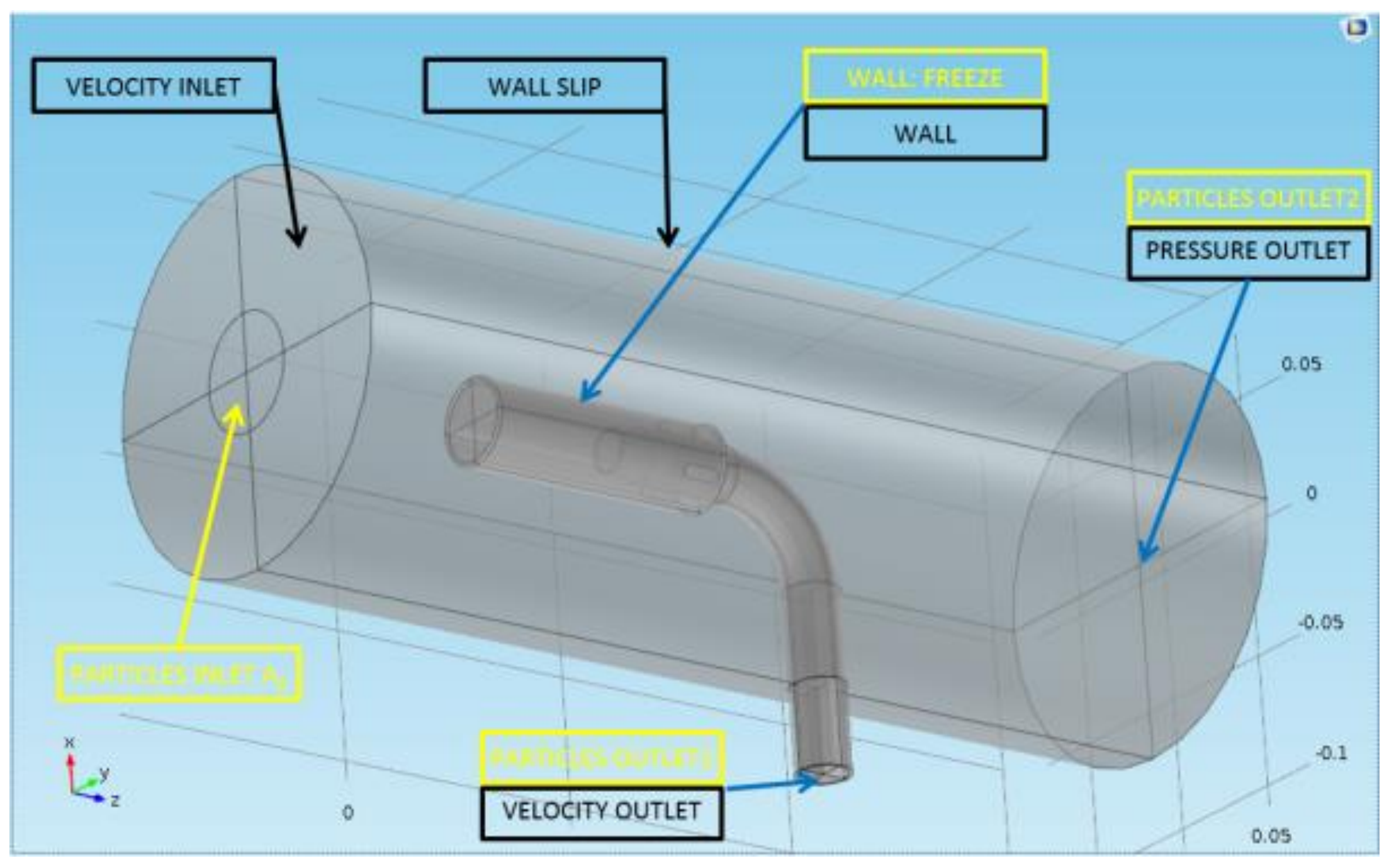

Figure 2. Boundary conditions details

Results: The Figure 3 shows the capabilities of the numerical model to reproduce the available experimental data (transmission ratio) for a commercial shrouded probe. The other figures show the velocity field, the particle trajectories and the transmission ratio for the two probes.

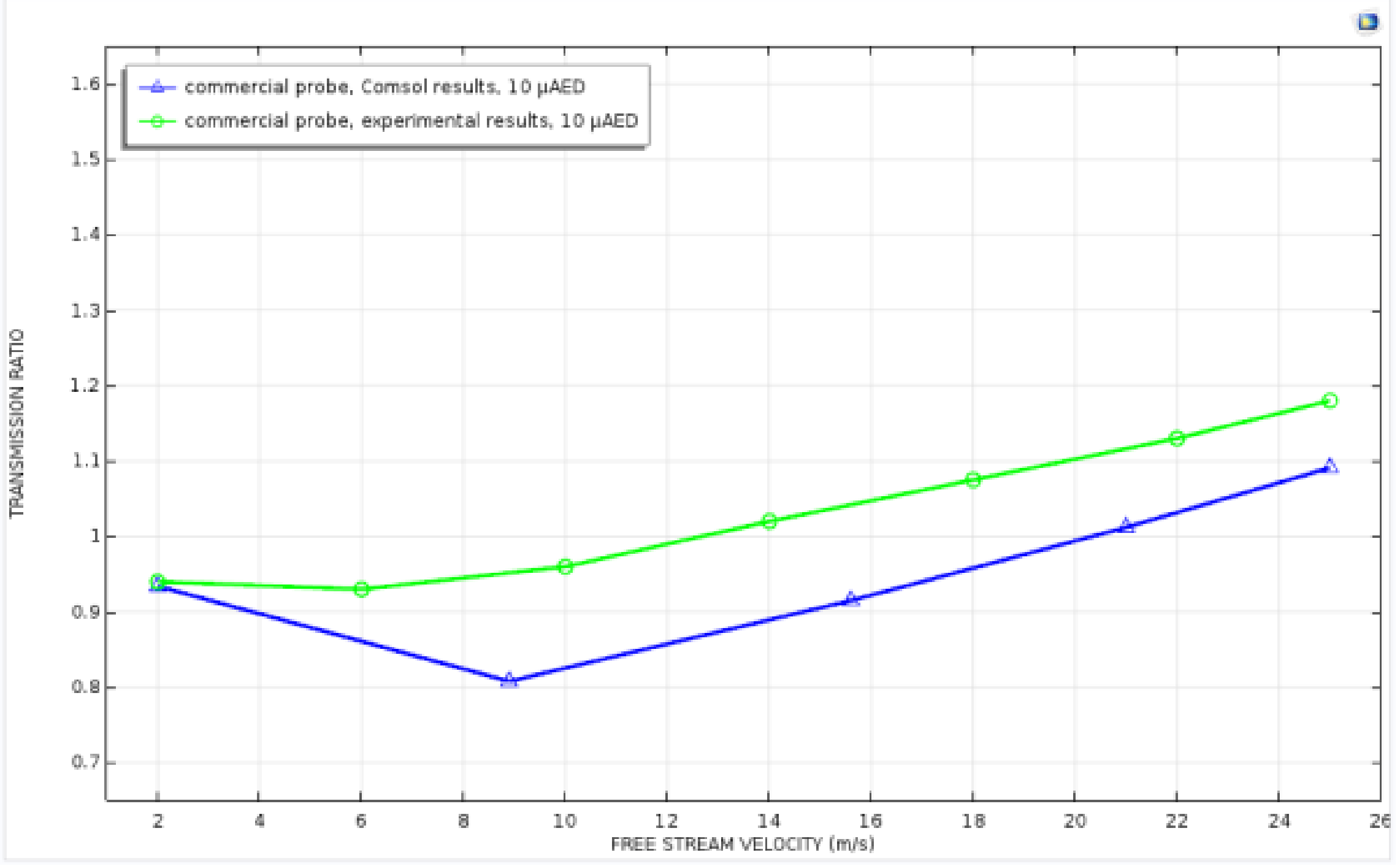

Figure 3. Comparison of transmission ratio for commercial probe

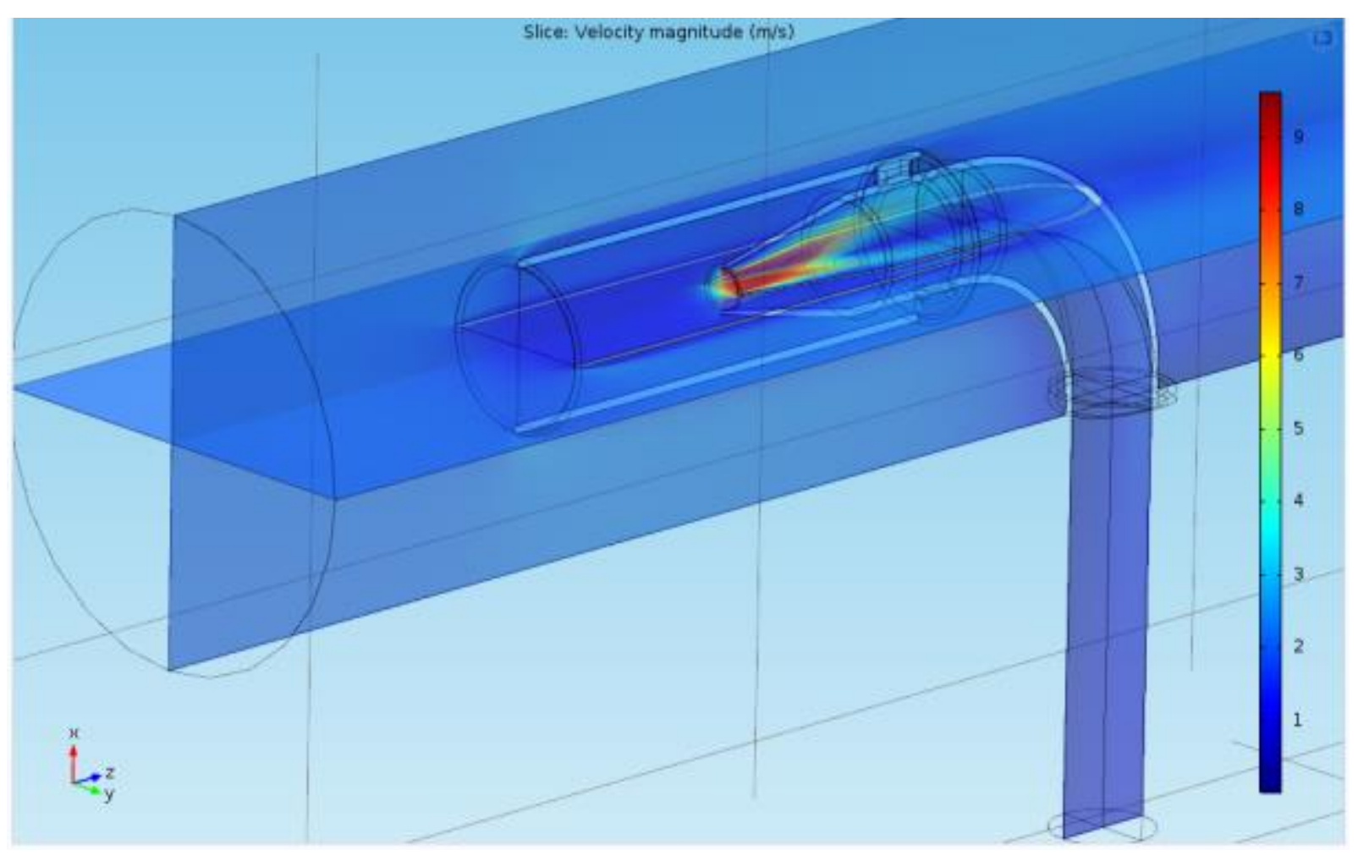

Figure 4. Multislice plot of velocity magnitude field for commercial probe at minimum air stream velocity (2 m/s)

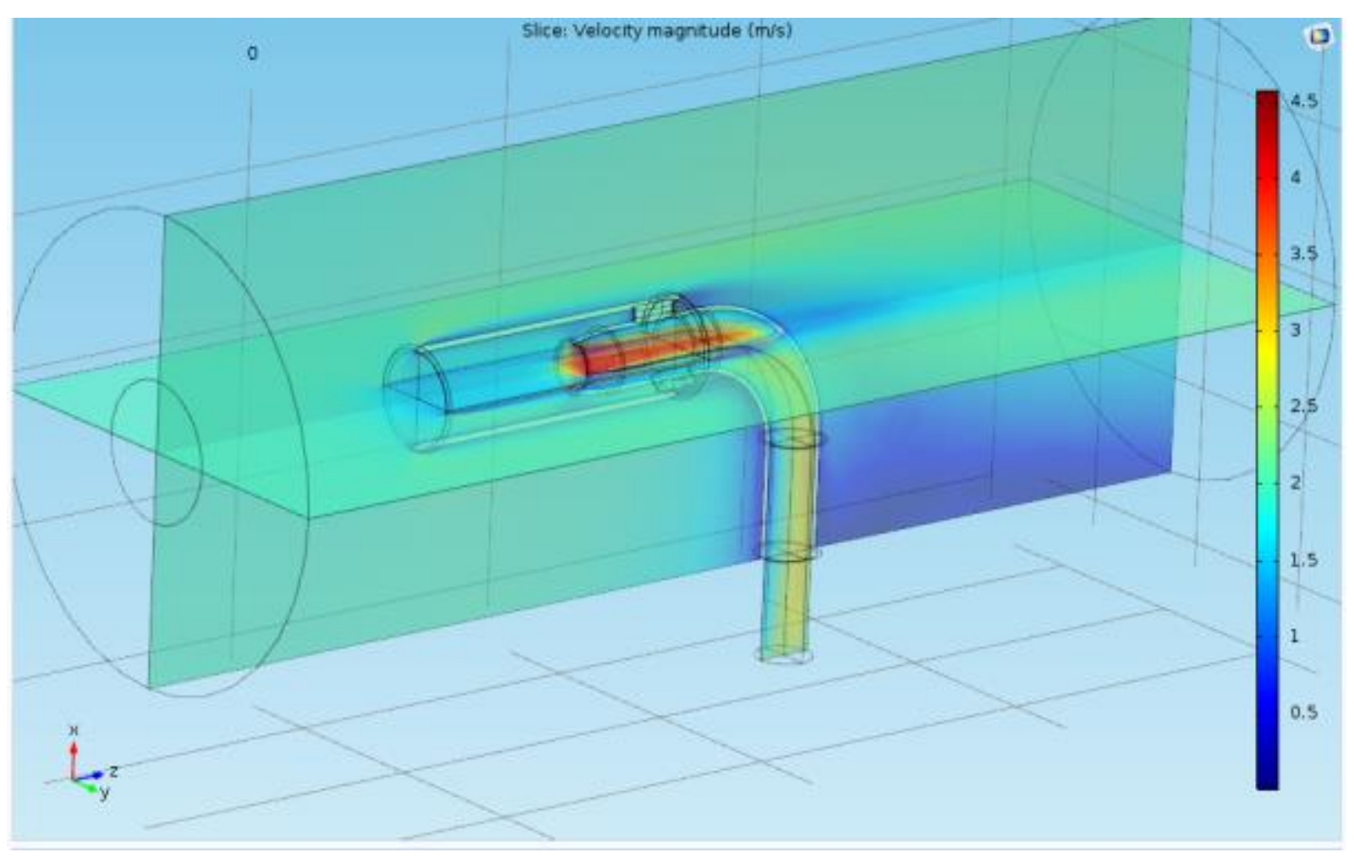

Figure 5. Multislice plot of velocity magnitude field for new concept probe at minimum air stream velocity (2 m/s)

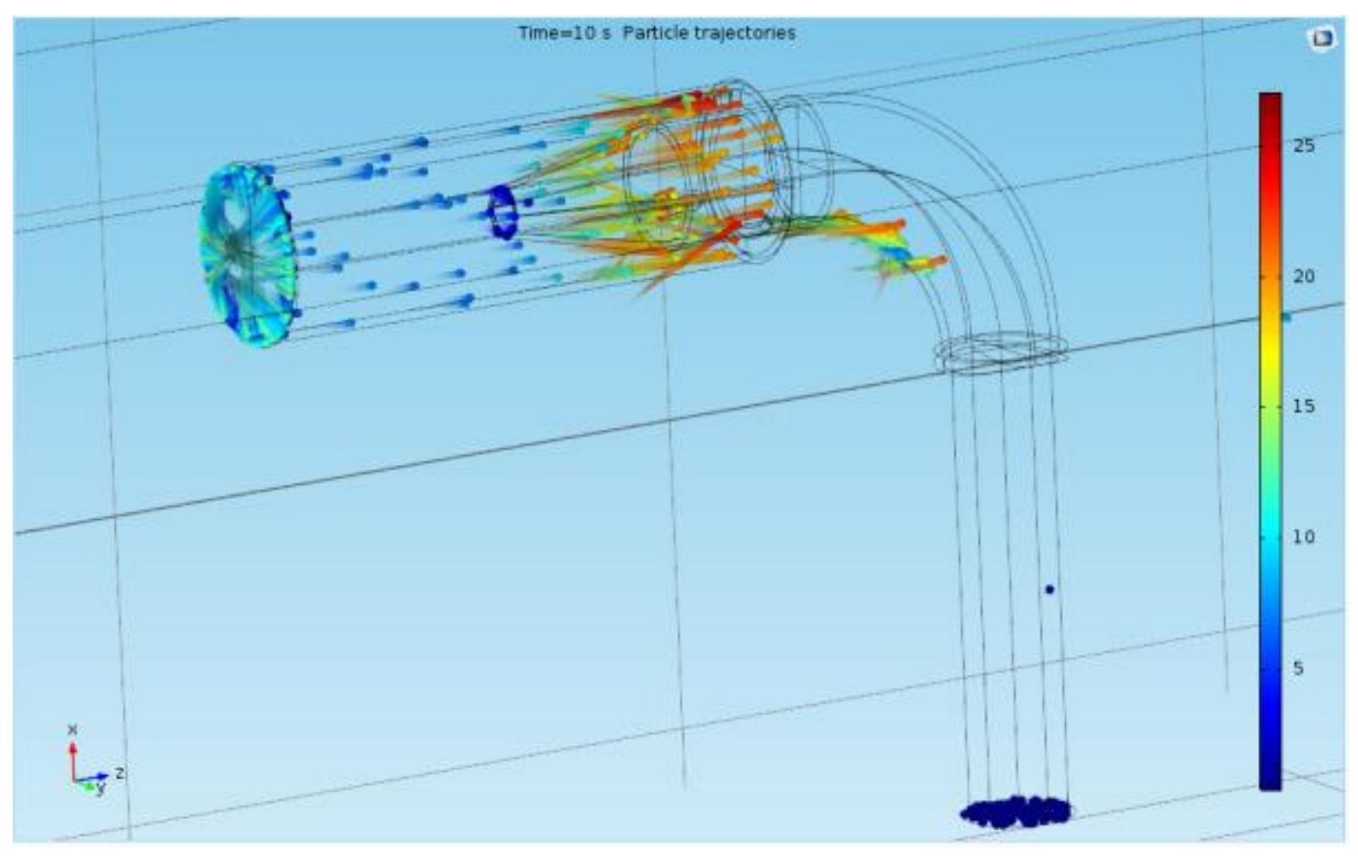

Figure 6. Particle trajectories (comet tail diagram) for 5 µm aerodynamic diameter and maximum air stream velocity (25 m/s) for commercial probe

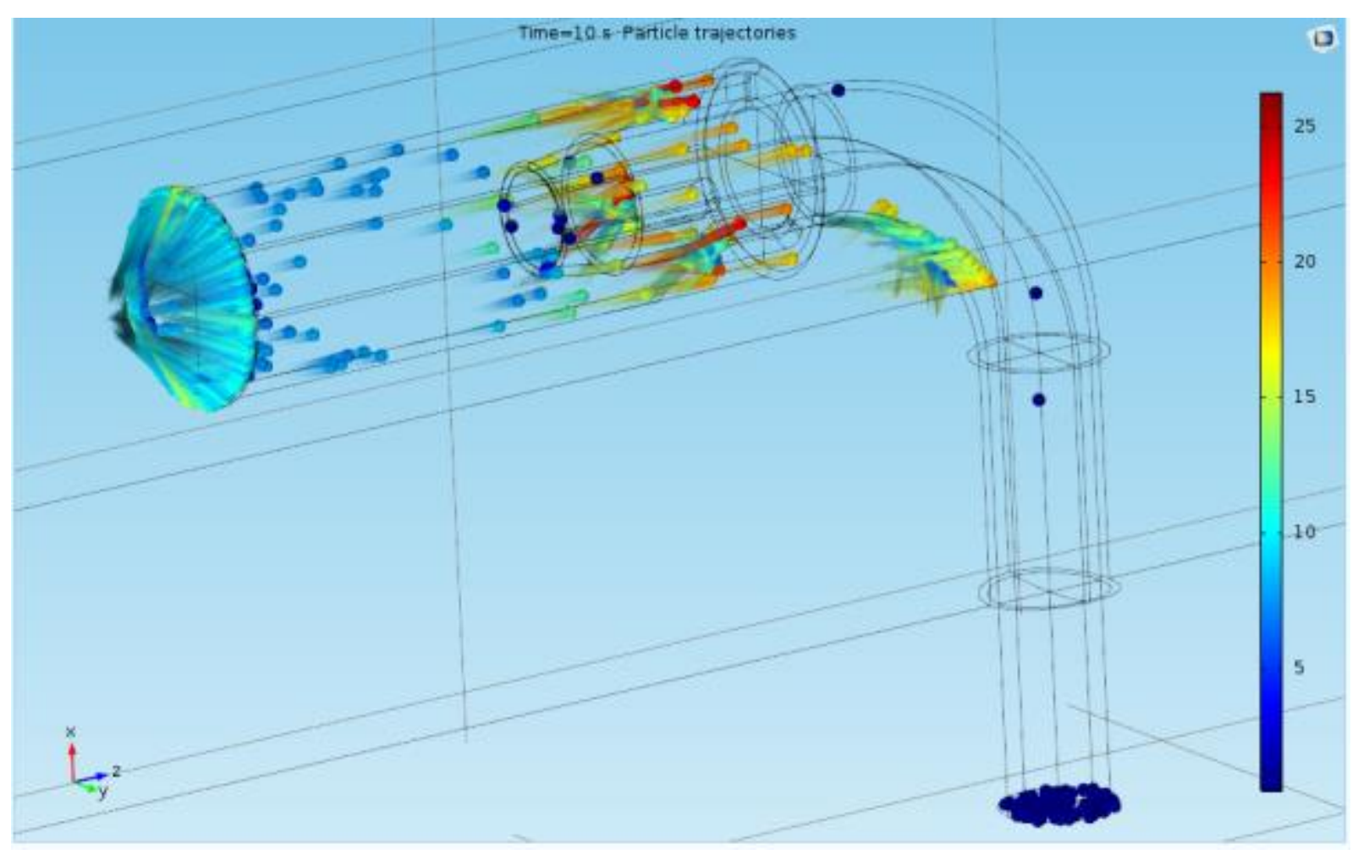

Figure 7. Particle trajectories (comet tail diagram) for 5 µm aerodynamic diameter and maximum air stream velocity (25 m/s) for the new concept probe

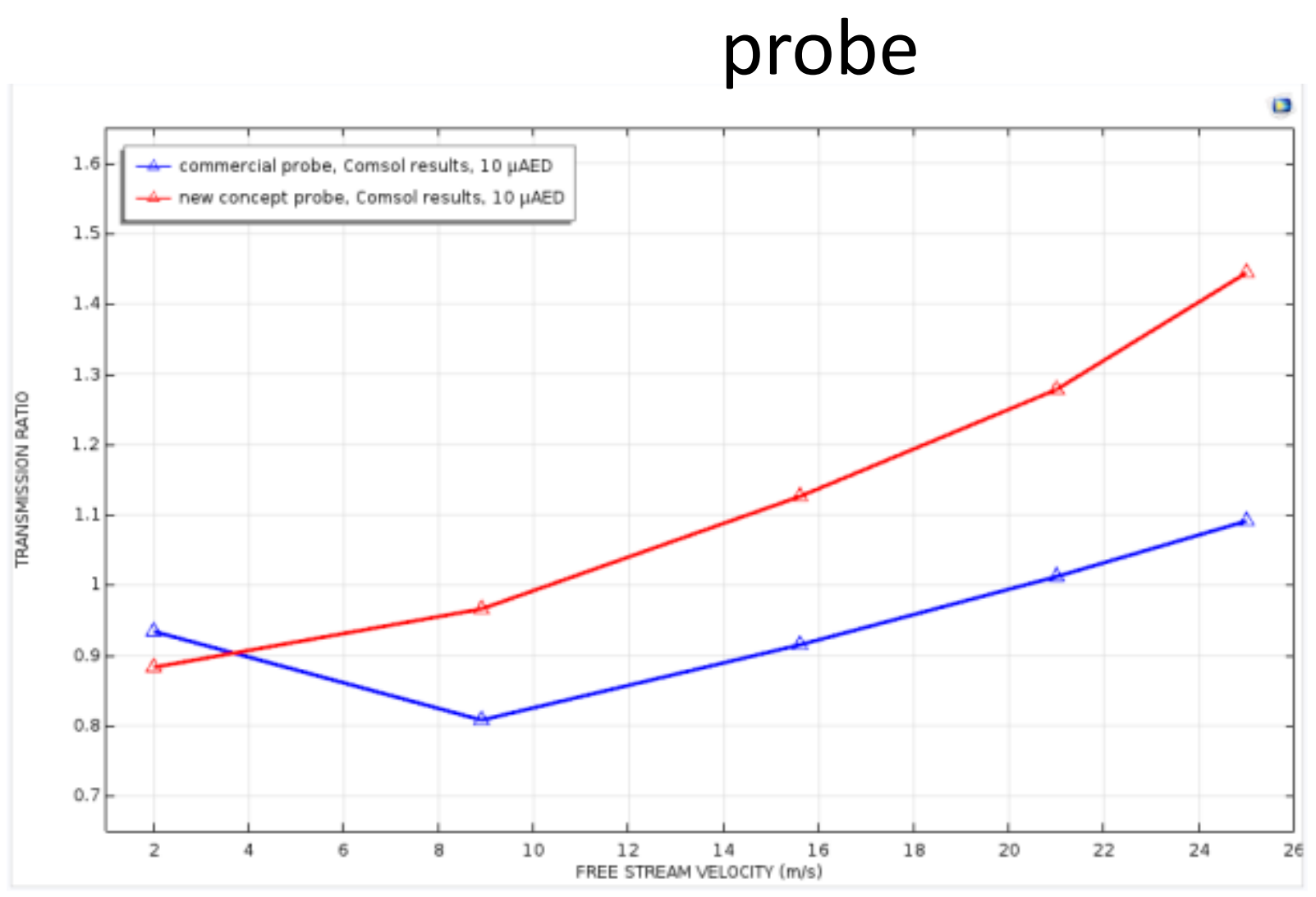

Figure 8. Comparison of transmission ratio for commercial probe and new concept probe for 10 µm aerodynamic diameter

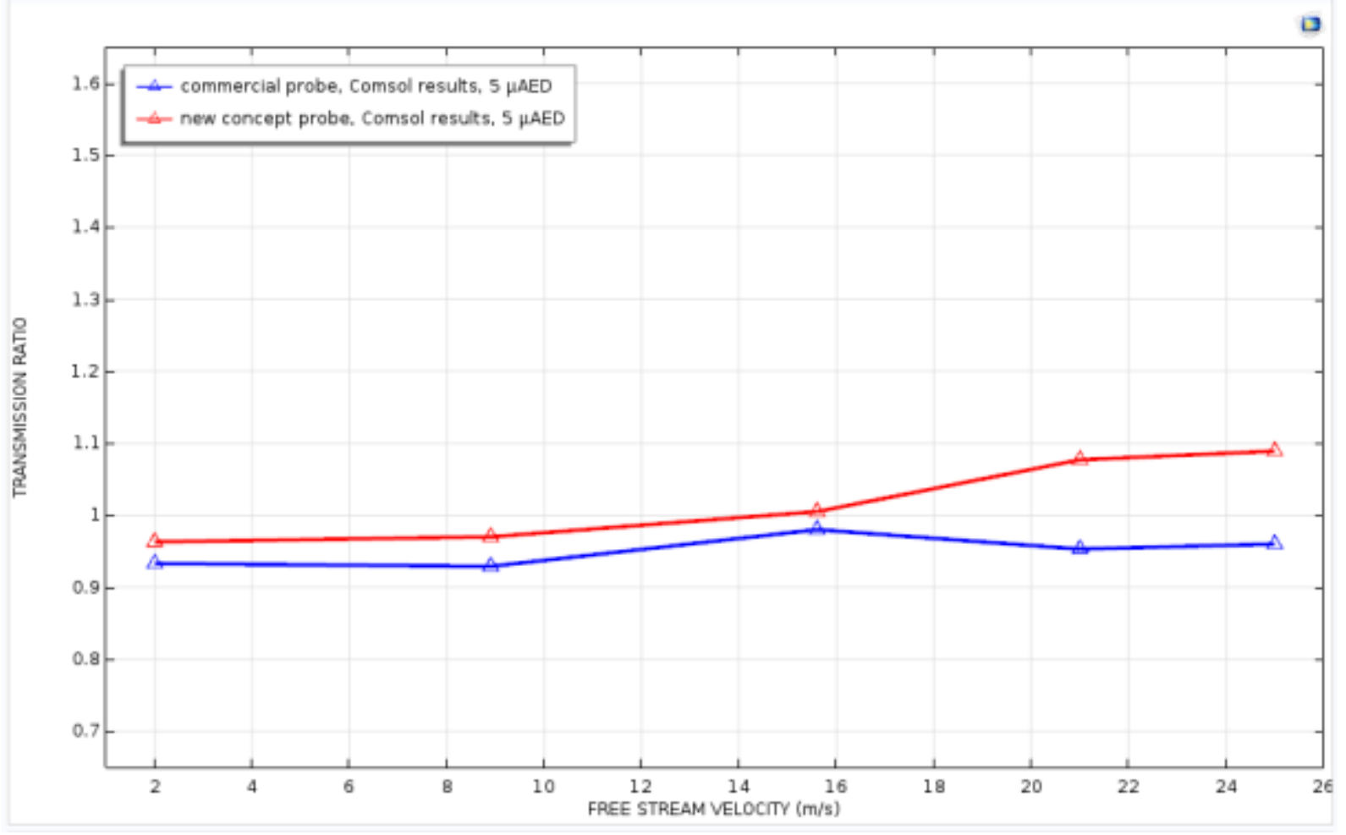

Figure 9. Comparison of transmission ratio for commercial probe and new concept probe for 5 µm aerodynamic diameter

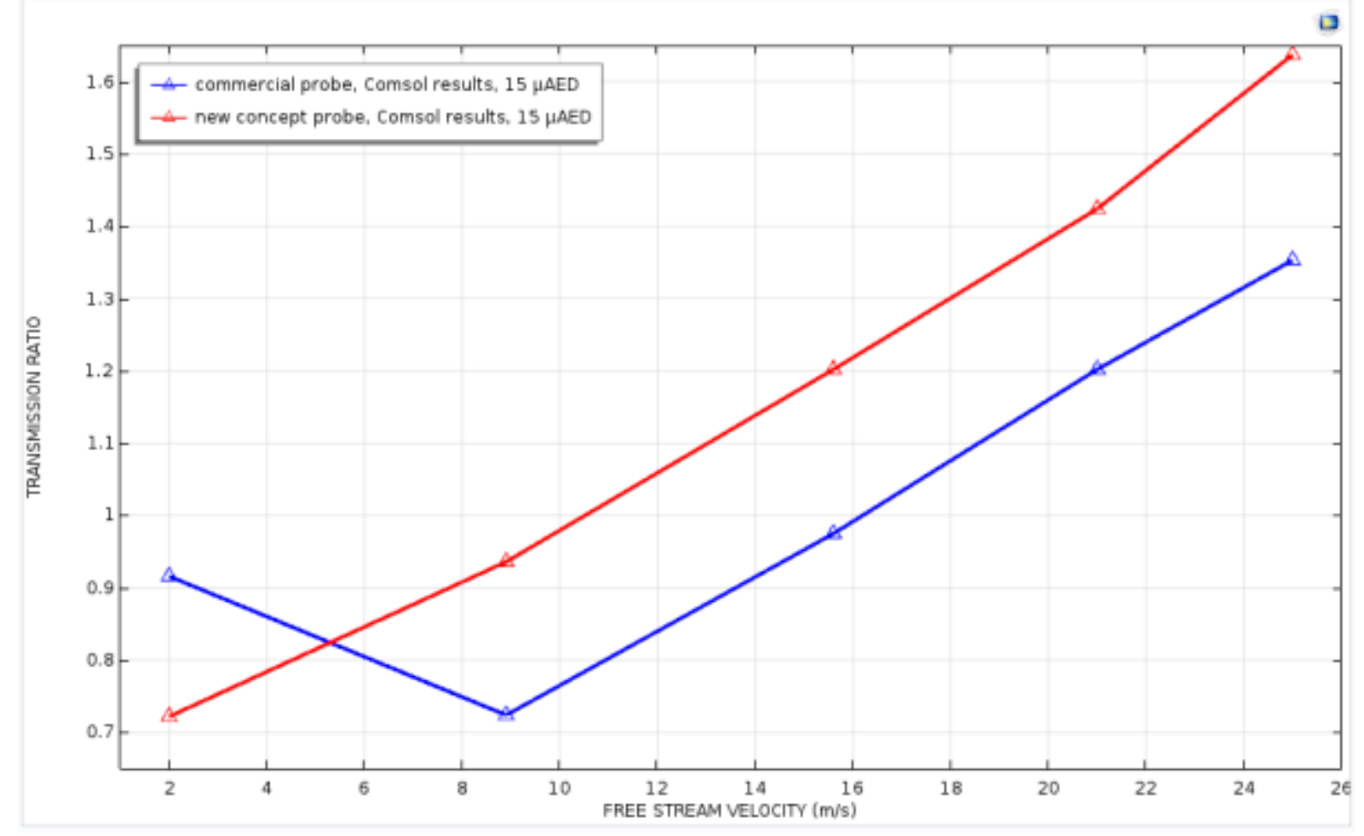

Figure 10. Comparison of transmission ratio for commercial probe and new concept probe for 15 µm aerodynamic diameter

Conclusions: The results presented in this study confirm the capability of COMSOL Multiphysics® as a multiphysics simulation tool. The study allowed us to design a new concept of shrouded probe that meets the ISO 2889 requirements.

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