FIRST

TELESCOPE

SPECIFICATION

PT-RQ-04671 (ISSUE 1/A)

January 1998

	Name	Signature
Prepared by	B. Guillaume ESA/ESTEC/PT	
	T. Passvogel ESA/ESTEC/PT	T. Passvogel
Approved by	F. Felici ESA/ESTEC/PL	
Approved by	W. Gray NASA / JPL	

DOCUMENT CHANGE RECORD

Issue / Rev. Date	Approved	Signature
November 1997	F. Felici, FIRST/Planck Project Manager (Acting) ESA/ESTEC, Noordwijk	
Issue / Rev. Date	**Pages affected / Brief description of change**	**Signature**
1/A January 1998	All changes on pages listed below are indicated by bold vertical lines in the left hand margins. i, iii, 1-1, 2-1, 2-2, 2-3, 3-3, 3-4, 4-1, 4-3, 4-5, 4-6, 5-1, 5-2, 5-6, 5-7, 5-9, 5-10, 5-11, B-2, B-3, B-4, B-5, B-6, B-7	F. Felici

DISTRIBUTION LIST

COMPANY	NAME	DIVISION	No. of COPIES
JPL/Pasadena	Gray, W.B.		2
	Cohen E.J.		1
ESA/ESTEC	Anderegg, M.	PIP	1
	Brunner, O.	YMD	1
	Collaudin, B.	YCT	1
	Felici, F.	PL	1
	Estaria, P.	PT	1
	Guillaume, B.	PT	1
	Hoegen, M. von	PTQ	1
	Maagt, P. de	XEA	1
	Oremus, R.	PIC	1
	Paßvogel, T.	PT	1
	Pilbratt, G.	SA	1
	Raynal, R.	QMM	1
	Reynaud, P.	ECP	1
	Schaap, H.	PT	1
	Ulbrich, G.	XA	1
	FIRST/Planck project	PT	5

TABLE OF CONTENTS

1. INTRODUCTION

The Far InfraRed and Submillimetre Telescope (FIRST) mission is the fourth cornerstone of the ESA long term space science programme. It is a dedicated astronomical observatory for spectroscopy imaging and photometry, operating in the spectral range between 85 and 600 µm wavelength. The operational orbit shall assumed to be an orbit around the second Libration point (L_2) in the earth/moon - sun system at an average distance of 1.5 million kilometre from the earth.

The present concept for the FIRST telescope is based on an axisymmetric, 3.5-m-diameter Cassegrain or Ritchey-Chrétien design. The telescope is protected by a sunshield in order to avoid direct solar radiation to the primary and secondary reflectors and their structures and to provide a stable thermal environment which minimizes temperature variations across the telescope.

Due to the science requirements, high initial accuracy and in-orbit thermal stability are required by the telescope to enable spectroscopy and photometry in the far infrared and submillimetre frequency range.

2. SCOPE

This specification establishes the performances, design, development and qualification test requirements for the FIRST telescope.

2.1 Terms and Acronyms

AD	Applicable Document
BOL	Begin of Life
CFRP	Carbon Fibre Reinforced Resin
CTE	Coefficient of Thermal Expansion
EOL	End of Life
EP	Entrance Pupil
FIRST	Far Infrared and Submillimetre Telescope
FOV	Field-of-view
LOS	Line Of Sight
MGSE	Mechanical Ground Support Equipment
MOS	Margin of Safety
N/A	Not applicable
OGSE	Optical Ground Support Equipment
PA	Product Assurance
PLM	Payload Module
PSF	Point-Spread-Function
RD	Reference Document
RH	Relative Humidity
RMS	Root Mean Square
S/C	Spacecraft
TBC	To be confirmed
TBD	To be determined
WFE	Wave Front Error

2.2 Abbreviation List for Requirements

The requirements in this specification have been systematically numbered. The code applied consists of four letters and three digits. The four letters start for the telescope with TE, continued with an abbreviation of the area concerned. The numbering convention is illustrated in the table below.

Requirement Type	Abbreviation	Specification paragraph
Functional and General Requirements	TEFU-xxx	3.
Mission and Performance	TEPE-xxx	4.
Environmental, Design and Construction	TEEN-xxx	5.
Verification	TEVE-xxx	6.

2.3 DOCUMENTS

The following documents of the exact issue shown form a part of this specification. In the event of conflict between documents referenced herein and the content of the specification, the contents of this specification shall be considered a superseding requirement.

2.3.1 Applicable Documents (AD)

The following documents form a part of this specification.

Ref	No	Issue - date	Title
1.	ESTEC/WMA/he/ FIRST/3	4 - Mar 97	FIRST L_2 Radiation Environment
2.	ESA PSS-01-201	1 - Aug 83	Contamination and cleanliness control
3.	ECSS-Q-70A	Apr 96	Materials, Mechanical Parts and Processes
4.	ESA PSS-01-702	1 - Mar 83	A thermal vacuum test for the screening of space materials
5.	PT-RQ-04683	Sep 97	Product Assurance Requirements for FIRST/Planck Satellite

6.	ESA PSS-01-736	1 - May 81	Material selection for controlling stress corrosion cracking
7.	XA94/177/RC	Nov 1994	Durability requirements for FIRST optical coatings
8.	ARIANESPACE	2/1 - Mar 96	ARIANE 5 Users Manual
9.	ESA PSS-01-301	2 - Apr 92	Derating requirements applicable to electronic, electrical and electro-mechanical equipment

2.3.2 Reference Documents (RD)

The Telescope Provider is invited to refer to the following documents for guidance.

Ref	No	Issue	Title
1.	PSS-03-203	1 - Feb. 94	Structural Materials Handbook Vol. 1 and 2
2	PT-PL-TN-04228	1/1- Jun 97	First/Planck Feasibility Assessment
3.	PL-0000231	Aug 1997	FIRST/Planck Satellite System Specification
4.	CSG-RS	4/0	CSG Safety Regulations
5.	PT-PL-02220	1 - May 96	Alignment Plan

3. GENERAL REQUIREMENTS

3.1 Description of FIRST Telescope

The Telescope is composed of:

a primary reflector,
a secondary reflector,
a reflector support structure (tripod, bipods etc ...),
an interface triangle and mechanical fixation devices to the primary reflector,

A telescope heating system will be included for in-orbit contamination release from optical surfaces and for bake-out of the telescope.
The telescope interface triangle provides for the interface with the telescope support truss structure which is part of the Payload Module (PLM). The telescope and the PLM shall be thermally decoupled to the maximum extent.

3.2 General Functional Requirements of the Telescope

TEFU-005 The telescope primary reflector shall collect the electromagnetic radiation and shall deliver the collected power via the secondary reflector to the focal plane units.

The sunshield of the spacecraft will provide a stable thermal environment to the telescope and will therefore protect the telescope from direct Sun irradiation during all mission phases and modes and will provide for overall straylight reduction.

3.3 Axis System of the Telescope

The following axis system shall be used for the telescope: the basic coordinate system shall be a right handed Cartesian system with its origin located at the point of the centre of the interface triangle of the telescope, within the plane defined by the interface triangle lower interface. The X-axis is perpendicular to this interface plane, positive towards the target source. The Z-axis is in the plane normal to the X-axis such that nominally the Sun will lie in the XZ-plane (zero roll axis with respect to the Sun), positive towards the Sun. The Y- axis completes the right-handed orthogonal reference frame.

3.4 Optical Axis System of the Telescope

The telescope optical axis is defined by the axis of rotation passing through the centre of the secondary reflector and the centre of the telescope field-of-view.

3.5 General Interface Requirements

The figure 3.5-1 summarises the different interfaces with the telescope.

3.5.1 Mechanical

TEFU-010 The telescope interfaces mechanically with the PLM interface structure via 3 hard points on the telescope interface triangle which shall allow alignment and mounting of the complete telescope to the PLM.
These interfaces shall be consistent with the structural stiffness and strength requirements as defined in chapter 6.

TEFU-015 One triangle interface point shall be located on the -Z-axis, at a distance of 1037 mm (tbc) from the X-axis. The other interface points shall be within the Y/Z Plane.

TEFU-020 The structural interface of the telescope and its accessibility shall allow an easy and reproducible assembly and alignment of the complete telescope to the PLM.

TEFU-025 The location of PLM interface plane (fixation plane) is 915 mm (tbc) below the main reflector vertex.

3.5.2 Thermal

3.5.2.1 Thermal Interface with Sunshield

The thermal interface between the telescope and the sunshield is a radiative coupling.

TEFU-030 3 Sunshield interface temperature cases shall be considered for the telescope/sunshield thermal interface:

Cold case	Nominal case	Hot case
130 K tbc	140 K tbc	150 K tbc

TEFU-035 The Sunshield surface properties shall be used as defined below:

Cold case		Nominal case		Hot case	
ϵ_{ss} BOL	ϵ_{ss} EOL	ϵ_{ss} BOL	ϵ_{ss} EOL	ϵ_{ss} BOL	ϵ_{ss} EOL
0.04 tbc	0.06 tbc	0.04 tbc	0.06 tbc	0.04 tbc	0.06 tbc

3.5.2.2 Thermal Interface with PLM

The thermal interface between the telescope and the PLM is a radiative and conductive coupling.

TEFU-040 3 PLM interface temperature cases shall be considered for the two telescope/sunshield thermal interfaces:

	PLM 1	PLM 2
Cold case	130 K tbc	80 K tbc
Nominal Case	140 K tbc	90 K tbc
Hot case	150 K tbc	100 K tbc

TEFU-045 The PLM surface properties shall be used as defined below

Cold case PLM1		Nominal case PLM1		Hot case PLM1	
ϵ_{PLM} BOL	ϵ_{PLM} EOL	ϵ_{PLM} BOL	ϵ_{PLM} EOL	ϵ_{PLM} BOL	ϵ_{PLM} EOL
0.04 tbc	0.06 tbc	0.04 tbc	0.06 tbc	0.04 tbc	0.06 tbc

Note: For simplicity reasons it will be assumed that the PLM1 surface properties and temperatures extend to the sunshield.

Cold case PLM2		Nominal case PLM2		Hot case PLM2	
ϵ_{PLM} BOL	ϵ_{PLM} EOL	ϵ_{PLM} BOL	ϵ_{PLM} EOL	ϵ_{PLM} BOL	ϵ_{PLM} EOL
0.8 tbc	0.7 tbc	0.8 tbc	0.7 tbc	0.8 tbc	0.7 tbc

TEFU-050 The telescope is conductively coupled to the PLM via the triangle interface. This conductively coupled interface shall be designed with a total conductance value below 5 mW/K, considering the performance temperature range of the telescope.

3.5.3 Electrical

TEFU-055 All telescope surfaces shall be conductively coated and grounded.

TEFU-060 The electrical interface resistance between the telescope and the S/C grounding system shall be less than 1Ω.

TEFU-065 Provision shall be made for heaters and thermal sensors on the telescope.

TEFU-070 For decontamination release and/or bake-out the electrical power consumption of the telescope shall be lower than 600 W with 28 V.

3.5.4 Interface with Spacecraft Sunshield

The height of the sunshield from the PLM interface plane (fixation plane) is TBC mm.

Note: *The sunshield protects the telescope against direct sun illumination. In agreement with document RD-3 the sun is kept at 90° - 30°/+ 15° from the X-axis and from the 90° ± 5° from the Y-axis.*

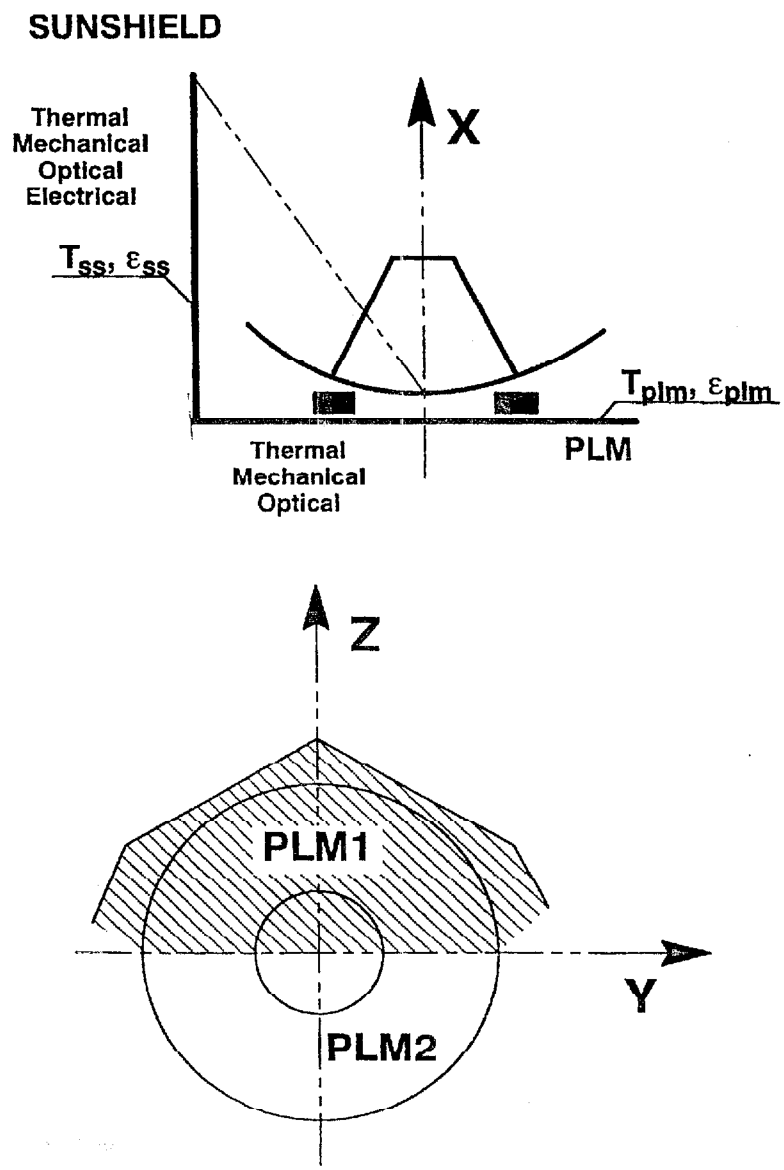


Figure 3.5-1: Interface Telescope / Sunshield / PLM

4. MISSION AND PERFORMANCE REQUIREMENTS of the TELESCOPE

4.1 General Specifications for the Telescope

4.1.1 Telescope

The general configuration of the telescope is shown in Figure 4.1-1.

The telescope shall comply with the following specifications:

TEPE-005 The average telescope temperature shall be within a temperature range of 70 K to 90 K (TBC).
This is called the **Performance Temperature Range.**

TEPE-010 The telescope shall be designed to meet its performance within the Performance Temperature Range.

TEPE-015 The optical free diameter of the Primary Reflector shall be 3500 mm +2mm, - 0 mm.

TEPE-020 The f-number of the Primary Reflector shall be 0.5

TEPE-025 The area obscuration ratio including:
- tripod with secondary reflector and its shadowing
- "cone in secondary"
shall be: ≤ 0.03 (with respect to the paraxial entrance pupil).

TEPE-030 The distance of the primary reflector vertex-best on axis focus shall be
- by construction value $t_b = 975$ mm ± 10 mm
- this value shall be measured with the accuracy defined in 4.3.3.

TEPE-035 The distance of the telescope fixation plane to the primary reflector vertex t_v shall be less than 125 mm (see Figure 4.1-1).

4.1.2 Heaters

The telescope will be designed to allow the decontamination of the optical surfaces in the early orbital phase by means of heaters.

TEPE-040 The heaters shall allow an increase of the orbital average temperature of the telescope to the contamination release and bake-out temperatures, defined as maximal temperatures in para 5.5 for a minimum duration of 3 weeks (tbc).

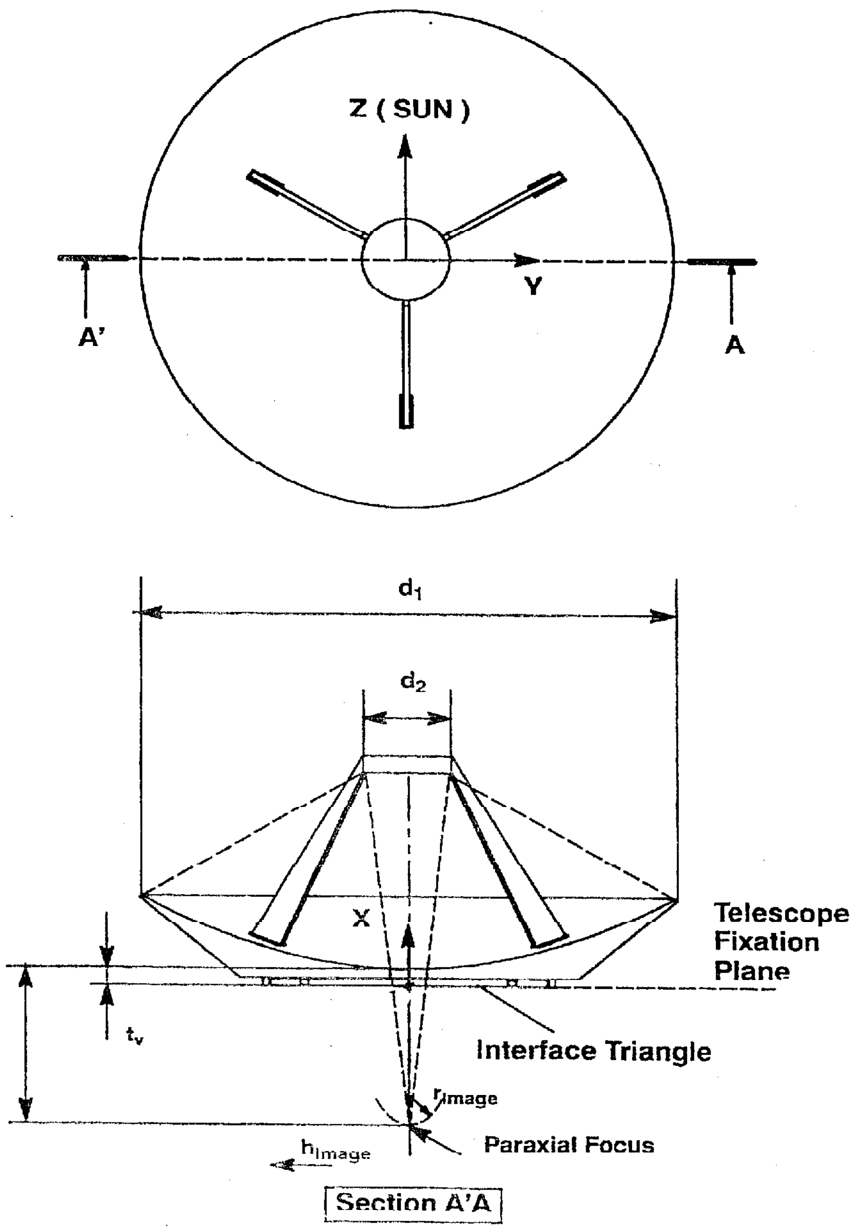


Figure 4.1-1 TELESCOPE CONFIGURATION

4.2 Optical Requirements

4.2.1 Telescope Performances

The telescope shall comply with the following optical performance requirements till the end of its life:

TEPE-045 Operating wavelength range 85 µm to 600 µm.

TEPE-050 Telescope total WFE Budget ≤ 10 µm rms
≤ 6.0 µm rms (goal)

These performances shall be met within the performance temperature range for the complete FOV.

TEPE-055 Relative spectral transmission [a] ≥ 0.97 BOL [b]
≥ 0.98 BOL (goal) [b]
≥ 0.95 EOL (goal) [c]

This shall be demonstrated

- at any wavelength λ within the operating range measured on witness samples over a sampling interval of $\Delta\lambda/\lambda = 1/100$
- and by analysis over the entire FOV.

TEPE-060 Non-uniformity of relative spectral transmission [d] ≤ ± 0.01.

TEPE-065 The aperture stop location shall be implemented at the secondary reflector.

TEPE-070 The system focal length shall be 28.5 m ±0.05 m and the f-number of the telescope shall be f/D = 8.68, where D is the diameter of the effective aperture.

TEPE-075 The Field-of-view (FOV) shall be ± 0.25°, free of vignetting

TEPE-080 The telescope shall maintain the specified performance over its lifetime without the need for a refocussing mechanism.

TEPE-085 The telescope design shall be such as to avoid narcissus effect.

4.2.2 Straylight

The Straylight requirement for the telescope including the sunshield, is defined w.r.t. the straylight level obtained at a specified detector element location. The definition of the optical components and properties between the Primary reflector and the detector element, as far as relevant for the straylight verification is called the **PLM/Focal Plane Unit Straylight model** and will be provided by ESA.

The following straylight requirements apply over the full operational wavelength range:

- Scattered light

TEPE-090 Sources outside telescope FOV:
for Moon, with aspect angle from 30° to 60° (tbc) w.r.t. to the LOS and ±30° (tbc) azimuth angle around the z direction:
< 1.0% of background radiation induced by self-emission of the telescope.

TEPE-095 Sources inside FOV:
over the entire FOV at angular distances ≥ 3' from the peak of the point-spread-function (PSF): $< 1 \cdot 10^{-4}$ of PSF peak irradiance (in addition to level given by diffraction).

- Self-emission

TEPE-100 The straylight level, received at the defined detector element location of the PLM/Focal Plane Unit Straylight model by self emission, not including the self emission of the telescope reflectors alone, shall be ≤ 10 % (tbc) of the background induced by self-emission of the telescope reflectors.

- Notes and definitions:

a. The relative spectral transmission $\tau(\lambda)$ of the telescope is defined by

$$\tau(\lambda) = \phi(\lambda) / \phi_0(\lambda)$$

with
$\phi(\lambda)$ integrated flux [W] leaving the telescope in image space
$\phi_0(\lambda)$ integrated flux [W] entering the telescope through its entrance pupil within the unobstructed areas.

b. At acceptance and delivery of the telescope.

c. The design life is specified in paragraph 5.1

d. The non-uniformity of the relative spectral transmission is defined as the maximum deviation between the relative spectral transmission values for any 100 mm diameter area within the entrance pupil (EP) and the average relative spectral transmission determined for the full EP area of the telescope.

4.2.3 Coating

The optical coating of the telescope reflectors will be designed for the operating wavelength defined in 5.2.1.

TEPE-105 The coating shall comply with the durability requirements defined in AD-7.

TEPE-110 The durability requirements of the optical coating shall be verified with representative samples from the same coating batch/material as the reflectors.

TEPE-115 The optical coating shall be connectable via the telescope grounding with the spacecraft grounding system. The interface for the connection is TBD.

4.3 Physical Requirements

4.3.1 Dimensions of the Telescope

TEPE-120 The telescope and its interfaces shall not exceed the size of the dynamic envelope defined in Figure 4.3-1.

4.3.2 Mass properties

TEPE-125 The total mass of the Telescope with the electrical heaters shall be minimized and shall not exceed 260 kg.

4.3.3 Alignment

TEPE-130 The telescope shall be equipped with optical alignment references (cube and pinball) for the purpose of PLM-telescope alignment. These alignment references shall represent an orthogonal telescope reference frame.

TEPE-135 The actual on-axis point of the best focus shall be positioned and located within a cylindrical tolerance volume perpendicular and centred on the X-axis of the telescope. The volume of the cylinder shall be ± 10 mm (with a goal of tbd) in cylinder-axis (X-direction) and ± 10 mm (with a goal of tbd) in diameter.

TEPE-140 The centre of the telescope field of view in the focal plane shall be known with respect to this reference frame with an accuracy of ±5 mm in lateral direction and ±9 mm (defocus) in axial direction (with a goal of tbd).

TEPE-145 The secondary reflector shall be positioned with a lateral accuracy of ±5 mm (with a goal of tbd) with respect to this reference frame and its position shall be known with an accuracy of ±1 mm (with a goal of tbd).

TEPE-150 The alignment references shall be visible also after completion of integration of the telescope with the PLM.

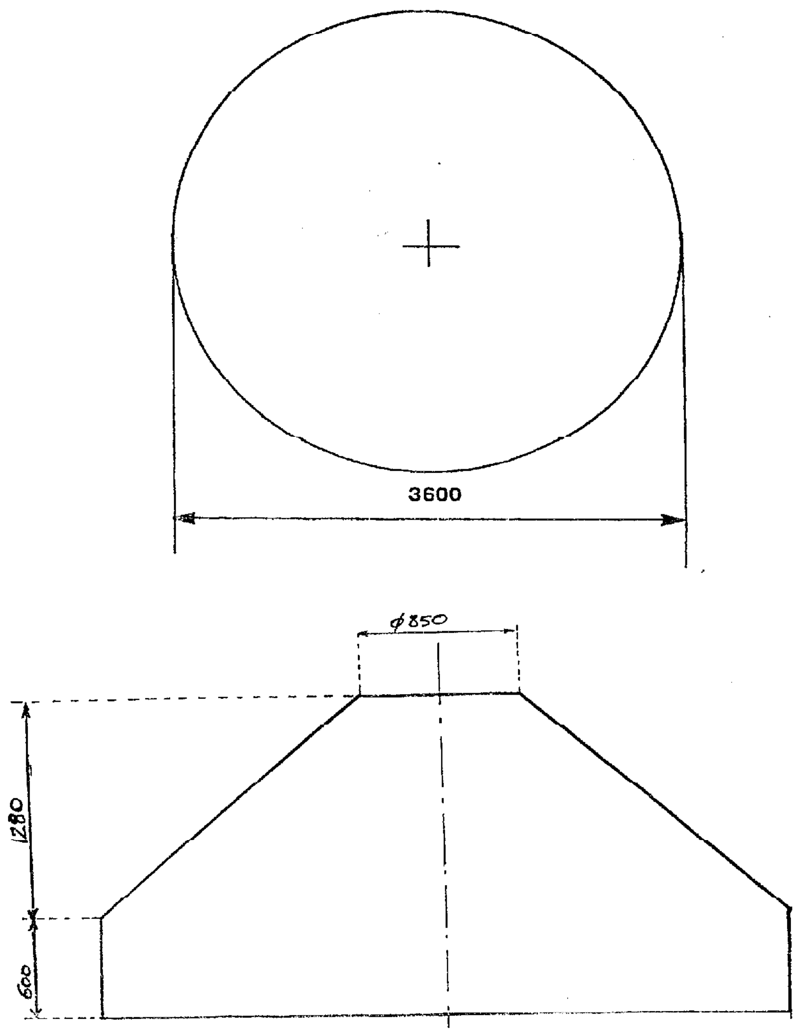


Fig. 4.3-1 **TELESCOPE SIZE of DYNAMIC ENVELOPE**

5. ENVIRONMENTAL, LIFETIME, DESIGN and CONSTRUCTION REQUIREMENTS

5.1 Lifetime, Storage and Transport

5.1.1 Lifetime

TEEN-005 The design life of the Telescope for FIRST shall be 6 years of on-ground operations (including the storage conditions) followed by 4.5 years of in-orbit operations with no performance degradation to a level inferior to that given in this specification.

5.1.2 Storage Environment

TEEN-010 The storage conditions and storage environment (container, clean room ...) shall not degrade the performances of the telescope as defined in section 5.2.

5.1.3 Transportability and Handling

TEEN-015 The telescope shall be able to be transported fully assembled in any angular position between vertical and horizontal in an adequate transportation container. The design of the telescope shall allow its handling in and out of the transport container and its handling during the tests and when integrated to the spacecraft.

TEEN-020 The container shall have the following maximum outer dimensions:
width: tbd
height: tbd
length: tbd

TEEN-025 The design of the container for the telescope shall be compatible with all ground operations for a transport to and within Europe and in Guyana and for a shipment from Europe to Guyana.

TEEN-030 The transportation environment (loads, temperatures, humidity, pressure ...) shall not exceed the design specifications of the telescope listed in the chapter 6 of this specification.

5.2 Pressure - Humidity - Moisture Pick-up

5.2.1 Pressure

TEEN-035 The Telescope shall withstand any external air pressure between ambient (0.115 MPa) to vacuum (<10^{-4} Pa).

TEEN-040 The primary reflector of the telescope shall provide adequate means of venting and shall be able to cope with the depressurisation profile as defined in the ARIANE 5 Users Manual AD-8.

TEEN-045 Cavities within the telescope shall have adequate means of venting which can cope with the depressurization profile as defined in the ARIANE 5 Users Manual AD-8.

5.2.2 Humidity

TEEN-050 The Telescope shall be designed to withstand a relative humidity (RH) without performance degradation of 20% RH to 95% RH, non-condensing.

5.2.3 Moisture Pick-up

TEEN-055 Moisture pick-up of the telescope material shall be considered in the design of the telescope and measures shall be defined such that moisture does not degrade the optical performance of the telescope beyond the requirements defined in 4.2.1.

5.3 Radiation

TEEN-060 All materials of the telescope shall be able to withstand the radiation environment (type, total dose and dose rate) as defined in the applicable document AD-1 with a safety factor of 2.

5.4 Cleanliness/Cleanability

TEEN-065 All parts of the telescope shall be designed and manufactured such that they are cleanable in order to be able to remove contamination deposited during on-ground operations.

TEEN-070 The cleanliness to be maintained during the on-ground operations and the in-orbit lifetime of the telescope shall be such that the telescope transmission does not degrade beyond the limits specified in Section 4.2.1. The exposure of the optical surfaces to the ambient has to be minimised.

TEEN-075 The optical surfaces of the telescope with their reflective surfaces shall be designed to withstand cleaning operations without degradation of the specified performance of the telescope.

TEEN-080 The maximum molecular contamination for the telescope shall not exceed $2.10^{-7}g/cm^2$ at delivery including the ground storage. Particulate contamination shall be smaller than 300 ppm.

5.5 Thermal environment

5.5.1 Temperatures of the Telescope

TEEN-085 The telescope design shall withstand with margins a temperature range from 60K to 358K in vacuum.

TEEN-090 Furthermore the telescope shall be able to withstand the temperatures defined in the table here below.
The performance of the telescope specified in 4.2.1 shall not be degraded when it is tested in the temperature range 60K - 100K.

Range Type	*Min Temperature*	*Max Temperature (bake-out & contamination release)*
Acceptance Temperatures of the Telescope	65 K*	353 K
Qualification Temperatures of the Telescope	60 K*	358 K

*Note: It is not required that the above ranges are verified by test but they shall, however, be verified on sample basis for a better evaluation of the performance of the telescope during its life in orbit.

5.5.2 Thermal Shock/Thermal Cycling - Bake-Out

<u>Thermal Shock</u>

TEEN-095 The telescope with its optical coating shall be able to withstand a cooldown induced by a radiative temperature change of the TV facility from Room Temperature to 90 K under vacuum within 5 hours.

Thermal Cycling

TEEN-100 The telescope shall withstand without degradation in vacuum three (3) cycles of temperature variations between 90 K and the maximal temperature defined in table of paragraph 5.5.1 for acceptance/ qualification and nine (9) cycles of temperature variations between 90 K and the ambient. Each cycle shall include a soak time long enough to achieve thermal equilibrium of the telescope (the equilibrium condition is reached when any temperature rate-of-change is lower than 1°C/hour).

Bake-Out

TEEN-105 The telescope shall withstand without degradation a bake-out with the temperatures as defined in 5.5.1 during acceptance and qualification test for a duration of 15 days (tbc).

5.6 Design and Construction Requirements

5.6.1 Mechanical Stiffness Requirements

The telescope shall be designed to the satisfy following structural stiffness requirements:

TEEN-110 - longitudinal eigenfrequency > 60 Hz

TEEN-115 - lateral eigenfrequency > 45 Hz

TEEN-120 - Local modes (i.e. with an effective mass below 10% of the total mass) shall be > 6 Hz in lateral direction and > 31 Hz in longitudinal direction.

5.6.2 Flight Limit loads

TEEN-125 The flight limit loads shall be applied for the structural design considering in addition the safety factors defined in paragraph 5.6.3:

Primary Reflector (*)	20 g axial and 15g lateral
Secondary Reflector Assembly (*)	50g axial and 40g lateral
Tripod (*)	50g axial and 40g lateral

(*) The axial and lateral loads can have any sign and have to be combined.

5.6.3 Mechanical Strength Requirements

5.6.3.1 Safety Factors

TEEN-130 The telescope shall withstand the worst combinations of mechanical and thermal loads without degradation.

Following safety factors are defined for the dimensioning and verification of the equipment to cover uncertainties of load factor evaluation, material data and analysis as well as to avoid undesirable influences of manufacturing tolerances.

TEEN-135 To cover the qualification test loads the flight limit loads shall be increased by the qualification factor:

- Qualification factor $j_q = 1.5$

To avoid permanent deformation or any elastic deformation resulting in performance degradation the following yield safety factor shall be applied:

- Yield safety factor $j_y = 1.1$

To avoid rupture, buckling or permanent deformation leading to loss of functionality, the following ultimate safety factor shall be applied:

- Ultimate safety factor $j_u = 1.25$

Additional factors (e.g. fitting factors for load introduction points, stress concentration at cutouts or welding/casting factors, etc.) shall be justified by prior experience or test evidence.

5.6.3.2 Sizing Factors

TEEN-140 For the design of the telescope, the following sizing factors shall be applied to the limit loads defined in 5.6.2:

- Load at yield failure point:

$$F_y = j_q \cdot j_y \cdot F_{limit}$$
$$F_y = 1.5 \cdot 1.1 \cdot F_{limit} = 1.65 \cdot F_{limit}$$

- Load at ultimate failure point:

$$F_u = j_q \cdot j_u \cdot F_{limit}$$
$$F_u = 1.5 \cdot 1.25 \cdot F_{limit} = 1.875 \cdot F_{limit}$$

TEEN-145 The material strength data for metals as well as composites with a 99% statistical probability at a confidence level of 95% (A-values) shall be used for Margin of Safety evaluation.

5.6.3.3 Structural Design Margins

TEEN-150 All structural elements shall be designed to exhibit a positive margin of safety (MOS) after application of the relevant safety factors (yield and ultimate) for all worst load cases.

The margin of safety is defined as the ratio of the allowable load (or stress) to the applied load (or stress):

$$MOS = \frac{\text{Allowable load (or stress)}}{\text{Applied load (or stress)}} - 1$$

5.6.4 Sinusoidal Vibrations of the Telescope

During flight, the FIRST telescope is subjected to static and dynamic loads which result from the ARIANE 5 steady state acceleration and low frequency vibration. For the qualification of the telescope, the random vibration loads are covered by the acoustic vibration test (see Chapters 5.6.5). Therefore, random vibration testing is not required.

5.6.4.1 Sinusoidal Vibrations - Acceptance Levels

TEEN-155 The acceptance sine vibration test spectrum to be applied at the base of the telescope is the following:

Vibration Type	Axis	Frequency	Vibration Level
acceptance sinusoidal vibration spectrum (sweep rate 2oct/min)	Y, Z (lateral axes)	5 Hz -16 Hz 16 Hz - 50 Hz 50 Hz - 100 Hz	6.7 mm peak 6.7 g 3.5 g
	X (axis of symmetry)	5 Hz - 18 Hz 18 Hz - 70 Hz 70 Hz - 100 Hz	6.7 mm peak 8.5 g 4.5 g

Note: A notching procedure can be agreed on the basis of the dynamical analysis results and after a low level run

TEEN-160 Low level sine test shall be performed to determine resonance frequencies to evaluate the behaviour of the test fixture and item integrity. Resonance search shall be carried out before and after vibration test for each axis between 5 to 2000 Hz with a level of 0.5 g (sweep rate: 2 oct/min).

TEEN-165 During the sine vibration acceptance tests, the loads on the telescope components shall not exceed the Flight Limit Loads as defined in paragraph 5.6.2 multiplied by the yield safety factor.

5.6.4.2 Sinusoidal Vibrations - Qualification Levels

TEEN-170 The qualification sine vibration test spectrum to be applied at the base of the telescope is the following:

Vibration Type	Axis	Frequency	Vibration Level
Qualification sinusoidal vibration spectrum (sweep rate 2oct/min)	Y, Z (lateral axes)	5 Hz -16 Hz 16 Hz - 50 Hz 50 Hz - 100 Hz	10 mm peak 10 g 5 g
	X (axis of symmetry)	5 Hz - 18 Hz 18 Hz - 70 Hz 70 Hz - 100 Hz	10 mm peak 13 g 7 g

Note: A notching procedure can be agreed on the basis of the dynamical analysis results and after a low level run

TEEN-175 Low level sine test shall be performed to determine resonance frequencies to evaluate the behaviour of the test fixture and item integrity. Resonance search shall be carried out before and after vibration test for each axis between 5 to 2000 Hz with a level of 0.5 g (sweep rate: 2 oct/min).

TEEN-180 During the sine vibration qualification test, the loads on the telescope components shall not exceed the Flight Limit Loads as defined in paragraph 5.6.2 multiplied by the yield safety factor multiplied by the qualification factor.

5.6.5 Acoustic Vibrations of the Telescope

During flight, the FIRST telescope is subjected to acoustic vibrations defined in the ARIANE 5 launcher User's Manual, AD-8.

5.6.5.1 Acoustic Vibrations - Acceptance Spectrum

TEEN-185 The acceptance spectrum for acoustic vibration test is as follows:

Octave Band Centre Frequency (Hz)	Acceptance Level	Test Tolerance
	(O dB: ref. $2x10^{-5}$ Pascal)	
31.5	124	-2, +4
63	130	-1, +3
125	135	-1, +3
250	139	-1, +3
500	134	-1, +3
1000	128	-1, +3
2000	124	-1, +3
4000	120	-4, +4
8000	116	-4, +4
Overall Level	142	-1, +3
Duration	1 minute	

Note: The tolerances indicated in the above table allow for standard test-equipment inaccuracy.

TEEN-190 The design of the telescope shall guarantee that during the acoustic acceptance test the Flight Limit Loads as defined in paragraph 5.6.2 multiplied by the yield safety factor are not exceeded.

5.6.5.2 Acoustic Vibrations - Qualification Spectrum

TEEN-195 The qualification spectrum for acoustic vibration test is as follows:

Octave Band Centre Frequency (Hz)	Qualification Level	Test Tolerance
	(O dB: ref. $2x10^{-5}$ Pascal)	
31.5	128	-2, +4
63	134	-1, +3
125	139	-1, +3
250	143	-1, +3
500	138	-1, +3
1000	132	-1, +3
2000	128	-1, +3
4000	124	-4, +4
8000	120	-4, +4
Overall Level	146	-1, +3
Duration	2 minutes	

Note: The tolerances indicated in the above table allows for standard test-equipment inaccuracy.

TEEN-200 The design of the telescope shall guarantee that during the acoustic qualification test the Flight Limit Loads as defined in paragraph 5.6.2 multiplied by the yield safety factor multiplied by the qualification factor.

5.7 Interchangeability

TEEN-205 Each element of the telescope shall be directly inter-changeable in form, fit and function with other element of the same part number (configuration item number). The performance characteristics and dimensions of like units shall be sufficiently uniform to permit interchange with a minimum of adjustment and recalibration.

5.8 Maintenance

TEEN-210 The telescope design shall be such as to require a minimum of special tools, test equipment etc. to perform calibration, adjustment, fault identification and unit repair. Periodic maintenance requirements during storage and ground life shall be minimized and declared.

5.9 Reliability

TEEN-215 Electrical and electro-mechanical parts shall be selected in accordance with AD-10 and to optimise the reliability for the mission.

TEEN-220 Failure of one element shall not prevent the other from performing its intended function, nor the overall equipment from meeting its performance requirements.

5.10 Parts, Material and Processes

5.10.1 General

TEEN-225 The mechanical parts, material and processes shall comply with the requirements and environments as specified herein and with AD-3.

5.10.2 Dissimilar Metals

TEEN-230 To avoid electrolytic corrosion, dissimilar metals shall not be used in direct contact.

5.10.3 Magnetic Materials

TEEN-235 Magnetic materials shall be used only if necessary for equipment operation. Materials used shall minimize the permanent, induced and transient magnetic fields, with attention paid to minimizing surface currents.

5.10.4 Fungus Nutrient Materials

TEEN-240 Materials that are nutrients for fungus shall not be used when their use can be avoided. Where used and not hermetically sealed, materials shall be treated with a suitable fungicide agent. If materials are used in a hermetically sealed enclosure or are used and stored in a continuously controlled environment, fungicide treatment will not be necessary.

5.10.5 Flammable, Toxic and Unstable Materials

TEEN-245 Toxic and unstable materials shall not be used. Flammable materials should be avoided as far as possible.

5.10.6 Mechanical Parts

TEEN-250 The selection of mechanical parts shall be justified by analysis, evaluation tests and their qualification for the required application shall be demonstrated.

5.10.7 Finish

TEEN-255 The surfaces of each major item of telescope shall be adequately finished to prevent deterioration from exposure to the on-ground and in-orbit environments that might jeopardize fulfilment of the specified performance.
(Additional information on finish such as plating requirements, type and thickness of paint, coatings, etc., may be specified as required).
Surface finish shall comply with the requirements document AD-7.

5.10.8 Outgassing

TEEN-260 Basic acceptable outgassing criteria for the selection of the materials are Total Mass Loss (TML) $\leq$ 1% and Collected Volatile Condensable Material (CVCM) $\leq$ 0.1%.

In case of materials used in the vicinity of optical elements, the more stringent requirement of Recovered Mass Loss (RML) ≤ 0.10% and CVCM ≤ 0.01% shall apply. It should be noted that outgassing characteristics are determined during a vacuum test at 125°C for 24 hours acc. to AD-4.

5.10.9 Cleanliness/Contamination Control

TEEN-265 All parts, materials and processes used for the telescope shall be selected such that the telescope transmission specification can be met as given in 4.2

TEEN-270 The telescope shall be designed such that contamination sensitive surfaces can be covered by suitable means to minimise or to avoid contamination (see also AD-2)

TEEN-275 Optical surfaces shall comply with the requirements as defined in AD-7.

5.7.10 Susceptibility to Stress Corrosion

TEEN-280 Metallic materials selected shall be free from stress corrosion cracking according to AD-6.

5.11 EMC Requirements

TEEN-285 All exposed surfaces that can collect eletrical charges shall be made conductive to avoid electro-static charge and particular contamination. The surface conductivity shall be better than 1 MΩ per square.

TEEN-290 All metallic items shall be electrically grounded with a resistance of less than 100Ω to the interface grounding point.

5.12 Identification and Marking

TEEN-295 The identification and marking shall be done in accordance with the configuration item number respectively part designation, model designation, serial number as relevant and defined in the configuration control requirements.

5.13 Workmanship

TEEN-300 The Telescope Provider shall define workmanship requirements for the telescope items.

TEEN-305 The surface roughness R_q of the optical faces of the reflectors of the telescope shall be ≤0.6 μm.

TEEN-310 Telescope items hardware shall be accompanied with a set of workmanship samples representative for each lot/batch of the manufacturing and integration process.

The samples shall serve for following purposes:

1. evaluation of material integrity
2. evaluation of surface reflectivity and stability
3. evaluation /measurement of optical surfaces
4. evaluation of the manufacturing parameters
5. life samples
6. contamination samples
7. destructive samples for material characterization
8. others as required, i.e. reference/traceability samples

Several samples shall be used as part of the qualification programme (e.g. coating durability).

5.14 Refurbishment

TEEN-315 The telescope shall survive all environmental testing and ground life without performance degradation and without the need for refurbishment.

5.15 Facilities

TEEN-320 All GSE items which will be used for handling and testing the telescope shall be delivered together with the telescope.

6. VERIFICATION REQUIREMENTS

6.1 Verification Methods, Programmes and Matrices

6.1.1 Verification Programme

TEVE-005 The Telescope Provider shall establish a verification plan in accordance with the verification matrix defined in Annex B.
The verification plan shall be reviewed by ESA.
The plan shall define how the requirements are being verified. The verification can be done by test, analysis or inspection.

The plan shall define the:
- objective of the tests
- type of test to be performed
- sequence of tests
- hardware to be tested
- description/objectives of the qualification test
- level of test parameters
- special facilities/equipment needed
- acceptance/rejection criteria.

TEVE-010 In addition the Telescope Provider shall investigate and analyse the following points which are critical for a CFRP telescope design:

- Investigate the sensitivity of all critical manufacturing and system parameters (for CFRP e.g. Fibre/Resin ratio and Fibre/resin variation along the surface and the thickness, variation of thickness of the primary reflector, variation of CTE, homogeneity of face sheets and core ...) based on representative samples in order to validate the adequacy of the selected design and manufacturing process. These analyses shall also demonstrate how the different parameters shall be tailored in order to reach the performance of the telescope.

TEVE-015 During the development of the telescope and its primary reflector, the Telescope Provider shall evaluate and update the WFE budget.
Annex A presents a typical WFE budget tree for the FIRST telescope.

6.1.2 Verification by tests and samples

TEVE-020 The test sequence for the verification of the telescope shall be performed in agreement with the table defined in Annex C.
Additional tests may be added if considered necessary.

TEVE-025 The Telescope Provider shall clearly define responsibilities for the execution of tests.

TEVE-030 The Telescope Provider shall as part of his test/verification plan and procedures clearly define rejection/acceptance criteria in compliance with the objective of the test.

TEVE-035 The Telescope Provider shall define conditions when a retest may be acceptable.

TEVE-040 The effect of moisture shall be measured on sample basis. Based on these results a telescope moisture control plan shall be established to demonstrate TEEN-055.

TEVE-045 All samples used for verification in the development programme of the telescope shall be representative of the manufacturing process and of the environmental lifetime of the final telescope (i.e. bake-out and contamination release temperatures, thermal cycling, thermal shocks ...).

6.2 Analysis, Inspection and Test

TEVE-050 The requirements verification matrix shall be controlled by the Telescope Provider as a minimum in agreement with the table of Annex B. Furthermore a rationale as to why various parameters are verified by analysis, inspection, similarity with other models or by testing shall be established by the Telescope Provider.

6.3 Telescope Verification Testing

6.3.1 Mechanical Verification Testing of the Telescope

TEVE-055 The mechanical verification of the telescope shall be performed in agreement with the specifications listed in section 5.6 and shall be performed before the thermal verification.

6.3.2 Thermal Verification Testing of the Telescope

TEVE-060 The verification of the optical performance of the telescope shall be performed by a combination of tests and analysis.

TEVE-065 The thermal qualification and acceptance testing of the telescope assembly shall be compatible with a LN_2 shroud cooled facility.

TEVE-070 The optical performance of both the qualification and the flight model telescopes shall be as a minimum demonstrated for an average telescope temperature of below 85 K (tbc) and close to 90 K. For both temperatures the worst case environment w.r.t. temperature gradients as resulting from the cold, nominal and hot cases defined in paragraphs 3.5.2 and 5.5.1 shall be applied.

TEVE-075 The compatibility of the teloscope design with the contamination release and bake-out temperatures as defined in para 5.5.1 shall be demonstrated by test for both the qualification and flight models.

TEVE-080 The compatibility of the qualification model of the telescope with the thermal cycling requirements as defined in para 5.5.2 shall be demonstrated by test.

TEVE-085 The compatibility of the qualification model of the telescope with the thermal shock requirements as defined in para 5.5.2 shall be demonstrated by test.

TEVE-090 The compatibility of the flight model of the telescope assembly with the thermal cycling requirements as defined in para 5.5.2 shall be demonstrated by test (tbc).

6.4 Deliverables

TEVE-095 The Telescope Provider shall provide documentation for the transportation of the telescope together with necessary GSE and handling support equipment for delivery.

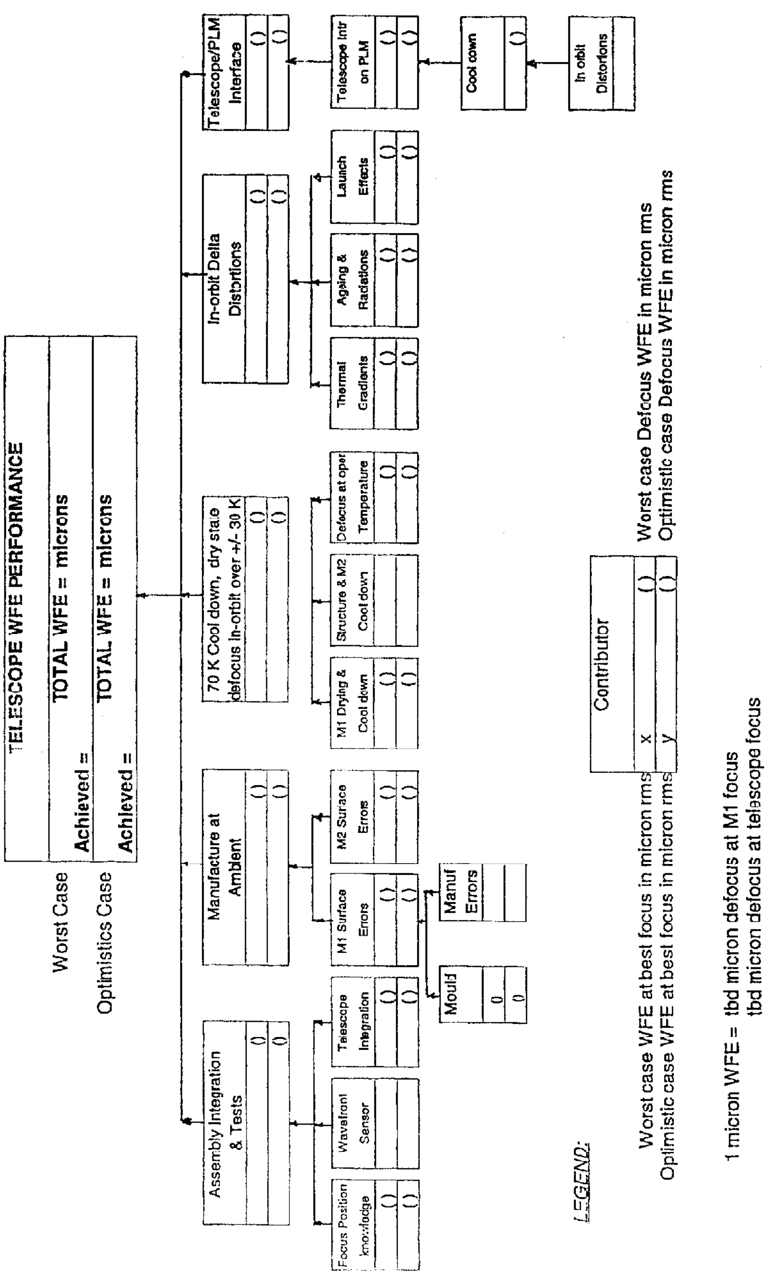
TEVE-100 Prior to the delivery, an Acceptance Review shall take place on the basis of the documents provided four weeks in advance.

TEVE-105 The following hardware shall be delivered:

- one qualification model and one flight model telescope as defined in this specification with associated documentation;
- a transport and storage container including the necessary documentation and log books;
- the Ground Support Equipment including handling, optical and alignment equipment and a protective cover to avoid the contamination of the telescope together with documentation and manuals.

ANNEX A:

WFE TREE BUDGET VERIFICATION


TELESCOPE WFE PERFORMANCE
Worst Case
Achieved = TOTAL WFE = microns
Optimistics Case
Achieved = TOTAL WFE = microns
Assembly Integration & Tests
Manufacture at Ambient
70 K Cool down, dry state defocus In-orbit over +/- 30 K
In-orbit Delta Distortions
Telescope/PLM Interface
Focus Position knowledge
Wavefront Sensor
Telescope Integration
M1 Surface Errors
M2 Surface Errors
Mould
Manuf Errors
M1 Drying & Cool down
Structure & M2 Cool down
Defocus at oper Temperature
Thermal Gradients
Ageing & Radiations
Launch Effects
Telescope Intr on PLM
Cool down
In orbit Distortions
LEGEND:
Contributor
Worst case WFE at best focus in micron rms
Optimistic case WFE at best focus in micron rms
Worst case Defocus WFE in micron rms
Optimistic case Defocus WFE in micron rms
1 micron WFE = tbd micron defocus at M1 focus
tbd micron defocus at telescope focus

ANNEX B:

VERIFICATION MATRIX

CHAP 3				
Requirement	Verification			
	Inspection / Review	Analysis	Test	
			Telescope	Sample
TEFU-005	x	x		
TEFU-010	x	x		
TEFU-015	x	x		
TEFU-020	x	x		
TEFU-025	x	x		
TEFU-030		x		
TEFU-035		x		
TEFU-040		x		
TEFU-045		x		
TEFU-050		x	x	
TEFU-055	x			
TEFU 060	x		x	
TEFU-065	x			
TEFU-070	x			

CHAP 4				
Requirement	Verification			
	Inspection / Review	Analysis	Test	
			Telescope	Sample
TEPE-005	x	x	x	
TEPE-010	x	x	x	
TEPE-015	x	x		
TEPE-020	x	x		
TEPE-025	x	x		
TEPE-030	x	x		
TEPE-035	x	x		

CHAP 4				
Requirement	Verification			
	Inspection / Review	Analysis	Test	
			Telescope	Sample
TEPE-040		x	x	
TEPE-045	x	x	x	x
TEPE-050	x	x	x	
TEPE-055	x	x	x	x
TEPE-060		x		x
TEPE-065	x			
TEPE-070	x	x		
TEPE-075	x	x	x	
TEPE-080	x			
TEPE-085		x	x	
TEPE-090		x		
TEPE-095		x		
TEPE-100	x	x	x	
TEPE-105	x			x
TEPE-110	x			
TEPE-115	x			
TEPE-120	x	x	x	
TEPE-125	x			
TEPE-130	x			
TEPE-135	x		x	
TEPE-140	x		x	
TEPE-145	x		x	
TEPE-150	x			

CHAP 5					
Requirement	Verification				
	Inspection / Review	Analysis	Test		
			Telescope	Sample	
TEEN-005	x	x		x	
TEEN-010	x	x			
TEEN-015	x				
TEEN-020	x				
TEEN-025	x				
TEEN-030	x				
TEEN-035	x	x	x		
TEEN-040	x	x			
TEEN-045	x	x			
TEEN-050	x	x		x	
TEEN-055	x	x		x	
TEEN-060	x			x	
TEEN-065	x			x	
TEEN-070	x			x	
TEEN-075	x			x	
TEEN-080	x			x	
TEEN-085	x	x	x	x	
TEEN-090	x	x	x	x	
TEEN-095	x	x	x	x	
TEEN-100		x	x	x	
TEEN-105		x	x	x	
TEEN-110		x	x		
TEEN-115		x	x		
TEEN-120		x	x		

CHAP 5				
Requirement	Verification			
	Inspection / Review	Analysis	Test	
			Telescope	Sample
TEEN-125		x		
TEEN-125		x		
TEEN-130		x		
TEEN-135		x		
TEEN-140		x		
TEEN-145		x		
TEEN-150		x		
TEEN-155	x	x	x	
TEEN-160	x	x	x	
TEEN-165	x	x	x	
TEEN-170	x	x	x	
TEEN-175	x	x	x	
TEEN-180	x	x	x	
TEEN-185	x		x	
TEEN-190	x		x	
TEEN-195	x		x	
TEEN-200	x		x	
TEEN-205	x			
TEEN-210	x			
TEEN-215	x			
TEEN-220	x			
TEEN-225	x			
TEEN-230	x			
TEEN-235	x			
TEEN-240	x			
TEEN-245	x			

CHAP 5				
Requirement	Verification			
	Inspection / Review	Analysis	Test	
			Telescope	Sample
TEEN-250	x	x		x
TEEN-255	x			x
TEEN-260	x			x
TEEN-265	x			x
TEEN-270	x			x
TEEN-275	x			x
TEEN-280	x		x	x
TEEN-285	x		x	x
TEEN-290	x		x	x
TEEN-295	x			
TEEN-300	x			
TEEN-305	x		x	x
TEEN-310	x			x
TEEN-315	x			
TEEN-320	x			

CHAP 6				
Requirement	Verification			
	Inspection / Review	Analysis	Test	
			Telescope	Sample
TEVE-005	x			
TEVE-010	x	x		x
TEVE-015		x		
TEVE-020	x			
TEVE-025	x			
TEVE-030	x			

CHAP 6				
Requirement	Verification			
	Inspection / Review	Analysis	Test	
			Telescope	Sample
TEVE-035	x			
TEVE-040	x			x
TEVE-045	x			x
TEVE-050	x			
TEVE-055	x			
TEVE-060	x			
TEVE-065	x			
TEVE-070	x	x	x	
TEVE-075	x			
TEVE-080	x			
TEVE-085	x			
TEVE-090	x			
TEVE-095	x			
TEVE-100	x			
TEVE-105	x			

ANNEX C:

TEST SEQUENCE

The test sequence for both the qualification model and the flight model of the telescope shall be as a minimum the following:

1. 3-D Contour measurement of the telescope
2. Optical Performance Measurement at Room Temperature
3. X, Y, Z axes Sine Vibrations
4. Optical Performance Measurement at Room Temperature
5. Acoustic Vibrations
6. Optical Performance Measurement at Room Temperature
7. Bake-out and Contamination Release in vacuum performed with heaters of telescope
8. Thermal Shock
9. Optical Performance Measurement at a temperature <85K
10. Optical Performance Measurement at a temperature close to 90K
11. Thermal Cycling
12. Optical Performance Measurement at a temperature <85K
13. Optical Performance Measurement at a temperature close to 90K