2018-01-1317

Virtual Temperature Controlled Seat Performance Test

Mark Doroudian, Swapnil Salokhe, Ramesh Dwarampudi, Mohsen Battoie, Ata Shiravi
ESI North America

Gabriella Almasi, Michael Medoro, Michael Kolich,
Ford Motor Company

ABSTRACT

The demand for seating comfort is growing – in cars as well as trucks and other commercial vehicles. This is expected as the seat is the largest surface area of the vehicle that is in contact with the occupant. While it is predominantly luxury cars that have been equipped with climate controlled seats, there is now a clear trend toward this feature becoming available in mid-range and compact cars. The main purpose of climate controlled seats is to create an agreeable microclimate that keeps the driver comfortable. It also reduces the "stickiness" feeling which is reported by perspiring occupants on leather-covered seats. As part of the seat design process, a physical test is performed to record and evaluate the life cycle and the performance at ambient and extreme temperatures for the climate controlled seats as well as their components. The test calls for occupied and unoccupied seats at several ambient temperatures. This paper presents the approach that was used to replace the physical test with a virtual test.

Key Words: Heated, Ventilated, Seat, Life Cycle Performance, Cushion Compression, Thermal Comfort, Virtual Seat Solution

1. INTRODUCTION

Computational methods have been used for more than a decade to evaluate the structural performance of a seat assembly for occupant safety during the seat design process [1] [2]. Virtual seat manufacturing and testing tools and methods have also been used in the seat design process to predict mechanical comfort [3]. The ability to predict occupant thermal comfort during seat design process would add a new functionality to the toolbox for virtual prototyping of seats. This functionality would be required to evaluate the performance of seat components that have been added for heating, cooling, and ventilation. Occupant thermal comfort depends on cabin air temperature, cabin air stream velocities, solar radiation, and seat thermal state. However, because a significant portion of the occupant surface is in contact with the seat, the seat thermal performance has a significant impact on the occupant thermal comfort. Thermal comfort is subjective. Seat centric human thermal comfort models are being developed to predict subjective evaluation of perceived seat thermal performance. In the meantime, objective targets are used to evaluate the thermal performance of seats. The Life Cycle Test is one of the objective tests used in the seat design process to evaluate climate controlled seats at ambient and extreme temperatures. Figure 1 shows a section cut through a ventilated seat. The test is performed with a complete seat and fitted with production intent programmed module and production intent harnesses, pig tails, wires, and fastenings tightened to specifications. During the heating mode test, life cycling is performed at ambient temperatures in the ranges of -20C to 20C with the seat occupied and unoccupied. As the life cycle test is performed the temperature distribution on the seat surface is recorded by thermographic images. This seat performance life cycle test requires the existence of a physical seat.

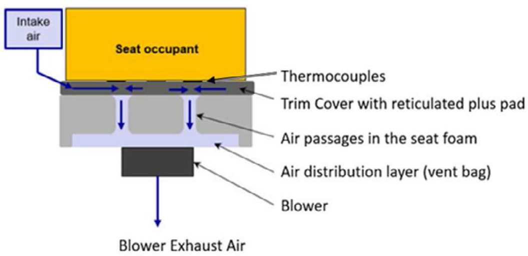

Figure 1 Illustrates a section cut through a ventilated seat

This paper presents the modeling method that was developed to enable the designer to virtually perform the seat performance and life cycle test prior to the availability of a physical seat prototype. The seat that was virtually tested had a heating and ventilation system. Seat ventilation is a feature that is built into the seats. Ventilated seats function via several small fans in the seat cushion and backrest. The fans draw air from inside the cabin and into the seat. The air enters the seat through perforations in the seat cover, through the spacer material below the seat cover which is an air permeable fabric, then goes through plastic ducts and reaches the fan. In some seats air direction is reversed and is directed at the occupant.

2. SEAT VENTILATION TEST

2.1 Unoccupied Seat Ventilation Test

The Temperature Controlled Seat Performance test is a multi-step detailed physical test which is designed to objectively evaluate the seat thermal performance of a seat. One of the steps in this test is used to evaluate the ventilation system of a seat. For the ventilation test the seat is secured to a holding/carrying fixture that ensures the seat is mounted in vehicle position and is adjusted to its design position of the cushion and back angle and track position. The seat is placed in a climate controlled chamber and soaked to a 40C for a period of time. Following soak, the chamber door is opened and the ventilation system is actuated at the highest setting for 10 minutes to allow the seat to cool down to the ambient temperature. The seat surface temperature is monitored by a number of thermocouples. Thermograph images are also taken to record the seat temperature distribution.

2.2 Occupied Seat Ventilation Test

The occupied seat ventilation test preparation is similar to the unoccupied seat test procedure up until the seat is soaked. For this test after the soak, the chamber door is opened and a heated manikin is placed on the seat. The shape of the heated manikin is patterned after a 50th percentile back and buttock/thigh form based on the SAE J826 Manikin [4] without the head form and without the legs. The manikin is heated to 36C and maintained at 36C during the test. The weight of the heated manikin is 80 Kg based on a 95th percentile occupant weight. During placement of the manikin on the seat, special care is taken to avoid air gaps between the thermocouples and the manikin.

Once the manikin is placed on the seat, the ventilation system in the seat is actuated and run at the highest setting for 10 minutes with the manikin sitting on the seat. During the test the seat surface temperature is recorded using the various thermocouples on the seat surface. After 10 minutes, the manikin is removed from the seat and a thermograph image of the seat is taken to recorded.

3. VIRTUAL SEAT VENTILATION TEST

3.1 Seat Modelling

The seat used for this study is a production driver seat with heating elements and a ventilation system. The FE mesh of the seat contained the frame, suspensions, foam blocks, heating pad, cover, padding, and the seat attachment systems, and is shown in Figure 2. The frame is considered as rigid since the model is only used for seating and thermal simulations, which do not result in significant frame deformation. All other components are deformable and connected to each other through joints and contacts.

The foam and padding properties are extracted from measurement of quasi-static compression and traction stress-strain laws. The cover properties are extracted from measurements of quasi-static traction laws in different directions.

The modelling method has been extensively validated through comparison between simulation and real tests for H-point and pressure distribution measurements, [5-7].

Since the ventilation test involves heat loss from the seat, the heat transfer from the seat must be included in the simulation. The two dominant modes of heat transfer in the seat are convection and conduction.

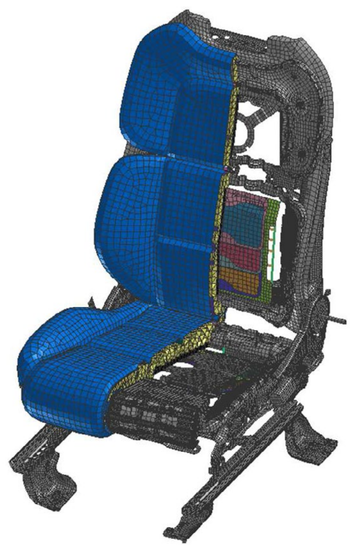

Figure 2 FE mesh for a production seat model

Heat convection in the seat occurs by air flow through the seat. Heat is transferred from the surfaces of seat cover, foam and other seat material to the air as it flows over the seat surfaces. The faster the air moves the higher the heat transfer coefficient, h W/m2.K, the more heat is removed from the seat material.

$q = h * A * (T_{surf} - T_{air})$

Where:

- q is the heat transfer, Watts
- h is the heat transfer coefficient, Watts/m^2.Kelvin
- A is the surface area of the seat regions that is being washed by the air, m^2
- Tsurf is the seat surface temperature, Kelvin
- Tair is the air temperature near the seat surface, Kelvin

Heat also conducts through the seat by conduction. The amount of heat stored in the seat is governed by the specific heat of the seat material. These material properties are defined by the Fourier's law

$\rho C\ \delta T/\delta t = \mathrm{div}(\lambda.\mathrm{grad}\ T)$

Where:

- ρ is the density, kg/m3
- C is the specific heat, J/kg.K
- λ is the thermal conductivity, W/m.K

A typical apparatus which may be used to conduct the physical test of the material testing for thermal conductivity and specific heat is shown in Figure 3.

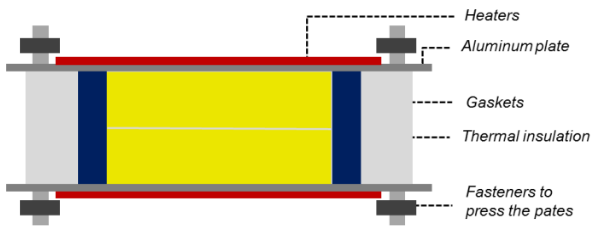

Figure 3 Image of testing apparatus for thermal conductivity and specific heat

Specific heat and thermal conductivity may be constant or a function of temperature. Thermal conductvity may also depend on the level of compression reached by the material after sitting of the occupant. The foam which is represented by the yellow color material in Figure 3 is compressed by tightening the fasteners and compressing the foam. This allows the foam to be compressed to a fixed level while the temperatures are measured to

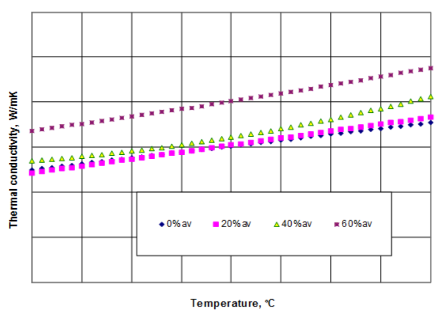

Figure 4 Foam thermal conductivity vs. compression strain

compute thermal conductivity and specific heat. Figure 4 shows the average curves (av) for the thermal conductivity of a typical automotive seat foam material at several different compression levels [8]. These test results make sense. Thermal conductivity increases as the foam is compressed because air, which is not a good conductor, is being squeezed out.

The contacts are defined between various seat components: foam, heating pad, spacer material, and seat cover, These contacts are defined to manage the mechanical interaction, but also for the thermal interaction. The conductance is defined by a conductance value which is a function of the distance between two interfaces. If the distance between two interfaces is near zero and the interfaces are in contact, the heat is transferred with no loss. As the distance between the interfaces increases, less heat is conducted across the interfaces; Figure 5 shows the contact conductance.

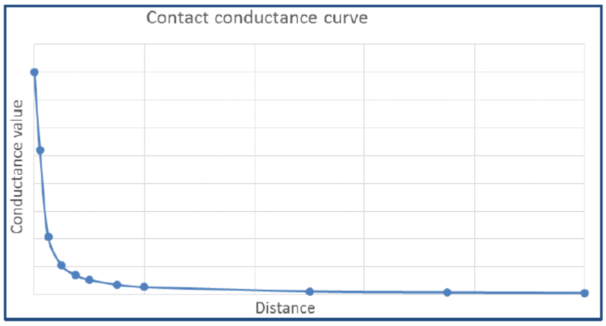

Figure 5 Contact conductance

The convective heat transfer coefficients are computed by constructing a flow model of the air passages in the seat and solving the Navier Stokes equations to determine the flow velocity and temperature in the seat passages.

3.2 Unoccupied Seat Ventilation Simulation

The ESI Virtual Seat Solution (VSS) was used to construct a realistic virtual seat model which would be representative of a product resulting from a virtual assembly line. The manufacturing simulation included the interaction of the overbuilt foam, pad compression, and the cover deformation. The stresses in the cushion and backrest due to fabrication of the seat were computed. These stresses were later used in the occupied seat simulation. The process for simulating the ventilation test is shown in Figure 6.

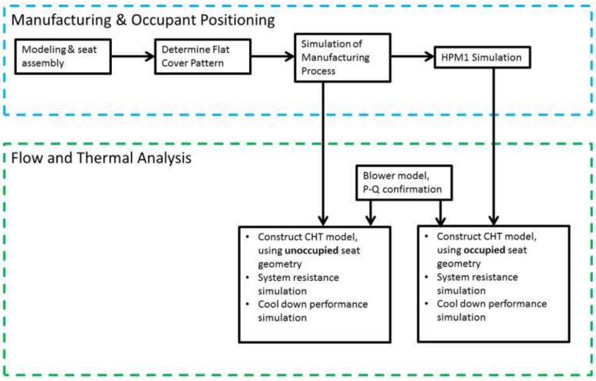

Figure 6 Seat ventilation simulation process flow chart

The seat manufacturing simulation which was performed using ESI's Virtual Seat Solution provided the geometry of the seat while the seat is unoccupied, left image in Figure 7, as well as the geometry of the seat while the seat is occupied, right image in Figure 7. The geometry of the foam block in unoccupied shape was used to construct a flow model of the air passages in the ventilated seat.

Figure 7 Virtually manufactured seat, unoccupied on the left, occupied on the right

The flow model included the blower, the vent bag, the air passages in the seat foam, the spacer material, and the perforated leather seat cover. The blower curve was used in the model to represent the blower wheel. This way the flow rate through the seat could be computed taking into account the pressure drop from the perforated leather cover, through the foam passages and across the vent bag. Figure 8 shows the blower curve as well as the resistance for the vent bag and the perforated seat cover, heater pad and spacer material. The vent bag in the flow model was assumed to be rigid. This assumption was made to simplify the model since the volume of the manifold upstream of the blower was not significantly changing due to vent bag deformation.

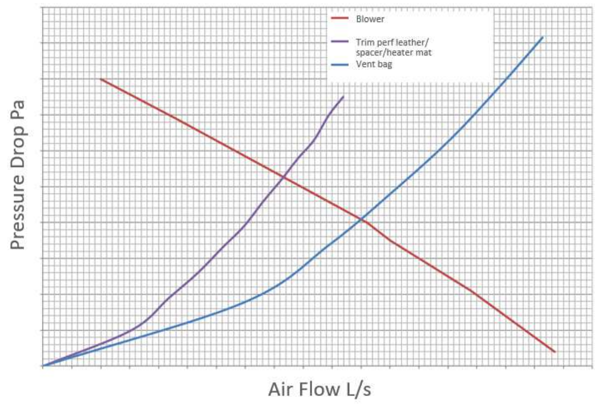

Figure 8 Blower curve and System Resistance for the Seat

A further simplification for the flow modeling was to split the volume around the seat into a zone representing the chamber which would be soaked to 40C and a larger volume which would be representing the ambient at 20C. This allows for one single flow model to be used for the soak and ventilation simulation. Figure 9 shows a section colored by temperature through the unoccupied seat flow domain at the end of soak.

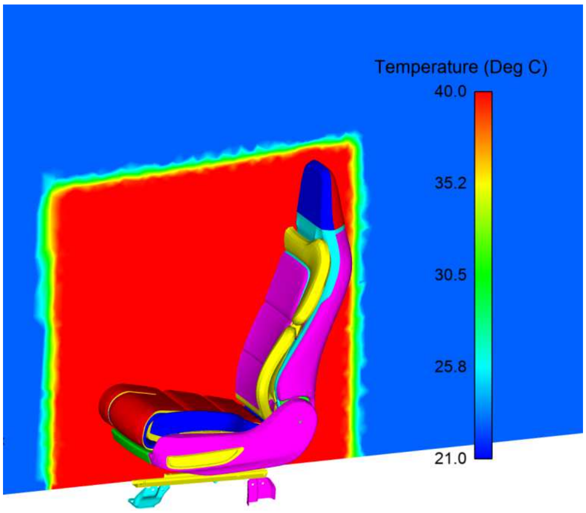

Figure 9 Section through the flow domain at the end of soak time

At the start of the ventilation simulation which was called time =0 seconds, the smaller subdomain containing the unoccupied seat was initialized to 40C to represent the seat having been soaked at 40C. Following the soak, the blowers in the seat and back rest were turned on to evacuate the air in the seat by blowing the air out under the seat. The left image in Figure 10 shows the streamlines colored by velocity. The velocity near the surface of the perforated leather is slower than through the foam passages. This is needed to take away the heat from inside the foam. The image on the right shows the temperature distribution on the surface after 4 minutes.

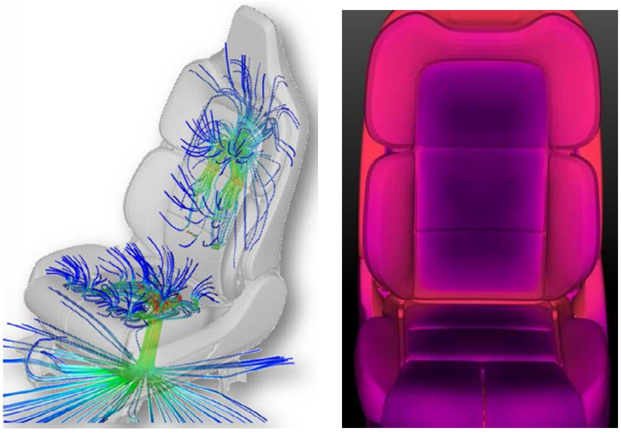

Figure 10 Left image, streamlines show the air flow entering into the seat and being ejected under the seat and behind the seat. Right Image, predicted temperature distribution on the seat surface

The thermocouple data on the seat and back rest were averaged and compared to the temperature results from the VSS ventilation simulation. The results, shown in Figure 11, seem to be in agreement. The temperatures at the start of the simulated test are higher by a few degrees than the physical test. This may be due to the way soak is simulated and the events at time t=0 seconds. At t=0 seconds the test chamber door is opened and perhaps this actions provides a better mixing of the outside ambient air and the air inside the chamber.

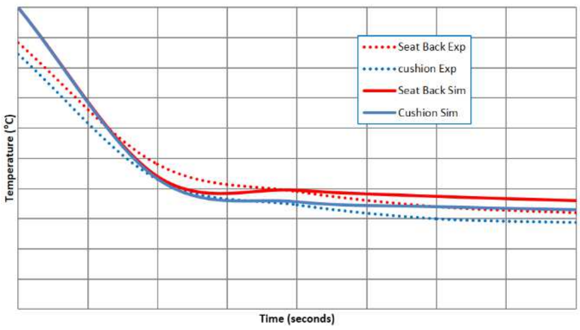

Figure 11 Average Seat and Backrest Temperatures

3.3 Occupied Seat Ventilation Simulation

The seating of manikin on the seat was performed in VSS to compute the shape of the seat and back rest.

This deformed seat geometry was used in VSS to create the flow domain of the seat in the occupied state. Figure 12 shows the nodal displacement of this seat following the placement of the manikin on the seat. The manikin deformed the shape of the seat cushion and the back rest. The air passages inside the seat foam and the back rest foam were distorted because of the manikin weight. Furthermore, a portion of the perforated holes in the seat cover and the back rest were blocked by the manikin.

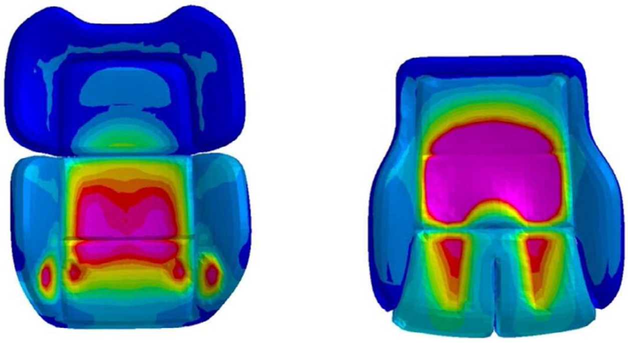

Figure 12 Nodal deformation on the seat cover

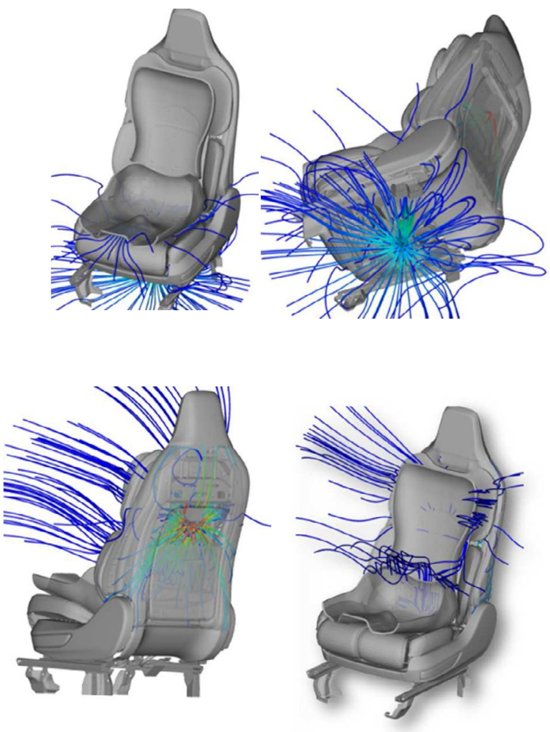

Figure 13 Streamlines through the occupied seat and back rest colored by velocity.

The seat was initialized and the ventilation simulation was performed in a similar manner as to the unoccupied seat. Flow streamlines through the occupied seat are shown in Figure 13. The flow into the seat was blocked through the holes which happened to be covered by the manikin. However, flow through the remaining uncovered holes continued to ventilate the seat. The holes in the space between the thighs which were not covered by the manikin allowed air to enter the seat cushion. This resulted in slightly lower seat surface temperatures between the thighs. This was also observed on the back rest on either side of the manikin as shown in Figure 14.

Figure 14 Surface temperatures on the occupied seat

CONCLUSION

In this study a process was developed to perform the seat ventilation tests as part of the design study. In the past this test could be performed only when a prototype was made available. However, this process allows for evaluation of production seats at an early design stage. The uniqueness of this process is that the structural analysis discipline has been chained with the fluid dynamic discipline to perform ventilation simulation on an as manufactured seat. Furthermore, the seat is then mechanically occupied by a heated manikin and the cushion and seat back are deformed due to manikin loading. The seat ventilation is then performed on the deformed seat with the deformed ventilation ducts in the cushion.

The results of the ventilation simulation have so far been in line with the available physical test data. The next steps would be to apply this methodology to more seats to gain confidence in the approach and further streamline the process for implementation in Ford's seat development process.

REFERENCES

1. M. Kolich, S. Nunez, N. Montmayeur, R. Dwarampudi, C. Marca, "Virtual Seat Manufacturing and Testing for FMVSS202a Backset Prediction", SAE Paper 07 DHM-11, 2007
2. M. Kolich, S. Nunez, N. Montmayeur, R. Dwarampudi, C. Cabane, C. Marca, "Virtual Seat Comfort Engineering through Hardness and Initial Softness Prediction", SAE Paper 07 DHM-11, 2007
3. M Kolich, C Marca, R Dwarampudi, C Cabane, "Using Virtual Seat Prototyping to Understand the Influence of Craftsmanship on Safety, and Seating Comfort", SAE International Paper 2011-01-0805
4. Standard SAE J826 Rev. Nov2008, Devices for Use in Defining and Measuring Vehicle Seating Accommodation
5. A. Savary, J. Makala, N. Montmayeur, C. Marca, "Vritual Seat Comfort Design", IQPC Congress "Innovative Seating", 2007
6. N. Montmayeur, E. Haug, C. Marca, H.-Y Choi, S. Sah, "Numberical, and Experimental Analysis of Seating and Riding Comfort"< SAE Paper 04DHM-3, 2004
7. C Marca, C Borot, "Thermal Comfort Prediction for Heated Seat", The 11th Seat R&D Symposium

8. M Kolich, P Hoke, D Dooge, M Doroudian, E Litovsky, J Kleiman, "Influence of Temperature and Mechanical Compression on Thermophysical Properties of Car Interior Foam Plastics Insulation" , Journal of Elastomers & Plastics, 2014, Vol. 46 (2) 132-143

CONTACT

Michael Kolich; Ford Motor Company