

Appendix 1. The ELT Design Study

This appendix provides a brief descriptive of the Work Packages of the ELT Design Study. Work Packages are outlined in section A-1.1 and a more detailed description is provided in A-1.2 to A-1.10. The list of participants is provided in Appendix 2

A-1.1 Work Packages

WBS No	Descriptive Title	Leading participant	Short description and specific objectives of the task
01000	<i>Project Coordination & Management</i>	ESO	Overall coordination of the project, reporting to the EC. Operation of the Project Office. Project management and top level system engineering incl. management of interfaces. Verification and consolidation of technical and managerial data.
02000	Science requirements	INAF	Consolidation and prioritization of top level requirements applicable to 50- to 100-m visible and near-infrared telescope.
04000	Wavefront Control	ESO	Technical and managerial coordination of tasks No 04100 to 04800; reporting to Project Management.
04200	Metrology	ESO	<p>Objectives:</p> <ul style="list-style-type: none"> • Feasibility and performance of a metrology system for coarse alignment of the optics of an Extremely Large Telescope; • Feasibility and performance of low-cost position sensors for the phasing of segments. <p>Tasks: development, design, supply and testing of cost-effective metrology systems, in particular alignment systems and position sensors for the phasing of segments. Fabrication of 24 position sensors for WEB. Feasibility study for serial production and integration of up to 20,000 position sensors.</p>

04300	Position actuators	ESO	<p>Objective: feasibility of nm-accuracy, cost-effective segments position actuators.</p> <p>Tasks: development, design, supply and testing of actuators for the positioning of segments; supply of 18 position actuators for the Wind Evaluation Breadboard (04800); feasibility study for cost-effective serial production and integration of up to 10,000 units.</p>
04400	Characterization of image properties	ESO	<p>Objectives: quantify crucial system requirements in relation to science objectives.</p> <p>Tasks: Parameterization of image properties in relation to scientific requirements, error sources, design and fabrication constraints; determination and specification of most suitable parameters for the characterization of science image contrast.</p>
04500	High contrast imaging	ESO	<p>Objectives: identify and quantify extreme contrast imaging techniques (mainly for Exoplanets imaging and spectroscopy).</p> <p>Tasks: review, development of high contrast imaging methods. Identification of most promising techniques, performance evaluation (by way of simulations); implications on system / subsystems specifications.</p>
04600	APE (Active Phasing Experiment)	ESO	<p>Objectives: representative testing of control strategies and techniques.</p> <p>Tasks: Design, construction, laboratory and on-sky testing of a technical instrument emulating active wavefront control functions of an Extremely Large Telescope, including three distinct on-sky phasing techniques.</p>
04800	WEB (Wind Evaluation Breadboard)	ESO	<p>Objectives: quantify ability to cope with high frequency wind disturbances.</p> <p>Tasks: Design, construction, verification and on-site testing of a bench emulating 7 segments, including electromechanical support systems and support structures. The bench will eventually be exposed to wind flow on a representative observatory site (la Palma, Canary Islands, Spain), in order to ascertain the performance of the segments supports and control systems in relation to wind excitation, with a view to verifying that high spatial and temporal frequency wind disturbances can be controlled to acceptable accuracy.</p>
05000	Optical Fabrication	ESO	Technical and managerial coordination of tasks 05100 and 05200; reporting to Project Management.
05100	Silicon carbide prototypes	ESO	<p>Objectives: validate Silicon Carbide as a suitable substrate for segmented apertures, improve figuring techniques in relation to segment edge misfigure (eliminate the need for wasters).</p> <p>Tasks: fabrication and testing of 1-m class Silicon Carbide segments (up to 8 pcs): segments design and fabrication process optimization; evaluation of polishable overcoatings and alternatives to diamond slurries; control of high spatial frequency misfigure.</p>
05200	Optical finishing and edge control	UCL	Development of optical finishing processes for fast, cost-efficient removal of high spatial frequency misfigure on classical substrates and Silicon Carbide, with particular emphasis on the control of segment edge misfigure.
06000	Mechanics	ESO	Technical and managerial coordination of tasks 06100 to 06400; reporting to Project Management.

06100	Structural ropes	ESO	<p>Objective: improve stiffness of telescope structures (qualify alternative to steel ropes).</p> <p>Tasks:</p> <ul style="list-style-type: none"> • Define alternative material to steel ropes. • Define fittings and mechanical interfaces. • Define thermal compensation and tension control devices. • Define maintenance criticality and concept. • Define suppliers and costs.
06200	Composite structural elements	ESO	<p>Objectives: reduce structure mass at critical locations; improve structural performance (stiffness, safety).</p> <p>Tasks:</p> <ul style="list-style-type: none"> • Define alternative material to steel cylindrical pipes. • Define fittings and mechanical interfaces. • Define manufacturing and installation methods. • Define maintenance criticality and concept. • Define suppliers and costs.
06300	Magnetically levitated systems and linear drives	ESO	<p>Objectives: evaluate an alternative to friction drives, with a view to relaxing dimensional tolerances of an ELT kinematics, improving performance, reliability and simplicity of the kinematics control system.</p> <p>Tasks:</p> <ul style="list-style-type: none"> • Define an integrated solution of Magnetic Levitation, guidance and linear drives applied to ELT requirements. • Define different kinds of geometry. • Define Specifications for an eventual construction of a prototype. • Define maintenance criticality and concept. • Define suppliers and costs.
06400	Characterization of the friction drive and bearing	ESO	<p>Objective: characterize the performance of a friction drive solution (telescope kinematics).</p> <p>Tasks: design, fabrication and testing of a breadboard friction drive; provide cost estimate and potential suppliers for the production of several hundreds units.</p>
08000	Enclosure & infrastructure	Grantecan	Technical and managerial co-ordination of 08100 and 08300; reporting to Project Management.
08100	Enclosure concepts	Grantecan	<p>Objectives: conceptual design and characterization of enclosure concepts.</p> <p>Tasks: Specification, statement of work and follow-up of the conceptual design of 3 enclosure concepts. The design will include studies on cost and feasibility; analysis of structures, materials and mechanisms, in relation to size.</p>
08300	Wind studies	ESO	<p>Objectives: characterize and quantify wind buffeting on structures and optics.</p> <p>Tasks: Specification, statement of work and follow-up of wind studies. Computational fluid dynamics and wind tunnel test will be carried out. The influence of the enclosure type on the telescope performance will be studied from the mechanical point of view (wind buffeting on the primary mirror) and from the thermal point of view (air renovation in the telescope chamber).</p>
09000	Adaptive optics	INAF	Technical and managerial co-ordination of 09200 to 09600; reporting to Project Management.

09200	1st generation AO & MCAO design for ELTs	ESO	<p>Objectives: Develop a roadmap for the implementation of Adaptive Optics on a European ELT, incl. 2 conceptual designs, Single Conjugate (SCAO), Ground Layer (GLAO), and 1 straw man design of a dual-conjugate AO system for ELT.</p> <p>Tasks: Analysis of the Scientific top level requirements, and input interfaces, development of 2 conceptual and 1 strawman designs, review of the system trade-off, development of the two AO conceptual designs (SCAO, GLAO), organize 2 conceptual design reviews.</p>
09300	Large format, high density DMs R&D	ESO	<p>Objectives: development of large (2-4m) adaptive mirror solutions.</p> <p>Tasks: Specification and analysis of three possible large deformable mirrors with 100-50mm (DM-TEC 0), 25 (DM-TEC 1) and 10 mm (DM-TEC 2) actuator inter-spacing. Trade-off studies for the selection of the best type of actuators for DM-TEC 0 and DM TEC 2. Design and development of prototypes for DM-TEC 0 (actuator only), DM-TEC 1 and DM-TEC 2.</p> <p>Manufacturing of a 650 mm flat thin shell using double face large dimension polishing machine. Manufacturing of curved thin glass membrane mirrors involving slumping technique.</p>
09400	Novel AO concepts	INAF	<p>Objectives: develop AO concepts for high sky coverage down to visible wavelengths.</p> <p>Tasks: studies, at conceptual level, of novel concepts in Adaptive Optics, with particular focus on 1) wavefront sensing assisted by artificial Laser Guide Stars and 2) resolution of cone anisoplanatism in telescopes with apertures in the 50 to 100m range.</p>
09500	AO & MCAO simulations	ESO	<p>Objectives: Develop analytic and numerical simulation tools to support the design activities defined in WP 09300. Provide performance estimates of the SCAO, GLAO, dual conjugate AO for given input parameters provided by WP 09300</p> <p>Tasks: Analysis of the Scientific Top Level Requirements and input parameters. Develop the analytical and numerical simulation tools for the SCAO, GLAO, Dual conjugate AO systems for an ELT diameter of 60-100 m. Provides first order performance estimates for the strawman design review. Provide accurate performance estimates for each AO system at their respective conceptual/straw man design review.</p>
09600	Algorithms for reconstruction & control	INSU	<p>Objectives: optimize Adaptive Optics reconstruction algorithms and control; relax computing power requirements; provide Real Time Computer (RTC) conceptual designs for WP 09300</p> <p>Tasks: Define and analyse the AO system parameters (SCAO, GLAO, Dual Conjugate AO), define control and reconstruction algorithms, define Real Time Architecture estimate the RTC computing time, dimensioning using classical (full matrix) methods and identification of critical issues, development and analysis of new methods. Evaluate performance of algorithms, control and platform.</p>
10000	Observatory & science operations	ESO	Analysis of technical and scientific operational scenarii for an ELT.
11000	Instrumentation	UKATC	Technical and managerial coordination of tasks 11100 to 11300; reporting to Project management

11100	Point designs	UKATC	<p>Objectives: produce advanced point designs of up to three instruments.</p> <p>Tasks: utilizing results from DS38 pursue 3 conceptual designs in sufficient detail to establish their full scientific potential and their implications and requirements for the Telescope design. Candidate designs are:</p> <ul style="list-style-type: none"> • WFSPEC (Wide-Field seeing-limited or Boundary-layer-corrected Optical/NIR Spectrometer) • MOMSI (Multi-Object and Multi-field Spectrometer and Imager for operation with MCAO in the NIR/optical) • MIDIR (Mid-IR spectrometer and imager).
11200	Other design prospecting	UKATC	<p>Objectives: produce instruments conceptual designs.</p> <p>Tasks: pursue Phase A studies of 8 instrument concepts to confirm the 3 selected in activity #11100, maximize understanding of telescope design impacts and scientific relevance, and provide broader perspective on ELT instrumentation requirements. Concepts include: WFSPEC, MOMSI and MIDIR, plus Planet Finder (XAO-coronagraphic instrument seeking terrestrial-sized planets, HiTRI (High time-resolution Instrument), HISPEC (very high spectral-resolution optical/NIR spectrometer), GRB-catcher (Imager-spectrometer for rapid response to transient phenomena) and SCUBA-3 (large-format submm imager). A survey for innovative new concepts will also be carried out.</p>
11300	Atmospheric Dispersion Compensation	UKATC	Initial study of Atmospheric Dispersion and its compensation will be carried out to inform the other Phase A studies.
12000	Site Characterization	Université de Nice	Objectives: define the 5 top astronomical sites suitable to install an ELT under best conditions, and characterize them. Review, discuss and synthesize the site observations.
12100	Review of site parameters space	Université de Nice	<p>Objectives: define standard site parameters for an ELT.</p> <p>Tasks: review the relevant parameters to fulfill the goals of an ELT, including but not limited to Adaptive Optics and Multi-conjugate AO.</p>
12200	Instrumentation, measurements and modelling	Université de Nice	<p>Objectives: design, build and operate standard site measurement equipment.</p> <p>Tasks: construct and set up an instrumentation adapted to fulfill 12100 requirements. Homogeneous, standardized measurements of these parameters at all the sites.</p>
12300	Large scale atmospheric properties	Université de Nice	Investigate wave front properties over large baselines (100-200m).
13000	System layout, analysis & integrated modelling	Lund University	Technical and managerial coordination of interfaces to other work packages, reporting to Project Management.

13100	Integrated modelling – development of tools	Lund University	<p>Objective: Establish integrated simulation tools to predict system performance under influence of disturbances from atmospheric turbulence, wind, gravity and temperature...</p> <p>Tasks: For a cluster computer, formulate algorithms, set up framework, code, and validate building blocks for integrated simulation of an Extremely Large Telescope including subsystems such as structure, control systems, telescope optics, adaptive optics, wavefront sensors, and deformable mirrors. Establish and validate models of atmospheric seeing and wind disturbances. Crosscheck models using control theory wherever possible. Establish ordinary differential equation solvers for large, stiff systems on cluster computers.</p>
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Table A- 1. ELT Design Study - overview of the Work Packages.

A-1.2 Wavefront control

This Work Package covers the development of essential, non-adaptive wavefront control technologies, the assessment of diffractive properties, and the development and evaluation of high contrast imaging techniques. All tasks in this Work Package are directly relevant to OWL and were indeed initially conceived as integral part of its development. They have been transferred into the ELT Design Study framework because of their relevance to any ELT design.

Internal Metrology – Any ELT will have to rely on internal metrology systems to guarantee coarse alignment of the optical surfaces and phasing of the segmented ones.

Analysis of the OWL design shows that controlling relative distances of the optical surfaces within 10 ppm (goal 1 ppm) provides significant advantages (performance, overheads) for subsequent closing of the active optics loop –including fine alignment. FOGALE⁷⁷ is developing a fibre extensometer, which itself is an evolution of the subsystem delivered to SALT and used to track the prime focus payload alignment. A proof-of-concept experiment is foreseen, and if successful a prototype fibre extensometer will be tested on the VLT.

A second task of FOGALE is the development of position sensors for controlling local piston between adjacent segments. Bandwidth, accuracy and low cost⁷⁸ are essential requirements. The current baseline is inductive sensor technology, capacitive sensors being a backup. After prototyping and laboratory testing, a set of 24 sensors will be delivered for subsequent integration into the WEB experiment (see below). The sensors main specifications are listed in Table A- 2, and the design volume and implementation in Figure A- 9 and Figure A- 2.

Characteristic	Specification	Remark
Short term noise:	< 0.2nm/sqrt(Hz)	over the bandwidth [1;100] Hz
Long term noise:	< 5 nm/sqrt(Hz) (TBC)	over the bandwidth [5.8.e-6;1] Hz.
(includes the low frequency drift of the sensor over a period of 2 days)		
Maximum operation range	+/-0.5mm	
Absolute accuracy	≤ 0.1% of measuring range	
Bandwidth	≥ 100 Hz at -3dB	The position shall be delivered in digital format at a rate of up to 1kHz.

Table A- 2. Position sensors main specifications.

⁷⁷ A French SME specialized in metrology systems.

⁷⁸ Target cost ≤ € 1,000.- per unit sensor, taking into account a total production of up to 20,000 units.

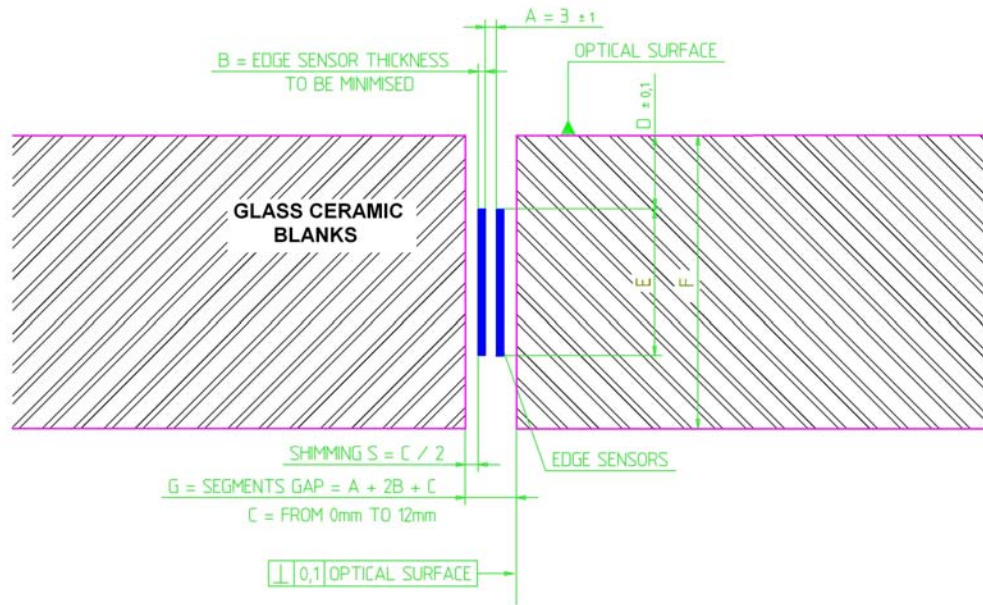


Figure A- 1. Allocated volume for the Position sensors (Glass ceramic blanks).

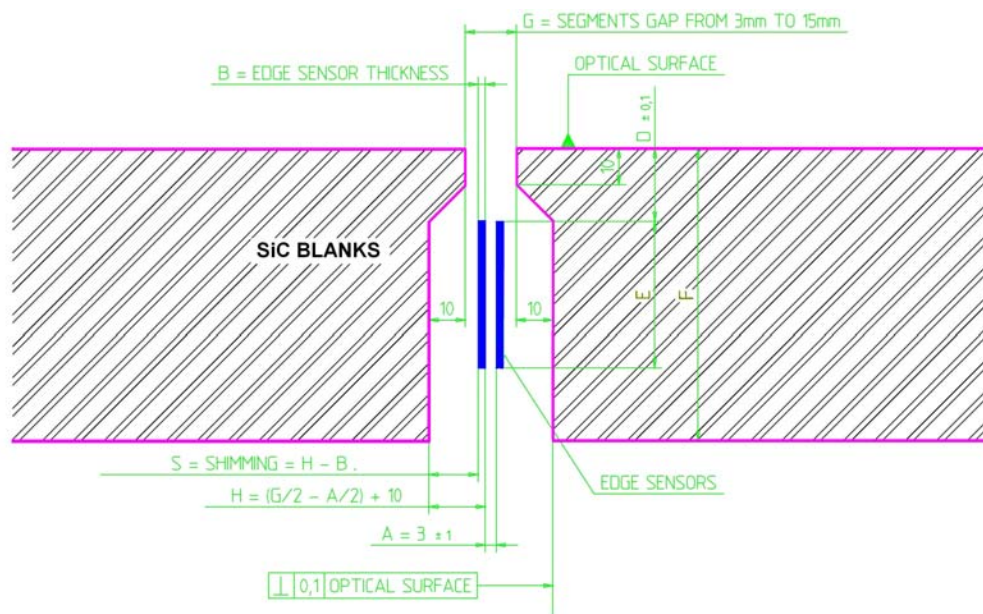


Figure A- 2. Allocated volume for the Position sensors (Silicon Carbide blanks).

Position actuators – This task covers the development and testing, under ESO contract, of actuators for the active positioning of the segments. Technical specifications are provided in reference document RD502. In the following we assume 2-stages actuators, with a coarse stage for low frequency, large amplitude correction and a fine stage for high frequency, fine adjustment.

Two types of actuators are under development, one for solid, glass or glass-ceramic segments, one for lightweight, presumably Silicon Carbide segments. Table A- 3 gives the essential characteristics of the position actuators, and their implementation is shown in Figure A- 3. A total of 18 actuators, 9 of each type, will be delivered for integration and testing in WEB.

Characteristic		Requirement	Goal
Max. axial load ⁷⁹	Glass ceramic segments	1,700 N	N/A
	SiC segments	600 N	N/A
Minimum axial resonance frequency		120 Hz	N/A
Accuracy	Coarse stage	± 0.05 mm	± 0.01 mm
	Fine stage	± 5 nm	± 2 nm
Stroke	Coarse stage	15 mm	30 mm
	Fine stage	0.5 mm	1.0 mm
Closed Loop Bandwidth	Coarse stage	0.5 Hz	N/A
	Fine stage	10 Hz	20 Hz
Maximum unit cost ⁸⁰	Glass ceramic segments	€ 4,000.-	€ 3,000.-
	SiC segments	€ 3,500.-	€ 2,000.-

Table A- 3. Position actuators, essential characteristics.

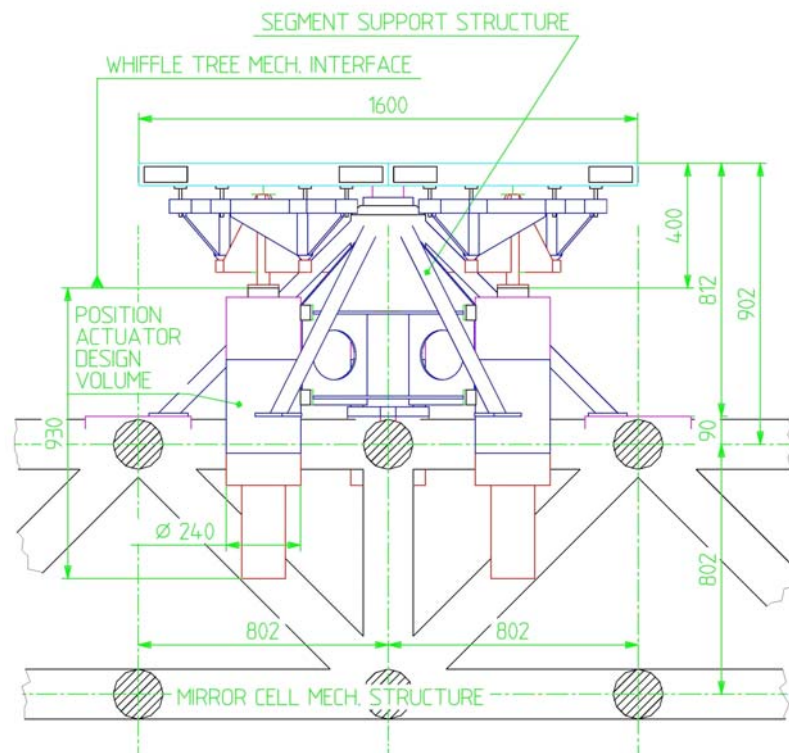


Figure A- 3. Position actuators. Implementation and design volume.

Wind Evaluation Bench – WEB is a crucial experiment for the assessment of performance under wind excitation. Being high temporal hence spatial frequencies the most hazardous ones (and the most difficult to model), experimentation does not require building a large subset of an ELT primary mirror. Currently in the design phase (see Figure A- 4 and Figure A- 5), WEB will incorporate 7 aluminium panels emulating either solid or lightweight segments, and be exposed to open air at a representative site (ORM on La Palma). One panel is rigidly fixed on a structure emulating the primary mirror support substructure, the other 6 mounted on position actuators

⁷⁹ In compression and tension.

⁸⁰ assuming a production of up to 10,000 units.

and fitted with edge sensors. The edge sensors signal will be regularly cross-checked by means of laser metrology or equivalent. The bench can be rotated azimuthally and inclined to vary its orientation with respect to wind. A skirt can be mounted around the outer edge to avoid that measurements be contaminated by turbulence at the edge of the assembly. WEB will, therefore, allow direct measurement of phasing performance under representative conditions. Detailed specifications are available in RD503.

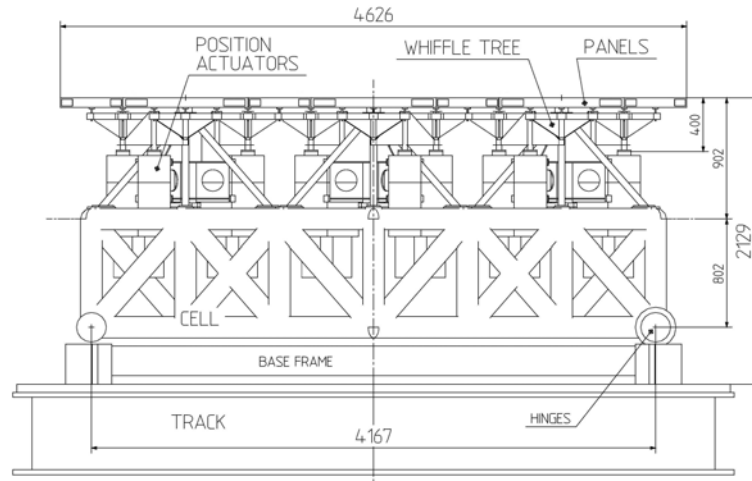


Figure A- 4. WEB 0° layout (zenith), side view.

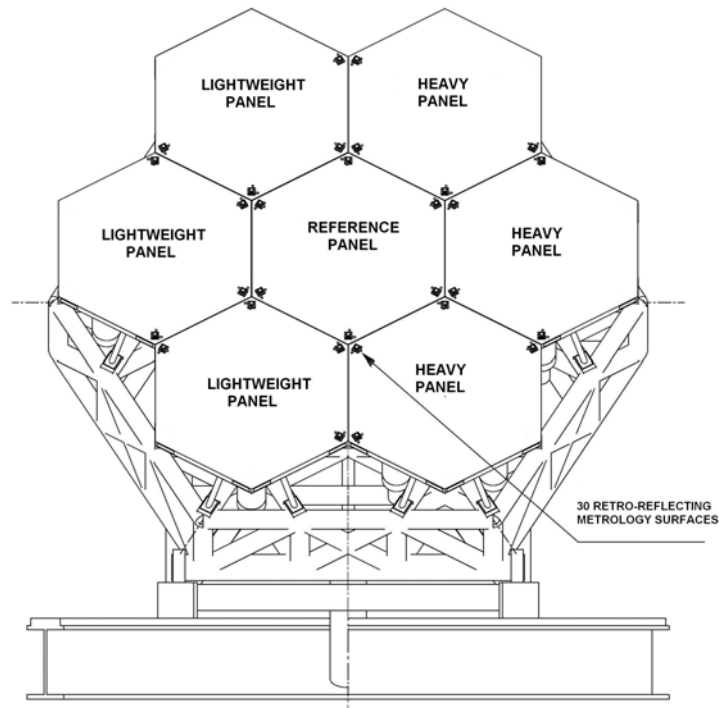


Figure A- 5. WEB 60° layout, front view.

The WEB experiment shall be completed by end of 2007, in-time for a final decision as to open air operation and for the final specifications of the actuators (taking into account the fact that the segments substrate technology will be selected by 2008, see also section A-1.3). ESO has overall responsibility for the experiment; other main contributors include IAC, MEDIA, and JUPASA.

Active Phasing Experiment – The essential purpose of the APE experiment is to explore, integrate and validate non-adaptive wavefront control schemes and technologies for an ELT. This includes:

- Evaluating and comparing the performance of phasing wavefront sensors, in the laboratory and on-sky;
- Integrating segmented aperture control into an active system (including field stabilization and active optics), and driving both the active system and the segments control system from the output of the system.

To this end, APE is conceived as a technical instrument to be installed and tested on-sky at a Nasmyth focus of a VLT unit telescope and shall have two options:

- The telescope shall provide all active functions (field stabilization, focusing, centering, active deformable mirrors) and the APE instrument shall emulate the optical effect of segmentation only.
- Or the telescope shall provide only the active deformable mirrors functions and the APE instrument shall emulate the optical effect of segmentation and shall command the other active functions (field stabilization, focusing, centering).

In practice, this is to be realized by re-imaging the telescope pupil onto a small segmented mirror (ASM), and by directing the output beam(s) of the instrument towards a metrology module (see Figure A- 6 for a block-diagram of the instrument and Figure A- 7 for the layout of the optical design).

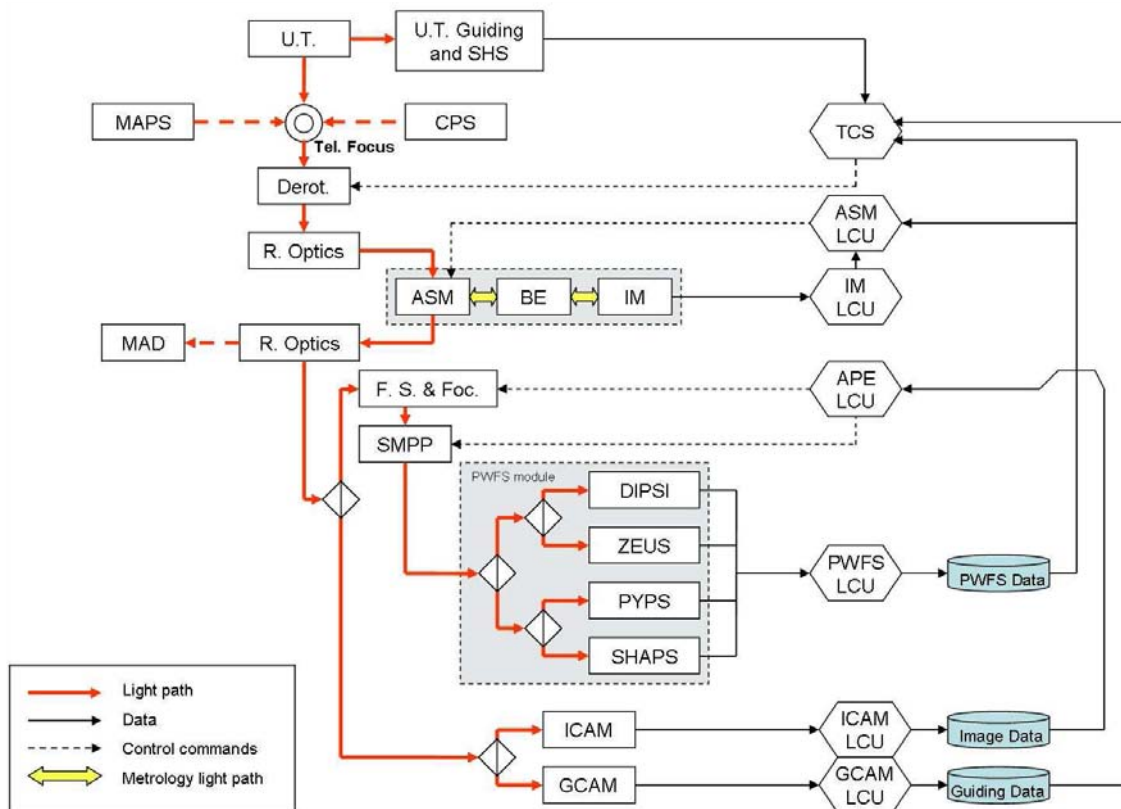


Figure A- 6. Block-Diagram of APE.

The segmented mirror will be controlled in piston and tip-tilt of the segments, being it implied that each segment would be mounted on 3 position actuators. The phasing wavefront sensor module will include four phasing wavefront sensors PWFS, each based on a different technology (curvature sensor, phase filtering, pyramid sensor, Shack-Hartmann sensor).

Tests will be performed stepwise as specified in Reference Document RD508, and include:

- Open- or deferred closed-loop laboratory measurements of the performance of the phasing WFS on a point-like polychromatic source;
- Open- or deferred closed-loop laboratory measurements of the performance of the phasing WFS on a point-like polychromatic source, in the presence of atmospheric turbulence (the latter being emulated by suitable turbulence generator). Wavefront offsets may be introduced in the input beam to emulate field aberrations.
- Open- or deferred closed-loop laboratory measurements of the performance of the phasing WFS and of the guiding & active optics WFS, in real conditions at the focus of a VLT unit telescope.

These tests will be performed with a single segmented mirror, and then repeated after introducing a piston plate simulating a secondary segmented mirror in the light path, with a view to emulating multiple segmentation with mismatched patterns. In a possible follow-up to the above, APE may be interfaced to MAD for laboratory testing of the combined two systems.

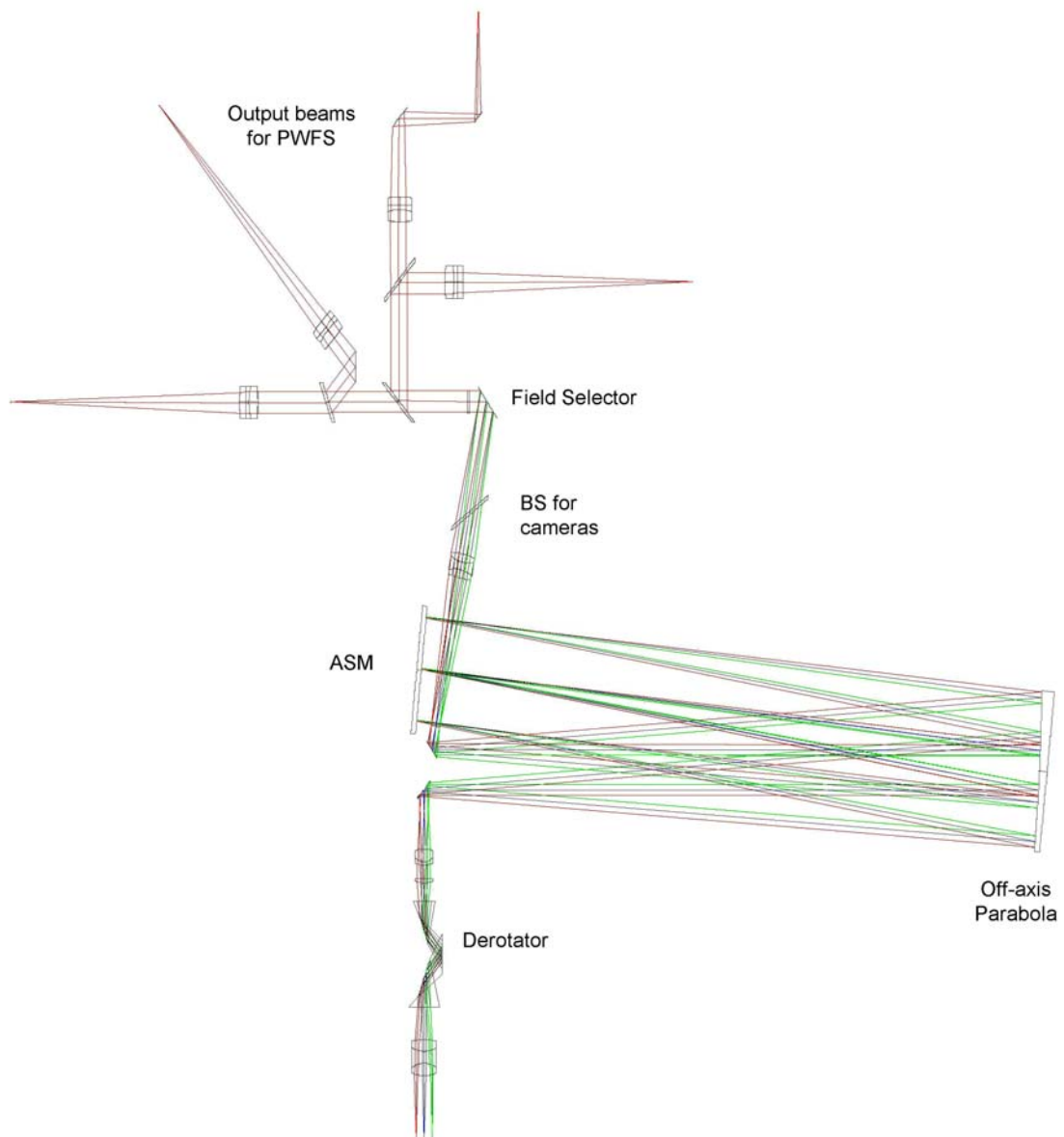


Figure A- 7. APE optical design; the telescope focus is at the bottom of the figure. PWFS: Pyramid WaveFront Sensor; BS: Beam Splitter; ASM: Active Segmented Mirror.

To a large extent extrapolation of current telescope technologies to extreme sizes relies on proven fabrication technologies. Indeed there is little doubt that the major components of a giant telescope could readily be produced. At system level, however, successful integration and performance will rely on complex, interacting control systems. APE is conceived as a crucial test and learning tool i.e. as a major step towards alleviating system risks.

Currently in the design phase, APE shall deliver laboratory and on-sky results by 2007, in-time for the final design of OWL active and phasing control systems. ESO has overall responsibility for the instrument; other main contributors include the FOGALE, IAC, INAF and INSU (Laboratoire d'Astrophysique de Marseille).

Characterization of image properties – Not strictly speaking a subset of wavefront control, characterization of image properties forms part of a global approach towards specifying performance. A similar undertaking with the VLT led to a consistent formalism⁸¹ towards specifying performance and establishing error budgets [7]. The essential objectives of this task are

- To translate science requirements into performance criteria which can be subsequently used for error budgeting and specifications.
- To establish a consistent description of image properties, with a view to allowing scientists to perform simulations and assess performance in relation to their science objectives.

In view of the fact that most science objectives require at least some degree of adaptive correction, the role of diffraction is primordial and this task is considerably more complex than it was with the VLT.

The main contributor is ESO.

High contrast imaging – Very high contrast imaging techniques are required, most notably for exoplanets. Several techniques are described in RD22 and are explored in the framework of the ELT Design Study. Diffraction by the segmented aperture is an evident –and unavoidable– source of concern. There are indications, however, that this effect could be alleviated to some extent, by using suitably designed –albeit rather complex– apodization masks. It should be noted that coronagraphic techniques become more efficient with extremely large telescope diameter, because a given angular size of the mask corresponds to a correspondingly larger area in terms of λ/D .

The main contributors are INSU and ESO.

A-1.3 Optical fabrication

The optical fabrication Work Package focuses on the validation of Silicon Carbide as an alternative to conventional glass-ceramics material. According to industrial studies (see RD9 and RD10), moderately lightweight silicon carbide blanks⁸² could be an alternative to conventional glass or glass-ceramic. Optical figuring is substantially more expensive (see RD11 and RD12) but substantial simplification of the telescope structural design and higher bandwidth of the segments phasing control system would potentially compensate for such drawback. Silicon carbide blanks, however, are not directly polishable to acceptable micro-roughness and a polishable overcoating is generally required.

The main tasks of this Work Package are:

- To determine optimal characteristics (technology, process, thickness) of polishable overcoatings;

⁸¹ See also RD501.

⁸² With an aerial mass of 45 to 70 kg/m²

- To verify whether or not such overcoatings introduce non-repeatable bimetallic effects;
- To determine a suitable (i.e. compatible with cost-effective serial production) process for the production and finishing of the segments, and in particular for the control of edge misfigure.

To this end, a total of up to eight 1-m class SiC segments will be produced and tested (see RD510 for a complete definition of tasks). Four blanks were already supplied to ESO by BOOSTEC (Figure A- 8) and have been shipped to the optical manufacturers. Up to four more will be purchased from a different blank supplier. The segments will be polished and tested by SAGEM and SESO with support by the Laboratoire d'Astrophysique de Marseille. By end 2007 all segments will be polished and tested, allowing for a final decision on OWL primary mirror technology by 2008.

As for Wavefront Control, this Work Package is directly relevant to OWL. The Boostec blanks were ordered on OWL budget before the inception of the ELT Design Study.

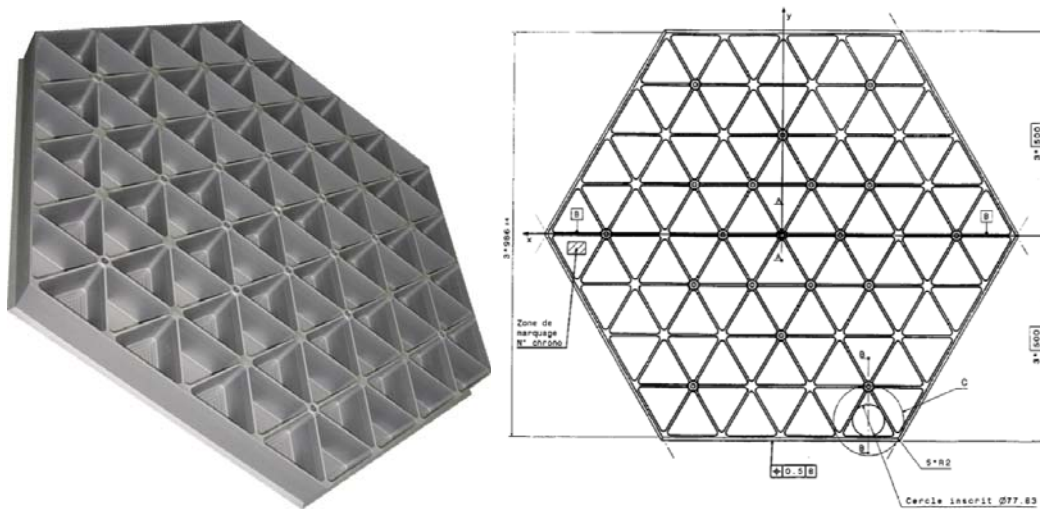


Figure A- 8. 1-m silicon carbide BOOSTEC blank prototype.

A-1.4 Mechanics

The mechanics Work Package concentrates on

- The use of advanced materials in targeted applications: structural ropes, composite structural elements;
- The testing of friction drives;
- The evaluation of magnetic levitation as an alternative to friction drives.

Structural ropes, composite elements – A detailed definition of the tasks is given in reference documents RD510 and RD512.

In order to minimize obscuration, all ELT concepts apply tensioning ropes to stabilize slender structural elements located in the upper part of the altitude structure, and to increase global mode frequencies (see also 9.4.4.2). Steel cables provide adequate tensile strength, but are quite heavy. Synthetic fibres with very high specific stiffness and strength are now commonly used in suspension bridges; they are made by incorporating fibres into a matrix to form a composite bundle. This is then twisted with others to form a rope. Similar solutions could be adopted for OWL tensioning ropes. A study is under way with MEDIA, with particular emphasis on ropes dimensioning, interface couplings and thermal aspects (see RD510).

For evident reasons, upper structural parts of the telescope must have highest possible stiffness and lowest possible mass. High static and dynamic performance, superior safety characteristics, low wind cross-section and low weight are essential requirements. OWL design and analysis shows that these requirements could be made with all-steel structures, but also indicate that significant advantages could be obtained by targeted use of composite materials. A detailed study by MEDIA is under way, with a view to comparing the relative performance and cost of a typical secondary mirror steel truss substructure with a composite one (see RD512 for a complete definition of the tasks).

These studies will be undertaken in 2006 and completed by mid-2007. The main contributor is MEDIA.

Magnetic levitation – Magnetic levitation is a potential alternative to friction drives, with major advantages in terms of dimensional tolerances (tracks) over large distances, and in terms of stiffness, which is essentially provided by the control system. Safety is likely to be very high as well, the technology having to meet highest safety standards for transportation.

Preliminary discussions with experts at University of Lausanne indicated that the technology might be applicable to OWL kinematics. A theoretical study will be contracted by ESO and is due for completion by mid-2007.

Friction drive breadboard – Classical hydraulic pads and tracks being ruled out for reason of unrealistic dimensional tolerances over very large scales, extremely large telescopes will have to rely on friction drives (or magnetic levitation, see above) for their kinematics. A control analysis (see RD14 and RD15) performed with OWL friction drive shows that effective friction compensation can be incorporated into the control system. The friction drive breadboard is essentially the experimental verification of such analysis. The conceptual design of the breadboard, which is currently in the design phase and will be tested by AMOS, is shown in Figure A- 9. The definition of tasks and the technical specifications are provided in reference documents RD513 and RD514, respectively.

The main contributors are AMOS and ESO.

All activities in the Mechanics Work Package are directly relevant to OWL design and construction.

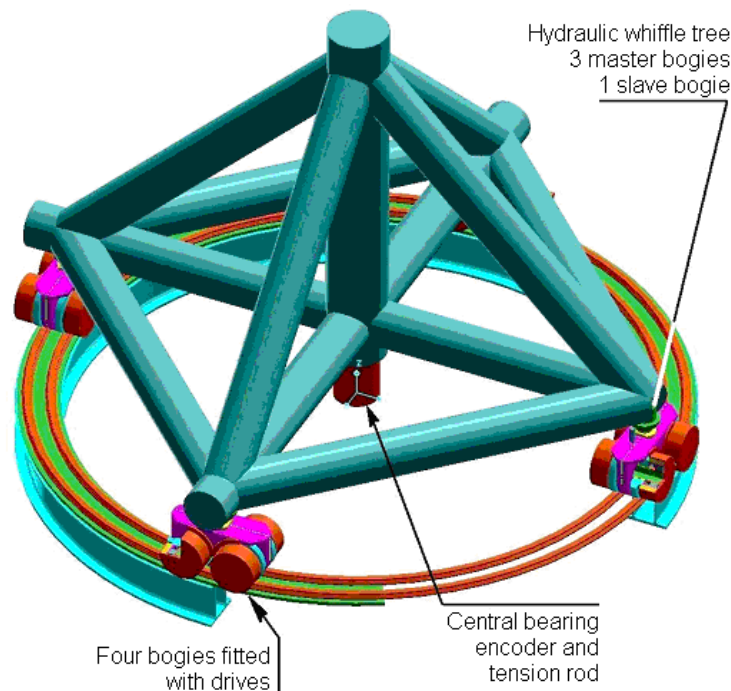


Figure A- 9. Friction drive breadboard

A-1.5 Enclosure & wind studies

This Work Package covers the conceptual design of low-cost enclosure concepts for Extremely Large Telescopes with a diameter of 50 to 100-m (see RD516 for a detailed definition of tasks), and the performance of wind simulations and wind tunnel tests, with a view to assessing, most notably, the effectiveness of wind screens (see RD517). GRANTECAN is supervising the enclosure concept studies and ESO the wind studies.

The enclosure concepts elaborate on the sliding and co-rotating enclosure concepts, with a view to evaluating the merits and cost of both. An open call has been issued for the development of a third alternative.

The wind studies will provide quantitative information on the wind loads and on the turbulent pressure structure function on the telescope main optics, inside an enclosure and behind a wind screen. The aerodynamic turbulent load will be characterised in a wide frequency range, up to about 10 Hz full scale, in wind tunnels qualified to provide reliable information up to this frequency limit. To characterise the air volume renovation and the thermal behaviour in the telescope chamber Computational Fluid Dynamic simulations will be performed being this method better suited than wind tunnel tests to analyse thermally driven phenomena.

The contributors are GRANTECAN, IAC, ESO, CIMNE, Galway University, and ITER.

The activities under the Enclosure & Wind Studies Work Package are seen as complementary to the OWL development, which will pursue design-specific aspects of said activities.

A-1.6 Adaptive Optics

The adaptive optics Work Package covers concepts development, point designs, thin shell development and prototyping, as well as simulations and control algorithms. All activities in this Work Package are directly relevant to OWL, with the sole exception of the development of an adaptive mirror technology with low actuator density (DM-TEC-0, see below).

First generation AO and MCAO designs – This includes the conceptual design and analysis of single conjugate, ground layer and multi-conjugate AO subsystems (Natural Guide Stars). The essential objectives are to acquire experience in the design of first generation subsystems, evaluate their potential performance, identify critical issues and derive realistic specifications. This task is under ESO responsibility, with contribution by INAF. A detailed definition is given in RD518.

High actuator density, large deformable mirrors – Three technologies are explored:

1. DM-TEC-0: Low order, large amplitude correctors;
2. DM-TEC-1: IR correctors for 50- to 100-m class apertures, the corrector being part of the telescope optical train;
3. DM-TEC-2: High order correctors, either as part of the telescope optical train or as post-focal correctors.

Typical actuator interspacing is 80-100-mm for the first technology, 25 mm for the second, and 10-mm for the third. The assumed corrector size is in the range of 2-m upwards for the first two, and up to ~2-m for the third.

The technology development includes:

1. DM-TEC-0
 - 1.1. Feasibility study of Large, up to 2-m class Deformable Mirror with 100-mm actuator spacing (DM-TEC 0) including the development of a high efficiency electromagnetic

actuator, distributed lateral support of the thin shell, back structure with suitable stiffness-weight ratio. Development and testing of an actuator prototype.

- 1.2. Demonstration of slumping of concave/convex thin glass shells based on hot slumping of borosilicate type glass on a polished mould. The technology for 0.5 m size mirror samples will be developed and tested in the 1-10 mm thickness range.
2. DM-TEC-1
 - 2.1. Feasibility study of Large, up to 2-m class Deformable Mirror with 25-mm actuator spacing (DM-TEC 1) including the study of distributed lateral support of the thin shell, the study of the back structure with suitable stiffness-weight ratio, the study of the actuator to shell interface in terms of optical mirror quality.
 - 2.2. Development of a scaled down prototype to validate the design and technology solution.
3. DM-TEC-2
 - 3.1. Feasibility and conceptual design study of a 2-m class deformable mirror unit with 10-15 mm actuator spacing (DM-TEC2), including design, development, fabrication and testing of a demonstration prototype.
 - 3.2. Manufacturing of a flat ~600 mm thin glass shell for Large deformable mirror with thickness of 1.5 mm goal 1mm

Novel AO concepts - Another essential task is the prospective development of novel AO concepts, with emphasis on alternative routes to using Laser Guide Stars: Pseudo-Infinite Guide Stars (PIGS, see section 8.4.5.1), Sky Projected Laser Array Shack-Hartmann (SPLASH, see 8.4.5.2), Virtual Wavefront Sensors (8.4.5.3) or Variable Wavefront Sensors (8.4.5.4).

A detailed definition of the tasks is provided in RD519. The main contributors are ESO, INAF, Laboratoire d'Atrophysique de Marseille and SESO.

AO & MCAO simulations – In cooperation between ESO, INAF and LUND University, simulation tools are being developed, with a view to predict performance and eventually integrate adaptive optics into an Integrated Modelling Tool.

Algorithms for reconstruction & control – This task covers the development of algorithms for wavefront reconstruction and control, with a view to minimizing computational requirements and making best effective use of the data collected by the metrology systems. The main contributors are ESO, IAC, INAF, and University of Padova.

A-1.7 Operations

The tasks and objectives of this Work Package are outlined in section 2.8. The main contributor is ESO. The underlying activities were initially conceived as part of OWL development, and transferred into the framework of the ELT Design Studies for its relevance to (virtually) any ELT design.

A-1.8 Instrumentation

The instrumentation Work Package covers exploratory designs of possible instruments, complemented by design and analysis of atmospheric dispersion compensators. This activity is complementary to specific instrument conceptual designs undertaken for OWL under ESO

contracts with European prominent Institutes. The timeframe for the conceptual design of OWL instruments (completion by fall 2005) allows for ideal feedback to the corresponding effort in the ELT Design Study (start in fall 2005).

The exploratory designs are addressed in two phases. The first phase includes brief conceptual designs and analysis of a relatively wide variety of possible instruments. The Representative Instruments currently envisaged are:

- GRB (Gamma-Ray Burst) Catcher
- High-resolution Spectrometer (HISPEC)
- High Time-Resolution Instrument (HiTRI)
- Mid-IR Instrument (MIDIR)
- Multi-Object Multi-field Spectrometer-Imager (MOMSI)
- PlanetFinder
- Submillimetre Common-User Bolometer Array -3 (SCUBA3)
- Wide-Field Spectrometer (WFSPEC)
- Innovative Instrument Concepts

In the second phase, up to three conceptual designs will be pursued in more details. The instruments which will be included in the second phase will be selected on the basis of the science case and of the results of the first phase.

The detailed definition of tasks is provided in reference documents RD520 and RD521. The contributors are UKATC, ESO, ASTRON, DURHAM University, Galway University, INSU, Leiden Observatory, MPIA and Oxford University.

A-1.9 Site characterization

This Work Package covers all activities required to undertake a standardized site characterization campaign. The first step is to compile a comprehensive list of relevant parameters and define corresponding metrics, with a view to establishing a template figure of merit. The parameters space is extended to all characteristics which may affect performance, cost, schedule, and design of an ELT. Under ESO contract, a software tool (FRIOWL) is under development. This tool allows dynamic screening of databases (ground meteorological stations and satellite databases) according to selected criteria and to assess the variability of such criteria over decades. Where necessary, dedicated instrumentation is being designed and built, and will be installed on candidate sites. The detailed definition of tasks is given in reference document RD522.

Two sites, ORM and Paranal, will be taken as test cases and their statistics fed into the model. This does not imply that these sites have de facto been pre-selected; further measurements in Argentina and the Moroccan Atlas, as a minimum, are planned. This activity should be viewed in the global framework of site searching for Extremely Large Telescopes, with continued feedback between project groups worldwide, consolidation and sharing of databases, and a general convergence towards measurements standards.

In addition, this Work Package includes the direct measurement of turbulence properties over large scales. The few measurements of outer scale of turbulence conducted so far by Université de Nice at various sites are generally in the 20-30m range, occasionally decreasing to values as small as 8 m. There is indeed anecdotic evidence that the VLT regularly provides a Point Spread Function sharper than the seeing inferred by Paranal seeing monitors, which rely on Kolmogorov model. Measuring turbulence amplitude over large scale is necessary to derive

specifications for the maximum amplitude of adaptive correction, which has potentially strong impact on deformable mirror technology.

These activities will be completed about one year ahead of the time at which a decision about OWL site is required. Main contributors are Université de Nice, IAC, and ESO. The site characterization Work Package is evidently relevant to OWL and allows for a more extended effort than could be undertaken by a single organization.

A-1.10 Integrated modelling

This task covers the design and coding of a toolkit for integrated simulation of optical, structural, and controls performance of Extremely Large Telescopes with a segmented primary mirror and adaptive optics. It includes, in particular:

- Definition of a suitable architecture for the software
- Subsystem models
 - Submodel for simulation of telescope structures, suitable methods for model reduction;
 - Rigid body dynamics for a segmented primary mirror
 - Submodel of a typical control system for a segmented mirror using edge sensors, singular value decomposition.
 - Secondary, tertiary, quaternary, quinternary and hexary mirror position control.
 - Deformable mirrors and their controllers.
- Ray tracing through conic mirror systems; sensitivity matrices
- Simulation model of a generic typical wavefront sensor
- Building block for simulation of an adaptive optics controller.
- Model for estimation of atmospheric aberrations from suitable atmospheric models
- Submodels describing typical wind disturbance scenarios using either standard spectra, wind tunnel data, or results from computational fluid dynamics runs.
- A separate module will establish a graphical user interface to allow the user to input data and to do a first “sanity verification” of the input data.
- Computation of PSF and other key data
- Visualization and presentation of results

The main contributor to this task is Lund University. A detailed definition of the tasks is provided in RD525. It is expected that most tools developed in the framework of this Work Package will eventually be integrated by ESO into an OWL end-to-end model.