Towards an optimal enclosure for the future large telescope in the ORM

G. Pescador, J. Castro

G. Winter, P. Cuesta

ABSTRACT

The preservation of the excellent image quality of the "Roque de los Muchachos" Observatory (ORM) is one of the most important design criteria for the enclosure of the future large telescope. Additionally, the cost of a large telescope and its instrumentation is so high that it would be regrettable if its own enclosure deteriorates the telescope performance for astronomical observations.

For this reasons, the IAC and CEANI are conducting an aero and thermo-dynamical study based on numerical simulations, attempting to minimize the seeing degradation due to factors within the control of the designers. This paper will firstly describe the general concept of the enclosure we are planning for the future "Gran Telescopio Canarias" (GTC) and secondly the set of three dimensional simulations we are conducting to evaluate the effect on seeing of four different enclosure topologies located at two possible sites.

Keywords: Large telescope **-** dome seeing **-** telescope enclosure **-** thermal turbulence

1. INTRODUCTION

The performance of the telescope is extremely dependent on the seeing, so even a slight local seeing degradation has to be carefully prevented. This subject has become one of the most interesting challenges in the last decade or so and many efforts have been made attempting to understand and solve the dome seeing problem. However, the studies carried out by different projects have come to different solutions, and the results obtained by wind tunnel tests are not conclusive.

The environmental conditions of the site: wind velocities and directions, temperatures, the particularities of the topography of each place and the physical characteristics of the telescope and its instrumentation, among others, imply different solutions for each telescope. That is why, in attempting to anticipate solutions we will use numerical simulations as a tool to evaluate the best site for the telescope and the best geometry for its protection. Of course, we are aware that strenuous efforts will have to be done in optimising the geometry selected.

About 100 different simulations are foreseeable for the study of the future large telescope enclosure. Initially the influence of other nearby installations on the telescope performance and vice-versa will be studied. Furthermore the influence of the specific characteristics of the topography of two sites pre-selected for the erection of the GTC will also be studied. The paper will initially describe the criteria we will follow to design the enclosure (whichever the geometry) and later on will discuss the phenomena to be studied, the method developed for calculation, the parameters to be considered in the evaluation of the results and the general plan of the simulations we are conducting.

2. DESCRIPTION OF THE POSSIBLE SITES

Telescopio Canarias." The Observatory is located at about 2400 m over the sea level in the island of La Palma, in the Canary Islands, Spain.

Site number 1 is at 2300m, in a slope between the Nordical Optical Telescope (NOT) and the Italian National Telescope (GALILEO). Site number 2 is 100 m below the first one, on a flatter part of the observatory, at about 400m from the Italian telescope. Fig. 1 shows the two site locations.

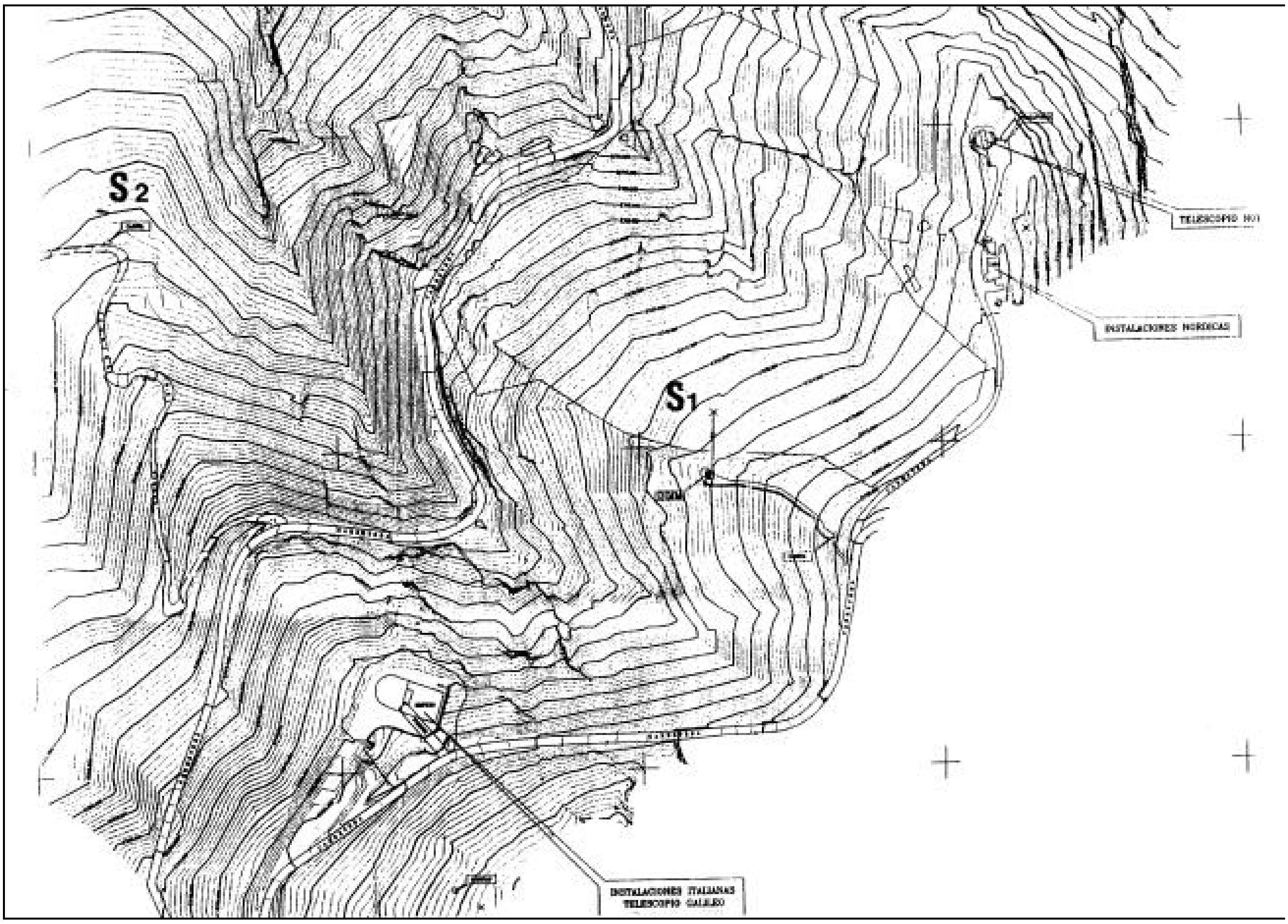

Fig. 1. Location of the two sites preselected for the GTC

3. TELESCOPE ENCLOSURE DESIGN CRITERIA

The ideal situation for observation, from the point of view of seeing degradation, would be to have the telescope completely exposed to ambient air, meaning no enclosure at all. But unfortunately that premise is not possible as the telescope needs protection, when not in operation and when in operation. When not in operation, the enclosure has to protect the telescope from adverse weather conditions, such as: snow, rain or dust. And when in operation, against wind to avoid possible vibration of the telescope structure or the primary mirror itself.

The performance of any ground based telescope, especially a large one, is extremely dependent on seeing. The seeing measurements in the ORM have shown values of 0.2 arcseconds and so, strenuous efforts will have to be done to minimize the seeing contribution due to the enclosure. The aim is to have negligible effects on the seeing conditions, then, the dome seeing, S_D, should be less than 0,03 arcseconds.

In order to achieve that aim, the enclosure must maintain thermal equilibrium during observations, the difference in temperature between the telescope and the outside ambient air must be minimized, within 1°C.

3.1 Design premises

The GTC enclosure will be designed considering, among others, the following premises:

• The enclosure will be designed to prevent air from the turbulent surface layer entering or flowing over the telescope chamber. The telescope chamber height above the ground is critical and will be different for different enclosure styles. A topology which does not increase the upstream thickness of the turbulent surface layer (the "up-lift effect") is desirable since this reduces the enclosure height and cost.

• The enclosure will incorporate controllable vents for maximum natural ventilation during observations. The wind will be allowed to flow smoothly and with little resistance through the enclosure, avoiding turbulence and stagnation. The control of the vent area is important, depending on the flow direction and on the wind velocity, additionally this will help to prevent dust from entering the enclosure when strong winds appear, and to avoid shaking of the telescope structure.

• Other provisions for limiting the wind force effects on the telescope, such as a porous windscreen, are likely to be necessary in order to retain the beneficial effect on the images produced by good ventilation, without losing the gain due to excessive shaking of the telescope structure. An efficient wind blind to shield the telescope from wind buffeting will be provided.

• It has been proven, that at moderate wind speeds, the ventilation rate associated with even a small vent area is much larger than the capacity of an active ventilation system, nevertheless air forced ventilation should be provided to help the air flushing during observation when the wind speed is not high enough, e.g. less than 4m/s outside the dome.

• The thermal behaviour of the dome, specially during the observing time, will depend mostly on the low thermal mass of the structure. Reducing the weight of the structure is the most direct method of minimizing this heat load. Also the geometry and the design of the structure itself will have an important effect on reducing the thermal inertia. The size of the telescope chamber must be the minimum necessary to reduce the air volume to be renewed; Additionally, the internal and external surfaces of the dome will have to be coated with a low emissivity paint, so that they can be insulated against solar heating and also to prevent subcooling by radiation to the cold sky during the night. The enclosure floor will insulate the telescope chamber thermally from the enclosure base. It will also reduce the air volume inside the telescope chamber to a minimum. For the time not used for observations, solar heating is normally a prime contributor to thermal problems, thus insulation, and air conditioning during the day will be provided.

• The heat generating equipment inside the telescope chamber will be kept to the absolute minimum: the control room, the workshops and the astronomers facilities will be in the service building. The enclosure will incorporate cooling systems provided to remove heat from essential equipment, instruments and from the telescope oil support system. The heat removed will be expelled to the outside well away from the telescope, taking care not to disturb other telescope observations.

But there are also a lot of considerations which will have to be kept in mind to achieve a successful telescope enclosure design: initial cost, operational costs, ease of preventing water and dust leaks, a system to remove the ice from near the dome shutter, and provisions for telescope maintenance and support are also important issues. An effective air removal system will be studied to keep the optics free of dust. The geometry will also depend on the operations one wants to do inside the telescope chamber. e.g.. recoating process, secondary changes, instrument mounting in the different focal stations, etc.(these imply the use of lifts, cranes, platforms etc.). These must all be considered when choosing a telescope enclosure topology.

3.2 Design compromises

Designing an enclosure for a large telescope is a compromise. Among others, we have contradictory issues due to different kind of needs:

- The temperature in the light path and around the telescope must be homogeneous with the outside temperature, in order to keep the effects of induced turbulence to an absolute minimum. However the telescope facilities are a continuous heat generation source, e.g. the hydrostatic bearing plant, the motors, etc....

- The enclosure must provide natural ventilation, to continuously renew the air inside the telescope chamber. However, the wind must be controlled to avoid vibrations of the telescope structure or even of the primary mirror. The vents, if not well designed, could also cause mechanical turbulence.

- The enclosure topology should be completely symmetric, with a smooth geometry to avoid turbulence. It must be as small as possible to reduce the air volume to be renewed and high enough to be well away from the surface layer. However, these premises sometimes complicate other needs, such as telescope maintenance provisions and the last one increase the cost.

- The roof should be flat to avoid streamlines going up into the lightpath of the telescope. However the snow would cause more problems in a flat roof.

- Insulation and cooling systems must be provided, but in the case of a large telescope and with the premise of accurate control of the temperature, the cost of an efficient temperature control system could be very high.

Designing an efficient enclosure for a large telescope is not a trivial problem. Of course one option could be to have a wide range of possibilities open and to design all the refrigeration equipment to be 100% efficient, but this is costly and even risky and it is better to invest time money and personal efforts from the beginning, during the conceptual design. That is why we are conducting this study.

4. THE TURBULENCE PROBLEM

Obstacles to the flow cause turbulence. When the wind approaches the enclosure, it encounters some resistance and continues flowing through and around the enclosure. The air which goes inside the telescope chamber, exits in different directions and joins the streamlines which had gone around the external walls, and continues flowing in the downwind direction. The most rapid flushing, without turbulence, would occur in the case of no obstacles, when the air could flow straight through. Unfortunately, this is impossible because of the presence of the enclosure, the telescope, the instrumentation and the additional devices, which will cause the air flow to become turbulent. It is logical that the enclosure geometry has important effects on the air flow behaviour, and so, the enclosure design has to be carried out to minimise this effect.

4. 1 Thermal turbulence

Thermal differences cause the air to move following the principle of convection. The refractive index of air depends on temperature, and so, movement of air masses at different temperatures in the light path cause image degradation. The vertical mixing of ambient air in the telescope chamber becomes a more serious problem as the size of the telescope chamber increases and constrains on enclosure induced image degradation become more stringent.

But the problem is not only a matter of heat sources. Cooling could be as bad as heating. The main source of telescope enclosure induced image degradation is the production of air pockets either warmer or cooler than ambient. In an ideal telescope enclosure, the air inside the telescope chamber is continually replaced by ambient air before it has the opportunity to be warmed or cooled. It is also recommended that the same limits should be placed on the power of the heat sinks as is placed on heat sources.

Since the aim is to equalise the air temperature, we should say homogenization instead of refrigeration.

4.2 Mechanical turbulence

Turbulent air with a homogenous temperature does not cause image degradation, but it is still a source of many problems:

- The turbulence could cause vibrations of the telescope tube.

- The turbulent air can easily transport dust inside the telescope chamber, and could make this dust to get onto the optics.

- The turbulence can increase the surface layer, and specially when the telescope is pointing downwind, the vertical temperature gradient on the outside of the enclosure can also become an important concern and the efforts to position the pier above the surface layer will be jeopardized.

- Additionally, the mechanical turbulence enhances the problem of thermal turbulence because of two reasons: firstly it causes the air to stay longer inside the dome without being renewed (its temperature rises, due to the presence of heat generation sources, and produces air pockets), and secondly it helps in the mixing of air pockets at different temperatures.

As an approximation we could say that the seeing degradation is linearly proportional to the heat dissipation and the mixing length[1], which means that the larger the telescope is, the bigger the problem.

4.3 The "Up-Lift Effect"

If the ground is more or less flat, and the air 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 thermaly disturbed and also to carry dust, so for a telescope enclosure, one would prefer the air stream in the ground boundary layer to remain parallel to the ground and not rise up into the lightpath of the telescope. Water tunnel tests carried out by the JNLT project[2] and those done by Siegmund (et al)[3] showed that flow streams typically divide into one part that flows around an obstacle more or less horizontally, and another part that flows up and over the top. This has been called the "up-lift effect."

To decide wether this will happen at a given telescope site, we need to know the typical height of the ground boundary layer. Information on this item is available for various different locations at the ORM and the results have being very positive, showing that the surface layer is very near the ground, at about 6m over it. The observations made by the telescopes already installed in the observatory have confirmed those results and proven their reliability. Nevertheless we are aware that this height depends very much upon the local conditions of a specific site and it varies for different meteorological situations. We will start measurements of the surface layer at the end of this year.

5. THE SIMULATIONS

We have structured our study in 4 phases. Phase 1 includes the selection of the model for the numerical simulations, as well as all the work involve with the selection of the atmospheric scenarios (meteorological study and topographic study). With phases 2 and 3 we attempt to find answers to the following questions: what effects do prominent topographical features have at the proposed sites under a variety of environmental scenarios.

The set of simulations proposed on phase 2 will provide information on the thickness and intensity of turbulent boundary layers over the entire region covered by the topographical study, which include both possible sites, for a wide variety of wind conditions (including different speeds and directions) and the corresponding temperature stratifications.

These simulations will also provide information on the possible effects caused among the different observatories already installed in that area of the ORM on the GTC facilities and viceversa. These possible effects will be studied from the turbulence point of view, not only the mechanical turbulence, but also the thermal turbulence that any telescope installation could cause as a heat generator.

The set of simulations proposed on phase 3 will give us information to decide on the optimal geometry to be considered for the GTC enclosure.

5.1 The model

After studying various alternatives, the model selected for the numerical simulation is the Reynolds Stress Method (RSM)[4]. The RSM accounts for non-local effects by solving differential transport equations for the Reynolds stresses. In three-dimensional flows, all (six) components of the Reynolds-stress tensor are finite and hence the complete model involves the solution of a differential transport equation for each, together with an additional one for a turbulence length-scale related quantity. This model has also been modified to incorporate atmospherical stratification.

The ability to abandon the cumbersome wall-reflections term without compromising the validity of the complete closure model has been viewed as an important prerequisite to the wider acceptance and use of Reynolds-Stress-transport-models for practical engineering calculations. Speziale, Sarkar & Garski proposed a model (SSG)[5] for the complete pressure strain correlations, which differs form the "standard one" in being quadratic in the Re-stresses and , as such, potentially capable of representing the complex interactions between the mean flow and the turbulence fields but also applicable without wall-reflections terms.

Within the different RSM models available, we have chosen the SSG non linear model mainly regarding the following:

- The fact that this model considers the anisotropic characteristics of the normal strains. This is of crucial importance for the correct representation of the shield strains generated.

- The ability to incorporate terms of Reynolds strains generated due to heat flows coming from stable and non-stable temperature stratifications.

- Better performance for the representation of complex interactions between the main flow and the turbulent fields.

- No need to use the wall-damping terms present in the pressure-strain term to account for wall-proximity effects.

- Very good results demonstrated in predicting profiles of the atmospheric boundary layer.

- Very accurate correlations between stress and strains which contributes to the Reynolds tensor.

5.2 The selection of the scenarios

5.2.1 The topography

The topographic features are absolutely necessary to be considered

To obtain valid results, from the simulations, they have to be carried out in three dimensions with high resolution and accurate topographical representation of the sites. For this reason we have done a strong effort to accurately obtain the topographical features in a wide region including the observatory (ORM) and its surroundings. This region includes an area roughly 5 kilometres in extent north-south by 4 kilometres in extent east-west. The rectangle extends from the preselected sites 1 km to the south, to include the Caldera due to serious concerns about its possible effects over site number 1 during south wind conditions; 4 km to the north, since the prevailing winds on the island are northerly; 2 km to the east and 2 km to the west.

The detailed topographic data for the sites including the nearest installation have being specially developed for this study due to the requirements of high accuracy on the representation for the simulations on short scales. Fig. 2 shows a view of the ORM region in its gridded form as used for the medium scale airflow simulations.

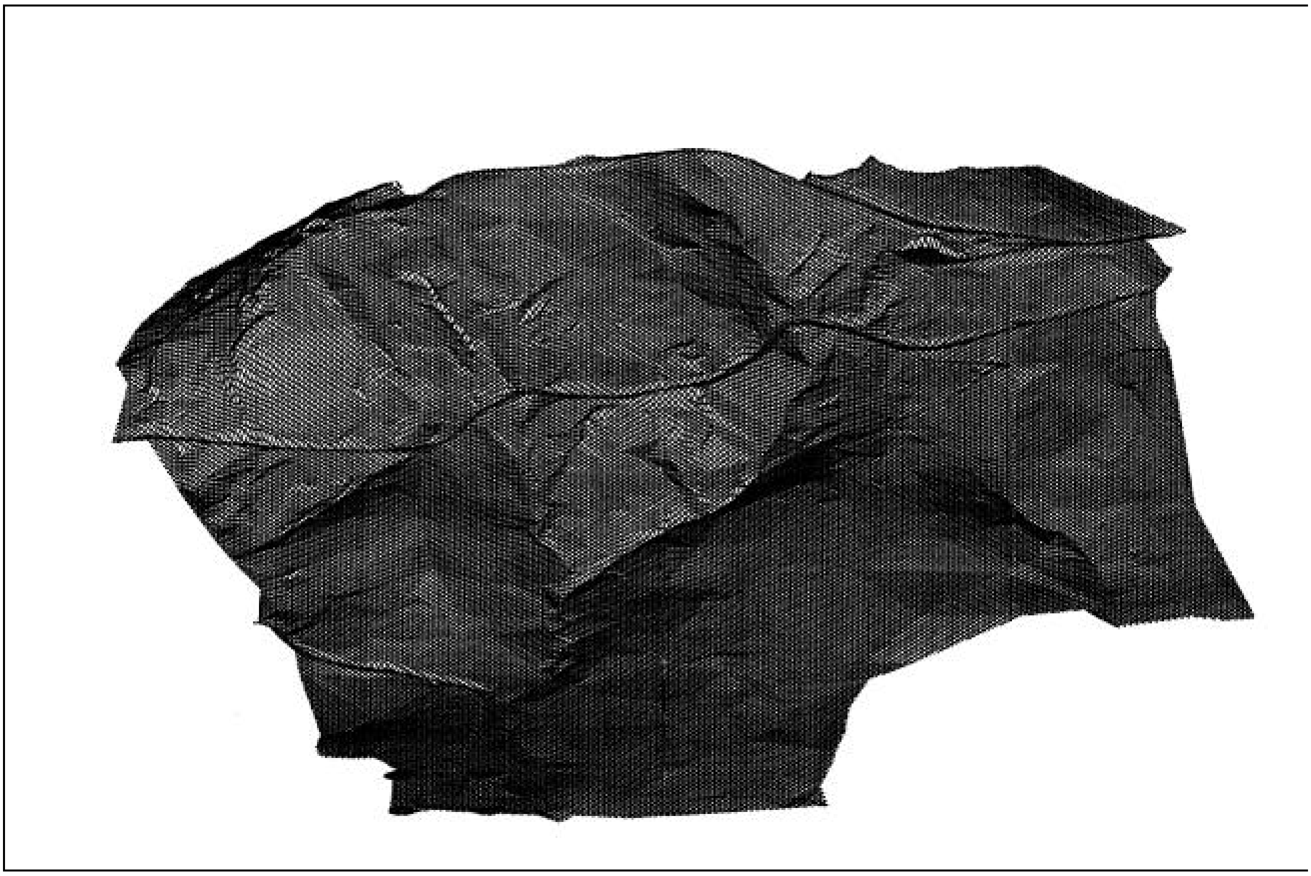

Fig. 2 Grid of the surface of the ORM area to be used in the simulations

5.2.2 The meteorological analysis

A exhaustive meteorological analysis has being done in order to define the simulation scenarios to represent at least the 85 % of the possible environmental situations. Any scenario is defined based on the wind conditions and the temperature stratification under those conditions.

Apart from the information obtained from our own meteorological towers positioned in each of the two pre-selected sites, we have completed this information with Radiosonde data obtained during the last 4 years in Tenerife by the Meteorological Institute. We have also used the database of other installations in the Observatory which have kindly offered their collaboration.

We have finally selected 10 different scenarios, most of them corresponding to the prevailing winds, which in La Palma are mainly North, North-east and North-west, and we will also considered the South wind, situation which occurs less than 5% of the time, but that is of great interest due to the presence of the Caldera.

We will also consider different thermal stratifications for each of the wind directions, these stratifications coming from the statistical meteorological analysis and the comparison between both, the conditions measured at the ORM and the free air conditions measured by the radiosonde.

5.3 The telescope enclosure topologies to be studied

Four enclosure topologies will be studied. There are not many different geometries for structural buildings to chose from, especially considering the basic parameters that any telescope enclosure should accomplish. The geometries selected are widely known and correspond to already working telescopes or projects in course.

The figures on the following page show the geometries of the enclosures considered for our study.

1. The first consists of a cylinder similar to the VLT enclosure solution[6]. The "dome" is a cylinder with a diameter slightly larger than the base, surrounded by wind vents and with a double slope roof to reduce the snow weight problem on the upper part of the shutter. The shutter consists in two gates in the form of an "L," which open laterally over an outer part of the cylinder. Fig. 3 on the following page, shows the basic scheme which defines this type of enclosure.

2. The second option is an octagonal building incorporating a trapezoidal rotating part. Fig. 4 shows this model. The shutter doors when opened form singular "wings" on the sides of the structure. The enclosure has also louvres on the back. This topology could be compared to that of the NTT[7] or Galileo enclosures.

3. The third is the Gemini project enclosure style[8]. The base of the building is a cylinder and the dome has a cylindrical part followed by an hemisphere. This solution propose a ventilation scheme based on doors on the cylindrical part of the rotating structure which open up and down in the exterior, changing the hemispherical geometry to a cylinder when these doors ar fully open for ventilation. In our study we have a slightly different solution which does not affect the exterior geometry when the vents are opened, more similar to the NOT solution. See Fig. 5

4. The fourth alternative to be considered corresponds to the Keck 10 m telescope enclosure[9]. This is the largest optical telescope in existence. The dome has the form of an sphere truncated at the base, and supported on a cylindrical building. The dome diameter is larger than the diameter of the base. In this case, the dome would incorporate vents. Fig. 6 shows a sketch of this geometry.

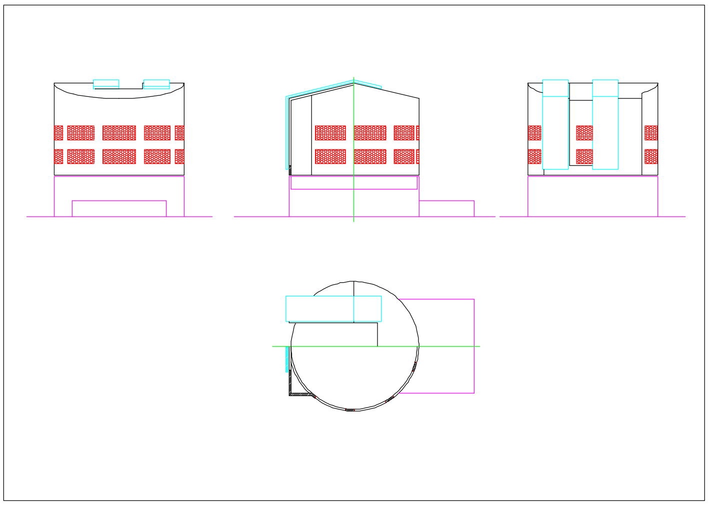

Fig. 3 Enclosure model number 1

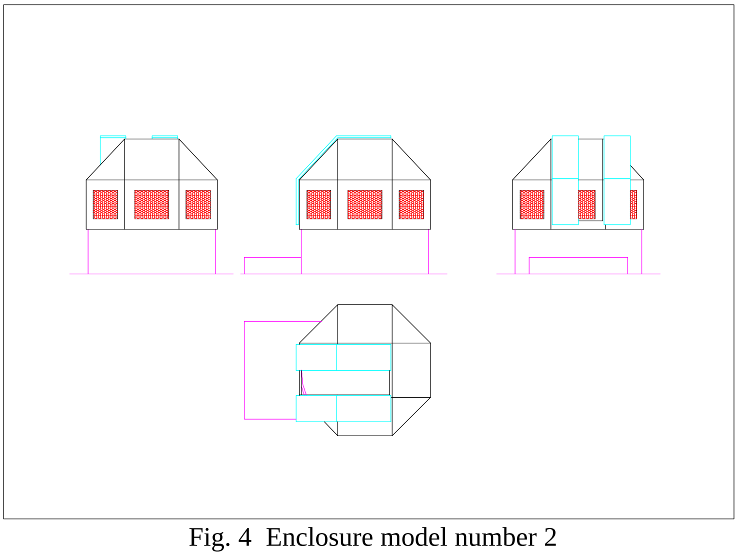

Fig. 4 Enclosure model number 2

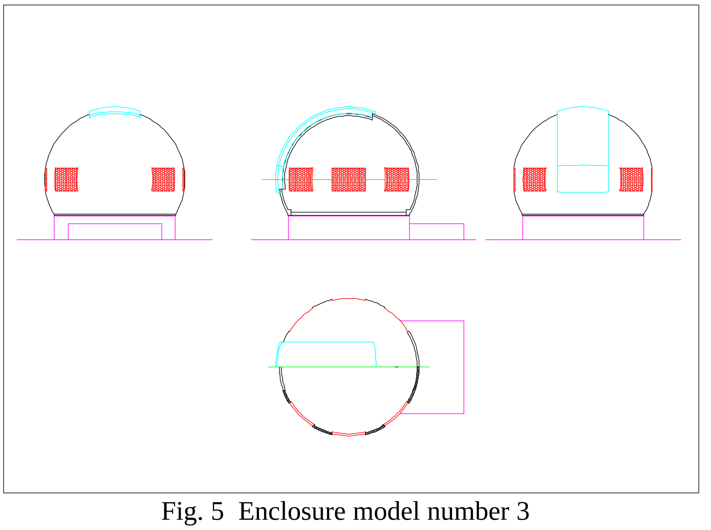

Fig. 5 Enclosure model number 3

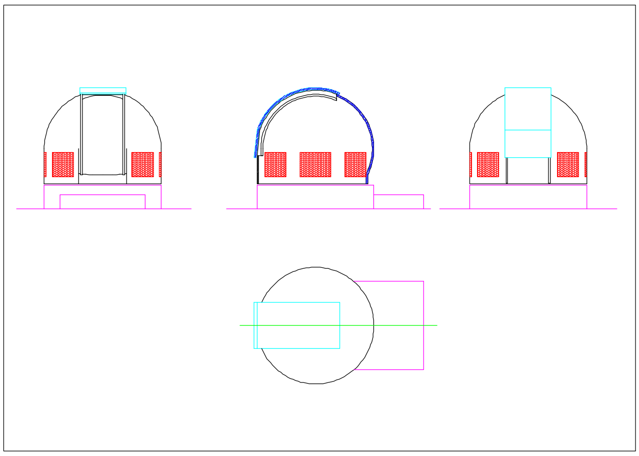

Fig. 6 Enclosure model number 4

6. CONCLUSIONS

It is worthwhile to study different alternatives for the enclosure topology from the beginning to anticipate problems and also to make easier the optimization of the geometry selected. Numerical simulations will help us in the selection of the best geometry and also will give us more tools to decide on the best site to locate the telescope on the ORM.

The telescope chamber height above the ground is critical and will be different for different enclosure styles. A topology which does not increase the upstream thickness of the turbulent surface layer (the "up-lift effect") is desirable since this reduces the enclosure height and cost.

The main source of telescope enclosure induced image degradation is the production of air pockets either warmer or cooler than ambient. In an ideal telescope enclosure, the air inside the telescope chamber is continually replaced by ambient air before it has the opportunity to be warmed or cooled. However, flow characteristics are only one component of a successful telescope enclosure design, provisions for limiting the wind force effects on the telescope and also many considerations for the proper operation of the telescope have to be kept in mind.

From the "seeing degradation point of view," the main problem when designing an enclosure for a large telescope is to avoid thermal turbulence. However, the mechanical turbulence is also a menace to excellent observations.

The geometry selected will have to be optimized from the flushing efficiency point of view; this will be done using both numerical simulations and wind tunnels (the scale must be found to be suitable for obtaining valid results). Additionally, a thermal model of the telescope enclosure will be made, to evaluate various strategies for minimizing local sources of image degradation. Direct and diffuse insolation, conduction, radiation to the sky, and the thermal inertia of the walls, roof, interior air, and structural steel will also be included in that study.

7. ACKNOWLEDGMENTS

We acknowledge the collaboration of the "Instituto Nacional de Meteorología," for providing access to the Radiosonde data files. The collaboration of the different institutions at the "Observatorio del Roque de Los Muchachos" for their support, specially the NOT, is deeply appreciated. The collaboration of the people involved in the site testing, for maintaining the equipment and for doing the measurements under difficult conditions is also remarkable.

We would also like to acknowledge the help of many individuals who are working hard to make this study successful and those who have contributed in preparing this paper.

8. REFERENCES

1. WOOLF, N., Dome Seeing. Publications of the Astronomical Society of the Pacific. 91.523.529. August 1979. pgs. 523 - 529.

2. ANDO, Hiroyasu, et al. Some Air Flow Properties of Telescope Enclosures Estimated from Water Tunnel Tests. JNLT Technical Report No.3. April 1991.

3. SIEGMUND, Walter A., et al. Flow visualization of four 8m telescope enclosure designs. SPIE Vol. 1236, 1990. pgs. 567 - 574.

4. LAUNDER, B.E. et al., Progress in the development of a Reynolds stress turbulence closure, J. Fluid Mechanics, 68, 1975

5. SPECIALE, C.G., et al., Modeling the pressure-strain correlation of turbulence, an invariant dynamical systems approach, J. Fluid Mechanics, 227, 1990. pp. 245-272.

6. ZAGO, Lorenzo., The Design of Telescope Enclosures for the VLT. ESO Conference and Workshop Proc. No. 42. April 1992. pgs. 235 - 346.

7. WONG, W.Y. and BARR, L., Planning the National New Technology Telescope (NNTT): V., Enclosure Design Options, Advanced Technology Optical Telescopes IV, SPIE vol. 628, 623, 1986.

8. RAYBUOLD, K., et al., Gemini Enclosure and Support Facility Design Philosophy and Design Description, in Advanced Technology Optical Telescopes V, Larry Stepp, Editor, Proc. SPIE 2199, 1994, pp 452-464.

9. NELSON, J.E., MAST, T.S., Construction of the Keck Observatory, in Advanced Technology Optical Telescopes IV, Proc. SPIE 1236, 1990, pp 47-55.