The Product Assurance and AIV strategy from the ASTRI Mini-Array project to the SST Programme

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ABSTRACT

The ASTRI Mini-Array is an international project led by the Italian National Institute for Astrophysics (INAF) to construct and operate an observatory dedicated to gamma-ray astronomy in the TeV spectral band. The ASTRI Mini-Array is currently under construction and will consist of an array of nine innovative Imaging Atmospheric Cherenkov Telescopes located at the Teide Astronomical Observatory, operated by the Instituto de Astrofisica de Canarias, in Tenerife (Canary Islands, Spain).

In this work we present the Product Assurance programme we implemented for the project, which defined the strategy and the organization for the management of the quality control. We also describe the adopted assembly, integration and verification approach, which foresees that the telescopes are first of all integrated and verified in factory by the supplier; only after this phase was successfully passed, they were preliminary accepted and moved to the Teide Observatory for the final on-site validation by INAF. Finally, we report how the experience gained with ASTRI and the lessons learned will be used in view of the Small Sized Telescopes to be provided for the Cherenkov Telescope Array Observatory.

Introduction

The ASTRI (Astrophysics with Italian Replicating Technology mirrors) Mini-Array is an international collaboration, led by the Italian National Institute for Astrophysics (INAF), devoted to the realization of an array of nine dual-mirror aplanatic imaging atmospheric Cherenkov telescopes of 4-m class. They will be deployed at the Teide Observatory on Tenerife, in the Canary Islands [1].

The ASTRI Product Assurance (PA) Programme [2] defined the:

- ✓ strategy and organization for the management of the quality control
- ✓ applicable quality requirements for design, procurement, and AIT/AIV
- ✓ guidelines to manage the acceptance of the deliverable items
- ✓ requirements for the quality check of the raw materials, the machining procedures and the personnel qualification
- ✓ verifications and inspections to be performed during the manufacturing process, and how to report them
- ✓ requirements for the identification and traceability of materials, equipment and items

Here we describe how this PA programme was implemented during the manufacturing of the ASTRI telescopes.

PA requirements for design and verification

The requirement allocation and verification was performed according to the canonical "V-diagram (Fig. 1): the requirement allocation was performed with a top-down logic, while the requirement verification was performed with a bottom-up approach.

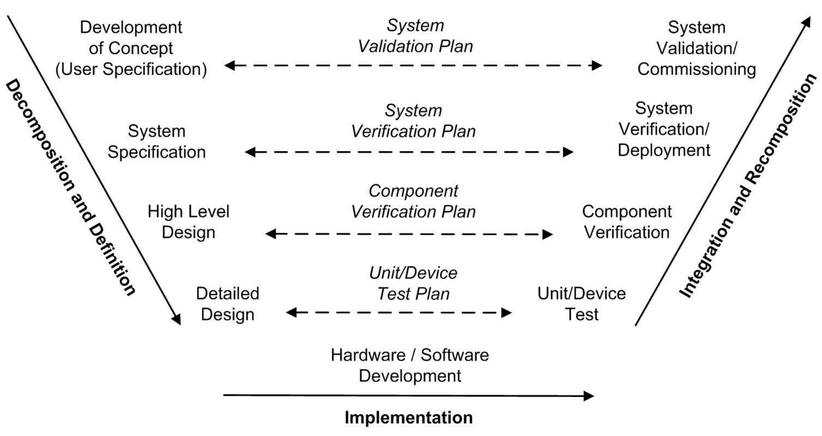

Fig. 1: "V-diagram" for the requirement allocation and verification

PA requirements for HW items

QA requirements for HW identification, traceability, and inspection:

- ✓ product identification with a product number and a serial number
- ✓ traceability of materials, items, personnel and equipment related to procurement, manufacturing, inspection, test, assembly, integration, and operation activities
- ✓ periodic calibration and maintainance of any inspection, measuring, and test equipment
- ✓ secure storage in specific identified and labelled areas, of incoming materials, intermediate items, and end items, and control over acceptance into and withdrawal from storage areas

QA requirements for HW packaging, transportation, and installation:

- ✓ critical and costly items were protected against shocks, dust, water, and temperature gradients
- ✓ shock, tilt, humidity, and temperature sensors were employed during the transportation
- ✓ shipped items were marked and labelled, and accompanied by proper handling and packing or unpacking procedure and any relevant safety procedure

QA requirements for HW manufacturing:

- ✓ to procure defect-free raw materials and components
- ✓ to have stable production processes
- ✓ to perform adequate controls along the production chain
- ✓ to employ trained personnel for operating the processes
- ✓ to apply workmanship standards

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mechanical structures were realized according to the international standard **UNI EN 1090-2:2018** and the **Execution Class 2**

Before the beginning of the production phase:

- ✓ a specific Manufacturing Plan documented the planning of manufacturing, assembly, integration, and test (MAIT) operations, and of relevant inspections
- ✓ a Manufacturing Readiness Review (MRR) took place, with the aim to verify that the criticalities had been solved, the project documents were ready and the necessary resources were available

During the production phase:

- ✓ purchased raw materials were subjected to incoming inspections, carried out according to well-defined procedures
- ✓ machining activities of mechanical items (such as, for example, weldings, paintings, and thermal treatments) were performed according to procedures qualified by external, certified and independent entities
- ✓ verification activities, such as the Non-Destructive Tests (NDTs) for welds, were executed by applying certified procedures
- ✓ Key Inspections and Mandatory Inspections of the on-going activity were performed by, respectively, the manufacturer personnel and INAF personnel

PA requirements for Software

The PA responsible for the SW:

- ✓ prepared, maintained, and applied a specific Software Product Assurance Plan (SPAP), based on the principles of the standard ECSS-Q-ST-80C, which defines the SW QA/PA requirements to be applied for the whole software development lifecycle process of all the software products.
- ✓ used Process Metrics to manage the SW development and to assess the quality of the development processes
- ✓ controlled that the SW was always under configuration control, thus assuring traceability of the developed software configuration items
- ✓ mapped the requirement verification with an overall Verification Plan

PA requirements for procurement

- ✓ selection of manufacturers and suppliers was driven by proven ability in procurement of materials, parts, and components needed by the project
- ✓ a quality agreement with the selected external suppliers was included in all procurement contracts; the only exception was for commercial products off the shelf (COTS)
- ✓ each purchaser exercised surveillance over all the activities carried out by its suppliers through the definition and execution of proper audits, reviews, mandatory inspection points, as well as direct supervision at the suppliers' facilities

Assembly, integration, and verification strategy

Each subsystem was tested according to the scheme in Fig.2:

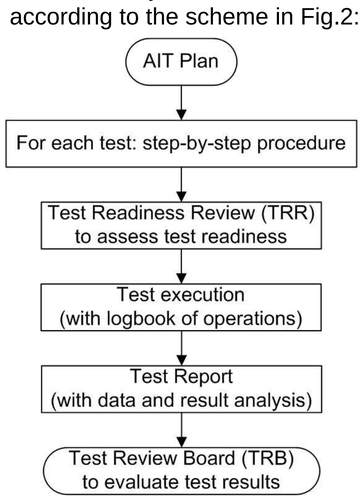

Fig. 2: flow-chart of the test approach

Mirror production completed at the end of 2019, with the delivery of 200 ASTRI M1 segments and 10 M2 mirrors [3]

7 mechanical structures manufactured during 2024:

1) First telescope assembled and integrated in factory (mechanical mounting, electrical cabling, mirror integration and SW installation)
2) Verification of all the functional, physical, and operational requirements which did not need the sky observations
3) Preliminary Acceptance of the first telescope
4) ⇒ End of 2024: 6 telescopes (structure + mirrors) packed and shipped to the ASTRI Mini-Array site at Tenerife + 1 telescope left in factory as a "test bench"
5) March 2025: 6 telescopes assembled, integrated, and tested at the Teide Observatory
6) Spring 2025: on-site validation tests successfully completed
7) June 2025: 7th telescope packed and shipped to Tenerife
8) Summer 2025: Final Acceptance Review of the full array

Lessons learned in view of the Small Size Telescopes for CTAO

Serial production of ASTRI mirrors:

- ✓ demonstrated that the manufacturing process was stable and ensured the production of mirrors conforming to specifications
- ✓ proved that the acceptance criteria adopted by the industrial supplier were reliable

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mass production of the SST mirrors (started in Spring 2025) is well set up and under control

Manufacturing of the ASTRI mechanical structures: a fundamental test bench for the identification and verification of the quality criteria

- ✓ definition of a clear and comprehensive Quality Control Matrix
- ✓ identification of the Key Inspection Points (KIPs) and the Mandatory Inspection Points (MIPs) along the manufacturing process
- ✓ identification of Visual and Magnetoscopic tests as non-destructive tests for the weld verification
- ✓ demonstration that it is essential to perform a telescope verification as complete as possible already in factory, in order to detect immediately possible problems and to minimize their impact on site

ACKNOWLEDGEMENTS

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References: [1] Scuderi S. et al. 2022, *JHEAp* **35**, 52-68 [2] La Palombara et al. 2022, Proc. SPIE 12187, id. 121871I [3] La Palombara N. et al. 2022, JATIS **8**(1), 014005 1-26