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SOME AIRFLOW PROPERTIES OF TELESCOPE ENCLOSURES ESTIMATED FROM WATER-TUNNEL TESTS

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ABSTRACT

The traditional telescope enclosure shape is a cylinder topped by a hemispherical dome. Studies of seeing conditions inside telescope domes indicate a need to provide substantial air ventilation to prevent image degradation due to thermal variation of the air within the dome. Although the traditional enclosure shape was initially chosen for the Japan National Large Telescope, studies of the hydrodynamic properties of this style compared to two alternative styles indicate that changes may be desirable. Water-tunnel tests were made using 1:500 scale models of the enclosures. Flow patterns outside and inside the enclosures were observed using streams of dye or bubbles. For all enclosure styles, an exterior component of flow was found that was "uplifted" over the top of the enclosure and divided from the original main flow stream direction at different levels depending on the model characteristics. We also found that an external horizontal guiding vane significantly affected the location of the stagnation point. It is important that the stagnation point be above the turbulent boundary layer at the site. Enclosures with flat or near-flat roofs appear to be superior. The time to flush out the enclosure was measured and found to vary with enclosure style, orientation of the viewing slit, and ventilation provisions. Sidewalls on either side of the telescope were found to be beneficial and also vents more or less orthogonal to the slit opening improved flushing conditions.

Key words: telescope enclosures–dome seeing–telescope ventilation

1. Introduction and Background

The traditional telescope enclosure shape is a cylinder topped by a hemisphere, and the height of the enclosure is usually intended to position the telescope above any turbulent boundary layer near the ground, which avoids mixing air cooled (or heated) by the ground with air at a different temperature passing through the light path. Arguments favoring the traditional shape are:

A. The hemisphere causes less disturbance in the wind blowing past and, hence, less turbulence is likely to exist in the light path, which could draw air at a different temperature into the light path.

B. The smooth aerodynamic shape results in less force on the building from the wind; hence, less vibration is transmitted through the ground to the telescope and less structural strength is required.

C. The wind forces are essentially symmetric about a vertical axis through the hemisphere (neglecting forces due to the shutters, etc.) which means that the hemisphere (dome) driving mechanism is not required to overcome large torques produced by the wind.

D. The hemisphere is an efficient shape for enclosing a telescope that points to all angles in the sky above the horizon.

While these arguments do have validity, it is now realized that man-made thermal effects around and

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within the telescope enclosure have been a major source of image degradation ranking in importance or even exceeding upper-atmospheric seeing which often takes most of the blame for bad images (Beckers & Williams 1982; Coulman 1985; Rosch 1987; Bely & Lelievre 1987). Roddier et al. 1990 have made recent studies of seeing conditions at Mauna Kea, Hawaii, and compared them to those at La Silla, Chile. Their findings, for several telescopes and conditions, indicate that free atmosphere seeing (i.e., the upper atmosphere) produced only from 15% to 36% of the total angular image blur measured in the telescope focus. Dome seeing and ground boundary-layer turbulence were blamed for the majority of the remaining image blur.

Since 1979 the Multiple Mirror Telescope (MMT) on Mount Hopkins in Arizona has been operated successfully inside a corotating rectangular building, the first of its kind. In 1989 the European Southern Observatory (ESO) began successful operation at La Silla of the 3.5-m New Technology Telescope (NTT) which is housed in an octagonal building that corotates with the telescope. In both cases, the enclosure shutters are the biparting style which effectively exposes the telescope to the wind entering through the front and top of the building. Interior sidewalls are built on both sides of the telescope which seems to aid the flow of air in and out of the building. The NTT enclosure has an adjustable louvered vent at the rear behind the telescope and a flexible windscreen made of canvas strips in an open net configuration that can be raised to partially block the wind. In both cases, seeing caused by the enclosure is claimed to be very small. The NTT has achieved images of 0.33 arc sec containing 80% of incident starlight (*Physics Today,* May 1990, p. 17) which indicates the enclosure seeing must have been quite small although it was not measured directly. In a recent study of seeing at the MMT, Cromwell, Haimmerle & Woolf 1990 estimate interior "dome seeing" at less than 0.2 arc sec FWHM and median site seeing at 0.59 arc sec FWHM at 500 nm wavelength. Good air circulation around the telescope is credited in part for the good images.

A portion of the total seeing effect may be due to seeing in the telescopes by the mirrors, especially the primary mirror which typically has a large heat capacity. These effects have been studied by Lowne 1979, Barr et al. 1990, and Iye et al. 1990 who all found significant seeing effects occurring when the mirrors were at different temperatures than the adjacent air. They also found that these effects can be minimized or even eliminated by adequate air ventilation of the mirror surfaces.

Ideally, the telescope, the surrounding enclosure, and the adjacent air would somehow remain together in exact temperature equilibrium without exchanging any heat, but air temperatures in enclosures do change during the night and heat exchange occurs unevenly for various parts of the telescope. Under these conditions, ventilation is desirable to remove thermally disturbed air. The chief source for ventilation in a telescope enclosure is the wind which, in the past, was regarded as the enemy because it can shake the telescope and carry dust. However, telescopes have become shorter and stubbier in shape due to the adoption of faster primary-mirror focal ratios, and it is possible to design them to acceptably withstand larger wind forces that might be caused by ventilation.

Predicting the flow of wind in and around complicated structures is still an inexact science. Considerable help may be obtained from the use of "water-tunnel" tests, commonly used in fluid dynamic studies, in which small models of the enclosure and telescope are placed in a transparent tunnel filled with water flowing at a controlled velocity. Siegmund et al. 1990 have recently performed such studies for several possible enclosure configurations for 8-m telescopes. Streamers of colored dye or bubbles which produce visible streamlines are introduced upstream from the model or inside the model through small capillary tubes. By watching the behavior of the streamlines, one can estimate how air would circulate around and through the telescope enclosure.

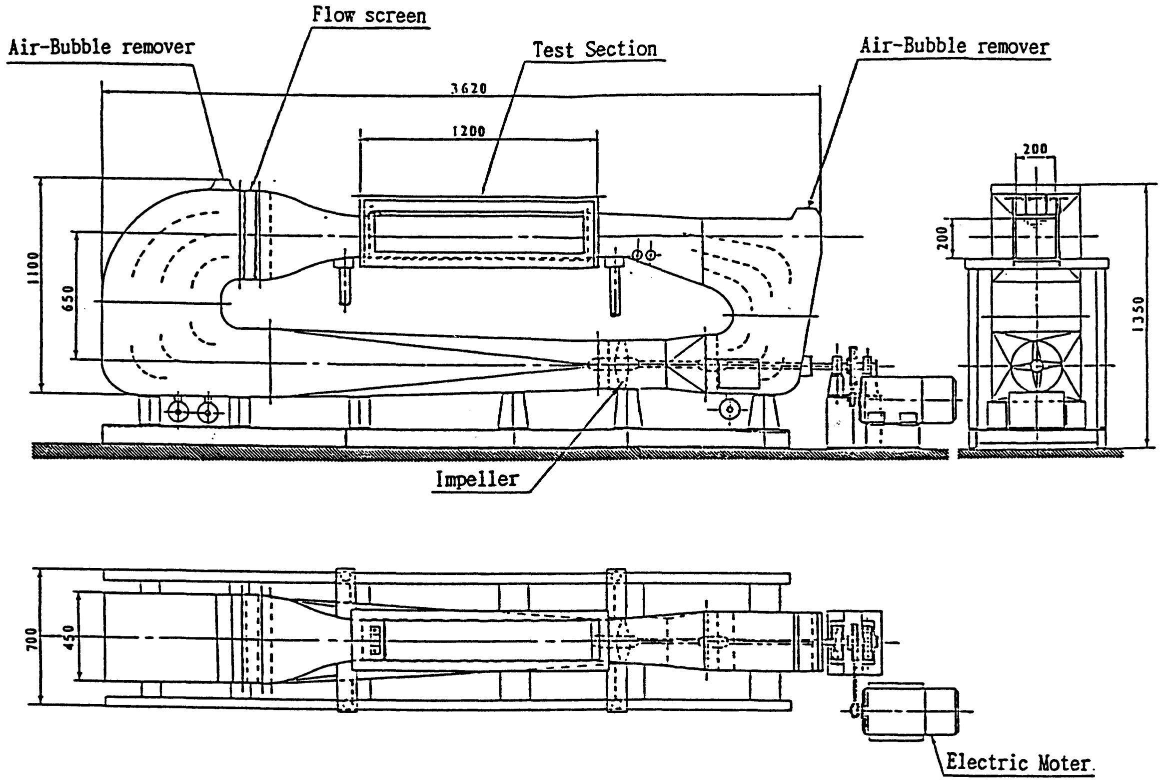
The Japan National Large Telescope (JNLT) Project group initially adopted a conventional hemispherical dome for the telescope enclosure design but has more recently begun to consider alternative styles. A water-tunnel testing setup has been developed and three different enclosure styles have been tested under a variety of simulated ventilation conditions. We describe the experimental work and endeavor to form useful conclusions that may assist other projects facing a similar design problem. Where possible, we compare our results to those of others.

2. The Experimental Setup

2.1 *The Water-Tunnel Facility*

The water-tunnel test for the telescope enclosures was performed at the National Aerospace Laboratory, Japan, using the Vertical Circulating Water Channel (VCWC) shown by two line-drawing views in Figure 1. The VCWC test tunnel, where the enclosure models were mounted, is 20 cm × 20 cm in cross section and is 120 cm long. Water-flow velocities (u) were controllable within the range 0.01–2.0 m s^{-1}. By adjusting flow velocity, tests were made in the Reynolds Number range 10^4–10^5 measured in the flow outside the model (Re $= D\,u/\nu$ where D is a characteristic distance and ν is the kinematic viscosity). This differs from the real situation where Re will be approximately 10^7; however, above a certain value of Re, flushing effects in the enclosure become independent of Re. A dimensionless parameter (τ) of flushing time is defined to be

$$\tau = T\,u/D \ ,$$



Circurating Water Channel

Type	Vertical Circulating Water Channel
Flow velocity	0.01~2.0 m/sec
Velocity uniformity	± 3 %
Turbulence intencity	2 %
Standing wave	± 1.5mm
Surging	± 1.5mm
Nozzle contraction	5.06
Test section	0.2X0.2X1.2(m)
Impeller	250mm Dia

Circulating Water Channel
(National Aerospace Laboratory)

FIG. 1—Top, side, and end views of the Vertical Circulating Water Channel (VCWC) used in tests of enclosure models. A motor-driven impeller causes water to flow around to the left (side view) through baffles leading into the test section where the models are mounted. Capillary tubes are placed upstream of the models to introduce dye streamers or hydrogen bubbles which provide visible indication of the flow patterns around the models.

where T = time required to flush the enclosure model (see discussion in Section 3.2)

D = distance span across the enclosure in the direction of flow (80 mm in the present case)

u = flow velocity .

Figure 2 is a plot of measured values of τ as a function of Re and it is seen that τ is not affected above about Re = 3×10^4. Accordingly, our flow visualization tests were made near this region, but not beyond due to the need to keep flow velocities low enough for easy visual observation of flow patterns.

Flow patterns inside and outside of the telescope enclosure models were visually indicated by the paths traced out by streamers of dye or hydrogen bubbles released upstream of the models. All of the experiments were recorded on video tape by means of cameras mounted in viewing positions above the models (looking down) and to the side (viewing perpendicular to the water flow).

2.2 *The Telescope Enclosure Models*

The telescope enclosure models were mounted on a flat plate and were made to a 1:500 scale which limited the blockage factor in the test section of the tunnel a maximum of ~ 15%. At 15%, the blockage factor is large enough to produce small changes in flow velocities compared to those with no model present; however, our purpose was to compare differences in flow patterns and relative flushing times which would not be greatly affected by small velocity changes, particularly for our situation involving low velocities with smooth outer surfaces on the models. Provisions were made to rotate the models

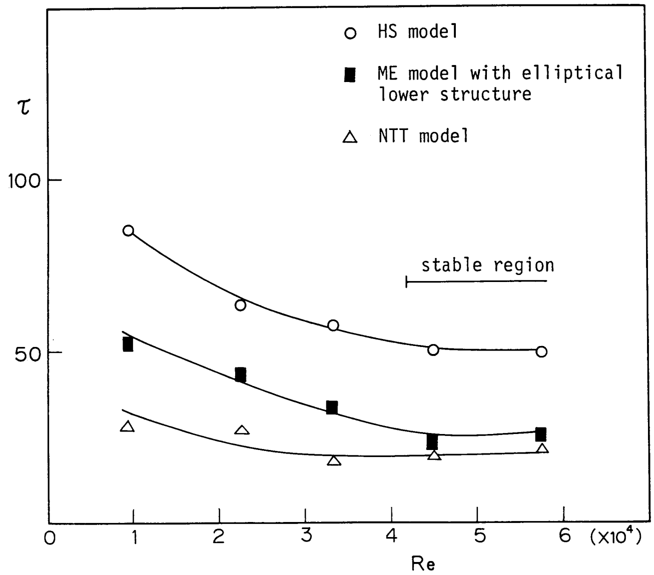


FIG. 2—Dimensionless time parameter (see text) versus Reynolds Number (Re). This plot indicates the beginning of the region where flushing conditions in the models become independent of Re which is the desired region for conducting flow visualization tests.

manually to various azimuth angles which simulated the normal variability of the wind direction.

Top and side views of the three basic models used are shown in Figure 3. The basic styles are:

(a) The traditional hemispherical dome, but with more air vents than are customarily used. We use the identifier "HS" for this model in this paper. An optional feature was the ability to install "sidewalls" on either side of the telescope, effectively isolating it from the rest of the enclosed hemispherical volume.

(b) A "straight-sided trapezoidal" building with many of the features of the ESO 3.5-m NTT enclosure. Our model differs from the NTT in having side vents in addition to vents at the rear of the telescope; however, we used the NTT name to identify this model.

(c) A modified cylindrical building which we will call the "Modified Ellipse" or "ME" style because it is not a simple cylindrical form. One ME option used an elliptical base on which the upper rotating portion on the building was mounted. The base could be oriented, independent of the upper building, with either axis of the ellipse in line with the flow. But the elliptical base major axis was always oriented to the flow direction in the water-tunnel test, since the wind direction at the site is mainly east-west. The upper part of the building also has an elliptical shape (viewed from the top) modified by rectangular projections that provide for vents in the sidewalls near the front slit and the rear vent openings. Additional venting is provided at the rear of the telescope similar to the NTT style.

Provisions were made to add porous screens in the lower part of the entrance slit to simulate the effect of a windscreen. We could also add a horizontal plate extending out from the model below the entrance slit to act as a flow divider at various heights above the ground level. Due to the different model shapes, it was impractical to make the vent areas identical, especially as the models were rotated in the flow stream. Instead, we created vents in the models to simulate those that might be achieved in a practical structure. Thus, our results are intended to be useful in comparing telescope enclosure styles. The locations of the vent areas are shown in Figure 3 and the fraction of the vent areas over the surface area of the models are listed below for general information.

HS Style: 33%
NTT Style: 40%
ME Style: 35%

3. Results and Discussion

Many hours of video tapes were made of the various tests. We can only summarize briefly the complex effects that are visually evident from the tapes. We will comment on two basic themes:

A. The flow past the outside of the enclosure which was indicated by the dye and bubble injection stream-

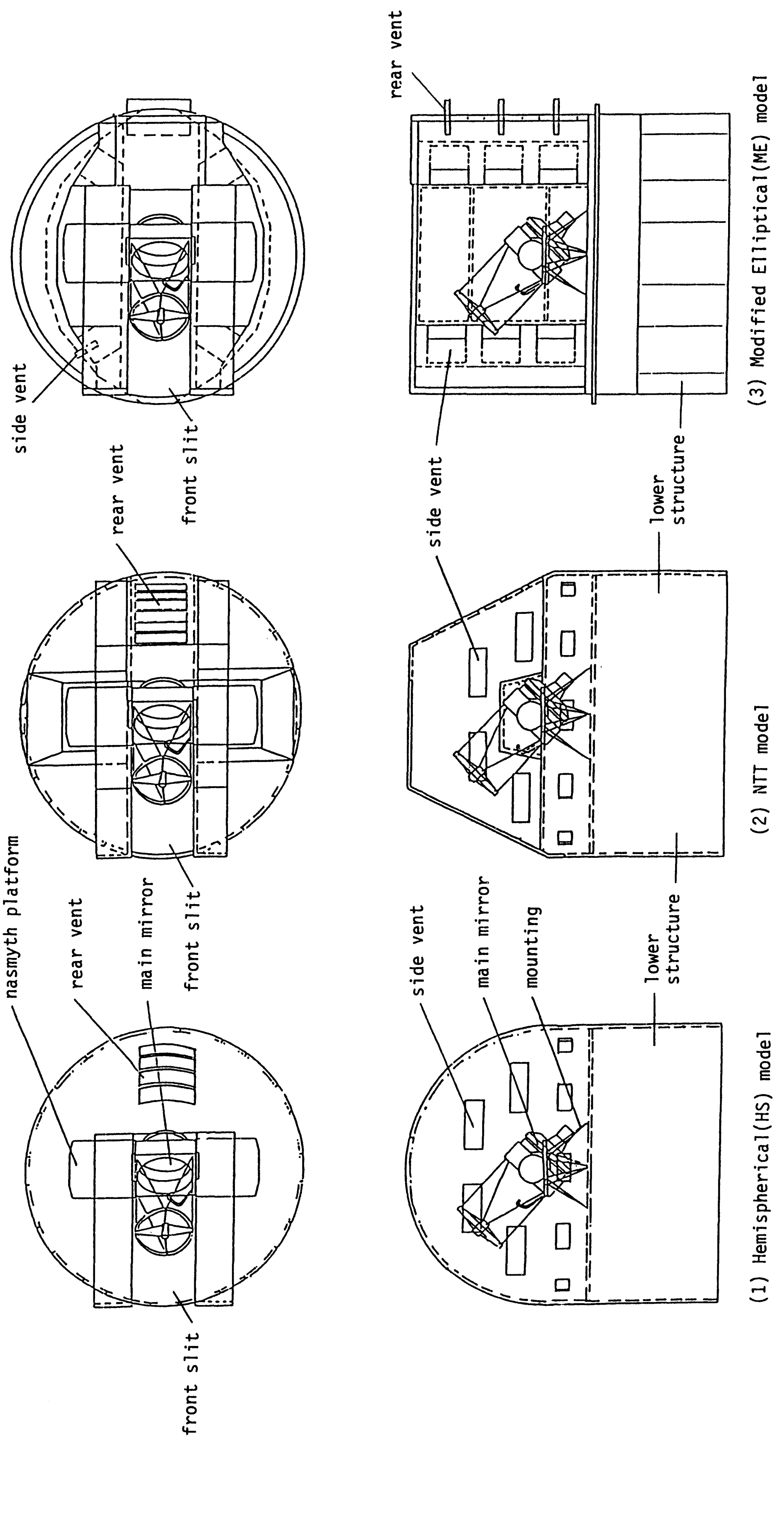


FIG. 3–Top and side views of the three telescope enclosure models tested in the present experiment. Descriptions of the models are given in the text.

lines, and

B. The efficiency of flow through the enclosure measured in terms of the "flushing time".

In the commentary to follow, we will tend to use the terms "flow" and "air" interchangeably because we are extrapolating the water-flow test results to the airflow at a real telescope enclosure. Our comments, of course, are based on the water-tunnel tests.

3.1 *Flow Past the Exterior of the Enclosure—The "Uplift Effect"*

If the ground is more or less flat, and flow is moving parallel to the ground, any obstacle in the flow stream will obviously cause it to divide in order to flow past the obstacle. In general, the air layer nearest the ground is most likely to be thermally disturbed and also to involve dust, so for telescope enclosures, one would prefer the air stream in the ground boundary layer to remain parallel to the ground and not rise up into the light path of the telescope. Our water-tunnel tests, and those done by Siegmund et al., showed that flow streams typically do, in fact, divide in such a way that one part flows around an obstacle more or less horizontally as we would like, but another part flows up and over the top. We call this the "uplift effect". Pictures of the three models are shown in Figure 4 with bubble streamers flowing past that clearly illustrate the uplift effect. The stagnation point between the horizontal and the uplifted flow should, if possible, be well above the height of the ground boundary layer. Otherwise, even though the telescope may be mounted higher than the height of the boundary layer, the "up-and-over" part of the flow stream may still be able to carry disturbed air into the light path. To decide whether this will happen at a given telescope site, one needs to know the typical height of the ground boundary layer which, unfortunately, depends very much on the local conditions at the site and must be measured. Such measurements for the JNLT site on Mauna Kea were made in 1987 by Ando et al. 1989 in which the microthermal activities were measured at several heights and the height of the ground boundary layer was found to be about 13 m on average. However, the enclosure style also plays a part as indicated in the results shown in Figure 5.

Figure 5 shows a dimensionless parameter (h/D) which is a measure of the height of the stagnation point of the approaching flow (h) plotted against Re for the different models with windscreens of 64% porosity. In this experiment the slit was always oriented directly into the flow direction. Data for the ME style are shown for an elliptical base and for a traditional cylindrical base. Notably, the ME style with the elliptical base is superior to the one with a cylindrical base and also to the other two enclosure styles. Changing the degree or type of porosity in the windscreen had no significant effect on the measured h/D values as shown in Figure 6.

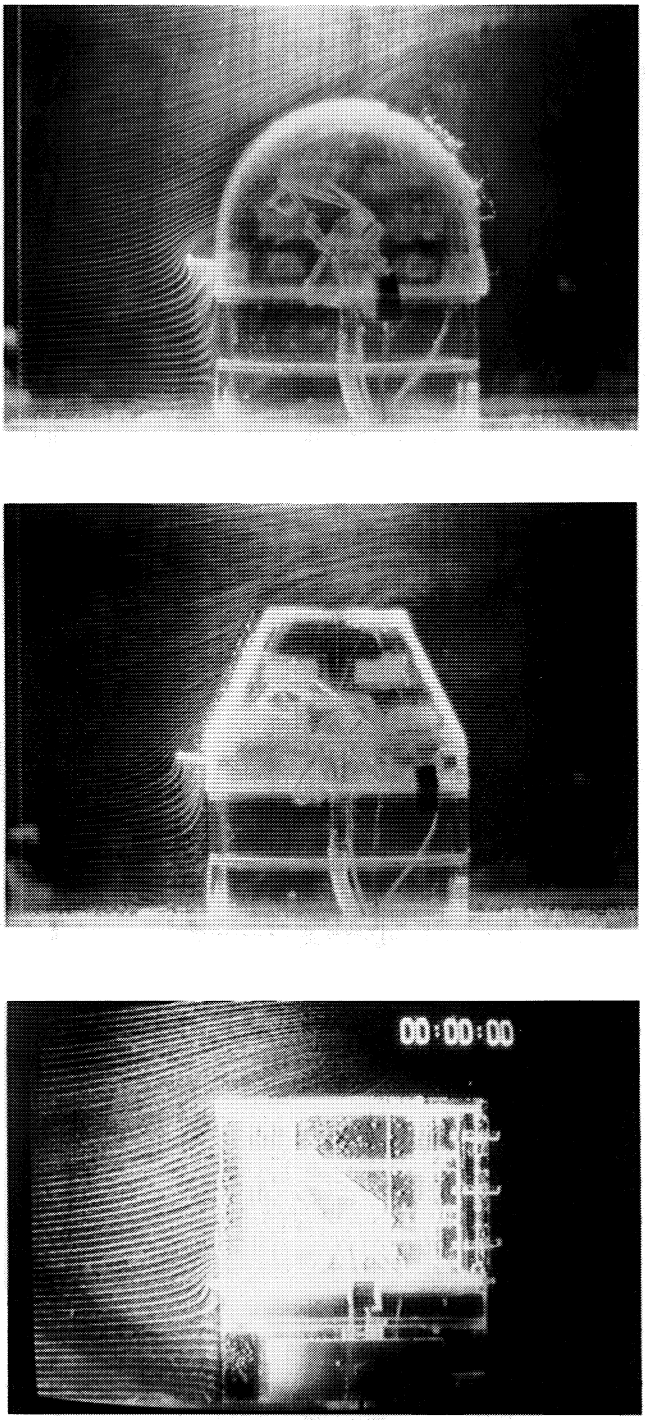


FIG. 4–Photographs of the three models with bubble streamers indicating the flow pattern past the enclosures. Notably, all three exhibit an "uplift" component of flow that originates below the viewing slit which could carry thermally disturbed ground-layer air into the light path. The telescope enclosure should be tall enough to keep the separation point of the uplifted flow above the ground layer. It is evident that the flat-roofed model causes less uplifting than the other two.

If air is moving horizontally, horizontal surfaces cause the least disturbance. This statement seems to say the obvious, but it is another way to say that an enclosure with

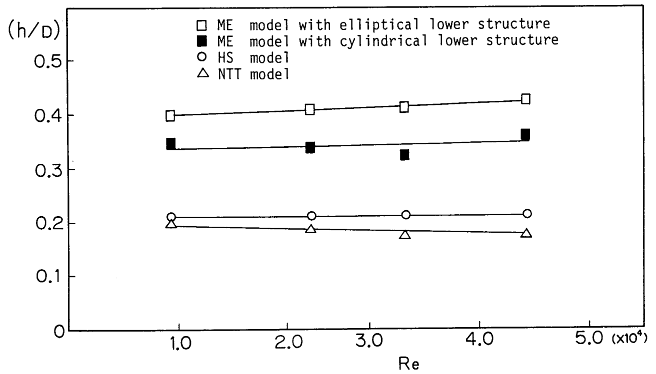


FIG. 5–A dimensionless parameter (h/D) containing the height above ground of the separation point of the "uplift" flow from the original main stream flow direction plotted versus the Reynolds Number. All models have a windscreen of 64% porosity at the lower part of the slit. Larger values of h/D are desirable, and it is evident that the ME style enclosure (see text for description) is superior to the other two styles tested. The ME style on an elliptical base is superior to one on a cylindrical base.

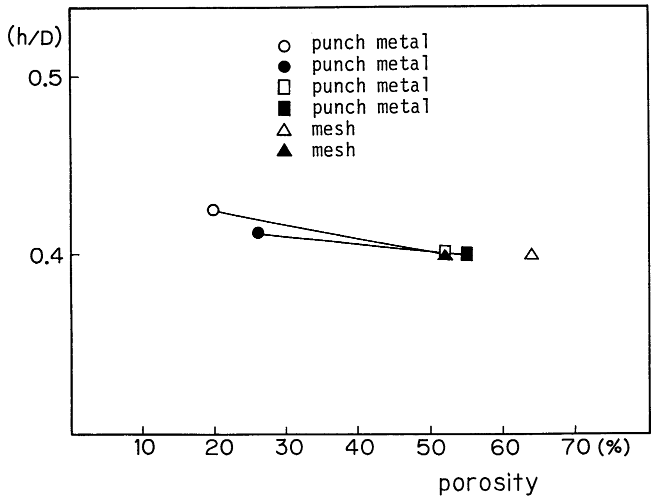


FIG. 6– Dimensionless parameter h/D plotted versus percentage of porosity in windscreen simulators placed into the models. It is evident that only small effects occur as the porosity is increased.

a flat roof (the ME style in these tests) causes less uplifting of the air flowing past than does one with a pitched roof or a hemispherical dome roof. This also agrees with the findings of Siegmund et al. in which they found less uplift for enclosure styles with flat or near-flat roofs.

To gain further insight into the effect of an "overhang", we attached a horizontal flow guiding vane, or plate, below the front entrance slit. In Figure 7 the dimensionless parameter, h/D, is plotted against a similar dimensionless parameter that involves the height above ground (h') of the horizontal flow guiding vane. The idea for the guiding vane occurred after we realized the need for keeping the uplifted flow stagnation point as high above the ground as possible. Implementation of the guiding vane on the enclosure would take the form of a simple

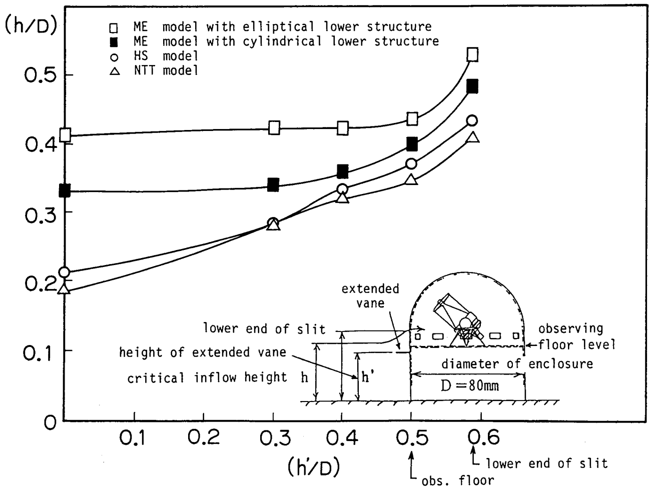


FIG. 7–Dimensionless parameter h/D plotted versus a similar parameter containing the positional height of a horizontal, flow-dividing plate attached to the models at various locations below the viewing slit. The ME style enclosure, which has a built-in "overhang" that acts like a horizontal flow divider, does not benefit from the plate until it is located at the bottom of the viewing slit. The other two models do derive benefit from the horizontal plate, approaching the performance of the ME model as the plate is positioned nearer to the bottom of the viewing slit. These results show the beneficial effect of a horizontal flow divider extending from the enclosure.

horizontal structure attached to the rotating part of the building below the viewing slit. The vane conceivably could be extended completely around the building for maximum effect. It is seen from Figure 7 that the guiding vane does affect the value for h' rather significantly for the HS and NTT models but has less effect on the ME style until the plate positional height approaches the lower level of the entrance slit. This is due to the fact that the ME style has the "overhang" and the others do not. These results argue strongly for either an "overhang" feature in the enclosure or its equivalent in the form of a horizontal flow divider extending horizontally outward from the building. The best location, based on our tests, appears to be just below the opening for the viewing slit (i.e., as high as possible without interfering with telescope observations).

3.2 *Flow Inside the Enclosure—Flushing Effects*

With a continuous wind flowing past, an enclosure often has some of the characteristics of a directional flow nozzle. Air enters the enclosure, encounters some resistance, and circulates through it in some manner, then makes an exit in a direction defined largely by the enclosure shape and the interior obstructions. Moving air has momentum which helps to predict how it will pass through the enclosure. Airflow occurs in the direction of reduced pressures. Obstacles to flow (e.g., the telescope) cause the flow to become turbulent and can create downstream vortices. These are general observations that we have seen frequently in the water-tunnel tests. In general, one may say that the most rapid flushing will occur when air flows straight through with no turbulence, but this rarely occurs either in practice or in testing. We were, therefore, interested in the efficiency of flushing that is likely to occur.

Measurements were made of the time required for the flow to flush away a small volume of dye injected inside the enclosure model. This "flushing time" was affected by the enclosure style, the orientation of the slit with respect to the flow stream, and auxiliary venting provisions. To minimize the subjective aspect of the measurements (i.e., different people had different estimates of when the enclosure was "clear" again), we averaged the findings of many observers. Figure 8 is a summary of these findings. In addition, we make a few general remarks below about observed flow behavior. The orientation of the slit opening is listed first beginning with 0° orientation which is when the slit opening faces directly into the flow.

0°—Air blows directly through the slit onto the telescope. Good ventilation will occur if air vents are placed at the rear of the enclosure to allow the air to escape without recirculating inside the building. Otherwise, flow will be turbulent inside the enclosure, finally escaping upward through the viewing slit. Since the slit is the largest opening, some provision for restricting the entering flow may be desirable. This is the traditional function of a "windscreen", which typically has the form of a shutter that is raised to fill the lower portion of the slit below the line of sight of the telescope. If the windscreen is solid, however, a region of low-pressure stagnation can form behind the screen and vortices may form in the flow stream. A better arrangement is to provide some "porosity" in the screen to allow some of the air to pass through in a manner similar to that for the NTT. We simulated windscreens with different degrees of porosity in some of our tests, but the small scale prevents us from drawing numerical conclusions from the data. It was evident that porous screens did restrict the flow and that porosity helped reduce the formation of vortices behind the screen.

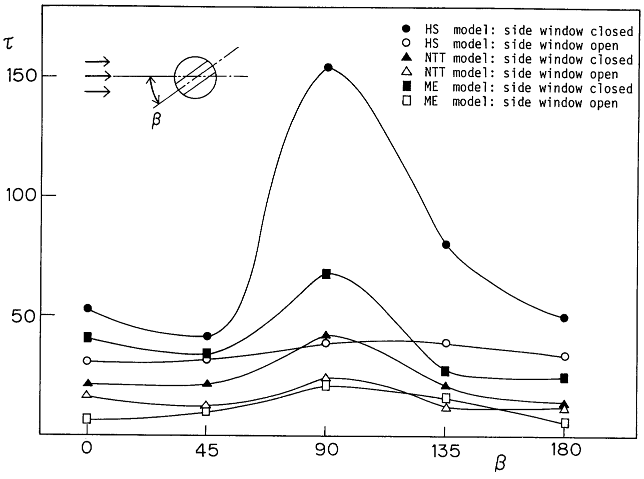


FIG. 8–Measured time to flush out a sudden dye injection from the interior of the enclosure model versus orientation angle β of the viewing slit to the flushing flow stream. These results relate to the ability of the wind to flush thermally disturbed air from the telescope enclosure. The benefit obtained from open vents (windows) in the sides of the enclosures is most pronounced for orientation angles near 90°.

45°—At this angle, air is literally forced to change direction and enter the building because the slit acts like a huge scoop facing into the flow stream. If the building is more or less circular and there are no major obstructions around the interior walls, the air will tend to circulate inside the building in vortex fashion with a region of stagnation near the center which is approximately where the telescope primary mirror was located in our tests. Eventually, air will flush out through the upper slit or side vents in the building (if provided), but this circular interior flow is not desirable because it causes considerable buffeting of the telescope while providing poor overall flushing of the building. However, if vertical "sidewalls" are installed on both sides of the telescope and vents are provided at the rear in the style of the NTT, air entering the slit is directed through the flow channel defined by the sidewalls and escapes through the rear vents. Good flushing action occurs around the telescope. One must also be concerned about the regions of the building that are effectively isolated by the "sidewalls" and provide enough ventilation to prevent air from these regions "leaking" into the light path. Based on our tests, we would recommend the incorporation of sidewalls in the enclosure, regardless of its exterior shape. In this regard, we apparently agree with the designers of the MMT and NTT buildings.

90°—This is a condition of potential stagnation inside the enclosure for all styles that we tested if the viewing slit and rear vents are the only means of ventilation. Flow pressure is equal at both places so there is no tendency for air to enter the building. Vents on the upstream and downstream sides of the building are necessary to encourage flushing flow past the telescope. This is more complicated if sidewalls have been installed, but one of the enclosure styles, the ME style, was equipped with sidewall vents near the slit and rear vents. We found significant improvement in flushing at the telescope when the upstream vent near the slit and the downstream vent diagonally opposite were opened. If the rear vents were already opened, opening of the downstream side vent was not necessary to obtain good flushing. Flow entering through the side vent collided with the opposing sidewall and was forced to flow in both directions 90° to its original path. One of these components went out the slit, the other past the telescope to achieve the desired ventilation. This feature is an argument favoring the ME style.

135° and 180°—In general, flushing was reasonably good for both of these situations if the rear vents were open and poor if they were not. When rear vents were open, it was noticeable that flow into the models was likely to pass through and out the viewing slit with very little tendency to circulate in turbulent fashion around inside the enclosure. The slit (the exit) obviously had more area for flow passage than the rear vents (the entrance) which leads us to the conclusion that it is desirable to have more area for the air to leave the enclosure than to enter it. Our data do not provide enough information to establish a preferred ratio of areas, but we again see the wisdom of having a windscreen at the slit, possibly with adjustable porosity, and the ability to regulate the opening of the rear vents.

A rooftop vent on the downwind side of a pitched roof is in a low-pressure region which will cause the interior of an enclosure to be ventilated by flow from lower levels. This fact is well-known to building architects. The telescope slit must open all the way to the top of the building and frequently functions like a rooftop vent. When this occurs, air from inside the enclosure will be drawn out through the slit and air from near the ground is likely to be drawn in to replace it. If there are no other vents in the building, a condition of stagnation and thermal turbulence is likely to occur as our tests showed. Vent openings, well above the ground boundary layer, are desirable so that the telescope is flushed with "thermally clean" air under these conditions.

4. Conclusions and Recommendations

Our studies lead us to make the following statements which may be regarded as recommendations for designing future enclosures or comments about the consequences.

A. The wind should be allowed to flow smoothly and straightforwardly through the telescope enclosure. It is desirable to avoid excessive turbulence and stagnation which can be accomplished by proper usage of a porous windscreen, sidewalls at the telescope, and an adequate number of vents.

B. The turbulent boundary layer should be prevented from entering the enclosure. The enclosure height above the ground is critical and will be different for different enclosure styles. A flat roof and a horizontal vane below the entrance slit are helpful features.

C. Provision for vents in the sidewalls of the enclosure are useful for obtaining ventilation of the telescope when the slit is oriented orthogonal to the wind. Without such vents, stagnation conditions will exist in the enclosure.

D. With greater ventilation, there is a stronger possibility of dust at the telescope. Provisions for cleaning the optics will be required.

E. Ventilation provisions will mean greater maintenance and operating complexity, especially until experience in the best arrangements is obtained. There is a slightly greater risk of damage to the telescope in case of vent system failure which should be guarded against.

It should be noted that some sites, such as Mauna Kea, are significantly more windy than others. For such locations, greater concern will exist about the possibility of wind buffeting on the telescope and its effect on telescope pointing. Provisions for limiting the effect on the telescope, such as a porous windscreen and adjustable vent louvers, are likely to be necessary in order to retain the beneficial effect on the images produced by good ventilation without losing that gain to excessive shaking of the telescope.

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