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PRELIMINARY STUDIES INTO THE REDUCTION OF DOME SEEING USING AIR CURTAINS

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Abstract. We report on an initial experimental evaluation of using laminar flow air curtains for reducing turbulence. We demonstrate that the turbulent flow induced seeing can be very significantly reduced by using an air curtain to isolate the two sides of an aperture, thus avoiding mixing of air and the associated turbulence. A computational fluid dynamics model is used to investigate the potential that this method has for reducing dome seeing in current and future astronomical telescopes, and results are presented. We hypothesise that if such air curtains are used on a telescope then AO system requirements can be relaxed, and we detail future experiments that we are intending to carry out.

1 Introduction

Laminar flows of air, or air curtains are used in many applications to segregate two regions of air: Supermarkets use air curtains to retain warm air within the shop at open entrances. Refrigerated displays also use air curtains to separate chilled air from ambient air without a physical barrier. Similarly, operating theatres use air curtains to provide a sterile operating space by segregating clean and dusty air.

An air curtain is created by establishing a flow of air that is reasonably laminar between the two mediums. Air attempting to flow between mediums is entrained by the laminar flow, as shown in Fig. 1.

Here, we investigate the potential of using an air curtain to effectively close a telescope dome aperture, and thus reduce the turbulence generated by the interaction of incident wind with the edge of the dome aperture. The question to be answered is whether air curtains can be used to reduce ground layer seeing.

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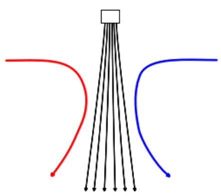

Fig. 1. A figure demonstrating the principle of air curtain operation. The black lines show the particle trajectories of an air curtain, while the red and blue curves demonstrate the entrapment of air particles on either side of the curtain.

Fig. 2. A figure showing a model of the WHT dome with an air curtain placed across the dome aperture entrance.

2 Modelling of air flow

Using a computational fluid dynamics software package, we have modelled air flow past a model of the dome of the 4.2 m William Herschel Telescope (WHT), as shown in Fig. 2.

For modelling purposes, to demonstrate the mixing of air within and outside the dome, we provide a differential in air temperature at the start of the simulations. Warmer air is then propagated past the telescope dome, and the mixing of warm and cold air studied, both with and without an air curtain present. The model for the dome aperture is 6 m wide, and the shutter cover is 1 m thick, providing a non-smooth obstacle for the air to pass over, encouraging the introduction of turbulent flow. The air speed is assumed to be 5 ms^{-1} and simulations are run until steady state solutions are found. The air curtain speed is 10 ms^{-1}.

From Fig. 3, it can be seen that the presence of an air curtain is able to significantly reduce the mixing of warm and cold air both inside and outside the telescope dome. The examples provided here are for wind incident from behind the dome, and at 90° to the dome. However, we found that regardless of wind direction relative to the dome, the air curtain was able to significantly reduce turbulent mixing.

These computational fluid dynamical models show that laminar air flow across a telescope dome aperture can significantly reduce air mixing within the dome, and thus reduce dome seeing. The success of these models means that further investigation, in the form of laboratory demonstration, is required.

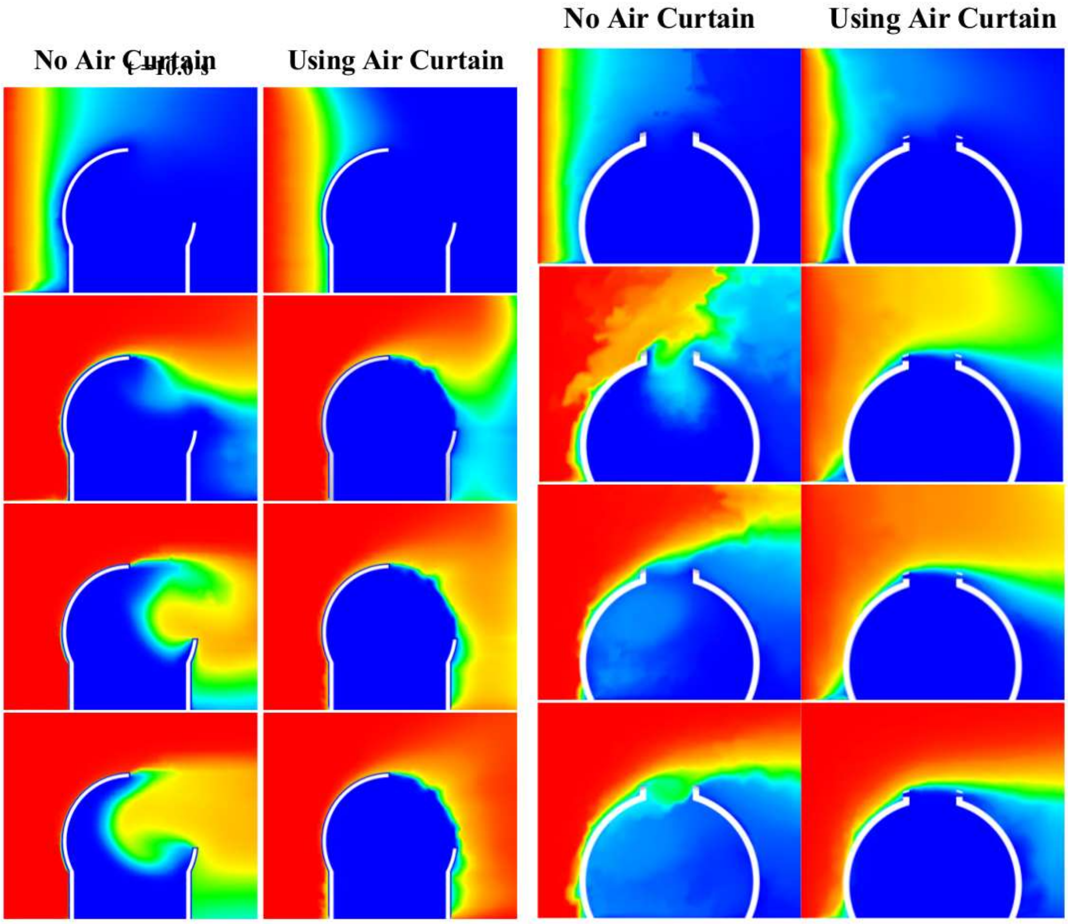

Fig. 3. A figure showing a computational fluid dynamical model of wind passing the WHT dome with and without an air curtain. The first column shows wind incident from behind the dome, with no air curtain, viewing the dome from the side, while the second column is the same with an air curtain reducing in far less turbulence. The third column shows a view of the dome from above, with wind incident across the dome aperture, without an air curtain, while the fourth column shows the effect of the air curtain. The rows represent the passing of time, from 2.5 to 10 seconds in 2.5s steps.

3 Laboratory validation

A model telescope dome 60 cm in diameter was created and an air curtain implemented across the dome aperture, as shown in Fig. 4. The air curtain itself was generated by using a fan to force air through a number of tubes which were then arranged linearly along the edge of the dome. Using tubes in this way reduced cross flow within the air curtain, and ensured that the air flow across the dome was more laminar.

An air sink was placed at the opposite side of the dome, to encourage the air curtain to maintain its linear motion.

Preliminary investigations of the air curtain effect were carried out using the Schlieren imaging technique, with apparatus as shown in Fig. 5. Here, a collimated beam is passed through the region of turbulence under investigation and then brought to a focus. The turbulence itself is created using a fan heater blowing slowly across the aperture. At this focus, a sharp "knife edge" is placed, allowing phase gradients to be observed. The pupil

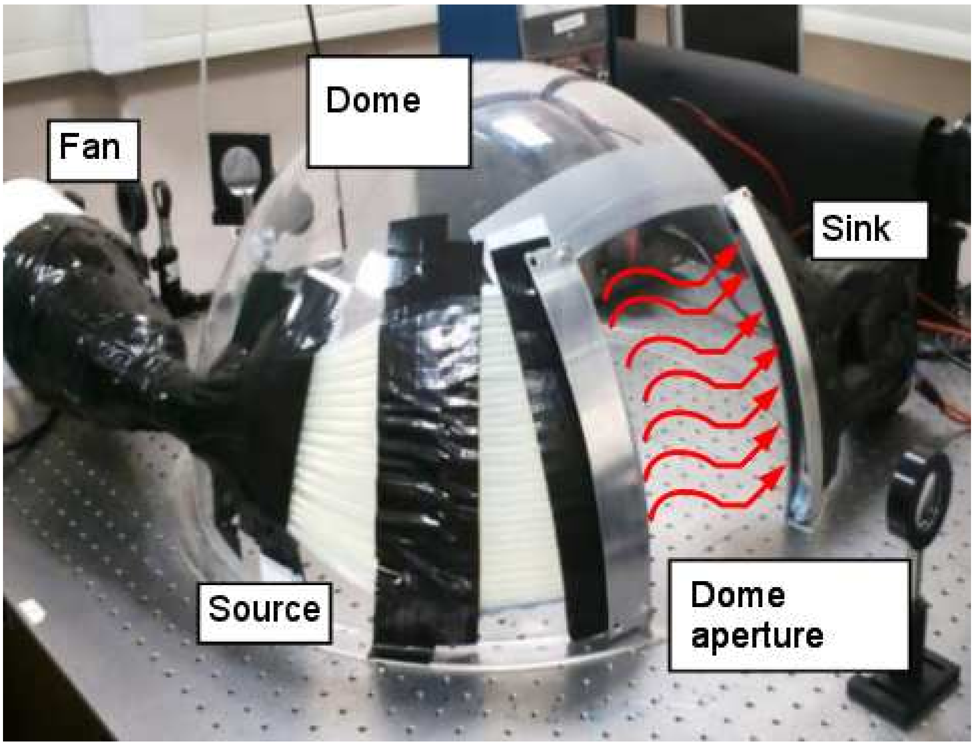

Fig. 4. A figure showing the bench setup with the model dome and air curtain.

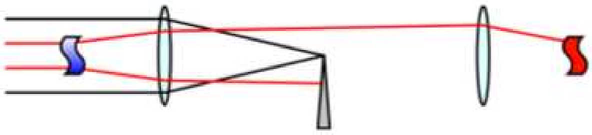

Fig. 5. A diagram showing the principle behind the Schlieren imaging technique.

plane corresponding to the focus is then imaged, and phase inhomogeneities are then made visible. Fig. 6 shows the Schlieren image taken with and without an air curtain in place across the bench dome aperture, and it is evident that the turbulence is greatly reduced in the presence of the air curtain.

3.1 Wavefront variance

Schlieren imaging is a qualitative technique, and although it clearly demonstrates the reduction in turbulence when using an air curtain, we cannot say more than that. Therefore, a Shack-Hartmann sensor (SHS) was also used, and slope variance computed and used as the performance metric. Here, as shown in Fig. 7, a collimated beam is passed through the turbulence (the hot air source) with turbulent flow direction represented by the red arrow. An air curtain (represented by the blue arrow) is placed across the dome aperture. The light beam is then re-imaged, passed through the lenslet array and focused onto the detector. A uEye camera from IDS Imaging was used as a wavefront sensor, and interfaced with the the Durham adaptive optics (AO) real-time controller (DARC) real-time control system (RTCS) [1,2]. The wavefront was reconstructed using the CuRe algorithm [3], and a Zernike decomposition performed. The variance of Zernike modes is

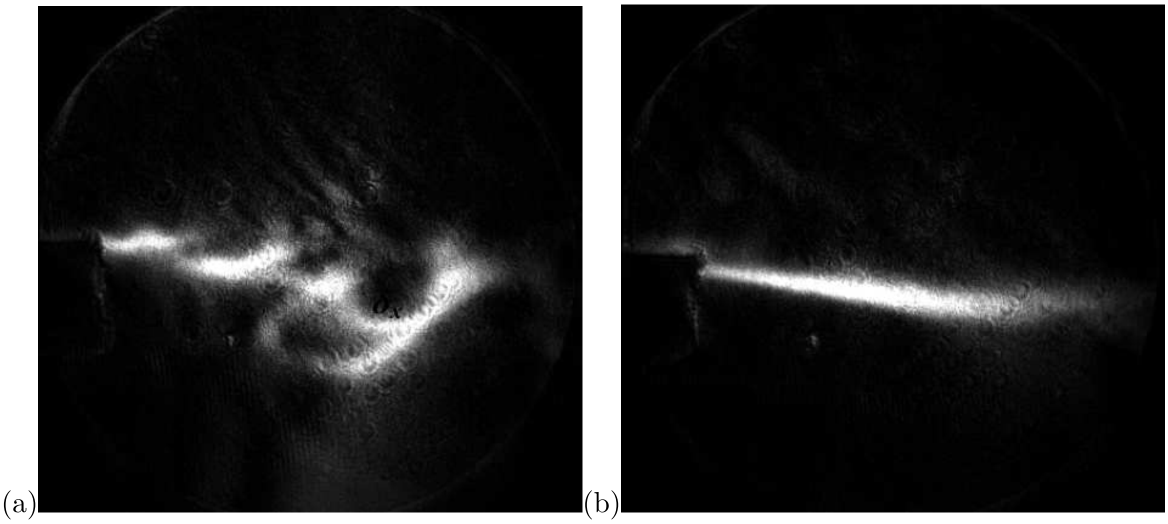

Fig. 6. (a) A Schlieren image of turbulence induced by a sharp edged aperture (the dome) when no air curtain is present. (b) As for (a), but when an air curtain is present.

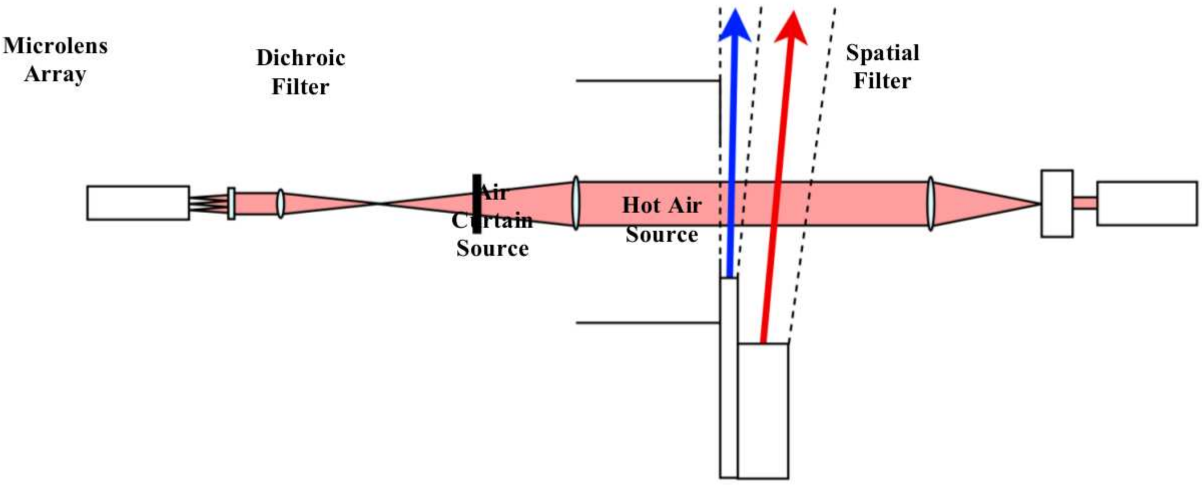

Fig. 7. A schematic diagram showing the bench setup with hot air source (to produce turbulence), dome, air curtain and SHS wavefront sensor.

shown in Fig. 8. From this figure, it is clear that significant turbulence is created by the presence of the dome, and that this is significantly reduced by the air curtain.

Since the model dome is a three dimensional structure it was also possible to investigate the effect of the air curtain as a function of angle of incident turbulence. Results are shown in Fig. 9, which again clearly show the benefit of using an air curtain, with significant reductions in wavefront variance.

3.2 Future work

We have clearly demonstrated that air curtains are effective at removing a significant amount of dome induced turbulence. However, we have not yet investigated what proportion of ground layer turbulence is due to the dome, and what is due to the turbulent atmosphere itself. This we will investigate. We also need to demonstrate that an air curtain can be extended over a distance of several meters so as to be relevant to current

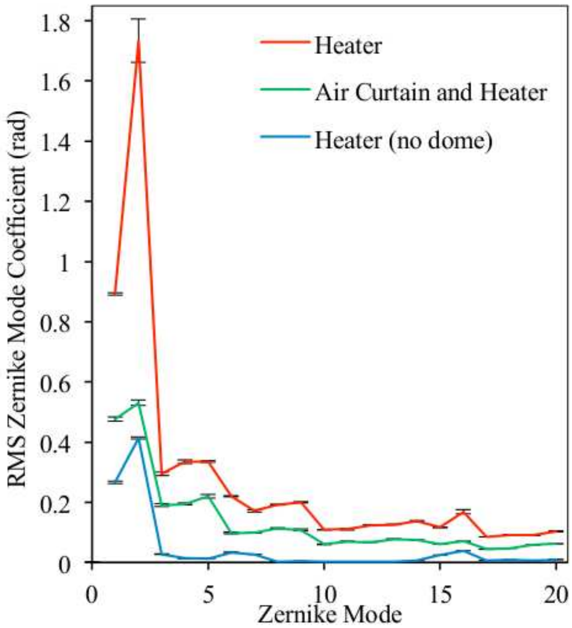

Fig. 8. A figure showing Zernike variance as a function of Zernike number for free space turbulence (blue), for dome induced turbulence (red), and dome turbulence reduced using an air curtain (green).

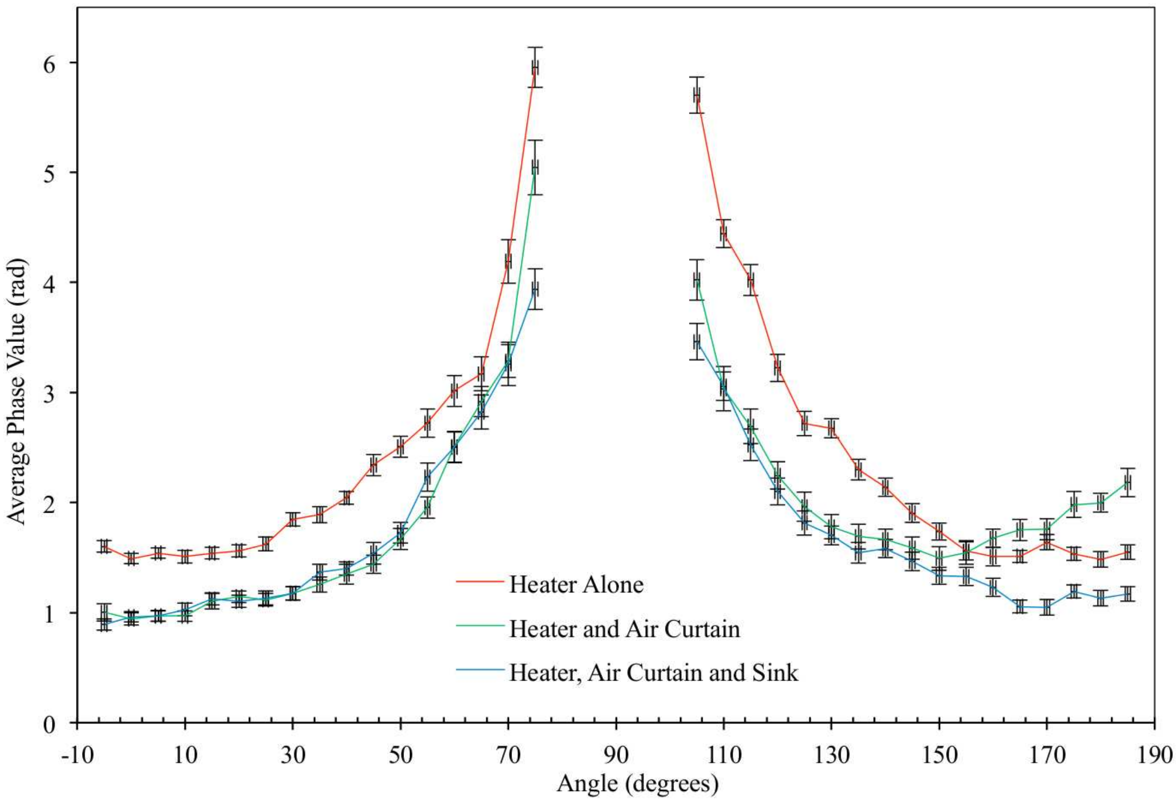

Fig. 9. A figure showing wavefront variance as a function of turbulent airflow incident angle relative to the dome aperture.

astronomical telescopes. We will also seek to implement an air curtain system on an astronomical telescope.

4 Conclusions

We have demonstrated that laminar air flow, or air curtains, can be used to significantly reduce dome induced turbulence and hence have great potential for improving astronomical image quality, and reducing the specifications required for AO systems. Our investigations have included numerical modelling and laboratory validation. The next step in this work is demonstration on an astronomical telescope.

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