CFD AND EXPERIMENTAL CORRELATION OF THE DEFROST FLOW AND VEHICLE'S WINDSHIELD DEFOGGING

Thiago Luís Zolet, thiago.zolet@multicorpos.com.br or thiago.zolet@fiat.com.br
Fiat Automóveis S/A and Multicorpos Engenharia

Getúlio Gusmão Dutra, getuliodutra@gmail.com
Gustavo Fonseca de Freitas Maia, gustavo.maia@fiat.com.br
Leonardo Vinicius Mendes Pereira, leonardo.vinicius@fiat.com.br
Fiat Automóveis S/A

Abstract. *The vehicle windshield and side windows defogging performance has direct influence under driver safety. When the vehicle is not equipped with air conditioner and loaded with maximum occupancy, the defroster system must correctly direct the flow in order to defog the windshield and side Windows. This process can't take too long and must guarantee a minimum fog-free area to increase driver's visibility.*
This paper intends to demonstrate the defogging simulation methodology developed by FIAT Brazil and Multicorpos Engineering. It uses CFD simulations with StarCCM+ software. Experimental data obtained from climatic chamber is used to compare the numerical data and validate the methodology.

***Keywords**: Automotive Defrost System; Defogging; CFD*

1. INTRODUCTION

Nowadays, the world automotive industry is increasingly looking for new technologies to improve the satisfaction of passengers in the vehicles (Hott et Al., 2008), the criteria of the consumers in choosing and buying a car have changed, and now it involves not only aspects related to cost and performance of the vehicle, but also the aspects of security and comfort (Gameiro da Silva, 2002).

The windshield defogging performance is a very important requirement for the vehicle safety because it affects directly the driver's forward visibility. Some countries have specific standards for windshield demisting performance (Hucho, W. H, 1998). At FIAT Brazil, an internal standard describes all procedures to test fog removal using only the heating system. It is expected that reaching a minimum defogging performance level using only the heater, at least the same performance would be reached using the air conditioner as well.

Mist on the car windows occurs when the temperature of the glass is cooler than the ambient temperature. The water in the air condenses on the glass as soon as it reaches its dew point. Misting can occurs either inside or outside of the car windows. Demisting the outside of the windshield is as easy as turning on the wipers. The interior is a little more complicate and requires more time.

It is kwon that the best way to demist the windshield is lowering the interior absolute humidity to avoid the water from condensing. Air conditioner besides lowering the temperature removes the humidity from air, preventing the moisture rejection of the passengers to fog up on the windshield. However, according to the FIAT records, about 50 percent of the vehicles produced to the Brazilian market in 2010, from the same model used in this study, were equipped with air conditioner (Fiat Automóveis S/A, 2010) and in very low temperatures AC systems may have no effect on defogging. According to that, still very important to develop a good air flow distribution on the defroster to increase de defogging time using the heater of the vehicle.

2. HVAC SYSTEM

HVAC System is responsible to reach climatic comfort and safety in the vehicle habitat in many ambient conditions, this component control the air passages for the outside to inside or the air inside itself. In a hot and sunny day using the air conditioner the HVAC system is set-up to orientate the air flow to the passenger's body and head, in a very low ambient temperature it is set to warm-up the air and orientate the flow to the passenger's foot. In the same way HVAC can be used to orientate the flow to the windshield to defroster in case of a layer of ice at the out said of the windshield in very cold regions or just defog in case of low temperature and high humidity inside the vehicle. According to Farag and Huang, (2007) to achieve the de-icing performance standards, several design parameters should be considered, such as defroster nozzle outlet location, air impingement angle, cross-section area of the defroster nozzle and its optimum shape, and finally the number of nozzle outlets needed which depends on the vehicle and the packaging space. The same concept can be used for the defog performance.

3. EXPERIMENTAL AND NUMERICAL PROCEDURES

3.1. Experimental test

To measure the defog system efficiently a test simulating the use of the vehicle in condition of full occupancy in cold ambient conditions is required, in this paper a standard test (Fiat Automóveis S/A, 2007) for defog performance is used to develop a good defog system of one specific vehicle and compare with CFD results.

The climate chamber temperature is set up to -3°C while the vehicle is soaked until coolant and lubricant are stable at facility test temperature. A steam generator is placed inside the car to simulate physiological amount of moisture produced by five people. With the vehicle closed, steam is generate for five minutes. At this time of the test, the clock is set to zero and the engine is started. HVAC unit is set to maximum heat and fan speed, external air intake and air distribution in the defrost position. The steam generator remains in operation until the test is completed.

At 2, 4, 6, 8 and 10 minutes the test operator traces the defogging pattern into a paper. These patterns will be used to evaluate the performance level of the defogging system as to validate the transient CFD simulation The Fiat standard for defog test divides the windshield in two areas, as can been seen on figure 1. The section “A” represents 90% of the windshield superficial area and section “B” represents the driver's forward view. Section “A” has to be 90% demisted and section "B" has to be completely clean at the end of the experimental test (Fiat Automóveis S/A, 2007).

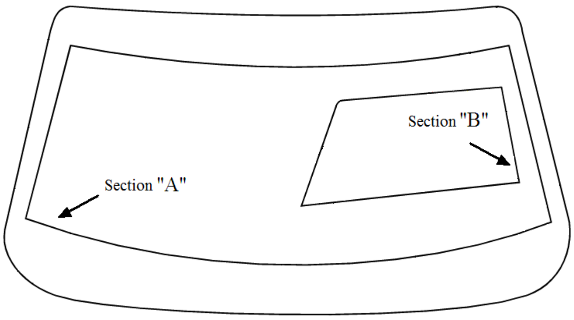

Figure 1. Windshield sections for defogging test.

To be easier to understand and visualize the distribution of the flow and temperature at the windshield, is helpful to use a thermograph camera. As can been seen on figure 2 the hottest points according the picture show the places that the velocity field is higher.

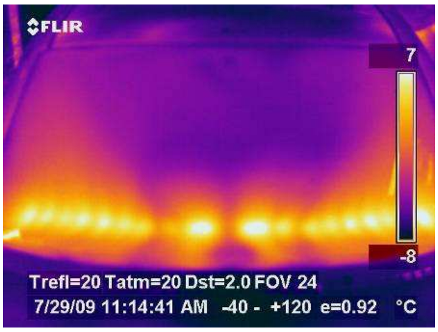

Figure 2.windshiel thermograph picture during the test.

After the transient test is performed and there is no more fog layer, air distribution and velocity over the windshield are measured. In order to do that, a grid over the windshield is traced, the vertical lines start from the midpoint of the window and working outwards at 50mm intervals in both "+Y" and "-Y" directions. The horizontal lines are spaced 50mm from each other too.

The probe used to measure air velocity is a thermo anemometer with measurement range from 0,2 to 20,0m/s. The anemometer is positioned to measure the highest velocity on each point of the grid. Fiat standard has specifics objectives for average air velocity over the windshield. This objective guarantees good performance in the defogging test.

3.2. CFD Simulation

CFD, or Computational Fluid Dynamics, is nowadays widely used in automotive industry. CFD can provide an engineering insight, offering a better knowledge of what happens in various industrial processes, resulting in improved design. CFD method solves the partial equations that govern the fluid flow, including the Navier-Stokes equations, the Continuity end Energy equations. The discretisation of the equations is made to obtain the description of the flow field of interest (CFD Online, 2010).

In this work CD-Adapco´s Star-CCM+ software was employed. The volume mesh was built using trimmed (predominant hexahedral) cells and the most common of the Reynolds Average Navier-Stokes turbulence model, the k-epsilon model, was used. Figure 3 shows the geometric domain of interest, composed by the defrost air ducts and the vehicle´s cabin. Some geometric simplifications were made in order to reduce the mesh complexity and solver iteration time.

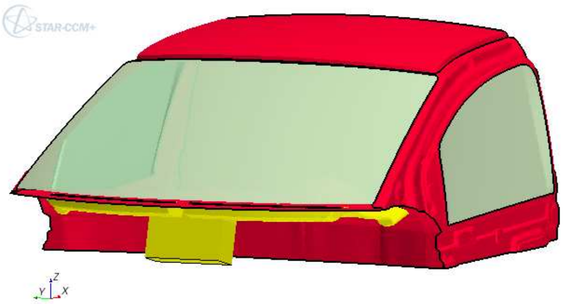

Figure 3. Geometric domain of interest

To simulate the transient part of the test, Star-CCM+ employs a simplified approach to obtaining a defogging simulation inside a cabin windshield. The major hypotheses are (CD-Adapco´s Star-CCM+):

- The fog layer is not represented as a phase in the inner volume mesh, but is modeled by functions, thus the fog layer does not flow.
- A steady state calculation is performed to initialize the convection flow field.
- the condensation/evaporation of the fog layer does not affect the flow field.

The defogging model is based on solving an additional scalar transport equation that represents the mass fraction of water vapor. A source/sink term for the scalar is considered for condensation/evaporation of the fog layer as well as the latent heat required for transition.

When there is a difference between the water vapor content at the fog layer and the cell next to this surface, the model will calculate a rate of evaporation or condensation depending on the conditions. The assumptions are:

- The vapor content in the air does not affect the thermal properties of the vapor-air mixture.
- The water vapor mass is neglected with respect to the total mass in a cell.

Inlet air flow temperature was assumed to be dependent with time. Temperature values were acquired using thermocouples during the experimental tests. Ideal Gas model was used for the flow.

For the simulation of the air distribution and velocity over the windshield, a steady state calculation was performed. Another assumption assumed that inlet air flow density is constant and temperature is not time-dependent.

4. RESULTS AND DISCUSSION

Figure 4 shows the experimental result from the defogging test for the studied vehicle. The blue layer shows the defogged area of the windshield in the time.

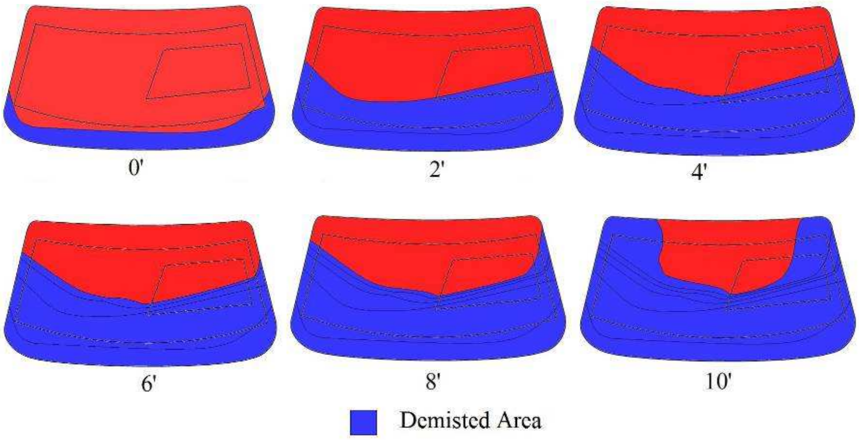

Figure 4. Experimental defogging patterns.

Figure 5 shows the thermograph picture of the windshield at the end of the test, showing a higher temperature at the both sides of the windshield meaning that the air velocity at that location is high.

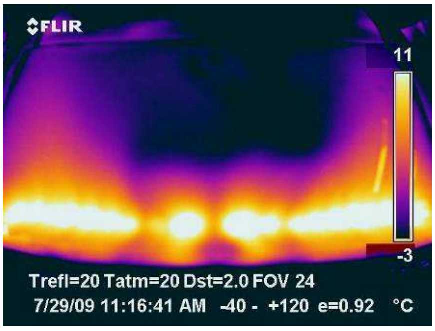

Figure 5. windshield thermograph picture at the end of the test.

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At the end of the test, section "A" was 80% demisted while section "B" was 71%, consequently, the defrost concept was not approved for application in the vehicle. As soon as the problem was recognized, CFD simulations were carried to improve demisting level performance. Figure 6 shows the simulation using the defogging model as describe before.

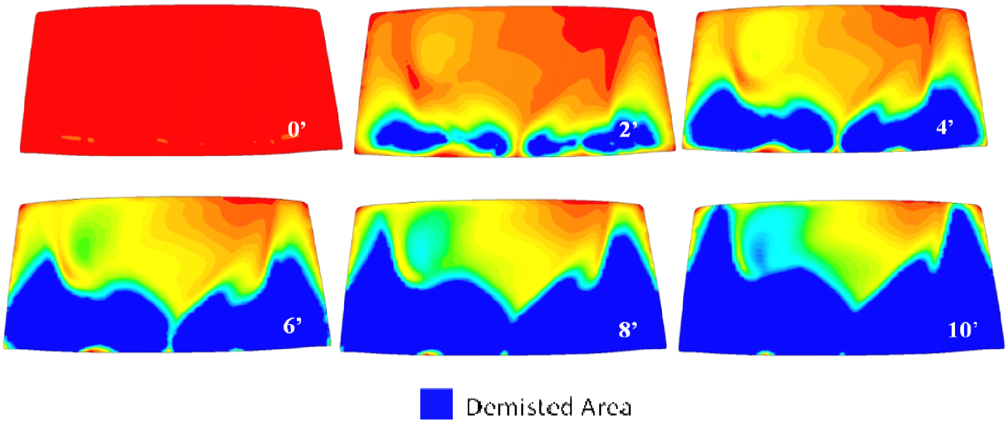

Figure 6. CFD defogging results for the windshield.

There is a good qualitative agreement between the experimental and numerical results. Due to the need to have a good choice of initial fog layer thickness over the windshield, the quantitative results from the first simulation do not agree with the experimental results. There are some areas misted in the CFD results that are demisted in the experimental test, for the same physical time.

To find the ideal fog layer thickness would be necessary much more hours of simulations, according to that the next approach tried to correlate only the flow distribution and velocity field over the windshield with the defogging performance using a steady state calculation, in order to reduce the turn-around time. Figure 7 shows the experimental measurements and velocity field from CFD simulations:

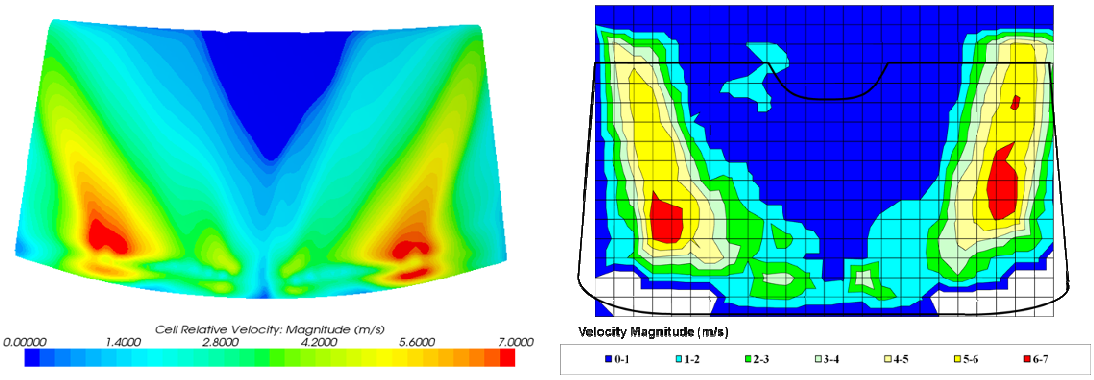

Figure 7. Velocity magnitude over the windshield: CFD and experimental results

It can be noticed that the regions on the both sides of the windshield, where the velocity magnitude field is higher, demisted earlier than the regions next to the middle of the screen, where there is a large area with zero velocity. As a matter of fact, the regions with zero velocity did not demist at the end of the 10 minutes test, so a new design of the defrost who provides a homogeneous distribution of the flow is necessary. Figure 8 shows the initial defrost outlet design.

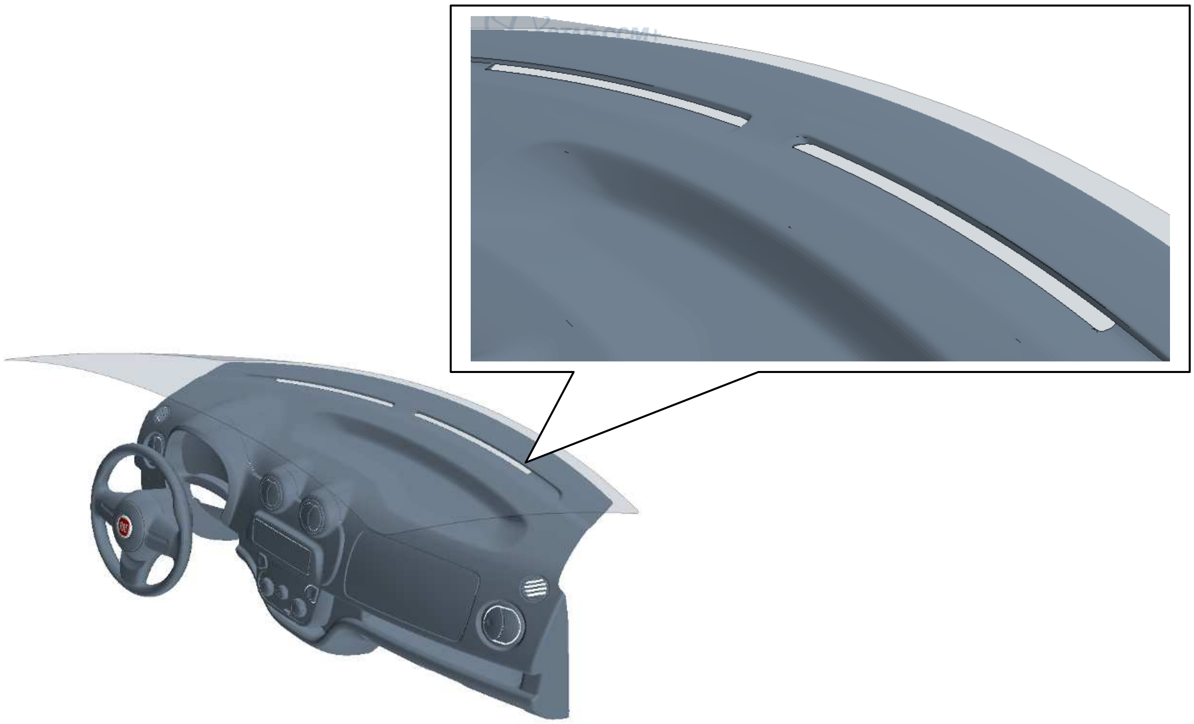

Figure 8. Initial defrost design.

The initial design of the defrost outlet leads the air flow going directly to the peripheries of the windshield (as seen on figure 7). From this point several fin designs were proposed until one could achieve the homogeneity required. The steady state CFD simulation approach was used. The final fin design is presented on figure 9:

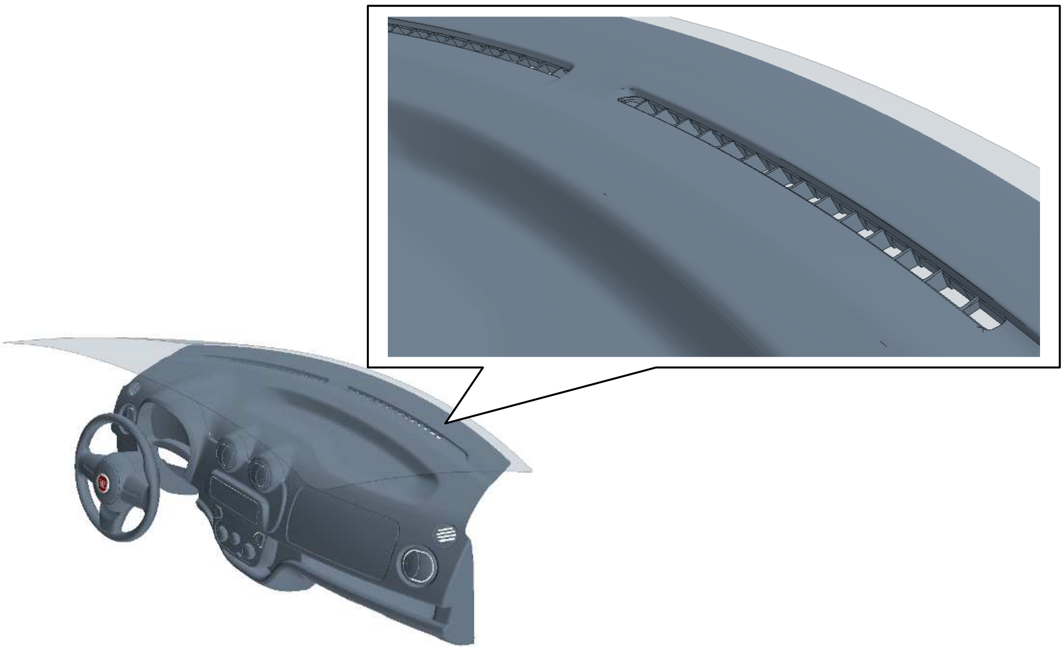

Figure 9. Final design of the defroster, fins included.

The new simulated velocity field achieves the homogeneity and minimum velocity field required at FIAT standards. A physical prototype of the new defroster design was manufactured and experimental test was carried out. Figure 10 shows the steady state CFD simulation and experimental results for the air velocity field of the new defroster fin design.

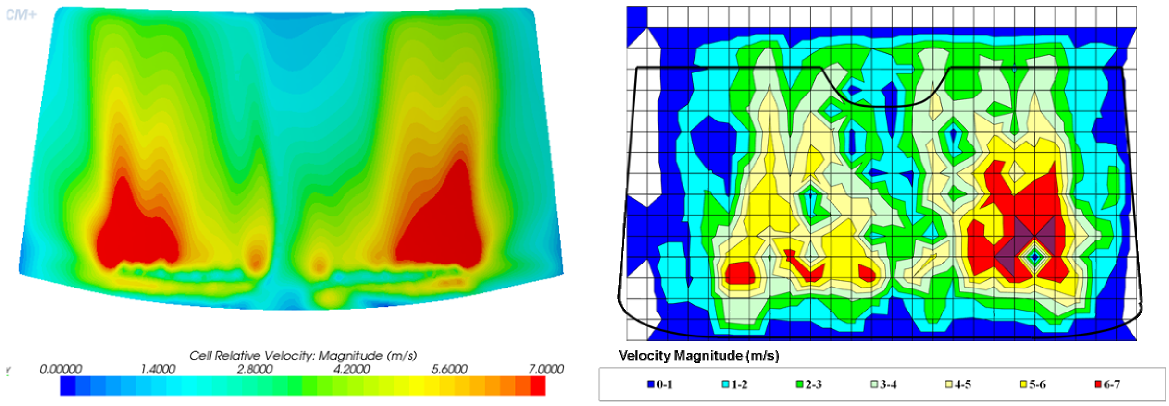

Figure 10. Final design velocity magnitude over the windshield: CFD and experimental results.

As expected, the defogging system efficiency was increased. In six minutes the windshield was totally clear. As can be seen at figure 11, the driver's view area (section "B") was totally demisted in only four minutes due the enhanced air distribution reached with the new fins design.

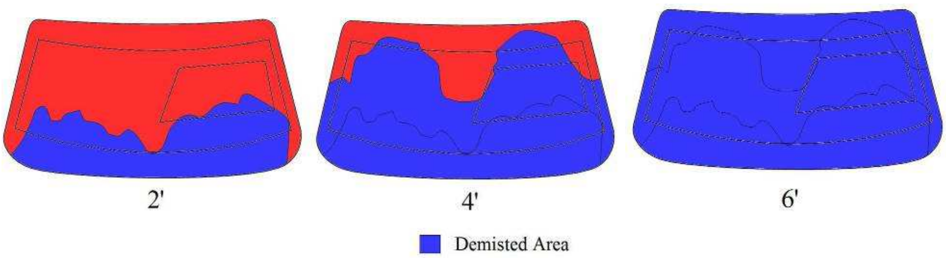

Figure 11. Experimental defogging patterns for the final fins design.

As can be seen in figure 12 the temperature distribution was improved by the better velocity field.

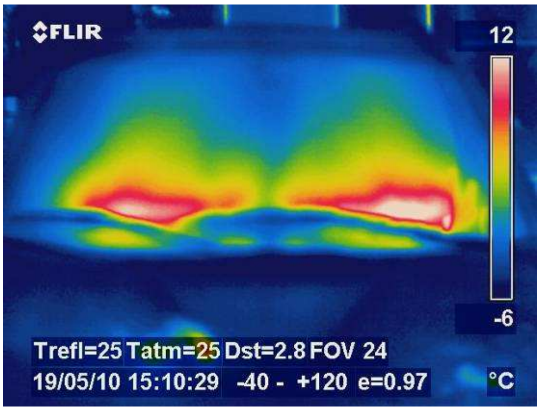

Figure 12. windshield thermograph picture at the end of the test.

5. CONCLUSIONS

The steady state CFD approach revealed to be useful when designing a new defrost system. Evaluating the air flow homogeneity and predict what areas of the windshield will demist first, improving the driver's visibility. This approach has its turn-around time shorter than using an unsteady state simulation using the Defogging Model. However it is very important to notice that only homogenous flow evaluation is not sufficient to conclude that there will be a good demisting performance. Supposing one can design a defrost system in such way to have a good air flow homogeneity over the windshield, but low air velocity field, this design has a good chance to don’t demist all areas of interest from the windshield at the end of the required time. So, as soon as the evaluation of the homogeneity and velocity field is concluded, an unsteady Defogging simulation can be used to prove that the defrost system will be able to demist the windshield areas of interest under required time.

6. REFERENCES

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