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KEY TECHNOLOGICAL SOLUTIONS FROM THE SESAR PROGRAMME TO IMPROVE AIR TRAFFIC SAFETY

Summary. The dynamic development of the air transport market has led to a significant increase in air traffic in a highly fragmented and relatively small European airspace. This situation could, in the near future, render the currently functioning European air traffic management (ATM) system obsolete and incapable of providing the high safety standards demanded by the ICAO and Eurocontrol. Recognizing the urgency in finding a solution to this problem, the EU gas launched the Single European Sky (SES) initiative, along with its technological pillar, the Single European Sky ATM Research (SESAR) programme, which seeks to enhance air traffic safety, support the sustainable development of the air transport system and improve the overall performance of ATM and air navigation services, so that they meet the requirements of all airspace users. This paper presents a selection of the SESAR programme’s key technological solutions, such as approaches based on area navigation (RNAV)/Global Navigation Satellite Systems (GNSS), and the “remote tower” concept, which have been developed to maximize the safety and efficiency of the new European ATM system.

Keywords: air traffic safety, SESAR solutions, air traffic management (ATM) system, remote tower, RNAV (GNSS) approach procedures

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1. INTRODUCTION

Nowadays, aviation is one the most dynamically developing branches of transportation, with air transport driving global economic growth, employment, trade links and tourism [2]. Each year, more than 37.4 million flights climb into the air carrying about three billion passengers and nearly 50 million tons of freight around the world [2]. In relatively small Europe, approximately 10 million flights carry over 1.6 billion passengers annually, which emphasizes the crowded state of the airspace over our heads [9]. Taking into account the European Commission forecasts, air traffic in Europe is expected to more than double in the next 20 years and even triple in some regions. Unfortunately, the current ATM system is close to becoming obsolete and ill-suited for the rapid, economic and reliable development of air transport in Europe. This situation may mean that, in the near future, the European ATM system will be incapable of providing the high safety standards demanded by the ICAO and Eurocontrol. Seeking a solution to this urgent problem, in March 2004, the EU launched the SES initiative, which constitutes an institutional reform of ATM that aims to reorganize European airspace and enhance the performance of air navigation services. However, an institutional reform has not been enough to achieve the performance objectives of SES. A paradigm shift in the technological reform of ATM was also needed. To this end, SESAR is the technological pillar of SES and an essential enabler for its implementation [10].

2. CURRENT THREATS TO THE EUROPEAN ATM SYSTEM

Since the late 1990s, the growing EU dimension has made aviation transport more dynamic and stronger than when it was dealt with on a state-by-state basis. The expansion of the single European economic area based on a common market was also the impulse for the development of the air transport market and the creation of many new airline companies. Nowadays, the air transport industry in the EU provides 7.8 million jobs and contributes 475 billion euros (3.9%) to the EU gross domestic product [1]. Unfortunately, the development of air transport in Europe on this scale has also led to a significant increase in air traffic, which is a growing problem for the increasingly obsolete ATM system. This thesis is confirmed by the statistics: in 2009, the European ATM system controlled about 10 million flights, which, on some very busy days, equated to more than 33,000 flights per day; in 2020, the number of yearly controlled flights is expected to reach 17 million, with peaks of about 50,000 flights per day. However, an increase in air traffic is not the only problem to be addressed as part of the reconstruction of the European ATM system. No less important an issue is the fragmentation of the European ATM system, which is currently organized on the basis of more than 60 controlled sectors and brings together national networks of air routes without any European optimization. As a result, each flight is, on average, 50 km longer than the optimal route, what creates needless fuel consumption, gas emission of about five million tons of CO_2 and an additional cost of one billion euros per year. The total losses of the aircraft operators caused by the current European airspace fragmentation are estimated to be four billion euros per year [8], not to mention its negative impact on flight safety.

3. CHARACTERISTICS OF THE SESAR PROGRAMME

Recognizing the urgent need to resolve the above problems, the European Commission in 2004 came forward with ambitious project to reform the architecture of European ATM, namely, the SES initiative [16]. This project proposes a legislative approach to meet the future capacity and safety needs at a European rather than a local level. The main objectives of SES are: to enhance current air traffic safety, to contribute to the sustainable development of the air transport system, and to improve the overall performance of ATM and air navigation services, thereby meeting the requirements of all airspace users [8]. In order to fulfil these objectives, the European Commission set high-level goals for the SES initiative, to be met by 2020 and beyond [19]:

- tripling ATM system capacity to reduce delays
- reducing ATM system costs by 50%
- improving safety by a factor of 10
- reducing the environmental impact of each flight by 10%

The full implementation of SES and the achievement of its main objectives and goals are determined by deployment of new ATM technologies and procedures. The SESAR programme is the technological pillar of SES, which aims to give the Community a high-performance air traffic control (ATC) infrastructure, which will enable the safe and environmentally friendly development of air transport, as well as benefit fully from the technological advances of other EU programmes, such as Galileo. The main assumption of this programme is to integrate and coordinate research and development activities, which were previously undertaken in a dispersed and uncoordinated manner in the Community. SESAR is composed of three phases: a definition phase, a development phase and a deployment phase, which were established to define, develop and deploy a high-quality, new generation of ATM technologies, systems and procedures compliant with SES objectives and requirements [15].

SESAR programme implementation is divided into three “concept steps”, each of which brings the ATM system closer to achieving the above-mentioned objectives and goals. These steps are capability-based and not fixed in time.

Step 1: “Time-based operations” - This step is focused on flight efficiency, predictability and the environment. The goal is a synchronized European ATM system where partners are aware of the business and operational situations and collaborate to optimize the network. During this step, time prioritization for arrivals at airports is initiated, data links are widely used and initial trajectory-based operations are deployed.

Step 2: “Trajectory-based operations” - This step is focused on flight efficiency, predictability, environment and capacity. The goal is a trajectory-based ATM system where using European airspace is optimized by sharing, within the network, easy accessible information about trajectories of flights and airspace users’ priorities. The step initiates four-dimensional- (4D-) based business/mission trajectory management using System Wide Information Management (SWIM) and air/ground trajectory exchange to enable tactical planning and conflict-free route segments. Airspace use will be optimized through dynamic demand and capacity management, queue management, flexible military airspace structures, direct routing and dynamic airspace configurations. To support the use of business/mission trajectories, a full set of advanced controller tools will be deployed. These tools exploit the increased amount and quality of information, in particular, the reduced uncertainty on trajectory prediction. Separation modes will be enhanced with airborne separation assistance systems providing increased situational awareness for the pilot. Airport operations will become seamless through the use of automation support tools, while full integration of departure, arrival and surface management will be linked to demand and capacity balancing. Runway throughput is optimized due to dynamic wake vortex management, the optimization of the runway occupancy time and weather resilience.

Step 3: "Performance-based operations" - This step will achieve the high performance required to satisfy the SESAR target concept. The goal is the implementation of a European high-performance, integrated, network-centric, collaborative and seamless air/ground ATM system. European airspace will operate as an efficient continuum with two airspace categories, where user-preferred trajectories are managed with new modes of separation, including cooperative air/ground separation. Human roles and responsibilities will be more "management task-oriented" than tactical and supported by system automation, decision support and monitoring tools. Air and ground safety nets will operate in a compatible manner, adapted to new separation modes. The step is realized through the achievement of SWIM and collaboratively planned network operations with user-driven prioritization processes (UDPPs) [5].

4. SESAR'S KEY TECHNOLOGICAL SOLUTIONS

For the proper implementation of the three subsequent SESAR concept steps, it was necessary to determine essential operational and technological changes, which must be made in the current ATM system. These changes are grouped by six key features [5]:

1) Moving from airspace to 4D trajectory management - This feature assumes the systematic sharing of aircraft trajectories between various participants in the ATM process to ensure that all partners have a common view of a flight and have access to the most up-to-date data available to perform their tasks. This enables the dynamic adjustment of airspace characteristics to meet predicted demand with minimum distortions to aircraft trajectories.

This feature is characterized by two general solutions:

- Airline operational control (AOC) data sharing, which helps to increase aircraft trajectory prediction accuracy with the use of characteristic operational data, such as aircraft take-off mass and cruising speed.
- User-preferred routing, which consists of planning a direct route, defined as the shortest available distance between the published entry and exit point inside a complex airspace, resulting in reduced flight time, fuel burn and noise footprint [22].

2) Traffic synchronization - This feature covers all aspects involved with improving arrival/departure management. It is focused on achieving an optimum traffic sequence resulting in significantly less need for ATC tactical intervention, as well as the optimization of climbing and descending traffic profiles. This feature is characterized by the following five solutions:

- Approach procedures with vertical (APV) guidance, based on GNSS, which allows for the execution of landing operations under bad weather conditions in airports that are not equipped with an instrument landing system (ILS).
- The Arrival Management and Point Merge procedure, which replaces tactical radar vectoring, thereby reducing communication workload and increasing collective traffic predictability.

- An enhanced departure manager allows for the establishment of a pre-departure sequence, which will improve traffic predictability, airport capacity, cost and environmental effectiveness, and safety.
- Point Merge in complex terminal manoeuvring areas (TMAs) is a new procedure designed with precision navigation (P-RNAV) technology, which merges traffic into a single entry point, resulting in the efficient integration and sequencing of inbound traffic, together with continuous descent approaches (CDAs).
- The extensive use of P-RNAV will reduce radar vectoring, which is still used today, in order to decrease air traffic controllers' (ATCRs') workload and help to improve the design and organization of TMAs [4, 27].

3) Network collaborative management and dynamic/capacity balancing - The essence of this feature is the successive realization of operation planning from the long to the medium and short term. All civil and military ATM stakeholders are progressively sharing precise data about flights (mission trajectories and military airspace demands) to build a real-time common traffic and operational picture known as the Network Operations Plan (NOP). This database allows for better planning of traffic and available airspace use. When an imbalance between traffic demand and available airspace capacity occurs, capacity shortfall scenarios are collaboratively agreed and implemented. So far, this feature is implemented by one solution:

- Automated support for dynamic sectorization provides supporting tools for adapting the capacity to traffic load by grouping and de-grouping sectors, together with managing the staff resources [23]

4) SWIM - This is SESAR's most important enabler, which gathers and shares access to all ATM information, including aeronautical, flight, airspace capacity, aerodrome, meteorological, air traffic flow and surveillance data [26].

5) Airport integration and throughput - This feature aims at achieving the full integration of airports into the ATM network, which will lead to increasing runway throughput and improving surface movement management. This concept is realized through the implementation of the following solutions:

- The remote tower concept provides ATC services and aerodrome flight information services (AFIS) for regional aerodromes, which are currently too expensive to implement and staff a conventional manned facility, with a small number of air operations.
- The Airport Departure Data Entry Panel (ADDEP) is a low-cost and simple tool to enable small regional airports to compute and share aircraft electronic pre-departure data to the ATM network.
- The time-based separation (TBS) procedure provides consistent time-spacing between arriving aircraft, which improves runway approach capacity under strong headwind conditions [17].

6) Conflict management and automation - This feature aims to reduce air traffic controllers' task load per flight by implementing integrated computerized tools and systems. According to this concept, the role of ATCR will change from a tactical arrangement, such as aircraft vectoring, to overall system management and accepting proposed solutions. Highly important part of this feature are ground and airborne safety nets, which, through the use of new surveillance, refer to a system-wide information sharing in order to provides a last safety layer against the risk of collision and other hazards. Implementation of this concept is determined by four key solutions:

- An en-route air traffic organizer (ERATO) is an electronic decision-making toolkit for area controllers, which consists of a medium-term conflict detection (MTCD) monitoring aid and a conflict resolution assistant (CORA).
- An enhanced short-term conflict alert (STCA) comprises electronic algorithms to support controllers in identifying possible conflicts for steady and manoeuvring aircraft by generating early warning alerts.
- An enhanced airborne collision avoidance system (ACAS) is an electronic on-board system, which detects the risk of mid-air or near mid-air collisions between aircraft, as well as generates resolution advice for pilots. When a traffic advisory occurs, enhanced algorithms automatically reduce the vertical rate on the approach to the selected flight level, which significantly reduces traffic perturbation, while not increasing flight crew workload.
- Multisectoral planning represents an operational procedure that helps to increase airspace capacity as an effect of reducing controller workload per flight through the better use of workforce, as well as the distribution of workload among controller teams (flexibly fitting resources to existing demands) [20].

Each of the six abovementioned key features is composed of a set of interrelated and cooperating technological solutions, which will be implemented in accordance with the adopted path (three concept steps). This paper presents only a selection of the most advanced and innovative technological solutions from SESAR, which are aimed at improving air traffic safety in the form of GNSS-based approaches and the remote tower concept.

4.1. GNSS-based approaches

GNSS represent one of the cornerstones of the SESAR concept from an infrastructure perspective and provide positioning data to support navigation, surveillance and airport applications, as well as used as a common time reference to synchronize ATM systems, on-board equipment, communication networks and operations [28]. GNSS, as a generic term, refers to all satellite navigation systems and their augmentations, such as the Global Positioning System (GPS), Galileo, Glonass, Compass, aircraft-based augmentation systems (ABASs), satellite-based augmentation system (SBASs) and ground-based augmentation systems (GBASs) [3].

The widespread availability of high-performance radio navigation systems on all types of aircraft and, in particular, the introduction of GNSS for aviation purposes has made it possible to use RNAV in the approach phase of the flight. The main difference between conventional (ILS, NDB, VOR) and RNAV approaches is in using the on-board area navigation system and GNSS position information to compute waypoints, which describe the path to be flown, instead of headings and radials to/from ground-based navigation aids [12].

The operational implementation of RNAV (GNSS) approach procedures with vertical guidance (APV) was primarily prompted by ICAO Assembly Resolution 36-23, which called for member states to implement APV procedures (Baro-VNAV and/or SBAS) to all instrument runway ends by 2016, either as primary or as backup approach procedures. Resolution A36-23 was updated at the 37th Assembly of the ICAO by Resolution A37-11, which sets out RNAV approaches without vertical guidance (such as straight-in LNAV) as an acceptable alternative to APV on aerodromes, where there is no local altimeter setting available and where there are no aircraft suitably equipped for APV operations [6].

Outside the ICAO guidelines, the implementation of APV (Baro-VNAV or SBAS) procedures in EU countries is additionally supported by directives in the *European ATM Master Plan* and the *SESAR ATM Concept for 2020+*. In accordance with assumptions of

SESAR's key feature, that is, traffic synchronization, the EGNOS-based localizer performance with vertical guidance (LPV) approach procedure was validated during a two-day ATC real-time simulation activity, which took place at Glasgow Airport on 15-16 November 2011. The simulation demonstrated that LPV approaches can be safely integrated into the operational environment with only a minor increase in ATCR workload [18].

The existing core satellite constellations, such as GPS, GLONASS and Galileo, are not able to meet strict ICAO aviation requirements. To meet these operational requirements for various phases of a flight, positioning information derived from core satellite constellations requires appropriate corrections. These corrections are obtained in the process of augmentation, which is carried out by using one of three basic augmentation systems: ABASs, SBASs or GBASs. An ABAS relies on avionics processing techniques or avionics integration to compute corrections to satellite positioning signals. The other two augmentations use ground monitoring stations to verify the validity of satellite signals and calculate corrections to enhance accuracy. An SBAS delivers this information via geostationary earth orbit (GEO) satellites, while a GBAS uses a VHF data broadcast (VDB) from a ground station [7].

Unfortunately, due to its high establishment (an estimated 1.5 million US dollars per aerodrome) and maintenance costs, as well as the fact that appropriate avionics are not presently feasible or available for smaller aircraft, using a GBAS has been recognized as a local solution for capital city airports, rather than for low traffic/passenger volume regional aerodromes [13]. Therefore, the ICAO and the EU recommended the implementation of cheaper and more accessible SBAS-based approaches.

As shown in Figure 1, a standard SBAS comprises [7]:

1) a network of ground reference stations to monitor GPS/GLONASS signals
2) a master station, which collects and processes reference station data and generates SBAS messages
3) an uplink station, which sends messages to GEO satellites
4) GEO satellites, which broadcast SBAS messages to the aircraft

SBAS architecture consists of a network of precisely positioned ground reference stations, designed to monitor, collect and process satellite positioning signals. The ground reference stations receive satellite signals and send them to ground master stations, which then take measurements of signal delay and other errors (for example, ionosphere and solar activity) that can impact signal accuracy. Using the signal error measurements, master stations compute corrections to the satellite position information and send it as SBAS messages via uplink stations to GEO satellites. These satellites broadcast SBAS messages to aircraft equipped with an internal SBAS receiver integrated with a flight management system [28].

Currently, all implemented SBAS national programs, such as the Wide Area Augmentation System (WAAS) in the USA, the European Geostationary Navigation Overlay Service (EGNOS) in the EU, the Multifunctional Satellite Augmentation System (MSAS) in Japan and the GPS-aided Geo-augmentation Navigation (GAGAN) system in India are compatible, interoperable and comply with a common global standard. In other words, all operators equipped with an SBAS-capable receiver can benefit from the same level of service and performance, no matter the coverage area they are in [11].

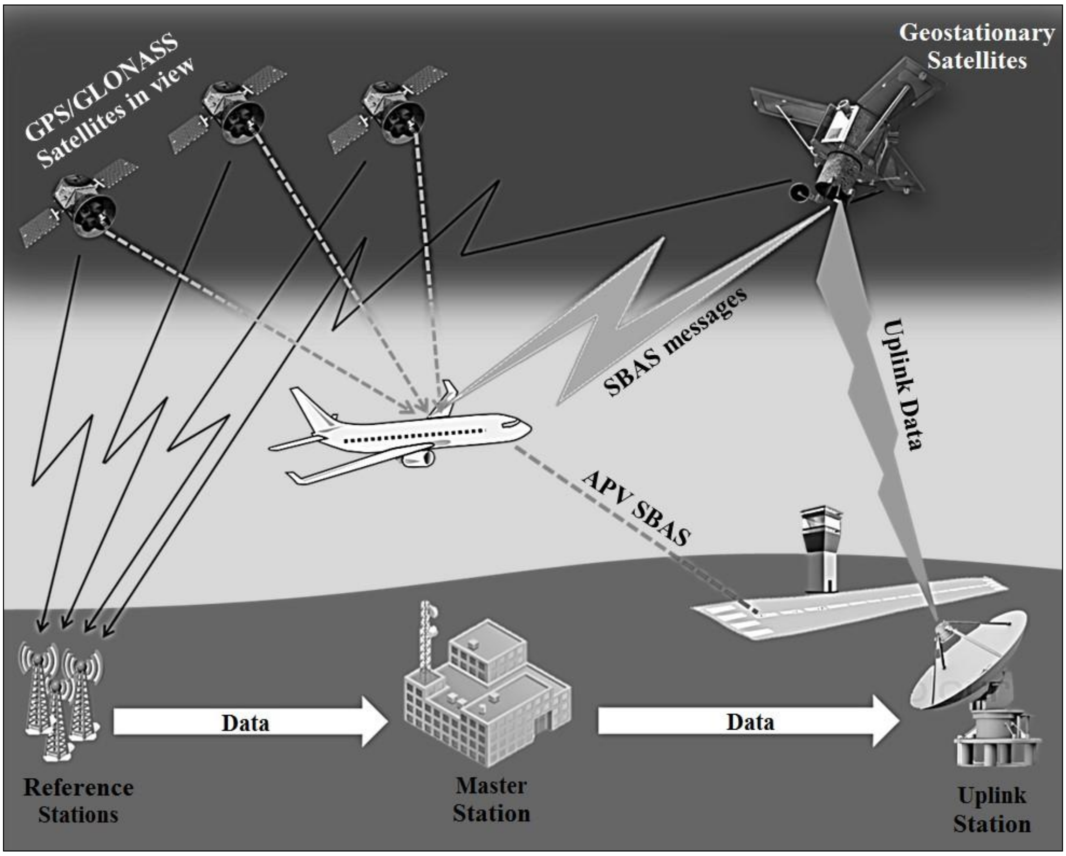

Fig. 1. SBAS architecture

4.2. Remote tower

The main aim of the remote tower concept is to provide air traffic control services (TWR) or AFIS already provided by a local aerodrome with tower facilities from a remote location. The aerodrome view will be captured by cameras and reproduced in the remote tower centre (RTC). The aerodrome visual imaging can be overlain with information from additional sources (such as infrared or radar sensors) and enhanced via digital image processing technology, which will improve controllers' situational awareness in low-visibility meteorological conditions (e.g., fog, precipitations). Obviously, the controllers will also have access to all necessary work tools, including voice communications (radios, phones), lighting and navigation aid controls and flight plan/meteorological information-handling systems [25].

The main targets for the SESAR remote tower concept are small, low-density aerodromes (usually single operations, rarely exceeding two simultaneous movements) and seasonal tourist airports with occasional medium traffic density (more than two simultaneous operations), which today are struggling with low business margins [21]. From a remote tower location, the remote ATCO/AFISO will be able to provide ATS to one or more airports and their adjacent airspace at a time. In other words, through centralized resource pools, remote tower facilities will generate lower maintenance, staffing and training costs and be able to operate for longer periods. Additionally, this concept will also result in the significant reduction of the local control tower's infrastructure maintenance costs, which will minimize losses in airport revenue. The remote tower can also be a suitable solution in case of planned and unplanned contingency events, such as control tower repairs or emergency situations (fire alarm, bomb threat) [21].

The essence of the SESAR remote tower operating method is removing local ATCO (TWR or AFISO) working positions from an aerodrome's control tower building to an RTC, which will contain several remote tower modules (RTM), similar to sector positions in an approach or area control centre. Each RTM will be remotely connected to one or several low density airports. The ATCO will provide air traffic control services based on an out-of-the-window view captured by video and infrared cameras deployed in different parts of the airfield (tower view and/or multiple viewpoints). The visual reproduction can be overlain with information from additional sources, such as surface movement radar, surveillance radar, automatic depend surveillance-broadcast (ADS-B), multilateration or other available positioning, and surveillance systems. All collected data will be displayed on monitor screens, projectors or similar technical solutions, which will guarantee a uniform, smooth and high-quality visual view (see Fig. 2). The visual reproduction of the aerodrome can be optionally supplemented by airport sound reproduction (such as engine noise, wind noise etc.). It is worth mentioning that visual reproduction technology can offer certain benefits compared to the standard out-the-window view. For example, sensor data from multiple, sometimes non-optical, sensors (ground-based and aircraft-based) may be fused, analysed and presented together on the visual reproduction in a way that further enhances the ATCO/AFISO situational awareness, especially in low-visibility conditions. The remote tower concept will also introduce the ability to record visual information, which will create enhanced and unique opportunities to support incident/accident investigations [21].

Except for the functionalities mentioned above, the RTM will be equipped with technical functions and systems, currently found in local facilities, which are necessary to provide services, such as [21]:

- communications: VHF/UHF radio, ground radio system, rescue (SAR) radio, telephone, optionally data link (CPDLC)
- flight plan processing system;
- manoeuvring of ground lighting, navigation aids, alarms etc.
- signal light gun
- system for reproducing the “binocular” view, e.g., pan-tilt-zoom camera
- surveillance: radar scope or alternative solution (multilateration, ADS-B, visual tracking)

The validation exercises performed at the Angelholm-Helsingborg Aerodrome and Værøy Heliport in Scandinavia proved that providing ATS remotely is a safe concept. ATCRs involved in the remote tower validation exercise felt that RTCs, when coupled with advanced technical enablers, could provide enhanced safety and capacity, in comparison to the local tower environment, especially in low-visibility conditions (IFR traffic). Participants also observed that visual reproduction could potentially lead to limitations, such as the deterioration of ATCO's depth perception, which, in some cases, can increase the need to hold and, in turn, negatively affect the capacity to handle VFR traffic [24].

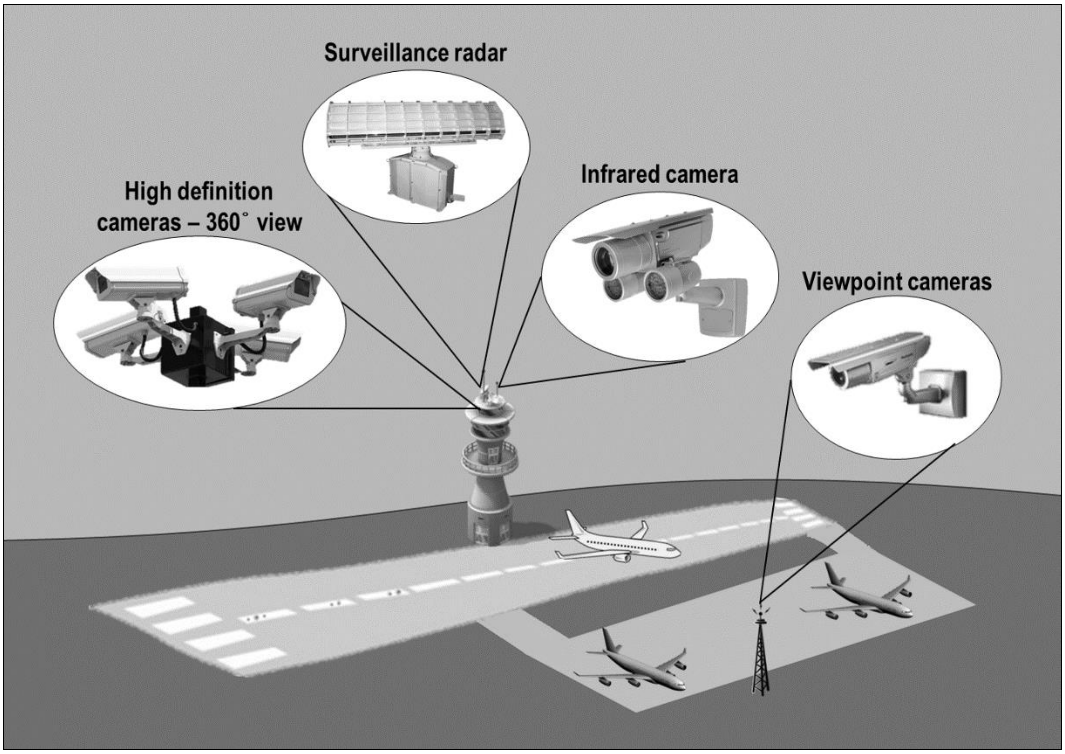

Fig. 2. Airport sensor deployment

5. CONCLUSION

To sum up, the deployment of the SESAR initiatives' key technological solutions, such as RNAV (GNSS) approaches and the remote tower concept, offers, in addition to the undisputed economic benefits, a significant increase in air traffic safety, especially in small regional airports' airspace. In the case of RNAV (GNSS) augmented approaches, the increase in air operation safety has resulted from providing pilots with better situational awareness than when using conventional non-precision approaches, thereby reducing the risk of a controlled flight into terrain. Almost all SBAS approaches offer vertical guidance down to a decision height of 75 m (250 ft), which is less than the ILS Category I minimum. Another advantage in implementing RNAV approaches is that it enables better access to airports that are not equipped with precision approach and landing systems, as well as airports where precision approach aids are out of service (APV operation backup solutions in case of ILS outages). Regarding the en-route phase of a flight, introducing RNAV procedures will help to enable curved approaches and continuous descent paths, which will reduce the impact of aviation on the environment (less noise and CO2 emissions). Using SBAS augmented RVAV approaches will also bring particular benefits for helicopter operations, such as offshore, mountain rescue and emergency medical services. Realizing a substantial reduction in the decision height and allowing for approach procedures to be developed from any direction, RNAV (GNSS) approaches will improve the safety and accessibility of helipads in poor weather conditions.

In the case of remote tower concept implementation, the level of air operation safety has been increased by the ability to use a wide range of aeronautical data from multiple, sometimes non-optical, sensors (such as surface movement radar, surveillance radar, ADS-B and multilateration), which will significantly improve ATCO/AFISO situational awareness, especially in low-visibility (IFR) conditions. The Remote Tower concept will also introduce the ability to record visual information, which will create enhanced and unique opportunities to support incident/accident investigations. Moreover, it can be a suitable solution in the case of planned and unplanned contingency events, such as control tower repairs or emergency situations.

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