3D Velocity Measurements within an Automotive Air Handling Unit using a single 5-Beam LDA Probe

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1. Introduction

The expectations of a customer purchasing a vehicle have increased significantly over the past years. The driver and passengers expect to be comfortable, whether commuting to work or travelling long distances. An important contributing factor is thermal comfort. The expectation is for the cabin temperature to rapidly adjust to a "comfort" setting, and for this "comfort" setting to be maintained throughout the journey. The climate system within a vehicle must therefore be able to cope with extreme ambients, and be flexible enough to cope with changing conditions over a single journey. To cater for extreme ambients, vehicles are increasingly fitted with air-conditioning – indeed in many vehicle ranges this is now standard. To cater for the second requirement (maintaining thermal comfort) Electronic Automatic Temperature Control (EATC) is now widely available. A further customer expectation is for the climate control system to be quiet, with any air-rush noise kept to an absolute minimum.

The above requirements place considerable constraints on the design of one of the key components of the climate control system, namely the Air Handling System (AHS). Its purpose is to draw in ambient air, either cool or heat it by passing it through heat exchangers within the Air Handling Unit (AHU) generally located underneath the instrument panel, and then via ducting distribute the air within the cabin. There is very little package space for the AHU, and what package space there is, is increasingly restrictive due to the many other components within the instrument panel (air bags, satellite navigation, wiring looms, etc.). Meeting all the airflow and heat transfer targets within the available package space is therefore a demanding task. Added to this are the increasingly short design / development cycles, and the increased cost pressures which now exist.

The solution employed by the Visteon Corporation, as well as other climate control system suppliers, is to use CAE tools such as Computational Fluid Dynamics (CFD) to design and develop the AHU and indeed the whole climate control system. However, it is essential that this CAE be correlated against experimental data. Following an introduction into the AHU and the benefits of CFD, this paper describes the application of 3-component laser Doppler anemometry (LDA) to provide this important validation.

2. Description of an Air Handling Unit

Figure 1 shows a typical Air Handling System (AHS), which forms a major part of the entire climate control system. The air enters the cowl near the bonnet / windscreen interface. From there the air passes into the Air Handling Unit (AHU), the first elements of which are an air intake housing, a blower wheel and a scroll. The air then passes into the main distribution housing of the AHU and (if air conditioning is fitted) through a first heat exchanger (evaporator core) to cool the air. After the evaporator the airflow is directed through the second heat exchanger (heater core) if heating is required. If not then it is directed to bypass the heater core. Blending doors control how much air bypasses the heater core and further doors control to which of the ducts (defrost, panel and floor) the air is finally directed before it exits into the cabin.

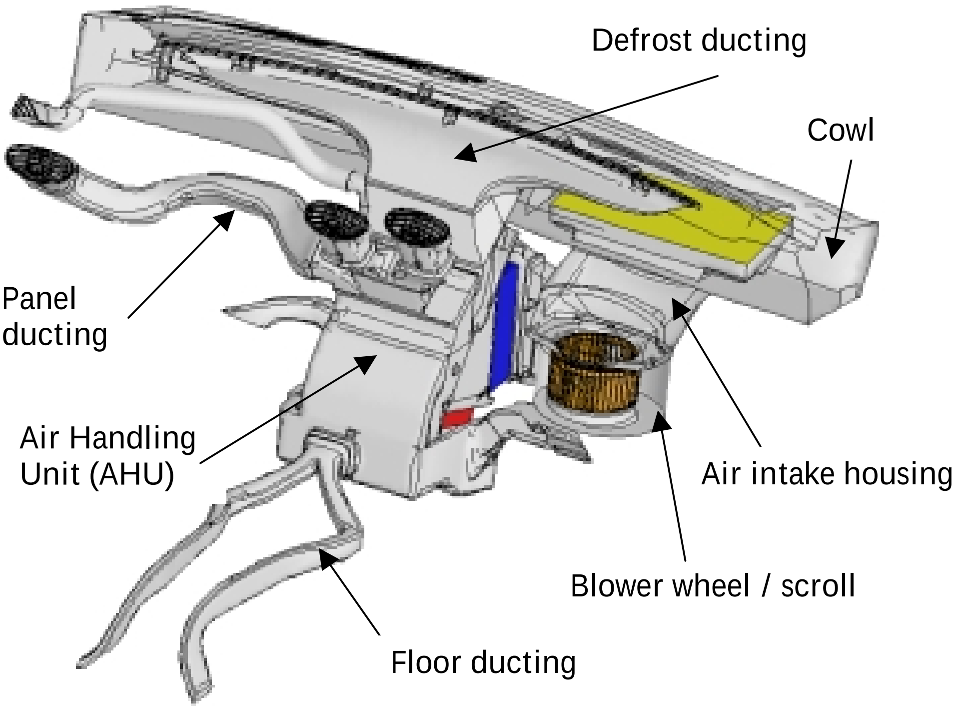


Figure 1 – Typical Air Handling System (AHS)

When designing the AHU (Figure 2) there are several targets that need to be met. The most obvious are the overall pressure drop across the unit and the maximum volume flow rate discharged (required to cope with the most extreme ambient conditions). However to maintain thermal comfort once it is reached, especially with the introduction of EATC units, a further key parameter becomes the temperature difference between the different outlets (floor/defrost or floor/panel). If the difference is too high then passengers do not reach thermal comfort. To control this a linear variation between the outlet temperature (measured at the AHU outlets) and the temperature door position (which controls how much of the airflow bypasses the heater core) is required. The final key targets are in terms of NVH (Noise, Vibration and Harshness), as high NVH is the principal reason a driver or passenger reduces the blower setting to a level lower than that might be required to achieve or maintain thermal comfort.

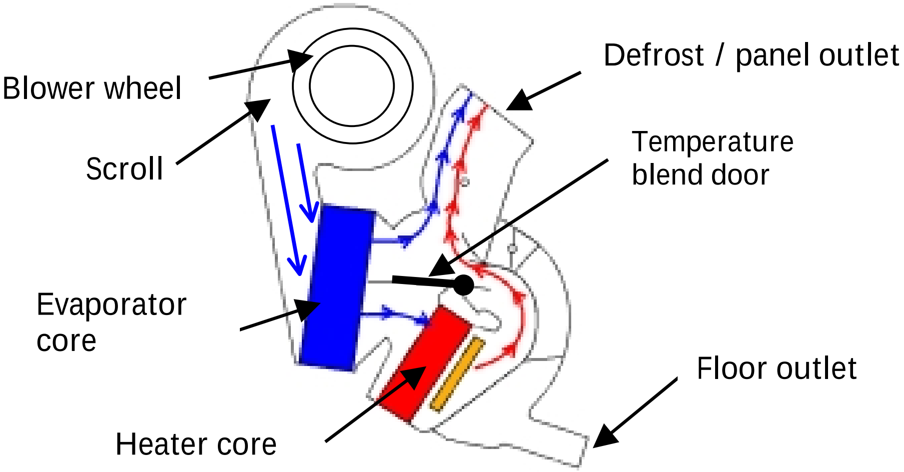


Figure 2 – Cross section through typical Air Handling Unit

3. The role of Computational Fluid Dynamics in the development of the AHU

Ensuring that the targets can be met within the very tight development schedule and strict financial constraints, requires extensive use of CFD. Producing and then testing numerous prototype parts is no longer an option in the automotive industry. CFD is therefore employed to optimise the flow behaviour throughout the entire AHU as well as the rest of the AHS (cowl, and instrument panel ducting). Direct assessments as to the volume flow rate, pressure drop, temperature stratification, etc. can therefore be all readily made throughout the development process. With the outlet conditions of the AHS known the complete vehicle cabin can also be modelled by CFD; hence assessments of the overall cabin airflow distribution and ultimately demist / defrost performance and passenger comfort can be made.

Only when CFD has provided the optimum iteration within the package and concept constraints are prototype parts then produced. These prototype parts can then be tested and assessments made as to their performance relative to the pre-set targets. "Fine-tuning" can then, if necessary, be made to these prototype parts. However this fine-tuning is generally expensive and can cause delay in the vehicle development programme.

From the above it is evident therefore that there is currently extremely high reliance upon CFD in the design and the development of the climate control system and the AHU in particular. It is therefore essential that this CFD be thoroughly validated. Within the Visteon Corporation this is provided by extensive use of laser Doppler anemometry (LDA).

4. Use of Laser Doppler Anemometry to validate CFD

The airflow within the AHU is extremely three dimensional, especially within the blower and scroll area where strong, complex, and highly rotational flows are expected. For this reason all the velocity measurements within the AHU have been acquired using a 3D LDA system. The Dantec Dynamics FibreFlow LDA system employed consists of two optic heads mounted on a fully automated three-dimensional traverse mechanism and linked by means of two 10 metre long fibre-optic cables to a 5Watt Coherent laser. Both optic heads are free to be rotated within their respective gimbal mounts, which, in turn, can be swept and dipped to provide the required optical configuration. Two pairs of beams (green and blue) are emitted from one optic head (2D) and a third, violet, pair from a second (1D) optic head. Processing is carried out by Dantec Dynamics Burst Spectrum Analysers (BSA).

Seeding is provided far upstream of the AHU, using SPT seeding generators and Ondina oil. To provide the required optical access within the AHU there are two solutions. The optimum method is to produce a clear Perspex unit – however in many cases this is not possible and therefore small glass "windows" need to be inserted. It is however important to ensure that these windows are small enough not to interfere with the flow field (the blower scroll for example does not have any flat surfaces). Consequently to provide 3-component measurements through these small windows it has been necessary to bring the two optic heads as close as possible together. The chosen front lens for these measurements was 310mm. Longer focal length lenses (eg 1000mm) would have improved the optical access but the resultant reduction in the data rate, and especially in the accuracy of the 3rd component (resolved component, towards the optic head), proved unacceptable. In order to therefore maximise, for a given window, the region within the AHU where data could be acquired, a significant number of different optical configurations (different sweeps and dips) were required; each one requiring a new alignment of the laser beams (from the two optic heads) to a common point. This proves time-consuming. The solution employed was therefore to upgrade the existing 2D optic head to a 3D optic head (5-beam probe) and dispense with the second, 1D optic head.

The Dantec Dynamics 5-beam probe consists of a single optic head with two violet beams, one green, one blue and finally a combined (green and blue) beam. The 3 components of velocity can therefore be determined using a single optic head, which significantly improves the optical access. Provided the window thickness is only 1mm or 2mm, and provided the angle of the optic head relative to the window front surface does not exceed a certain value, the sweep and dip of the optic head can be varied significantly without need for re-alignment. For a given window, the 5-beam probe therefore enables measurements to made within a much larger area of the AHU, much faster, and without need for frequent re-alignment. This offers considerable advantages compared with the more conventional, twin optic head, set-up. However it is essential that the transformation matrix (transforming measured velocities to required, orthogonal, velocities) is determined as accurately as possible. This is essential for the determination of the 3rd or resolved component, which has large values making up the elements of the transformation matrix. For this reason a short focal length lens is used (240mm) and a high precision method employed to determine the matrix elements and the calibration factors.

This technique (Ref. 1) requires determining the coordinates of the intersection of the five beams with two planes at a known separation, followed by simple vector algebra manipulation. The accuracy of the technique is guaranteed through the use of a pin-hole alignment technique first described in Ref. 2. This pin-hole consists of a 50micron diameter pin-hole with a light dependent resistor mounted immediately behind and a multimeter to measure the resistance output. By positioning the pin-hole at a suitable position and observing the output from the light dependent resistor the centre of the laser beam can be aligned to an accuracy of 0.01mm relative to the pin-hole, and the corresponding "X", "Y" and "Z" coordinates noted. The process, with the pin-hole's position fixed, is repeated for all 5 beams, each time noting the traverse coordinates. This is then repeated for a second "Y" position corresponding to the beams being intersected by a second plane. Finally the 10 sets of traverse data are inserted into a spreadsheet that uses simple vector algebra to determine both the three calibration factors and the elements of the transformation matrix.

5. Results from the 5-beam Probe

Figure 3 below shows a typical plane across the inlet of the blower wheel, for a generic AHU. Such data provides the vital inlet conditions to the CFD. The colour depicts the axial velocity component directly into the blower; overlaid are the velocity vectors showing the velocity within the data plane.

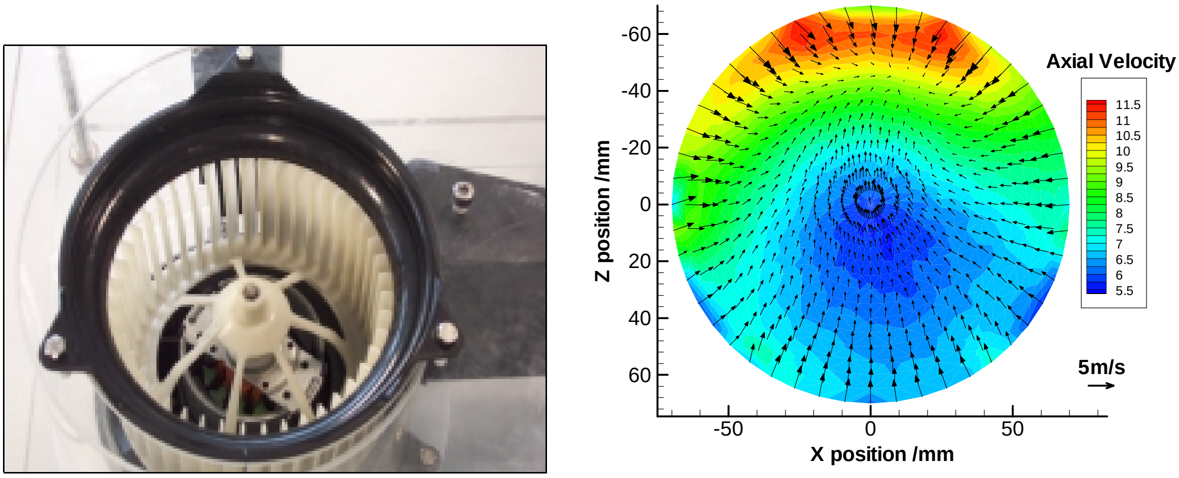


Figure 3 – Velocity contour map showing inlet velocity into a generic AHU

Figures 4 and 5 show typical results around the scroll for different AHUs. The colour depicts the tangential component of velocity; overlaid are the velocity vectors that show the velocity within the data plane. Both required the insertion of a glass window and both reveal the high complexity of the airflow and hence the need for 3-dimensional measurements.

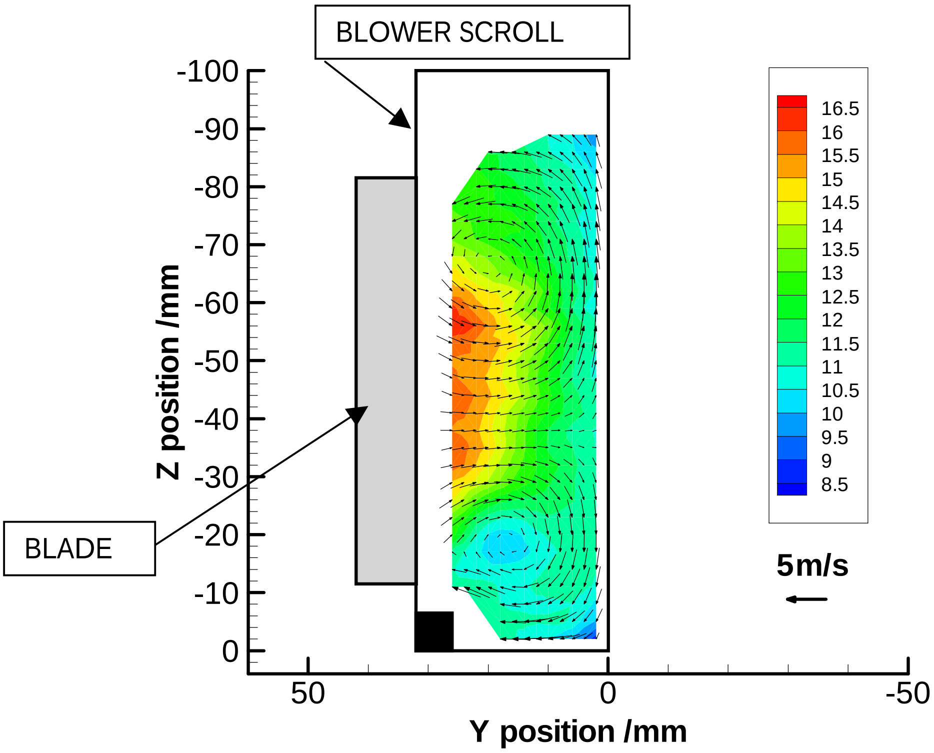


Figure 4 – Velocity contour map showing velocity distribution within a generic AHU blower scroll

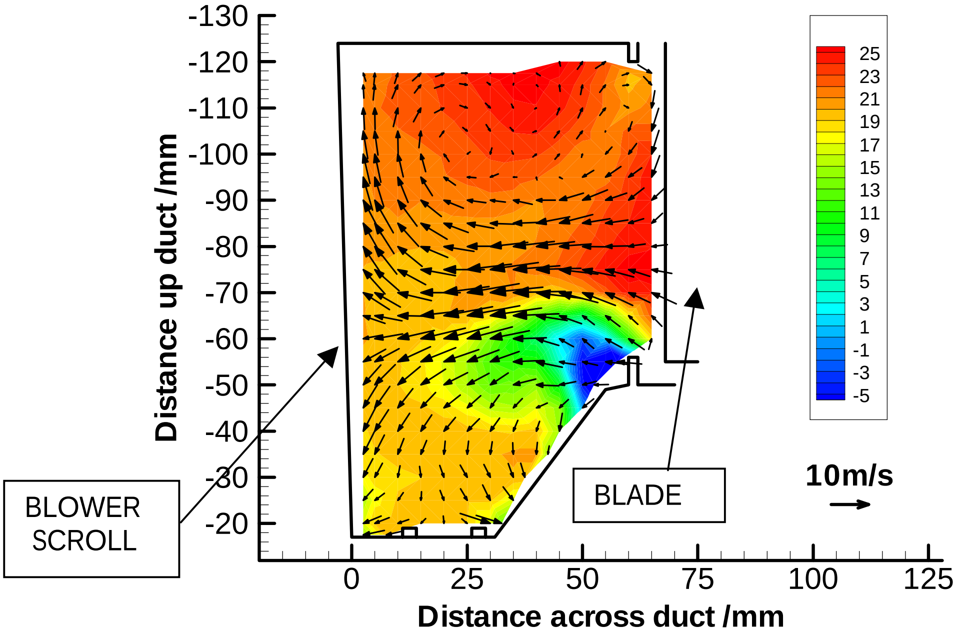
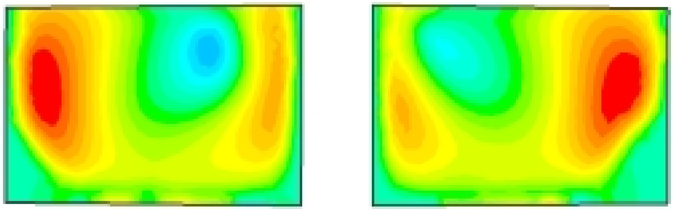


Figure 5 – Velocity contour map showing velocity distribution within a generic AHU blower scroll

Finally, Figure 6 below provides results from CFD analyses and LDA measurements acquired at the exit of the AHU in panel mode. The results show the excellent correlation in this case between the CFD and LDA results.



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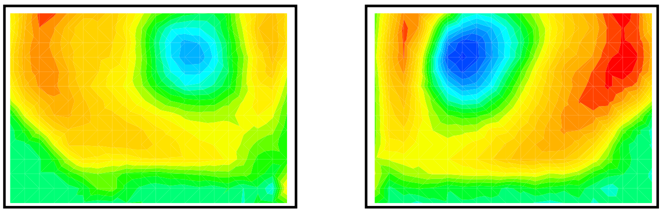

Laser Doppler Anemometry

Figure 6 – Contour maps at exit of AHU showing excellent correlation between CFD and LDA

6. Conclusions

The paper introduces the need to provide accurate 3D velocity measurements to validate the Computational Fluid Dynamic (CFD) methods employed in the development of the Air Handling Units that form such a key part of the climate control system within a vehicle. Without the extensive use of CFD the increasingly short development period could not be adhered to. In addition the provision of numerous levels of prototype parts is prohibitively expensive. Three component laser Doppler anemometry (LDA) has proved to be the ideal tool for such a validation / correlation exercise. The paper describes how the use of a single 5-beam probe to provide such data has greatly simplified the data acquisition process. Provided extreme care is taken over the transformation matrix even the 3rd, resolved, component can be accurately acquired.

7. References

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