MAGELLAN PROJECT

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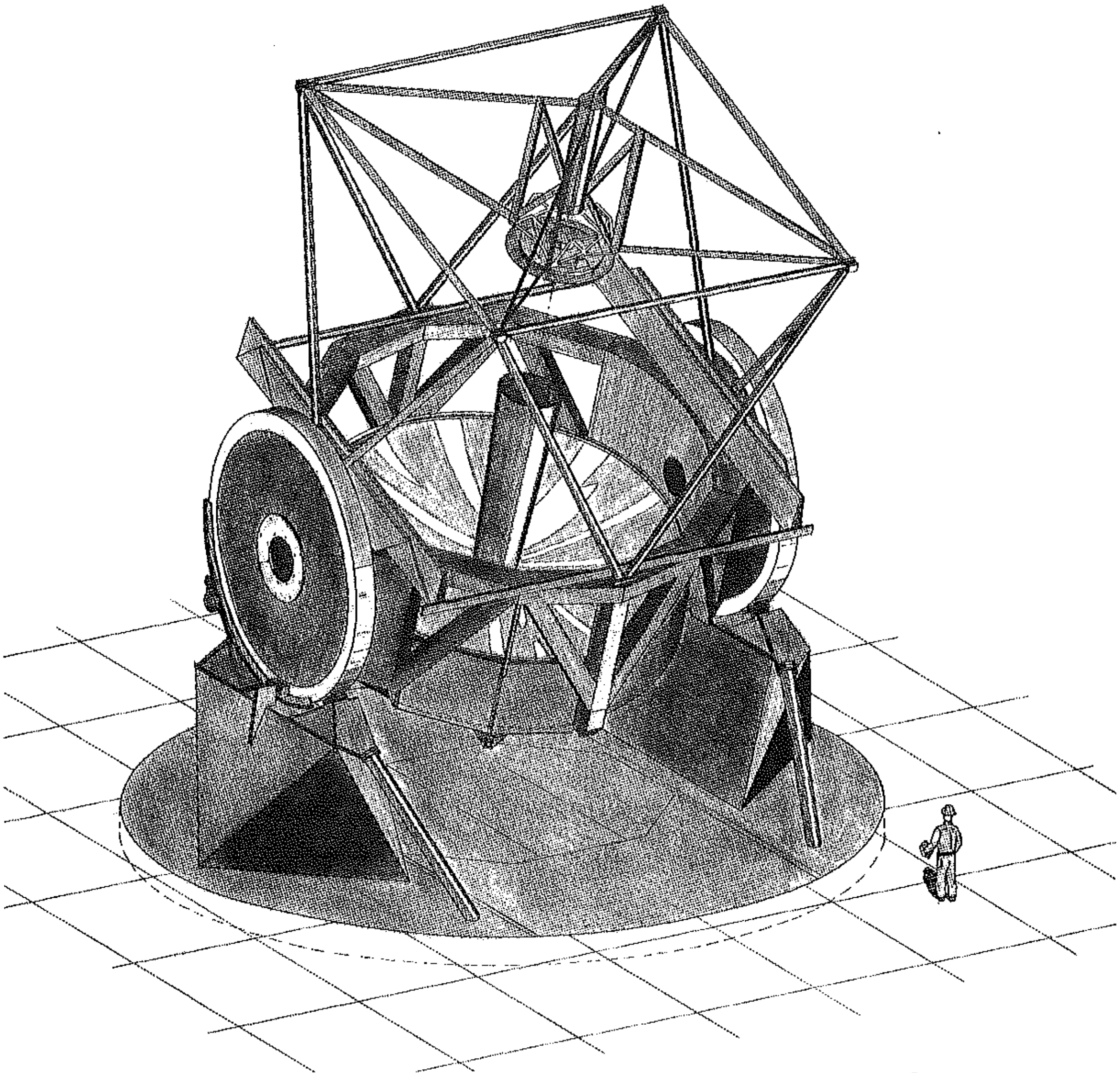

Flow Visualization of the Octagonal Telescope Enclosure

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1. INTRODUCTION

The preservation of image quality is one of the most important design criteria for a telescope enclosure. Image quality is adversely affected by the presence of fluctuations of air temperature in the light path. (No evidence exists linking pressure fluctuations, e.g., due to turbulent flow, to image degradation in ground-based telescopes.) An ideal enclosure is one that has no adverse affect on image quality. This ideal can be approximated by a design in which the air inside the telescope chamber is continually replaced by ambient air before it has the opportunity to be warmed or cooled by the surfaces of the telescope enclosure.

A telescope enclosure often represents 15% to 25% of the cost of the telescope project. Unfortunately, a poorly designed telescope enclosure design can degrade the image quality of an otherwise excellent site. It is hoped that a better understanding of the interaction of the fluid and the enclosure will lead to improvements in the design of the telescope enclosure and preservation of the intrinsic image quality of the site.

The enclosure for the 8-meter telescope for the Magellan Project (known generically as the octagonal design) is a modified hemispherical enclosure. (See Magellan Report No. 4, March 1989). The enclosure shutters are bi-parting. Each shutter consists of three flat panels. The octagonal concept permits convenient vent openings in the rectangular vertical flat wall panels and in the three 45 degree rectangular roof slopes of the telescope chamber. In addition, vents are installed in the stationary part of the chamber immediately below the octagonal rotational section. (Editor's note: The latest design calls for 23 doors in the chamber, 10 in the rotatable, octagonal section and 13 in the stationary, hexdecagon section, all from approximately 10 to 30 square meters each. See Magellan Report No. 25, Page 11 for an illustration). These openings, when not in use, are closed by large weatherproofed, insulated, bifold doors such as those found on hangars. The enclosure is supported on columns so that there is free circulation under the observing floor except for the central obstruction by the telescope pier.

An earlier study of four 8-meter telescope enclosure designs has shown that the octagonal enclosure topology compare favorably to other common topologies.[1] The paper describing the earlier study expands on many of the ideas discussed herein.

In the current study, we use dye in a water tunnel to trace flow around and through a model of the Magellan octagonal telescope enclosure, support building and telescope. We differentially compare flow attributes for this model with different vent configurations. The enclosure model is oriented at various angles with respect to the flow direction, while the support building remains fixed.

2. DESCRIPTION OF THE EXPERIMENT

This research was performed using the 13 m long water tunnel of the Aeronautics and Astronautics Department of the University of Washington. The test section is 3 m long and 0.76 m square. The maximum flow speed is 0.6 m/s. The flow speed used was 10 cm per second. At the model scale, this represents 18 m/s (40 MPH).

The Reynolds number is the most important parameter affecting flow in this system. In particular, typical wind speeds are high enough that buoyancy effects are negligible in a reasonable telescope enclosure design. The Reynolds number is

$$Re=\frac{VD}{\nu}$$

where V is the flow velocity, D is a characteristic dimension, and ν is the fluid kinematic viscosity (0.9×10^{-6} m^2/s for water and 13.9×10^{-6} m^2/s for air). Typically, the Reynolds number in a scale model is too small because of the dependence of V and D on the scale. The lower viscosity of water partially offsets the effect of the scale change.

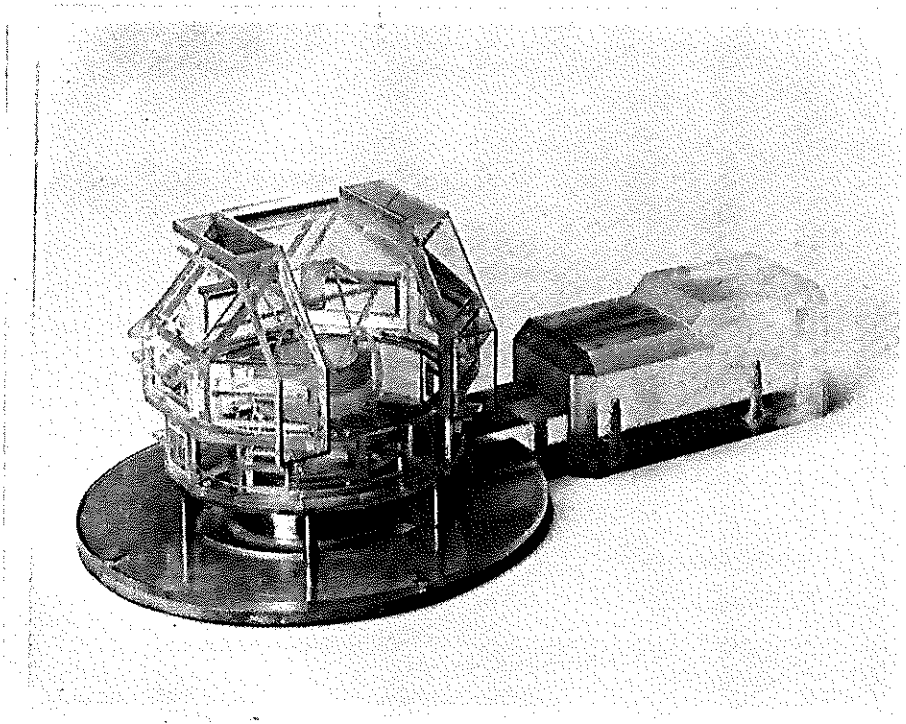

Figure 1: Octagonal enclosure. This is a hemispherical topology approximated with flat surfaces. The shutters move laterally outward to uncover the slit. Vents openings are visible in the wall and the roof panels. The doors that close the vent openings when not in use, fold in half when open and extend perpendicularly outward from the wall surface. In this open position, they act to deflect flow into the telescope chamber. The enclosure is supported on columns. This allows air to flow under the telescope chamber around the pier.

The Reynolds number for the model system is about 4,000 based on the width of vent openings. For the actual structure and typical wind speeds, the Reynolds number will be 2×10^5. Fortunately, for a shape which is not streamlined, flow patterns do not change much once the Reynolds number is above several thousand. In several cases, we increased the flow speed to about 50 cm/s to insure that our results were not sensitive to the Reynolds number.

An acrylic model of the telescope enclosure, telescope, and support building (figure 1) was used. The scale was 180:1. The model blocked about 8.6% of the test section area, an acceptable value. With higher blockage, the walls of the test section can significantly influence flow around the model. The model was mounted upside down on a flat base plate 1.58 m long. The proposed enclosure site is actually somewhat curved but, since the radius of curvature is a factor of 10 larger than that of the telescope enclosure, the use of a flat base should not significantly affect results.

A 3 mm rod was taped to the model base plate about 0.45 m upstream of the model to generate a turbulent boundary layer. The trailing flap of the model base plate was adjusted to control the stagnation point on the leading edge and thereby the thickness of this layer. The boundary layer thickness was adjusted to be equivalent to approximately 5 m at the model scale.

Fluid flow through the telescope chamber and around the enclosure was examined with the shutters directed at various angles to the flow. The support building was in a fixed location 90^0 with the long dimension perpendicular to the flow (See windrose in Magellan Report No. 17 page 2). The enclosure shutters were always in the open position. Active ventilation, e.g., via blowers, was not considered in this study, for at moderate wind speeds, the effectiveness of even a small vent area is much greater than that of a practical active system.

Three types of experiments were performed. In the first, dye is injected into the flow upstream of the model from nine probes in sequence. Probe number six is on the centerline of the enclosure; the other probes are equally spaced at 25 mm intervals on either side of the center. The spacing was coarser in front of the support building. For each sequence of observations, the probe heights are identical, but are varied from sequence to sequence.

In the second type of experiment, a measured amount of dye is injected directly into the telescope chamber. Observing the rate at which dye disappears from the chamber indicates the flushing rate. Dye remains in stagnant spaces longer than in spaces which are well flushed.

In the third type of experiment, a measured amount of dye is injected into the wake of the enclosure near the ground. The behavior of this dye indicates the extent that air, overcooled by the ground, might be carried into the light path and disturb the image quality. The telescope enclosure orientation is 180^0, where image quality is most likely to be affected by an adverse wake.

3. RESULTS

In this report, the orientation of the building is described by the angle between the telescope azimuth and the direction from which flow occurs. In other words, 0^0 corresponds to the shutters facing upstream and 180^0 is downstream.

In the first model configuration, all vents were fully open except for the front two mid-level vent openings which were closed. These are the openings directly behind the vertical shutter panels.

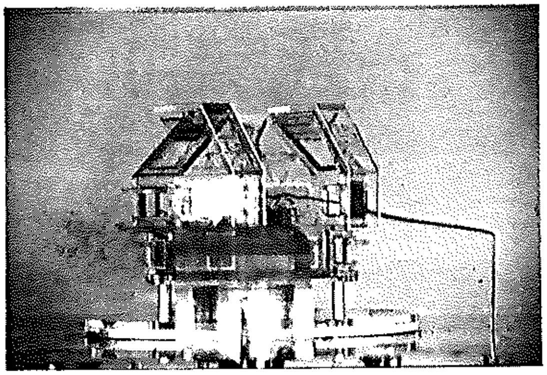

Figure 2: With all vents open, except the two front mid-level vents behind the vertical shutter panels, and no windscreen, flow across the telescope chamber is mostly horizontal with only moderate vertical mixing.

We observed that flow through the telescope chamber was mainly horizontal in all orientations and levels. Figure 2 shows a typical example at mid-level in the telescope chamber. The dye flows across the telescope chamber exiting mostly through a mid-level vent. At a site with an otherwise stable temperature gradient, vertical mixing of the air would result in increased image degradation.

In other studies of enclosures at treeless sites, we have observed that streamlines tend to rise as they approach the telescope enclosure. One figure of merit describing this effect is enclosure height degradation (EHD) which is the amount of rise of the lowest streamline that consistently enters the telescope chamber. This is important because this streamline is most likely to be contaminated with air from the turbulent boundary layer. The open base of this design allows fluid to flow under the telescope chamber floor and results in an

EHD near zero (figures 3 and 4). In enclosures with closed bases, an EHD of 2 to 5 m is typically observed.

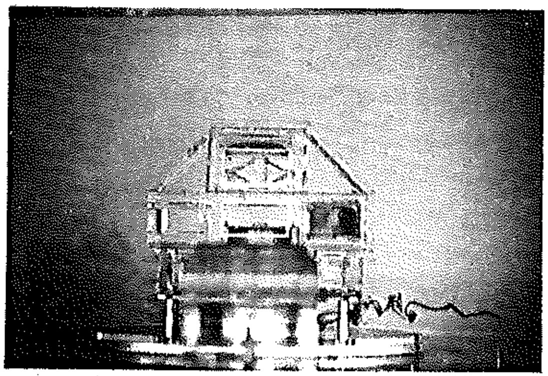

Figure 3: The dye traces flow in the turbulent boundary layer near the ground. At an actual telescope site, the turbulence in this layer is responsible for transporting air cooled by the ground to levels where it may degrade image quality. The open base of this design allows this layer to flow under the telescope chamber floor. This minimizes enclosure height degradation (see text for definition) and improves flushing of the enclosure wake.

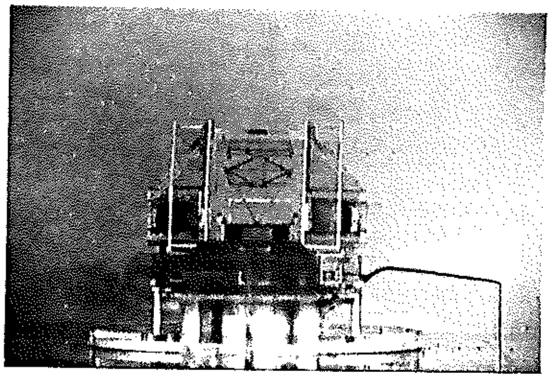

Figure 4: The lowest streamline which enters the telescope chamber shows no tendency to transport fluid upward from the turbulent boundary layer.

In previous studies of this basic topology, we have observed a strong tendency for fluid to be drawn over the telescope and up through the portion of the shutter in the light path. This is undesirable since this air may have been heated or cooled by surfaces inside the telescope chamber. We find that the open doors in the 45^0 roof panels of the octagonal enclosure deflect flow downward into the upper part of the telescope chamber. This opposes an upward flow and results in more favorable nearly horizontal flow in the telescope chamber. Although some fluid did exit the telescope chamber through the slit above the telescope, the effect was small compared to other telescope enclosures that we have examined.

The support building does cause a small asymmetry in the flow pattern. Dye injected directly upstream of the enclosure center invariably flowed around the side away from the support building. Put in different terms, the support building moves the stagnation point on the telescope enclosure closer to the support building. We do not expect this effect to have any adverse impact on the performance of this design.

Figure 5 shows flushing times from flooding tests where the telescope chamber is filled with dye. The numbers are the times required to completely flush a constant volume of injected dye from the telescope chamber. The end of flushing is subjective; we estimate the error of these measurements to be about 20%. The flushing time is twice the volume change time as measured by exhausting a model through openings in the telescope chamber floor with a pump.

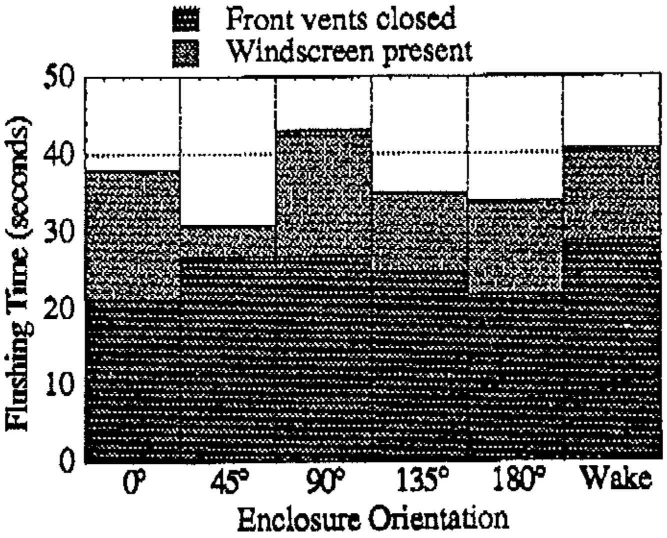

Figure 5: Flushing times from flooding tests where the telescope chamber is filled with dye. The vents are open except as noted. The numbers are the times required to completely flush dye from the telescope chamber. Flushing times are quite uniform as a function of enclosure orientation indicating the effectiveness of the vents. The windscreen increases the flushing times at all orientations.

Flushing times are quite uniform as a function of enclosure orientation indicating the effectiveness of the vent openings. These flushing times correspond to a 18 m/s wind speed; scaling to 5 m/s (11 mph), a more typical mountaintop windspeed, gives flushing times in the range of 73 to 92 seconds or approximately 90 volume changes per hour. Figure 6 illustrates a typical flushing test.

The telescope enclosure wake also flushed quickly (about as fast as the telescope chamber itself) and dye was not drawn upstream over the telescope. Indeed, as soon as dye reached the level of the roof of the telescope enclosure, it was quickly swept downstream.

The support building wake does not seem to be a problem. Wake effects are minimized since the portion of the building immediately adjacent to the telescope enclosure is quite low and the wake associated with this portion of the building is minimal. The wake from the higher portion of the support building will be smaller than was observed in the water tunnel since it is partially buried in the mountaintop. Even in the rare event of wind at an oblique angle to the support building, the wake is still small enough that it is not likely to extend above the level of the telescope primary mirror.

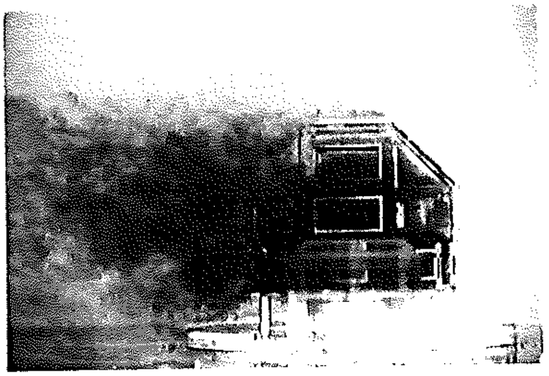

Figure 6: With the same configuration as in Figure 2, flushing of the telescope chamber is excellent. Flushing through the slit above the telescope is relatively minor compared to other enclosure designs we have studied.

In the second test configuration, the front mid-level vents were opened and a windscreen covered approximately the bottom half of the slit. The windscreen consisted of two layers of fiberglass drywall tape which had about 50% area density.

We observed that the front openings, those at mid-level shadowed by the shutters, are very effective at ventilating the telescope chamber especially at angles between 30^0 and 60^0. At angles between 150^0 and 180^0, they serve to exhaust the telescope chamber. With the vents closed, we observe the formation of a high velocity jet on the exterior of the enclosure in the space between the open shutters and the enclosure panels. At an enclosure orientation of 150^0, this jet was directed toward the ground, potentially generating airborne dust and stirring up the boundary layer. The formation of this jet was inhibited by these open mid-level front vents.

The windscreen causes a uniform increase in flushing time except at 45^0 where the effect of the open front vents partially offsets the windscreen effect. In actual use, the windscreen would be raised only during times of higher than average winds. This will make observed increase of flushing time relatively unimportant.

During high winds and angles larger than 60^0, a windscreen provides little shielding of the telescope from wind buffeting. To provide additional shielding the vents can be closed.

The third test configuration consisted of a partially closed windscreen (as in the second configuration) and half closed vent openings in order to investigate their shielding effectiveness. We observed that streamlines entering the remaining vent openings traced flow at speeds at least equal to the freestream flow. These jets hit the telescope in some orientations and are a potential source of wind buffeting since this configuration is intended to be used during high winds. Jets from the upper vents were directed downward toward the primary mirror.

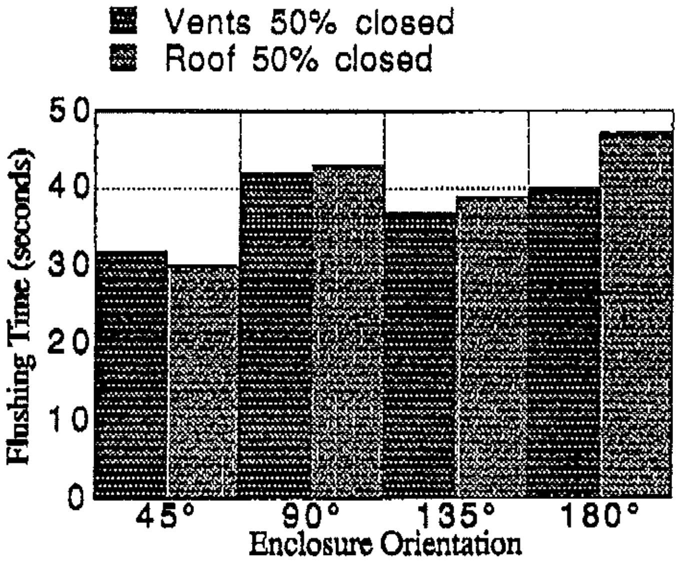

Figure 7: Flushing times from flooding tests where the telescope chamber is filled with dye. The vents are 50% closed for both cases. In addition, in the second case the rear half of the rooftop portion of the slit opening is covered with tape. Flushing times are not affected significantly by covering the rear of the slit opening. For both cases, the flushing times are similar to those obtained with a windscreen present.

In the fourth test configuration the windscreen was removed while the vents were left 50% closed. Flushing times were found to be comparable to times measured for the windscreen only case (second configuration). The results are plotted in Figure 7.

Radiative cooling of the telescope chamber through the open shutter amounts to 100 to 200 W/m^2 under average conditions. This cooling is a potential source of cold air and can be reduced in principle by covering the portion of the shutter over the telescope which is not in use. In the last test configuration, we investigated this approach by covering the rear half of the rooftop portion of the shutter opening. The vent openings were 50% closed as in the fourth configuration. This change had little effect on flushing times (Figure 7).

All modifications to the initial configuration resulted in an increase in the amount of fluid exiting the rooftop portion of the shutter opening. It is clear from these results that the presence of large unobstructed openings in the walls of telescope chamber are responsible for minimizing adverse flow above the telescope. Closing half of the rooftop portion of the shutter opening (last configuration) caused no significant benefit or harm in this regard.

The initial configuration had the most favorable wake interaction. Partially closing the vents caused fluid from the upper part of the wake to flow upstream at roof level over the telescope.

4. DISCUSSION AND RECOMMENDATIONS

Flow characteristics are only one component of a successful telescope enclosure design. Shielding of the telescope from wind buffeting and the radiation environment, initial cost, operations cost, ease of preventing water, snow and dust leaks, and provisions for telescope maintenance and support are also important issues. These factors must all be considered when choosing a telescope enclosure topology. The following recommendations emphasize only the optimization of flow characteristics.

The open base of this design is a very successful feature in that it significantly reduces enclosure height degradation. It is likely that flow through this region improves flushing of the enclosure wake. Also, it may be possible to use this flow to reduce the coupling of the thermal mass of the structural steel in the base and floor supports to the interior of the telescope chamber. This feature should be retained in the enclosure design.

The open doors associated with the 45^0 roof openings enhance the effectiveness of these vents and improve flow through the upper portion of the telescope chamber. The front middle level vents help flush the telescope chamber and improve exterior flow despite their location behind the vertical shutter panels. These features should be retained.

When a vent is partially closed, e.g., to reduce wind induced motion of the telescope in high winds, we find that a jet of fluid enters the telescope chamber through the remaining opening at speeds higher than the free stream velocity appears to impinge on the telescope. These jets may be less troublesome at full scale because of Reynold's number differences. However, closing the vents enough to prevent such jets from shaking the telescope may result in inadequate flushing of the telescope chamber. Consideration should be given to installing flow diffusers in the lower portion of the vent openings to disrupt this jet effect and to produce more uniform flushing.

Attempting to control wind induced motion of the telescope by closing vents or adding a windscreen had an adverse effect on flow over the telescope. It is likely that the open downstream vents are responsible for suppressing this flow pattern. If this speculation is correct, high winds could be handled by partially closing vents only on the upwind side of the telescope enclosure. The windscreen should then only be used at angles less than about 60^0. Consideration should be given to testing this approach and adding more vents at the lowest vent level. These changes should improve flow in the wake of the telescope enclosure as well.

Consideration should be given to providing a gap between the under surface of the shutters and the upper surface of the roof so that air can flow freely through this space when the shutters are open. This should spoil lift above the roof and reduce flow upward through the shutter. Care should be taken to insure that flow from this gap is not directed downward toward the telescope since the velocity will be high and buffeting of the telescope could result. Flushing of the adjacent volume over the telescope should improve and cost impact will be low. This modification should help suppress the formation of the exterior jet observed in the first test configuration.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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