Postprint of Ventilation Study for Lifting Passage of Xinglong 2.16-meter Telescope Dome

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Date: 2019-11-27T00:00:00+00:00

Abstract

Dome seeing originates from atmospheric turbulence near the telescope induced by the dome, resulting in degraded imaging quality and observation accuracy. Poor dome seeing wastes excellent site conditions. Dome ventilation is an indispensable component in the design of large telescope domes and can effectively mitigate dome seeing issues. To reduce the impact of dome seeing on the Xinglong 2.16-meter telescope, a design for retrofitting the dome' s lifting passage into ventilation openings was developed, and computational fluid dynamics software was employed to analyze the ventilation effectiveness. The analysis results demonstrate that retrofitting the dome' s lifting passage into ventilation openings can enhance the rate of thermal equilibrium between the dome interior and exterior, stabilize the air within the dome, and consequently reduce dome seeing effects. Based on the ventilation effectiveness simulation results, the ventilation strategy can be optimized. Research on dome ventilation can provide a reference basis for the ventilation retrofit of the 2.16-meter telescope dome, thereby improving telescope imaging quality and efficiency.

Full Text

A Study on Ventilation of the Hoist Duct for the Xinglong 2.16-meter Telescope

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Abstract

Dome seeing arises from atmospheric turbulence near the telescope caused by the enclosure, degrading imaging quality and observation precision. Poor dome seeing wastes excellent site conditions. Dome ventilation has become an essential component in large telescope dome design, effectively mitigating dome seeing issues. To reduce the impact of dome seeing at the Xinglong 2.16-meter telescope, this study proposes converting the dome’ s hoist duct into a ventilation opening and analyzes the ventilation effectiveness using computational fluid dynamics software. The results demonstrate that this modification accelerates thermal equilibrium between the dome interior and exterior, stabilizes internal air flow, and consequently reduces dome seeing effects. Based on these ventilation simulations, optimal ventilation strategies can be designed. This research provides a reference for the dome ventilation retrofit of the 2.16-meter telescope to improve imaging quality and observation efficiency.

Keywords: Dome venting; Xinglong 2.16-m telescope; Computational Fluid Dynamics; Dome seeing

0 Introduction

The Xinglong Observatory’ s 2.16-meter optical telescope has been in operation since 1989. Its hemispherical dome measures 23 meters in diameter and 15 meters in height, with low-thermal-capacity aerated concrete insulation walls and convection zones in the dome structure. Due to the British-style equatorial mount requiring substantial slewing space, the dome volume is exceptionally large at approximately 5,600 m³. This large volume creates significant thermal inertia, making it difficult to achieve rapid thermal equilibrium between the interior and exterior air using only a few exhaust systems. Furthermore, natural wind entering through the dome slit generates turbulent phenomena inside the dome, affecting observation precision through dome seeing effects.

Dome ventilation has become indispensable in large telescope dome design, effectively solving dome seeing problems by promoting horizontal air circulation between the dome interior and exterior, thereby improving observation precision. Installing a series of natural ventilation windows on the dome surface represents an effective and economical ventilation method that utilizes natural wind to remove heat and turbulent air, rapidly achieving thermal equilibrium conditions. However, retrofitting existing domes with extensive natural ventilation windows faces numerous constraints, requiring detailed structural strength analysis and consideration of construction conditions for the existing dome. Such modifications entail excessive time and economic costs while potentially disrupting normal telescope operations.

The 2.16-meter dome contains a 4m × 3m hoist duct for primary mirror coating. Converting this duct into a ventilation opening could create convection with the slit opening, substantially increasing ventilation efficiency and improving observation quality. This paper presents the design for converting the hoist duct into a ventilation opening and analyzes its effectiveness using Computational Fluid Dynamics (CFD) software, comparing ventilation performance with and without the vent to provide a reference for the dome ventilation retrofit of the

2.16-meter telescope.

1 Ventilation Scheme Design

The location of the hoist duct for the Xinglong 2.16-meter telescope is shown in [Figure 1: see original paper]. Based on the dome structure, the retrofit design introduces the ventilation duct to the floor below, then turns 90 degrees westward to exhaust through the dome wall. According to the wall structure, the exhaust opening is designed as 1m × 1m. For safety, a protective mesh is installed at the hoist duct opening inside the dome to prevent falls. Before installation, the existing floor at the hoist duct must be removed and partially modified to secure the mesh. The mesh features a grid structure that ensures personnel safety without impeding ventilation effectiveness ([Figure 2: see original paper]).

[Figure 3: see original paper] shows a cross-sectional view of the ventilation duct. The duct floor consists of a movable panel that opens easily. During primary mirror coating, the panel opens without affecting the hoist duct' s function. The openable panel is approximately 3 meters above ground, allowing unobstructed personnel passage. Two controllable-speed exhaust fans are installed above the ceiling, capable of operating simultaneously or as backups, providing an exhaust volume of approximately 55,000 m^3/h (calculated at 10 air changes per hour per fan).

2.1 Telescope Dome Model

The 2.16-meter telescope dome has a total height of 35 meters, with the rotating dome section measuring 15 meters high and 23 meters in diameter, featuring a 5-meter-wide slit opening. The telescope' s 3D model was constructed based on engineering drawings. To reduce computational load and processing time, the model was simplified by removing minor and internal components that do not affect ventilation. The resulting CFD analysis model comprises four parts: dome, mount, telescope tube, and fluid domain ([Figure 4: see original paper]). Since this study focuses only on internal dome ventilation, the fluid domain represents the interior air volume of the dome.

2.2 Parameter Settings

According to meteorological data from the Xinglong Observatory, typical nighttime wind speeds range from 1 m/s to 2 m/s. Therefore, this analysis sets the ambient wind speed at v = 1 m/s, with external air entering the dome through the slit. The exhaust opening is located on the dome' s outer wall ([Figure 4: see original paper]), with an exhaust velocity of v = -15 m/s simulating the exhaust fans (based on a fan capacity of approximately 55,000 m^3/h and a 1 m^2 opening area, yielding ~15 m/s). This study employs a pressure-based k-transient model suitable for slow, incompressible flow, the same model used in

TMT’ s dome ventilation research. The initial interior dome temperature is set at 278 K, with external air temperature at 273 K.

3 Calculation Results Analysis

Based on the dome slit orientation, this paper analyzes three different slit-vent angle configurations, comparing ventilation effectiveness with and without active exhaust.

3.1 Ventilation Analysis at 180° Slit-Vent Angle

As shown in [Figure 4: see original paper], with the dome slit facing east, external air enters primarily through the slit opening. Temperature variation observations indicate thermal equilibrium is reached in approximately 600 seconds without ventilation and 500 seconds with active exhaust. Therefore, data from the 500-second mark are analyzed.

[Figure 5: see original paper] and [Figure 6: see original paper] present temperature and turbulence intensity distributions, respectively. The comparative analysis reveals: (1) Temperature: Under these input conditions (wind speed, direction, temperature), active exhaust achieves thermal equilibrium with the exterior at approximately 500 seconds, faster than the non-ventilated case, facilitating rapid dome seeing reduction. (2) Turbulence intensity: Within the telescope’ s optical path, maximum turbulence intensity reaches 42.51% without active exhaust versus 61.35% with it—a reduction of approximately 30%. At the mirror cover edges, values are 78.82% and 137.39%, respectively. (3) Wind speed distribution and vectors: With active exhaust, wind speed above the primary mirror baffle is 1.21 m/s compared to 1.22 m/s without exhaust. At the telescope’ s windward surface, speeds are 1.31 m/s and 3.20 m/s with and without active exhaust, respectively, while maximum interior dome speeds are 3.90 m/s and 7.00 m/s. (4) Wind vector maps clearly show airflow patterns. With active exhaust, air flows toward the hoist opening and is expelled, whereas without exhaust, vortices form on the leeward side after passing the telescope, with air still exiting through the slit and higher wind speeds around the telescope.

3.2 Ventilation Analysis at 90° Slit-Vent Angle

As shown in [Figure 7: see original paper], with a 90° slit-vent angle (slit facing north or south; the north-facing case is analyzed here), external air still enters through the slit but at a reduced distance from the vent. Simulation parameters match Section 3.1. Temperature observations show equilibrium at approximately 360 seconds without ventilation and 400 seconds with active exhaust, so data from the 360-second mark are analyzed.

[Figure 8: see original paper] and [Figure 9: see original paper] show the results. The analysis indicates: (1) Temperature: Active exhaust achieves equilibrium at approximately 400 seconds, slightly slower than the non-ventilated case (360 seconds). On the side opposite the exhaust channel (upper right dome in [Figure 8b: see original paper]), cooling is slower because incoming cold air exits through the left-side exhaust without reaching the dome’ s right side. (2) Turbulence intensity: Within the optical path, maximum turbulence intensity is 15.89% with active exhaust, with an average of 3.76% throughout the dome. Without ventilation, maximum turbulence above the primary mirror baffle is 58.62%, with a dome average of 9.17%. Active exhaust thus produces lower and more uniform turbulence distribution. (3) Wind speed distribution: Wind speed above the primary mirror baffle is approximately 0.75 m/s with active exhaust versus 0.88 m/s without. Maximum dome wind speeds are 4.25 m/s and 2.24 m/s (near the mirror cover). (4) Wind vectors: With active exhaust, the side opposite the vent experiences lower wind speeds. Without ventilation, higher speeds near the mirror cover create multiple vortices inside the dome.

3.3 Ventilation Analysis at 0° Slit-Vent Angle

As shown in [Figure 10: see original paper], with a 0° slit-vent angle (slit facing west), simulation parameters match Section 3.1. Temperature observations show equilibrium at approximately 200 seconds without ventilation and 250 seconds with active exhaust, so data from the 200-second mark are analyzed.

[Figure 11: see original paper] and [Figure 12: see original paper] present the results. The analysis shows: (1) Temperature: Active exhaust achieves equilibrium at approximately 250 seconds, slightly slower than the non-ventilated case (200 seconds). Similar to Section 3.2, the area above the side opposite the exhaust channel (right side of the slit in [Figure 11b: see original paper]) cools more slowly because incoming cold air only partially reaches the dome’ s right side before exiting. (2) Turbulence intensity: The contrast is pronounced. Within the optical path, maximum turbulence intensity is 10.49% with active exhaust, with a dome average of 3.43%. Without ventilation, maximum turbulence above the primary mirror baffle is 68.24%, with a dome average of 7.89%. Active exhaust significantly improves turbulence distribution. (3) Wind speed distribution: Wind speed above the primary mirror baffle is approximately 0.67 m/s with active exhaust versus 0.92 m/s without. Maximum dome wind speeds are 6.25 m/s and 1.87 m/s (near the mirror cover). (4) Wind vectors: Active exhaust creates relatively stable flow patterns, while without ventilation, higher wind speeds above the primary mirror generate multiple vortices.

3.4 Analysis of Exhaust Fan Airflow Impact

Changes in exhaust fan airflow inevitably alter turbulence conditions inside the dome, making analysis of different airflow rates essential for fan selection. Simulation parameters match Section 3.1, with a 0° slit-vent angle (slit facing west). The exhaust velocity is set to 9 m/s, providing approximately 6 air changes per hour—lower than the previous configuration. In this case, thermal equilibrium is reached at approximately 560 seconds with active exhaust. For comparison, data from the 500-second mark are analyzed.

Comparing [Figure 5: see original paper], [Figure 6: see original paper] (high-volume fans) with [Figure 13: see original paper] reveals: (1) Temperature: Active exhaust achieves equilibrium at approximately 560 seconds, faster than the non-ventilated case (600 seconds), though the reduced exhaust velocity increases equilibrium time. (2) Turbulence intensity: Maximum turbulence intensity above the primary mirror baffle is 32.80%, lower than both the non-ventilated case (61.35%) and the high-volume case (42.51%). The dome average turbulence intensity is 12.04%. (3) Wind speed distribution: Wind speed above the primary mirror baffle is 1.31 m/s with active exhaust versus 1.22 m/s without. At the telescope's windward surface, speeds are 1.41 m/s and 3.20 m/s with and without active exhaust, respectively, with a maximum dome wind speed of 3.85 m/s. Compared to the high-volume fan case (Section 3.1), wind speed distribution changes are minor. (4) With lower-volume fans, wind speeds around the telescope decrease (wind vector colors are lighter than in the high-volume case), though vortices still persist without ventilation.

These results indicate that lower-volume exhaust fans facilitate temperature reduction and turbulence intensity decrease, producing smaller turbulence intensity than high-volume fans while slightly reducing wind speeds near the telescope. Therefore, the lowest-volume fan meeting air exchange requirements should be selected, ensuring adequate ventilation and thermal equilibrium rates while minimizing turbulence intensity and wind speeds.

4 Conclusions and Outlook

This paper proposes a method to improve dome seeing at the Xinglong 2.16-meter telescope by converting the hoist duct into a ventilation duct, modeling and analyzing ventilation effectiveness. The results demonstrate that this retrofit accelerates thermal equilibrium between dome interior and exterior, stabilizes internal air, and reduces dome seeing effects. Specific findings include: (1) With the slit facing east, the hoist duct retrofit effectively accelerates cooling and achieves rapid thermal equilibrium, reducing both turbulence intensity and wind speed to improve dome seeing. (2) With the slit facing north, south, or west, cold external air exits through the west-side vent, potentially slowing cooling on the dome' s east side, though turbulence intensity and wind speed throughout the dome and near the telescope are significantly reduced. (3) Increasing fan power improves heat exchange rates but raises costs and power consumption. (4) The lowest-volume fan meeting air exchange frequency requirements should be selected. (5) Once temperature equilibrium is achieved and turbulence parameters stabilize, the vent can be closed.

Beyond dome ventilation research, the Xinglong operations team has conducted multiple studies to improve the 2.16-meter telescope' s imaging quality and efficiency, including Tip/Tilt system development to enhance energy concentration and primary mirror cell cooling to reduce mirror seeing. Combined with this dome ventilation research, these efforts provide a reference basis for the dome ventilation retrofit, promising further improvements in telescope imaging quality and efficiency that will comprehensively enhance the scientific value of the 2.16-meter telescope.

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Note: Figure translations are in progress. See original paper for figures.

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