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SESAR SOLUTION 97.1 CONTEXTUAL NOTE TRL4

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DIGITAL TECHNOLOGIES FOR TOWER

This Contextual Note is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement 874470 under European Union's Horizon 2020 research and innovation programme.

Abstract

This TRL4 contextual note illustrates all relevant aspects of SESAR Solution 97.1 in support of Solution TRL-4 Maturity Gate.

Solution 97.1 investigates the use of new human-system interaction enabled by Virtual and Augmented Reality applications (such as Head Mounted See-Through Devices) in Tower environment, aiming at reducing ATCOs head-down time and increasing situational awareness. Validations focussed on virtual Tracking labels, use of in-air gestures and controller's attention guidance.

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Table of Contents

Abstract 4

1 Purpose 6

2 Improvements in Air Traffic Management (ATM) 7

3 Operational Improvement Steps (OIs) & Enablers 9

4 Background and validation process 11

5 Results and performance achievements 13

6 Recommendations and additional activities 15

7 Actors impacted by the SESAR Solution 16

8 Impact on Aircraft System 17

9 Impact on Ground Systems 18

10 Regulatory Framework Considerations 19

11 Standardization Framework Considerations 20

12 Solution Data pack 21

List of Tables

Table 1 Solution relevant OIs 10

Table 2. Solution Enablers 10

Table 3. Solution Data Package 22

List of Figures

Non è stata trovata alcuna voce dell'indice delle figure.

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1 Purpose

This contextual note introduces SESAR Solution 97.1 with a summary of the results stemming from R&D activities conducted. It provides to any interested reader (external and internal to the SESAR programme) an introduction to the SESAR Solution in terms of scope, main technical and performance benefits, relevant system impacts as well as additional activities to be conducted during the next validation phase. This contextual note complements the technical data pack comprising the SESAR deliverables required for TRL4 Maturity Gate and further validation phases[1].

1 "The opinions expressed herein reflect the authors' view only. Under no circumstances shall the SESAR3 Joint Undertaking be responsible for any use that may be made of the information contained herein."

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2 Improvements in Air Traffic Management (ATM)

The solution "Virtual/Augmented Reality applications for tower" addresses the development of new human machine interface (HMI) interaction modes and technologies at the Controller Working Position based on Virtual and Augmented Reality enabling devices. The key aspect of this concept is to enable the user to a new mode of interaction, more immersive and interactive, facilitating the information retrieving and correlation, still preserving the level of attention.

A virtual information layer is superimposed on the Out of the Tower view by means of Augmented Reality enabling devices, specifically see-through head-mounted displays, so to decrease the head down time and increase the situational awareness. Head-up computer-generated overlays complement the information received when looking out of the window via V/AR interface, in all weather conditions and especially under LVC.

Specifically, overlays can potentially show a variety of information such as traffic labels associated to the traffic, weather information, aerodrome perimeters, key surface building/objects. As a result, as the needed information is provided in the head up position, the controller's need to switch to head down position is dramatically reduced and his mental strain to retrieve and correlate data is relieved. The situation awareness can be built faster and can more easily be maintained, with benefit in terms of productivity, eventually leading to more efficient and safe operations.

Attention Capturing and Guidance can find room as well for implementation through AR overlays, including visual and aural cues, aimed to raise and drive ATCO's attention towards potentially critical situations. Controllers have been exposed to different types of alerts potentially coming from airport safety nets such as Go-around Detection and Runway Incursions, but provided through the AR device, to compare the differences in Attention Getting with respect to traditional tower control and to evaluate the advantages of Attention Guidance.

Being such devices able to interpret body movements, codified hand gestures can be translated into digital input to the systems, allowing the users to control or interact with devices by means of simple gestures without physically touching them. Interaction with systems has been performed via virtual menus visualised as holograms, to sort data, visualise maps and even to issue non time critical clearances (start up and push back).

The benefits for this SESAR Solution are:

- In tower controllers' performance:
    - the virtual overlay, superimposed on the OTW view and contextually referred to the current traffic, allows an easier airport **information accessibility**, avoiding the switch from head-down 2D visualization to head-up perspective view and the mental strain to correlate HD information (currently on CWP) and outer real environment, and encouraging the ATCOs to work predominately in head up mode; thus, the situation awareness can be built faster and easily be maintained thanks to their wearable device, thus relieving the mental strain to retrieve data and properly correlate them. Anyhow, it is true that (potential) degradations in SA can be due to the information

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representation such as overlaps or missing information; thus, the feedback is strongly related to the quality and quantity of the presented information.
    - the updated information provided by V/AR will improve **situational awareness** in LVC, producing an improvement in the resilience of airports.

- In airport safety, as the highlight of safety nets in the virtual overlay will reduce the possibility of a human error of overseeing/missing alerts.
- In innovation of operating methods through a new human machine interaction mode.

These improvements have been validated in a real Small/Other airport and in simulated Very Large and Medium airports, while they may be applicable in all airport sub-operating Environments.

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3 Operational Improvement Steps (OIs) & Enablers

This Solution is linked to a new OI, the POI-0039-SDM named "Virtual/Augmented Reality, attention guidance and air gesture for tower controllers", composed of the following technologies:

- Virtual and augmented reality in different applications (e.g. smart screens, head-on display) including Tracking labels, to allow tower ATCOs to conduct safe operations under any meteorological conditions while maintaining a high taxiway and runway throughput, and increase the ATCO's situational awareness in particular in the context of abnormal situations.
- Use of in-air gestures for user interaction, to speed up and make simpler human-system interaction.
- Attention control for V/AR applications, to enable to guide the attention of the controller, especially in a highly automated environment to important events to support the future monitoring task of the controller.

Technologies associated with Solution 97.1 have been defined by Solution team and submitted for endorsement in the Master Plan[2].

OI Step code	Title	Description	Rationale
POI-0039-SDM	Virtual/Augmented Reality, attention guidance and air gesture for tower controllers	Use of V/AR technologies to present head up visual information to tower controllers when watching aircraft in landing, taxing to/from the gate/stand and take-off, to present equivalent out of the window view in low visibility conditions, to interact with V/AR interface by air gestures and to guide controller's attention to critical ATC situations. These are expected to improve ATCO productivity and situation awareness.	Head-up computer-generated overlays in all weather conditions complement the information received when looking out of the window via V/AR interface, providing equivalent visual support even in very low visibility condition. Air Gesture interactions with V/AR interface reduces the need for head-down. Attention Guidance raises ATCO's attention to highlight ATC critical situations via visual and optionally via auditory cues on the V/AR interface. These enhancements should improve ATCO

[2] Applicable Integrated Roadmap dataset is DS23.

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OI Step code	Title	Description	Rationale
			situational awareness and productivity, eventually leading to more efficient and safe operations.

Table 1 Solution relevant OIs

Enabler Code	Title	Description	Background	Coverage
AERODROME-ATC-103	Virtual and Augmented Reality systems for Tower ATC	Introduction of new Augmented Reality vision systems superimposed onto the out of the tower view encourage the ATCO to work in head-up position resulting in an improvement of the controller situational awareness and productivity in any visibility conditions	RETINA	Full
AERODROME-ATC-104	Controller productivity enhancements by Air gestures for Tower ATC	Air Gesture interactions with V/AR interface will reduce the need for head-down, resulting in improvement of ATCO human performance.	Mobile devices, No background in ATM.	Full
AERODROME-ATC-105	Attention Guidance in V/AR applications for aerodrome tower operations	Introduction of new automated functions for attention guidance in V/AR applications for improving situational awareness of aerodrome tower controllers.	16.04	Full

Table 2. Solution Enablers

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4 Background and validation process

Previous SESAR work provides the baseline for V/AR related research. The following work and related recommendations for improvement have been considered:

- RETINA (Resilient Synthetic Vision for Advanced Control Tower Air Navigation Service Provision)

  The Exploratory Research Project RETINA investigated the use of augmented reality in the control tower. The proposed concept consists in the provision of synthetic information superimposed onto the actual OTW view and it was validated through human in the loop simulations where the external view was provided to the user in a semi-immersive virtual environment.

  The project achieved the following technical challenges:

  - Compatibility of the technology used with the current data provision format;
  - Capability of non-invasive tracking of the user position;
  - Capability of providing the user with a conformal head-up view of synthetic information overlapped to the out of the tower view.

  The most important contribution provided by the project concerns operational benefits in three main Key Performance Areas: Human Performance, Capacity, and Safety.

  - Human Performance: the proposed concept provided quantified benefits in terms of mental workload, temporal workload, performance, effort, frustration, information accessibility, and reduction of head-down time.
  - Capacity: the solution could contribute to the removal of some restrictions in low visibility conditions with positive effect on airport capacity and throughput. This effect was quantified for a specific testcase on Bologna Airport by means of HIL simulations during the validation. It is worth mentioning that this benefit is subject to the assumption that comparable enhanced vision systems are available for pilots in the cockpit. Moreover, the increase of capacity in LVC implies a direct effect on the delay reduction with positive effect on punctuality, predictability and resilience.
  - Safety: the solution contributed to safety improvement as it enhances situational awareness.

- SESAR2020 W1 PJ05 (Remote Tower for Multiple Airports):

  PJ05 addressed, in several validation exercises, aircraft label information in the OTW panoramic view of a remote tower working position, that was deemed very helpful by controllers, as the additional information increased Situational Awareness. Information available in a conventional tower could ideally be merged with the OTW view in the tower so to reduce the head-down time of controllers. The experience has been valuable to understand issues related correlation and synchronicity between the visually identified object and an object location based on surveillance sensor information, in order not avoid wrong indications or misinterpretation.

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- SESAR2020 W1 PJ03B (SAFE):

  In this framework, NLR performed a validation exercise “Improving Predictions and Conflict Detection for Taxiway Operations” which introduced conflict alerting on taxiways and in the apron areas. Recommendations from this validation activity addressed the issue of required head-down time to notice any warnings given on radar displays. Scenarios carried out for validation of the taxiway conflict detection tool could be taken as a basis for investigation of displaying alerts for controllers in conventional towers with V/AR devices.

In Wave 2, the research on Virtual and Augmented Reality applications for tower has been addressed in the frame of Solution 97.1, through a chain of three technical validation exercises:

- one RTS conducted by NLR in April 2021 at NARSIM Validation Platform in Schiphol environment, with focus on Attention Guidance aspects;
- one RTS on Tracking Labels and Air Gestures based on V/AR technology conducted by ENAV/UNIBO/DBL at UNIBO CAVE simulator, in Bologna airport environment;
- one Shadow Mode validation on Tracking Labels and Air Gestures based on V/AR technology conducted by ENAIRE/CRIDA at Vitoria Airport.

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5 Results and performance achievements

The three validations which took place in Solution 97.1 proved the technical feasibility of the AR concept in an ATC Tower, both in simulated environment and in physical tower, presenting AR information on a head mounted display (namely the HoloLens 1 or 2, benchmark product supplied by Microsoft) to enable specific features as defined by each exercise objectives.

Different configurations were realized to enable specific features according to each exercise objectives: Tracking Labels, Air Gestures, Attention Capture and Guidance in V/AR environment.

Alignment of virtual objects with real outside view could be successfully achieved and has been appreciated and deemed useful by controllers. As the labels of the involved aircraft were in view, there was no need to look down to consult the deck physical equipment, so the overall head down time to monitor the airport situation was reduced. Activation of additional overlays could be implemented both in simulated and in physical tower environment, in some cases to a greater extent as much as the visibility conditions got worse. However, the expectable level of trust is likely to improve with a fine tuning of the virtual interface design characteristics, such as the size/position of flight tags (to avoid overlaps) or possibly the look and feel of displayed overlays (to overcome situations where high brightness from external sources, such as the sun, could render the visual Augmented Reality information imperceptible). As the HoloLens limits the augmented visual range, ATCO can feel overstimulated to move their head in order to see the augmented information or they can find difficult to fill in the paper strips.

Controllers found that the technology is very intuitive and requires short time for acquaintance. Weight of wearable devices was deemed acceptable for last generation models, while for first generation ones could lead to experience some heavy head.

Specific A-R overlays implemented to provide attention guidance in case of runway incursions or go-around detection were deemed very effective and efficient, and furtherly improvable with some design adjustments (e.g. reconsidering duration and position of some alerts). Anyhow, A-R guidance allows the ATCO to be more rapid with instructions concerning safety-relevant events. The attention cues positively affected human error (amongst other things) and the head-up time was improved in the solution scenarios. In some cases, the perceived potential for Human Error decreased thanks to the V/AR system especially for ground controllers.

Additionally, laboratory tests showed V/AR applications improve Resilience by increasing situational awareness in Low visibility conditions while maintaining workload within acceptable limits. The use of the glasses was shown to be beneficial to safety at night or in LVC, provided that the surveillance data feed is reliable, without data dropout and tag jumps.

The improvement in terms of information accessibility resulted in a beneficial impact on situational awareness, which can be built faster and easily be maintained. After participation in experiment, controllers' positive attitude regarding AR is increased.

Adequacy of usability level seems to vary depending on the maturity of the specific implementations and is negatively affected in case of interface design and hardware issues, so that several potential improvements to the design have been identified, to be fixed before the concept can be introduced.

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This is even more true for the Air Gesture solutions, where workload can be negatively affected due to the usability issues related to this specific application.

6 Recommendations and additional activities

At the end of the Technical Validations on V/AR, the following recommendations are made to support the future steps of validation of this Solution:

- The benefits in human performance and safety rely on the Human Machine Interface (HMI) usability that shall be improved by a number of possible specific refinements of information and alerts display (augmented field of view display, label design, size, position of data, frequent refresh, brightness, shadows, overlapping, quantity, filters for flyovers, duration…).
- It has been proved that the AR system can be fed with ADS-B data instead of surveillance data. Nevertheless, some intrinsic drawback in the use of ADS-B, such as the rate of data display and surface coverage, remain to be solved to avoid safety concerns.
- The display of safety nets in head-up should be further investigated in non-nominal conditions.
- Air gestures:
    - The chance to put in place a specific training for the air gestures could be evaluated, in order to improve the user's capability to correctly use the air gesture function.
    - Usability of HMI should allow the clearance input into the ATC System in a timely manner, without increasing the controller workload.
- Ergonomics:
    - Last generation devices should be preferred;
    - compatibility of AR see through device and prescription glasses should also be investigated.

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7 Actors impacted by the SESAR Solution

Virtual and Augmented Reality applications have an impact on the:

- TWR Ground ATCO,
- TWR Runway ATCO,

who may benefit from new Augmented Reality overlays superimposed on the OTV, which decrease the ATCO head down time and improve the controller situational awareness and productivity in any visibility conditions.

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8 Impact on Aircraft System

This solution investigates technologies for tower and has no impact on Aircraft Systems.

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9 Impact on Ground Systems

The Technological Solution will consist of additional systems to complement the CWP HMI currently used.

The Tower controller will be equipped with V/AR devices that will display the following information:

- Airport layout with digital georeferenced data, including the restricted and closed areas;
- Identification and tracking of aircraft (or vehicles) on the airport surface;
- Safety alerts, with visual and aural cues;
- Weather info.

Different sources have been investigated in the solution as feeders of the information presented into the Augmented Reality devices to the controllers such as MLAT, SMR and ADS-B.

Safety alerts are provided by the available airport Safety Nets systems.

A ground router will have to be installed in the tower and connected to the V/AR device in order to exchange the above-mentioned data.

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10 Regulatory Framework Considerations

Firstly, wearable devices bring qualms about ergonomic aspect. Side to the Regulations currently applicable to ATC Towers concerning the working environment risk factors, V/AR devices characteristics, such as weight and consequent impact on mental/physical strain, should be in line with the country occupational health and safety regulations. Solution 97.1 results have outlined that the latest generation devices are lighter and therefore preferrable for a comfortable use throughout the working session. Colours and appearance of visual cues should be in the hands of ATM system providers to design the user experience in accordance with the many feedback received by involved controllers on label size, duration of alerts etc.

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11 Standardization Framework Considerations

As from results of PJ.16-04 on Attention Guidance, it would be beneficial if input and output channels are standardized. On the output side, a standardized interface between the HMI and the support system e.g. in case of highlighting aircraft labels would ease communication between different hardware/software manufacturers.

Besides, AIXM should be considered for the exchange of digital aeronautical information / data.

As part of PJ.05-W2-97.1 activities, a communication of the findings and results of the Solution to EUROCAE Technical Advisory Committee has been carried out. As a result of this coordination, some guidance has been provided with regards to the standardisation needs:

- EUROCAE ED-87E “MASPS for A-SMGCS including Airport Safety Support Service Routing Service and Guidance Service” should be considered for the Virtual and Augmented Reality functionalities, e.g. for the identification and alignment of elements in the V/AR devices.
- It is recommended that the development of specific ATC applications on existing COTS products is conducted keeping in consideration the safety requirements for this environment.

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12 Solution Data pack

As from agreement with SJU, *one* unique Data Pack is provided for the two PJ.05-W2-WP3 Solutions 97.1 and 97.2, with dedicated paragraphs for each of them.

The D3.1 Solution PJ.05-W2-97.1 and 97.2 TRL4 Data Pack includes:

Solution Data Pack	
Systems Requirements consolidation	**Technical Specification/Interface Requirements Specification (TS/IRS) TRL4 - Final version** D.3.1.022 Edition date: 28/09/2022 Edition: 00.02.04
	TS/IRS Part II (SAR) D.3.1.022 Edition date: 03/10/2022 Edition: 00.00.04
	TS/IRS Part IV (HPAR) D.3.1.022 Edition date: 30/09/2022 Edition: 00.01.00
	PAR *(Additional document for technological solution, non PMP)* Edition date: 12/10/2022 Edition: 00.01.00
Cost Benefit Analysis tailored for the specific Technological Solution (CBAT) TRL4	**Cost Benefit Analysis (CBAT) Final - TRL4** D3.1.071 Edition date: 26/10/2022 Edition: 10.00.01
Technical Validation Report (TVALR) TRL4	**Technical Validation Report (TVALR) Final version – TRL4** D.3.1.051 Edition date: 15/11/2022 Edition: 00.13.00

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Initial Technical Validation Plan (TVALP) defining the validation roadmap for TRL 6	**Initial Technical Validation Plan (TVALP for TRL6)** D.3.1.080 Edition date: 7/10/2022 Edition: 00.01.00

Table 3. Solution Data Package

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