Investigation of vacuum cleaner performance through vacuum head modifications

Whirlpool Corporation is the number 1 major appliance manufacturer in the world; in 2015 70 million products were sold in more than 170 countries, with 97.000 employees in 70 manufacturing and R&D centers, investing $1 billion in capital and R&D centers annually.

NAR North America, LAR Latin America, EMEA Europe Middle East and Africa, ASIA, are the four major Regions.

Whirlpool's EMEA, whose headquarter is in Comerio (VA) Italy, is the number 1 in the EMEA Region and number 2 in Europe,with 24.000 employees speaking over 40 languages and 15 industrial sites in 8 Countries. In addition to internal manufacturing, Whirlpool is using OEM/ODM for new businesses.

The Company is strongly committed to delivering high performance products to the customer, while being sustainable and environmentally friendly. Over the last year the figures have been outstanding: -27% of water consumption, -11% in energy consumption, -8% of waste production.

Aim of the work

Whirlpool is relatively new to the vacuum cleaner market and is leveraging the Hotpoint brand in EMEA Region. Despite the OEM/ODM approach for this product, Whirlpool aims to conduct a comprehensive performance analysis of the product's key parts.

The vacuum head is probably the most important part in assuring the best balance between ErP Regulation compliance, performance in all use cases and a pleasant user experience.

In recent years the ErP regulation has introduced the concept of real performance; moving the customer's attention away from misleading figures like electric motor power (Watts) and suction power (Air-Watts), to performance figures that are closer to the cleaning performance, such as dust pick-up on hard floors and carpets.

The CFD model

Baseline

A 3D numerical model of the vacuum cleaner head was created by EnginSoft based on CAD geometry provided by Whirlpool. Parts were imported into ANSYS CAD/MESHING system and merged together to get an acceptable connectivity. Missing parts,

connections and boundary conditions were also generated.
The ANSYS CFX solver was used to evaluate the system's fluid dynamics.
The CFD model replicates the test conditions according to the above mentioned ErP regulations ;the vacuum head rests on the floor, centered on a 45 degrees inclined guide that contains the dust. A semispherical air plenum surrounding the volume completes the computational domain.
With this approach, the air enters the vacuum head from the semispherical opening (ambient) and is guided along a flexible duct toward the vacuum cleaner's body (not modeled here).
The resulting CFD model is shown in figures 1 and 2.

Every part of the vacuum head is modeled and includes:

- the fully shaped bottom part in contact with the floor. This is an important geometrical detail, since this leakages are the regions where the air can be sucked in by the vacuum cleaner under the blower's action
- the elbowed hood that guides the incoming air into the flexible duct
- the rubber flap in the rear bottom part of the vacuum head
- the flexible connections to the rigid duct

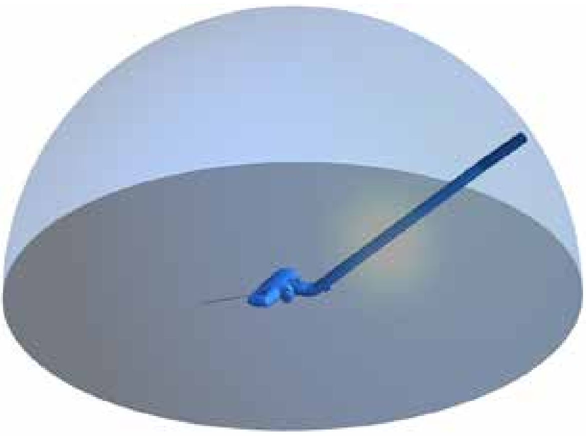

Figure 1 - CFD model of the Valuum Cleaner

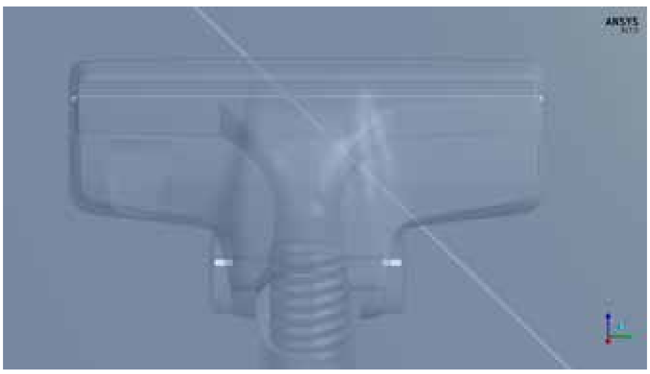

Figure 2 - CFD model of the Valuum Cleaner

Model Tuning
The air motion is generated by a centrifugal blower; In order to account for this effect, the blower's working curve has been implemented in the solver by a 3D region with a momentum source reproducing the blower's working curve.
Also, to properly set the numerical model a 3D porous loss has been considered;given the mass flow rate in the free sucking condition, where the vacuum head is not constrained (rested) on the floor, the resistance coefficient has been tuned in order to meet the supplied mass flow rate.
In other words, the equivalent resistance simulates the rest of the vacuum cleaner, not explicitly modeled. For this reason, this resistance coefficient has been used for all the studied simulations.

Under an imposed pressure drop, resistance and blower curve, the solver outputs the mass flow rate and the fluid-dynamic filed thru the overall computational domain.
The mass flow rate (thus the blower working point), the level of depressurization and the air's flow direction in the bottom region of the vacuum head (floor-vacuum head interaction) are the main objectives to consider in comparing the different designs.

Optimization Results
From the baseline results, three kind of configurations have been studied, corresponding to three geometrical modifications. This was done mainly to investigate the sensitivity of the system's performance to geometric variations.

Modification 1 – new shape of the hood's entrance area (Figure 3)
Given the same available pressure drop, this modification slightly increases the mass flow rate. This effect, although not as strong as expected, still represents useful information about how the system reacts to such modification.

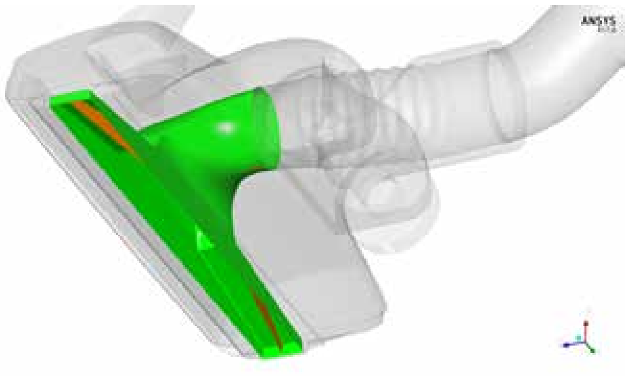

Figure 3 - New shape of the hood's entrance area

Modification 2 – curved shape of the rubber flap (Figure 4)
This configuration has the greatest potential to improve the system's efficiency in the studied scenario.
To best compare the performance of the baseline and modification 2 configurations, they have been simulated with the real blower curve (head-flow rate). The result shows that, although the mass

flow rate increase through the hood are similar, the percentage of air captured from the crevice is much higher. This would lead to a better behavior of the vacuum cleaner in the test conditions.

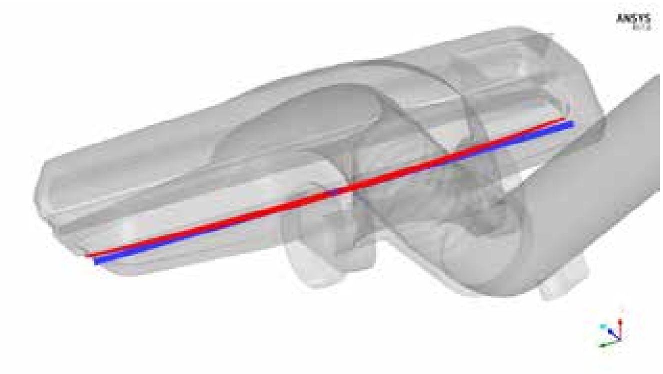

Figure 4 - Curved shape of the rubber flap

Modification 3 – new shape of the hood's elbow (Figure 5)
Given the same available pressure drop, this modification leads to no appreciable increase in mass flow rate. However, there is benefit to the smoothness of the flow when air is sucked from the outside and guided from the vertical to the horizontal direction. Therefore the elbow suffers less back flow.

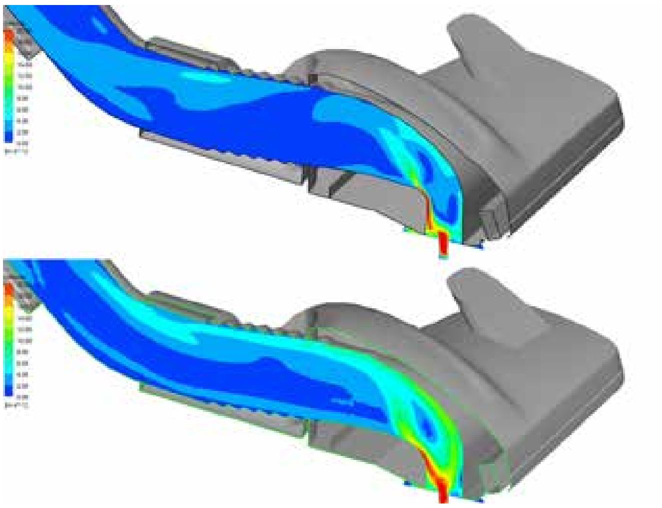

Figure 5 - New shape of the hood's elbow

Conclusion
The approach used, based on the testing scenario, has a general meaning. It is reasonable to consider that similar modifications on different vacuum head might lead to similar responses.
It has to be noted that while modification 2 improves the air flow coming from the crevice, it is a relatively low cost improvement.
Modification 2 appears to be the most promising method to increase the system performance.
Furthermore, a more detailed CFD study could be considered, by introducing the vacuum cleaner's body, the blower system and multiphase effects via the lagrangian approach for dust simulation.

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Marcello Riderelli Belli - Whirlpool Corporation
Luca Brugali, Anna Rosa Troia – EnginSoft

For more information: Luca Brugali, EnginSoft
l.brugali@enginsoft.it

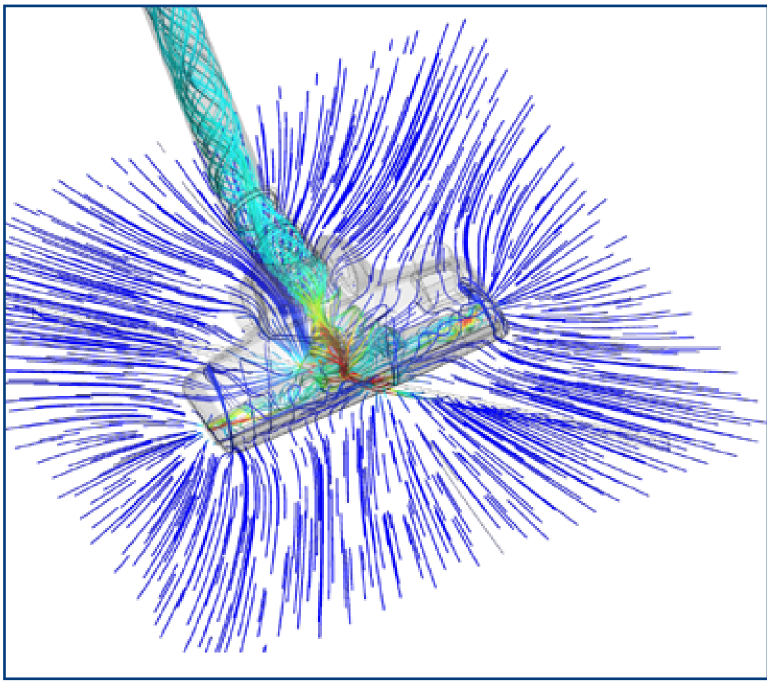

Figure 6 - Qualitative behavior of the air entering the brush

Using ANSYS in Appliances

Consumer expectations for home appliances are high: Users demand that a given product will perform day in and day out — and last for many years. Reputation for reliability and energy efficiency are key product selling points. It is critical that all possible scenarios for a new product's failure be tested before it goes to market. Appliances manufacturers perceive computer based modeling as the most promising if not only way forward.
Though reliability is crucial, consumers have come to expect products easier to use, are smaller in size but operate at maximum capacity, to consume less energy and emit less noise.

By using simulation analysis tools, designers can evaluate alternatives and refine designs early in the process, when it is less costly to make changes. The need for physical prototypes is also reduced, resulting in a shorter development cycle and a quicker to-market time.

Keeping costs in line, maintaining quality and reliability, and striving for continual innovation are key business drivers. ANSYS simulation and modeling tools can help companies meet these consumer challenges in a wide range of sub-industries.

EnginSoft is ANSYS Channel Partner and could support your company in finding the best solution to meet appliance design needs.