Integration Of CFD Analysis In Product Development Process Of Kitchen Range Hoods

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INTRODUCTION

The aim of the CFD analysis on hood ventilation systems is usually to investigate the hood performance in terms of efficiency improvement, noise reduction or pollutant removal. The aim of this work is the integration of CFD in a business reality, carrying out a CFD model to add a **new phase to the product development process**, obtaining practical advantages in terms of performance of different configurations without constructing prototypes and consequently benefits in term of cost, time and resources saving.

AIM OF WORK & METHODOLOGY

In this work the purpose is to implement in the product development process a *CFD analysis of hood performance*. The Elica Haiku hood has been chosen to create the CFD model. ***All those components that influence the fluid dynamic parameters of the hood were identified***, modelled and included in the CFD model following an *O.V.A.T. (One Variable At Time) procedure* (as seen in [4]), summarized in the workflow of the figure 2.

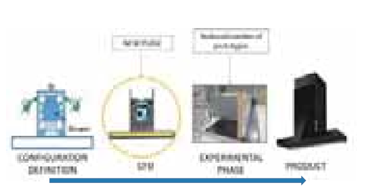


Figure 1. *Product development process: a first configuration is defined, then a CFD analysis of multiple configurations takes place. After that, an experimental phase is necessary to validate the numeric results. Finally, the product can be realized.*

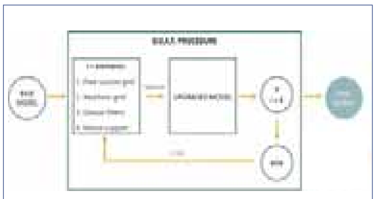


Figure 2. *First, a "**base model**" is created and simulated, where the motor group is the only element. Then, the i=1 element is added to the previous model in order to obtain the first "**upgraded model**". Once the upgraded model has been simulated, there is a check on the "i" value. When i=i+1 a new upgraded model is created and simulated, so the cycle starts again. When i=4 the cycle stops and the **final CFD model** is obtained*

The final CFD model has to be *experimentally validated* in terms of the Fluid Dynamic Efficiency of the hood, FDE hood (defined in European Commission's Delegated Regulation No 65/2014 of October 2013, supplementing Directive 2010/30/EU):

$$FDE_{hood} = \frac{Q_{BEP} * P_{BEP}}{3600 * W_{BEP}} * 100 \quad (1)$$

where, Q_{BEP} (m³/h, rounded to the first decimal place) is the flow rate of the domestic range hood at Best Efficiency Point; P_{BEP} (Pa, rounded to the nearest integer) is the static pressure difference of the domestic range hood at Best Efficiency Point; W_{BEP} (W, rounded to the first decimal place) is the electric power input of the domestic range hood at the Best Efficiency Point.

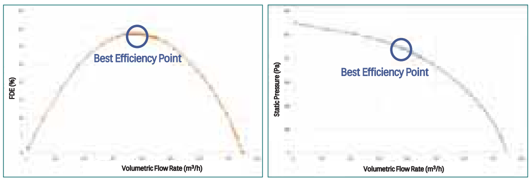
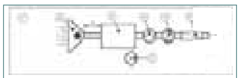


Figure 3. Measured data by Elica Propulsion Lab



a) Five times the diameter of the pipe
1) Airflow extraction range hood
2) Range hood
3) Pressure compensation chamber
4) Orifice plate for airflow measurement
5) Auxiliary fan
6) Baffle
7) Static pressure gauge

Figure 4. Airflow test bench diagram

CFD SIMULATIONS: STEPS

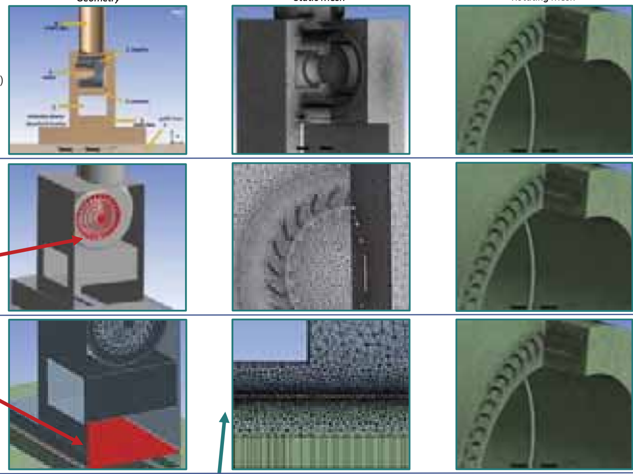
Geometry | *Static Mesh* | *Rotating Mesh*

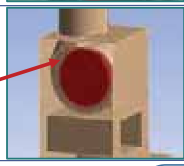
Base model (motor group only)

1st Upgraded Model (free suction side grid)

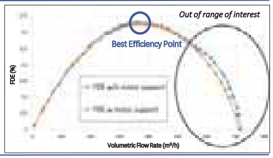
2nd and 3rd Upgraded Model (aesthetic and filtering grids)

4th Upgraded Model (motor support)





This component, *whose motor support influence is significant only for volumetric flow rate values higher than 500 m3/h*, can be excluded because the experimental tests showed that *the range of interest is between 200 and 450 m³/h*. Therefore, the *3rd Upgraded Model corresponds to the Final Model*



The aesthetic grid and the grease filters have been modelled as a single POROUS MODEL . This allows reducing mesh elements, meaning a benefit on computational cost

CFD SIMULATIONS: DETAILS, RESULTS & CASES STUDY

MESHING METHODS [5]:

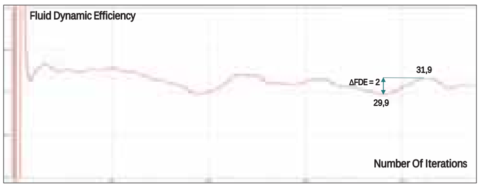
- *Inflation* method guarantees a correct solution of the boundary layer in case of a turbulent flow;
- *Sizing* method allows to refine the mesh in those zones that are interesting for the analysis (such as grids and interfaces). Concerning the interfaces, the sizing settings shall be the same in order to get a good connection of the two meshes;
- *Multizone* method allows the automatic realization of a structured mesh in regular geometries, such as the quiet room (which is a parallelepiped). This guarantees a reduction of the number of mesh elements.

MESH QUALITY AND SENSITIVITY ANALYSIS

Three *mesh quality parameters* are controlled in order to obtain *convergence and reliability* of the solution: *Orthogonal Quality, Skewness, Aspect Ratio.*

Orthogonal quality min = 8,3*10⁻²
Skewness max = 0,917
Aspect ratio max = 107,8
Number of elements = 11,7 mln

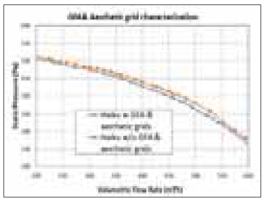
Orthogonal quality min = 1,6*10⁻²
Skewness max = 0,984
Aspect ratio max = 121,3
Number of elements = 8,6 mln



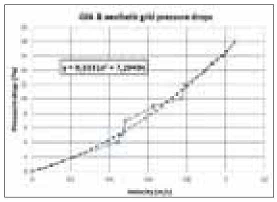
POROUS MODEL CHARACTERIZATION:

$$-\frac{dp}{dx_i} = K_{lin} * U_i + K_{quad} * |U| * U_i$$

Evaluated through EXPERIMENTAL TESTS



Blue curve: *measured pressure with aesthetic and grease grids*
Orange curve: *measured pressure without aesthetic and grease grids*



*Second-grade polynomial (dotted curve) that approximates the measured **pressure drops – velocity curve***

$$K_{quad} = \frac{9.3331}{0.035} = 266.667 \left(\frac{kg}{m^4}\right) \quad (2)$$

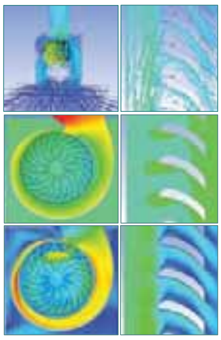
$$K_{lin} = \frac{7.2949}{0.035} = 208.426 \left(\frac{kg}{m^3 * s}\right) \quad (3)$$

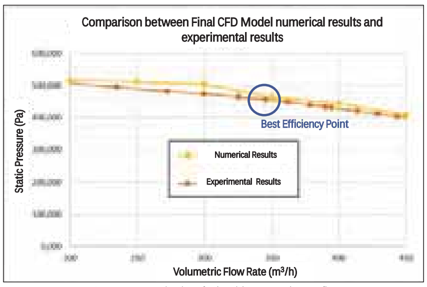
RESULTS AND EXPERIMENTAL VALIDATION

Stream Lines

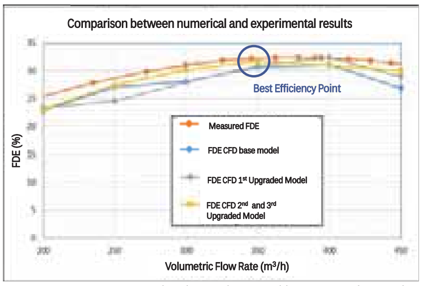
Static Pressure

Velocity





Comparison between ***measured and CFD final model pressure-volumetric flow rate curves***



At BEP is possible to observe how **numerical results approach to measured data at every step of O.V.A.T. cycle**

The O.V.A.T. cycle allows a step-by-step approaching of numeric and measured results.

The CFD Best Efficiency Point, in other words that point where the FDE reaches its maximum value which occurs at 350 m³/h in this case, approaches at every step to the measured maximum FDE value.

Table below reports *CFD and measured FDE values* (the BEP is highlighted)

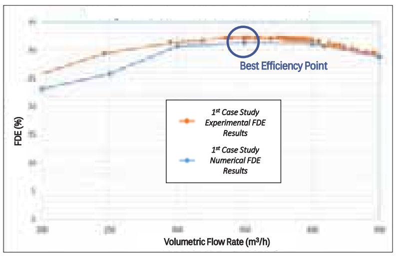
	Final CFD model validation		
Q (m³/h)	Measured FDE (%)	Numerical FDE (%)	Percentage difference (%)
200	25.43	22.44	11.8
250	28.69	27.16	5.2
300	31.04	30.52	1.6
350	32.30	31.33	3.1
400	32.28	30.62	5.3
450	31.26	26.49	15.3

$$percetage\ difference = \frac{|numeric - measured|}{measured} * 100 \quad (4)$$

The Final CFD Model has been applied to two cases study in order to observe its flexibility

1st Case Study

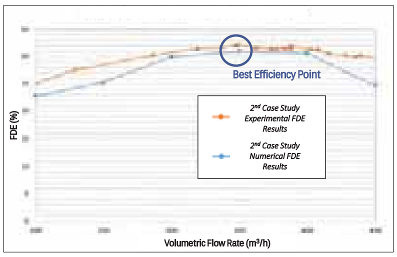
Original motor has been replaced with a different one, meaning that the new motor characteristic curves have been implemented in CFX-Pre. A new measure of FDE took place in order to compare experimental data and numerical results



	1st case study CFD model validation		
Q (m³/h)	Measured FDE (%)	Numerical FDE (%)	Percentage difference (%)
200	25.8	23.1	10.5
250	29.6	25.8	12.8
300	31.4	30.7	2.2
350	32.3	31.4	2.8
400	31.9	31.2	2.2
450	29.5	28.8	2.3
500	28.2	21.0	25.5

2nd Case Study

In this case, *some geometrical dimensions have been modified*, in particular the dimensions of the box that contains the motor group and the aspiration surface. A new measure of FDE took place in order to compare experimental data and numerical results



	2nd case study CFD model validation		
Q (m³/h)	Measured FDE (%)	Numerical FDE (%)	Percentage difference (%)
200	24.8	22.7	9.1
250	28.0	25.3	10.7
300	31.1	29.9	3.9
350	32.4	31.5	2.7
400	32.5	30.6	6.1
450	31.5	24.7	27.4

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