# PREDICTING AND IMPROVING THE PERFORMANCE OF A BAGLESS VACUUM CLEANER USING CFD

**[1]Francisco J. Campos▲, [2]David Sykes, [2]Jim Ferguson**
[1]ICON Ltd., UK
[2]Hoover Candy Group, UK

KEYWORDS –

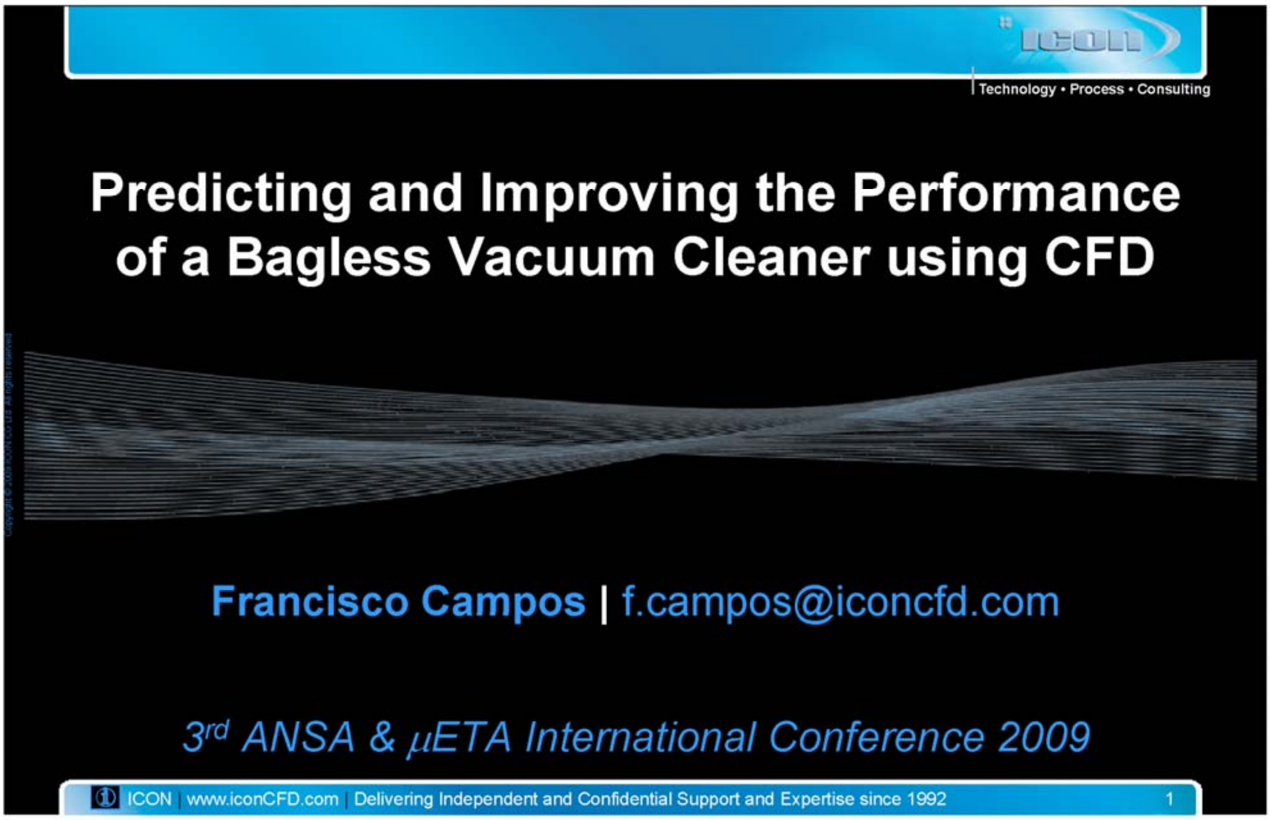
ABSTRACT – Centrifugal cyclones used as inertial gas-solid separators are widely employed in the design of modern vacuum cleaners to eliminate the need for dust bags and minimize suction losses. The vacuum cleaner performance, rated in terms of separation efficiency and pressure losses, is mainly dependent on the individual efficiency and proper arrangement of the cyclone separation devices.

In this work a methodology based on Computational Fluid Dynamics (CFD) is presented to predict and characterise the overall performance of a bagless type vacuum cleaner designed and manufactured by Hoover Candy Group. Attention was focused on the second separation stage, comprising a cluster of twelve cyclones operating in parallel and responsible for discarding the smallest solid particles.

The optimisation code modeFrontier was first employed to run a semi-empirical model for predicting centrifugal cyclones performance in order to define the shape of the cyclones in the 2nd separation stage. A total of 7,200 design evaluations were performed using a genetic type algorithm to maximise separation efficiency and minimise pressure losses.

The performance of the baseline and optimised cyclones was evaluated by means of CFD. First, a model of a single cyclone was defined to verify the results obtained with the semi-empirical model. Second, the baseline configuration was tested in the full vacuum cleaner assembly. In both cases ANSA was used to define tetrahedral grids with near wall prismatic layers, while the CFD solutions were obtained in ANSYS CFX. For the latter a Reynolds Stress turbulence model was used in conjunction with Lagrangnian particle tracking to ensure proper representation of the physics involved.

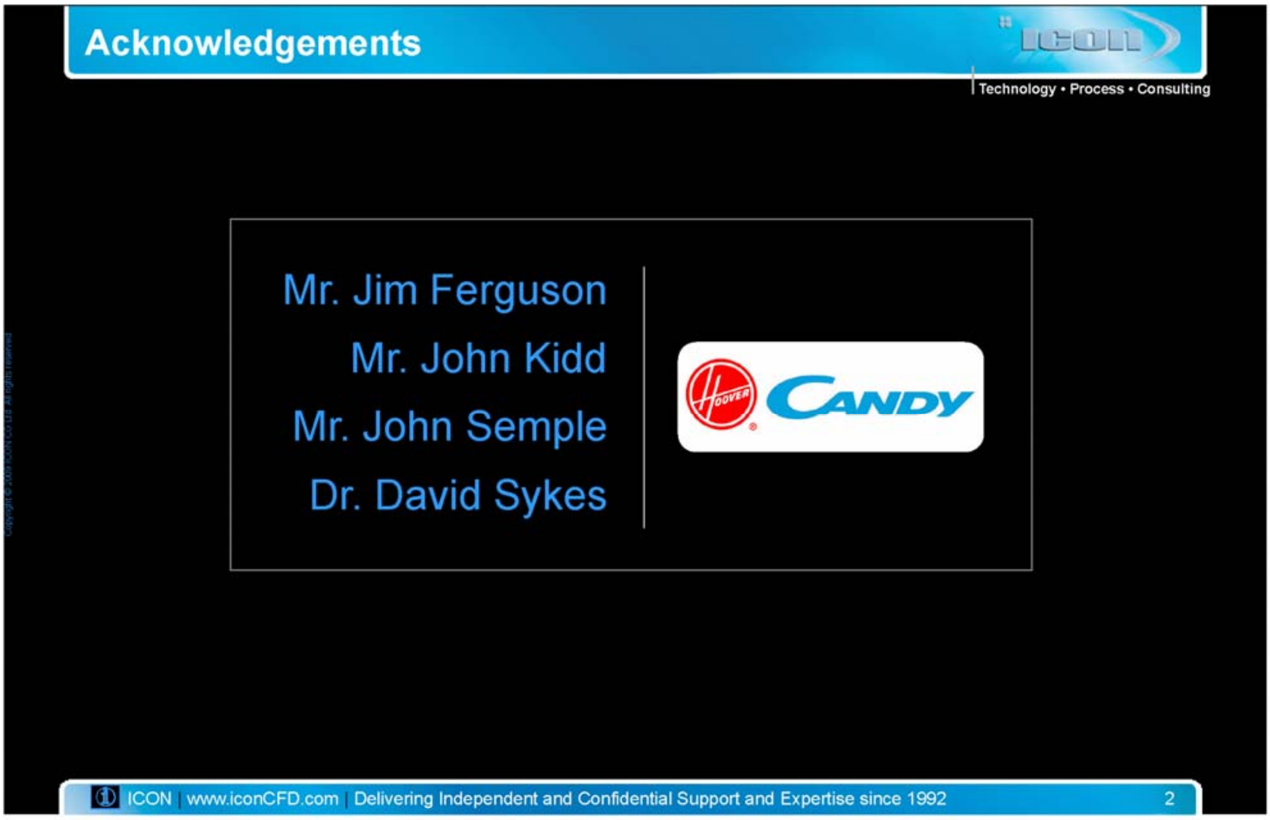
The CFD solutions for the full vacuum cleaner assembly revealed the presence of cross flows at the funnel dust collector (or hopper). The hopper was redesigned accordingly to achieve a 5% increase in separation efficiency. The introduction of the optimised cyclone separators, on the other hand, led to a decrease of 100 Pa in pressure losses at standard operating conditions.



# Predicting and Improving the Performance of a Bagless Vacuum Cleaner using CFD

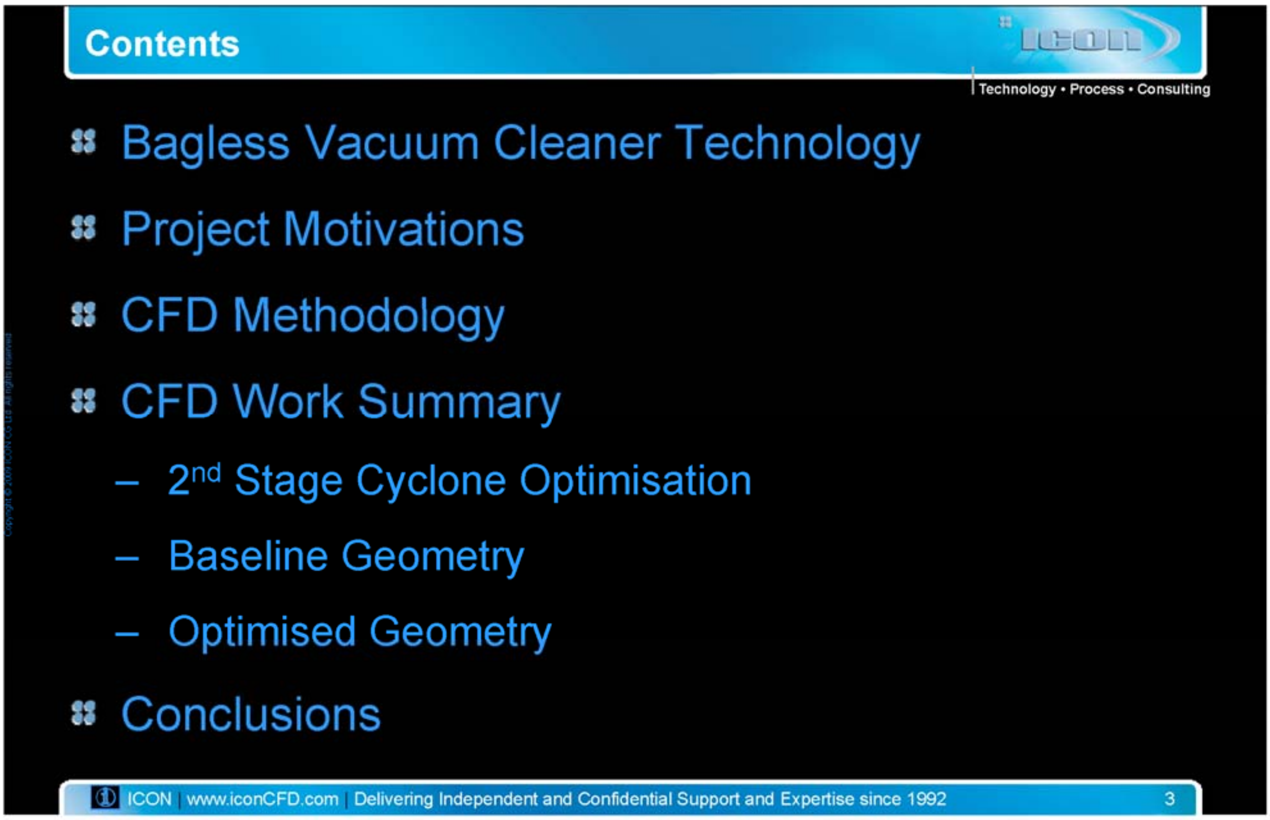
**Francisco Campos** | f.campos@iconcfd.com

*3rd ANSA & μETA International Conference 2009*



## Acknowledgements

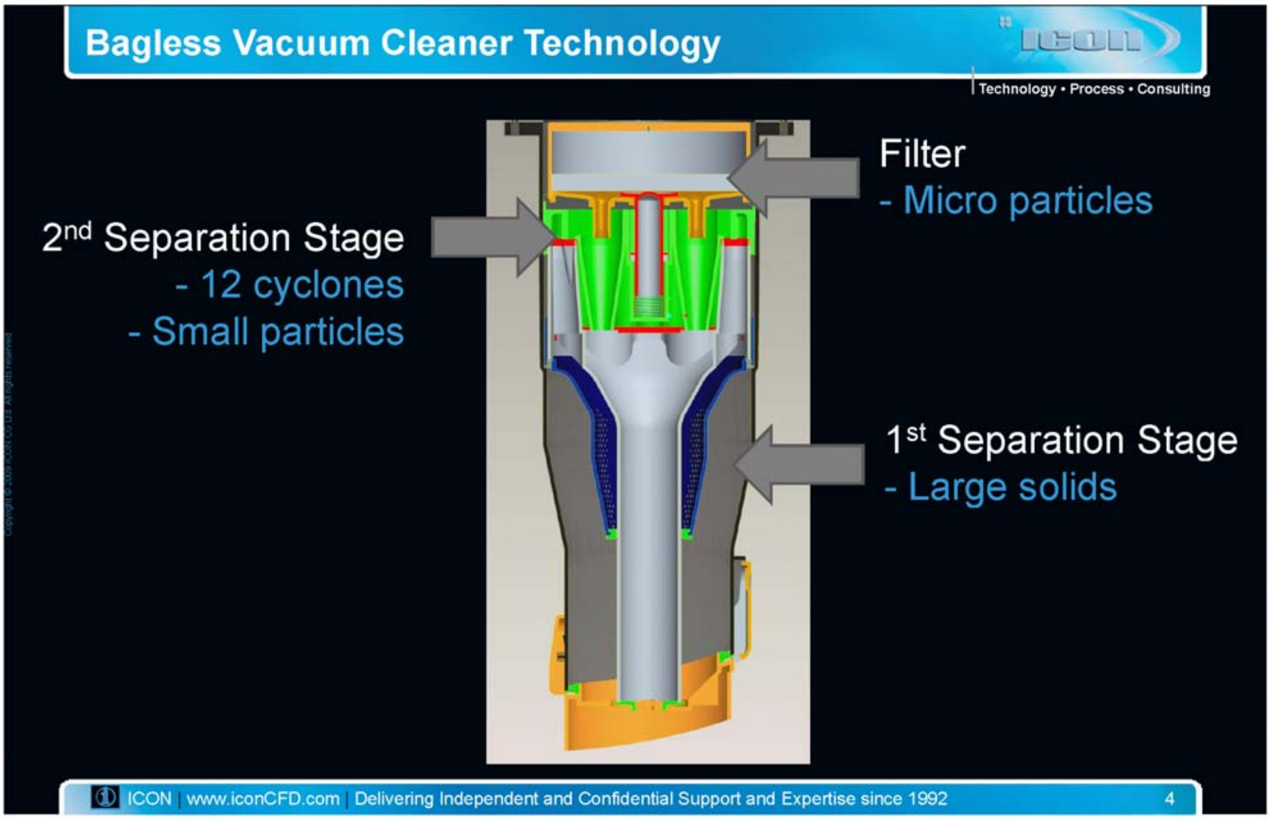
Mr. Jim Ferguson
Mr. John Kidd
Mr. John Semple
Dr. David Sykes



## Contents

Technology • Process • Consulting

- Bagless Vacuum Cleaner Technology
- Project Motivations
- CFD Methodology
- CFD Work Summary
  - 2nd Stage Cyclone Optimisation
  - Baseline Geometry
  - Optimised Geometry
- Conclusions



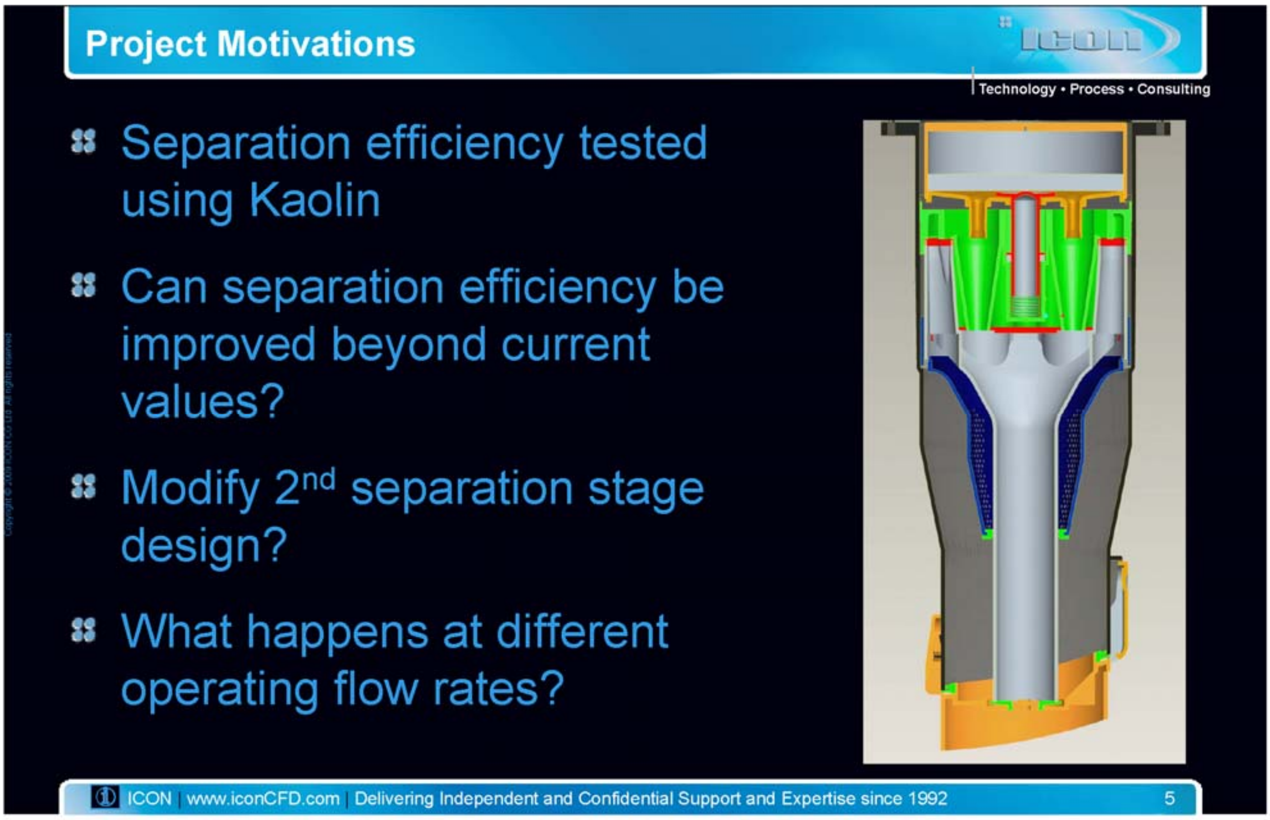
## Bagless Vacuum Cleaner Technology

Technology • Process • Consulting

2nd Separation Stage
- 12 cyclones
- Small particles

Filter
- Micro particles

1st Separation Stage
- Large solids

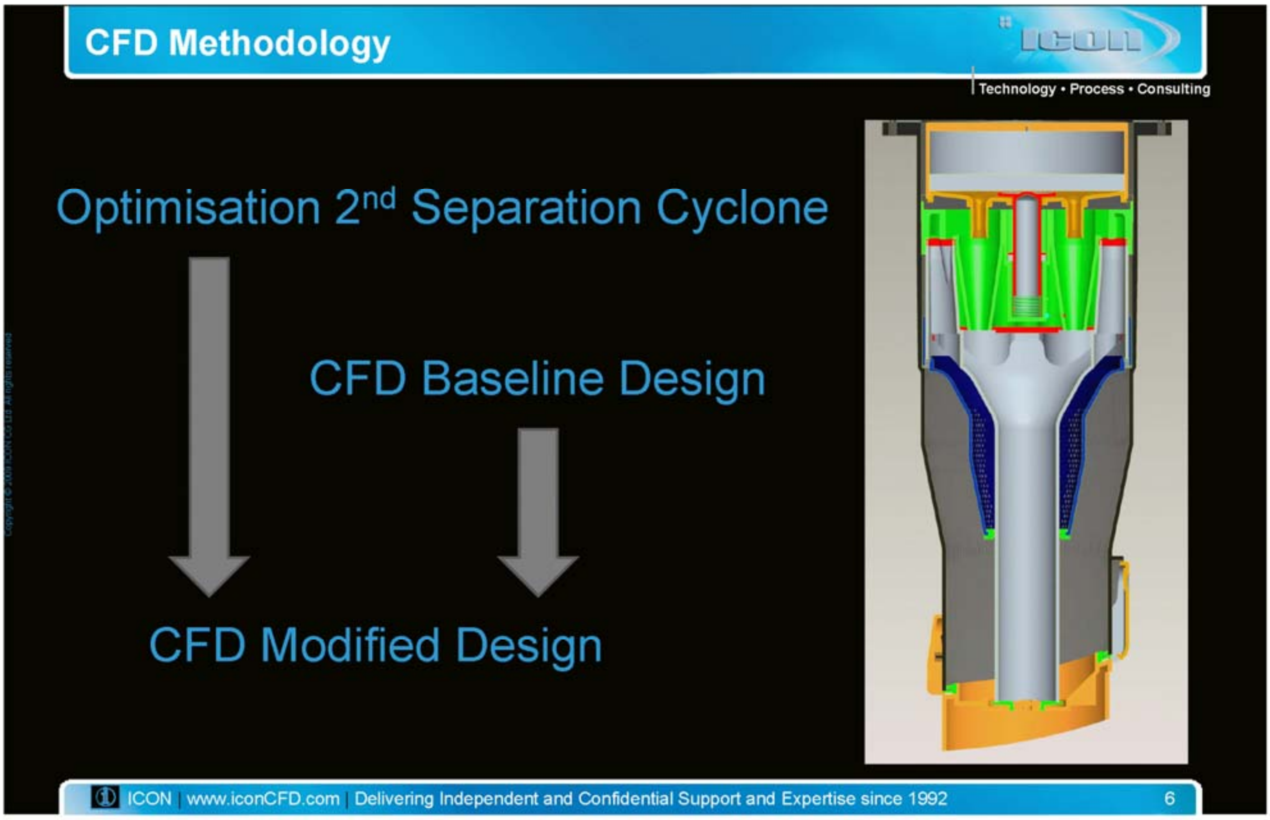


## Project Motivations

Technology • Process • Consulting

- Separation efficiency tested using Kaolin
- Can separation efficiency be improved beyond current values?
- Modify 2nd separation stage design?
- What happens at different operating flow rates?

ICON | www.iconCFD.com | Delivering Independent and Confidential Support and Expertise since 1992 5



## CFD Methodology

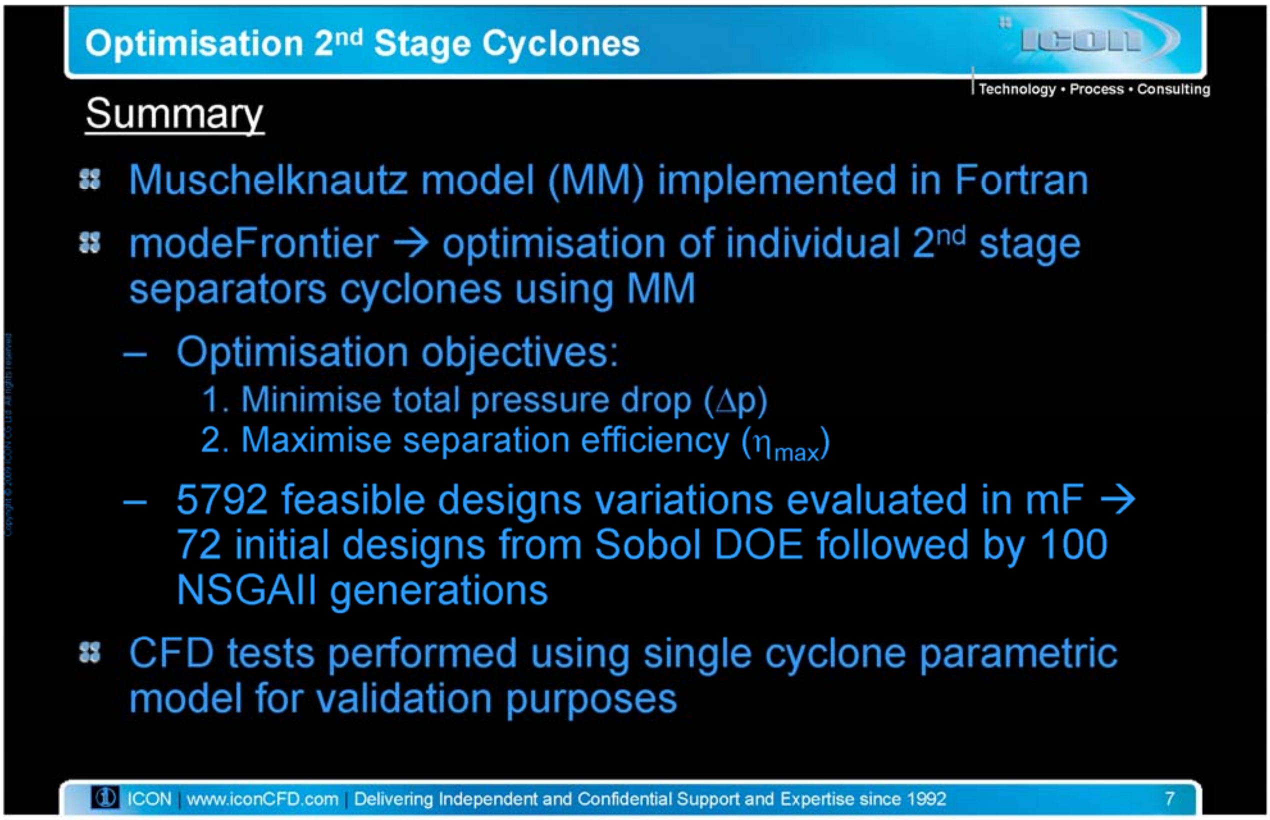
Technology • Process • Consulting

Optimisation 2nd Separation Cyclone

CFD Baseline Design

CFD Modified Design

ICON | www.iconCFD.com | Delivering Independent and Confidential Support and Expertise since 1992 6

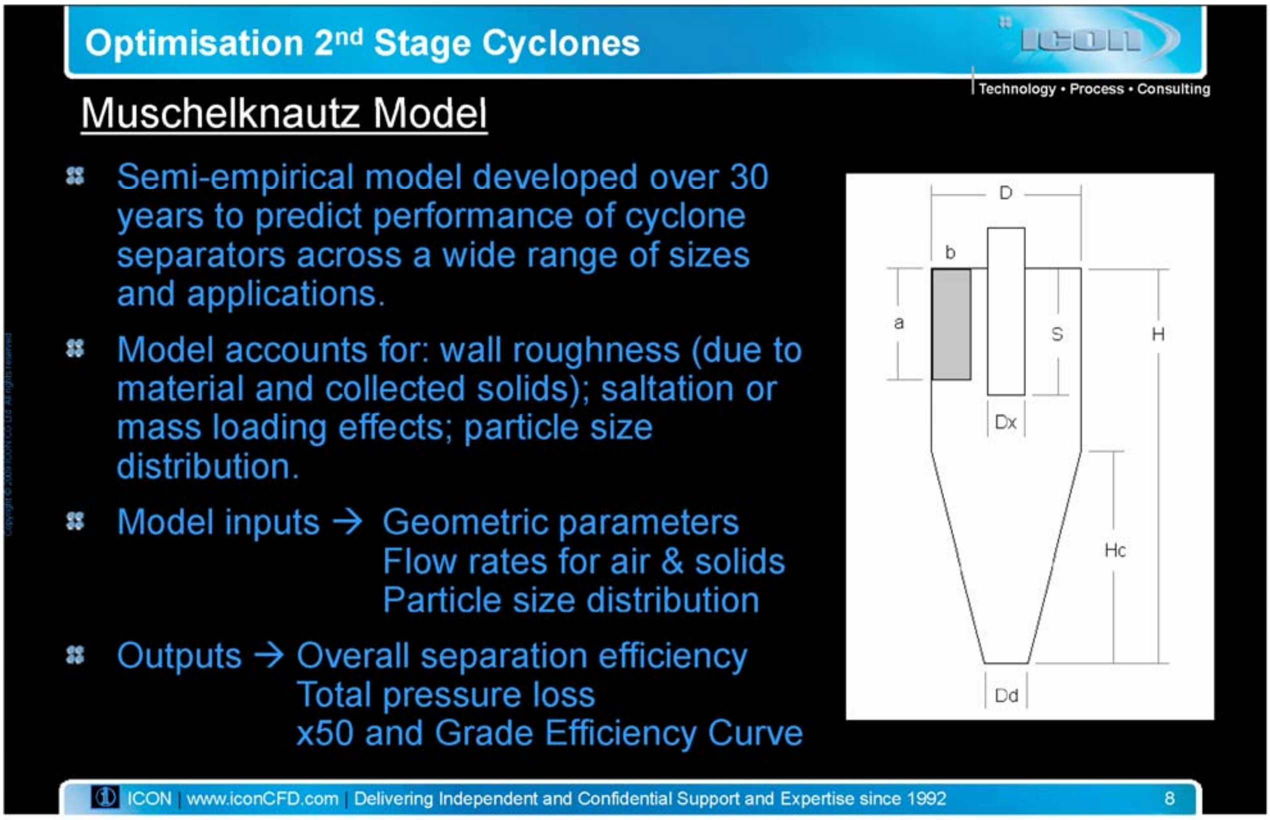


## Optimisation 2nd Stage Cyclones

### Summary

- Muschelknautz model (MM) implemented in Fortran
- modeFrontier → optimisation of individual 2nd stage separators cyclones using MM
  - Optimisation objectives:
    1. Minimise total pressure drop ($\Delta p$)
    2. Maximise separation efficiency ($\eta_{max}$)
  - 5792 feasible designs variations evaluated in mF → 72 initial designs from Sobol DOE followed by 100 NSGAII generations
- CFD tests performed using single cyclone parametric model for validation purposes

ICON | www.iconCFD.com | Delivering Independent and Confidential Support and Expertise since 1992 7

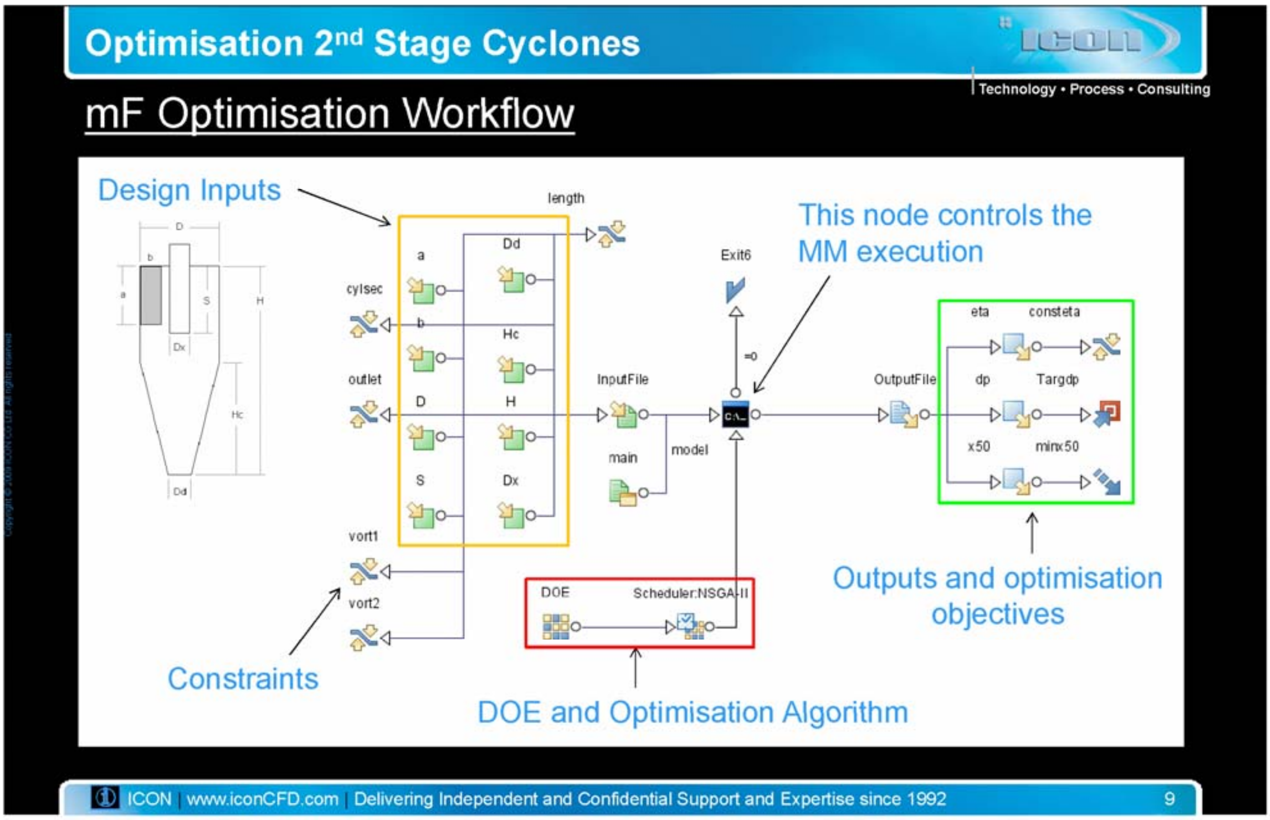


## Optimisation 2nd Stage Cyclones

### Muschelknautz Model

- Semi-empirical model developed over 30 years to predict performance of cyclone separators across a wide range of sizes and applications.
- Model accounts for: wall roughness (due to material and collected solids); saltation or mass loading effects; particle size distribution.
- Model inputs → Geometric parameters
  Flow rates for air & solids
  Particle size distribution
- Outputs → Overall separation efficiency
  Total pressure loss
  x50 and Grade Efficiency Curve

ICON | www.iconCFD.com | Delivering Independent and Confidential Support and Expertise since 1992 8



## Optimisation 2nd Stage Cyclones

Technology • Process • Consulting

### mF Optimisation Workflow

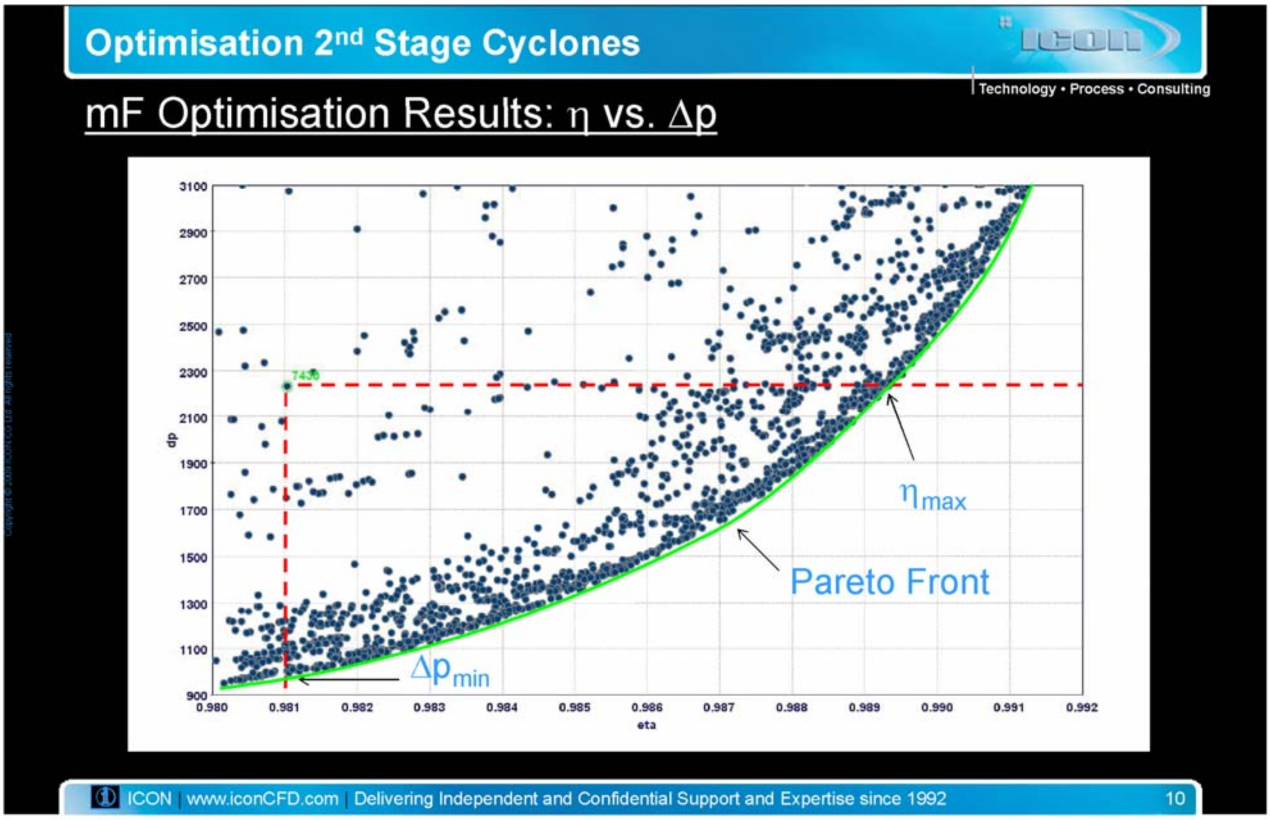
Design Inputs

This node controls the MM execution

Outputs and optimisation objectives

Constraints

DOE and Optimisation Algorithm



## Optimisation 2nd Stage Cyclones

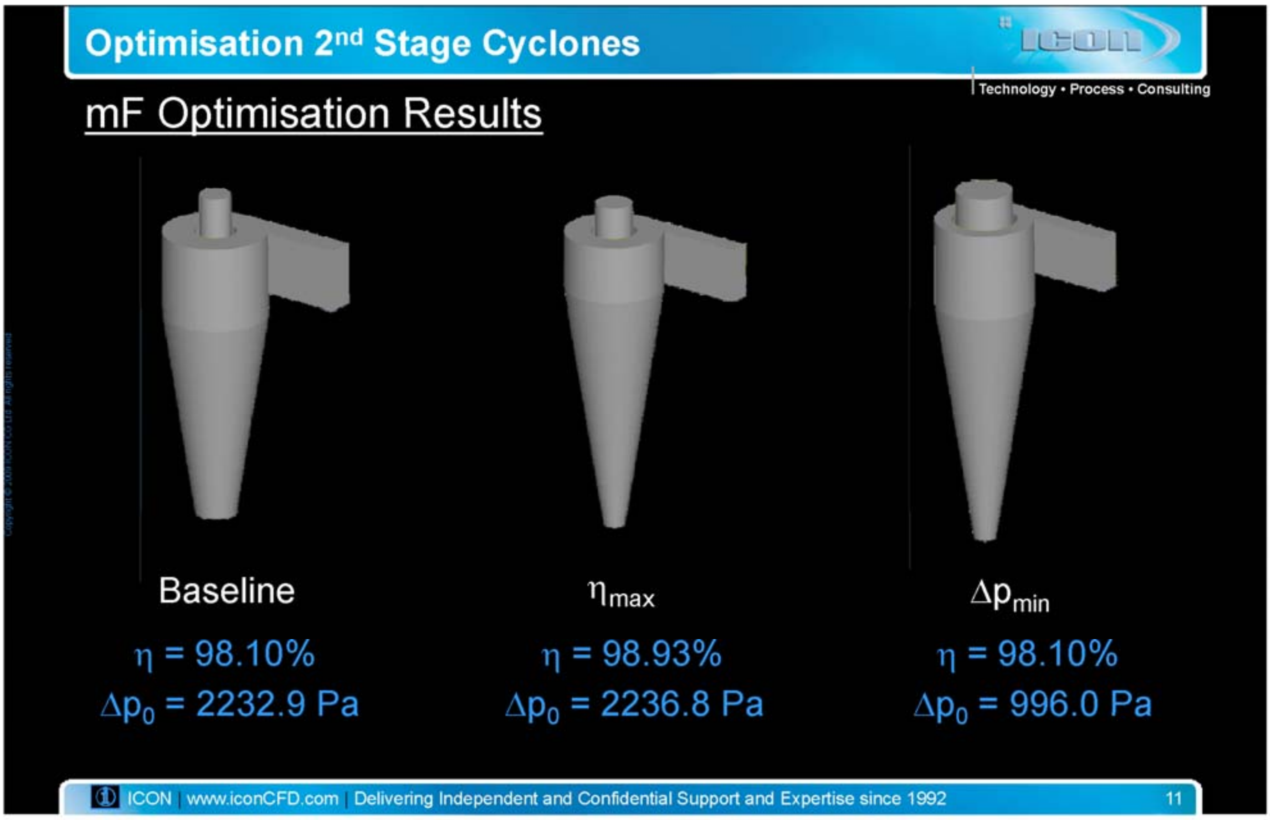
Technology • Process • Consulting

### mF Optimisation Results: η vs. Δp

$\eta_{max}$

Pareto Front

$\Delta p_{min}$

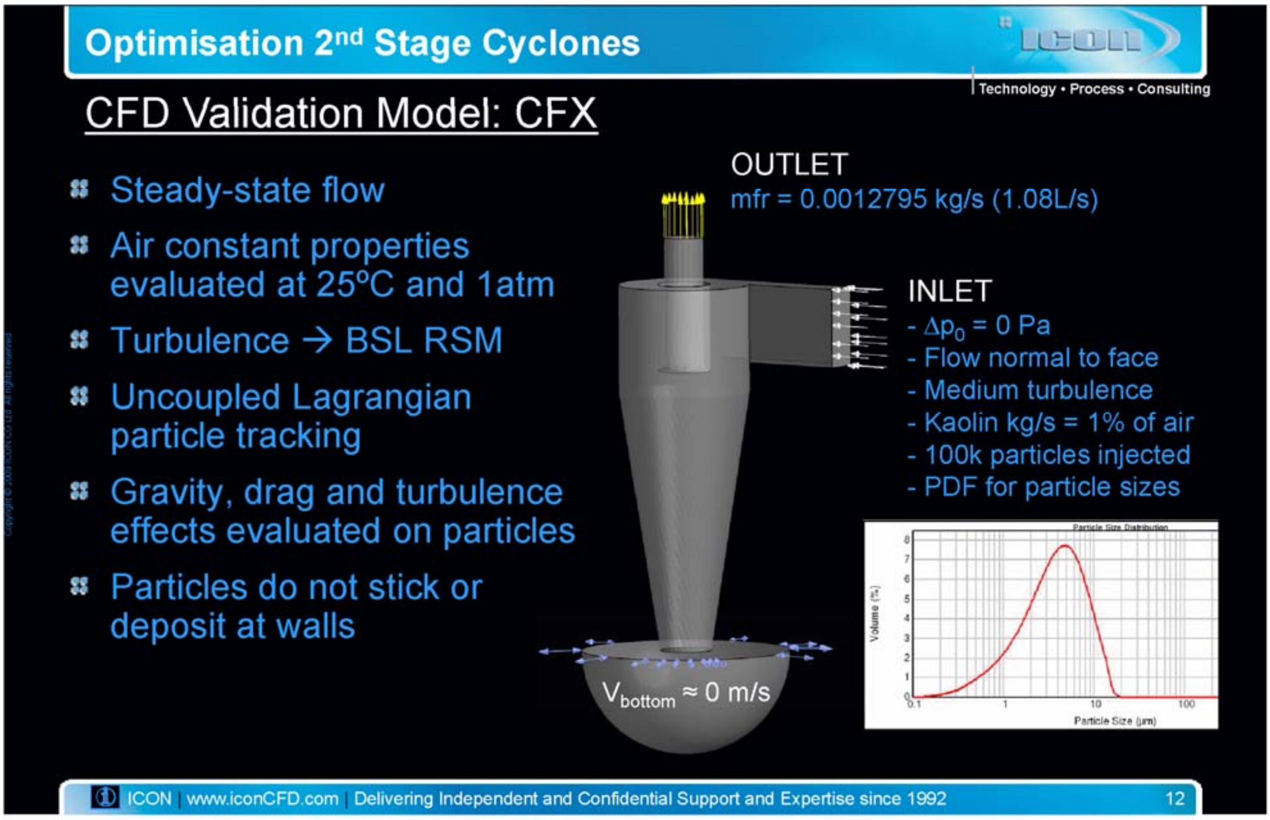


## Optimisation 2nd Stage Cyclones

Technology • Process • Consulting

### mF Optimisation Results

| Baseline | $\eta_{max}$ | $\Delta p_{min}$ |
|---|---|---|
| $\eta$ = 98.10% | $\eta$ = 98.93% | $\eta$ = 98.10% |
| $\Delta p_0$ = 2232.9 Pa | $\Delta p_0$ = 2236.8 Pa | $\Delta p_0$ = 996.0 Pa |



## Optimisation 2nd Stage Cyclones

Technology • Process • Consulting

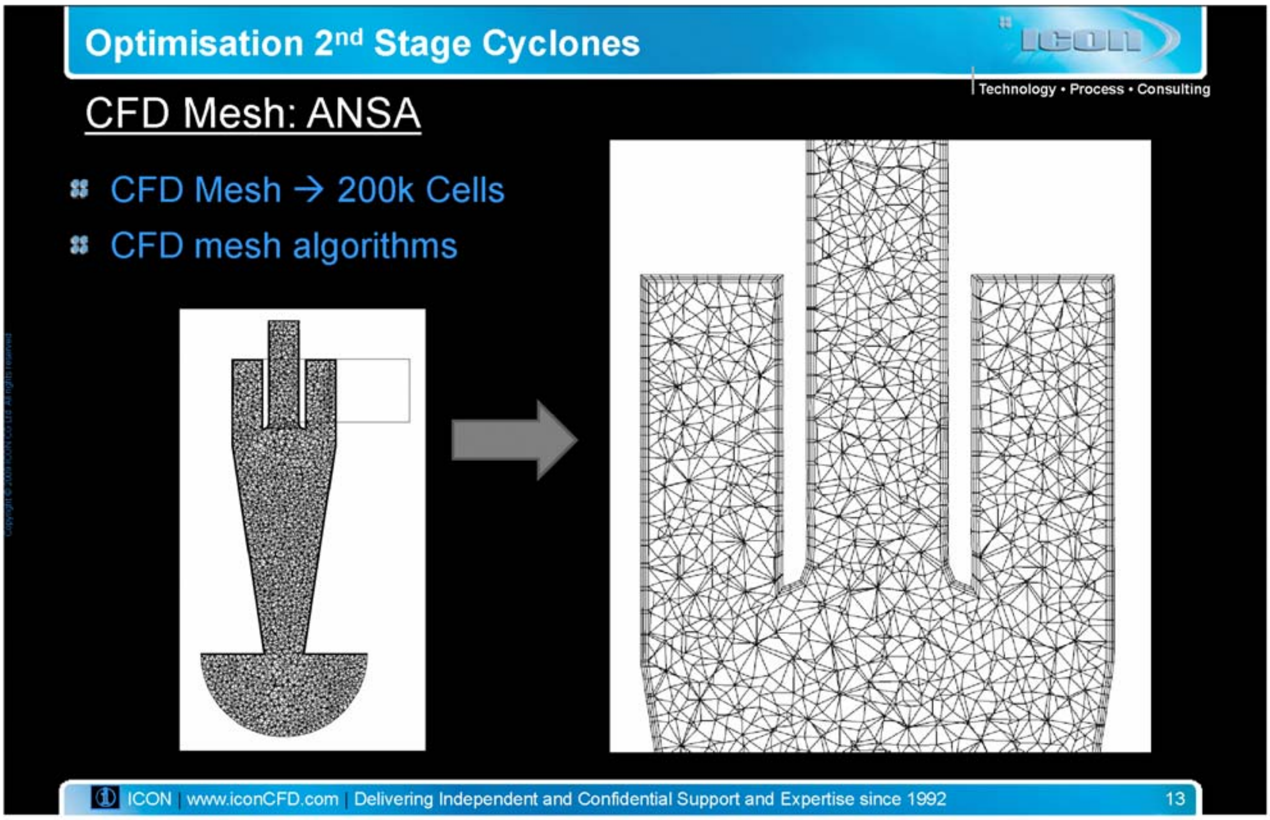
### CFD Validation Model: CFX

- Steady-state flow
- Air constant properties evaluated at 25°C and 1atm
- Turbulence → BSL RSM
- Uncoupled Lagrangian particle tracking
- Gravity, drag and turbulence effects evaluated on particles
- Particles do not stick or deposit at walls

OUTLET
mfr = 0.0012795 kg/s (1.08L/s)

INLET
- $\Delta p_0$ = 0 Pa
- Flow normal to face
- Medium turbulence
- Kaolin kg/s = 1% of air
- 100k particles injected
- PDF for particle sizes

$V_{bottom} \approx 0$ m/s

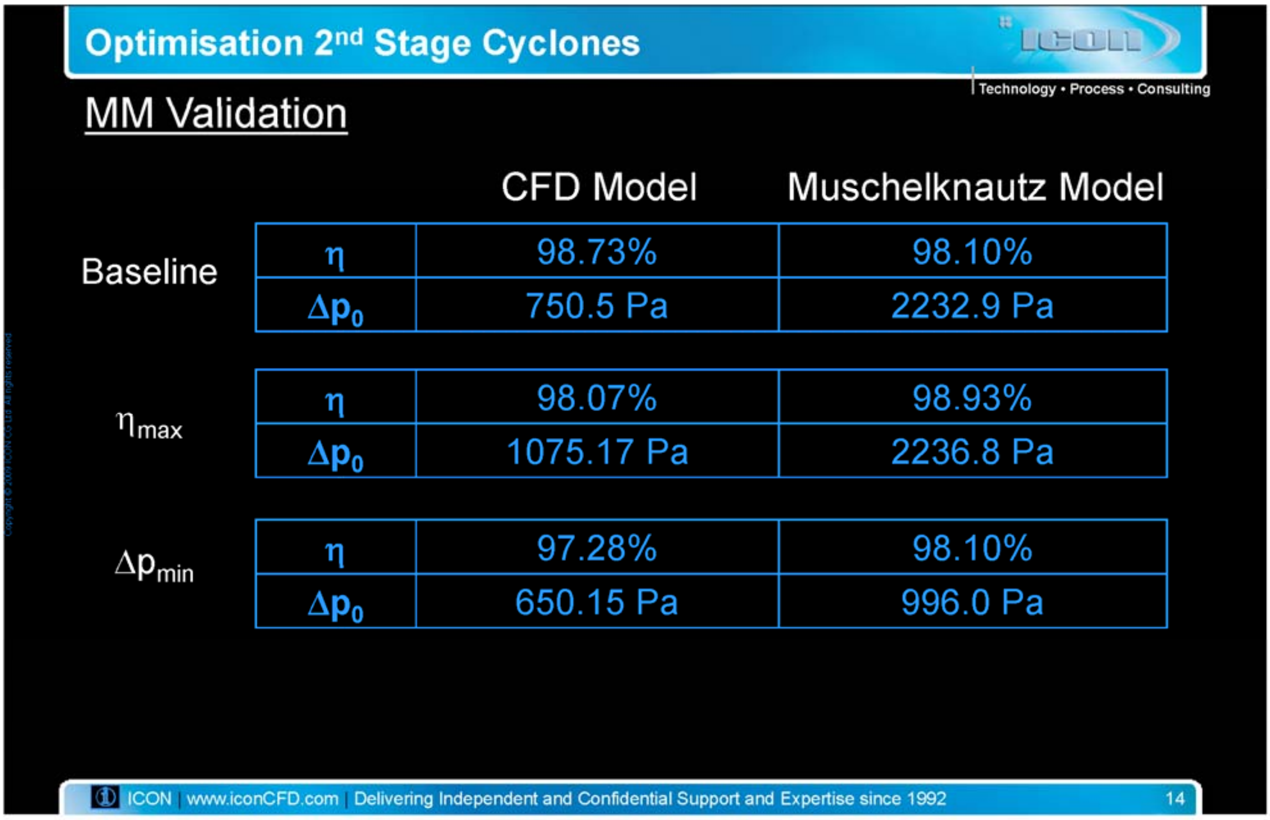


## Optimisation 2nd Stage Cyclones

Technology • Process • Consulting

### CFD Mesh: ANSA

- CFD Mesh → 200k Cells
- CFD mesh algorithms

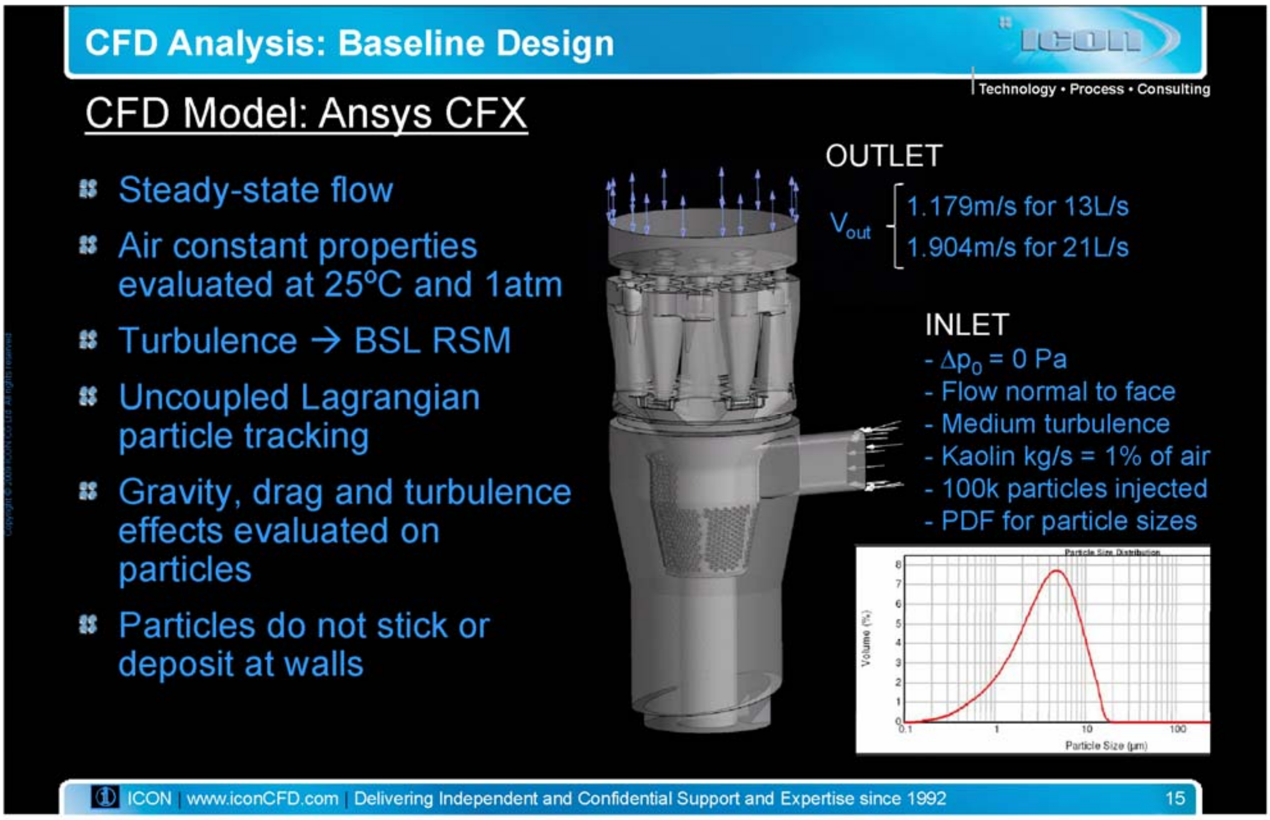


## Optimisation 2nd Stage Cyclones

Technology • Process • Consulting

### MM Validation

| | | CFD Model | Muschelknautz Model |
|---|---|---|---|
| Baseline | $\eta$ | 98.73% | 98.10% |
| | $\Delta p_0$ | 750.5 Pa | 2232.9 Pa |
| $\eta_{max}$ | $\eta$ | 98.07% | 98.93% |
| | $\Delta p_0$ | 1075.17 Pa | 2236.8 Pa |
| $\Delta p_{min}$ | $\eta$ | 97.28% | 98.10% |
| | $\Delta p_0$ | 650.15 Pa | 996.0 Pa |



## CFD Analysis: Baseline Design

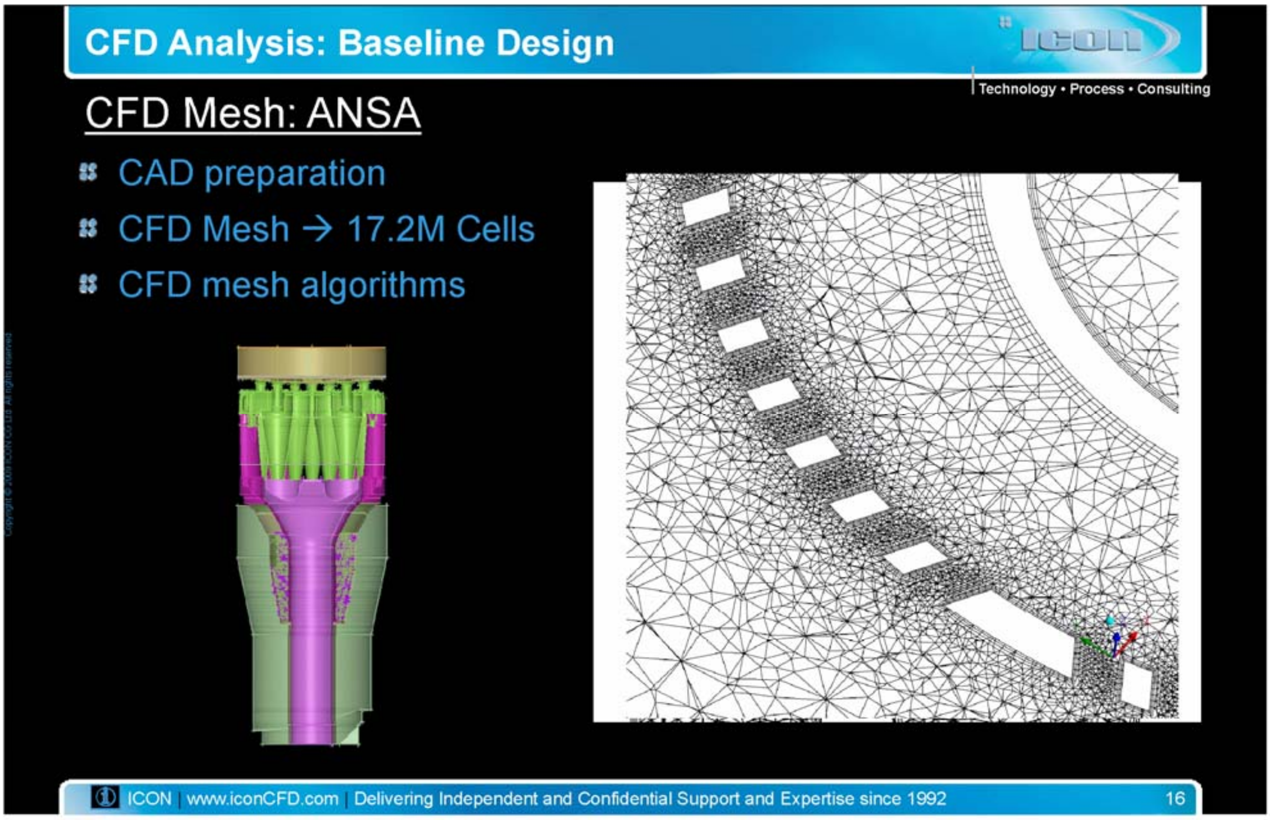
### CFD Model: Ansys CFX

- Steady-state flow
- Air constant properties evaluated at 25°C and 1atm
- Turbulence → BSL RSM
- Uncoupled Lagrangian particle tracking
- Gravity, drag and turbulence effects evaluated on particles
- Particles do not stick or deposit at walls

OUTLET

$V_{out}$ 1.179m/s for 13L/s
1.904m/s for 21L/s

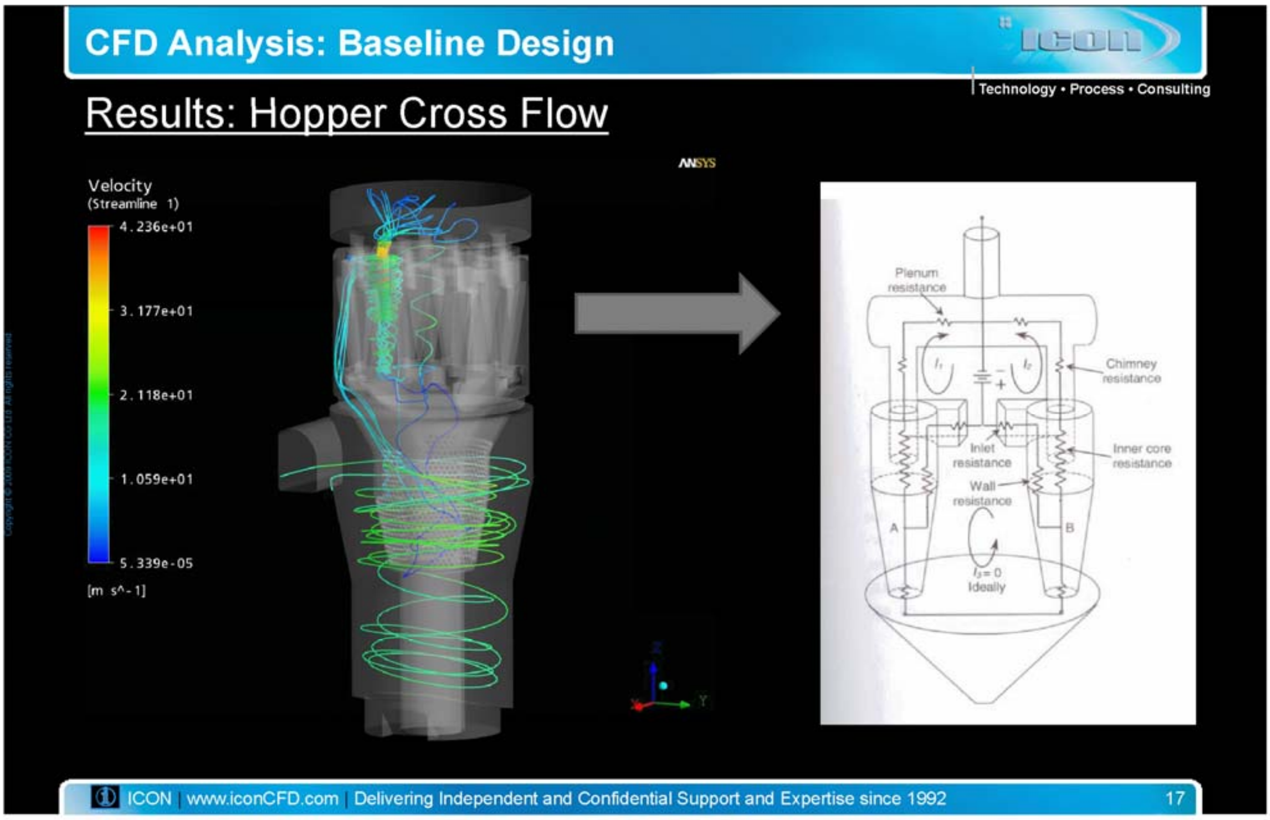
INLET
- $\Delta p_0$ = 0 Pa
- Flow normal to face
- Medium turbulence
- Kaolin kg/s = 1% of air
- 100k particles injected
- PDF for particle sizes



## CFD Analysis: Baseline Design

### CFD Mesh: ANSA

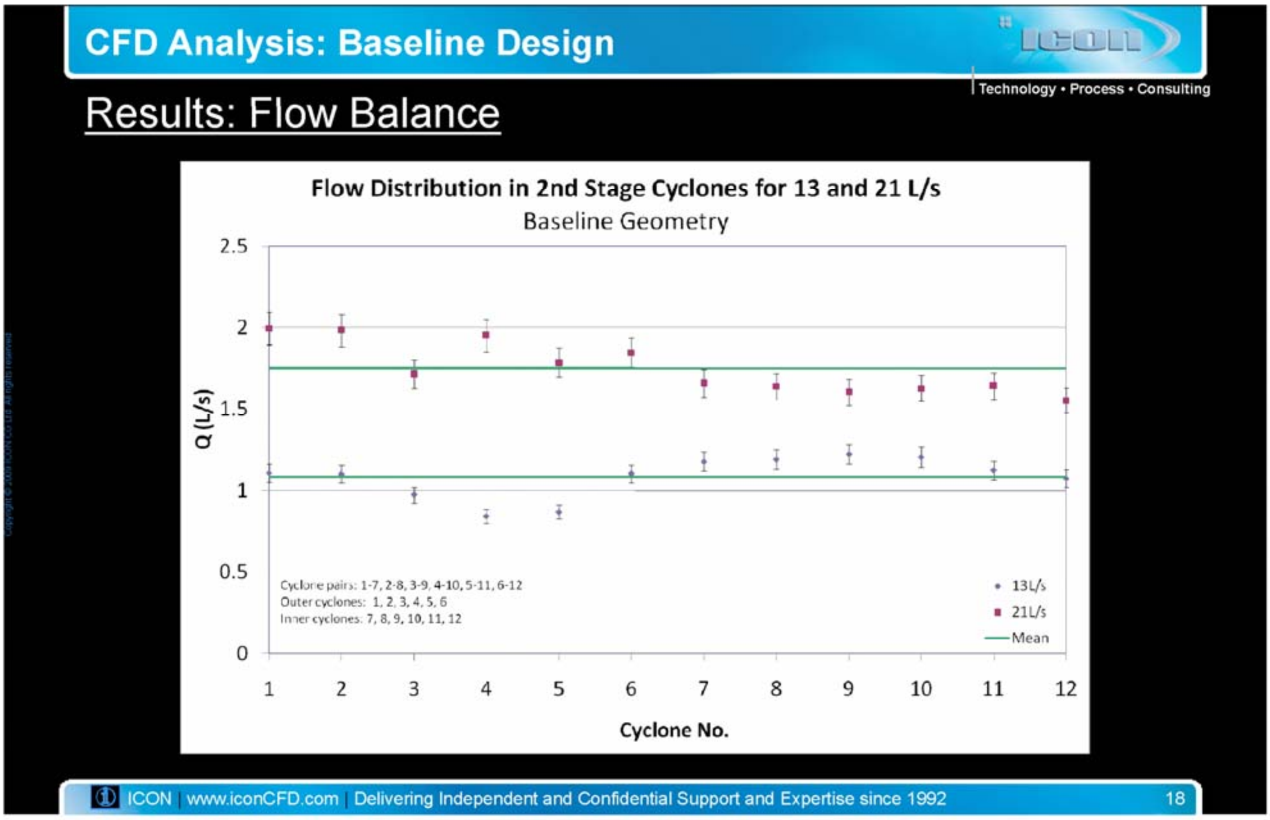
- CAD preparation
- CFD Mesh → 17.2M Cells
- CFD mesh algorithms



## CFD Analysis: Baseline Design

Technology • Process • Consulting

### Results: Hopper Cross Flow



## CFD Analysis: Baseline Design

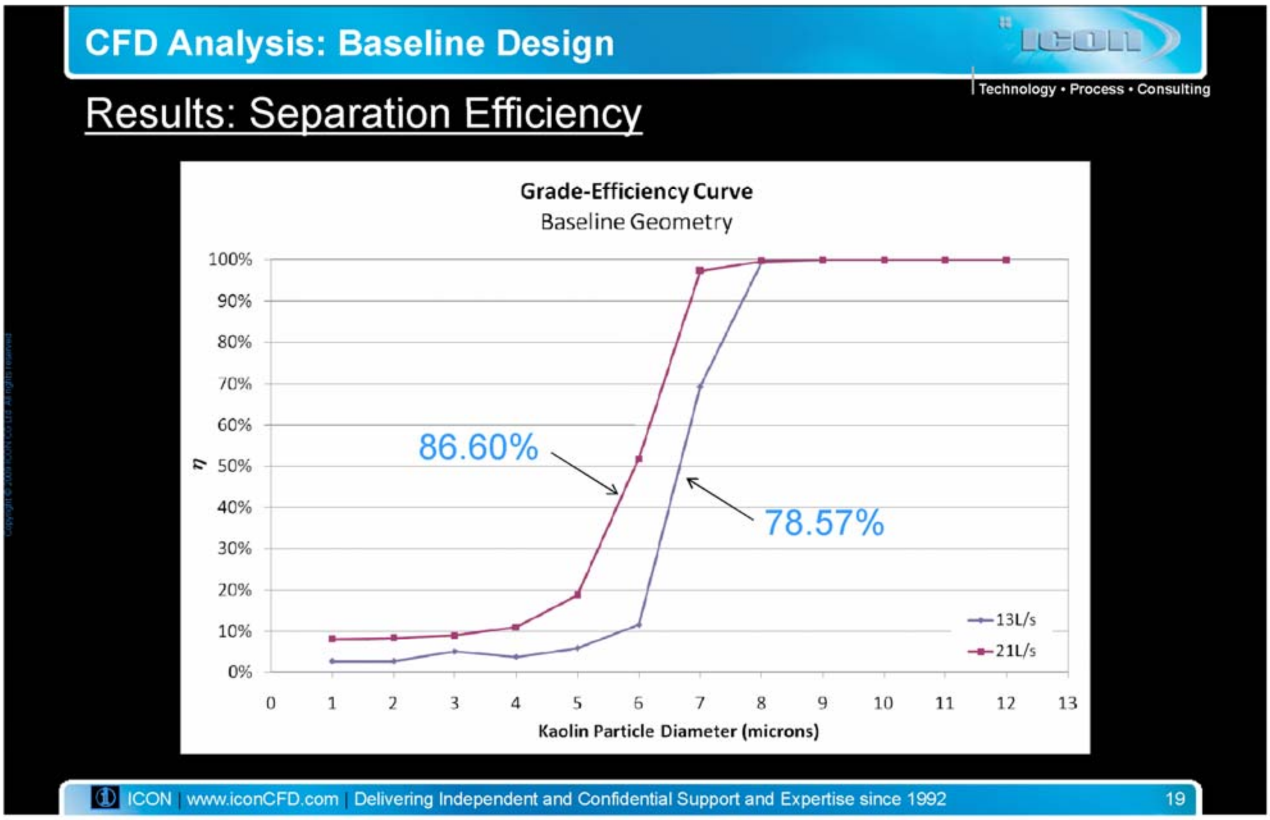
Technology • Process • Consulting

### Results: Flow Balance

Flow Distribution in 2nd Stage Cyclones for 13 and 21 L/s

Baseline Geometry

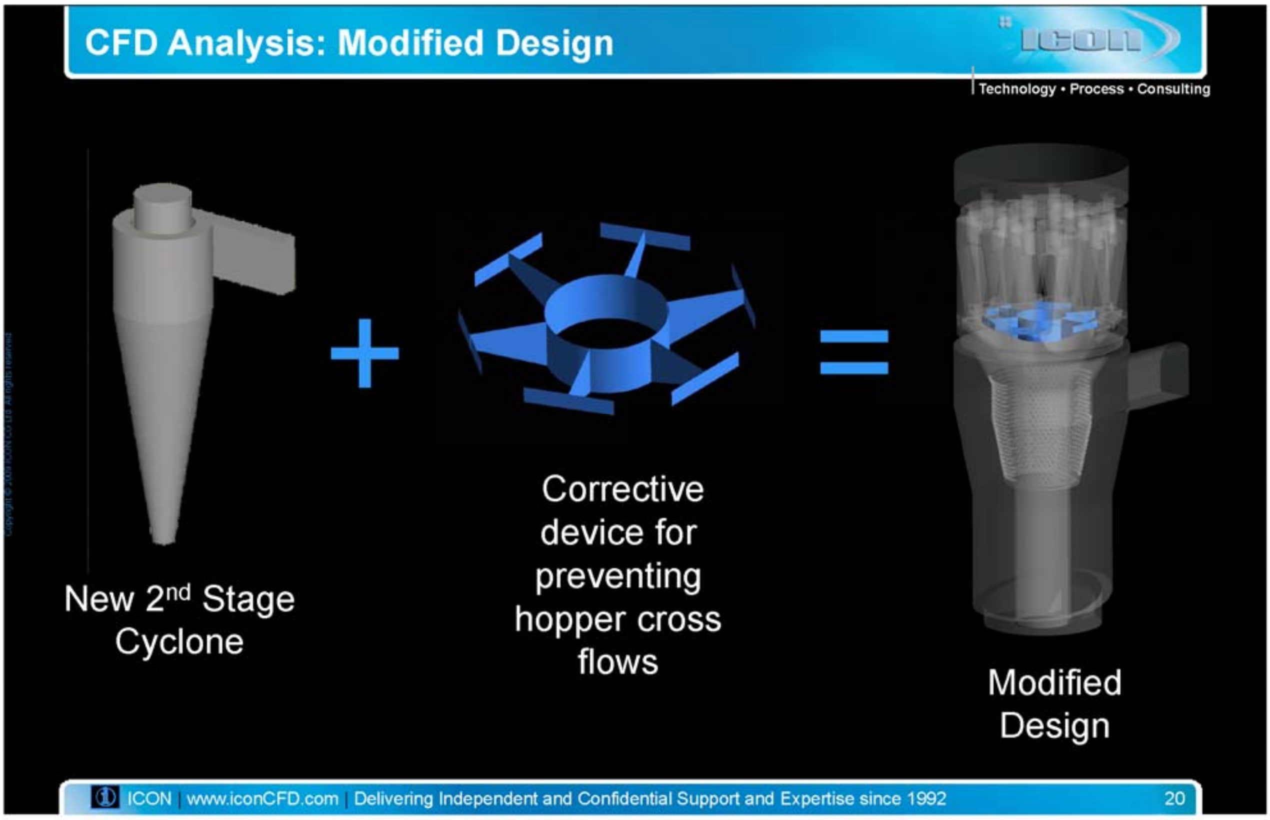
Cyclone pairs: 1-7, 2-8, 3-9, 4-10, 5-11, 6-12
Outer cyclones: 1, 2, 3, 4, 5, 6
Inner cyclones: 7, 8, 9, 10, 11, 12



## CFD Analysis: Baseline Design

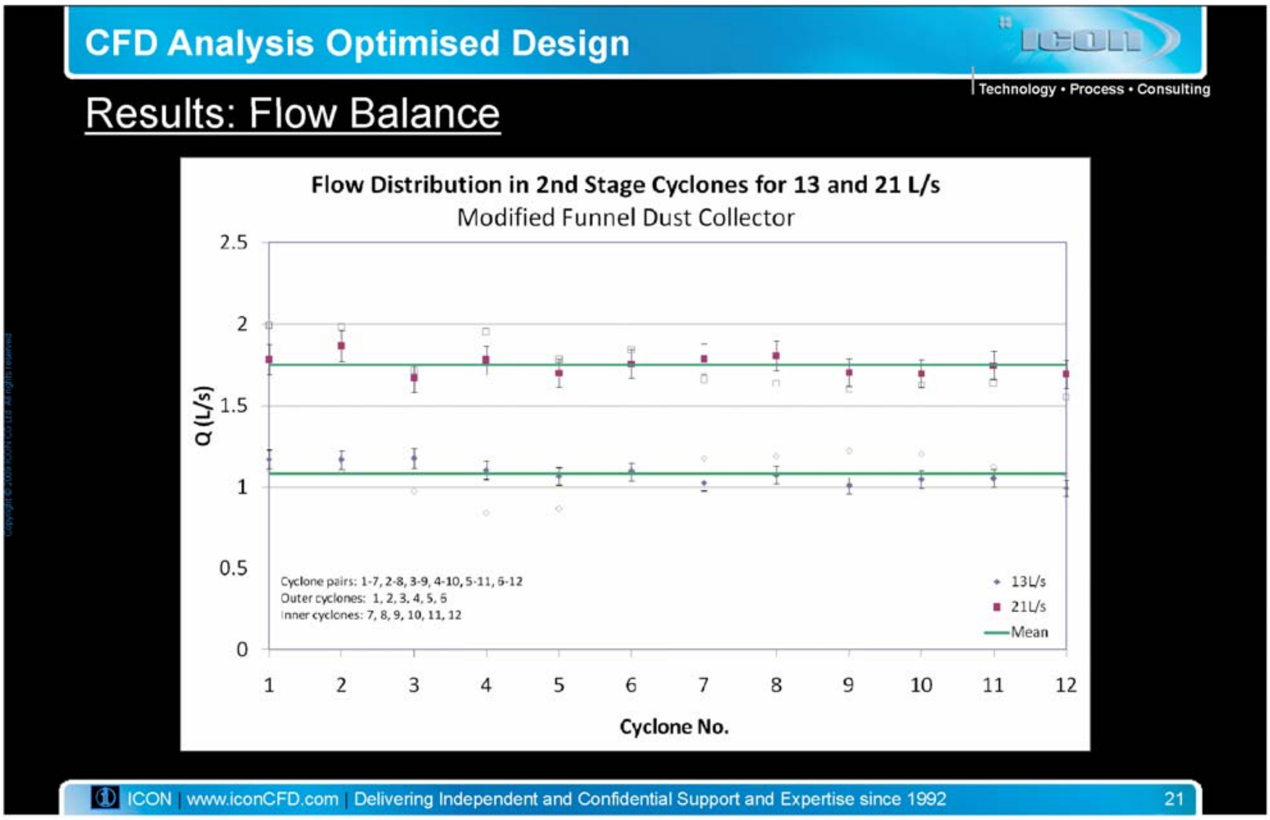
Technology • Process • Consulting

### Results: Separation Efficiency



## CFD Analysis: Modified Design

Technology • Process • Consulting

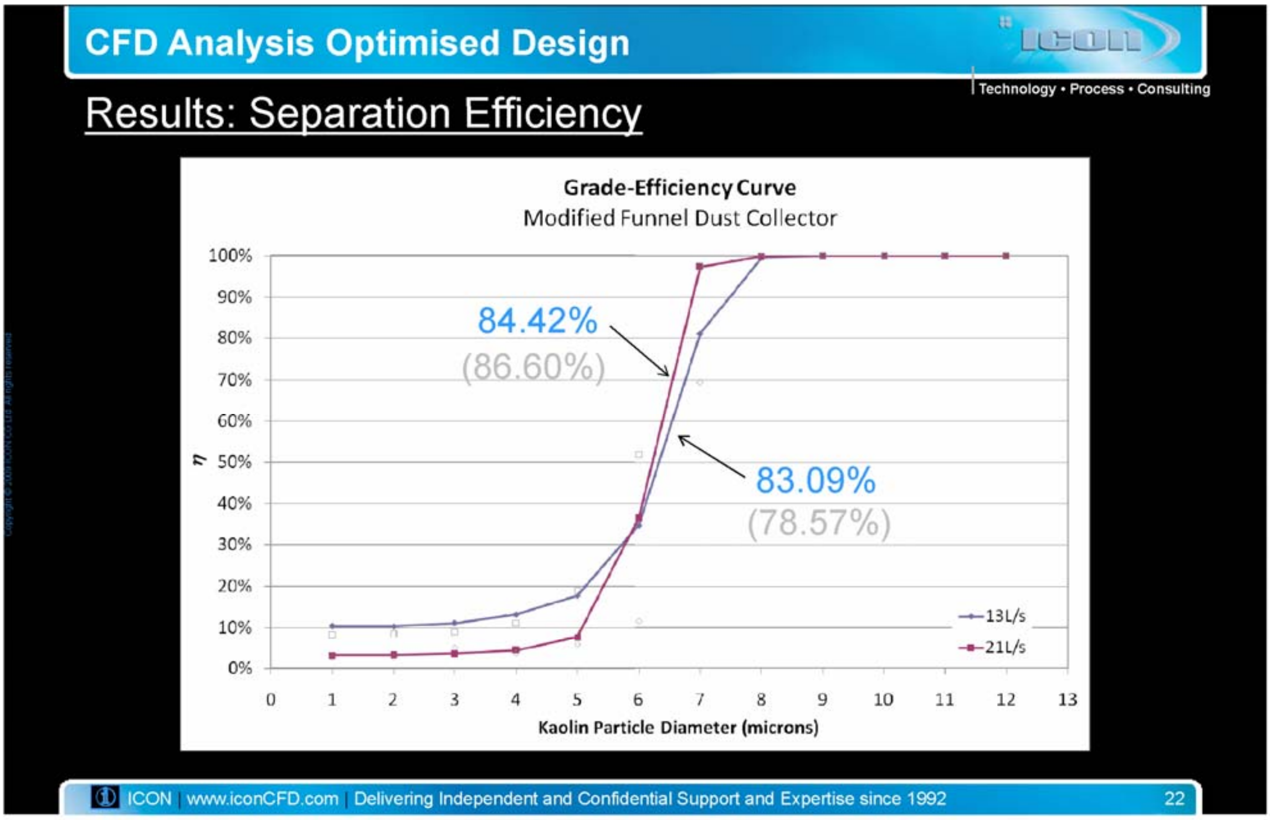


## CFD Analysis Optimised Design

Technology • Process • Consulting

### Results: Flow Balance

ICON | www.iconCFD.com | Delivering Independent and Confidential Support and Expertise since 1992 21

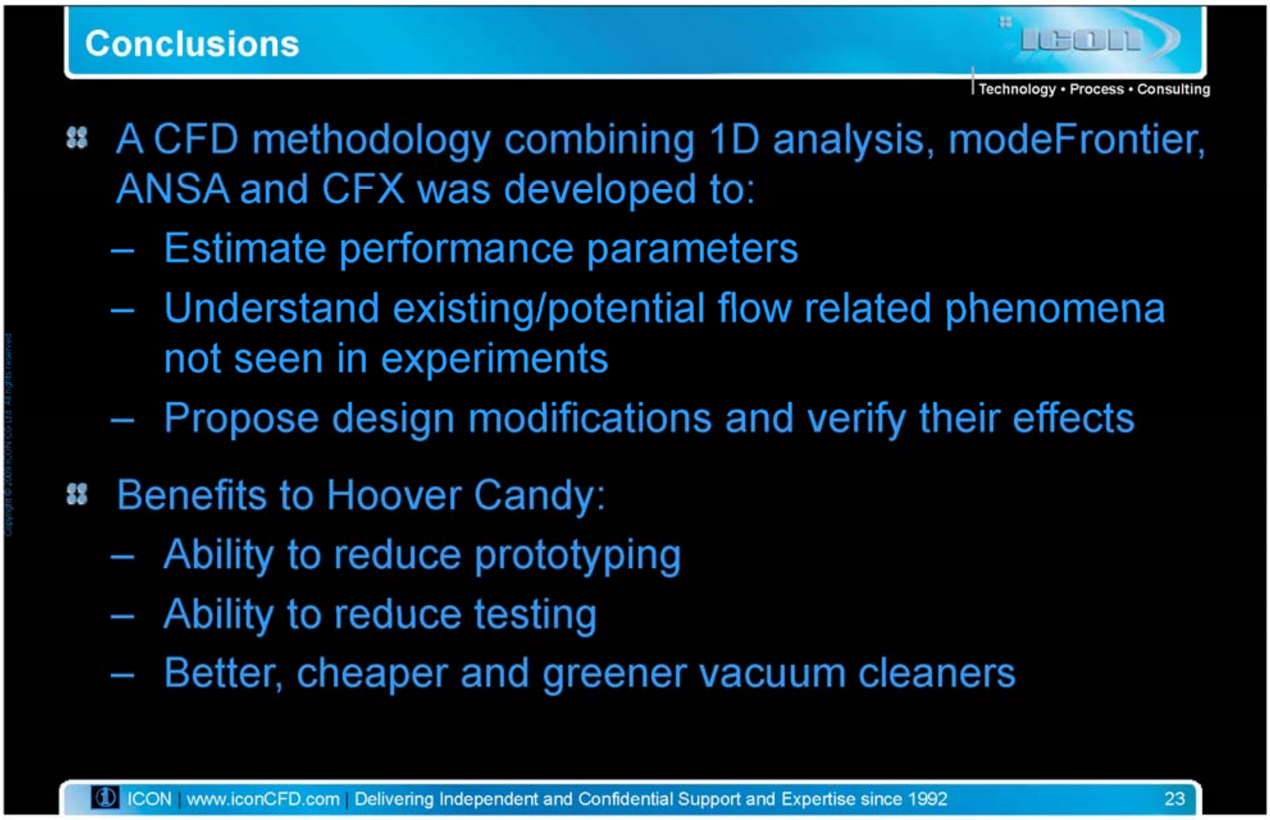


## CFD Analysis Optimised Design

Technology • Process • Consulting

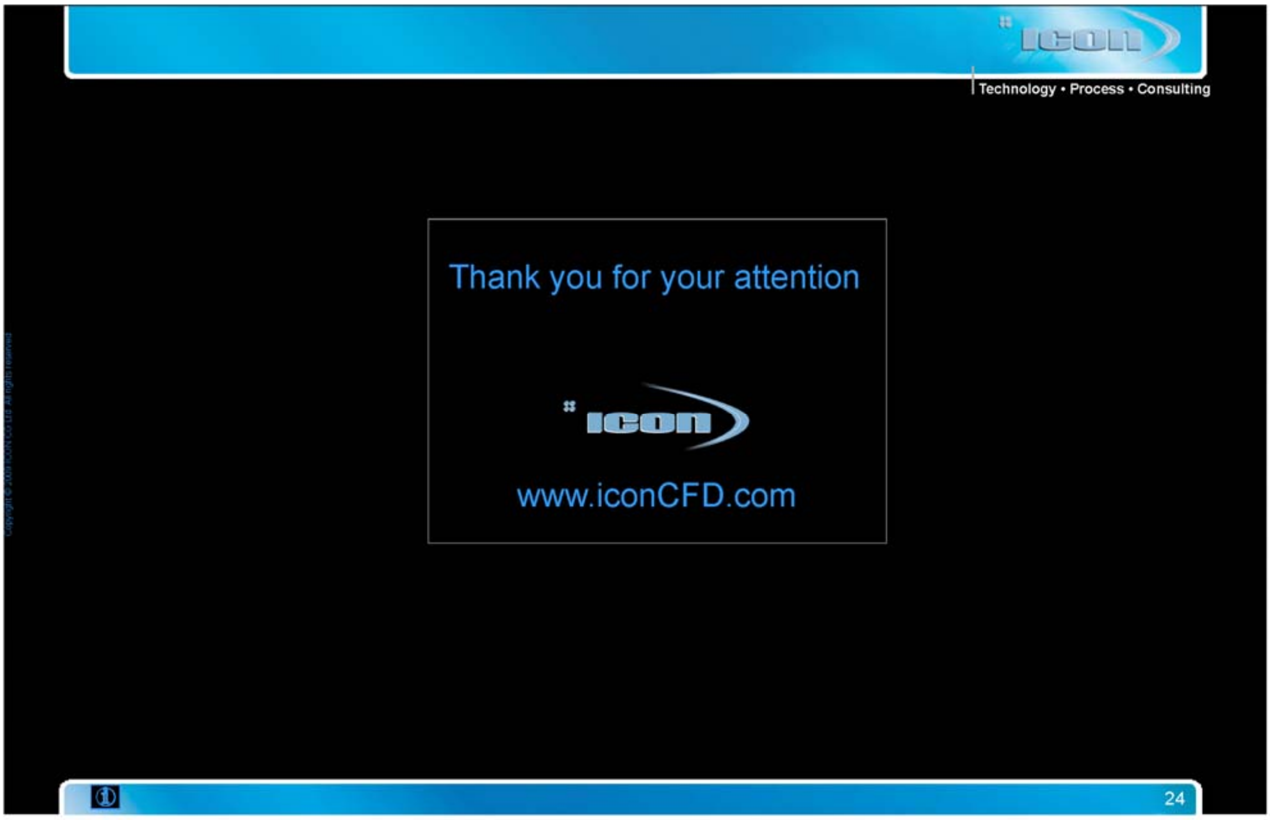
### Results: Separation Efficiency

ICON | www.iconCFD.com | Delivering Independent and Confidential Support and Expertise since 1992 22



## Conclusions

- A CFD methodology combining 1D analysis, modeFrontier, ANSA and CFX was developed to:
  - Estimate performance parameters
  - Understand existing/potential flow related phenomena not seen in experiments
  - Propose design modifications and verify their effects
- Benefits to Hoover Candy:
  - Ability to reduce prototyping
  - Ability to reduce testing
  - Better, cheaper and greener vacuum cleaners



Thank you for your attention

www.iconCFD.com