Modern military ATM systems and their optimalization in integrated civil and military ATC

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Abstract – **Military ATM systems represents important part of air traffic control systems in the national and international airspace of Europe. In the light of the need for the increasingly efficient use of limited airspace, it is gradually transformed into the conditions of integrated civil-military air traffic management, both nationally and internationally, in which the civilian commercial sector creates unprecedented pressure to prioritize civilian airspace use and civilian air traffic management. Military ATM systems that have been developed so far as parallel versions of civilian ATM systems, partially adapted to the specific efforts of military air forces, have led to a gradual reduction of their scope and efficiency gains while reducing costs. The methods and practical possibilities of this seemingly contradictory approach are described in this text, many of these methods were implemented in practice in the national conditions of the Czech Republic and at international level of air traffic control and can therefore be considered appropriate to meet the requirements imposed on them.**

Keywords—ATM, ATC, flight data, radar data, processing, optimization, remote tower

I. INTRODUCTION

Military ATM systems are designed for the needs and support of military air traffic management at national and international level of air traffic control. Historically, military air traffic management can be considered as the first systematically organized and deployed airspace management at national level, both at the level of conventional visual and radar management and in enforcement of air traffic rules in the national airspace. With the expansion of civilian and cargo air transportations in the 1920s and 1930s, this originally unified service was split, with creation of civilian air traffic management service, with prioritization of military air traffic control. The end of the Cold War and closer air traffic control coordination in the airspace of European states caused a reversal in the 1990s, as the growing pressure of the civil commercial airline sector and the rapidly growing number of civilian and cargo flights forced individual states and international air traffic management to reevaluate the existing approach and formulating new requirements for priorized civil air traffic control in terms of the common use of airspace areas and sectors, as well as in terms of transferring part of the air traffic management responsibilities to civilian authorities. An air traffic control model was gradually created in the Czech Republic where military flights and military airplanes are controlled and organized by military air traffic control authorities only in the served military district, while the remaining operations in line and navigation flights are taken over by the civil aviation authorities' operation, with the exception of combat flight operations and flight operations within the NATINADS service. This development forced not only the reevaluate legislative but also practical changes, when the regulation of the airspace management was implemented into the conditions of the integrated civil and military environment and at the same time measures were taken to adapt the practice of the military.

II. CURRENT STRUCTURE OF MILITARY ATM SYSTEMS

The structure of the military ATM system, according to the current overview of ATM systems in its general theoretical form, consists of three mutually redundantly connected segments:

- System core
- Airport segment
- Supporting segment of other operating services

A. System core

The core of the system is the basic information processing unit of the military ATM system, which collects, processes and distributes system, operating and control data serving the needs of the ATM system and supporting individual operating services. System core is a server structure, built on a pair of redundant servers running on a UNIX-like operating system with a reliability corresponding to the general requirements for critical systems. The core system task is to process, distribute and coordinate overview information, flight plan data, ASM data, meteorological data, AIP status data, and continuous autonomous technical monitoring of the ATM system core, its other segments, their operating parts and the associated core technical supervision center. An important part of the system core is usually a separately operated system of objective documentation which, following the monitoring functions of the system, records the entire operation, activities and interventions of operators and system technicians and serves as a credible, objective and binding basis for investigating and identifying problems, errors and critical situations during the operation of the system. An additional part of the modern implementation of the core of the ATM system is the parallel development and operation system core duplicated for the development of the main system upgrade, the testing of update and modernization software packages and the implementation of the preparatory work prior to the introduction of the new software into the operating system conditions. An important function of the supplementary system is the ability to train operators and operate the system and simulate its operating states for training and demonstration purposes.

B. Airport segment

The airport segment is usually built in the main airport operating buildings of each airport connected to the system. The requirement for airport segment systems is processing, displaying and distributing surveillance data from local radar sensors and meteorological data from local sensors and external meteorological systems to the airport segment operator workstations and transferring them to the core of the ATM system. Additionally, the aerodrome segment facilities must allow local planning and preparation of flights and flight plans (including activation and deactivation of flight sectors), distribution of local airspace management data, and information on the state and operational situation of the airport [3]. From the point of view of the safety of the operation of the airport segment, it is essential that the aerodrome segment systems allow emergency operation independent of the core of the system, using the available data. As with the core of the system, it is a matter of continuous, objectively recorded monitoring of individual components and systems of the airport segment through an integrated monitoring system and a local technical supervisor with the distribution of operational data to the central monitoring system located in the core system segment.

The basis of the system equipment of the airport segment is again the server structure, built on a pair of redundant servers running on a UNIX-like operating system with reliability corresponding to the general requirements for critical systems. System consist by systems for processing and distributing surveillance information, meteorological information processing and distribution systems, systems of processing, planning and preparation of flight operations, TWR console, TWR assistant console, APP console, PAR console and METEO console (all consoles are equipped by instructor-trainee interface that allows training, audited activity and operator examine as part of routine qualification checks).

Surveillance information processing and distribution systems allow the distribution of unprocessed surveillance information obtained from local or external sensors and the processing and distribution of multiradar plots. These plots are created from unprocessed surveillance data of local and external systems using weighted sector calculations with statistical target location probability determination. As a source of location data, primary (PSR) and secondary (SSR) radar position information, multilateration systems, passive radar systems, and pre-processed multiradar plots of international radar systems and networks (RADNET) are used in the ATM system. The computed multisensor surveillance information is distributed to the local TWR and APP workstations and to the ATM system core. A special type of surveillance information is information with a higher accuracy class obtained from a local precision approach radar (PAR) and serving as an ILS complement to accurately route the aircraft approaching the airport at.

Meteorological information processing and distribution systems process meteorological data from local and external weather sensors and, in conjunction with meteorological data and meteorological models distributed within the central meteorological system, provide TWR, APP and PAR operators, as well as users of flight planning, predicted meteorological information to serve flight management and air traffic management.

Flight operations processing, planning, and preparation systems are used to prepare the bases of individual flight operations, flight operations planning and the definition of requirements for pre-flight preparation and aircraft preparation. From the point of view of the ATM system, the transmission and distribution of flight plans and documentation for the activation, deactivation and reservation of reserved airspace are implemented in the system.

The TWR console is operated by the TWR operator performing the air traffic control in the airfield and airplane movement on the airport. The system provides the operator with overview information from the system of processing and distribution of surveillance information, current meteorological information from the meteorological information processing and distribution system. Additionally, the console through the ATM system is linked to an equipment management and technical security system allowing the operator to control, manage and supervise the operation of the airport lighting and aerodrome emergency systems. Adding to the TWR work console is the TWR Assistant's work console, which is equipped like a TWR work console, and its operator supports and complements the TWR operator's activities and reduces the burden placed on them [2].

The APP console is operated by an APP operator performing radar air traffic control in a controlled area of the airport. The system provides the operator with surveillance information from the processing and distribution system of surveillance information and current meteorological information from the meteorological information processing and distribution system [2].

The PAR console is operated by the PAR operator performing precise control and guidance of landing planes on the airport's runway descent axis. The system provides the operator with surveillance information from the processing and distribution system of surveillance information and current meteorological information from the meteorological information processing and distribution system [2].

The METEO console is operated by an operator of the meteorological service of the airport, which is provided with meteorological information from local and external meteorological sensors. This information is supplemented by data acquired by the operator through direct physical measurements and data from external meteorological systems and meteorological models. From the information received, the operator is assembled and circulated through the system a periodic report on the current weather conditions at the aerodrome and the controlled airport and meteorological conditions on its operating areas.

C. Supporting segment of other operating services

The supporting segment of other operating system services is built in a branch structure, usually with a direct connection to the core of the system, and in the most basic concept, this segment includes workstations for Civil-Military coordination and communication console, Search and rescue console and Airport information service console whose description of the function and equipment is as follows

The Civil-Military coordination and communication console is operated by the Civil-Military coordination operator, which is provided with Flight data planning, shared and coordinated with the civilian air traffic control sector through the operator.

The search and rescue console is operated by the search and rescue operator, which is provided with the current surveillance data, current meteorological and flight planning data. The operator's task is in condition a state of emergency or, in the event of an emergency occurrence in air traffic control, to coordinate the search for missing airplane and flight operations to ensure crew and passenger rescue and to provide assistance to an airplane in distress, using all available military and civilian land and air resources. The system outputs of the search and rescue console are absolutely prioritized within the system, and the operator, with respect to the usual security standards, has the authority to interrupt the routine activities and tasks of system core and airport segment operators and prioritize action to prevent and remedy of the consequences of emergency situation.

The airport information service console is operated by an operator of an airport information service that collects flight planning data, equipment management data and status data of the airport segment, and conducts its necessary public distribution through AIP, AIC, NOTAM, PIB, etc. messages. in the form and within the deadlines for efficient use of airspace, airport facilities and timely information of all air traffic controllers.

III. PERSPECTIVE TRENDS IN OPTIMALIZATION OF MILITARY ATM SYSTEMS

The structure of the modern military ATM system, according to the current overview of ATM systems is basically same as theoretical form of current military ATM systems but it is different in specifications and functions.

The core of the system is the basic information processing unit of the military ATM system, which collects, processes and distributes system, operating and control data serving the needs of the ATM system and supporting individual operating services. System core is a server structure, built on a pair of redundant servers running on a UNIX-like operating system with a reliability corresponding to the general requirements for critical systems. The core system task is to process, distribute and coordinate overview information, flight plan data, ASM data, meteorological data, AIP status data, and continuous autonomous technical monitoring of the ATM system core, its other segments, their operating parts and the associated core technical supervision center. An important part of the system core is usually a separately operated system of objective documentation which, following the monitoring functions of the system, records the entire operation, activities and interventions of operators and system technicians and serves as a credible, objective and binding basis for investigating and identifying problems, errors and critical situations during the operation of the system. An additional part of the modern implementation of the core of the ATM system is the parallel development and operation system core duplicated for the development of the main system upgrade, the testing of update and modernization software packages and the implementation of the preparatory work prior to the introduction of the new software into the operating system conditions.

The airport segment is usually built in the main airport operating buildings of each airport connected to the system. The requirement for airport segment systems is processing, displaying and distributing surveillance data from local radar sensors and meteorological data from local sensors and external meteorological systems to the airport segment operator workstations and transferring them to the core of the ATM system. Additionally, the aerodrome segment facilities must allow local planning and preparation of flights and flight plans (including activation and deactivation of flight sectors), distribution of local airspace management data, and information on the state and operational situation of the airport. From the point of view of the safety of the operation of the airport segment, it is essential that the aerodrome segment systems allow emergency operation independent of the core of the system, using the available data. As with the core of the system, it is a matter of continuous, objectively recorded monitoring of individual components and systems of the airport segment through an integrated monitoring system and a local technical supervisor with the distribution of operational data to the central monitoring system located in the core system segment.

The basis of the system equipment of the airport segment is again the server structure, built on a pair of redundant servers running on a UNIX-like operating system with reliability corresponding to the general requirements for critical systems. In addition, to the system are attached systems for processing and distributing surveillance information, meteorological information processing and distribution systems, systems of processing, planning and preparation of flight operations, TWR console, TWR assistant console, APP console, PAR console and METEO console (all consoles are equipped by instructor-trainee interface that allows training, audited activity and operator examine as part of routine qualification checks).

Surveillance information processing and distribution systems allow the distribution of unprocessed surveillance information obtained from local or external sensors and the processing and distribution of multiradar plots. These plots are created from unprocessed surveillance data of local and external systems using weighted sector calculations with statistical target location probability determination. In practice, the credibility of the information from the individual sensors is evaluated empirically, and on the basis of this assessment, the individual sensors are hesitant, and their data is, with the wavering credibility, integrated in the resulting plot with multisensor position information. As a source of location data, primary (PSR) and secondary (SSR) radar position information, multilateration systems, passive radar systems, and pre-processed multiradar plots of international radar systems and networks (RADNET) are used in the ATM system. The computed multisensor surveillance information is distributed from the information processing and distribution system to the local TWR and APP workstations and to the ATM system core. A special type of surveillance information is information with a higher accuracy class obtained from a local precision approach radar (PAR) and serving as an ILS complement to accurately route the aircraft approaching the airport at landing at a distance of 20 nautical miles from the runway threshold. This information is not multisensor-processed and is transmitted directly to the PAR console.

Meteorological information processing and distribution systems process meteorological data from local and external weather sensors and, in conjunction with meteorological data and meteorological models distributed within the central meteorological system, provide TWR, APP and PAR operators, as well as users of flight planning, predicted meteorological information to serve flight management and air traffic management.

Flight operations processing, planning, and preparation systems are used to prepare the bases of individual flight operations, flight operations planning and the definition of requirements for pre-flight preparation and aircraft preparation. From the point of view of the ATM system, the transmission and distribution of flight plans and documentation for the activation, deactivation and reservation of reserved airspace are implemented in the system.

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The APP console is operated by an APP operator performing radar air traffic control in a controlled area of the airport. The system provides the operator with surveillance information from the processing and distribution system of surveillance information and current meteorological information from the meteorological information processing and distribution system.

The PAR work console is operated by the PAR operator performing precise control and guidance of landing planes on the airport's runway descent axis. The system provides the operator with surveillance information from the processing and distribution system of surveillance information and current meteorological information from the meteorological information processing and distribution system.

The METEO work console is operated by an operator of the meteorological service of the airport, which is provided with meteorological information from local and external meteorological sensors. This information is supplemented by data acquired by the operator through direct physical measurements and data from external meteorological systems and meteorological models. From the information received, the operator is assembled and circulated through the system a periodic report on the current weather conditions at the aerodrome and the controlled airport and meteorological conditions on its operating areas. This information is distributed both to the system core and to the external systems on the METEO console and to the related meteorological information processing systems.

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The airport information service console is operated by an operator of an airport information service that collects flight planning data, equipment management data and status data of the airport segment, and conducts its necessary public distribution through AIP, AIC, NOTAM, PIB, etc. messages. in the form and within the deadlines for efficient use of airspace, airport facilities and timely information of all air traffic controllers.

Previous list of basic requirements for functionality and equipment of the military ATM system exceeds the requirements of the current civilian ATM system defined by ICAO and Eurocontrol to ensure the necessary civil air traffic control functions. In practice, therefore, the gradual approximation of the scope of the military ATM system and of the services provided by civilian ATM systems

A. Reducing the scope of the military ATM system

Compared to a common civilian ATM system, there is a clear difference between the military ATM system in the use of the PAR service, which is currently being discussed as redundant and is about its abolition in the next generations of the military ATM system. Civilian ATMs fully comply with this service in accordance with the standard ILS system at the given published aerodrome category. This practice is based, first, on the requirements to reduce the financial costs of operating systems where the commercial sector seeks to minimize costs while maintaining adequate air traffic safety and, on the other hand, is the result of an agreement adopted by ICAO laying down framework deadlines for exchanging, leaving and replacing older radio navigation systems by new and more promising solutions. Unfortunately, replacing of old systems (ILS) are often abandoned for high costs and security reasons (GNSS is not independent and everytime accesable system).

The PAR system was left in a military use primarily for its ability to implement, along with ground RWY light equipment, a precise approach and landing of landing planes on the RWY, regardless of the airplane's landing equipment and the capability of the airplane or its pilot to approach and land on RWY using modern landing radio navigation systems. The pilot is guided on approaching to landing via PAR, where the PAR operator observes the deviation of the landing aircraft from the descending axis in the horizontal and vertical directions, and send the necessary corrections for compliance with the downward axis to airplane until the plane reached defined point of decision where pilot according with his own visual assessment (RWY visibility and visually assessed status) decide to land or revert landing. However, leaving the PAR system at least within military airports, leaves military and civilian authorities the option of a readily available solution in the event of an aircraft being driven to land due to technical problems or inappropriate landing using conventional radio navigation landing systems, which is particularly important for military air traffic control in the case of war conditions.

A logical argument for leaving the PAR system in modern military ATM systems is the costs of this service. In case that it be decided to abandon the PAR service in military ATM system in accordance with civilian practice, it would mean significant operating savings that include the operation of the PAR radar (energy requirements, necessary energy backup, ATM data transfer requirements), the PAR console and technical supervision of its operation. From the personnel point of view, it would be possible to operate each airport segment and the systems connected to it with 4 operators and 2 PAR radar techniques with annual savings. In current business sessions, it would save more than € 270,000 each year for each airport segment, with an analogous reduction in the downstream costs of major repairs and upgrading of technical equipment and replacement of technical and service staff. The compromise solution between these two options is to reduce PAR services to a centralized service using Remote Tower technology as described in Part C.

B. *Reduction of technical equipment of the military ATM system*

With regard to the high interconnection and interconnection of individual parts of the military ATM system and the quality of their connectivity to individual external sensors and sensors operating both within the ATM military system and within the civil sector, a long-term effort is being made to reduce its own ATM military sensors while maintaining all the necessary functions and requirements of the ATM system. In this case, it is a reassessment of the technical equipment of the airport segment, especially in terms of equipment and overview sensors. At present, the standard surveillance equipment on one airport segment consist of 2D Primary Surveillance Radar SRE (PSR), 2D Secondary Surveillance Radar SSR and 3D Precision Approach Radar (PAR).

This sensory equipment assembly covers the TMA, specifically in the case of surveillance radar PSR and SSR, it is a 360 ° sector with a radius of 20 nautical miles and, in the case of PAR, a 20-nautical mile segment covering the airport's descent axis, without the need for additional external sensors [1] [2].

The interconnectedness of a system combining sensory equipment and external sensors and sensors allows areas with sufficient external surveillance sensors to allow for the omission of their own surveillance sensor in the area, and for the operation of TWR and APP services continue to use a multiradar plots composed of tracks of external sensors of the appropriate quality. From a military ATM system point of view, however, in this case, it is essential to use position information from the PSR sensors under the control of authorities subordinate to the national authority, because if the services are used in combat conditions, the SSR sensors cannot be considered reliable in terms of suppression of the onboard transponders both own and foreign aircraft, and the availability of sensors and surveillance data from international sources cannot be expected. An important argument for the planned sharing and forwarding of position and survey information is that, apart from saving financial and reducing the amount of technical equipment, easier management and regulation of airspace saturation by SSR questions and responses whose unregulated quantities can still be combined with natural multipliers and other questions systems (MLAT, TCAS) to cause airspace suppression and queries resulting in the loss of SSR's position information and the introduction of a significant system error into the data provided for the implementation of the TWR and APP service. While this regulation is in direct subordination to the national authority, which is responsible for sufficient regulation, in practice, minimal efforts are being made to launch it only after the collapse of the European radar network in 2014 due to the over questioning of airspace in Central Europe.

Whilst surveillance sensors can be reduced in the context of reducing the technical equipment of the aerodrome, the same approach cannot be applied to PAR radar and airport meteorological equipment that is directly linked to the situation and conditions at a particular airport and cannot be replaced by any remote complement. Experiments with the derivation of meteorological information by approximations from information from distant locations at the end of the 1990s have shown that the credibility of such approximated information is less than 70 percent and is therefore untrustworthy from the point of view of current legislation [4].

C. *Reduction of deployment sites of the military ATM system*

Currently, the most promising trend to reduce the scope and location of deploying a military and civilian ATM system is to use the Remote Tower technology. It is a remote-control technology when the installation of an airport segment is limited to the sensory part of the ATM system and its technically supervised core. The TWR, APP and PAR workplaces themselves are then located entirely outside, usually in one place, which reduces staffing costs and security features. The sensor segment of the airport segment is furthermore complemented by a video platform built at the premises of the airport's main operational facility or other suitable airport location. It consisted by matrix of high-resolution cameras statically scanning the entire airport area at least within the original field of view of the TWR site and selectively focused camera designed to monitor, monitor and monitor selected aerial, terrestrial and natural (bird, animal) targets, usually equipped by laser rangefinder.

The TWR operator's workplace is then equipped by a screen on which the output of the camera segment of the airport segment and a separate view of output from the selective camera which can be directed to object of interest.

This modification of the ATM system requires a significant increase in the capacity, reliability and reliability of the connection between the core of the system (from the point of view of realization, the installation of remote workstations to the minimum possible proximity of the core of the system appears to be the most appropriate) and the airport segment, field of the airport segment as well as associated systems such as radiocommunication, telephony and control and signaling of operational status of airport equipment and airport rescue equipment. If this situation is achieved, it is possible to proceed to a substantial reduction and reorganization of the individual services and sites of the operators based on the statistical evaluation of the workload of the individual workplaces and their operators and consequently to carry out their merger and mutual representation regardless of their original location.

The model solution of this reconstructed military ATM system can be represented for the ATM system with the system core and the four airport segments marked A, B, C and D. In case we want to build a system that transfers all the services and workplaces of the airport segment 1: 1 ratio, it would be necessary to build the following work console at this remote location whose operation requires 64-80 operators in 24/7 mode.

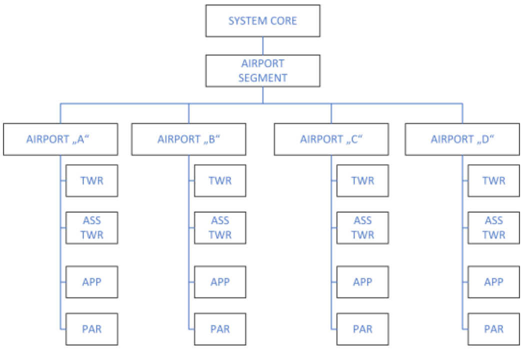

Fig. 1 – Basic model of ATM system for four airbases

The system can be easily optimized by unifying the geographically closest locations of the airport segments into pairs (for example, consider the closest pair A-B and C-D) when pairing is combined with less busy services under one associated service station. It is necessary to maintain a separate TWR work console for each of the airports, since it is neither technically nor in terms of training and qualification of operators able to make a smooth transition between two airports when managing the airport movements (it depends on specific situation, tarmac configuration and configuration of support equipment on each airport, which needs experiences with them and can make misunderstandings and error during ground operations management). However, it is possible to merge the operations of the TWR assistant consoles. Similarly, it is possible to combine the work of the APP workplace operators, which are newly managing the geographically close sectors and their movement (the situation is significantly facilitated by the limitations of the workload of the military ATM system operators in integrated military civilian air traffic management) and PAR, which is currently serving landing guidance on two airports. The resulting system configuration requires 40-50 operators in a 24/7 mode to save more than € 850,000 in routine sessions per year, while maintaining all the services provided in a comparable security and reliability class, with an initial investment of approximately € 7,500,000 including the construction of a new air traffic control center, the construction of a camera network at individual airports and the construction of parallel structures to the original consoles in the airport segment.

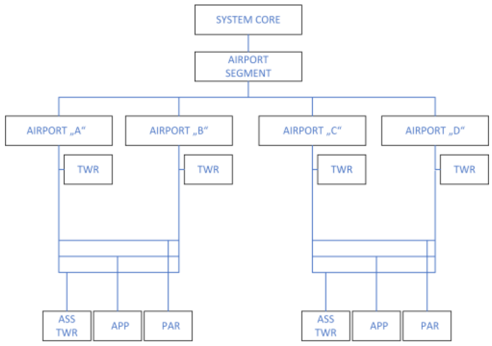

Fig. 2 – Reduced model of ATM system for four airbases

Practical tests of this technology have been carried out in the European Airspace since 2010 and testing of implemented optimized models of military and civilian ATM systems in several European countries is currently underway with a view to future massive deployment of this technology.

IV. CONCLUSION

This text presents three basic trends in the optimization of the modern model ATM military system with regard to their economic and practical efficiency. The most promising of these trends is the use of the Remote Tower technology that enables the TWR, APP, and PAR operators to merge into geographically close areas with significant financial savings and reduced technology costs and job security. In the future, with the further development of technologies and the implementation of algorithms for automatic control of information on the current situation and the operational status of the aerodromes, further possibilities of optimization of military ATM systems with the objective of fully automated air traffic control under peace conditions without operator intervention will be expected, thus achieving the highest possible class security and reliability of the system.

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