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THE VLT ENCLOSURE

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Abstract

The paper is divided in three parts. Part I briefly describes the enclosure concept which is being proposed for the VLT, recalling the main requirements and design options that have driven the project in this phase. The different components of the enclosure are discussed with emphasis on their design concept, functional role and possible alternatives.
Parts II and III (see separate abstracts) describe in more detail the inflatable domes and the linear wind screen.

Part I THE VLT ENCLOSURE CONCEPT

1 Introduction

Like other aspects of the VLT also the enclosure may appear innovating with respect to existing systems. In fact, although it may look very different from the classical domes, the enclosure of the VLT is designed to fulfill the same functions: sheltering the telescopes, wind protection, handling requirements, housing of control systems. The first part of this paper will illustrate in particular the relationship between the VLT functional requirements and the definition of the overall arrangement and the single components of the enclosure.

Parts 2 and 3 of the paper will then deal with the two more particular items of the VLT enclosure, namely the inflatable domes and the wind screen.

2 Enclosure design philosophy

The enclosure of the VLT and its different components are described in published VLT reports[1][3]. Therefore only a brief summary is given here.

There will be four independent telescope pillars. A building comprising the main control room and the Coude lab for incoherent beam combination will be placed near the centre of the array. Another separate building with the interferometric lab will be set parallel to the telescope array. Inflatable dome-like shelters will protect the telescopes when they are not observing. A platform-like structure will surround each telescope providing access, support for the shelters and the crane. In front of this platform, in the upwind direction, a wind screen will protect the telescope array in case of strong winds.

This design derives from an analysis of several requirements, many of them common to all telescope projects, some others specific to the VLT concept of a linear array. In general we have been able to identify some major functional characteristics and define correspondingly specific constructions. This approach was indeed facilitated by the general VLT concept of a linear array with 4 telescopes operated in the open air and is somewhat in opposition to the one of assuming a single complex construction (namely a classical dome) which must fulfill a rather long list of requirements. On the contrary, in the VLT project we have tried to separate the main functions required in different hardware elements. In this way design procedures are somehow made simpler as it is possible to optimise separately the single components. Also a greater flexibility is retained in adapting the overall configuration to an evolving VLT project.

As a first step the definition of the enclosure of the VLT was divided in two major subsystems: a base structure with the pillars, control rooms and laboratories, and a service and protection structure which serves to protect, access and maintain the telescopes. In parallel, we have always kept in mind that the general configuration must also be convenient from the point of view of logistics and handling, and transport of heavy equipment, the primary mirrors in particular. One must consider that the whole VLT arrangement will have to be set on the top of a mountain, i.e. the required surface should be minimised. In fact the available surface will anyway be limited in practice by the amount of rock that can be blasted with reasonable costs.

3 The base structure

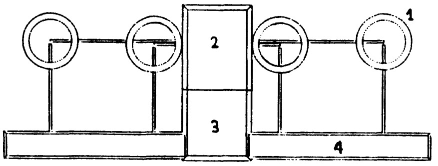
The base structure of the VLT enclosure is constituted by the telescope pillars, control rooms and laboratories. The four pillars, the main function of which is supporting the telescopes, are concrete structures of cylindrical shape with required rigidity. They will be aligned but for the minimum distance (1~2 m) to allow the light beam from the extreme telescopes through the intermediate ones. The optimum height of the pillars will be ultimately fixed by measurements of thermal turbulence near the ground.

The project of the other constructions is essentially driven by volume and location requirements.
The Coudé lab is placed at the centre of the array, between the bases of telescopes 2 and 3. This building will consist essentially of a square room 20×20m, subdivided into 4 instrument spaces 10×10m each. The combination of the four light beams takes place in the centre and at least four major instruments may stand permanently in the four rooms to receive the combined light beam.

Located parallel to the array is the interferometric lab: a long, narrow building placed along the linear array. Along its centre a stable slab serves as base for the moving table.

The 4 telescopes will be controlled from a unique location. The control room, presently annexed to the Coudé lab, may actually be placed anywhere, in particular in function of the site configuration.

1. **Telescope pillars.**
2. **Coudé lab for incoherent combination.**
3. **Control room.**
4. **Interferometry lab.**



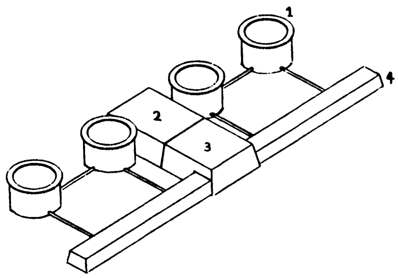


Figure 1: The base structure for the VLT compact configuration.

4 The service and protection structure

This subsystem is constituted of a complex of structures the main aims of which can be summarised as sheltering the telescopes when they are not operating, allowing easy maintenance and handling of major elements (mirrors in particular), and protecting them from high wind loading. One may note that it is the combination of these requirements in one construction, namely a classical dome, which makes its complexity and adds to its size.

Concerning the seeing aspect one may recall that one of the reasons to propose an open air arrangement of the telescopes during observation is that it would eliminate dome seeing. Therefore it is important that no new causes of thermal turbulence are created also in a domeless arrangement.

Telescope shelters

Fully closed sheltering must obviously be provided to the telescopes, when they are not in operation. In all precedent telescopes the function of shelter is associated to a telescope building which then is required to do more than just sheltering the telescope. For the VLT, however, the two concurrent aspects of open air operation and control from a (relatively) remote central location allows to define shelters that have only this protecting function and can and should be completely opened or removed during observation time. Thus, relatively simple structures can be designed such as the two types analysed during the feasibility phase: the inflatable domes presently proposed (see part II) and the movable shelters, heavier but which will be a reliable backup solution if for any reason the inflatable dome would be found unsuitable.

Handling

Most telescope buildings include a crane for maintenance operations which adds considerably to the size of the building. In the case of the VLT an analysis of maintenance operations lead to the conclusion that the combination of a single external crane, which will then work with the shelters open, and some smaller equipment within the shelters (lifts, a small mobile crane) would be a reasonable compromise in view of the cost saving with respect to having a bridge crane inside each shelter. A gantry crane moving on the service platform (cf. next §) is presently considered but a mobile crane on the ground level could become an interesting option in case of a low telescope pillar.

Service platform

The shelters must be supported by a fixed structure. Therefore we have defined a platform around each telescope which can fulfill several purposes: access to the telescopes, support and closing floor for the telescope shelters, support for a crane, telescope maintenance. This platform is presently defined as a light-weight steel lattice structure which reaches the level of the telescope base, from which the inflatable domes rise.

In fact this platform is the one item of the VLT enclosure whose design is driven from a combination of operational requirements and from the design of other components (domes, crane). Its design is also dependent on the pillar height and on thermal and aerodynamic considerations (cf. §7 of part II). Therefore its present definition is likely to be amended in the course of the project although its main structural characteristic of an open steel structure (for many aspects preferable to a concrete shell) is likely to remain.

Wind protection

As mentioned above the telescopes of the VLT array will be operated in the open air. To this end the telescopes are being designed to operate under winds up to 9 m/s at least. As this value would limit excessively the amount of observation time, a protection is required in case of stronger winds. Profiting by the fact that by night the wind on the Chilean sites is predominantly one-directional, a linear wind shield parallel to the array would be a very cost and performance effective solution. This wind shield is described in Part III: one should note, however, that, as the analysis of wind loading on the telescope elements is only preliminary, the wind shield is actually an *in-case-of* solution to a problem which is not yet fully investigated.

While this large wind shield is a good solution if the wind loading problem concerns mainly the tube structure, we might have an even more severe problem with the wind loading on the primary mirror, possibly if the option of a thin mirror is retained. There the in-case-of solution will be to rise the platform in order to enclose the lower part of the telescope in a recess as illustrated in fig. 3.

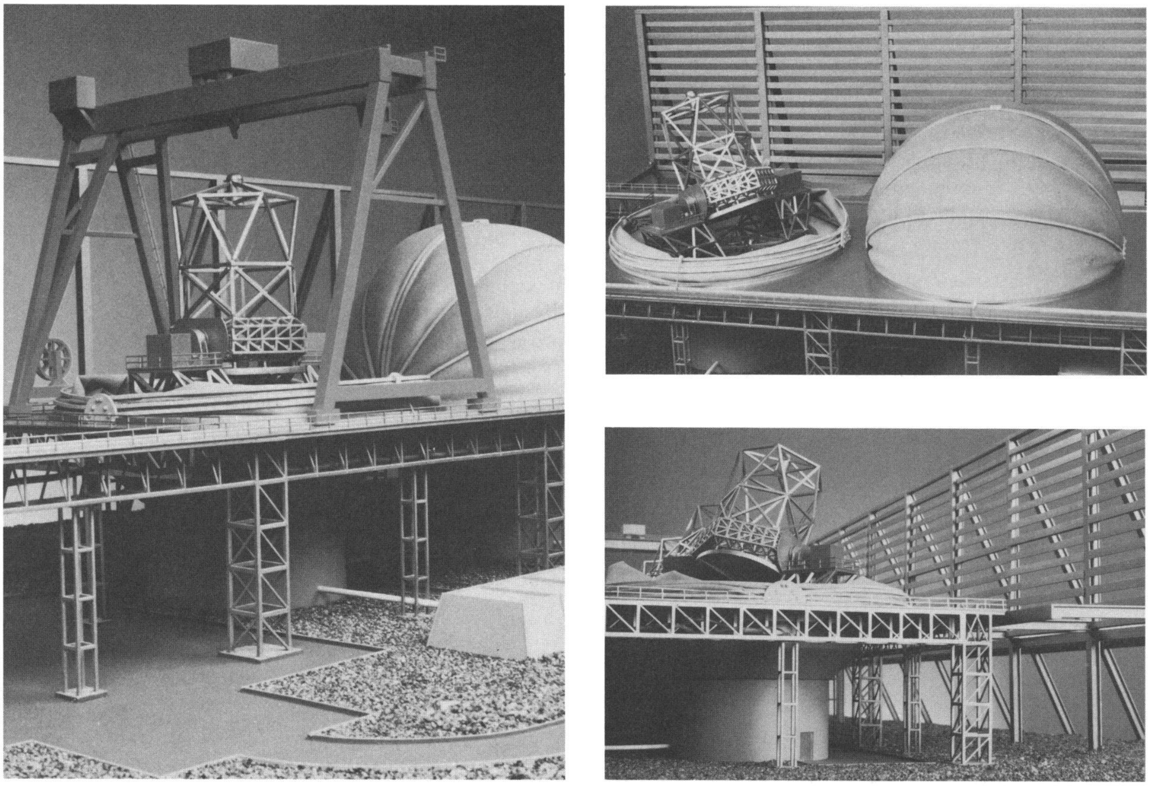


Figure 2: Photographs of a VLT model showing the inflatable domes, the service platform and the wind screen.

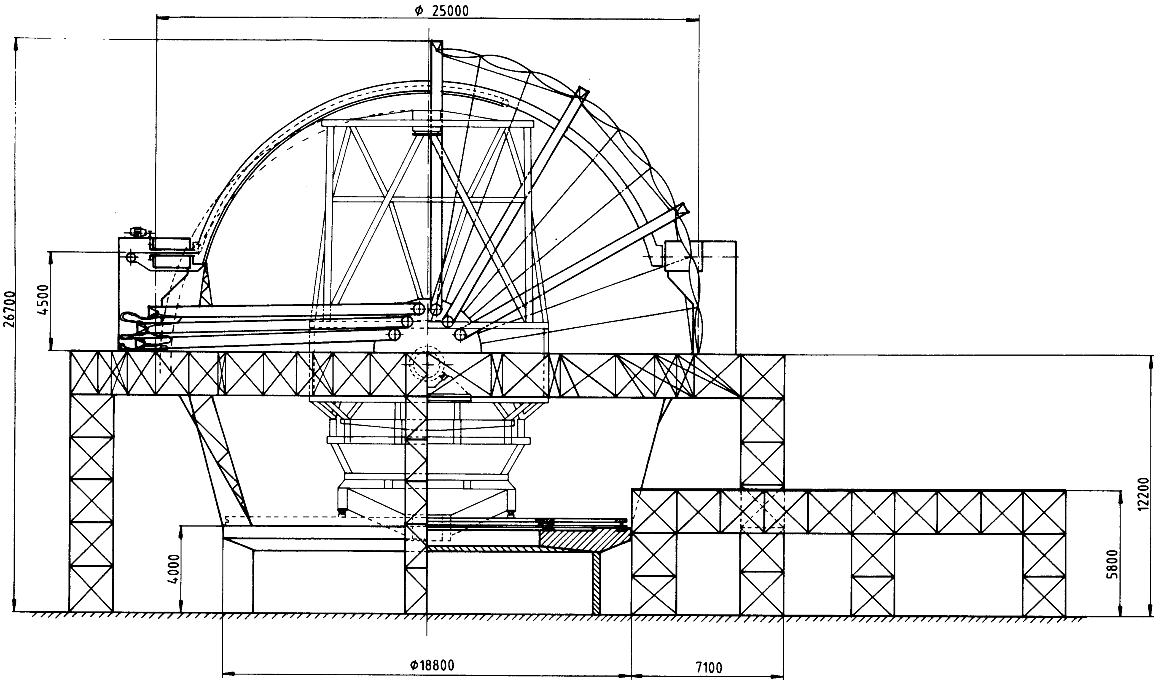


Figure 3: Alternative VLT enclosure with the mirror shielded from direct wind.

Part II INFLATABLE DOMES

Abstract

This part of the paper describes the inflatable structures proposed as an effective and low-cost telescope shelter for the VLT. This dome-like structure is constituted by a double wall fabric hemisphere supported by rigid hoops that open and closes in two symmetrical parts. The principle of the structure is to use air for inflating the double wall cover and, once the shelter is closed, the internal volume. The strength and stability are directly related to the inflation pressure which may vary from 3 to 30 mbar, according to the wind load acting in the structure. The components of the structure are described: the framework supporting the fabric, the double wall cover, the blowers. The specific requirements of an astronomical observatory are also considered: wind loading, thermal environment, reliability.

1 General

At the initial stage of the VLT project several options for the telescope shelters have been considered, among which classical domes and movable shelters. In this phase a proposal for an inflatable structure was formulated which, looking promising, was the object of a further study contract. The next phase will then be the construction and erection at La Silla of a 15-metres evaluation model, which, beside being used for housing optical tests connected with the VLT project, will provide more definite data on the quality and reliability of the solution.

Inflatable structures are used in a variety of applications. The most common being covers for playing fields, swimming pools, etc. More advanced uses include telecommunication antenna facilities which necessitate dust-free and metal-free environment. The experience of these applications can be readily applied to the design of a telescope dome. Inflatable structures are lightweight because they consist of a simple skin of fabric that is flexible and easy to use, transport and install. And in contrast to the general opinion, they are not weak or fragile.

2 Main design requirements

The purpose of the domes is to protect the telescopes when they are not in operation, in particular during the day.

The final size of the domes will be determined in further course of the project, as it depends on aspects related to the telescopes which are still in the process of definition: tube size, operation and maintenance requirements, mirror removal, admissible wind loading. At the present stage a diameter of 30 metres is being considered.

Other general specifications considered in the preliminary study are as follows:

- Planned site: La Silla or another Chilean site with altitude 2500-3000 m.
- Snow 20 cm. This is the likely maximum for occasional snowfall at La Silla. The design should, however, prevent that snow cumulates on the domes.
- Wind: 250 km/hr with the dome closed, 100 km/hr open or maneuvering.
- Seismic conditions: 0.3 g horizontal, 0.1 g vertical.
- Temperature: -5 to 30° C.

3 Description of the domes

Structure

Three types of hoops are used for supporting the fabric, see fig. 4 :

- Two main hoops that take up most of the loading, especially during maneuvering.
- Four secondary hoops that maintain the overall shelter shape when there is no internal pressure.
- Two auxiliary hoops that provide two intermediate support points for the other hoops guiding them and therefore decrease the loading during opening and closing. These auxiliary hoops will be tilted on the platform when the shelter is open and erected by means of a rack gear system.

Based on preliminary analyses and comparisons with existing structures, triangular steel lattice beams have been retained with overall cross-section dimension approximately 0.8×0.8 m and a weight of about 80 kg/metre length.

Cover

Each of the two sections of the double-wall cover consists of nine inflatable ribs of lenticular cross-section. The cover material is PVC impregnated fabric with a breaking strength of 35-40 Kg/mm^2, comparable with that of standard soft steel. This fabric can withstand tensile loads of 14 tons per metre length.

Maneuver system

The dome is designed for opening and closing at least once a day. This is a main difference from existing antennal radomes which are operated less frequently. There will be two maneuver modes: a normal automatic mode, microprocessor controlled, and a manual backup mode with safety functions preventing the order of some operations from being reversed.

A rack gear system will erect the auxiliary hoops. The power required for erecting in two minutes is about 3 kW per rack gear for a total of 12 kW.

The erection torque for the main hoops is too high to allow using a system similar to the one of the auxiliary hoops. This is why it is preferable to consider a cable system: winches are mounted at the top of the auxiliary hoops and cables hooked to the main hoops are used for erecting. The power required for erecting in two minutes is about 5 kW per side for a total of 20 kW for the entire dome.

Blowers

Due to their vital function, two blower units are specified:

1. A main electrically driven blower assembly.
2. A backup blower assembly with the same performance but driven by an internal combustion engine. It takes over automatically in case of power failure.

With the relatively high inflation pressure required to counteract the maximum wind pressure (cf. next §), it will not be efficient to keep the blowers continually operating at maximum capacity and pressure regulation must be provided. The regulation will be controlled by an anemometer to set the inflation pressure in function of the wind velocity. If the anemometer fails the system would switch to the extreme setting.

WEIGHTS	
• STEEL FRAME	35 tons
• COVER	5 tons
• BLOWERS	2 tons
• MANEUVER SYSTEM ACCESSORIES	5 tons
• TOTAL	47 tons
POWER	
• BLOWERS	5 kW
• DRIVES (MAIN)	20 kW
• DRIVES (AUX)	12 kW
• AIR CONDITIONING	10 kW

Table I - Summary of main data for a 30-m inflatable dome.

4 Wind loading

The flow pattern around a flexible envelope is a very complex phenomenon, with interaction between the flow and envelope displacements. A few wind tunnel tests with models of this type of structures are reported in the literature, which indicate that a critical parameter is the ratio P_i/q of the internal pressure to the dynamic pressure of the wind. In fact at sufficiently high inflation pressure $(\frac{P_i}{q} \geq 1)$ the flow approximates the one around the solid body and no structural instability is likely to occur.

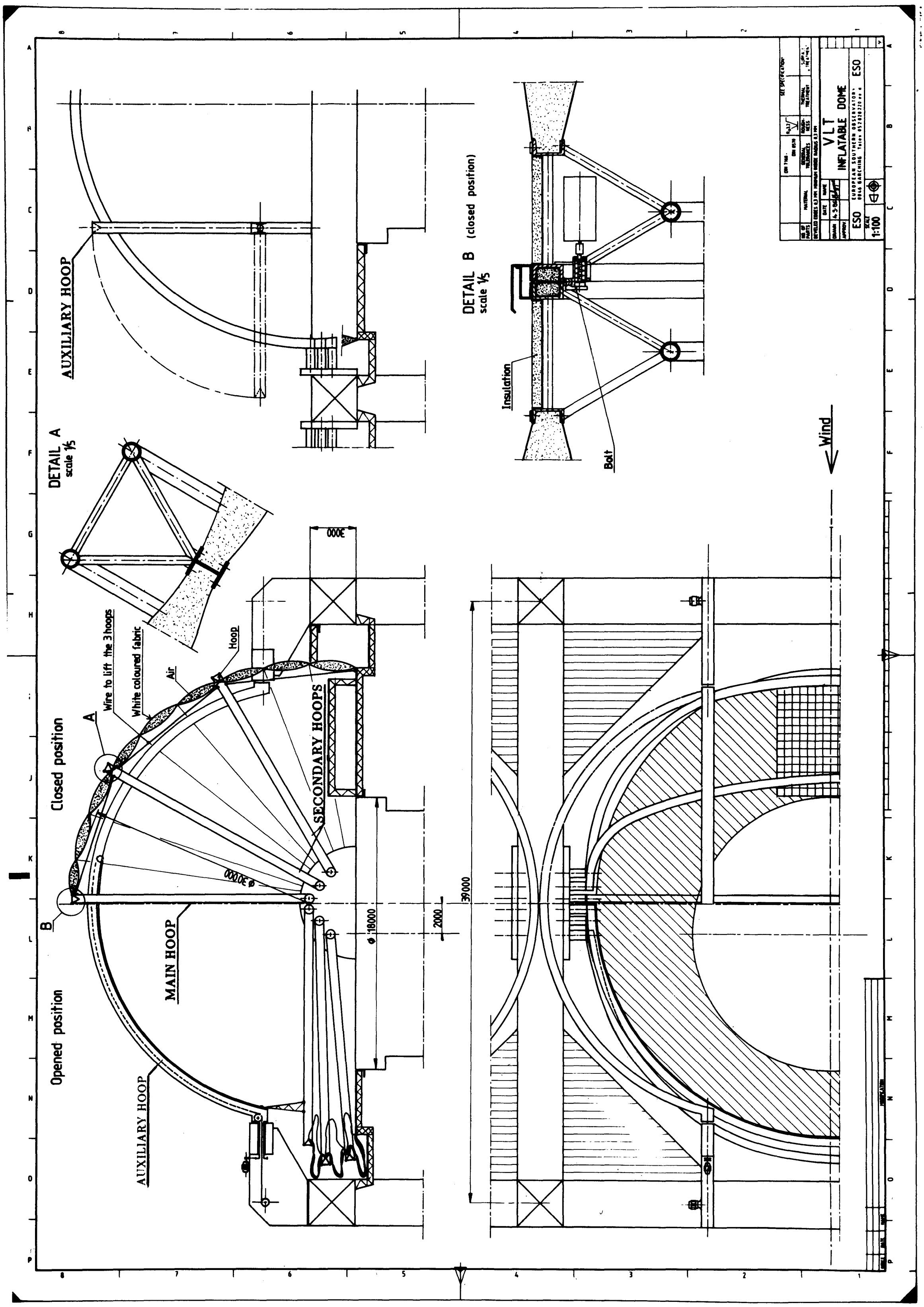


Figure 4: Assembly drawing of the inflatable dome

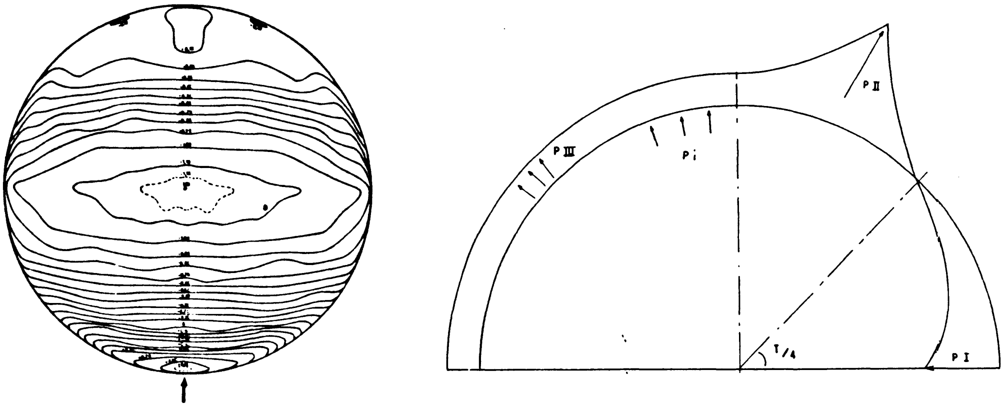


Figure 5: Wind pressure distribution (from ref.[9]).

Three zones are observed on the dome (fig. 5): a zone of varying pressure, a zone of varying suction, a zone of almost constant suction corresponding to the presence of the wake. On most of the surface the actual load is negative (suction). A P_i/q ratio of about 1 has been found satisfactory, from which a maximum required internal pressure of 2500 Pa is evaluated for a wind of 250 km/hr. With 100 km/hr this is only 372 Pa.

This preliminary analysis led to consider the following design values:

- Rib inflation pressure between 1000 and 3000 Pa.
- Internal overpressure P_i between 600 and 2500 Pa.

While the maximum design wind loading of 250 km/hr appears as the main dimensioning criterion for the structure, the case of closing the dome in a 100 km/hr wind has also to be checked. In this case the exact pressure distributions become very complex to be evaluated theoretically and even in wind tunnel tests. Nevertheless, although local pressure coefficients may be higher than for the closed configuration, the wind dynamic pressure is still 6.25 times lower, which gives a good margin. This suggests that a careful design, with reinforcements at expected weak spots will be a sufficient precaution for the initial 15-m test dome. Experience with this construction will then be utilised for the dimensioning of the VLT domes. To further decrease the risk it is envisaged to prescribe that the upwind side of the dome is always rised first, thus protecting the more sensitive interior of the downwind side.

5 Safety and reliability

The dome must be designed to provide completely safe and reliable operation. Its characteristics allow to take very high safety factors (of the order of 10) for the structural elements without incurring excessive weight penalties. The double-wall solution gives a high reliability to the shelter: If the main blower fails with an ensuing drop in internal pressure, the inflated ribs keep the fabric tensioned. If the external fabric is torn or leaks, the internal fabric is forced against the external one, thereby keeping the external shape, which is very important to resist high wind loadings.

The blowers are critical components since inflation largely determines the stability and strength of the dome. They use well-proven technology(i.e. centrifugal or squirrel cage fans, asynchronous motors, diesel engines) and the use of two independent units is foreseen. With the double wall cover, each unit will comprise two blowers with similar characteristics: one for the ribs, the other for the interior. The inflation circuit will then be designed so that all four modules are interchangeable. The safety can be further improved by twinning the units of neighbouring blowers.

6 Special requirements

Snow and ice

Experience has shown that snow is unlikely to accumulate on an inflatable structure:

- The round shape and smooth surface promote sliding.
- Heating, even slight, of the rib air melts a thin film of snow and ice, which then falls off.
- By decreasing and increasing the inflation pressure the ice is separated from the surface and falls off.

The last two operations may be routinely included in the opening procedure in winter.

Ultraviolet radiation

Little is known on the possible damaging effects of ultraviolet radiation on the plastic cover. It is anyway a simple procedure to take samples of the cover for strength and stiffness analysis at regular interval. This will be done in particular on the 15-metre test dome at La Silla.

7 Thermal performance

Single wall inflatable structures are often very poor insulators and may also experience a greenhouse effect. The situation is fortunately different for a double wall cover if some precautions are taken. In this paragraph the thermal performance of the domes is discussed. Then, in order to evaluate more completely the overall arrangement with inflatable domes from a thermal point of view, the situation with the dome open, that is the thermal effects on the exposed platform, is also described.

In both night and day cases the strategy for optimal thermal performance implies a careful design of radiative surface properties (thermal emissivity and solar absorptivity) in order to minimise the radiative heat transfer from and to the surface. In fact, if the radiative heat transfer is largely reduced, convection by the wind becomes the predominant mode, which tends to bring the system in equilibrium with air temperature. Also, since convective heat transfer rates are relatively low, the net heat fluxes into the structures and therefore conductive terms are reduced. Values for emissivity and solar absorptivity relevant to the VLT design are listed in table II.

	thermal emissivity ϵ	solar absorptivity α_s
Aluminised silicon resin paint	0.20	0.27
Aluminium foil	0.04	0.10
Aluminium alloy:		
- polished	0.05	0.37
- wheathered 20000 hrs	0.16	0.54
Aluminium vacuum deposited on duPont mylar	0.025	0.10
Titanox	0.885	0.154
White epoxy paint	0.88	0.25

Table II - Emissivity and solar absorptivity of some surfaces.

Case of dome closed

Like with a classical dome, the project objective is to maintain during the day an internal temperature close to the one expected during the night. Therefore the double cover will be designed for optimal thermal protection:

- White, TiO_2 pigmented, external surface.
- Both covers made completely opaque to prevent greenhouse effects.
- Insulated connections between the covers.
- The internal surface of the external cover and both surfaces of the internal one are aluminised.

During the day the white surface will never exceed ambient air temperature as the incoming solar radiation will be totally re-radiated. In fact the net radiative heat flux will be close to zero for $\alpha_S/\epsilon \simeq 0.3$. White pigments such as the one used on the dome surface will nominally achieve an even lower ratio[1]. The convective term will then be predominant and therefore the surface, with its low thermal constant will closely follow the air temperature.

If the interior of the dome is kept at average night-time temperature, some heat will be transmitted to the interior. A preliminary computation indicated this heat load to be less than 2 kW, considering a maximum day-night temperature difference of $10°C$. A larger heat load arises from the air required for leak compensation, which must unavoidably be taken at ambient temperature. With a careful design a renewal rate of less than $\frac{1}{2}$ volume/hr appears achievable which requires a cooling requirement, i. e. power extraction of $\simeq$ 7 kW.

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[1] Although some allowance must be made for dust. A regular cleaning may be foreseen, for instance during the opening of the shelter.

Dome open and platform exposed during the night

For all surfaces exposed during the night, such as the platform around the telescopes and inside the domes, the design objective is to minimise temperature differences with ambient air. Radiative loss toward a clear sky will tend to cool the surface. This loss is proportional to the emissivity of the surface and little dependent on air temperature, while convection (approximately proportional to the temperature difference) will work in the sense of limiting the cooling.

Therefore the telescope structure should be wherever possible treated for a low emissivity (it could be covered with thin aluminium sheet, as it is the case presently with the MMT) If it is made of tubular members of small diameter (say 15 cm) with a heat transfer coefficient of about 55 $W/m^2{}^\circ C$ with a 5 m/s wind, the night cooling will not exceed $0.3^\circ C$ with respect to ambient air, for $\epsilon = 0.05$. As the time constant of these members is of the order of 1 hour, these delta T's will also decrease quite rapidly.

The service floor inside the domes will be likewise treated for low emissivity: cladding with standard alumimium sheeting is proposed. In this way, during the day, almost no heat is transmitted by radiation between the internal surface of the dome and the inside structures and the only source of heat to the telescope may come from the temperature of inside air which can be effectively controlled.

For the platform outside the domes, which is also exposed to daylight, the best compromise would be an aluminised resin paint ($\alpha_S = 0.27$, $\epsilon = 0.20$). During the day heating would be limited to 3°C above air with a 5 m/s wind and convection on both sides[2]. During the night maximum cooling would be 1.3°C below air temperature with the same assumptions. To further decrease the risk of affecting the telescope seeing, one would place the platform level slightly below the main mirror, so that this one is out of the local thermal boundary layer. Above this layer, which for the surfaces and the range of wind velocities concerned here, has a thickness of the order of 10 to 40 cm, the flow is unaffected by surface temperature.

To complete the thermal analysis of the inflatable dome arrangement one should also consider the case of very low winds with gusts up to, say, 2 m/s. In this case the surfaces will cool further down than under the effect of forced wind convection, possibly to 4-6° below ambient air. The air layer nearest to the surface will be cooled correspondingly, although already few centimetres from the surface the cooling will be much less. This will make a very thermally stable configuration, such as it is sought in classical domes. However, a danger for seeing is given by the possibility of small bubbles of cold air elevated by wind gusts. This situation will be evaluated in particular tests.

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[2] Convection on both side of the service surface is possible if, as proposed, the support structure is made of lattice framework, which is largely permeable to the wind and which, for its higher convective tranfer coefficient and lower thermal inertia, should always stay within 1°C from air temperature.

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Part III THE LINEAR WIND SCREEN

Abstract

This part describes the initial analysis and design work for the large linear semi-permeable wind shield which will be part of the enclosure of the VLT. The wind shield will likely be the largest structure in the world made for this purpose: its screen elements will be 24 m high and 20 m wide, the entire structure will be about 35 m high and 160 m long. The paper includes a summary of the aerodynamic analysis, the description of the present design and an analysis of thermal effects on the flow.

1 General

During the initial feasibility study phase of the VLT project it was recommended to specify a limit on the incident wind velocity on the telescope, in order not to penalise excessively the design of structure and drives, which has already quite ambitious and severe requirements.
A preliminary analysis of wind conditions and their effect on the telescopes [2] led to propose this value to be set at 9 m/s, which appears to cover already about 65~70% of night time. As the maximum mean velocity for allowing telescope operation will be of the order of 18 m/s, in order to reach close to 98% of observing time, a wind screen will be in fact required to be effective when the wind velocity is between 9 and 18 m/s (that is about 30% of night time) and have a maximum efficiency of 50%.

Considering that all likely sites for the VLT present a predominant wind direction from the north, the simplest solution is to have a linear semi-permeable wind screen in front of the telescopes' array, which then would be placed normally to the main wind along an east-west line. Then, not to lose the favourable effects of (moderate) wind flow on seeing, the wind screen will be made such that it becomes effective only when the wind has a mean velocity higher than the value acceptable for the telescopes. In the occurrence of lower velocities the wind screen is removed and set horizontally.

2 Wind shield aerodynamics

The general requirements described above suggest that a semi-permeable screen would be more adapted than, say, a fixed structure or large deflectors.

A semi-permeable wind shield causes part of the incident flow to be deflected above, below (if there is space) and at the sides. This deflected flow is therefore accelerated. Another part of the flow crosses the screen with a lower velocity and thus opposes the formation of recirculation flow which an impermeable object would create. Some additional turbulence is created in the flow, mainly in the shear region between the accelerated and slowed streamlines above the screen, while a protected area with reduced velocity and turbulence is formed behind the screen. In first approximation the performance of a wind shield, that is the ratio of velocity without screen to the one with screen will be proportional to its permeability, defined as the ratio of open area to the total area.

The first step toward the design on the VLT shield was a survey of relevant data reported in the literature. A quite detailed investigation of semi-permeable screens in an atmospheric boundary layer wind tunnel is presented by Raine and Stevenson[6]. From their results with a 50% screen (fig. 6) it can be observed that mean wind velocities are rather homogeneously halved at distances of the order of 1.5 times the screen height, which can be envisaged for the VLT, given the requirement for some mimimum angle of view (30~35°). The screen should then be about 15 to 20% higher than the telescope. The turbulence caused by the screen is not excessive as a large part of the kinetic energy of the approach flow goes in the deflected and accelerated flow above the screen. Some additional turbulence is generated by the shear between the deflected and slowed flows, but behind the screen the actual turbulence is even decreased with respect to the approach flow values.

Extensive tests with wind shields were also performed by the CSTB[7] of Nantes, which in particular give data that allow to predict the extension of the protected area behind the screen. Fig. 7 shows an example of isoprotection geometry behind a non-permeable and a 50% permeable screen. Again the more regular extension of the protected region for the 50% screen appears favourable for the VLT case.

A parameter of importance in the evaluation of the VLT wind shield is the spectral density of turbulent energy behind the screen. This affects directly the tracking performance of the telescope, which is essentially dependent of the spectral energy density in correspondence of the first eigenfrequency of the structure. Ref.[6] shows that a shield causes an apparent shift of the gust spectrum. As the peak of the turbulence spectrum at a distance twice the screen height is found at a frequency of the order of U/h (U = mean speed undisturbed, h = screen height), it would appear that the predominant effect is the vortex caused by the screen height. Then, at higher frequencies the spectrum follows the classical Kolmogorov slope. However, this shift of the peak in the gust spectrum makes the wind shield less efficient with respect to the dynamic response of the telescope structures than with respect to the static loads as it was already concluded in ref.[2].

This survey of available data and their extrapolation to the VLT requirements resulted then in defining a 50% permeable shield, rising about 24 metres from the level of the service platform[3], with a total length of 160 metres, placed about 36 metres in front of the telescopes.

As a second step, before performing wind tunnel or reduced scale tests in the open, the air flow through this VLT arrangement was simulated numerically by means of a fluid flow finite element model to which a special type of semi-permeable element has been added. The model, two-dimensional, represents a cross-section of the VLT enclosure with open shelters. Different configurations were analysed, where the main parameters have been modified.

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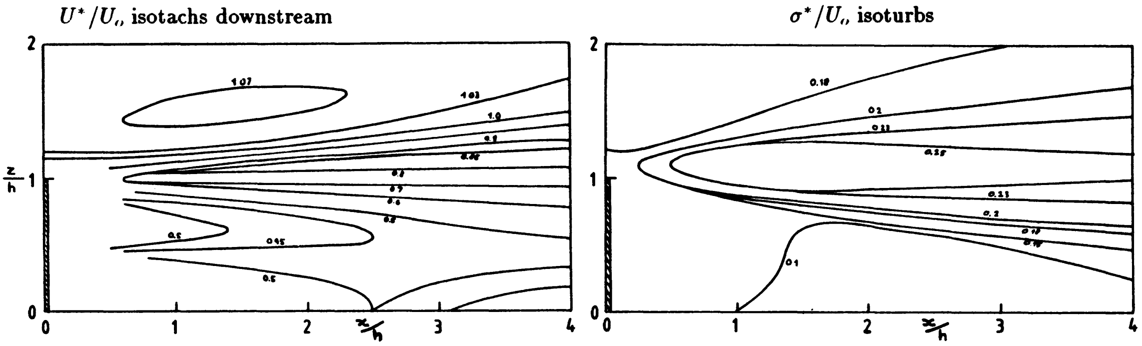
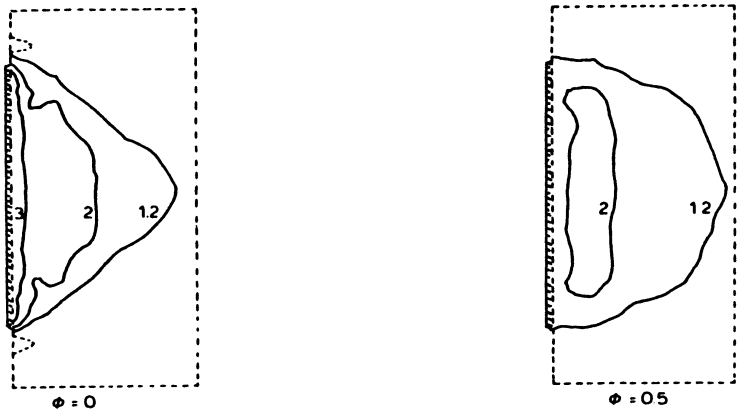
[3] With the present assumption that the level of the service platform is near the base of the telescope. A rised platform in order to protect the mirror in a recess (as shown in fig. 3) would result in a smaller wind screen.



U^*/U_0 isotachs downstream

σ^*/U_0 isoturbs

Figure 6: Isocurves for U^*/U_0 and σ^*/U_0 behind a 50% linear wind shield in a boundary layer wind tunnel (from [6]). U_0 is the mean velocity in the wind tunnel before the screen, while U^* and σ^* are the mean velocity and turbulence (rms) of the flow behind the screen. Note that σ_0/U_0 was 0.2 .



$\Phi = 0$

$\Phi = 0.5$

Figure 7: Example of protection behind a screen with permeability 0.5 and 0 (from ref.[7]). The isoprotection lines correspond to a protection factor defined with respect to both mean velocity and turbulence $P = \frac{U_0+\sigma_0}{U^*+\sigma^*}$.

The objectives of the study[4] were to compute the profiles of air velocity, turbulence and temperature in the telescope region.

The results obtained are extensively described in ref.[8] and have been summarised in the VLT reports No.44[1] and 46[3]. In spite of some approximations taken for the calculations of head losses, the model simulates quite accurately the main elements of flow pattern. In agreement with the results reported from wind tunnel tests, the model predicts an increase of the overall turbulence of the flow with respect to the free flow conditions. This increase is not very large: of the order of 30% and is found mainly in the shear region between the slowed and the accelerated flow above the screen. While in a large region behind the screen, in particular where the critical top part of the telescope is located, absolute turbulence will be lower than in free flow (fig. 8).

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[4] Performed under ESO contract by EPFL, Lausanne.

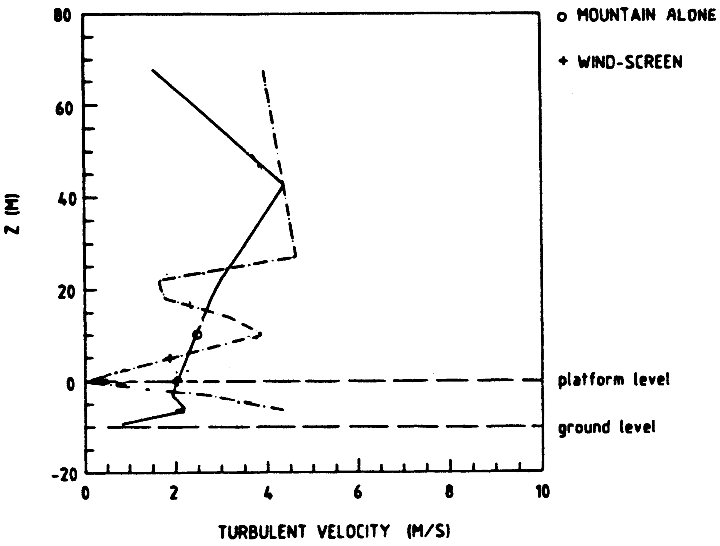

Figure 8: Turbulence profiles computed at the location of the telescope by the FEM model

3 Structure and operation

The design which is presently the preferred solution is illustrated in fig. 9. It is constituted by an array of semi-permeable screens that can be set in vertical position or removed horizontally. The screen elements are 20 metres wide and 24 metres high. They are supported by a steel frame structure. Note that the actual height of the structure may vary according to the height at which the telescope will be placed.

With respect to a louvers solution, which was also considered initially, the proposed configuration has some advantages :

- Low winds are left undisturbed, as in such cases the screen is removed. Therefore no unnecessary turbulence or thermal effect (cf. next §) are created. Also the obstacle to a very low angle of view is removed[5].
- The screens are not exposed to storms, hence saving structural weight and cost.
- Less mechanisms, lower complexity, then cheaper.

Each screen element is made of a frame which integrates panels made of 1-m wide plates with a 2-m spacing. The weight of each screen element will be of about 29 tons. The supporting frame structure is made of steel I and ◯ profiles and dimensioned for the maximum load conditions. Computations were made by means of a FEM structural program. The power required to move one screen element is estimated at about 20 kW. Eight 20-metre elements are required for the VLT configuration.

An alternative solution is shown in fig. 10. Here each screen segment is made of two elements which are stored on the two sides on the pillars. Design work is progressing in order to come to an optimum solution with respect to weight, simplicity and cost.

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[5] Except for the support poles, which rise lower than the screens.

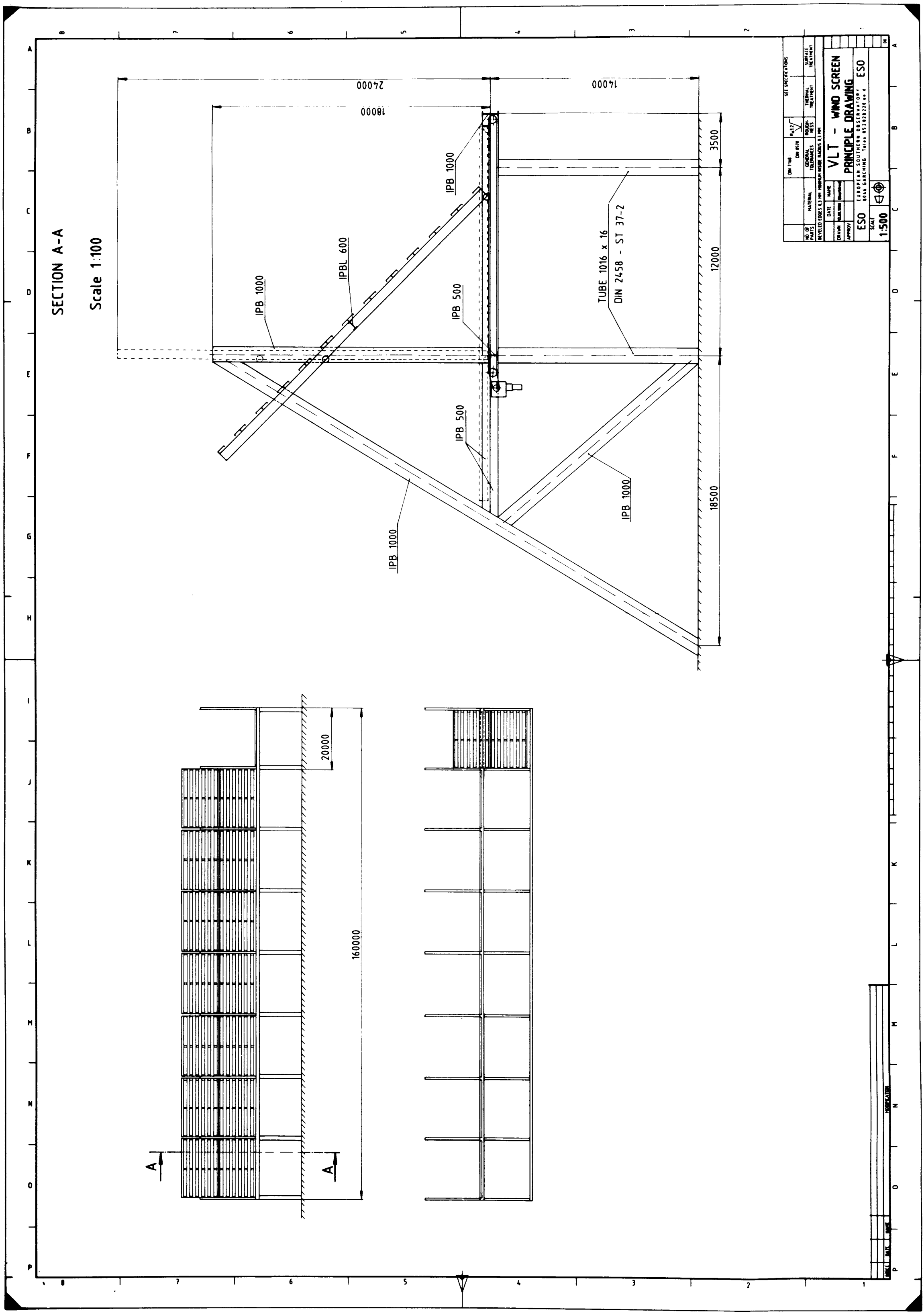

Figure 9: Assembly drawing of the VLT wind screen.

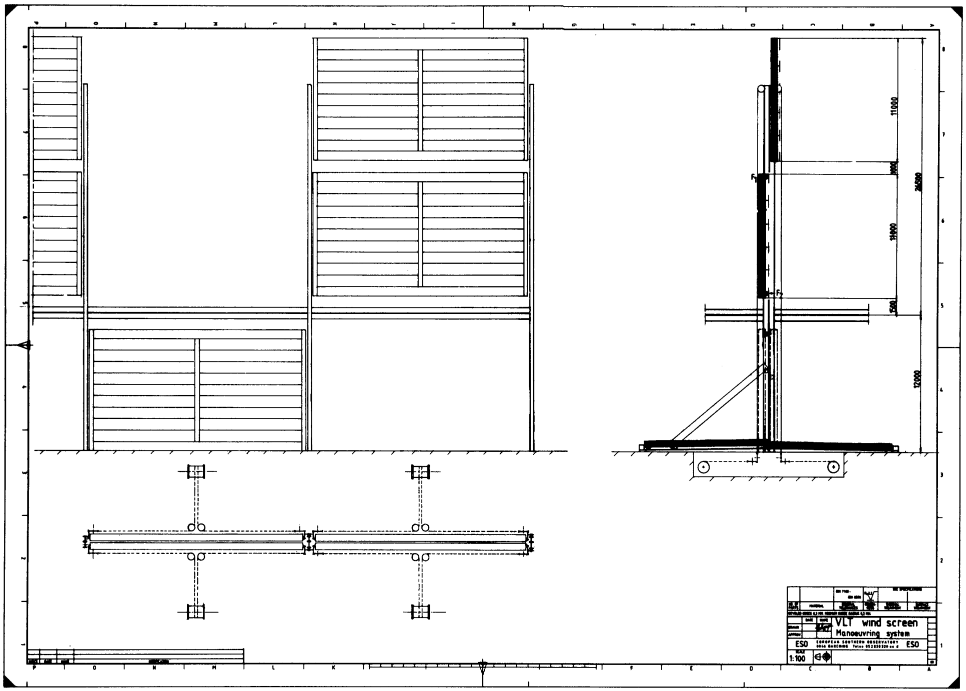

Figure 10: Alternative design for the VLT wind screen.

4 Thermal aspects

As has been noted above, the wind screen increases to some extent the turbulence with respect to the free flow conditions. The question is now rised whether this may significantly affect the seeing of the telescopes. Although a working theory of seeing in the near ground layer is still lacking, it is generally assumed that seeing is affected by a combination of mechanical turbulence and temperature variations in the flow. Thus the screen is likely to affect seeing if beside adding flow turbulence, it also modifies the temperature pattern of the free flow. It is then important to evaluate the thermal effects on the flow through the screen.

These effects are of two different types:

1. As the presence of the screen modifies the free flow pattern, it will also affect the original thermal stratification.
2. Forced convection heat transfer between the flow and the screen elements when they have different temperatures.

The first effect has been studied by means of the finite element fluid flow model described above. A mean temperature gradient of $0.0054°/m$ was input in the upwind flow. As it is shown in fig. 11 the temperature gradient is little affected: in the sheltered zone it shows a tendency toward neutralisation, possibly favourable for seeing, while re-joining the free flow value at greater height. The absolute temperature difference with no-wind-screen conditions is of the order of $3/100$ of $°C$. This appears also independent of the type of stratification, whether stable or unstable, possibly because the scale of buoyancy effects for thermal gradients of this magnitude is greater than the model's.

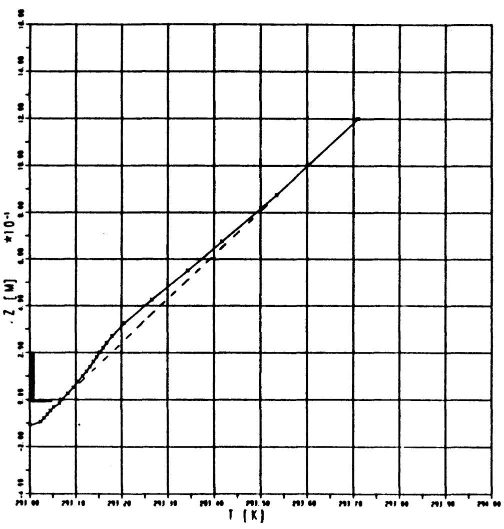

Figure 11: Vertical profile of the potential temperature behind the wind screen.
N.B. The dotted line shows the condition without wind screen.

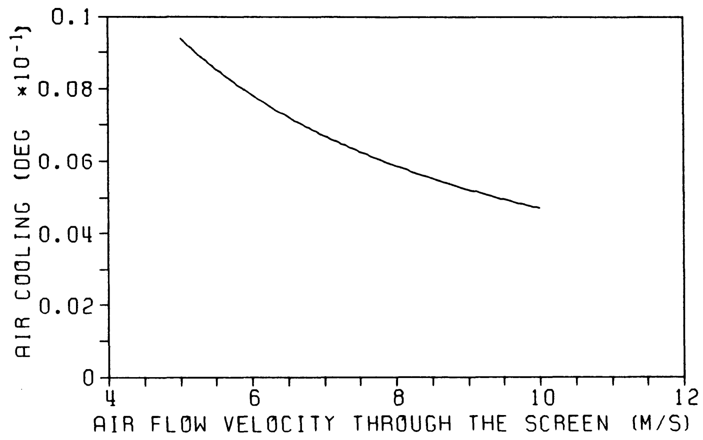

Figure 12: Air cooling through the screen in function of through-flow speed.

The second effect, forced convection heat transfer between screen and flow may be evaluated considering equilibrium conditions where the heat loss of the screen by radiation to the clear sky is compensated by the flow convection. The result of a computation, performed assuming an aluminised paint for the wind screen is shown in fig. 12: it gives the maximum air cooling through the screen in function of the range of possible through-flow speeds. This temperature drop will be inferior to 1/100 of $°C$.

In conclusion, the thermal effects of the wind screen on the flow appear small, of the order of a few hundreds of $°C$, but only further work and possibly some reduced scale tests on the site will be able to answer definitely the problem with respect to seeing.

Acknowledgements

The description of the inflatable dome is in large part a synthesis of the study report by SODETEG: the personal contributions of D. Saccomani and A. Bonneau are particularly relevant. Also much of the work for the VLT wind shield described here has been done with the help of contractors and consultants. I wish to thank in particular P. Lambert and D. Milan of NEYRPIC, Grenoble, J. Hertig and M. Beniston of EPFL, Lausanne and H. Ruscheweyh of TH Aachen. S. Malassagne of ESO contributed to the definition of the wind screen maneuvering systems.

References

[1] *Very Large Telescope, Interim report*, presented by the ESO study group, VLT report no. 44, Jan 1986.

[2] Zago L., *A first evaluation of the effects of wind loading on the concept of the ESO VLT*, VLT Note No. 41 .

[3] Zago L., *Enclosure and buildings for the ESO Very Large Telescope* VLT Report No. 46.

[4] Bonneau A. & Zago L., *Inflatable domes for astronomical telescopes*, Proc. SPIE Vol. 628 Advanced Technology Optical Telescopes III, Tucson, Mar 1986.

[5] Larger J.C., *Structures gonflables, synthese bibliographique*, Cahiers du CSTB No. 162.

[6] Raine J.K. & Stevenson D.C., *Wind protection by model fences in a simulated atmospheric boundary layer*, Jour. Ind. Aer., 2(1977) 159-180.

[7] Gandemer J., *The aerodynamic characteristics of windbreaks, resulting in empirical design rules*, Jour. Ind. Aer., 7 (1981) 15-36.

[8] Beniston M., Hertig J. & Zago L., *Analysis and design of the wind-shield for the ESO Very Large Telescope*, Proc. SPIE Vol. 628 Advanced Technology Optical Telescopes III, Tucson, Mar 1986.

[9] Wianecki J. & Driviere J., *Aérodynamique du batiment at des ouvrages d'art*, Annales de l'Institut Technique du Batiment et des Travaux Publiques, Suppl. No. 293, Oct 1972.

DISCUSSION

P. Léna: Do you intend to make real tests on the effect of a porous screen on the seeing, using a small ($\lesssim 1$ m) telescope exposed to wind at La Silla?

L. Zago: No real thought has been given to this up to now, but I agree it would be a very good idea, and we shall study the practical possibilities.

P. Charvin: As you did not mention icing problems, it seems you have some good reasons not to worry about it.

L. Zago: Icing conditions are successfully dealt with in similar existing structures:

1. The structure is round and very smooth so that ice has little chance to build on the surface; also the seal will be designed with this in mind.
2. Would ice still form on the surface, some procedures are available to get rid of it before opening:
   - Blowing some warmer air in the cover. As soon as a thin layer of water is formed, the ice will fall off.
   - Slightly deflating and then inflating the cover. Again the ice will separate and fall off.

I. Appenzeller: If there occurs a power failure while the dome is inflated and closed, would this affect its stability during a wind storm?

L. Zago: Yes, the system stability is critically dependent on power. This is why a back-up autonomous power supply is foreseen. As the dome can stay well inflated for some time without power, there is ample time for the independent power supply to take over.

J.P. Zahn: I wish to express my concern about the wind screen, as it is presented here. Isn't this a brute-force approach, where a large fraction of the kinetic energy of the wind is converted into (harmful) turbulence? Has no other design been considered and tested, for instance with an aerodynamical profile (which could potentially avoid the turbulence caused by the large shears)?

L. Zago: The wind screen essentially deflects and accelerates the flow above, below and at its sides, thus decreasing the mean flow rate behind it. There is some increase of turbulence but this is not a major fraction of the energy. There are no miracles in wind shield aerodynamics: if the mean flow is reduced somewhere, it will be accelerated somewhere else and flow shears and consequent turbulences cannot be avoided. These phenomena would appear in whatever configuration. One can and will act on design variables to get less (or more) turbulence in given regions.

R. Cayrel: 1) How well do the proposed inflatable shelters function in case of a tornado?
2) The sheltering function for the VLT must be supplied with a high safety factor, of the order of five. Do you have this safety factor with the inflatable structure?

L. Zago: 1) The shelters are dimensioned for a wind of 250 km/h which should cover any storm likely on the Chilean sites.
2) The safety factors for the support structure will be set according to the applicable civil engineering norms. A value of 10 is taken for the cover. However, with this type of structure, which cannot be fully represented in computations, high nominal safety factors are not by themselves a guarantee. Rather, a detail failure analysis and a particularly safe and careful design of critical spots will be required.

R. Cayrel: For the inflatable dome which has protected the CFHT during factory testing, the contractual value for maximum wind velocity was 150 km/h, but it did collapse three weeks after installation at a wind velocity of 65 km/h.