HMI Design Testing and Report

Deliverable ID:	**D5.2**
Project acronym:	**ATMACA**
Grant:	**101167070**
Call:	**HORIZON-SESAR-2023-DES-ER-02**
Topic:	**HORIZON-SESAR-2023-DES-ER-02-WA2-2**
Consortium coordinator:	**Eskişehir Teknik Üniversitesi**
Edition date:	**30 January 2026**
Edition:	**01.03**
Status:	**Official**
Classification:	**PU**

Abstract

This deliverable describes the design and early validation of the Human-Machine Interfaces (HMIs) developed within the ATMACA project. It outlines the human-centred design approach adopted, the design process leading from requirements to mock-ups and interactive prototypes, and the usability testing methodology applied with representative end users. The document covers the design of four HMIs and reports on the testing activities conducted on the ATC Tower and Flight Deck interfaces through remote, unmoderated usability evaluations. A high-level overview of the main usability findings is provided, while detailed analysis is deferred to dedicated validation deliverables.

Authoring & approval

Author(s) of the document

Organisation name	Date
Tommaso Vendruscolo / DBL	21/01/2026

Reviewed by

Organisation name	Date
Michael Regnault / ENAC	27/01/2026
Fulya Aybek ÇETEK	27/01/2026

Approved for submission to the SESAR 3 JU by

Organisation name	Date
Fulya Aybek Çetek / ESTU	30/01/2026
Stefano Bonelli and Tommaso Vendruscolo / DBL	30/01/2026
Raouf Hamzaoui / DMU	30/01/2026
Georges Mykoniatis / ENAC	30/01/2026
Ángel Carmona / SAERCO	30/01/2026
Sergun Özmen / THY	30/01/2026
Rosa María Arnaldo / UPM	30/01/2026

Rejected by[1]

Organisation name	Date

Document history

Edition	Date	Status	Company Author	Justification
01.01	21/01/2026	Initial Draft	DBL	Initial document for beneficiaries' data entries
01.02	27/01/2026	Reviewed version	DBL	Revision made in line with the reviewer´s comments.
01.03	30/01/2026	Final version	DBL	Approval of the Consortium

[1] Representatives of the beneficiaries involved in the project.

The beneficiaries/consortium confirm(s) the correct application of the Grant Agreement, which includes data protection provisions, and compliance with GDPR or the applicable legal framework with an equivalent level of protection, in the frame of the Action. In particular, beneficiaries/consortium confirm(s) to be up to date with their consent management system.

Copyright Statement

ATMACA

AIR TRAFFIC MANAGEMENT AND COMMUNICATION OVER ATN/IPS

ATMACA

This document is part of a project that has received funding from the SESAR 3 Joint Undertaking under grant agreement No [Click or tap here to enter Grant No.] under European Union's Horizon Europe research and innovation programme.

The UK participant (De Montfort University) is supported by UKRI grant number 10121610.

Table of Contents

List of figures

List of tables

1 Introduction

This deliverable presents the design and early validation (low-fidelity simulation) activities carried out for the Human–Machine Interfaces (HMIs) developed within the ATMACA project. It provides an overview of the design process adopted to develop the HMI solutions and of the methodology used to test and validate them with representative end users.

The document focuses on describing the approach, methods, and artefacts produced during the design and testing phases. Detailed results and quantitative analyses are intentionally out of scope and are addressed in D6.2 Exploratory Research Report (ERR).

1.1 Purpose and Scope of the Deliverable

The purpose of this deliverable is to document:

- the human-centred design approach adopted for the ATMACA HMIs;
- the design process leading from requirements to mock-ups and interactive prototypes;
- the usability testing methodology applied to validate the HMI designs;
- a high-level overview of the main usability findings.

The deliverable covers the design and testing activities performed on the ATC Tower HMI, the ATC En-Route HMI, the Flight Deck HMI, and the Provisioning Interface. While all four interfaces were designed following a common methodology, usability testing activities focused on the ATC Tower and Flight Deck HMIs, which directly support operational communication tasks (see 4.2 for additional details).

This document is intended as an **internal project deliverable**, providing a consolidated reference of the work performed and supporting alignment across project partners. It is not intended to replace or duplicate the detailed validation reports produced elsewhere in the project.

1.2 Context within the Project

Within the ATMACA project, the development of HMIs represents a key enabler for the implementation and validation of the proposed Concept of Operations (CONOPS) for digital air–ground communications.

The activities described in this deliverable build upon earlier project outputs, including:

- the operational assumptions and use cases defined in the Operational Services and Environment Description (OSED) [1];
- the Functional Requirements Document (FRD) [2];
- the HMI requirements defined in Deliverable D5.1 [3].

The design and testing activities documented here support the early validation of HMI interaction concepts and usability assumptions, contributing to the iterative refinement of the ATMACA solution.

2 HMI Design Approach

This chapter describes the approach adopted for the design of the ATMACA Human–Machine Interfaces (HMIs). It introduces the human-centred design principles underpinning the design activities and outlines the main design inputs, user roles, methodologies, and tools applied throughout the process.

Human-Centred Design Background

The HMI design approach adopted within ATMACA is grounded in **Human-Centred Design (HCD)** principles. HCD is a well-established approach within the broader field of Human–Computer Interaction (HCI), which focuses on the design of systems that effectively support human capabilities and limitations.

The concept of HCD emerged from early work on human-centred systems, emphasising the need for human and machine capabilities to be complementary rather than competing. Within this framework, HCD promotes the systematic involvement of users throughout the design lifecycle, ensuring that system behaviour, interaction patterns, and information presentation are aligned with real operational needs.

International standards such as ISO 13407 [4] define HCD as an iterative process integrating usability considerations into system development. Key characteristics of this process include early understanding of the context of use, explicit consideration of user and organisational requirements, iterative design and prototyping, and continuous evaluation against user needs [5].

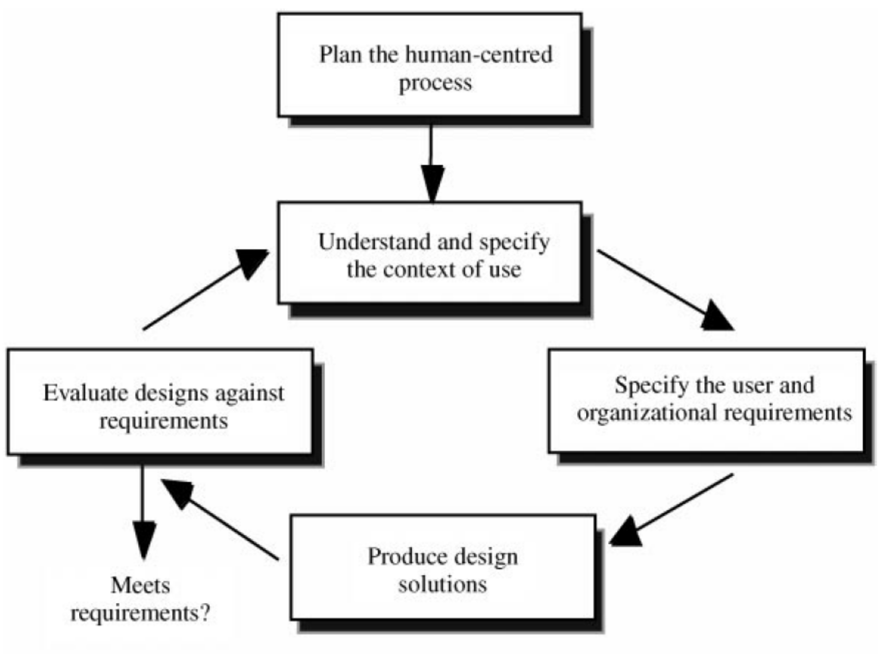

Figure 1. Human-centred design process [5]

Within ATMACA, HCD principles were applied pragmatically, focusing on early-stage validation of interaction concepts and usability rather than on exhaustive user studies. This approach supported rapid iteration and early feedback, consistent with the exploratory nature of the project phase.

2.1 Design Inputs and User Roles

The HMI design activities were informed by a combination of functional, operational, and user-centred inputs. The primary design drivers were:

- the Functional Requirements Document (FRD) [2];
- the HMI requirements defined in Deliverable D5.1, produced within Task 5.1 [3];
- the Concept of Operations (CONOPS) and operational use cases described in Deliverable D2.3 (OSED) [1].

These inputs provided a structured understanding of system behaviour, operational constraints, and user expectations, forming the baseline for the definition of interaction flows, layouts, and interface functionalities.

The design process explicitly considered the diversity of user roles interacting with the ATMACA system. The following roles were addressed:

- **Tower ATCOs**, covering delivery, ground, and tower functions;
- **En-Route and Approach ATCOs**, responsible for en-route and approach operations;
- **Pilots**, interacting with air traffic control through the Flight Deck HMI;
- **System administrators and technical coordinators**, interacting with the Provisioning Interface for system supervision and configuration.

Each HMI was designed to reflect the specific responsibilities and constraints of its target users, while maintaining a consistent interaction logic across interfaces. This consistency was considered essential to support usability, reduce training effort, and ensure a coherent user experience across operational domains.

2.2 Design Methodology and Tools

The HMI design activities followed an iterative, human-centred methodology aligned with the main phases of the HCD process, including understanding the context of use, defining user requirements, producing design solutions, and evaluating them against user needs.

In practical terms, the methodology was articulated into the following steps:

- definition of user roles and main interaction paths;
- development of wireframes to explore layout and interaction logic;
- creation of high-fidelity mock-ups to define visual structure and information hierarchy;

- development of interactive prototypes to support realistic user interaction and usability testing.

This iterative process enabled early identification of usability issues and progressive refinement of design solutions based on feedback from stakeholders and representative end users.

Figma was used as the primary design tool throughout all stages of the process, supporting collaborative design, rapid iteration, and the development of interactive prototypes. The same tool was used to prepare the prototypes later employed in usability testing activities.

Useberry was adopted as the user testing platform to support remote, unmoderated, and asynchronous usability evaluations. The platform enabled the integration of Figma prototypes, the definition of scenario-based tasks and questionnaires, and the collection of both quantitative interaction data and qualitative user feedback.

Overall, the adopted design approach provided a coherent and scalable framework for the development and early validation of the ATMACA HMI solutions, ensuring alignment between user needs, operational requirements, and interaction design choices.

3 HMI Design Process

This chapter describes the design process adopted to develop the Human-Machine Interface (HMI) solutions within the ATMACA project. The process followed a human-centred, iterative approach aimed at supporting diverse operational roles while ensuring usability, consistency, and alignment with the project functional requirements.

The design activities addressed four HMIs: the ATC Tower HMI, the ATC En-Route HMI, the Flight Deck HMI, and the Provisioning Interface. While all interfaces followed a common design methodology, different maturity levels were reached depending on their intended use and validation needs.

3.1 Design Inputs and Scope

The HMI design activities were grounded on the requirements and constraints defined in the Functional Requirements Document (FRD) and in Deliverable D5.1 - HMI Requirements. These inputs provided the baseline for identifying operational needs, user expectations, and system interactions to be supported by the interfaces.

The scope of the design process covered:

- the definition of role-specific user interactions;
- the development of coherent and consistent interface layouts;
- the preparation of artefacts suitable for usability testing and iterative refinement.

Three interfaces (ATC Tower, ATC En-Route, and Flight Deck) were developed up to interactive prototype level, enabling realistic user interaction and subsequent usability evaluation. The Provisioning Interface was developed up to high-fidelity mock-ups, reflecting its administrative and supervisory nature and its exclusion from usability testing at this stage.

3.2 User Roles

The design process explicitly considered the diversity of user roles interacting with the ATMACA system, ensuring that each interface reflected the responsibilities, workflows, and information needs of its target users.

The following roles were addressed:

- **Tower ATCOs**, covering delivery, ground, and tower functions, interacting with the ATC Tower HMI;
- **En-Route and Approach ATCOs**, interacting with the ATC En-Route HMI;
- **Pilots**, interacting with the Flight Deck HMI;
- **System administrators and technical coordinators**, interacting with the Provisioning Interface.

Each interface was designed to support role-specific tasks while maintaining a consistent interaction logic across the overall HMI ecosystem. This consistency was considered essential to reduce cognitive load and facilitate adoption in operational environments.

3.3 User flow definition

Based on the identified roles, the design process started with the definition of main interaction paths, describing how users interact with the system during typical operational activities. These user flows were not intended as exhaustive operational procedures but as representative interaction structures guiding the interface design.

For ATCO-oriented HMIs, the main interaction path can be summarised as:

1. assuming responsibility for a flight;
2. communicating with the flight by selecting predefined message templates or using free-text input;
3. completing the interaction and handing off the flight to the next ATC unit.

For the Flight Deck HMI, the interaction path focused on:

1. communicating with the Current Data Authority (CDA) – namely the ATCO – through structured message templates or free-text communication.
2. being transferred to the next data authority for subsequent communications.

These user flows were used as a reference throughout the design process to ensure that interface elements, navigation structures, and information hierarchies directly supported operational needs.

3.4 Wireframe development

Following the definition of user flows, low- to mid-fidelity wireframes were developed using Figma. The wireframes focused on layout structure, information grouping, and interaction logic, deliberately minimising visual detail to enable rapid iteration and early validation of design assumptions.

Wireframes were produced for all four interfaces, reflecting their specific operational scope and user roles:

- the ATC Tower HMI, supporting delivery, ground, and tower functions;
- the ATC En-Route HMI, supporting both en-route and approach operations;
- the Flight Deck HMI, supporting pilot communications with the data authority;
- the Provisioning Interface, supporting system supervision and configuration tasks.

The wireframes were reviewed internally to verify alignment with the defined user flows and with the HMI requirements derived from Task 5.1. Particular attention was paid to the clarity of information presentation, the separation of primary and secondary functions, and the consistency of interaction patterns across interfaces.

The resulting wireframes provided a consolidated basis for the subsequent mock-up and prototyping activities and served as a common reference during review sessions with consortium partners and representative end users.

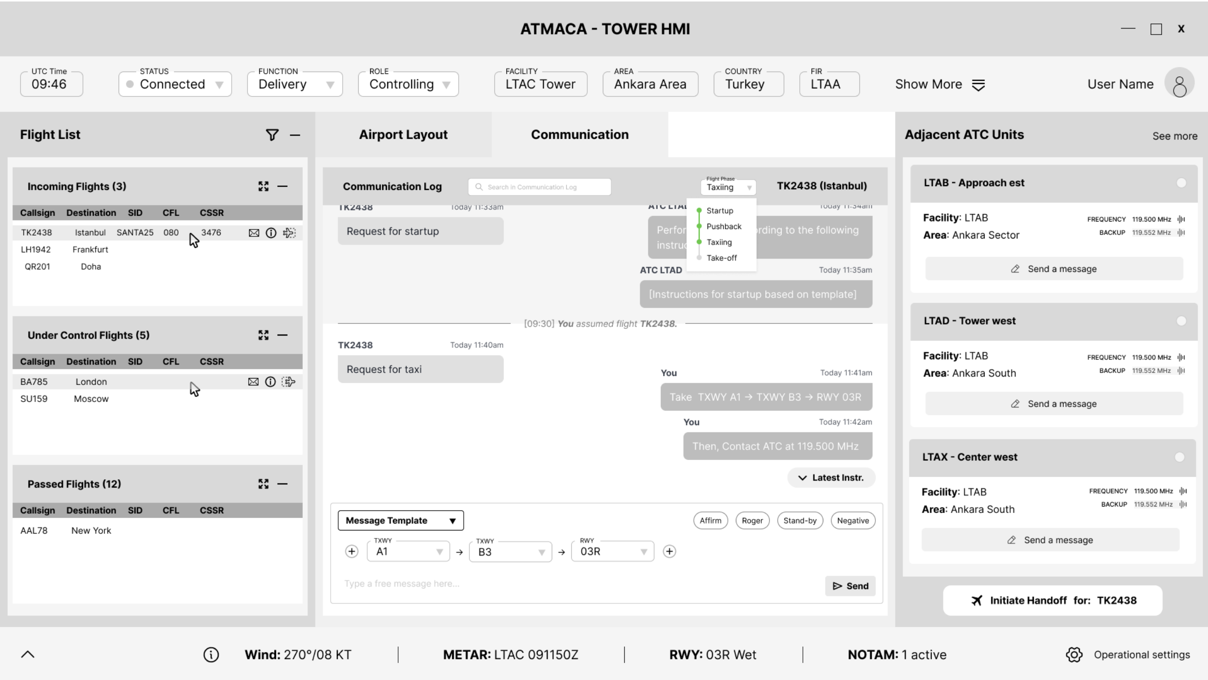

Figure 2. ATC Tower HMI Wireframe

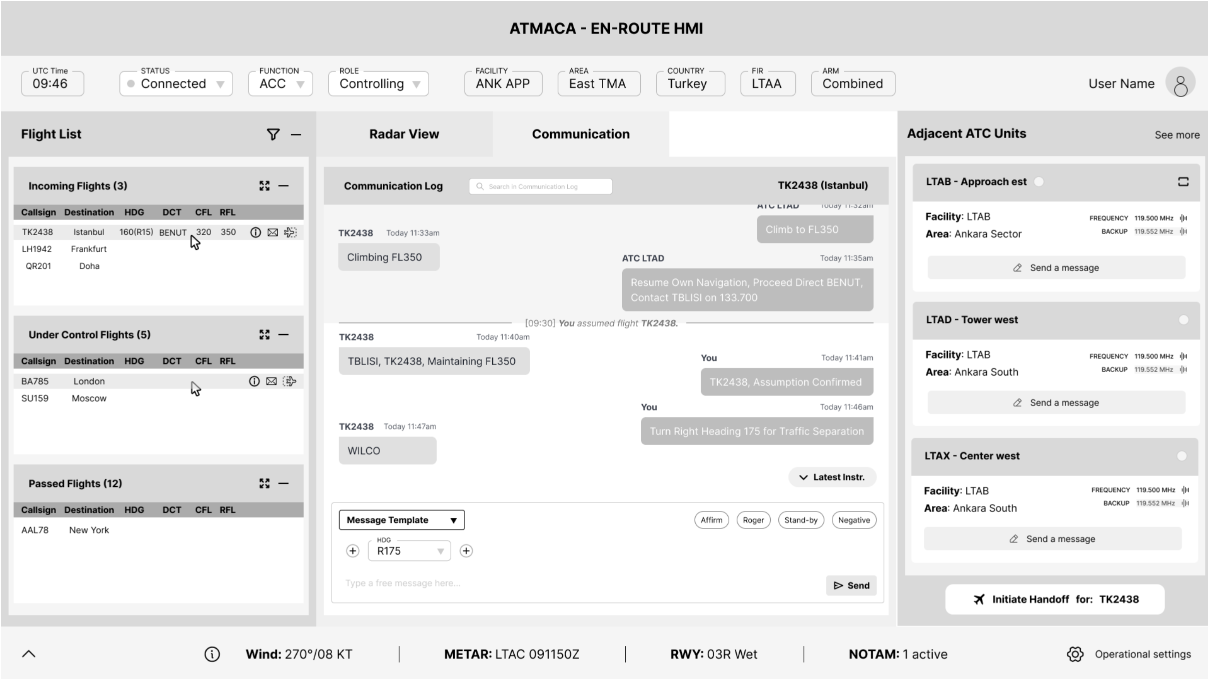

Figure 3. ATC En-Route HMI Wireframe

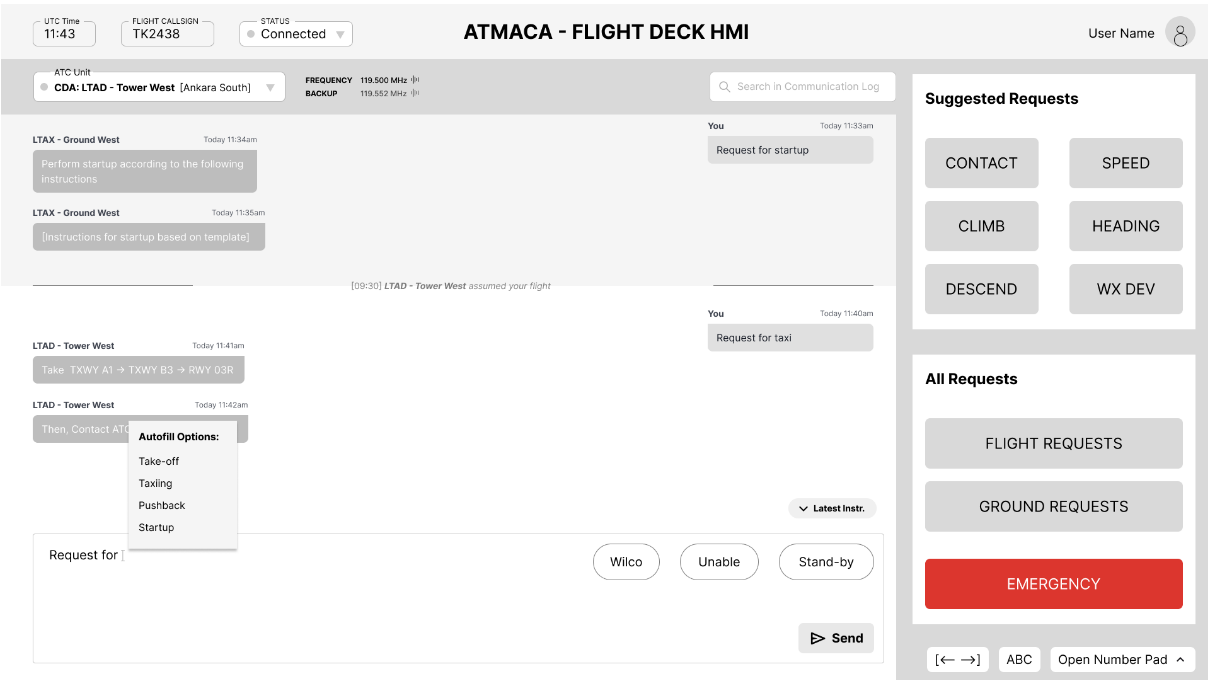

Figure 4. Flight Deck HMI Wireframe

EUROPEAN PARTNERSHIP
Co-funded by the European Union

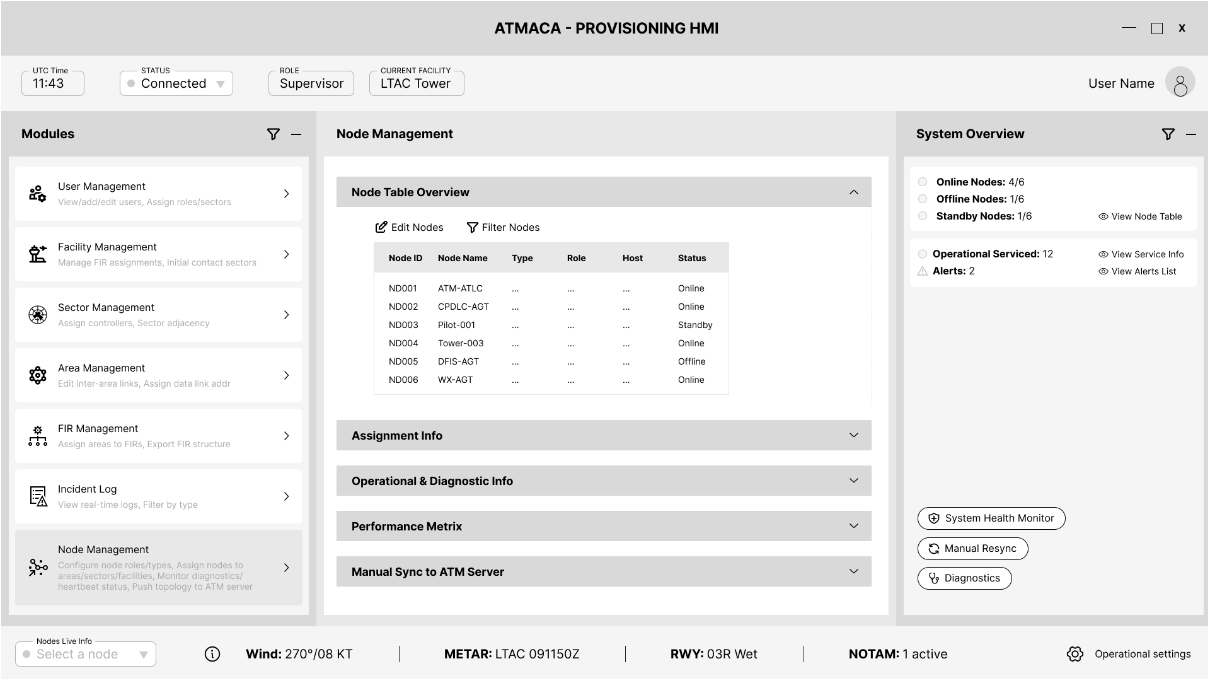

Figure 5. Provisioning Interface Wireframe

3.5 Mock-up Design

Building on the consolidated wireframes, refined through multiple iterative cycles with representative end users, high-fidelity mock-ups were developed to define the visual structure, information layout, and interaction elements of the ATMACA HMIs. The mock-ups were designed in alignment with the HMI requirements defined in Task 5.1, ensuring consistency with identified user needs, operational roles, and system behaviour.

Mock-ups were produced for all four interfaces. For the ATC Tower, ATC En-Route, and Flight Deck HMIs, the mock-ups represented an intermediate step towards interactive prototyping. For the Provisioning Interface, mock-ups constituted the final design artefact for this project.

The following subsections provide an overview of the content and structure of each mock-up.

3.5.1 ATC Tower HMI Mock-up

The ATMACA ATC Tower HMI mock-up is structured around a clear separation of operational functions, supporting tower ATCO activities across delivery, ground, and tower roles. The interface is organised into three main operational areas, complemented by a contextual information bar and an operations bar.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

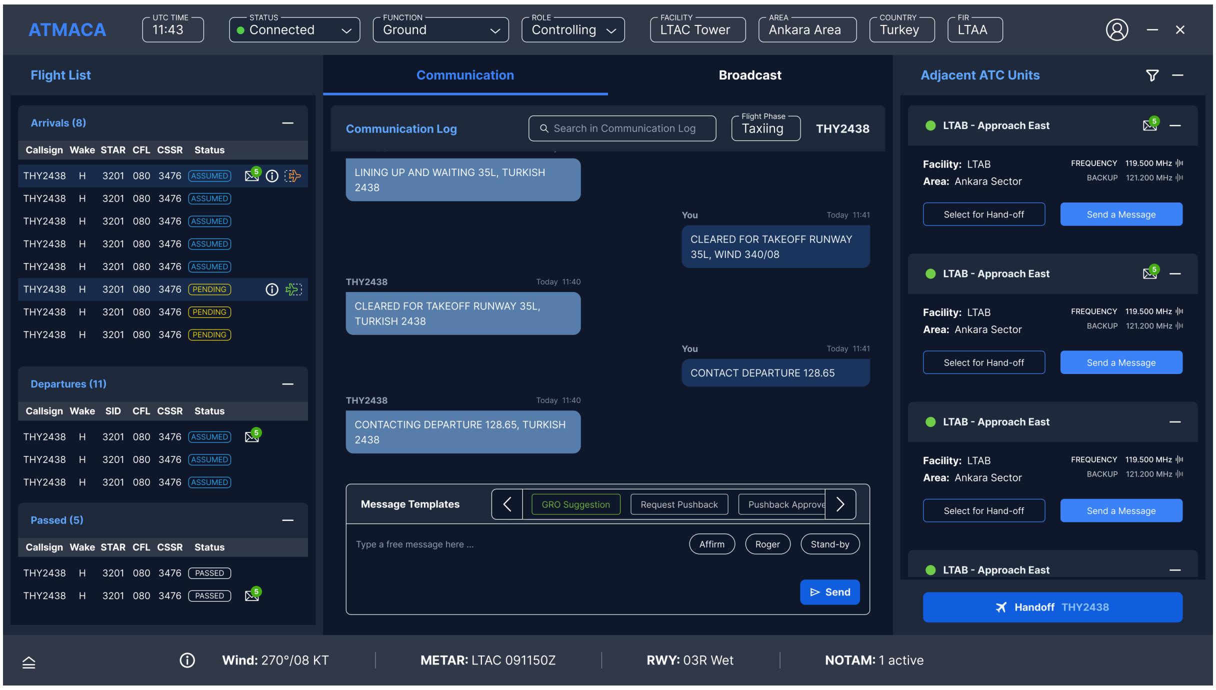

Figure 6. ATC Tower HMI Mock-up

The three main areas are:

- **Flight List**, located on the left-hand side, displaying arrivals, departures, and passed flights;
- **Messaging Window**, positioned centrally, supporting communication with pilots;
- **Adjacent ATC Unit List**, located on the right-hand side, supporting coordination and hand-off with neighbouring ATC units.

A **Context Bar** at the top of the interface provides high-level situational awareness and user profile information, while an **Operations Bar** at the bottom offers access to core actions and system functions.

The Context Bar displays general information related to the ATCO profile and operational context, including:

- current UTC time, used as system time reference;
- controller status, indicating connection and operational availability;
- assigned function, reflecting the operational domain currently covered;
- role, specifying whether the ATCO is operating in Controlling, Monitoring, or Mirroring mode;
- facility and area under operation;
- associated country and Flight Information Region (FIR).

The **Flight List** presents incoming and outgoing flights, together with flights already handed over. Each flight entry includes complementary operational data and a visual status indicator. Colour-coded labels are used to distinguish flights that have already been assumed by the controller from those pending assumption, supporting rapid identification and prioritisation.

The **Messaging Window** is the primary area for communication with the selected flight. It supports two communication modes:

- **Communication**, enabling one-to-one messaging with the pilot of the selected flight;
- **Broadcast**, enabling messages to be sent simultaneously to multiple flights, for example in emergency or contingency situations.

This separation allows the ATCO to manage routine and non-routine communications efficiently while maintaining clarity of message scope.

The **Adjacent ATC Unit List** displays neighbouring ATC units available for coordination and hand-off. Each unit entry includes:

- unit name, facility, and area;
- primary and backup frequencies;
- a control to initiate messaging.

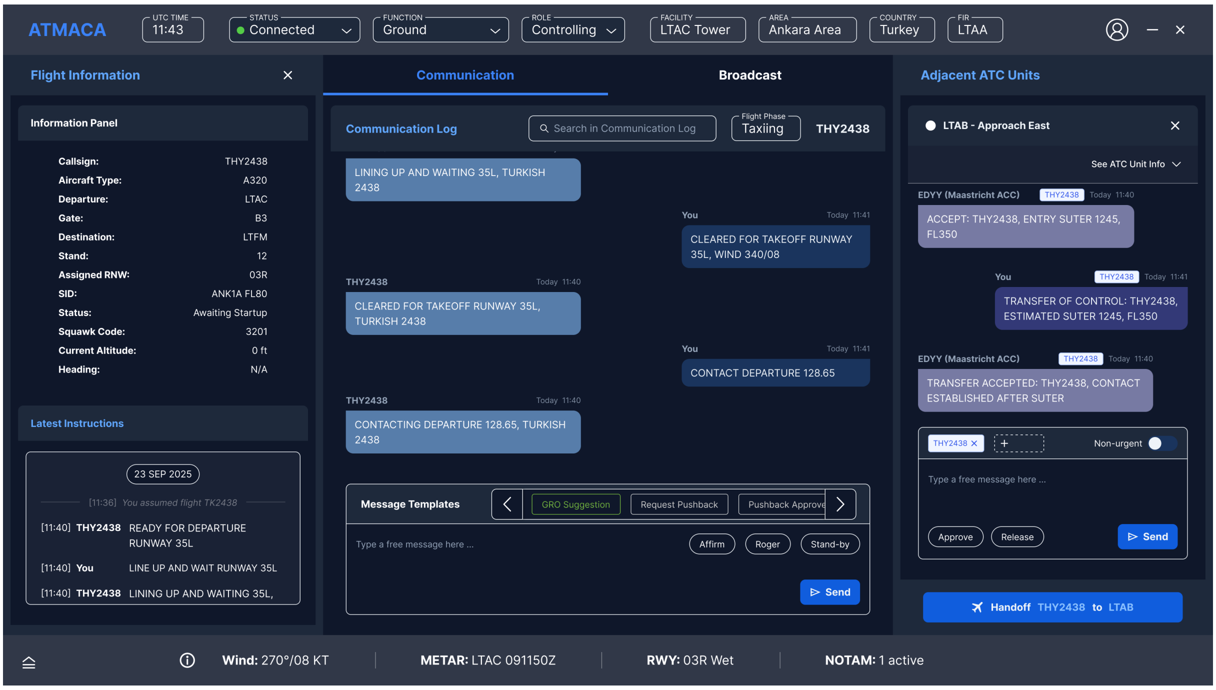

Figure 7. ATC Tower HMI Mock-up with flight information and ATCo-to-ATCo communication open

A coloured status indicator next to each unit provides immediate information on availability (connected, away, busy, or disconnected). Selecting an ATC unit designates it as the target for

EUROPEAN PARTNERSHIP
Co-funded by the European Union

coordination or hand-off. Once selected, the ATCO can initiate direct communication or complete the hand-off procedure, transferring the flight to the next ATC unit in a streamlined manner.

Overall, the ATC Tower HMI mock-up was designed to support rapid decision-making, minimise interaction steps, and maintain a clear operational picture during high workload conditions.

3.5.2 ATC En-Route HMI Mock-up

The ATC En-Route HMI mock-up follows the same overall layout, interaction logic, and visual structure as the ATC Tower HMI, ensuring consistency across ATCO-facing interfaces and facilitating role transitions. As such, only the elements that differ from the Tower HMI are described in this section.

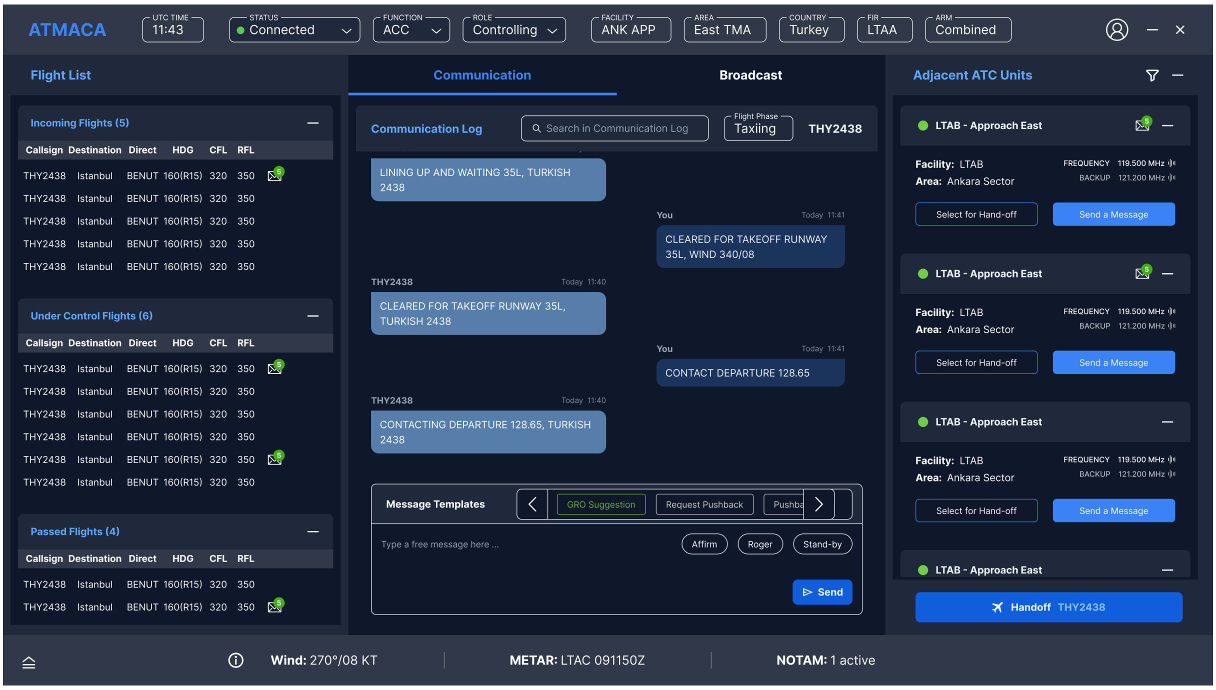

Figure 8. ATC En-Route HMI Mock-up

The main differences are related to the operational context and are reflected primarily in the **Context Bar** and in the organisation of the **Flight List**.

The **Context Bar** fields are adapted to the en-route operational environment. While preserving the same structure and presentation logic as in the Tower HMI, the displayed information reflects en-route or approach operations, including context-specific operational parameters relevant to these domains.

The **Flight List** organisation differs from the Tower HMI to better support en-route workflows. Flights are no longer divided into arrivals and departures. Instead, they are grouped as:

- **Incoming Flights**, corresponding to flights pending assumption by the controller;
- **Under Control Flights**, corresponding to flights already assumed and currently managed by the controller.

EUROPEAN PARTNERSHIP
Co-funded by the European Union

This organisation reflects the continuous nature of en-route operations and supports rapid identification of flights requiring action versus those already under active control.

All other interface elements, including the Messaging Window, Adjacent ATC Unit List, communication mechanisms, and hand-off procedures, operate analogously to the ATC Tower HMI, with flight data and contextual information adapted to the en-route operational domain.

3.5.3 Flight Deck HMI Mock-up

The Flight Deck HMI mock-up is designed to support pilot communications with the air traffic control data authority while minimising interaction complexity and workload. The interface focuses on clarity, rapid access to standardised requests, and continuity of communication across data authority transitions.

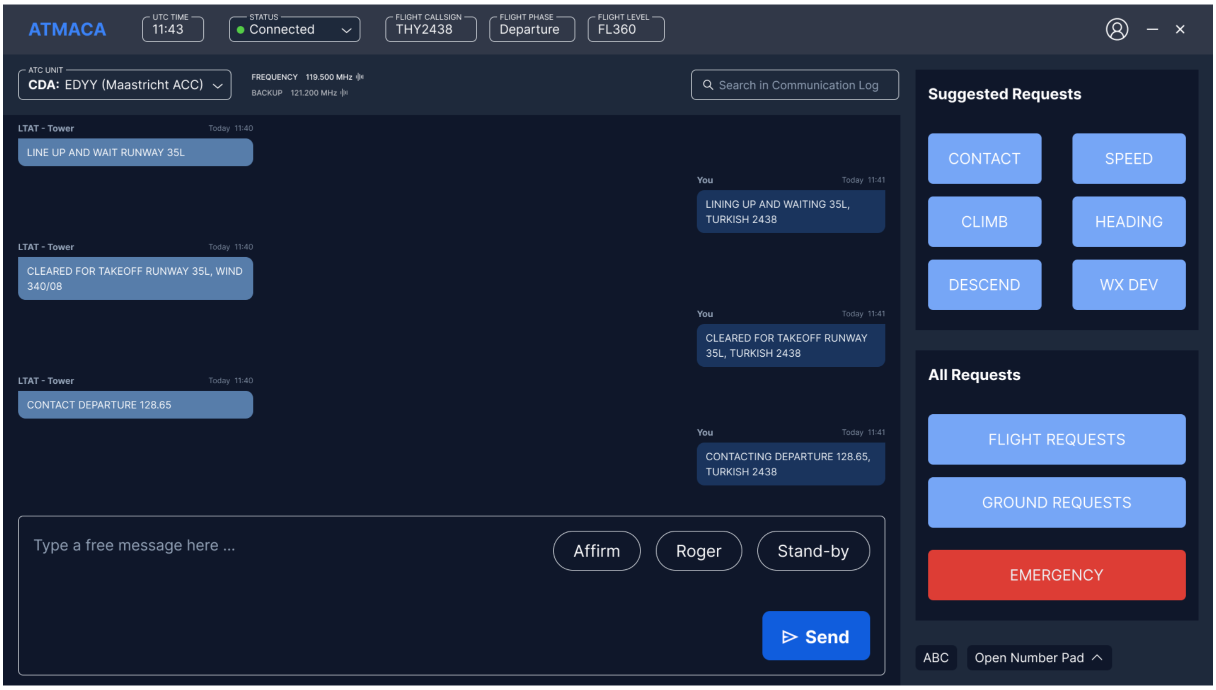

Figure 9. Flight Deck HMI Mock-up

The interface is structured into three main areas:

- **Context Bar**, located at the top of the interface;
- **Messaging Window**, positioned centrally;
- **Request Templates Panel**, located on the right-hand side.

The **Context Bar** provides key information related to the flight and allows the pilot to manage their operational status. It includes:

- current UTC time;

EUROPEAN PARTNERSHIP
Co-funded by the European Union

- pilot status, allowing the crew to indicate their current availability or operational condition;
- flight callsign;
- flight phase, automatically updated throughout the flight and shared with the ATCO;
- flight level, automatically updated and synchronised with the ATCO.

This information supports shared situational awareness between flight crew and air traffic control.

The **Messaging Window** is the primary area for communication with the relevant ATC unit, whether acting as the Current Data Authority (CDA) or the Next Data Authority (NDA). Through this window, pilots can initiate and manage message exchanges related to routine operations, requests, and non-routine situations.

The **Request Templates Panel** supports efficient message composition by providing structured, pre-defined request templates. The panel is divided into two main sections:

- a top section presenting the most frequently used request templates, allowing rapid access during routine operations;
- a lower section providing access to the full set of available templates, organised into:
    - **Flight Requests**, applicable during en-route operations;
    - **Ground Requests**, applicable within airport environments.

When a template is selected, the corresponding message is automatically pre-filled in the messaging input field, enabling quick review and submission while reducing free-text entry and the risk of communication errors.

In emergency situations, the interface provides dedicated support through an **Emergency function**. When activated:

- the relevant ATC unit is immediately notified of the emergency condition;
- an emergency message template is automatically made available in the messaging field, allowing the pilot to promptly report the situation if required.

Overall, the Flight Deck HMI mock-up was designed to facilitate clear, standardised, and timely communications with air traffic control, while supporting seamless transitions between data authorities and maintaining high levels of usability under both normal and abnormal operational conditions.

3.5.4 Provisioning Interface Mock-up

The Provisioning Interface mock-up represents a preliminary design of a supervisory and configuration dashboard for the ATMACA system. Unlike the operational HMIs, this interface was not fully refined or validated through usability testing and should be considered an exploratory mock-up intended to illustrate potential system management capabilities.

EUROPEAN PARTNERSHIP
Co-funded by the European Union

The interface is organised around a modular, dashboard-based layout supporting system supervision, configuration activities, and high-level operational monitoring. It is primarily intended for supervisory roles such as system administrators and technical coordinators.

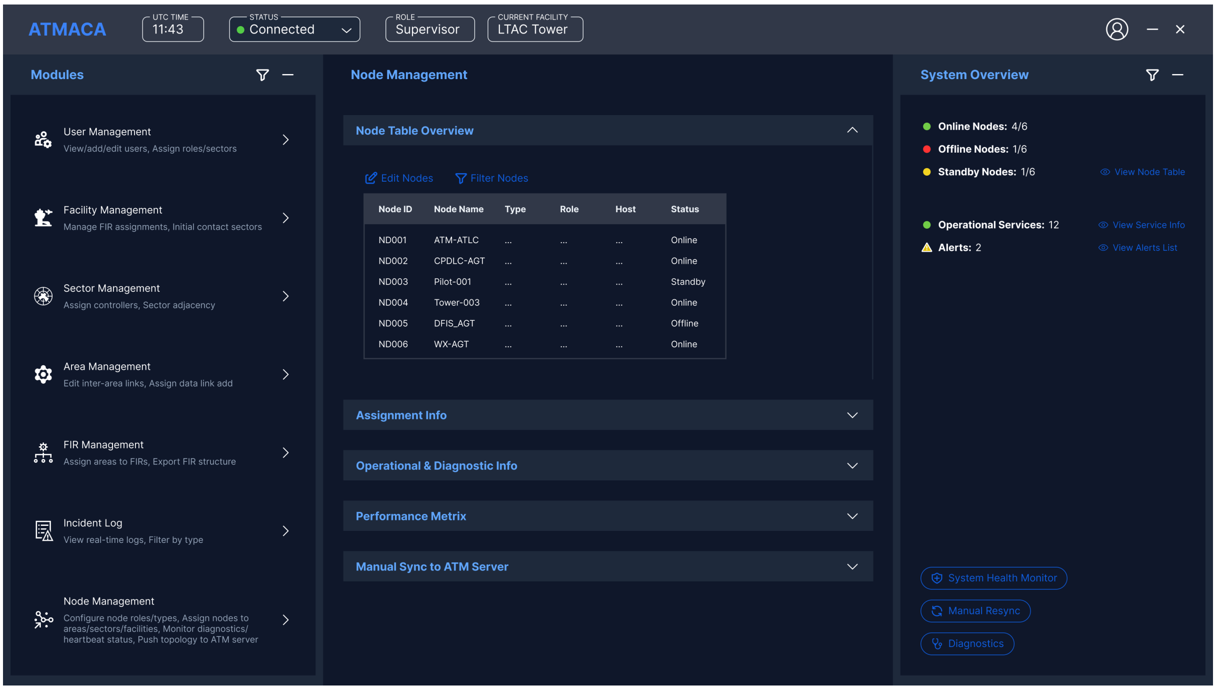

Figure 10. Provisioning Interface Mock-up

At the top of the interface, a **Context Bar** provides general session and system information, including:

- current UTC time;
- connection status;
- user role;
- currently selected facility.

The main workspace is structured into three vertical areas.

On the **left-hand side**, a navigation panel provides access to different functional modules, including:

- User Management;
- Facility Management;
- Sector Management;
- Area Management;
- FIR Management;
- Incident Log;

- Node Management.

Each module groups configuration or monitoring functions related to a specific aspect of the ATMACA system, such as user roles, sector and area assignments, FIR structures, and node configuration.

The **central area** focuses on node-related supervision and configuration. It includes a Node Table Overview listing system nodes and their main attributes, such as node identifier, type, role, host, and operational status (e.g. online, standby, offline). Additional expandable sections are provided to access further information, including assignment details, operational and diagnostic data, performance metrics, and manual synchronisation controls with the ATM server.

On the **right-hand side**, a System Overview panel provides a high-level snapshot of the overall system status. This includes:

- the number of online, offline, and standby nodes;
- the number of operational services;
- active alerts.

Quick-access controls are also provided for system health monitoring, diagnostics, and manual resynchronisation actions.

Overall, the Provisioning Interface mock-up illustrates a possible approach to centralised system supervision and configuration within ATMACA. While the layout and functional grouping reflect typical system management dashboards, the interface was not fully specified or iteratively refined during the project and therefore serves primarily as a conceptual representation rather than a finalised design.

3.6 Interactive Prototyping

For the ATC Tower, ATC En-Route, and Flight Deck HMIs, interactive prototypes were developed in Figma. These prototypes implemented clickable elements, navigation paths, and basic interaction behaviour, allowing users to simulate realistic operational tasks.

The prototypes were explicitly designed to support subsequent usability testing activities. As such, they focused on:

- key interaction sequences derived from the defined user flows;
- representative operational tasks;
- clarity of system feedback and state changes.

During later stages, the prototypes were adapted and refined to align with the specific test scenarios used in the usability evaluation, while preserving their original design intent.

3.7 Iterative Review and Feedback

The entire design process was characterised by continuous review and improvement loops. Feedback was collected qualitatively through iterative review sessions involving:

- project consortium partners;
- members of the advisory board;
- representative end users drawn from the consortium network.

In particular, one-to-one meetings with pilots and ATCOs were conducted between July and September/October 2025. These sessions provided direct insight into user expectations, usability concerns, and operational realism.

Feedback collected during these activities informed successive design iterations at wireframe, mock-up, and prototype levels. This iterative approach ensured that design decisions were progressively validated against user needs and operational context, and that identified issues could be addressed early in the design lifecycle.

4 HMI Testing Methodology

This chapter describes the methodology adopted to validate the ATMACA HMI designs through user testing activities. The objective of the testing was to perform an early assessment of usability, interaction flows, and role-specific functionalities, supporting the refinement of the HMI solutions prior to further development phases.

The activities described in this chapter focus on the testing approach and setup. A detailed analysis of results is intentionally out of scope and will be addressed in a dedicated deliverable.

4.1 Objectives and Usability Evaluation

The HMI testing activities were designed to support the early validation of the ATMACA Concept of Operations (CONOPS) and its associated HMIs through hands-on user interaction.

The main objectives were to:

- assess the usability and clarity of the proposed HMI designs;
- verify the coherence of interaction flows with operational practices;
- evaluate whether role-specific functionalities meet user needs and expectations;
- collect qualitative feedback to inform subsequent design iterations.

The validation approach was aligned with SESAR human performance principles and focused on early-stage usability rather than performance benchmarking.

4.2 Scope of the Testing Activities

The usability testing activities focused on the following interfaces:

- **ATC Tower HMI**
- **Flight Deck HMI**

The ATC En-Route HMI was not tested separately, as its structure, interaction logic, and functionalities are largely equivalent to those of the ATC Tower HMI. Given this high level of similarity, and considering that the ATC Tower HMI includes more complex templates and interaction patterns, the results obtained from the Tower HMI testing were considered representative and applicable also to the En-Route context.

The Provisioning Interface was considered out of scope for advanced usability testing, as it does not directly impact operational air traffic management activities and was developed as a preliminary mock-up rather than as an interactive operational interface.

4.3 Participants

The testing involved a limited but representative group of end users recruited through the project consortium network.

The participants included:

- **25 ATCOs**, representing tower operational roles;
- **14 pilots**, representing flight deck operational roles.

The involvement of operational end users ensured that feedback was grounded in real-world experience and operational expectations.

4.4 Testing Setup and Platform

The usability evaluation was conducted remotely using **Useberry**, an online user testing platform. The tests were:

- **unmoderated**;
- **asynchronous**;
- performed using **interactive Figma prototypes**.

Participants accessed the testing sessions via dedicated links distributed through the consortium network. Each participant completed the test independently, without live facilitation.

The testing activities were conducted between **early December and 10 January**.

4.5 Scenarios and Tasks

The testing was structured around two low-fidelity operational scenarios, namely a departure scenario and an arrival scenario involving a single aircraft. The scenarios were defined and documented in Deliverable D6.1 – Exploratory Research Plan (ERP) and were derived from the operational use cases described in D2.3 OSED.

The same two scenarios were applied to both the ATC Tower HMI and the Flight Deck HMI, resulting in four testing situations:

- departure scenario from the ATCO perspective;
- arrival scenario from the ATCO perspective;
- departure scenario from the pilot perspective;
- arrival scenario from the pilot perspective.

This approach enabled the evaluation of the same operational situations from complementary viewpoints, supporting consistency checks across roles and interfaces.

Co-funded by the European Union

Each scenario consisted of a sequence of tasks designed to reflect the main interaction paths defined during the HMI design phase.

4.6 Test Session Structure

Each Useberry testing session followed a consistent structure, including the following elements:

- introduction to the project and to the ATMACA context;
- demographic questionnaire and assessment of openness to technology;
- overview of the testing session and instructions;
- HMI walkthrough to familiarise users with the interface;
- execution of the departure and arrival scenarios, with task-based interactions;
- post-scenario questionnaires focusing on HMI usability and interaction quality;
- human performance-related questionnaires;
- open-ended questions and overall feedback collection.

Both positive and negative statements were used in the questionnaires to encourage balanced feedback. Additional role-specific questions were included for pilots where relevant.

All user interactions and responses were recorded by the platform, enabling access to both raw data and aggregated analytics.

4.7 Data Collection and Analysis Approach

The testing activities generated both quantitative and qualitative data, including:

- task completion indicators and interaction metrics automatically collected by the platform;
- responses to usability and human performance questionnaires;
- free-text feedback provided through open-ended questions.

For this deliverable, the results are used only to provide a high-level overview of usability outcomes. A detailed analysis and interpretation of the collected data will be presented in Deliverable D6.2 - Exploratory Research Report (ERR).

5 Overview of Usability Test Results

This chapter provides an enhanced overview of the usability testing outcomes for the ATMACA HMIs, combining questionnaire-based results, task performance observations, and qualitative feedback collected from ATCOs and pilots. The intent is to highlight key trends and insights emerging from the data, while detailed quantitative analysis is deferred to the Exploratory Research Report (D6.2 - ERR).

5.1 General Trends across User Groups

Across both user groups, the overall perception of the tested HMIs was positive. Most participants indicated that the interfaces were understandable, coherent with their operational role, and supportive of the main communication tasks addressed in the scenarios.

Responses to structured usability statements suggest that users generally found the interaction flows logical and the core functionalities aligned with their needs. This was reinforced by qualitative feedback, where several users described the HMI as *"clear and easy to navigate"* or *"adequate and useful"* for the intended purpose.

At the same time, users consistently highlighted that this was an early-stage design and identified opportunities for refinement, particularly related to visual prioritisation and feedback mechanisms.

5.2 ATC Tower HMI – Usability Insights

ATCO feedback indicates that the ATC Tower HMI effectively supports the main operational workflow of assuming, managing, and handing off flights. The separation between the Flight List, Messaging Window, and Adjacent ATC Unit List was generally perceived as intuitive and consistent with tower operations.

Several ATCOs appreciated the structured communication approach, particularly the use of message templates. However, qualitative feedback also highlighted sensitivities specific to the tower environment. Some participants expressed concerns about maintaining situational awareness in high workload conditions, for example:

"Using HMI in tower may lose control on the planes."

Others pointed to visual aspects that could affect usability under traffic-intensive situations:

"The colours are insufficient to define the traffics… it may make it difficult to handle the traffic."

These comments suggest that while the interaction logic was broadly accepted, visual saliency, colour usage, and prioritisation of information are key aspects to be refined in future iterations, especially for tower operations.

5.3 Flight Deck HMI – Usability Insights

Pilot feedback was generally positive regarding the clarity and structure of the Flight Deck HMI. The Context Bar was perceived as useful in supporting shared situational awareness with ATCOs, and the Request Templates Panel was consistently identified as a strong point of the design.

Pilots valued the availability of predefined templates, noting that they reduce free-text input and support standardised communication. One participant noted:

"The HMI design is clear and easy to navigate… overall, it supports task performance effectively."

At the same time, pilots provided constructive suggestions aimed at improving usability under real flight conditions. Several comments referred to visual and interaction aspects, such as colour usage, button size, and feedback mechanisms:

"Everything on the interface is in tones of blue. Some notification is required to get crew attention when a new message arrives."
"Buttons should be larger… visual and auditory warnings can be used."

These observations highlight the importance of multimodal feedback (visual and auditory) and ergonomic considerations, particularly in dynamic cockpit environments.

5.4 Cross-Role Observations and Scenario-Based Feedback

Using the same arrival and departure scenarios for both ATCOs and pilots enabled a cross-role assessment of communication flows. Feedback suggests that users from both roles perceived the interaction patterns as coherent and aligned with the intended Concept of Operations.

Both ATCOs and pilots emphasised the importance of predictability, clear status indication, and explicit feedback during communication exchanges and authority transfers. The consistency of these comments across roles supports the design choice of maintaining similar interaction logic while adapting data and presentation to role-specific needs.

5.5 Summary and implications

In summary, the usability testing confirmed that the ATMACA HMI designs provide a solid foundation for supporting digital communications between air and ground actors. The results indicate good acceptance of the core interaction concepts and workflows, with no critical usability barriers identified at this stage.

The feedback collected highlights a set of recurring improvement areas, mainly related to visual hierarchy, alerting mechanisms, and workload management in demanding operational contexts. These insights will directly inform subsequent design refinements and are analysed in detail in the Exploratory Research Report (D6.2 – ERR).

The results should be interpreted in the context of the scope and maturity of the project. The validation focused on low-fidelity, one-to-one interaction scenarios and was conducted at an early technology readiness level (TRL 2), with the objective of assessing core usability and interaction concepts rather than full operational performance. Within these boundaries, the positive outcomes provide early confirmation of the soundness of the proposed HMI design approach and support its further refinement in subsequent project phases.

Co-funded by the European Union

6 References

[1] ATMACA-SESAR, Deliverable D2.3, Operational Service and Environment Definition (OSED), 2025

[2] ATMACA-SESAR, Deliverable D2.2, Functional Requirements Document (FRD), 2025

[3] ATMACA-SESAR, Deliverable D5.1, Determination of HMI Requirement, 2025

[4] ISO. (2020). *Human-centered design processes for interactive systems*. Iso.org. https://www.iso.org/obp/ui/#iso:std:iso:13407:ed-1:v1:en

[5] Maguire, M. (2001). Methods to support human-centred design. *International Journal of Human-Computer Studies*, *55*(4), 587–634. https://doi.org/10.1006/ijhc.2001.0503

7 List of acronyms

Acronym	Description
ATC	Air Traffic Control
ATCO	Air Traffic Controller
CDA	Current Data Authority
CONOPS	Concept of Operations
ERR	Exploratory Research Report
FIR	Flight Information Region
FRD	Functional Requirements Document
HCD	Human-Centred Design
HCI	Human-Computer Interaction
HMI	Human Machine Interface
ISO	International Organization for Standardization
OSED	Operational Services and Environment Description

Table 1: list of acronyms