ENVELOPE AND BUILDINGS
FOR THE ESO VERY LARGE TELESCOPE

LORENZO ZAGO
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Abstract

This report presents a description of the enclosure and buildings for the ESO VLT at the present stage of definition after the conclusion of the first feasibility study phase. The concept presently proposed for the VLT assumes a linear array of four telescopes operated in open air. The telescopes will be supported by four independent 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. A platform-like structure will surround each telescope at a level about 6 metres below the elevation axis, providing access, support for the shelters and the crane, and some insulation from thermal and aerodynamic influence of the ground and underneath structures. In front of this platform, in the upwind direction, a wind screen will shield the telescopes array in case of strong winds during observation, while inflatable or movable shelters will protect the telescopes during the day and unfavourable weather.
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1 Introduction

The present concept for the ESO VLT is based on a linear array of four 8-metre telescopes, which provides the collecting power equivalent to a 16-metre telescope [1][2].

The VLT, like other new large telescopes which are presently being designed will depart considerably from existing telescopes in both the size and the structure concepts. In fact, plain extrapolation of the technological concepts of the largest present telescopes (3.5 to 5 m mirror diameter) to the size defined for the VLT lead to unacceptably high weights, hence costs, for both mirrors and telescope structure. Therefore, innovative solutions are sought.

The same applies to telescope enclosures. In fact, the familiar semi-spherical domes, which used to represent one of the major cost items in building the existing telescopes, are hardly acceptable for very large telescopes.

The VLT is a new and particular concept. It should be viewed in fact as a single instrument consisting of four aligned telescopes, even if it will be possible to use the telescopes independently. Therefore it can be expected that the optimum solutions for enclosure and buildings will depart from concepts generally valid for single telescopes.

As a starting point a set of basic requirements were formulated:

1. A stable base is required for each of the four telescopes.

2. The concept must include laboratories and in general adequate space for instrumentation and supply equipment, considering both joint and independent modes of operation of the telescopes. Control of the four telescopes should be effected from a central location.

3. Fully closed sheltering must be provided to the telescopes, when they are not in operation.

4. Also, a protection may be necessary to limit the wind loading on the telescopes' structure, in order not to penalise the structural design or decrease the amount of observation time.

5. For many applications it appears that telescopes of the size of the VLT can be justified only if the seeing quality is outstanding. Sites with
particular good seeing are envisaged. As a consequence the seeing should not be affected negatively by the enclosure arrangement.

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 north-Chilean 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.

From these general requirements an initial concept was formulated, described in the next paragraph. Then a series of feasibility studies, most of them with external contractors, were conducted to analyse and precise the general configuration and the main components.
The present report is a synthesis of this study phase.
Figure 1: Various telescope/enclosure arrangements
2 The initial approach

The process of designing an optimum building complex for the VLT is necessarily iterative. One will have to consider in first line the requirements of telescope protection and derive an integrated system for the VLT system; then verify compliance with all functional and operational requirements that have been evolving in the meantime, and adjust the design accordingly. Many types of telescope/enclosure arrangements could in principle be considered for the VLT as illustrated in fig. 1.

The design of conventional domes has been in great part finalised to the prevention of any wind disturbance on the telescope inside. In the latest telescope project, however, the familiar semi-spherical domes are giving way to lightweight box-like buildings largely open to the wind. The choice was initially dictated by cost considerations but the positive experience made with the MMT is confirming the trend toward a radical change of philosophy in the concept for telescope enclosures, which recognises that in many cases the open air environment is more favourable to optimum seeing conditions than the nominally stable and controlled environment inside a classical dome.

In closed domes, even very small temperature differences between the telescope and its environment will start natural convection processes. As the air flow velocities in natural convection are low, a lot of slightly warmer air stays floating around, mixing imperfectly with the cold air and causes the variations of index of refraction that degrade the images. A very tight control of all thermal sources and a cooled floor, which creates a stable inversion layer inside the dome, can be an answer to this problem. Past experience has shown that this is altogether difficult, expensive and in practice offers only a limited improvement.

If the telescope is exposed to the wind, whatever heat is transferred from the surfaces to the air is quickly swept away and does not affect the optical properties in the field of view. Minor temperature differences between surfaces and air, of the order of a few tenths of degree, which in a closed dome are sufficient to create unfavourable seeing effects, become irrelevant within a continuous air flow.

Although the wind has a positive effect on seeing, it may, however, cause important loads on the telescope structures and drives and the dynamic effect of wind turbulence may significantly affect tracking accuracy.
Also, wind loading on the primary mirror may deform it enough to affect its optical properties.

Without underestimating this problem, it was decided to propose for the VLT array an open air arrangement of the telescopes during observation, as a solution that would in the end both ensure optimum seeing conditions and minimise the enclosure cost.

In fact for telescopes in open air the environment conditions are essentially less complex and easier to evaluate than within a dome. Indeed free environment conditions can be considered independent variables with a statistical distribution, which can be known with great accuracy if sufficient measurements are available.

This makes design and technical solutions more reliable in the end, even if the conditions to cope with are for some aspects more unfavourable than within a dome.

The wind loading problem was recognised as an important constraint on the project. Therefore the concept which was proposed as an initial approach for the VLT was based on two basic assumptions:

1. that the telescopes can be designed for operation in open air, being able to perform adequately at least up to average wind loading conditions.

2. that on the site of the VLT the wind will blow predominantly from one direction, which is most probably north, as appears to be the general case in northern Chile at least at altitudes of the order of 2500-3000 metres. Therefore a fixed linear wind screen placed normally to the predominant wind direction would ensure telescope performance under more severe conditions.

Another factor considered in the proposed VLT definition is the possibility of performing interferometric measurements. In fact interferometry was retained as an important potentiality for the VLT. In the linear array concept, interferometric combination can be done in a separate laboratory, parallel to the array. This is viewed as an important feature of the VLT configuration which should allow:

- Easy switching to interferometry with no further disruption for normal observing.
- Independent use of the interferometer with smaller auxiliary telescopes. Considering that optical interferometry is still in the infancy and that its use with large telescopes will likely meet initial difficulties, this is a necessary step if interferometry is ever to be done with the VLT.

The general arrangement which came initially out of these considerations is illustrated in fig. 2. It consists of a massive and stable base on which the telescopes and the instrumentation laboratories rest. A surrounding independent structure reaches the level of the Nasmyth platforms so as to provide easy access, and to insulate the telescopes from the effects of the structures underneath.

Upwind, a fixed wind screen provides protection for the telescope against high wind loads. The top of the screen consists of movable deflectors that can extend the screen upwards, while being folded down when the telescope is pointing in their direction, in order not to interfere with the line of sight. The day-time protection is achieved by movable shelters that have at their back a system of louvers which will let the airflow through when the telescopes are in operation, so that turbulence created by the presence of the shelter is minimised. A gantry crane can serve all the telescopes, during the construction as well as later for maintenance.

The configuration described above was then our real starting point. It has been further analysed and precised, in some cases modified, as it is described in the next paragraphs.
Figure 2: Artist’s impression of the first concept of the VLT enclosure
3 The present concept for the VLT enclosure

3.1 The base structure - telescope pillars and laboratories

The core of the VLT configuration is constituted by the telescopes with their pillars and the laboratories and control rooms necessary to perform the observations.

The optimum distance between the telescopes is still being evaluated. On the one hand it is clear that compactness of the array limits the infrastructure cost. On the other hand, constraints are set by application and operational requirements. Interferometry in particular may set requirements on telescope spacing; at the present stage, however, no definitive conclusion has yet been reached.

The two possibilities envisaged here are:

1. In the first option the four telescopes are placed approximately equidistantly and close to one another. From the preliminary design specifications of the telescopes it appears that the possibility of independent observation of two contiguous telescopes requires a minimum distance of about 30 metres. At the centre of the array, however, the Coude laboratory imposes a minimum distance between telescopes 2 and 3 of about 38 metres.

2. In the second option the telescopes are placed at distances approximately in ratio 1:3:2, which appears in principle desirable for interferometric measurements. In order not to extend excessively the baseline it was proposed for this preliminary study to set the distances at respectively 30, 75 and 50 metres. The possibility of mobile telescopes, which is also being discussed by interferometricists, has not been explicitly considered in the present enclosure designs of the VLT, but has been beared in mind. At least for the case of point to point translation of a telescope, adapting of the enclosure design should not present excessive problems (see for instance fig. 10 at page 30).

The final choice of the distances between the telescopes will have an effect on the actual configuration of the VLT complex and also on the cost but will
not affect the basic layout concept. Therefore all options can be considered in this phase of the study.

The bases or pillars of the telescopes are concrete structures of cylindrical shape. The diameter, as required for supporting the telescope, is about 16 metres. With such large diameter a very high rigidity can be achieved with a relatively light structure. For a preliminary dimensioning a bending rigidity (EI) of \(5 \cdot 10^{12} \text{Nm}^2\) (e.g. ten times the value taken for the ESO NTT) was specified, which results in a cylindrical wall in reinforced concrete of 30 cm thickness.

A mirror assembly for beam recombination is placed inside the base (Fig. 3). Thus from strictly functional requirements the minimal height of the base would be about 4 metres. In fact the altitude axis of the telescope may have to be placed about 20 metres above the ground so that the optical performance is not affected by the higher wind and thermal turbulence normally present close to the ground. In this case the height of the pillar, considering the likely size of the telescope yoke (9-11 metres) should be about 10-12 metres. An analysis of ground induced seeing and near ground wind turbulence will ultimately fix this distance.

Concerning now the laboratories we note that in the array mode two types of observations will be possible with the VLT (see fig. 4):

1. Incoherent beam combination at the combined Coudé focus, placed near the centre of the array. The combined beam is then directed to a measuring instrument.

2. Interferometric measurements on a table moving parallel to the array.

In each case a dedicated building has to be foreseen.

Thus we are led to a principle configuration which consists of the following elements:

- The four pillars, aligned but for the minimum distance (1-2 m) to allow the light beam from the extreme telescopes through the intermediate ones.

- The Coudé lab, 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
Figure 3: Optical configuration of a telescope and the Coudé beam.
combination of the four light beams takes place in the centre. At least four major instruments may stand permanently in the four rooms to receive the combined light beam.

- The control room, in fact a building which also will include some storage and spare room, located near the centre of the array beside the Coudé lab. The actual location of this building depends on the distance available between the two central telescopes. If this distance is greater than 65 m, as it would be the case with the 1-3-2 configuration, it will be convenient to place the complex Coudé control in the sense of the array (fig. 5a). If this distance is smaller it is possible to place it transversally, with the control room being above the interferometric lab (fig. 5b).

- 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.
Figure 4: Beam combination with the VLT array.
Figure 5: Two possible configurations for the VLT base structure.
3.2 Wind screen and platform - aerodynamics considerations

As it was described in §2 the concept proposed for the VLT assumes that the wind is able to flow through the telescope, thereby increasing the heat transfer from the telescope components and sweeping it away at the same time, thus having a positive effect on the optical performance of the system.

The wind, however, will also cause loads on the telescope structures and drives and the dynamic effect of wind turbulence may significantly affect tracking accuracy.

At the present stage only a preliminary evaluation of wind loading and its effects has been done [3]. This analysis shows that if the drives and the control system can be designed to compensate both the quasi-static effects and any dynamic effect of the wind with frequency up to, say, 2 Hz, the dynamic response of the structure should not be greater than 1.2% of the uncorrected static deflection for the case of a mean wind speed of 9 m/s; even when the mean wind speed is of 18 m/s, this value reaches about 5%, which should still give an acceptable tracking accuracy.

A wind screen in front of the telescope would only slightly increase the tracking accuracy but more significantly reduce the static torque to be taken by the drives. Concerning wind loading on the main mirror, which is actively supported and therefore to some extent self-correcting, the main disturbing effects may come from the turbulence created by the flow passing through the tube structure. Reducing mean wind speeds by the wind screen should greatly decrease this problem.

A more conclusive analysis can be done, in particular by means of wind tunnel tests, when both the site wind conditions and the telescope structures are better defined.

Therefore, in order not to penalise excessively the telescope structure design, which has already quite ambitious and severe requirements, a limit has been tentatively set on the incident wind velocity on the telescope. The preliminary analysis of wind conditions and their effect on the telescopes [3] 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 either removed and set horizontally or, if a fixed frame is used, its panels are tilted to make as little drag as possible. Both technical solutions are described in §5.7 below.

From published experimental studies [4] in wind tunnels it results that an adequate performance with respect to the criterion of halving mean wind velocities is achieved by a screen with approximately 50% geometric permeability, placed in front of the object at a distance at least 1.5 times its height and slightly higher (by 20-25%) than the object to be protected.

In the initial concept we came to define a large surrounding platform at about the level of the Nasmyth platforms of the telescopes as a solution to various requirements: ease of access to the telescopes, support and closing floor for the movable shelters, separation and insulation from all thermal sources in the laboratories underneath, support for the wind screen. Continuing in this line of thought we considered that this platform could in fact be supported by columns only, letting part of the wind flow pass underneath.

There are several principal advantages in this solution:

- The air layers nearer the surface, which have the largest turbulence values and the largest velocity and temperature gradients, are captured under the platform. Also the wind screen will start from the platform level, so that the flow underneath is as unhindered as possible.

- The presence of the platform isolates the atmospheric environment of the telescopes from all thermal and aerodynamic effects of the ground and other buildings in the vicinity. These effects are potentially damaging for the seeing and often difficult to clearly identify and control.

Aerodynamic and thermal considerations are important in the platform
Figure 6:

Histograms of wind velocity-direction correlation for one year of data measured on Mount Paranal at a height of 10 metres above mountain top. Each line connects points that define the percentage wind stronger than the given mean wind velocity from a 10 deg sector. One recognises the dominant north wind typical of the region. The S-E (130 deg) peak appears to be a seasonal feature.

During the same period the frequency of mean wind velocities from all directions was:

- $V \geq 3\text{ m/s}$: 83.7%
- $V \geq 6\text{ m/s}$: 56.6%
- $V \geq 9\text{ m/s}$: 31.8%
- $V \geq 12\text{ m/s}$: 14.9%
- $V \geq 15\text{ m/s}$: 6.1%
- $V \geq 18\text{ m/s}$: 2.2%
design, as this is (with the wind screen, which in principle is effective only in case of strong winds) the only structure which may affect the wind flow on the telescope. Wind tunnel tests will be required to analyse these effects in detail. With respect to thermal considerations, the main requirements are a low thermal constant for the surface and, in thermal equilibrium conditions, minimal temperature differences with ambient air both during the day and during the night. A discussion of the thermal aspects in the design of the VLT enclosure is found in ref.[5].

From the structural point of view, the actual definition of the platform is dictated by the support requirements for the telescope shelters and the gantry crane. Depending on which type of shelter is finally chosen, the platform may be quite different structurally, as will be described in §5.9 below. The configuration will also depend on the spacing between the telescopes. If the telescopes are closely spaced then the platforms around the single telescope will be contiguous and the configuration will remind closely the initial concept of fig. 2. Otherwise the slabs around the telescope will also be spaced and only the rails of the gantry crane will connect the structure.

We have set tentatively the height of the platform surface at 15 metres above the ground reference level. This assumes that the altitude axis of the telescope is at 21 m (cf. fig. 3) and allows then a minimum clearance (about 1 m) between the telescope tube set in horizontal position and the platform surface, therefore minimising the volume required for the shelters. For the case where the telescopes are closely spaced and the surface slab is one continuous element, the height of 15 meters leaves also abundant space for laboratories and control rooms (cf. fig. 5) without hindering the flow under the platform.

Numerical simulation of air flow through this VLT arrangement were performed by means of a fluid flow finite element model [14][6]. The model, in two dimensions, represented a cross-section of the VLT enclosure in open position, with the platform, the wind screen and the movable shelters (cf. §3.3 below) in removed position. Different configurations were analysed, where the main parameters have been modified. The objectives of the study were to compute the profiles of air velocity, turbulence and temperature in the telescope region.

A typical result is shown in fig. 7. The finite element model, in two dimensions, represents a cross-section of the VLT enclosure in open position, with the service platform, the wind screen and the movable shelters in removed position. Different configurations were analysed, where the main geometric
parameters have been modified. In this analysis, a wind screen rising 24 metres from the platform level, itself 12 metres above ground level, and placed 36 metres in front of the telescopes was considered. Note the "quiet" region behind the screen.

These simulations indicated in particular that the presence of movable shelters removed downwind from the telescope does not affect significantly the flow conditions near the telescope. The height of the service platform appears to have some effect on wind screen efficiency: the higher the platform, the more effective is the wind screen in reducing wind velocities, and also the turbulence is reduced in most of the region near the telescope.

The results of the model, also, showed a strong dependency on the slope of the input velocity profile and on the amplitude of the vertical velocity component. It will then be important to get measurements of these parameters on sites before drawing more definite conclusions from the finite element model.
Figure 8: Profiles of mean wind velocity (a), turbulent velocity (b) in the telescope region behind the wind screen.
3.3 Telescope shelters

Movable roll-off shelters are a convenient solution to protect the telescopes during down-time and seal them from precipitations. The shelters are supported by the platform defined in the previous paragraph. They have a door at each end which tilts down on the platform to let the shelters move away from the telescopes with both ends totally open so that any air turbulence generation is minimised.

In order to minimise the cost of these structures each telescope should be sheltered with the tube in horizontal position.

If this was not acceptable, for telescope maintenance requirements for instance, larger shelters are envisaged, with an internal volume sufficient for telescope movement. These larger shelters are, however, quite heavier and more expensive because of the larger wind loading. They would also require a quite heavier support structure. In this case, also, the minimum distance possible between adjacent telescopes would increase to about 32 metres, unless really huge shelters are made which can accommodate two telescopes. Therefore a careful trade-off will be required to verify whether the advantages of a larger volume pay for the additional cost. Both options are described in some detail below in §5.6.1.

As a low-cost and light-weight alternative to movable shelters, inflatable domes are proposed. Such a dome (fig. 9) is constituted by a double wall fabric hemisphere supported by rigid hoops that open and close 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, mainly according to the wind load acting in the structure. When opened the shelters are completely stowable within the platform structure.

Inflatable shelters would be much cheaper than the movable ones. As they are also much lighter (45-60 tons against 200-400) and they are stored around the telescope, when in open position, some savings can also be made in the supporting structure. Although the design of the inflatable shelters can profit of the considerable experience that exists already with large antenna facilities, which have similar requirements, it must be noted that their application to telescopes, where frequent openings are required, is a novel concept which will require some further studies and tests to be assumed definitely as the optimal
Figure 9: Inflatable dome arrangement with one telescope.

solution for the VLT.

A summary description of these shelters is found in §5.6.2 below. Inflatable shelters have been defined likewise in two sizes, assuming respectively that the telescopes are stored horizontally or free to operate under shelter. It must be noted, however, that the choice of inflatable shelters, because of their hemispherical shape, slightly increases the minimum spacing between telescopes with respect to a solution with movable ones, unless it is assumed that two close telescopes are sheltered by a very large unit.
4 General configuration

The main aspects of the VLT enclosure have been identified and described in the previous paragraphs.

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. A platform-like structure will surround each telescope at a level about 6 metres below the elevation axis, providing access, support for the shelters and the crane, and some insulation from thermal and aerodynamic influence of the ground and underneath structures. In front of this platform, in the upwind direction, a wind screen will protect the telescope array in case of strong winds.

The single components of this concept are then described in some more detail in §5 below.

It must be noted that within this general concept, many possibilities and options are open as the VLT project is still at a too early stage to freeze a definite configuration. Among the open points the most important, for their many-sided implications on the VLT enclosure, are:

1. Distance between the four telescopes.
2. Small or large telescope shelters.
3. Movable or inflatable shelters.
4. Optimum height of the telescopes with respect to the ground. The actual height of the telescope pillars is of course related to the geometry of the telescope fork.

The first two points are essentially a question of weighing desired operational requirements against cost. The third point is mainly a matter of technology development to save cost and is also related to the previous points. The fourth point is a question of evaluating optimum seeing conditions, and the general aerodynamic behaviour and weigh it with the cost of the required structures. Measurements of site conditions and wind tunnel tests should provide most answers to this point.
Therefore, different configurations will be presented in the next figures, which illustrate some of the different options available (see also drawings A.1.1 and ff. in appendix A).

Some vertical dimensions have been tentatively fixed in all cases illustrated, although they could be varied with little impact on the rest of the configuration: it has been assumed that the telescope elevation axis is 21 metres above the ground reference level and that the platform height is set at 15 m. The wind screen height is 24 m from platform surface. The removable type of wind screen (cf. §5.7) is used for all illustrated cases.
Figure 10: Photograph of a model of the VLT configuration with movable shelters, with 30-75-50 telescope spacing. A possibility to have one telescope movable for interferometric measurements in the normal direction is illustrated in the drawing beside.
Figure 11: Photograph of a model of the configuration with inflatable shelters, with compact telescope spacing.
5 Description of the components of the VLT enclosure

Here follows a summary description of all components of the VLT enclosure complex.
A proposal for a formal general specification is found in appendix B.
Please note that frequent reference is made to the drawings included in appendix A.

5.1 Telescope pillars

A circular base of 16 m diameter is required for the telescope pillars. Three options are envisaged for the reinforced concrete structure of the telescope pillars (drawing A.2.1).

1. Standard cylindrical shell of thickness 30 cm.
2. Open frame, which lets the interior of the pillar open, thus avoiding that it becomes a heat sink and with possible advantages with respect to cooling of equipment.
3. Twelve-sided cylinder made of pre-fabricated elements.

Drawing A.2.2 illustrates with some more detail the configuration of the first option with, in particular, a service platform for maintenance purpose and an access door 2×3 m.
5.2 Coudé lab

The Coudé lab is situated aligned with the array, between telescopes 2 and 3, rising from the reference level.

Dimensions of the internal space: Length: 20 m
  Width: 20 m
  Height: 5 m

This building is articulated in 4 instrument spaces (10 × 10 × 5 m) around a central hole (diameter 3 m, depth 3 m) which, like the floor, is unconnected to the main structure. Four removable partitions may effectively separate the instrument spaces. Catwalks allow to reach the 4 instrument spaces. Thermal control and stable conditions are achieved by a cooled floor. In the solutions presented in drawings A.3.1/2, main walls, slabs and beams are pre-fabricated elements in reinforced concrete. As an option the structure may be reinforced so that 1-m thick concrete blocks can be placed on the roof to screen cosmic rays.

5.3 Control room

The control room is situated beside the Coudé lab, either along the array (drawing A.3.2) or transversally (drawing A.3.1) passing above the interferometric lab.

Main dimensions: Surface 200 m²
  Height 3.2 m above the false floor
  (plus 30 cm false floor)

In the solution presented here main walls, slabs and beams are pre-fabricated elements in reinforced concrete.
Access is possible from the Coudé lab catwalks by staircase and elevator.
Two 100 m² storage and service rooms are situated at the same level as the control room. Another storage room is situated underneath at the ground level.
5.4 Interferometric lab

The interferometric lab consists of a long building situated parallel to the array. Its actual length will depend on the total distance between the four telescopes. Here a length of 185 m, corresponding to a configuration preferred by interferometrists, is assumed.

In the solution presented in drawing A.4, main walls, slabs and beams are pre-fabricated elements in reinforced concrete with good insulating qualities.

The ground slab consists of three parts: two working spaces (2 x 185 m telescope-side and 3 x 185 m on the opposite side) separated by a ground slab laying on cork aggregate for optimal damping receiving the interferometric table.

One entrance is situated at one end, with four more doors (2 x 2.5 m) near the incoming light beams. A cooled floor will ensure thermal control and a stable environment. Walls and slabs will be painted, a special anti-dust paint being used on the floor.

5.5 Mirror maintenance building

A building for mirror maintenance will be part of the VLT complex, being, however, relatively independent from the other elements and its location will mainly depend on the ground configuration.

Dimension of the internal space:  
Length 52 m  
Width 14 m  
Height 6 m

The building is divided in 4 sections:

1) Storage: $12 \times 14 \times 6$ m
2) Cleaning: $12 \times 14 \times 6$ m
3) Aluminising: $20 \times 14 \times 6$ m
4) Services: $8 \times 14 \times 3.50$ m for pumps and other equipment.  
$8 \times 14 \times 2.25$ m at first floor for offices.

In the solution presented in drawing A.5, main walls, slabs and beams are pre-fabricated elements in reinforced concrete. A travelling crane (SWL 25 tons)
will allow the handling and the transport of the mirror from the storage to the aluminising section. The mirror will be in horizontal position, face up in all phases. It is presently envisaged to aluminise the VLT mirrors with the spattering process which requires a relatively low aluminisation tank. The general sequence of operations will be as follows:

1. The mirror, still with its cell, is placed in the storing room.
2. Separation of the mirror, the cell stays in the storing room.
3. The mirror is carried in the adjacent cleaning room and laid down on a fixed support.
4. Cleaning of the mirror from a cleaning module, moving above the mirror, which includes cleaning products, the required equipment (pumps) and space for one or two operators and is attached to the crane.
5. The mirror is raised and then placed in the bottom of the aluminisation tank, which can move on rails.
6. Aluminisation of the mirror.
7. Opening of the tank and transport of the mirror to the storing room for re-integration in the cell.

Special requirements for the cleaning room:

- Sealed partitions with neighboring sections
- Ventilation with filtered air.
- Supply of distilled water.
- Floor and walls with anti-dust and anti-acid coating.
- Water exhaust on the floor.
- Floor and walls coated with anti-dust paint.
Figure 12: Schematic of mirror maintenance building for the VLT.
5.6 Telescope shelters

Here follows a description of both types of shelters presently envisaged: movable and inflatable. The feasibility study for the movable shelters [8] was performed by the firm DANALITH, Copenhagen; for the inflatable shelters [9] by SODETEG, Paris.

5.6.1 Movable roll-off shelters

These shelters are made of a movable steel structure with a rectangular plan view. The support structure consists of transverse frames constructed as lattice work. Longitudinally the frames are interconnected by bracing. All the frames are supported on wheels and there must be motors on all wheels to ensure a sufficient safety margin at high wind loads. The maximum velocity will be about 0.28 m/s so that the shelters can be moved to or from the telescopes in less than 3 minutes.

The roof and wall cladding are either a sandwich construction assembled on the site or factory assembled composite units. Each shelter has two large doors hinged on the platform at both front and back ends (drawing A.6.3). In closed position the doors are set vertically and seal the telescope inside, also effectively locking the shelter during excessive wind loading. During observation the doors lay on the platform and the shelter is removed with both ends open so that the wind flow can pass through as undisturbed as possible. Two alternative sizes are considered:

1. The small shelter which requires that the telescope is positioned for sheltering in horizontal (or near) position. This is presently the nominal configuration.

2. The large shelter, which allows the telescope to be operated freely inside the shelter. For this type of shelter, lifting doors as shown in drawing A.6.4 were also proposed as there is sufficient space for stowing.
Small shelter
Main dimensions and data, see also drawing A.6.1:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
<td>26 m</td>
</tr>
<tr>
<td><strong>Width</strong></td>
<td>28 m external, 24 m free internal</td>
</tr>
<tr>
<td><strong>Height</strong></td>
<td>17.5 m external, 15.5 free internal</td>
</tr>
<tr>
<td><strong>Main frames</strong></td>
<td>6, for 12 wheels diameter 0.4 m</td>
</tr>
<tr>
<td><strong>Roof shape</strong></td>
<td>arch, radius: 19 m</td>
</tr>
<tr>
<td><strong>Access doors</strong></td>
<td>2, tilting, hinged on the platform</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>168 tons, without doors</td>
</tr>
<tr>
<td><strong>Door weight</strong></td>
<td>17 tons per unit</td>
</tr>
<tr>
<td><strong>Power required</strong></td>
<td>peak 70 Kw, can be reduced if a slower movement is accepted</td>
</tr>
</tbody>
</table>

Large shelter
Main dimensions and data, see also drawing A.6.2:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
<td>32 m</td>
</tr>
<tr>
<td><strong>Width</strong></td>
<td>32 m external, 30 m free internal</td>
</tr>
<tr>
<td><strong>Height</strong></td>
<td>24 m external, 23 m free internal</td>
</tr>
<tr>
<td><strong>Main frames</strong></td>
<td>7, for 14 wheels diameter 0.63 m</td>
</tr>
<tr>
<td><strong>Roof shape</strong></td>
<td>ridge, 15°</td>
</tr>
<tr>
<td><strong>Access doors</strong></td>
<td>2, tilting or lifting</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>386 tons, with doors</td>
</tr>
<tr>
<td><strong>Power required</strong></td>
<td>peak 90 Kw, can be reduced if a slower movement is accepted</td>
</tr>
</tbody>
</table>
5.6.2 Inflatable shelters

Each inflatable shelter consists of a double wall fabric hemisphere supported by rigid hoops that open and close in two symmetrical parts.

Three types of hoops are used for supporting the fabric, see fig. 13:

- 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.

Each of the two sections of the double-wall cover consists of nine inflatable ribs of lenticular cross-section (fig. 14). This 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.

Blowers provide pressure both inside the shelter and in the double cover (which is slightly overpressured with respect to the interior). The inflation pressure must vary according to the wind speed, the principle being that the internal pressure remains at all times greater than the wind dynamic pressure so that no instabilities may occur on the surface. Fig. 15 shows the types of pressure and deformation distribution for several values of the ratio \( \frac{P_i}{q} \) of the internal pressure to the wind dynamic pressure.

The hoop hinges will be set close to the platform level, so that when open and folded, the shelter is completely stowable within the platform, thereby minimising aerodynamic perturbations on the telescope. It must be noted, also, that as the hoop axes are necessarily slightly shifted with respect to one another and in order to ensure an optimum stowage of the cover, the plan view space required by the stowed shelter is slightly elliptic, with the hoop hinges on the shorter axis. From the point of view of wind
Figure 13: Framework for inflatable shelter

Loading during opening/closing operations it should be more convenient to set the hoop axis normally to the main wind direction. In case of strong wind the upwind half can be raised first, protecting then the operation of the second half. Main dimensions and data:

<table>
<thead>
<tr>
<th></th>
<th>30 m, small shelter</th>
<th>38 m, large shelter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>diameter/2</td>
<td></td>
</tr>
<tr>
<td>Space required</td>
<td>ellipse area with axes approximately 30 and 36 m, small shelter 38 and 45 m, large shelter</td>
<td></td>
</tr>
<tr>
<td>Power required</td>
<td>peak 70 Kw, average 20 Kw, plus eventual air conditioning 30 Kw</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>45-60 tons</td>
<td></td>
</tr>
</tbody>
</table>
Figure 14: Double wall cover (schematic)
Figure 15: Pressure and deformation distribution around a half spherical inflated structure
5.7 Wind screen

As described in §3.2 above the present definition for the wind screen is a 50% semi-permeable structure rising to about 24 metres from the platform and wide enough to shield the telescopes without edge effects. The screen elements are supported by an independent steel frame structure with braced columns (eventually anchored by guys) spaced about 20 metres.

Two concepts, removable screens and louvers, have been investigated in a feasibility study [11] performed by the firm NEYRPIC, Grenoble, France, while a concept based on self-adjusting louvers has been proposed by V. Caramaschi [15] :

5.7.1 Removable screens

This solution, which is presently the preferred one, is constituted by fixed elements that are set in position or removed horizontally on the platform level, according to the principle shown in fig. 16. The screen permeability cannot be varied but this solution has the advantages that low winds are left undisturbed, as in such cases the screen is removed, and that it is not exposed to storms, hence saving structural weight and cost. 20-metre wide elements are presently envisaged, each with a weight of about 35-40 tons. Each screen element is made of a frame which integrates panels made of 1-m wide plates with a 2-m spacing (drawing A.7.1, which, however, shows a 40-m element). The power required to move one screen element is about 20 Kw. Eight 20-metre elements are required for the compact VLT configuration, while nine should suffice for the 30-75-50 configuration, leaving a gap between telescopes 2 and 3 (cf. drawing A.1.1).

5.7.2 Orientable louvers

In this solution the whole screen frame is fixed and a variable permeablibty is obtained through the orientation of louvers. In the basic configuration the louvers are constituted by 1-m wide plates spaced by 2 m (drawing A.7.2).

The louvers rotational axis can be either horizontal or vertical. With a vertical axis, maintenance is facilitated, as the louvers operating device is at the platform level; while with horizontal louvers one has more flexibility in varying the screen permeability at different heights. In each case the louvers solution is
Figure 16: Principle of removable wind screen operation.
likely to require greater mechanical complexity with respect to the removable screens.

5.7.3 Self-adjusting louvers

This concept is an evolution of the previous one. The idea is to incorporate into the wind screen a series of hinged wings, which, moving to an equilibrium position between the aerodynamic pitching moment and a spring restoring moment, would create a number of convergent-divergent ducts to the wind; stopping partially the convergent paths, the air flow is constrained through the divergent ones. By choosing adequately geometric parameters, spring moments and adding a damping device, one could in principle realise a system where the permeability would automatically decrease with increasing wind velocity without active intervention. However, some disadvantages for this solution arise as a reliable theoretical evaluation is difficult and wind tunnel tests are required even for a preliminary dimensioning.
5.8 Gantry crane and other lifting equipment

The gantry crane is foreseen essentially for the installation and maintenance of the telescopes. A preliminary study [13] was performed by the firm DELTA MARINE, Gouda, NL.

The main requirements for the crane are:

- Safe working load 40 tons. This in the hypothesis that assembling of the telescope will take place on the site. If major elements (the tube or the yoke) were to be transported already assembled the SWL required would likely be of the order of 100 tons.

- Span 32 m. However, if inflatable shelters are assumed the span must be increased because of the stowage space for the hoops and the folded cover to about 41 or 48 metres, respectively for the small and the large shelters.

- Clearance under hook 3 m above top of telescope. With the latitude axis placed about 6 metres above the platform and assuming a radius of about 12 metres, this would make about 22 metres.

See drawing A.8 for an assembly view of the crane. The gantry crane is presently preferred to a mobile crane, of the type sketched in fig. 18 below, although this might be more flexible of use. The mobile crane as envisaged for the VLT would have a lifting capacity of 50 tons at a lifting height of 20 m (such cranes can reach also very high lifting heights, of course with decreasing load capacity) and would possibly weigh about 190 tons. On the negative side, however, larger arm oscillations which may be a problem during telescope construction and maintenance, and a cost about double that of the gantry crane.
For transporting personnel and small loads up to the telescope level, a series of lifts will be installed near each telescope. The type shown in fig. 18 below, proposed by SODETEG, Paris, is a rack type with a payload from 1000 to 2000 Kg according to the model. Power consumption is about 20 Kw per lift.
Figure 18: Lift
5.9 Service platform

Two alternative solutions for the service platform around the telescopes are presented here. The first one was conceived by the firm DELTA MARINE, Gouda, NL, [12] for the configuration with movable shelters. The second one, by the firm SODETEG, Paris, [10] is designed more specifically for the inflatable type of shelter.

For the cases with the movable shelters, the presently preferred construction consists of a framework of steel beams (I profiles up to 1 metre) supported by cylindrical 1-m diameter columns also in steel. The main set of beams is specifically designed to carry the load of the movable shelter and the gantry crane respectively, while a number of secondary beams carry the load of the tilting doors and provide support for the slab elements for service areas around the telescope.

Fig. 19 shows for instance the framework design for the 30-75-50 spaced configuration: according to the preliminary design about 740 tons of steel beams are required. The quantity of steel required for columns depends on the platform height: for 15 metres, this would make 260 tons. Several alternatives have been investigated for the slab elements and the present choice is for steel profile sheeting as shown in fig. 20, which can carry a load of about 200 Kg/m² with a maximum span of the order of 6-7 metres. Service paths for heavier loads can be arranged along the beams.

For supporting the lighter inflatable shelters a lattice structure made of rolled elements is proposed both for beams and columns (see for instance fig. 9 at page 27). As covering slab for service areas, corrugated steel sheeting or grating can be suitable. A schematic plan view for one unit is shown in fig. 21 below. The inflatable shelter is stowed in a recess formed of a peripheral structure all around the platform central hole and a floor, supported by short cantilever beams toward the inside of the hole. This floor is designed to be easily air-tightened.

With this relatively light structure a self-lift erection system will be possible as illustrated in fig. 22.
Figure 19: Framework design of the service platform for 30-75-50 configuration with movable shelters

Figure 20: Steel profile sheeting for service areas
Figure 21: Schematic plan view for 1 unit of the lightweight platform for inflatable shelters
Figure 22: Self-lift erection system
6 Acknowledgements

The present report is in great part a synthesis and an integration of several feasibility studies contracted by ESO. Therefore we wish to thank here all the persons at ESO and external contractors who contributed to the present definition of the VLT enclosure. We thank in particular J-L. Baldy and J. Rouel of CERN, Geneva; P. Sondergaard of DANALITH, Copenhagen; P. Lambert and D. Milan of NEYRPI, Grenoble; D. den Hertog and J. G. Vogtlander of DELTA MARINE, Gouda; A. Bonneau and D. Saccomani of SODETEG, Paris; J. Hertig and M. Beniston of EPFL, Lausanne; A. Decamps and C. Fol, civil engineers, Paris and Geneva.
References


Contract reports of VLT feasibility studies


APPENDIX

A  Drawings
A.1 General views

A.1.1 General arrangement of VLT enclosure
A.1.2 30-75-50 configuration with inflatable shelters
A.1.3 Compact configuration with inflatable shelters
A.1.4 Configuration with movable shelters and one mobile telescope
A.2 Telescope pillar

A.2.1 Options
A.2.2 Option 1 (reinforced concrete shell) with internal equipment
A.3  Coudé lab and control room

A.3.1  Option 1 (for close-spaced telescopes)
A.3.2  Coudé lab and control room
Option 2 (for 30-75-50 metres spaced telescopes)
A.4 Interferometric lab
A.5 Mirror maintenance building
A.6 Movable shelter

A.6.1 Small shelter
A.6.2 Large shelter
A.6.3 Tilting door for telescope shelter
A.6.4 Lifting door (large shelter only)
A.7 Wind screen

A.7.1 Removable screens
Les fondations verticales sont IPE 600.
Les fondations horizontales sont HEA 800.
Les piliers verticaux sont verticaux.
A.7.2 Orientable louvers
A.8 Gantry crane
Safe working load 40 t 100 t
Hoisting speed 5 t x 20 m/min 5 t x 20 m/min
40 t x 0.5 m/min 100 t x 0.5 m/min
Trolley traveling speed 1/10 1/10
Crane traveling speed 2/20 2/20
Length of crane track 190 + 15 m
Wheelload max. ± 575 kN
Total weight of crane 87 t / 80 t

PROJECT feasibility study of a large platform for the ESO
Very Large Telescope

SUBJECT gantry crane

delta marine consultants bv
1 H J Posthumusstraat phone (0) 1820 - 10700
P.O. Box 268 tel-9209 - mbm@w
2600 AG Gouda mail: cassette delta mc gouda
The Netherlands
APPENDIX

B VLT enclosure and buildings
tentative specification
1 GENERAL REQUIREMENTS

1.1 Environmental conditions

1.1.1 Location - The VLT will be placed on the top of a mountain in a desertic area in northern Chile. The probable altitude is between 2500 and 3000 meters.

1.1.2 Humidity below 20% most of the time.

1.1.3 Temperature range -10 to +30 deg C.

1.1.4 Typical day/night temperature drop 10 deg C.

1.1.5 During the night air temperature changes up to 1 deg/hr.

1.1.6 Soil conditions
  - Quality of rock, solid but fissured.
  - Allowable stress:
    - Vertical static load, 50-100 N/cm²
    - Edge pressure under static 0.3 g earthquake load 200 N/cm²
  - Density, 2500-2800 Kg/m³
  - Static module of elasticity, 45000 N/cm²
  - Angle of interior friction, 45 deg
  - Natural humidity, 3-10%

1.1.7 Snow and ice load t.b.d.

1.2 Enclosure integrity

1.2.1 The enclosure must survive wind of velocity up to 69 m/s (250 km/hr) including gust and seal the telescope against all precipitations.

1.2.2 The enclosure must survive seismic shock 0.3 g horizontal and 1.1 g up-lifting.

1.2.3 All mechanisms and all materials must have high reliability and low maintenance requirements.

1.2.4 All metallic surfaces shall be corrosion protected compatibly with the low humidity environment expected.
1.3 Operational requirements

1.3.1 Maximum wind velocity for telescope operation, 20 min mean, 18 m/s (65 km/hr).

1.3.2 For wind velocities, 10 min mean, comprised between 9 and 18 m/s, the enclosure must reduce the effective wind velocity, 20 min mean, on the telescope structure to maximum 9 m/s.

1.3.3 The telescope shelters must be capable of being closed in a 28 m/s (100 Km/hr) wind with only the emergency power system.

1.3.4 Ditto for all mechanisms related to closing down.

1.3.5 All mechanisms must operate in air temperatures from -10°C to +30°C, with and without the full sun and specified ice load.
2 TELESCOPE SUPPORT AND MAINTENANCE REQUIREMENTS

2.1 Telescope pillar

2.1.1 The telescope pillar shall be made of a ring structure in reinforced concrete.
2.1.2 External diameter 16 metres.
2.1.3 Minimum internal diameter for free volume 10 metres.
2.1.4 Height from floor t.b.d. (envisaged between 4 and 12 metres)
2.1.5 The pillar shall accommodate a telescope load of 300 tons distributed along a 16-m diameter ring.
2.1.6 Bending rigidity $E_I > 5 \times 10^{12} \text{ Nm}^2$. Wind load effects on the telescope shall not rotate the top base of the pillar more than 0.1 arcsec in a 28 m/s wind.
2.1.7 Eigenfrequency greater than 20 Hz.
2.1.8 Ground slab (5 tons/m$^2$).
2.1.9 Access to inside - One double door at floor level 2m x 3m (WxH). Openings of diameter 1.2m for light beams.
2.1.10 Floor and internal walls coated with anti-dust paint.
2.1.11 A circular platform (for maintenance and access to the telescope) shall be foreseen 2 metres below the top base. Spiralling staircase for access.

2.2 Telescope shelters
(The small shelter is assumed)

2.2.1 The telescope will be sheltered with the tube in horizontal position. No movement of the telescope are allowed under shelter.
2.2.2 The design of the shelters shall be such that, when removed from the telescope, it will not affect the free wind flow in the region of the telescopes.
2.2.3 The outer surface shall be coated in order to reflect and/or re-irradiate a maximum of incoming solar radiation.
2.2.4 The heat transfer coefficient across the shelter shall not exceed 0.47 W/m$^2$ deg.
2.2.5 Emergency power system. -

2.3 Gantry crane

2.3.1 Safe working load 40 tons.
2.3.2 Minimum span 32 metres.
2.3.3 Clearance under hook 3 metres above top of telescope set at zenith.

2.4 Mirror maintenance facility (728 m$^2$)
2.4.1 Height 6 metres.
2.4.2 Storage section for disassembling of primary mirror from cage (168 m²).
2.4.3 Cleaning section with demineralised water supply, floor drain, anti-dust floor and walls (168 m²).
2.4.4 Aluminising section (280 m²).
2.4.5 Service section for pumps and other equipment (112 m²).
2.4.6 25 tons travelling crane for mirror handling between storage, cleaning and aluminising sections.
2.4.7 Large access door to storage section
2.4.8 Total power requirements 250 Kw.
2.4.9 Supplies:
- electricity 380 and 220 V
- compressed air
- chilled water (5 deg C), 1000 litres/hour.
- argon
- liquid nitrogen (100 litres for an 8-hour operation) with exhaust pipes.
2.4.10 Special supplies for cleaning section: filtered air, demineralised water.
3 SPACE REQUIREMENTS: OBSERVING SUPPORT

3.1 Control room (200 m²)
  3.1.1 Air conditioned (50 Kw).
  3.1.2 Height above false floor 3 metres.
  3.1.3 Space for control consoles of all four telescopes, computer, electronics.
  3.1.4 False floor for cables.
  3.1.5 Anti-static carpeting over the false floor.

3.2 Coude lab (400 m²)
  3.2.1 Height 5 metres.
  3.2.2 Divided in four square sections 10 x 10 m, separated by movable partitions, accessed by four double doors W 2.5 x H 2.5 m.
  3.2.3 Central hole, diameter 3 m, depth 3 m.
  3.2.4 Independent ground slab.
  3.2.5 Climatisation by cooled floor. Average air temperature between 10-15 deg C, stable +/- 0.5 deg.
  3.2.6 Supplies: electricity 380 and 220 V, compressed air, chilled water (5 deg C) for instrument cooling (16 Kw).
  3.2.7 Exhaust pipes for nitrogen.

3.3 Interferometric lab
  3.3.1 Internal dimensions: width 6 m, height 3 m, length equal to distance between extreme telescope plus 30 metres.
  3.3.2 Independent ground central slab, width 1.5 m, for the interferometric table.
  3.3.3 Climatisation by cooled floor. Average air temperature between 10-15 deg C, stable +/- 0.5 deg.
  3.3.4 Supplies: electricity 380 and 220 V, compressed air, chilled water (5 deg C) for instrument cooling (16 Kw).
  3.3.5 Exhaust pipes for nitrogen.

3.4 Storage and service rooms (200 m²).
4 FACILITY SUPPORT (IN CASE OF AN UNDEVELOPED SITE)

4.1 Water storage system.
   4.1.1 2 tanks 100 m³.
   4.1.2 Distribution network.
   4.1.3 Preparation plant.
   4.1.4 Pumping station.

4.2 Septic system.

4.3 Power supply
   4.3.1 3 diesel generators, 500 Kw each
   4.3.2 machine house –
   4.3.3 fuel tanks 300 m³ –
   4.3.4 switch gear –
   4.3.5 distribution network –
   4.3.6 stabilised no-break power –
   4.3.7 mobile emergency generator –

4.4 Camp
   4.4.1 Housing for 50 persons 820 m².
   4.4.2 Kitchen-restaurant 250 m².
   4.4.3 Ware-house 1000 m².
   4.4.4 Workshop 500 m².
   4.4.5 Offices 200 m².
   4.4.6 Solar heating plant.

4.5 Access roads

4.6 Air strip

4.7 Communications (radio)