SST Programme: Verification Plan

SST-PRO-PLA-013

Version 1a

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1 Introduction

1.1 Telescope Overview

The Cherenkov Telescope Array Observatory (CTAO, see web page link at https://www.cta-observatory.org) will be made of sub-arrays with three different types of telescopes: large-sized (LST, 23 m diameter), medium-sized (MST, 12 m diameter) and small-sized (SST, 4 m diameter) telescopes. They are distributed in two observing sites, the Northern one in La Palma, the Canary Islands, and the Southern one in the Chilean Andes in the Paranal area. The CTA South “Alpha Configuration” would include LSTs, MSTs and SSTs. In particular, it envisages the construction and installation of 42 SSTs (a number that could increase up to 70 in future upgrades).

The SSTs are developed by an international consortium of institutes that will provide them as an in-kind contribution to CTAO. The SSTs rely on a Schwarzschild-Couder-like dual-mirror polynomial optical design, with a primary mirror of 4 m diameter, and are equipped with a focal plane camera based on SiPM detectors covering a field of view of ~9°. They are sensitive in the band from ~0.5 TeV up to ~300 TeV, providing the Observatory with sensitivity to the highest energies. The current SST concept has been validated by developing the prototype dual-mirror ASTRI-Horn Cherenkov telescope and the CHEC-S Cherenkov camera. Table 1-1 reports main properties of the Small-Sized telescope (SST), Figure 1-1 shows the telescope structure with its primary components.

Table 1-1. Small-sized telescope main properties

Small-Sized telescope (SST) main properties:	
Optical Design	modified Schwarzschild-Couder
Primary reflector diameter	4.3 m
Secondary reflector diameter	1.8m
Effective mirror area (including shadowing)	>5 m^2
Focal length	2.15 m
Total weight	17.5 t
Field of view	>8.8 deg
Number of pixels in SST Camera	2048
Pixel size (imaging)	0.16 deg
Photodetector type	SiPM
Telescope data rates (before array trigger)	>600 Hz
Telescope data rates (readout of all pixels; before array trigger)	2.6 Gb/s
Positioning time to any point in the sky (>30° elevation)	90s
Pointing Precision	< 7 arcsecs

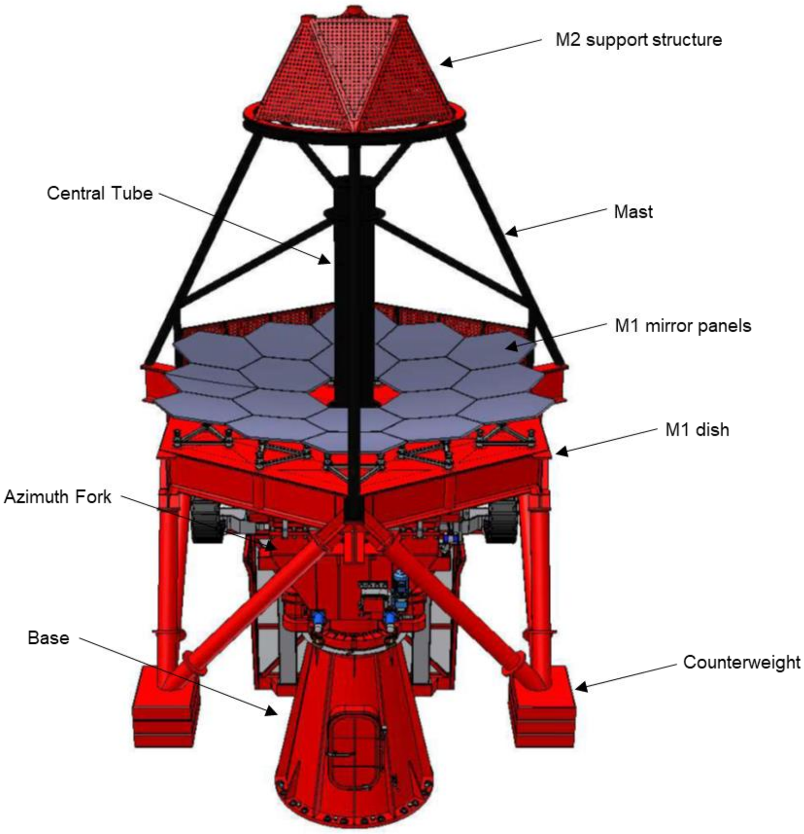


Figure 1-1: Primary components of the SST (courtesy of EIE Group SRL)

1.2 Scope & Purpose

The here described Verification Plan (part of the AIV) is the programme document which presents the Verification approach on the CTA-SST telescopes.

The Purpose of the document is to present at high level the verification strategy of the SST Telescope during the life of the project giving to the AIV/AIT team the right tools and guidelines to perform the complete verification process with respect to the requirements. The telescope verification will be performed by the SST Institutes involved in the consortium instead the AIT, detailed in other documents, will be performed by the industries involved to support the programme. The verification will be carried out on-site with the exception of the first telescope that will be integrated and verified also in the factory.

The contents of the AIV Plan will be consolidated before the Critical Design Review.

The current version of the document is based on the experience of the integration and verification of the ASTRI SST prototype telescope and of its assemblies. This is also based on the experience of the Team developed during the installation and management activities for the ASTRI-Horn prototype of the Serra La Nave (SLN) site of INAF where it is in operation.

1.3 Applicable Documents

[AD1] CTA Architecture Document v1.0 14.04.2018

[AD2] SST Architecture & Design Summary Report SST-PRO-DSR-004 1a

[AD3] SST-PRO-PLA_009 – SST Telescope Engineering Development and Verification Plan

[AD4] SST-AIT-PLA_011 – SST Telescope Factory AIT Plan

[AD5] SST-AIT-PLA_012 - SST Telescope On Site AIT Plan

[AD6] SST-MEC-DSR-001 - Mechanical Design Report

[AD7] SST-OPT-DSR-001 – Optics Design Report

[AD8] SST-CAM-DSR-001 - Camera Design Report

[AD9] SST-PRO-SPE-001 - Telescope Technical Requirements Specification

[AD10] SST-PRO-PLA-005 Product Assurance & Quality Plan

1.4 Reference Documents

[RD1] SST-PRO-SPE-001_1bD_Telescope_Technical_Requirements_Specification_draft

[RD2] Mirror segments preparation and installation operations (in preparation)

[RD3] Camera Installation and Removal procedure (in preparation)

1.5 General Specification and Standard Documents

[SD1] Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on Machinery, and amending Directive 95/16/EC

[SD2] MILITARY HANDBOOK: ELECTRONIC RELIABILITY DESIGN HANDBOOK - MIL-HDBK-338B

[SD3] MILITARY HANDBOOK: RELIABILITY PREDICTION OF ELECTRONIC EQUIPMENT- MIL-HDBK-217F

[SD4] Basis of Structural Design - EN Eurocode 0

[SD5] Steel – Design of Steel Structures – All parts - EN Eurocode 3

[SD6] Design of Composite Steel and Concrete Structures – All parts - EN Eurocode 4

[SD7] Design of Aluminium Structures – All parts - EN Eurocode 9

[SD8] Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 1: General requirements - EN 61010-1

[SD9] Safety of machinery, Functional safety of safety-related electrical, electronic and programmable electronic control systems - EN 62061,

[SD10] Safety of machinery -- Safety-related parts of control systems -- Part 1: General principles for design - EN ISO 13849-1

[SD11] Safety of Machinery – Emergency Stop – Principles for design - EN ISO 13850

[SD12] Low-voltage electrical installations - EN 60364 series

[SD13] Basic and safety principles for man-machine interface, marking and identification - Identification of equipment terminals, conductor terminations and conductors, 2010 - EN 60445,

[SD14] Insulation coordination for equipment within low-voltage systems - EN 60664 series,

[SD15] Reliability Modelling and Prediction reference - MIL-STD-756B

[SD16] System Safety - MIL-STD-882E

[SD17] Procedures for performing a Failure Mode, Effects and Criticality Analysis reference - MIL-STD-1629A

[SD18] EMC Directive 2004/108/EC

[SD19] Electromagnetic Compatibility (EMC) - EN 61000 series

[SD20] Functional Safety and IEC 61508, Functional safety of electrical/electronic/programmable electronic safety-related systems

[SD21] IEC 61131-3, Programmable controllers - Part 3: Programming languages

[SD22] Lightning protection standard - EN 62305:2011

[SD23] Cleanrooms and associated controlled environments — Part 1 - ISO 14644-1:2015

[SD24] ECSS-Q-ST-80C Rev.1 (15 February 2017)

[SD25] CTA-STD-OSO-000000-0002 1h CTA SW Licensing Policy

[SD26] CTA-SPE-OSO-000000-0001 1b Top-level Data Model

[SD27] CTA-SPE-COM-000000-0002 1e R1-Event Data Model

[SD28] CTA-STD-OSO-000000-0001 1a Software Programming Standards

1.6 Definition of Terms and Abbreviations

1.6.1 Abbreviations and Acronyms

ACADA	Array Control and Data Acquisition System
AIT	Assembly Integration and Testing
AIV	Assembly Integration and Verification
AMCU	Active Mirror Control Unit
ASTRI	Astrophysics with Italian Replicating Technology Mirrors
AZ	Azimuth
BKO	Bridging phase Kick-Off
CDR	Critical Design Review
CTA	Cherenkov Telescope Array
CTAO	Cherenkov Telescope Array Observatory
DR	Delivery Review
DVER	Design Verification Engineering Review
EL	Elevation
ERIC	European Research Infrastructure Consortium
ESC	Executive Steering Committee
FAR	Final Acceptance Review
FRC	France Contribution
HW	Hardware
IKC	In Kind Contribution
INAF	Istituto Nazionale di Astrofisica
INSU	Institut National de Science de l'Univers
KO	Kick-Off
MPIK	Max-Planck-Institut für Kernphysik
NC	Non-Conformance
OBSPM	Observatoire de Paris – PSU, CNRS
OP	Observatoire de Paris
PA	Product Assurance
PBS	Product Breakdown Structure
PM	Project Manage
PMC	Pointing Monitor Camera
PMP	Programme Management Plan
PO	Project Office
PQR	Production Qualification Review
PR	Product Review
PRM	Programme Manager

PRR	Production Readiness Review
PSE	Programme System Engineer
QA	Quality Assurance
QM	Quality Manager
RAMS	Reliability, Availability, Maintainability & Safety
SE	System Engineer
SOW	Statement Of Work
SQM	Sky Quality Meter
SRD	System Requirements Document
SSD	System Specification Document
SST	Small Size Telescope
SVR	System Verification Report
SW	Software
TAC	Thematic Assembly Centre
TRR	Test Readiness Review
VCD	Verification Control Document
WBS	Work Breakdown Structure
WP	Work Package
WPD	Work Package Description

1.6.2 Glossary

TERM	DEFINITION
"As Built" Configuration	The as-built configuration or applied configuration is defining the as-built status per each serial number of Configuration Item (CI) subject to formal acceptance.
"As Designed" Configuration	The as-designed configuration or Applicable configuration is defining the current design status of a Configuration Item (CI)
AIV	AIV is the Assembly Integration and Verification, which is referred to the integration activities related with the verification of the system or sub-system. In the framework of SST for briefness this term includes also the Assembly Integration and Testing which is related with the integration activities and testing to be performed during the integration at system and subsystem levels
Baseline	Set of information which describes exhaustively a situation at a given instant of time or over a given time interval.
Change	Vehicle for proposing modifications to an approved baselined data or the business agreement.
Configuration	Functional or physical Characteristics of a product defined in configuration definition documents subject to configuration baseline.
Configuration Item	Aggregation of hardware, software, processed materials, services or any of its discrete portions, that is designated for configuration management and treated as a single entity in the configuration management process. **NOTE:** A configuration item can contain other lower level configuration item(s).
Deviation	Written authorization to depart from the originally specified requirements for a product prior to its production.
Firmware	Firmware is software programmed onto an electronic device which is treated like a pure hardware.
Executive Steering Committee	The SST Executive Steering Committee (ESC) is the high-level decision-making body which will manage the strategic direction of the Programme and will be in charge of overseeing progress and facilitating global collaboration among the participating groups.
Institutes	Research Institutes involved in the SST Programme.
Contractor	Industry involved in the SST Programme which has a contract with an institute
SST-PRO	It is the team composed by Institutes and Contractors responsible, involved in the production of SST telescopes elements, which coordinate the project level activities.
Hardware	Hardware is a single or an assembly of physical electronic devices which cannot be changed in its user environment.
Item	Any part, component device, sub-unit, unit, equipment or device that can be individually considered.
Model	Physical or abstract representation of relevant aspects of an item or process that is put forward as a basis for calculations, predictions or further assessment useful for the preparation of SST production
Partners	are those entities taking responsibility for IKC delivery by signing IKC agreements with CTAO, plus any organisation identified by these signing entities as playing an essential role in SST delivery. The institutes are the partners of the CTA-SST consortium.
Product	A product (hardware, software, service) required in the frame of the program and included as element of the product tree having a unique identifier. A product may be deliverable or not.
Product Breakdown Structure	Hierarchical structure depicting the product orientated breakdown of the project into successive levels of detail down to the configuration items necessary to deliver the required functions. The Product Breakdown Structure (PBS) in general is influenced by Institutes/partners decisions to group certain products or by program history. It identifies products and their interfaces; it serves as the basis for the WBS
Service	Service is the result of at least one activity necessarily performed at the interface between the SST consortium and CTA and is generally intangible.
Software	Set of computer programs, procedures, documentation and their associated data.
SST-E2E	The SST end-to-end telescope, or simply SST, will consist of the SST Structure and the SST Camera (including all mechanics, mirrors, auxiliary devices and required software), integrated and commissioned on-site including all required documents. It ends at (and integrates into CTA via) the system interfaces specified by the CTA PBS.
SST Consortium	The SST Consortium then consists of the Partners and their associated Teams, where a Team is a set of individuals within a single organisation at a single location (such as a university group).
System	An entity of products assembled or working together for a well-defined specified purpose. In SST the term system can be utilised in alternative to Telescope End-to-End.
Sub-System	Like a system but a lower level. In SST the SST system is composed by the subsystem SST-MECH, SST-OPT, SST-TCS and SST-CAM.
Waiver	Written authorization to use or release a product which does not conform to the specified requirements
Work Breakdown Structure	Hierarchical representation of the activities necessary to complete a project.

2 Verification Subject

SST shall be an array of equal 42 units within the CTA-South Observatory. The array will cover an area of 10 km square (TBC) near the ESO sites of Cerro Paranal and Cerro Armazones in the Chilean Atacama Desert, see Figure 2-1.

Figure 2-1 CTA Installation Site, Atacama Desert Chile

SSTs shall be installed in a sub-set of the CT-Array, the Figure 2-2 shows the proposed array shape. The final disposition shall be decided by 2023 (TBC).

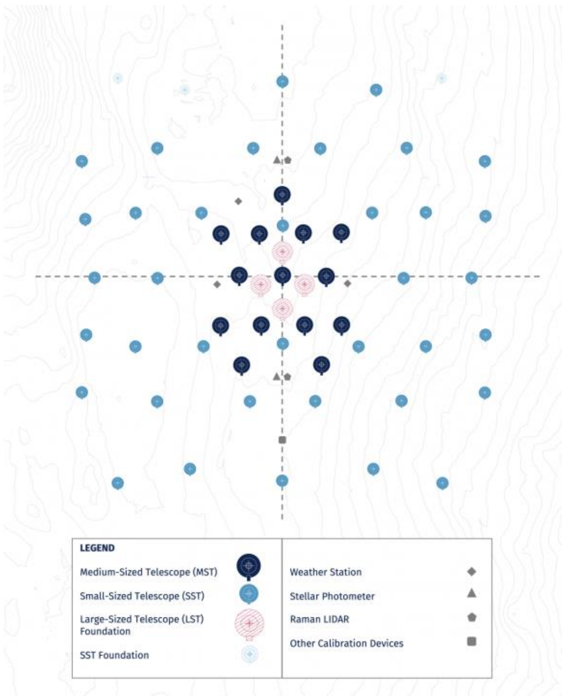


Figure 2-2 Proposed array distribution for telescopes sites

Figure 2-3 shows the high-level Product Breakdown Structure (PBS) which describes the subject of the verification for a single telescope.

The first level of the PBS (*blue*) is the SST Telescope system; the items at the second level of the PBS (*orange boxes*) are the telescope subsystems, i.e. the main items which constitute the telescope itself. This document will provide the plan for the verification of the subsystems integrated to compose the telescope.

Together with the verification of individual telescopes all hardware devices functionalities that connect the telescopes to the power network will also be verified during the commissioning phase which responsibility is in charge of CTAO.

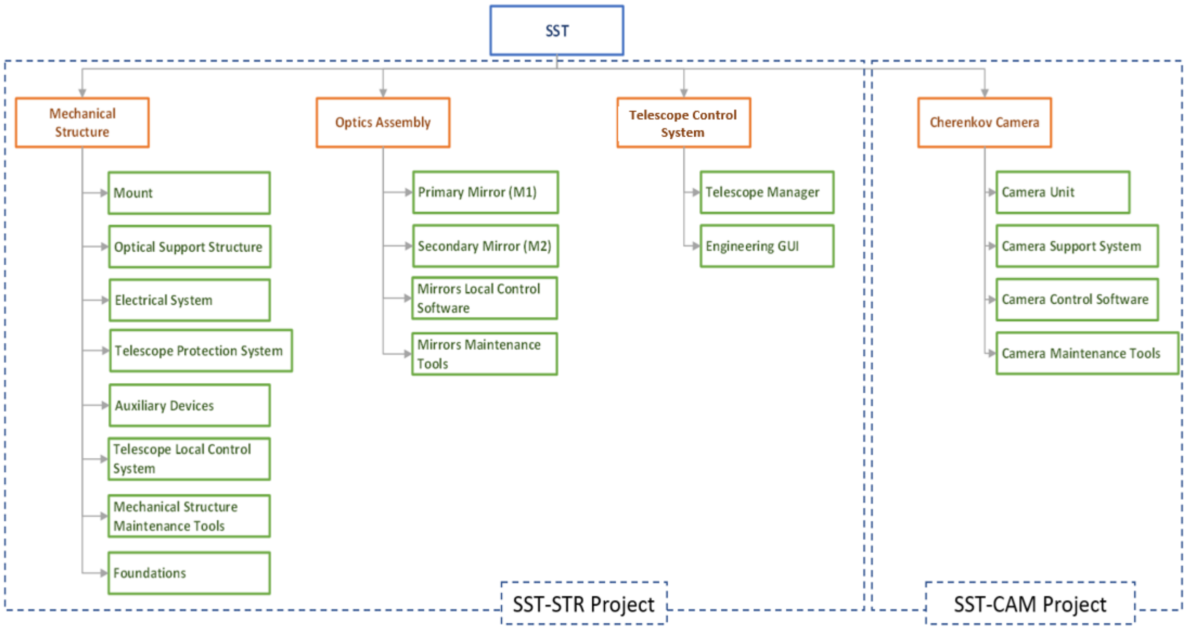


Figure 2-3 SST Telescope Product breakdown Structure

3 Verification Strategy

An effective verification strategy shall be identified and followed during the entire execution of the project to fulfil both budget and schedule constrains. The Verification Strategy also tightly depends on the Engineering Development and Verification Plan [AD3] that includes the Requirements Verification Matrix.

The integration of the telescopes will be done on site with the exception for the first telescope that will be integrated for the first time in factory to enable a fine tuning of the integration of all sub-systems and identify critical issues.

The integration and verification process of the first SST will be performed in factory as far as can be done due to constrains and limitation deriving from the installation site.

The Integration and Verification process of all the other telescopes will be routinely performed on site.

The prerequisite of the verification is the identification of all critical requirements that ensure that the SST project is building the right instrument. Once the requirements have been identified the Verification process shall demonstrate with objective evidence that the instrument is built in the right way.

The verification will start during the integration process when needed to proceed. The Integration plan reported here lists the activities aimed to verify that the Telescope system level technical specifications are met.

Once Verified the Instrument will go through the Science Validation process, which is beyond the scope of this document.

In some cases, the Verification is deeply connected with some Science Validation tests. That is the case, for example, for the validation of the primary and secondary mirror actuator system. In such cases the verification will be done, de facto, along with the correspondent Science Validation test or will accept the results of the tests.

3.1 Requirements identification

To perform the validation process we follow the approach described by the standard V model for validation as described in Figure 3-1.

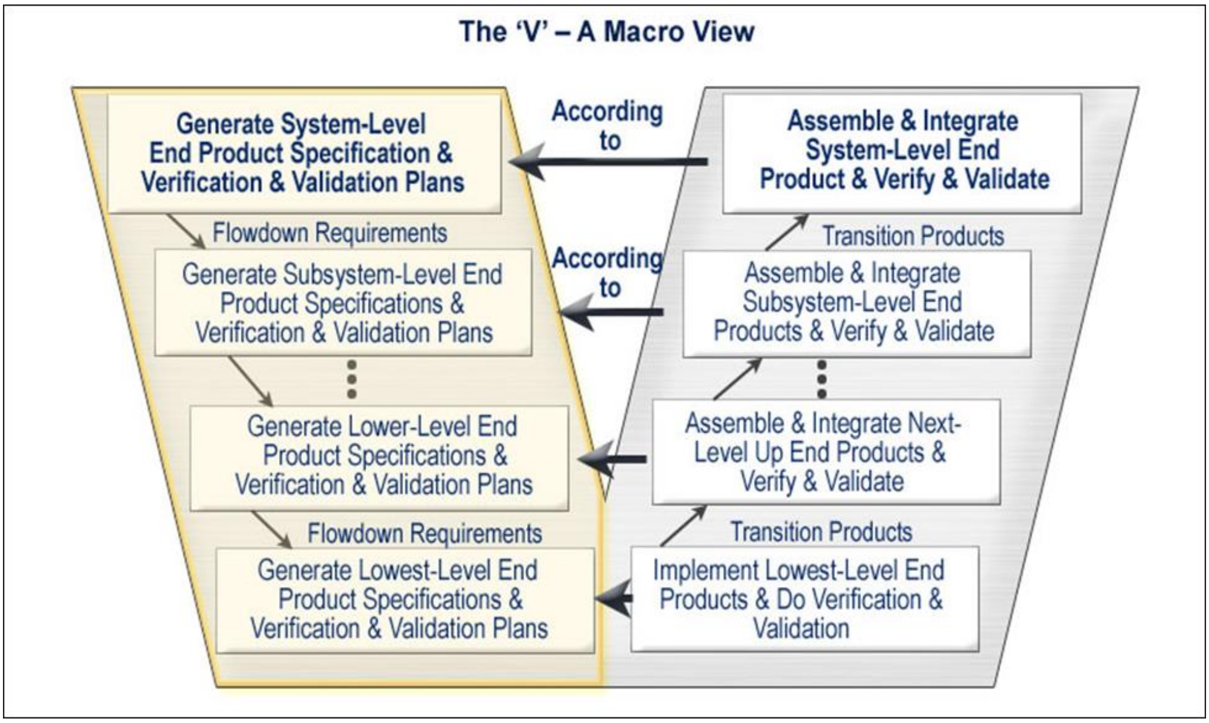


Figure 3-1 The standard V model for validation

Requirements shall be first extracted from the System Requirements Specification document, which is the highest-level description of the instrument. To validate the whole design, it will be needed to go much more in details referring to Sub-systems, Assemblies, Parts requirements. The lower-level requirements can be found in the specific Subsystem Technical Requirement Specification document for Camera, Structure and Optics etc.

The objective of the validation process would be also to have a list of requirements where for each of them has been identified a trace to a Requirement documentation. Traceability is important because it is a tool to check that the list is complete (no missing requirements) and consistent (no repetition).

3.2 Creation of the Verification Control Document

The first step is the creation of a Verification Control Document (VCD). It is a living document that lists all the requirements described in [AD9] and follows the verification status all along the project life. The VCD will be maintained updated by the AIV team and aligned with the Telescope Technical Requirements Specification document by the Configuration Manager.

This document will be in form of a table (Excel form) where each row corresponds to a Requirement. No extra tool for requirement management was needed or required so far. For each Requirement the following information is provided:

- ID: unique requirement identification number
- Parameter: parameter name
- Specification: requirement description
- Trace: reference to the applicable document from which the requirement is derived
- Applicability: applicability level (system, camera, optics, mechanics, software, auxiliary, control subsystem
- Verification method (see following section): this step is necessary to draw the verification strategy and because the different methods have usually different impacts on cost
- Reference schedule: reference to scheduled time when the requirement is verified (this point is important in order to check at the same time consistency and completeness of the verification approach)
- Reference document: reference to the output document delivered by the verification process
- Note: optional additional information
- NCR: reference number of the Non-Conformity Report (if needed)
- NCR status: status of the NCR (open/closed/use as is)
- RFW: reference number of the Request For Waiver (if needed)
- Requirement status (verified/not verified)
- Compliance: compliancy status

For each requirement a verification method shall be identified. Five different verification methods can be envisaged:

- Test (T). The requirement shall be verified by a dedicated test. This is the preferable option. (Test report shall be requested to pass the verification step)
- Analysis (A). The requirement shall be verified by a dedicated analysis. Because of many reasons a requirement cannot be always verified by test, so an analysis is requested instead. (An Analysis report shall be requested to pass the verification step)
- Review of Design (ROD). The specific requirement will be verified reviewing the design by a board of experts. (A reference to a Minute of Meeting (MOM) of the board shall be requested to consider the verification passed)
- Inspection (I). Some requirements can be verified easily by inspecting the hardware. (A Technical Report shall be requested to consider the verification process passed)

- Certification (C). Some requirements shall be certified by a third party. Usually, it is applied to those components that are procured from a supplier.

This step is necessary to draw the verification strategy and because the different methods have usually different impacts on cost.

In the case of HW or SW items provided by subcontractors or suppliers, the parameters to be validated and the applicable verification method will be defined in the SOW. As described in AD1, the traceability system will be based on log sheets. The logged operations relate to:

- Manufacturing (manufacturing record)
- Tests and Inspection
- Integration
- Non-Conformance (if necessary)

3.3 Verification Program

The precise reference to a specific verification step of each requirement will be the output of the identification process, as explained before. Nevertheless, at high level is already possible, due to the expertise of the SST project team, to identify well in advance verification stages/steps along the project needed to perform the verification strategy. This strategy is expected to be refined during the consolidation phase.

The goal of the Verification Program is to fill the VCD in all its fields in order to have a final and complete picture through the verification results.

3.3.1 Integration and Test

All the necessary Integration and Test activities will be organized in different Integration and Test Points, respectively, with the aim to verify specific subsets of interfaces and requirements. Integration and Integration Tests are beyond the scope of this Verification document. The output of the Verification performed along the Integration phase will be checked and introduced as annex wherever it is necessary for the on-Site Verification. Preliminary test matrix and test descriptions are reported in [AD3].

3.3.2 Verification Team

The organization of the AIV/T activities and its relationship with the SST team organization is presented in this paragraph.

The following groups are involved in the overall verification process:

- INAF
- OP-INSU
- Camera Team

More details on the organization of the AIT/V Team and their duties and responsibilities are presented in [AD3].

3.4 Problem Management

During Integration and Test activities unexpected events can occur, which can have negligible or important impacts on the activity continuation. These problems can be classified according to the relevance and impact (in terms of time, quality, and cost) on the project.

3.4.1 Deviations

Deviations are those problems which imply a modification in the planned activities but without any impact (in terms of time, cost and purpose) on their normal continuation. Typically, they are due either to contingent situations (e.g., missing tools) or to errors occurred in an integration/test procedure. A deviation always implies a Non-Conformance (NC): a minor NC if there is no impact on the documentation, a major NC if a change in requirement and/or procedure and/or Interface Control Document (ICD) is requested.

The person in charge of the activity shall be able to weight up in real time when this type of event occurs without stopping the on-going activity. He shall report this problem in the documentation relevant to the activity. The right way to deal with this type of problems is to issue a NC Report (NCR), either minor or major.

All deviations shall be discussed later in special meetings, which shall be defined by the AIV responsible. For the deviations which imply a major NCR an agreement between all the involved parties has to be reached in order to close them.

3.4.2 Minor Problems

Minor Problems are problems due to an error, of any type, for which the responsible for the activity has found a solution. These problems usually have a low impact on the activity schedule, which should be limited in terms of duration. Minor Problems shall be noted as for the deviations; moreover, they have to be reported to the responsible for the AIV activities and, for information, to the SE. The AIV manager can submit to the SE a variation in the schedule planning. A Minor Problem may generate a NC.

3.4.3 Major Problems

Major Problems are all the type of problems which block or delay significantly the normal continuation of the activities. They include an instrument failure which hampers the test execution, the shortage of resources, and the detection of unexpected or wrong results as regards the applicable requirements. A Major Problem may generate a NC. In case of a Major Problem encountered the on-going activity shall be stopped and its responsible, together with the AIV Manager, shall organize a technical/programmatic meeting, called Verification Control Board (VCB), to discuss the problem; also, the SE and the Project Manager (PM) shall participate to this meeting. A problem is considered as major if it has a transversal impact on the cost, execution time or purpose of the project.

3.4.4 Non-Conformity Report (NCR)

The definition of minor and major NCRs is determined by the severity of the problem [AD10]. Depending on their impact, two different types of NCs are defined:

- MAJOR NCs, which affect design requirements, test procedures and/or ICDs
- MINOR NCs, which do not affect the previous items

The format to be used in reporting problems will be defined by the Quality Assurance (QA) Manager. In any case, when reporting a Test Problem discovered during testing activities, the following information will be included:

- problem report identifier
- identifier of the Test Procedure/Test Case in which the problem has risen
- test set-up
- environment conditions at problem occurring
- configuration of the equipment under test (operating modes, connections, …)
- problem description
- possible/suggested solutions

4 AIV timeline schedule

The work flow of the key integration and test activities is shown in Figure 4-1. Based on the previous experience on the field with the ASTRI-Horn prototype and with ASTRI-MA the timeline for the integration process for an individual telescope is shown in Figure 4-8. The estimated time to complete this process on site is 40 working days. In the case of the first two telescopes, the process will take longer and can lasts up to 60 working days considering the learning time for the entire process. The first telescope will be also integrated and partially verified on factory in order to assess the entire process will be performed on site and so to anticipate any possible interface issues.

The integration timeline process is described in the next paragraph.

The On-Site Verification will start as soon as integration of the telescope ends and whenever is the case, will be integrated with science Verification tests.

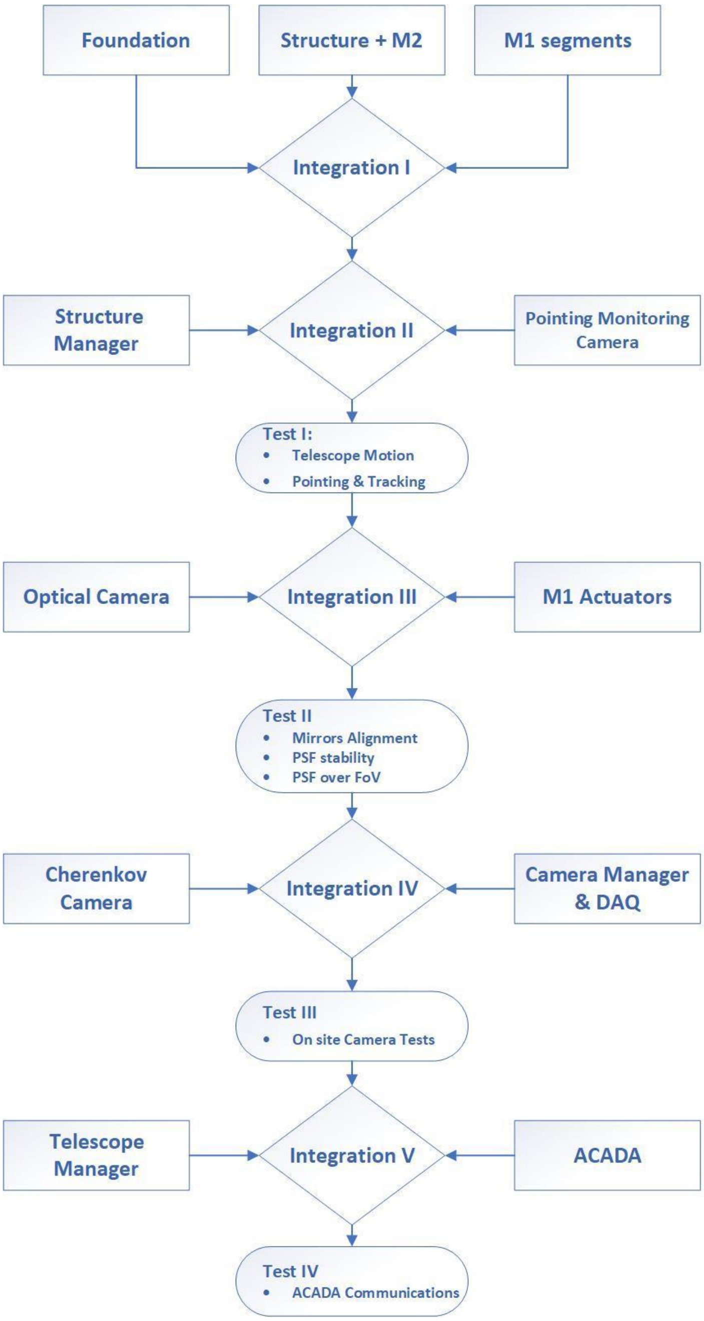


Figure 4-1: Work flow of the Key Integration and Test activities at SST system level

4.1 Timeline for the AI and Verification phases

In Figure 4-8 the overall process is followed giving educated guesses for the time needed to complete the steps. Whenever omitted row # refers to sequential rows showed in Figure 4-8.

We assume civil works are already complete, mature, and verified and that all infrastructures for power and network connection are already in place and ready to be used.

Safety and quality people will be present to follow the main steps. The starting date will be day=0. Here following the timeline step by step.

4.1.1 Install Mount (row 2)

Mount install starts with the installation of the mount base and fork including motors and telescope cabinets. The operation can last one full day. At the end of the operation the formwork for the grout must be put in place and the grouting shall be done.

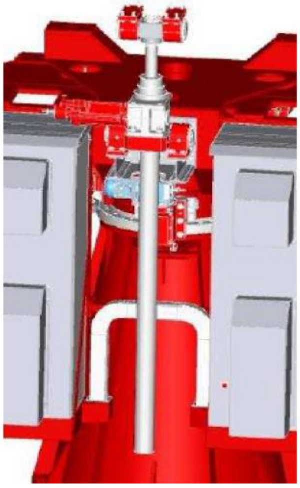
Figure 4-2: Basement (left), basement with cabinets installed (right), courtesy of EIE Group SRL

Grout needs about 4 days in which some curing must be performed.

The row 2 of the schema in Figure 4-8 shall be complete in 5 full days. People involved are from the contractor [AD5].

4.1.2 Install Optical Support Structure (row 4-5)

To proceed with installation of optical support structure the first operation is installation of the Elevation Actuator then the primary mirror (M1) Dish will be assembled and integrated. The primary mirror support structure is delivered on site disassembled in two pieces, then it must be assembled on the ground and after that installed on the fork and connected to the actuator.



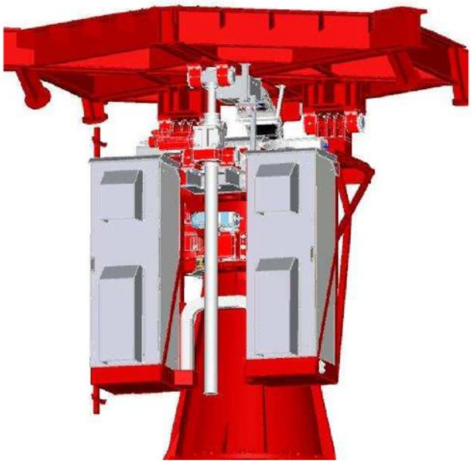


Figure 4-3: Elevation actuator in place (left), M1 dish structure mounted (courtesy of EIE Group SRL).

All described operations, row 4 in Figure 4-8, can be complete in 3 days by contractor people [AD5].

Once the primary mirror dish is in place the secondary mirror support structure can be put in place, followed by the secondary mirror structure. The installation of counterweights structure and counterweights shall follow.

Figure 4-4: Secondary mirror structure in place (courtesy of EIE Group SRL

To complete row 5 operations 3 days must be considered. The operation is in charge of contractor personnel [AD5].

The M2 protection cover shall be installed by SST AIT/V Team personnel.

4.1.3 Connection to network and power (row 6)

The connection of the “service cabinet” to telescope cabinet can last 1 day. Internal cabinet fibre and wires connection strongly depends on the status of preassembling of the cabinet (row 6 in Figure 4-8), if the cabinet is well preassembled, can be complete in 1 day. Personnel from contractor agency is in charge for those operations.

4.1.4 M1 segments and PMC/SQM installation (row 7)

Installation of the PMC/SQM assembly and functionality test shall be done in half a day. The full population of mirror segments last in all 2 days. At least 6 SST AIT/V Team people must be involved in the operations, 2 people working to the PMC/SQM subsystem and 4 people for segments.

PMC/SQM comes in a preassembled box, software control system already developed both for test and integration within the telescope control software. SST AIT/V Team people will verify functionalities based on the specific VCD.

Figure 4-5: The PMC installed on top the M2 support Structure (courtesy of EIE Group SRL)

Segments installation must be prepared in advance preassembling segments with pads and all needed mechanical equipment. Those operations can be done at the site in advance to avoid affecting the operation duration. The mirror segments preparation will be accurately described in [RD2].

The row 7 operations will last 3 days.

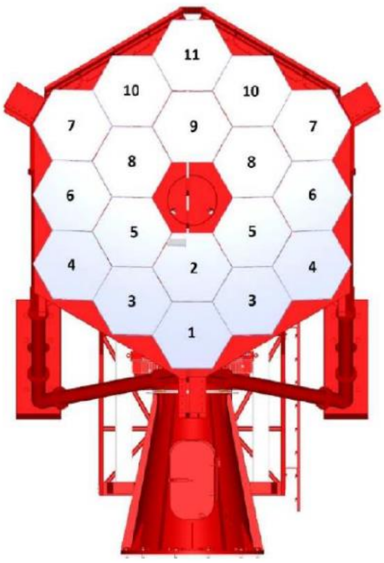


Figure 4-6: M1 segments in place, numbers give the suggested installation sequence (courtesy of EIE Group SRL).

4.1.5 Optical camera, start of SW integration tests (rows 8/9)

Providing the telescope structure is integrated including service assembly for mount/dismount of cameras, the integration of the Optical Camera is straight forward and half a day is needed. After the installation "Functional Tests" can starts.

Once Optical Camera is in place 3 good observing nights are needed to collect data to elaborate Telescope Pointing Model, measure Precision Accuracy and Pointing accuracy provided all instruments are nominally running.

The operations will be qualified and tested with the first telescopes. In the case of the first telescope, we assume a longer duration for this part of the verification tests.

Rows 8 and 9 will involve the work of contractor personnel for the installation of the camera and in case of need for the very basic telescope initial operations.

Tests must be performed by SST AIT/V Team personnel in charge of the tests and software operations, at least 4 people 2 of them certified for the use of the Cherry Picker.

1) M2 cover shall be removed for incoming tests.
2) ICT operativity test shall be done by SST AIT/V Team personnel.

All operations involved in row 8 and 9 will last 5 days.

4.1.6 M1 setup for alignment (row 10)

All mirrors must be already in place. The first operation is to put actuators in place (3 per segment). All 54 actuators must be put in place. The operation needs 2 full work days of 4 specialist people of the SST AIT/V Team, including cherry picker/software skilled people, supported by the contractor agency.

4.1.7 M1 segments alignment (row 11)

The operation must be performed from SST AIT/V Team personnel. Mirror segments control software must be already nominally operating. 1 observing night for the collimation and "gravity test" stability, 2 other nights are needed to perform additional tests for the PFS verification and additional optimisation of the optic system.

The operation is described in the Mirror Alignment Procedure [RD2, to be released] and will be performed by using the AMCU control software that is being developed and tested by INAF for the ASTRI-Horn Prototype and for the ASTRI-MiniArray.

4 SST AIT/V Team people involved, the operation will last 3 nights routinely. In the cases of telescope 1 and 2 more time is needed to refine procedures and software. Cherry Picker and software skill needed.

1 additional day to dismount the actuators and optical camera.

4.1.8 Cherenkov Camera/Chiller installation (row 12/13)

4.1.8.1 Introduction

Full functional and performance verification of an SST Camera Unit with respect to its Level C requirements is foreseen prior to shipping from the integration site. Pre-acceptance is therefore possible for units before shipping. On-site, once dismounted the optical camera (Opticam) the

Cherenkov Camera and its chiller can be put in place. The camera installation and removal procedure are illustrated in [RD3], to be released. A basic pre-integration verification is followed by installation in to the Telescope Structure and integration with respect to the Camera Supporting Systems and software elements installed at the On-site Data Centre. After that, a verification of successful integration is performed using only the Camera sub-system, prior to the full telescope verification described in Section 4.1.9. These operations can be done in 1 day, by at least 2 SST Structure and 2 SST Camera AIT/V team members.

4.1.8.2 Pre-integration verification

4.1.8.2.1 Camera Unit

The Camera Unit is removed from on-site storage and unpacked. A visual inspection for transport damage is performed. Power and network connections are established in a suitable (standard lab/office) environment. Functional testing is performed via software Telescope Manager/ACADA simulators, via the defined interfaces to these systems. If testing is successful, the unit is packed for transport to the SST location. Failure of automated testing results in more detailed inspection and a decision on returning the Unit, replacing LRUs, or other mitigation action.

4.1.8.2.2 Camera Supporting Systems and Interface tests

The Camera Interface Test Unit is installed at the Camera Unit location in the telescope, performing a simple automated test that network, power and clock connections are present and reliable.

A closed loop flow test is performed for the Chiller Unit at the telescope.

4.1.8.3 Integration in to Telescope

The integration of the Cherenkov Camera in to the SST Telescope consists of the following steps, after transport of the Camera Unit to the telescope location in protective case:

4.1.8.3.1 At Height/Focal Surface

Lifting and bolting of Camera Unit to the structure.

Connection of Camera Unit to cooling system (pipes to Chiller).

Connection of network cable, including fibre for clock signal.

Connection of power cable.

4.1.8.3.2 From Ground

- Power switch on.
- Lid open/close test using Local Mode.
- Cooling liquid flow test.
- Confirmation of correct power consumption, current flow.
- Confirmation of network and clock connectivity.
- Confirmation of expected internal Camera Unit humidity level.

See ‘SST Camera Maintenance Concept’ document [RD4] for more information.

4.1.8.3.3 Post-integration verification

After Camera Unit integration, Cherenkov Camera functionality is verified via the remote S/W interface. With two steps:

4.1.8.3.4 Daytime

Using a simulator for the Telescope Manager, cycling of camera states is performed via this interface. R1 Data and trigger timestamps are collected via a simulator of the ACADA R1 interface. These data are used to confirm expectations for in-situ electronic noise levels and triggering, and data delivery/integrity.

4.1.8.3.5 In Darkness (flasher tests)

One moonless night is needed for camera verification with the Telescope in parked position. Noise levels in the camera with photosensors on are checked against expectations and the camera calibration flasher is activated to provide a periodic trigger of the system.

These data are used for the derivation of flat-field coefficients and pixel time offsets, with a comparison to lab AIV values. These data also serve to verify triggering and flasher functionality.

All further verification takes place with the integrated SST and is described in the next section.

2 days and Personnel of the CTA collaboration will be needed. 4 SST AIT/V Team people, 2 of them with cherry Picker skills.

4.1.9 Post integration structure verifications (row 14)

The post integration verifications will last many days in the case of the first telescopes. Routinely will last 2 days/nights.

The pointing model #2 will take 2 nights followed by astrometric tests, PSF verification.

All 4 nights are needed for the post integration tests. Operators will be 2 SST AIT/V Team people supported by CTA personnel (TBC).

The following list of requirement verification tests shall be done at telescope level:

1) Check Azimuth encoder initialization
2) Check Azimuth speed and acceleration
3) Check Elevation speed and acceleration
4) Check Braking
5) Check Position closed loop bandwidth
6) Check Regular performance monitoring
7) Check Mount payloads and interface
8) Check Maintenance/access points
9) Check Telescope maintenance
10) Check Telescope parking speed
11) Check Flood protection
12) Check Safety signal
13) Check Drive control safety
14) Check Main axes range limits
15) Check Electrical safety
16) Check Observing pointing safety
17) Check EL Actuator Correct working
18) Check Tracking precision
19) Check Post-calibrating pointing accuracy
20) Check M2 Actuator range
21) Check M2 Actuator accuracy
22) Check M2 support position adjustment
23) Check SST Safety and M2 cover test, procedure and timing

Second telescope pointing model:

1) PSF check using Variance
2) T-point schedule 125 pointing (PMC + Cherenkov Camera)
3) PMC/Cherenkov Camera alignment tests Polaris, Zenith, Meridian measurements.

4.1.10 Fully integrated SST Verification (row 15)

Only aspects that cannot be conducted with the sub-systems separately are left to this final verification step of the full system. On completion of the documentation associated to this step of SST Verification, the SST is ready for the Acceptance Review (ACRV). The SST system-level verification is split in to three steps, described in turn below. Figure 4-1 provides an overview of the main steps and is referred to below.

4.1.10.1 Functional verification via ACADA interface

The first step in full SST verification is to test the full functionality of the SST is available via the ACADA interface. An ACADA simulator is connected to the Telescope Manager, and used to cycle through the available states of the State Machine, testing latencies, that forbidden transitions are blocked, and appropriate monitoring and logging information is received by the simulator. Configuration is also performed via the defined ACADA interface. The engineering interface is used to deliberately trigger alarm conditions and confirm that Alarms are correctly transmitted to the ACADA interface.

4.1.10.2 Telescope movement

Following the successful integration with ACADA, last verification of pointing and PSF and the verification of the ability to point the telescope structure must be checked again, using the ACADA interface.

The following two check shall be performed:

1) Movements/pointing/tracking final test of all systems operating.
2) T-point final verifications (few distributed sources).

4.1.10.3 Astrometric/PSF verification with stars

Tracking of selected star fields forms the basis of the final verification of the astrometric system, and the correct installation of the Camera with respect to the focal surface. Fields must be followed to cover the full range of azimuth and zenith required for operation. We anticipate that three cloudless nights are needed, and >20 targeted star fields. This rapid full-system verification is only possible due to the extensive verification process for the Telescope without Cherenkov Camera as described in Sections 4.1.5 and 4.1.9.

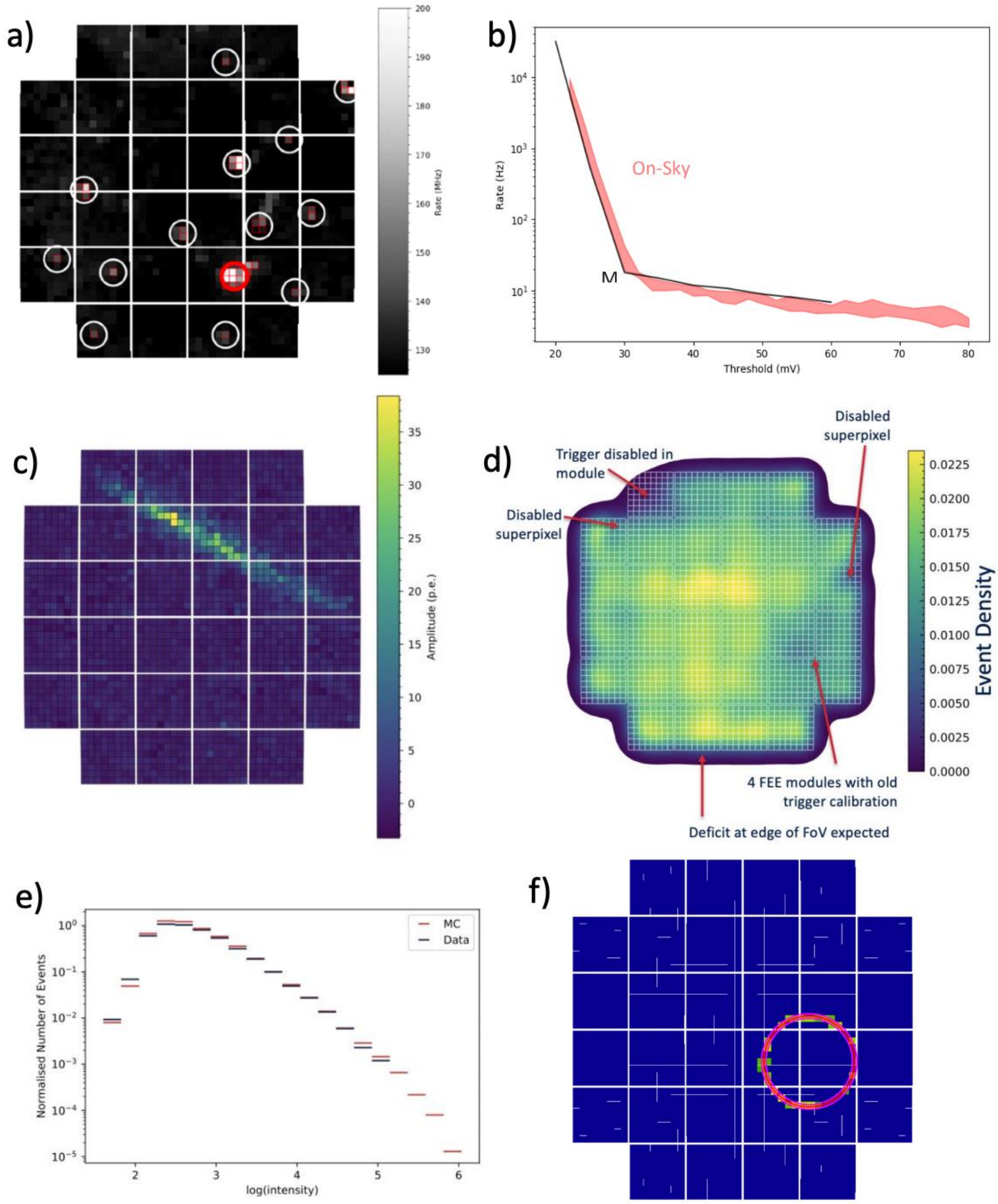


Figure 4-7: Illustration of steps in full SST AIV using examples from CHEC on ASTRI-Horn: a) Astrometric verification with stars and camera slow-signal monitoring. b) Rate versus threshold measurement and comparison to MC simulations. c) Capture of air-shower images and parameterisation. d) inspection of image Centre-of-Gravity distribution to identify problems. e) Comparison of image parameter distributions to simulations (in this case total image intensity/amplitude). f) identification and characterisation of muon ring images.

Camera slow-signal monitoring is the basis of routine astrometric measurements, the collected data sets will be analysed with the deployed pipeline to demonstrate that the Telescope pointing can be recovered using this system, to the required accuracy. This will be done both using rms of residuals from star fits and independent analysis of two sets of stars in each field. Consistency of the optical PSF with respect to expectations from the measurements of Section 3.4.1 is tested to confirm the correct positioning of the Cherenkov Camera with respect to the focal surface. Slow signal data are collected continuously, and hence the data collected under Section 5.4 below can be used for additional checks if needed.

At the end of this integration verification, a second telescope pointing model is produced:

4) PSF check using Slow Signal Data
5) T-point schedule 125 pointing (PMC + Cherenkov Camera)
6) PMC/Cherenkov Camera alignment tests Polaris, Zenith, Meridian measurements.

This operation will last 4 days. SST AIT/V Team personnel and CTA personnel will be involved in ACADA, Camera, Telescope aspects.

4.1.10.4 Air-shower measurements

Final verification of a Cherenkov Telescope requires Cherenkov light. The following sequence of verification is followed, with MC simulations acting as the reference point initially, and later on the values associated to previously accepted SSTs. This is a partially automated procedure for the first telescopes, become fully automated with the experience gained. A week of dark time in good weather is needed, followed by at least 3 days of time under moonlit conditions – including data taking up to the brightest conditions at which Observations are required.

4.1.10.5 Configuration adjustment

Via dark time observations with telescope pointing to zenith, and with periodic calibration flasher pulses, any modifications required with respect to laboratory settings for the camera are automatically extracted and adopted, as well as updated calibration coefficients such as relative time offsets between pixels and flat-field coefficients.

4.1.10.5.1 Air-shower trigger verification

Camera trigger rate (from cosmic ray air-showers and fluctuations of the Night Sky Background) is measured as a function of the L0 threshold, initially with Telescope pointing to zenith during dark time. After adopting standard trigger threshold settings, data is to be taken over the full range of zenith angles required in operation. The break point between air-shower triggering and dominance of NSB triggers at low thresholds (See Figure 10b) is a key acceptance parameter.

4.1.10.5.2 Air Shower parameter distributions

From the collected and calibrated data, parameter distributions are produced and compared to expectations. Expected distributions are initially taken from MC simulations, and later from measurements of previously accepted SSTs. Two categories of parameters are examined:

1. Pixel level values – including amplitude distributions, average pulse shapes and peak-time distributions.

2. Image parameters – in particular the Hillas Parameters: Image Amplitude, Width and Length, Time Gradient, and the uniformity of image Centre of Gravity across the camera.

Parameter distributions are to be tested as a function of ambient light level and Telescope zenith angle pointing. See Figure 10c, d and e.

4.1.10.5.3 Muon rings

The rate of identification of muon rings, and the parameters derived from muon images, are to be compared to expectations from simulations. The extracted muon efficiency (reflecting the overall telescope plus camera effective optical collection area or throughput) is a key acceptance parameter, and an independent confirmation of the procedure of Section 3.5). The consistency of the distribution of reconstructed muon ring thickness with expectations provides an independent check of the optical point-spread function across the full FoV. See Figure 10f.

4.1.10.5.4 Stability/Calibration system performance

Light flasher, pedestal and ASIC calibration data is to be acquired during all observations. These data are used to establish the correct function of the calibration system and the overall stability of camera.

The full verification programme above is to be repeated under bright moonlight conditions (close to the upper boundary in background light-level set for SST performance).

We note that gamma-ray source observations are not required for SST AIV. An individual SST is a part of the gamma-ray detection system but cannot (in the standard mode of CTA operation/data processing) be used for gamma-ray source measurements as a stand-alone unit. The role of an individual SST in the system is the precision measurement of air-shower images at the deployed telescope location. The verification that this role is met to the level of the requirements is met via the process of Section 5.3, supported by simulations of the whole CTA-S system and associated data processing chain.

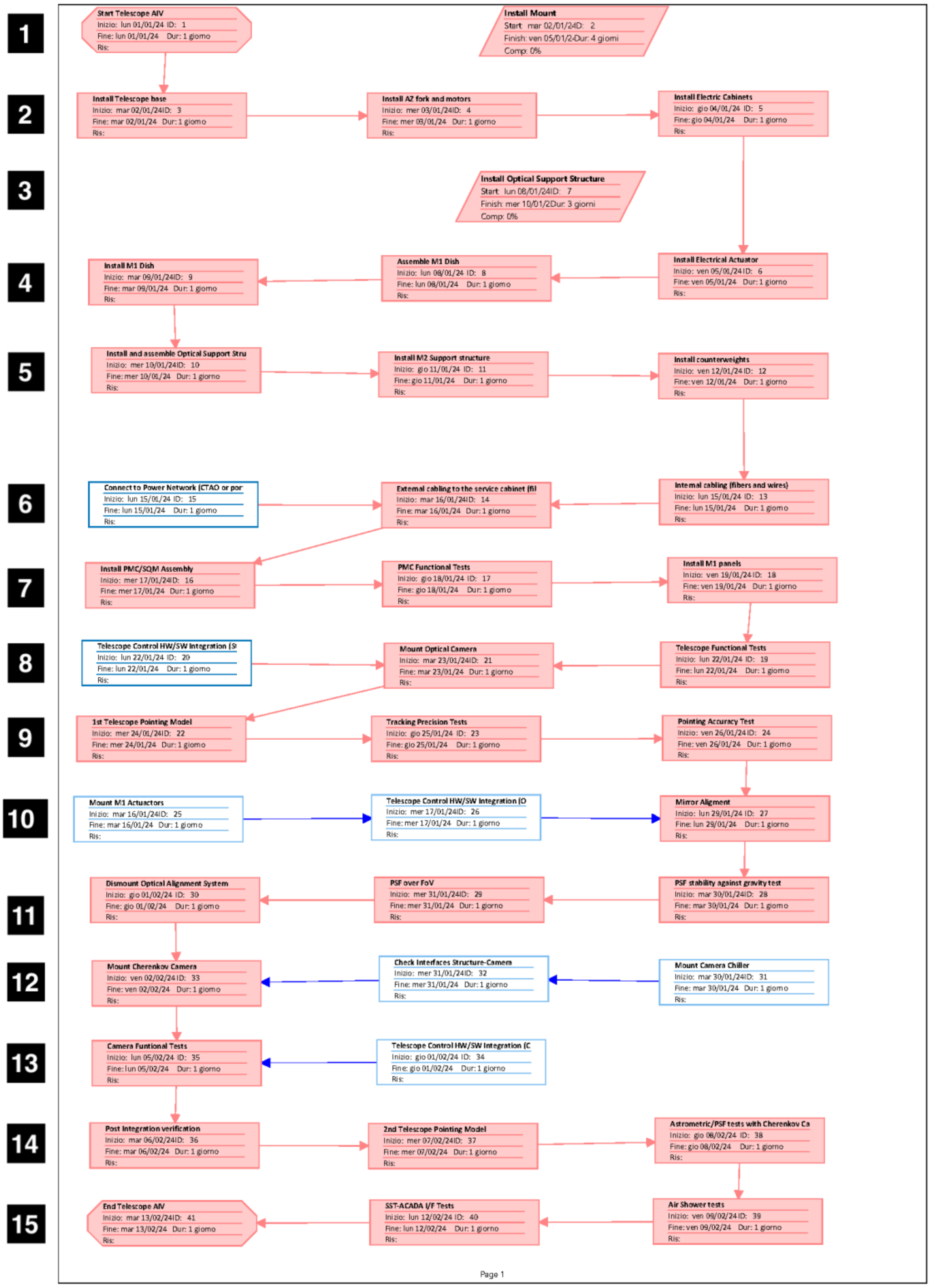


Figure 4-8 Timeline integration and AIV process for an individual telescope

5 Deliverables

The following documents will be delivered as outcome of the on Site AIV activity:

- Level C on site Verification Report
- Level D on site Verification Report

End of the document