25 years of Flight Centric ATC research – What happens next?

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In 2001, the idea of a new type of air traffic management concept called sectorless air traffic management was published for the first time. An idea that envisaged a complete restructuring of airspace to improve end-to-end quality of service and continuity of service by removing traditional sector boundaries and considering the resulting airspace as a single control area in which multiple controllers share responsibility for air traffic. Almost 25 years later, this concept, now known as Flight Centric Air Traffic Control, will reach technical readiness level 6 for implementation in low and medium complexity airspace when implemented at country level. This paper will discuss the historical development of the concept and summaries the results achieved. Even though reaching technical readiness level 6 normally marks the end of a concept from a research perspective, this paper also discusses why this is not the case for Flight Centric Air Traffic Control, which open research questions remain and why the development of this concept has lasted so long and yet has not been fully investigated.

I. Nomenclature

$ACM_{\square}$ = aircraft maneuver group
C_j = weighting coefficient, $j \in \{ACM, CDR, CON, COR, DET, EAP, MON, OBS, REA, RES, TOC\}$
$CDR_{\square}$ = conflict detection and resolution group
$CON_{\square}$ = group for first/last contact
$COR_{\square}$ = coordination group
DET = conflict detection group
$EAP_{\square}$ = extended ATC planner (EAP) tasks group
f = mode of communication (voice = 1, CPDLC = 2, LDACS = 3), index for some groups
$HMI_{\square}$ = human machine interface (HMI) interaction group
$MON_{\square}$ = monitoring activities group

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N_j = number of aircraft for groups
$OBS_{\square}$ = conflict responsibility group
$REA_{\square}$ = re-allocation group
$RES_{\square}$ = conflict resolution maneuvers group
T_j = task time, $j \in \{ACM, CDR, CON, COR, DET, EAP, HMI, MON, OBS, REA, RES, TOC, TOD\}$
TOC = top of climb group
TOD = top of descent group
WL = workload – total
WL_j = workload, $j \in \{ACM, CDR, CON, COR, DET, EAP, HMI, MON, OBS, REA, RES, TOC, TOD\}$
ω_j = weighting coefficient, $j \in \{ACM, CDR, CON, COR, EAP, HMI, MON, REA, TOC, TOD\}$

II. Introduction

Wars, economic crises, pandemics - the air transport sector is constantly faced with global challenges. Even if these events always have a direct impact on the demand for air transport, long-term observations show that none of these global crisis episodes have been able to disrupt the demand for air transport. Although there are indeed drops in demand for air transport shortly after such events, these are only short- term and air traffic recovers relatively quickly from such situations. And not only that, after every major crisis, demand not only returns to pre-crisis levels, but exceeds these levels within a very short period of time. Neither the terror attacks in 2001, the SARS pandemic in 2002 nor the global economic crisis of 2008/2009 were able to stop the trend. Usually it took up to two years, to recover after start of the shock (Fig. 1). [1]

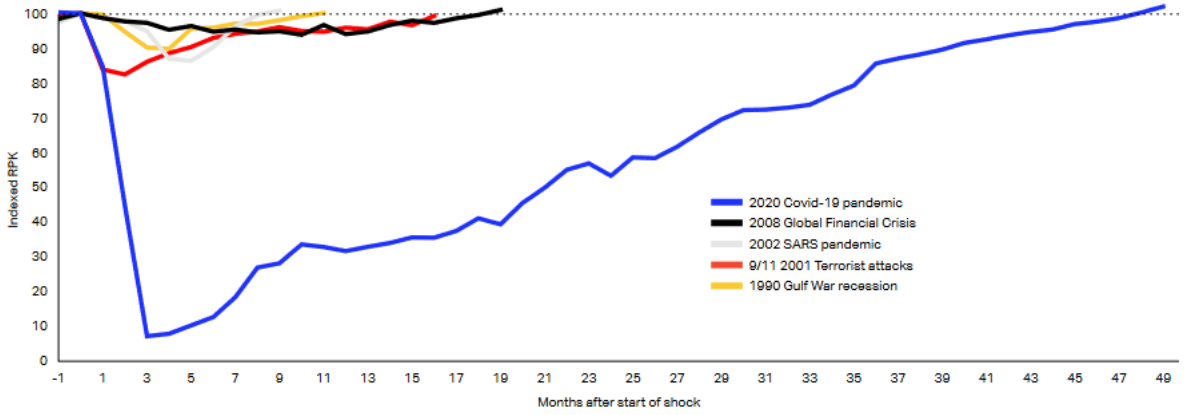


Fig. 1 Historic recovery of industry-wide RPK after global shocks [1]

Even the global Covid-19 pandemic and the war in the Ukraine, which coincided with the recovery phase of the pandemic, do not appear to have been able to stop this trend. On the contrary, most regions in the world, such as Latin America-Caribbean and Africa have already reached and in some cases exceeded the pre-2019 volumes, despite coronavirus-related staff shortages and a simultaneous unmet demand for aviation equipment. [2]

Looking in more detail at the trend in Europe for the period from 2023 to 2030, a return to pre-crisis levels is expected in 2025, resulting in a total number of 11.1 million flights per year. The base scenario indicates a further increase by 1.1 million flights up to 12.2 million flights per year for the following 5 years until 2030, while the most optimistic forecasts even expect an increase almost twice as strong by 2.2 million flights to 13.2 million flights per year in 2030 for Europe (Fig. 2). [3]

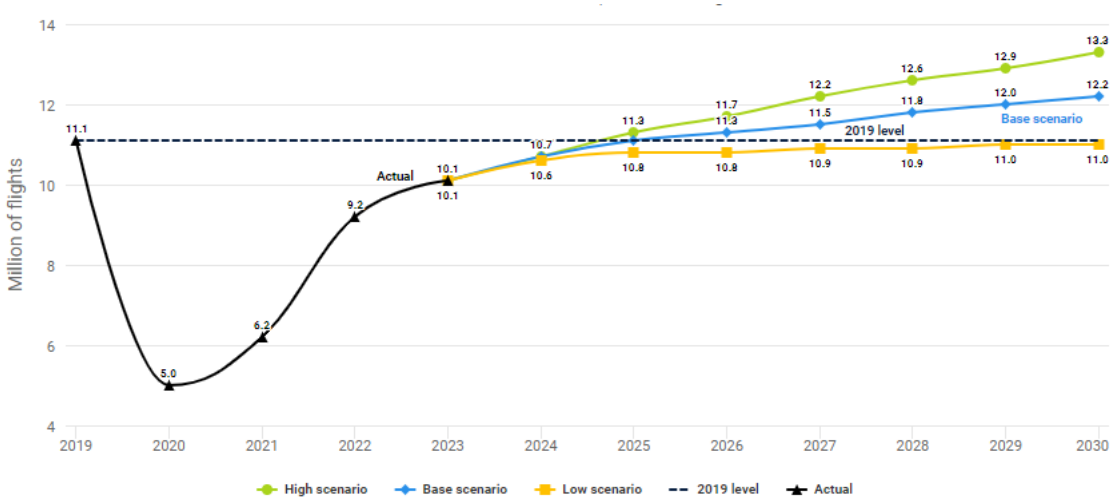


Fig. 2 7-year forecast for Europe - 2024-2030 – Update Q3/2024 [3]

While the demand for air transport steadily increased globally and in Europe, many other parameters of aviation also changed. While safety and cost efficiency were still the primary focus in the early 2000s, interest in aviation research has also developed in many areas. Today, European aviation research within the Single European Sky Air Traffic Management Research Programme (SESAR), which is based on the Air Traffic Management (ATM) Master Plan, focuses on many different aspects in order to solve the main problems of European air traffic management: Capacity, Cost efficiency, Operational efficiency, environment, Safety and Security all paired with higher digitalization and automation. [4][5]

A conceptual approach from 2001 by [6] which addressed the challenges of air traffic management of that time is now more relevant than ever: sectorless air traffic management, also known as Flight Centric Air Traffic Control (ATC). Over the past 25 years, the concept of sectorless air traffic control has gone through various stages of research and undergone constant changes in concept implementation, while the basic idea has always remained the same. The remarkable thing about this concept is its universal applicability, as it enables benefits in the areas of capacity, cost efficiency, operational efficiency and environment, while both safety and security remain unchanged compared to sectorized airspace. At the same time, the concept focuses on digitalization and automation and can be combined with many other state-of-the-art concept approaches, such as trajectory-based operations and dynamic airspace configuration, as well as various controller support tools. The concept therefore precisely addresses the objectives of the ATM masterplan. [4]

The specific aspect of the Flight Centric ATC (FCA) concept is the complete reorganization of the airspace. Instead of the conventional division of the en-route airspace within an area control center (ACC) into so-called sectors, which are usually controlled by a team of controllers consisting of executive and planner controller, in FCA the entire airspace is considered as a uniform area. [7] In this area, different controllers are responsible for controlling the aircraft, whereby it is always ensured that each aircraft is assigned to exactly one controller at any given point in time during its stay in the FCA airspace (Fig. 3). [8]

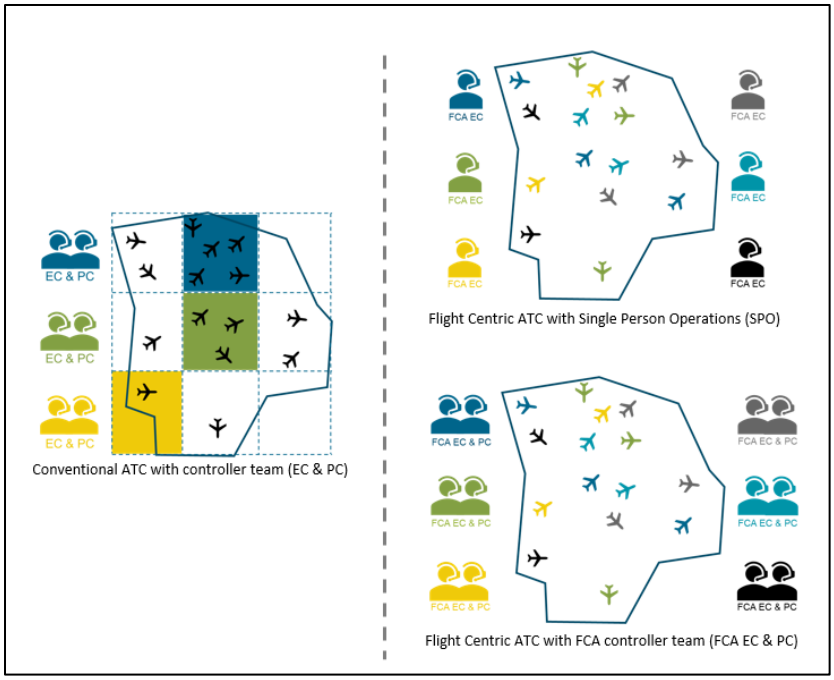


Fig. 3 Sectorized vs sectorless air traffic control [9]

This new type of distribution of aircraft to controllers, which is no longer fixed along static boundaries, offers the decisive advantage that every available controller can be optimally deployed without controllers being exposed to underload or overload due to the prevailing sector traffic density. Also, sector capacity no longer depends on the workload limit of the corresponding controller teams. [10] Such an improved, balanced, workload-based allocation of aircraft to controllers, which can be achieved through various types of allocation strategies using a human allocator or semi-automated to fully automated allocation centers, leads to two significant advantages [11][12]:

- Cost efficiency (controller productivity): Controllers in FCA airspace can be allocated flexibly and more effectively. If the volume of traffic remains the same compared to sectorized airspace, it can be controlled with fewer controllers.
- Airspace capacity: Conversely, due to the more effective allocation of controllers to aircraft, more aircraft can be controlled with the same number of controllers, while in the sectorized scenario no further increase in capacity can be achieved due to sector capacity limitations.

Over the past 25 years, the sectorless/Flight Centric ATC project has been continuously developed and refined. Various aspects regarding the controller team composition, the controller support tools, the allocation strategy, the controller radar human-machine interface and the degree of digitalization have been examined over the years. This thesis will first discuss the history of the concept (Chapter III) and, based on this, summarize the general conclusions of the various validation concepts (Chapter IV). Finally, Chapter V provides an outlook on the open research questions and the path forward to implementation.

III. History of research into Flight Centric ATC

The following chapter describes the research progress of the sectorless ATM/ Flight Centric ATC concept. After the concept was presented as a concept paper by [6] in 2001, the first real-time simulations in this area were carried out under the leadership of the German air navigation service provider DFS and the German Aerospace Centre (DLR) in the years 2008-2010 (Fig. 4). [13] This work was accompanied by a large number of publications by DLR, which resulted in a dissertation entitled ‘Feasibility analysis of sectorless and partially automated air traffic management’. [14]

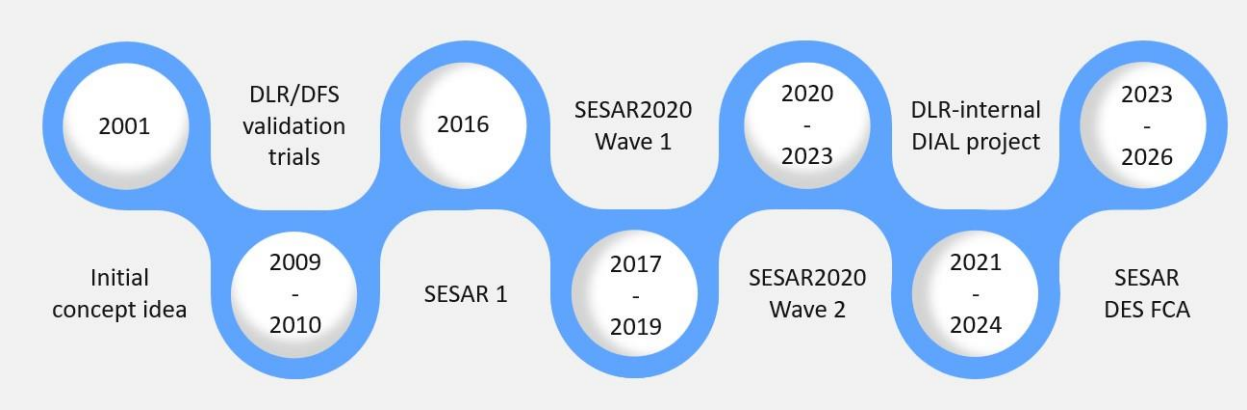


Fig. 4 Sectorless ATM/ Flight Centric ATC timeline

At international level, after an initial roadmap in the Single European Sky ATM Research Programme 1 (SESAR), the concept became known as Flight Centric ATC in the subsequent SESAR2020 programme and has now been seamlessly validated in the successive SESAR programmes (SESAR2020 Wave1 & Wave2, as well as SESAR DES) in collaboration of various project partners since 2017. [9][15][16][17] Parallel to this, the internal project DIAL and four master's theses have been carried out at the German Aerospace Centre. [18][19][20][21]

The following subchapters provide a more detailed insight into the respective research foci.

A. Initial concept ideas by Duong et al

In 2001 [6] introduced under the name of sectorless ATM a fundamentally new concept for Air Traffic Management which aimed to replace the previous sector-based approach. Instead of several successive sectors, the idea was to map a standardized, continuous flight path (trajectory) for each flight, which is monitored by a single controller from take-off to landing. This was intended to achieve two key improvements in particular:

1) End-to-end quality of service
    a. By eliminating multiple transfers of responsibility between different control centers and countries, the quality of service for the entire flight can increase significantly.
    b. One controller accompanies the flight from the departure to the arrival phase, which avoids frictional losses at sector boundaries, for example.
2) Continuity of service
    a. Even in areas with inadequate ground infrastructure (oceanic flights, remote regions in Africa, Asia or the Pacific), a continuous service can be provided as responsibility is no longer geographically limited.

In order to implement such a concept, [6] identified the following areas that need to be analyzed from an operational, technological, & human factor as well as economic and regulatory perspective:

1) Operational view
    a. Controller Work Position (CWP): What new requirements arise when switching from sector-based radar to trajectory-based management? How should the radar HMI be designed in order to be able to map both a local traffic overview (e.g. the next 40 minutes) and the entire flight route to the destination?
    b. Coordination between controllers: How is cooperation organized when several flights are involved in conflict situations and different controllers are affected?
    c. Handling of high-density areas: What consequences does the new architecture have on the route network, airspace structure and Air Traffic Flow Management (ATFM)?
    d. Human resources: What personnel challenges arise in a sectorless environment (e.g. in duty scheduling when a controller accompanies individual flights or routes on a long-term basis)?
    e. Transition phase and system failures: How can the transition from the previous system be organized, and what fallback strategies are necessary in the event of a failure of central servers or distributed computers?

f. Military flights: In what form will military flights be integrated? Are there special controllers that monitor purely military flights from A to Z, or are civil and military flights to be handled by the same "civil" controller?

2) Technological and Human Factors perspective
   a. System architecture: How can a globally distributed, standardized system be implemented that makes flight trajectories available to every controller in real time?
   b. Conflict coordination: What procedures are required to detect and coordinate conflicts between multiple aircraft? This involves an investigation into how conflict scenarios can be optimized and existing distractions minimized from the perspective of an individual controller.
3) Economical and Regulatory perspective
   a. Economic effects: What are the cost and benefit effects of switching to sectorless ATM?
   b. Organizational consequences: How will national and international responsibilities change if the airspace is no longer split into geographical sectors?
   c. Competition law issues: What regulatory adjustments are required to ensure fair competition between airlines, service providers and supervisory authorities?

The authors interpret their concept as 'revolutionary' and not just evolutionary and see it as a promising alternative for the future to cope with constantly increasing traffic volumes without burdening air traffic with rigid regulations and at the same time retaining controllers as a central factor for safety. Two possible role changes are discussed here:

1) Controller as airline's own flight manager: Instead of working for a specific control centre, a controller could act as an airline employee who monitors global flight routes and thus enables holistic planning within the airline.
2) Controller as dynamic flow manager: If many flights are combined in 'convoys' or route-based groups, a controller could no longer be responsible for just two aircraft, but for entire traffic flows - a role that would be closer to today's flow management, but organized in real time and decentralized.

With their study the authors pave the way towards a sectorless ATM with their initial concept study already in 2001. At the same time, however, they also show the difficulty of changing the existing sectorized concept and highlight the many open questions ('domains of investigation') that such a concept change entails. Nevertheless, initial simulations and prototypes suggest that the coordination problem in conflict situations is manageable with suitable optimization procedures and that the CWP concepts (dual displays, etc.) are promising. The authors assume that further detailed investigations, practical trials and step-by-step transition strategies will help to validate and further develop the sectorless paradigm in practice.

B. Initial validation activities by DLR and DFS

In 2010, real-time simulations were conducted at the DLR Institute of Flight Guidance in Braunschweig using the TrafficSim air-traffic simulator. Between 29 November and 9 December, validation trials involved eight air traffic controllers from Deutsche Flugsicherung. Scenario inputs were based on radar recordings provided by DFS from 10 September 2008, an exceptionally high-traffic day. Rather than artificially creating conflicts, actual traffic patterns were extracted and condensed into five distinct 30-minute scenarios to ensure a high density of potential conflict situations. The training scenario primarily featured flows between west and southeast, the second focused on south-to-north and west-to-southeast movements, the third encompassed all directional flows, and the fourth and fifth presented, for one controller, closely spaced west-to-south traffic and, for the other, a mix of all traffic types. To simplify the simulations, neither meteorological conditions nor temporary or permanent airspace restrictions were included.

The human-machine interface was designed to accommodate the spatially disparate positions of controlled aircraft by dividing the display into eight areas: six radar windows, one conflict-alert field and one overall situational overview. Each radar window employed uniform symbology and layout, presenting fundamental flight data such as position, altitude, speed, track history and flight-plan details with the currently controlled aircraft highlighted in magenta. Controllers could zoom each window independently, and, upon detection of a potential conflict, an automated warning message was issued. A minimum separation tool was integrated to calculate minimum separation distances between two aircraft, either vector-based or trajectory-based.

Four hypotheses guided the study [22]:

1) It is possible to manage six aircraft in one large sector by one ATCO.

2) Six radar tiles compiled on one single HMI work sufficiently according to the ATCOs; geographical proximity is not necessary to handle the traffic.
3) Given the new sectorless concept, an additional conflict detection tool is essential.
4) In addition to the conflict detection, resolution advisory tools are desirable.

Simulation results were largely positive: most participants regarded the sectorless concept as viable for future operations, while unanimously emphasizing the need for further development and research. Only one controller expressed fundamental opposition to both the concept and the supporting tools. Under normal traffic conditions, monitoring six aircraft simultaneously proved feasible; however, increased complexity in traffic flows reduced the controller's ability to allocate attention equally among all aircraft. Ergonomic constraints and display-size limitations further restricted the number of simultaneously viewable radar windows, as continuous monitoring without head movement was required. The trials underscored the critical importance of an automated 20-minute conflict-warning system: in a sectorless concept, the controller assumes both planning and execution roles and thus relies on long-range alerts that cannot be provided manually due to the inherent complexity and limited display scope. Future research should integrate realistic weather scenarios and airspace restrictions, evaluate the concept below flight level 350, and refine the developed support tools. [22][23]

C. Investigations as part of SESAR2020 Wave 1 and Wave 2 from 2017 to 2023

As part of the SESAR2020 Wave 1 project PJ.10 PROSA, the Flight Centric ATC concept was validated in the PJ.10-01b solution from 2017 to 2019 and achieved Technical Readiness Levels 2 and 4. A total of four validation exercises (VALP 001-004) were conducted, covering two different OI steps: application in a non-geographically restricted airspace with medium complexity (CM-0200-B) and application in a scenario with high to very high complexity (CM-0200-C). At the same time, the two enablers HUM 017 (Human Performance) and ER ATC 100 (Enhanced Resolution ATC) were included in the studies. The exercises focused on evaluating various allocation strategies - from dynamic, complexity-based approaches to static, flow-based procedures - new role and task allocations and the adaptation of the controller working position. In addition, procedures for coordination and communication between the involved stakeholders were analyzed. [24]

The first real-time simulation (VALP-001) focused on the feasibility of a complexity-based, dynamic aircraft allocation in a medium to high traffic volume in the airspace of the Budapest Area Control Centre above FL 325. The real-time simulation using BADA for traffic simulation served to determine ENV (FEFF) and PRD. Questionnaires were conducted to determine the controller workload so that CEF2 (ATCO Productivity) and CAP could be derived. This validation campaign was performed by the three partners: DLR, HungaroControl and Frequentis. [25] [26] In the second exercise (VALP-002), ENAIRE, INDRA, CRIDA and INECO combined real-time and fast-time simulations to evaluate roles, responsibilities and operational procedures for conflict management within the Flight Centric Area and with neighboring sectors in the Madrid ACC airspace (GND to Unlimited, excluding Madrid TMA and airports).

The third real-time simulation (VALP-003), carried out by DFS, analyzed the operational advantages of flow-based traffic management in an environment of medium complexity in northern Germany with connection to approach control, particularly with regard to cost and personnel efficiency as well as controller confidence and workload. Finally, VALP-004, organized by ANS CR, Eurocontrol and AgentFlyTechnologies, conducted a model-based fast-time simulation for the entire Prague ACC airspace across all altitudes to quantify the impact of different automation and allocation scenarios on capacity, cost, human performance and safety and to determine the lower bound for the application of FCA. [27]

At the end of the PJ.10-01b activities, it was shown that the Flight Centric ATC concept is basically operationally feasible. It was possible to define role and task structures that enable both a flow-based and a complexity-based traffic management approach in the Flight Centric airspace. Automated support for conflict detection and resolution proved to be indispensable, as the achievable performance gain correlates directly with the degree of automation. At the same time, a fundamental change in the perception of the situational awareness is required: surveillance tasks in particular must be largely or fully automated in order to enable controllers to perceive the situation in a new way. However, highly dynamic airspace configurations are outside the SESAR 2020 time horizon, while conventional adaptations such as sector swaps or day/night networks are already feasible. Regulatory changes to airspace organization and classification are not necessary, but targeted adjustments to the training and further training regulations for ATCOs are. [28]

To further refine the concept, the project team recommended a more dynamic filtering algorithm, to optimize the user-friendliness of the HMI and to expand the wide area communication system in such a way that it automatically switches to the data radio frequency of an aircraft as soon as it takes over. Demands for clearly defined requirements for digital voice transmission should be developed at workshop level. In addition, there is a need for a precise definition

of situational awareness in the Flight Centric context as well as improved conflict management recommendations - especially to avoid multiple conflict situations. Finally, future exercises should also cover non-nominal scenarios and the allocation of aircraft to controllers should be further optimized in order to sustainably increase the efficiency and safety of the overall system. [28]

As part of the PJ.10-W2-73 FCA project to further refine the Flight Centric ATC concept, five validation exercises were originally planned, of which only three could be carried out due to the COVID-19 pandemic. These reduced number of exercises failed to fully cover all conceptual elements, meaning that only an advanced, but not final, technical readiness level of TRL6 was achieved. [29]

The exercises carried out built on the results of the preliminary project PJ.10-01b and examined various allocation strategies, including complexity-based (dynamic) and flow-based (static) allocations, different role assignments and adjustments to the working positions of air traffic controllers under normal, abnormal and degraded-mode conditions. In addition, communication and coordination processes were analyzed. [30]

The first exercise (VALP-001) used a low-fidelity system to simulate the large-scale horizontal expansion of FCA in the en-route area using workload models and dynamic airspace management functions. It covered the entire ECAC airspace, divided into eight virtual airspace blocks, and also took into account operations in highly automated, small-scale airspaces with customized role profiles. The second exercise (VALP-002) focused on the airspace above FL325 within the Budapest ACC, an existing free-route area. Here, five sectors were merged into one FCA area and analyzed in real-time simulations - using BADA data - with regard to fuel efficiency, predictability, human performance and safety. In addition, workshops were held and the Frequentis WAC system was used to validate communication when implementing the FCA concept. In addition to normal scenarios, scenarios under abnormal and degraded conditions were validated. [7] The third exercise (VALP-005) evaluated the operational feasibility of the FCA concept in the upper airspace of Madrid ACC. A static allocation scenario was analyzed in which traffic flows were allocated to individual controller teams. Additional functions for conflict detection and resolution were integrated, in particular for dealing with imminent conflicts. The main target variables were cost and fuel efficiency as well as predictability, whereby safety aspects and human performance were not allowed to have a negative effect. [31]

The analysis showed that the operational feasibility of the FCA concept is closely linked to the volume of traffic and the complexity of the airspace under consideration. Single-person operation under Flight Centric ATC was found to be feasible under normal and abnormal conditions in dense traffic scenarios. Fully automated allocations using complexity and workload predictions were also found to be feasible. While transition procedures between conventional and FCA-based operating modes were considered practicable in principle, there was a significant decrease in situational awareness among controllers, although the number of conflicts did not change. [30]

The outcome of the project was, that potential future research should focus on the integration of artificial intelligence for fully automated allocation, the further development of automation levels beyond the current status and the clarification of liability issues in connection with highly automated systems and multiple control instances. There is also a need for in-depth analyses of the distribution of roles within the control team - particularly with regard to supervisor and network management functions - as well as civil-military coordination and operational procedures during the transition between conventional and FCA-controlled airspace surveillance. [30]

D. Activities at the German Aerospace Center between 2020 and 2024

In parallel to the activities within the framework of SESAR2020 Wave1/Wave2, additional activities were carried out at the German Aerospace Centre to validate the FCA concept. These included four master's theses and the internal DIAL project, which dealt with individualized and automated air traffic.

1. Master Thesis on a pattern analysis of ECAC-wide Flight Centric ATC scenarios using a self-developed analysis tool

As part of this master thesis, [18] developed an analysis tool to identify so called “corridors”, flight trajectories along which multiple flights share similar routes and to serve as the basis for a corridor-based alocation strategy within the Flight Centric ATC concept. The developed tool combines a clustering algorithm with an allocation procedure that ensures that each flight is allocated to exactly one cluster. As reference scenario, the tool was applied to scheduled flight trajectories as flown on June 28, 2019 within the ECAC region.

Using the same schedule data, a decentralized flight plan was then generated. For every airline operating a hub-and-spoke network, the actual origin / destination passenger flows were calculated; wherever passenger volumes exceeded a threshold, a direct connection was established. Flight tracks were simulated as great-circle routes between the respective airports, without regard for internal ECAC national boundaries, restricted areas, or existing airspace corridors.

Applying the analysis tool to the original flight plan demonstrated that the clustering algorithm forms a very solid foundation for defining corridors. However, the current allocation method based on each flight's longest overlapping segment needs revision. Instead, flights that repeatedly cluster together should be grouped. In addition, an automated procedure for detecting corridor intersection points must be integrated into the tool.
Overall, the original June 28, 2019 schedule clearly contains identifiable corridors, including segments where they intersect. Precise metrics on corridor number, length, and composition will become available once the above refinements are implemented, at which point corridors spanning longer segments can be defined and incorporated into the Flight Centric ATC's controller-assignment strategy.

In contrast, the decentralized flight plan did not yet yield meaningful clusters capable of supporting corridor development. It remains to be determined whether this is due to limitations of the analysis tool when applied to the decentralized plan or simply reflective of an absence of natural corridors in that system. Both the tool and the decentralized plan must therefore be revisited and, if necessary, augmented with additional data before a definitive conclusion can be drawn.

2. Master Thesis on the development and validation of a workload model for Flight Centric ATC including the change in controller tasks and consideration of the influencing factors of partial automation and clustering

As part of this Master Thesis, [19] developed, calibrated and validated a comprehensive workload model for a Flight Centric ATC system. Based on the task analysis of conventional sectorized airspace - based on Eurocontrol's Pessimistic Sector Capacity Estimation [32] and the paper on "The Sector Capacity Evaluation Considering the Controller's Workloads" by [33] - the approach of [34] was selected and adapted to the special features of sectorless flight operations. The total workload of a controller is calculated on the basis of the sub-workloads for monitoring (WL_{MON}), conflict detection and resolution (WL_{CDR}), coordination and communication (WL_{COR}), and aircraft maneuvers (WL_{ACM}). Each sub-workload is determined by the number of corresponding subtasks ($N_{MON,CDR,COR,ACM}$), the average duration per subtask ($T_{MON,CDR,COR,ACM}$) and a subtask weighting ($C_{CDR,COR,ACM}$). Finally, each sub-workload is also weighted in relation to the total workload ($\omega_{MON,CDR,COR,ACM}$) (1).

$$WL = \omega_{MON} \cdot (N_{MON} \cdot T_{MON}) + \omega_{CDR} \sum_{k=1}^{5} \left(N_{CDR_k} \cdot C_{CDR_k} \cdot T_{CDR_k}\right) + \omega_{COR} \sum_{l=1}^{4} (N_{COR_l} \cdot C_{COR_l} \cdot T_{COR_l}) + \omega_{ACM} \sum_{h=1}^{4} (N_{ACM_h} \cdot C_{ACM_h} \cdot T_{ACM_h}) \tag{1}$$

Based on this, [19] developed a universal workload formula for the Flight Centric ATC concept. In addition to the sub-workloads for monitoring (3), conflict detection and resolution (4), coordination and communication (5), and aircraft maneuvers (7), which were individually adapted for FCA, [19] added an additional sub-workload for the Top of Climb (WL_{TOC}) (6) to the total workload (2).

$$WL = WL_{MON} + WL_{CDR} + WL_{CON} + WL_{TOC} + WL_{ACM} \tag{2}$$

$$WL_{Mon} = \sum_{t=0}^{t_{max}} WL_{MON_t} \tag{3}$$

$$WL_{CDR} = \omega_{CDR,MON} \cdot \left(N_{CDR,MON} \cdot T_{CDR,MON}\right) + \omega_{CDR,DET} \cdot (N_{CDR,DET} \cdot T_{CDR,DET}) + \omega_{CDR,RES} \sum_{k=1}^{6} (N_{CDR,RES_k} \cdot C_{CDR,RES_k} \cdot T_{CDR,RES_k}) \tag{4}$$

$$WL_{CON} = \omega_{CON} \sum_{l=1}^{2} (N_{CON_l} \cdot C_{CON_l} \cdot T_{CON_l}) \tag{5}$$

$$WL_{TOC} = \omega_{TOC} \sum_{h=1}^{4} (N_{ACM_h} \cdot C_{ACM_h} \cdot T_{ACM_h}) \tag{6}$$

$$WL_{ACM} = \omega_{ACM} \sum_{h=1}^{4} (N_{ACM_h} \cdot C_{ACM_h} \cdot T_{ACM_h}) \tag{7}$$

For calibration purposes, human-in-the-loop simulations were carried out in which task times and weighting factors (especially for conflict monitoring/detection) were recorded and fed into the model. A second simulation campaign revealed the need for adjustments: Conflict-related tasks are continuously active and therefore need to be modelled differently. The implementation was carried out in the simulation environment, whereby various traffic scenarios (variations in flight volume and allocation principle) were simulated.
Two methods were used for validation:

1) Direct validation: comparison of the model workload estimates with subjective ISA values and objective LF/HF ratio of the controllers. The correlation between model output and ISA ratings confirms the basic quality of the model.
2) Indirect validation: Use of the workload model as an allocation strategy within the simulation. This showed that an improved load distribution is achieved, particularly with very high traffic density.

In addition, the influence of semi-automated communication (data link) was investigated; no significant workload advantages could be demonstrated in this case. Initial approaches to expansion using cluster analyses were outlined in order to take corridors and recurring flight groups into account in the allocation.

In conclusion, the authors emphasize that the model is a simplified representation of real working conditions and should be further refined - for example, through more precise weighting factors based on experienced controllers or through comparisons with alternative allocation strategies. Furthermore, one of the next research steps would be the transfer and re-validation of the model in a European-wide simulation environment.

3. Master Thesis on the development of a strategy for the allocation of aircraft to controllers in a Flight Centric ATM concept

A static, automatic allocation strategy for Flight Centric ATC was developed by [20] that combines the benefits of flow-, cluster- and conflict-based approaches with a conventional workload-based method in order to reduce the workload of air traffic controllers. A literature analysis revealed that pure controller time savings through specific allocations are limited. Rather, significant relief results from improved situational awareness and routine-building that facilitates mental modelling. Three static concepts were identified as promising:

1) Flow-based allocation: Aircraft following the same traffic flow have similar entry and exit points and routes. This shortens identification in the system, facilitates data synchronization and reduces the mental effort required for maneuvers in weather or emergency situations.
2) Cluster-based allocation: As a special case of the flow-based approach, it only groups aircraft together with similar routes and entry times that are close to each other. This increases the probability of identical situations and maneuvers, which further increases the relief effect compared to pure flows.
3) Conflict-based allocation: Aircraft that could predictably come into conflict are allocated to the same controller.

As these three categories only cover a portion of all flights, a fourth level supplements the assignment:

4) Workload-based allocation: All other flights are allocated to the controller with the lowest current workload, based on a workload calculation model.

Within the scope of this work, each individual strategy as well as a combined allocation strategy was analyzed. With the combined strategy, the system checks when an aircraft enters the FCA airspace segment, the following in sequence:

1) Cluster: Same or neighboring entry/exit waypoint, entry time within Δt_{max}, and controller load under $counter_{max}$.
2) Flow: Assignment to predefined traffic flows (based on highly frequented waypoints).

3) Conflict: Predicted conflict with already assigned flights - assignment only if controller still has capacity.
4) Load balancing: Assignment to current lightest flights if no other rule applies.

The prerequisite is a flight plan submitted at least 30 minutes before departure to enable conflict forecasts. However, the prediction quality depends on the route stability during the flight.

The evaluation of the simulations showed that the combined allocation strategy could not significantly reduce the overall fatigue of the air traffic controllers. However, the analysis of individual components revealed promising effects: For example, the flow-based approach led to significantly lower calibrated heart rates compared to the pure workload-based allocation, indicating reduced physiological stress. Furthermore, it was found that the time window Δt_{max}, which defines the maximum permissible difference in entry times in the cluster logic, is a significant lever: the effectiveness of clustering could be further increased by optimizing this parameter. Finally, the limited size of the simulated airspace proved to be a further influencing factor: in the relatively small test areas, it was easy for the controllers to fully monitor even scattered aircraft; in larger areas, however, this advantage is likely to diminish and depend more on the design of the user interface.

4. Master Thesis on the design of a controller display for use in an ECAC-wide flight-centric airspace

Within the scope of this master's thesis, [21] further developed a Flight Centric Aircraft (FCA) air traffic controller display in such a way that in the future it can be used in the entire ECAC area without losing clarity or restricting the situational awareness of the controllers. The display already developed by DLR for the comparatively small Hungarian airspace serves as a starting point. The boundary conditions and objectives for ECAC-wide use are defined and it is discussed why a direct depiction of the entire airspace on a 43-inch radar screen is not practicable either geographically or in terms of information presentation. For this reason, the concept is initially transferred to Italy as an exemplary region of medium size. Four main elements were combined for the new HMI design:

1) Map, for precise geographical positioning and as a basis for route optimization and conflict detection
2) Overview map, as a navigation aid and as a frame that shows which section of the map is currently displayed
3) Tile, for detailed views per aircraft, including monitoring, handover, route guidance and conflict resolution
4) Timeline, which displays time-critical messages (e.g. acceptance, delivery, conflict warning, etc.) on the screen.

These elements are designed according to ergonomic and normative specifications (e.g. Ecological Interface Design, DIN EN ISO 9241) as well as design guidelines for colors and visual factors in order to ensure intuitive perception and long-term retention of situational awareness. The evaluation was carried out using a simulation game and questionnaires with technical experts and pseudo pilots. All participants confirmed the basic usability of the display; they saw potential for improvement particularly in the reduction of system complexity and in the stronger linking of elements as well as in optimized attention guidance. The overview map was considered particularly useful in the case of “aircraft monitoring”, but showed some redundancy with other elements. The next step proposed is to analyze the system in real-time simulations and to investigate the geographical conditions and possible use of a conventional controller team. In the long term, it should be possible to transfer the concept to other ECAC countries (particularly those with a large west-east spread) in order to realize a uniform introduction and use of Flight Centric ATC displays in Europe.

5. DIAL Project

In the project ‘Der individualisierte und automatisierte Luftverkehr’ (DIAL), the influence of automation on air traffic management (ATM) was analyzed. Firstly, a fast-time simulation (FTS) was carried out in which potential savings in fuel consumption, flight distance and flight time were determined through the use of the L-Band Digital Aeronautical Communications System (LDACS). A human-in-the-loop simulation was then carried out in real time with internal DLR experts and active air traffic controllers. This real-time simulation had two main objectives: Firstly, the efficiency gains achieved in the FTS - based on defined validation objectives - were to be verified in a real situation. Secondly, the aim was to assess the effects of various air-ground communication technologies on the controllers' workload. For this purpose, aircraft were divided into three categories according to their equipment: those equipped exclusively with radiotelephony (R/T), those with controller-pilot data communication (CPDLC, e.g. VDL Mode 2) and those with additional LDACS, with both simulations taking place within the framework of the Flight Centric Air Traffic Control (FCA) concept. Previous SESAR studies had shown that FCA has the potential to reduce fuel consumption and deploy personnel more efficiently - effects that become more important as the size of the application

area increases. SESAR 2020 solutions PJ.10-01b and PJ.10-W2-73 already demonstrated the feasibility of FCA across multiple sectors of an Area Control Centre (ACC), and a current SESAR 3 project adapted the concept to multiple ACCs. DIAL continues this development by virtually merging the airspaces of all ECAC member states as well as the Flight Information Regions Shanwick, Santa Maria and parts of Bodo into a single FCA-controlled airspace. [35]

The project demonstrated a marked reduction in fuel consumption, flight times, and total distance flown. [36] Increasing the level of automation in conjunction with new airborne communication technologies led to a decrease in controller workload. However, this reduced workload had an adverse effect on controllers' self-reported engagement, as diminished vigilance and boredom set in—an effect that was especially pronounced when controllers handled only LDACS-equipped aircraft under the automated allocation scheme. Another notable finding was that reported workload levels in the CPDLC and R/T scenarios were nearly identical. It should be emphasized, though, that the expected advantages of CPDLC over R/T did not materialize in our experimental setup, due to the lack of background noise and radio congestion, the simplicity of the clearances, and the flawless reception conditions. [37]

E. Current investigations as part of the SESAR DES FCA project

Since June 2023, the Flight Centric ATC concept has been undergoing further development as part of the DES HE SESAR FCA project, the successor project to the SESAR 2020 PJ.10-W2-73 FCA solution. The aim of the project is to achieve TRL6 for a low and medium complexity airspace by the planned project completion in May 2026 and to close the remaining gaps of its predecessor project by then. To this end, seven research and innovation needs related to allocation, roles & responsibilities, conflict management, human-machine interface, conflict detection and resolution, communication and civil-military interaction must be fulfilled, as shown in Fig. 5. [38]

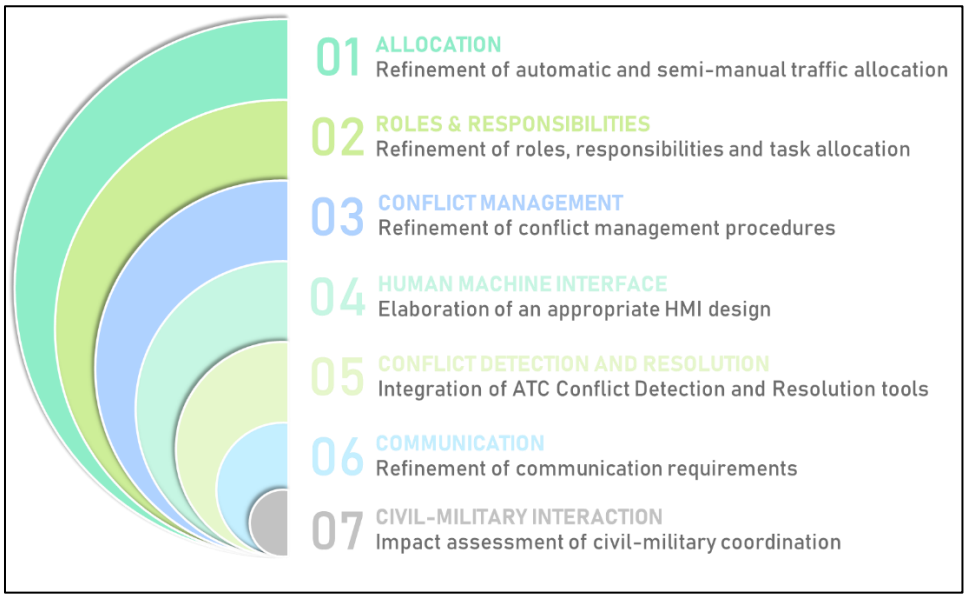


Fig. 5 SESAR DES FCA R&I needs [39]

The aforementioned key R&I needs were converted into the below listed normal, abnormal and degraded-mode use cases according to [40] and validated in two real-time simulations

1) Traffic allocation in Flight Centric ATC
2) Conflict Detection and Resolution in Flight Centric ATC
3) Ground - ground coordination (Flight Centric ATC – non-Flight Centric ATC)
4) Demand and capacity balancing (DCB) in Flight Centric ATC
5) Communication Failure in Flight Centric ATC
6) Adverse Meteorological Conditions in Flight Centric ATC
7) STCA, aircraft under control of different ATCOs
8) Military Flight Transiting Flight Centric ATC airspace
9) FCA position opening/closure

Exercise 1: In November 2024, DLR and UkSATSE conducted a real-time simulation (RTS) to investigate the Flight Centric ATC concept in Ukrainian airspace above FL 275. To this end, 21 sectors previously managed by four area control centres were combined into a single FCA airspace (Fig. 6). The simulation ran on DLR's TrafficSim platform and used traffic data from 28 June 2019 as well as BADA data for realistic flight performance models. Ten Ukrainian air traffic controllers worked individually and were supported by FCA-specific tools such as measurement, filtering and probing functions as well as conflict detection and resolution. The validated medium complexity scenarios of this simulation campaign included nominal non-nominal (e.g. adverse weather) and degraded-mode (e.g. conflict resolution failure) conditions. [40]

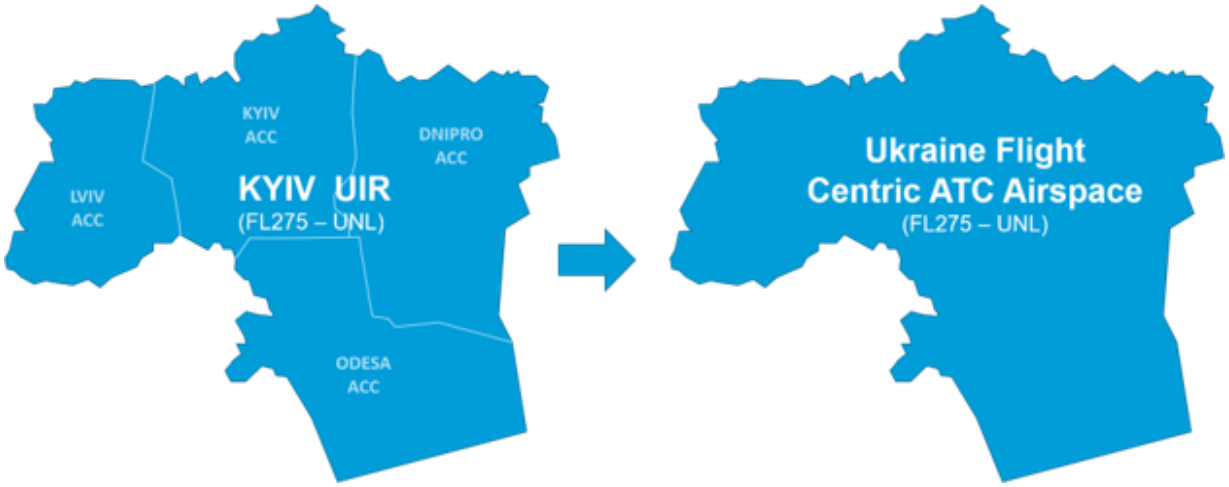


Fig. 6 Ukrainian airspace – sectored vs. Flight Centric ATC [41]

Under the leadership of ENAIRE, Exercise 002 was designed as a high-fidelity real-time simulation to evaluate the operational feasibility and potential benefits of the Flight Centric ATC concept in Spanish upper airspace. In the validated scenario, an FCA area was defined in the upper part of Madrid ACC above FL 365. Depending on traffic volume and complexity, between one and three air traffic controllers were assigned to this area. The Airstreams procedure was used to manage high traffic densities: This involves combining aircraft movements in structured flows in order to simplify control tasks in the FCA area and reduce the communication burden on controllers. Coordination within these streams was the responsibility of a newly introduced type of air traffic controller, the so-called Airstream Manager. The validation phase took place from 24 March to 4 April 2025 at the CRIDA Experimental Centre in Madrid. During this period, up to eleven ENAIRE air traffic controllers at different functional levels took part in the simulation runs in order to gain a comprehensive insight into the operational processes of an FCA area. Based on the results obtained, INECO conducted a full safety assessment to finally verify the safety performance of the concept. All simulations were carried out on the pre-operational ATC platform iTEC. INDRA extended both the system environment and the human-machine interface (HMI) with specific FCA functionalities, in particular advanced modules for conflict detection and resolution. In addition, the PUZZLE prototype developed by CRIDA supported the air traffic controllers in traffic assignment by predicting and analyzing the complexity of individual control tasks. [40]

In addition to these real-time simulations, a fast-time simulation is being carried out as part of this project to support the cost-benefit analysis in particular, focusing on the expected benefits in terms of cost efficiency and fuel efficiency for the entire ECAC airspace. [41]

At the present time, one year before the end of the project and after both real-time simulations have already been successfully carried out, it seems that the desired target of achieving TRL 6 can be realized as planned. This would close the circle 25 years after the first publication of the concept idea, at least for a national implementation in a low to medium complex airspace. The following Chapter IV shows the results achieved over the years, which, however, makes it clear that there is a need for further research on the subject of FCA in the coming years and that there are still open research questions which need to be addressed (Chapter V).

IV.Conclusion from research up to now

The following section summarizes the main conclusions of the FCA concept, divided into different sub-areas for allocation (A), team composition (B), the supervisor role (C), training and licensing (D) human-machine interface (E), air-ground communication (F), as well as performance & cost-benefit analysis (F). In this context, the research of the last 25 years and its continuous evolution is taken into account, so that the latest state of research is presented in each of these sub-chapters. Open research questions will be initially presented and further elaborated in Chapter V.

A. Allocation

Allocation is a very simple topic in conventional sectorization. Here, the allocation of aircraft to the responsible controller is already predetermined by the sector structure. This means that every aircraft entering a specific sector is automatically allocated to the controller in charge of that sector.

However, this type of allocation is no longer possible when considering the airspace as a uniform area in which several controllers share control responsibility. Instead, allocation strategies are required that distribute the aircraft among the controllers.

A number of different approaches to how an allocation can be set up have been described and validated in the context of Flight Centric ATC. A distinction is first made between the actors involved in the allocation [42]:
Automatic allocation involves a so-called "allocation center" performing all steps completely independently. All allocation rules are predefined, and there is no manual review of individual or all allocations. While this saves human resources, it poses the risk that factors such as the individual professional experience of a human controller, which is not known by the system, may not be considered. In manual allocation, on the other hand, a human allocates aircraft to air traffic controllers. This task is performed by the new role of the "allocator" who makes decisions based on his personal expertise. Unlike the automatic method, this approach allows special individual cases to be considered more effectively. However, this method reaches its limits when traffic is heavy or airspace is complex, and is therefore only suitable for manageable areas with low traffic density.

Semi-manual allocation combines both approaches and offers three options for interaction between humans and the system:

1) The allocator uses the system as a support tool and allocates flights manually,
2) The allocation performed by the system can be override by the human allocator or.
3) Parameters of the automatic allocation can be adjusted by the human.

In this way, the semi-manual approach combines the strengths of both approaches and can, in principle, be used for airspaces of any size and complexity.

Furthermore, the question of which parameters are considered in the actual allocation is crucial. A wide range of approaches (e.g. workload-based, flow-based, conflict-based, aircraft equipment-based allocation) are possible, which have been analyzed in detail in various studies. [43]

1. Workload-based allocation

A relatively simple workload-based approach was used in the DLR exercises within the framework of the SESAR2020 solutions PJ.10-01b and PJ.10-W2-73 FCA. In both cases, a pure allocation based on workload was carried out, which was performed fully automatically by an allocation center without supervision by a human. In general, the controllers considered the aircraft allocation strategy to be acceptable. However, it was suggested that aircraft already in conflict should also be allocated to the same controller at the time of allocation. This would eliminate the need for coordination between different controllers and improve situational awareness. However, this approach can only be implemented in relatively small FCA airspaces, as it is not possible to reliably predict conflicts in large sectors at the time of allocation. It should also be noted that such an approach actively circumvents the four-eyes principle if a single person operator (SPO) is used in the FCA concept. It is therefore recommended that this addition is only be used with conventional air traffic control teams or other team composition. [7][25][30]

In addition to this relatively simple workload-based allocation, [19] developed a more detailed workload formula for determining aircraft-based workload as part of a master's thesis at DLR and TU Dresden. This formula was validated in corresponding real-time simulations and demonstrated a new, more reliable method for performing the allocation. However, due to the COVID-19 situation at this time, the analyzed workload formula had to be limited somewhat (e.g. with regard to communication between air traffic controllers). [44] Based on this first pure Flight Centric ATC-related workload calculation formula, [10] developed a highly detailed formula (8) that not only included additional workload components, such as handling the HMI (WL_{HMI}), the top of descent (WL_{TOD}), communication

and coordination between controllers (WL_{COR}), reallocation (WL_{REA}), and extended ATC planner tasks (WL_{EAP}), but also considers the corresponding level of on-board communication equipment.

$$WL = WL_{MON} + WL_{HMI} + WL_{CDR} + WL_{TOC} + WL_{TOD} + WL_{CON} + WL_{ACM} + WL_{COR} + WL_{REA} + WL_{EAP} \quad (8)$$

It was shown that this advanced formula achieved better workload distribution than [19]. However, it must always be considered that many components of the workload are unpredictable and that the actual workload of an aircraft therefore differs from the predicted workload over time.

2. Aircraft equipment-based allocation

In an aircraft equipment-based allocation, aircraft are allocated to controllers based on the primary communications equipment. The basic idea here is that it is more straightforward for air traffic controllers to control aircraft with only one specific level of equipment than to have aircraft with different levels of communication equipment under their control at the same time. Based on this assumption, a corresponding examination was carried out in the DLR internal DIAL project. In the corresponding real-time simulation, aircraft with three different levels of communication equipment were used: radiotelephony, CPDLC services VDL Mode 2 (VHF datalink) and LDACS (L-band Digital Aeronautical Communications System). The analysis then compared two different allocation strategies: a purely workload-based allocation and an allocation based on aircraft equipment, in which the type of communication technology used was included as an additional parameter in the allocation decision. When allocations were made based on onboard equipment, the data showed that controlling aircraft equipped exclusively with LDACS required less effort than controlling aircraft with voice or CPDLC only. However, no clear advantages were found in terms of workload between pure workload-based allocation and allocation that also takes on-board equipment into account. The feedback does indicate, however, that the simultaneous management of aircraft with different levels of communication equipment can potentially compromise safety. [36]

3. Flow-, Cluster- and Conflict-based allocation

Flow-based allocation describes the assignment of aircraft to air traffic controllers purely on the basis of existing flows or based on the inbound heading into the corresponding FCA airspace. [20][30] Validations conducted as part of the Spanish exercise in PJ.10-W2-73 FCA project showed that the workload of air traffic controllers in the case under consideration can be considered generally acceptable. There were no significant imbalances between the various FCA positions, and the automatic allocation of traffic based on the heading was considered satisfactory. The static allocation strategy is also assessed as operationally feasible. [30] At the same time, however, it should be noted that this type of allocation reaches its limits in larger airspaces or when aircraft are very unevenly distributed across the traffic flows. [43]

Cluster-based allocation has conceptual parallels with traffic flow-based allocation. Unlike traffic flow-based allocation, which allocates aircraft solely on the basis of their traffic flow without taking into account their specific position within that flow, the cluster-based allocation method also takes the time aspect into account. Only those aircraft that are not only in the same traffic flow but also fly through it at approximately the same time are allocated to a single controller. This approach makes it possible for one controller to take charge of one or more such clusters. Allocating several aircraft operating in close proximity to each other to the same controller over a longer period of time leads to increased situational awareness of the allocated units. This is because the surrounding traffic situation is largely homogeneous for all aircraft within a cluster. In addition, the necessary interactions between air traffic controllers and aircraft, for example in the event of potential conflict situations, are often very similar, which reduces the air traffic controllers workload. As a result, air traffic controllers can monitor and control a larger number of aircraft efficiently using this procedure than with random allocation. [43] However, analyses of this allocation strategy showed that, depending on the duration of the cluster, relatively few aircraft can be grouped together in a cluster, particularly in continental Europe. [18] Furthermore, an initial study did not identify any clear advantage in terms of the controller's workload. [20] Accordingly, this approach cannot yet be considered mature enough to be used as an actual allocation strategy.

In conflict-based flight allocation, aircraft that are likely to be involved in the same actual or potential conflict are allocated to the same air traffic controller. The advantage of this method is that the controller responsible can solve conflicts more flexibly and strategically than if the aircraft involved were allocated to different controllers. This is particularly important when conflict resolution requires changes to the flight trajectories of several parties involved.

In such cases, the controller can issue the necessary maneuvers directly without having to consult other controllers first. However, a key problem with this allocation strategy is that it is based on predictions, which become increasingly inaccurate over longer planning horizons due to various uncertainties. Furthermore, when using a single person operator, this allocation strategy abandons the 4-eyes principle, which is considered critical by safety experts. [20][26]

Based on the different outcomes of the above-mentioned studies, [11] has defined eleven high-level requirements that should be considered when implementing an allocation center:

1) REQ-OPS-01: The Allocation Center, along with its individual components, shall be usable independently of the Flight Centric ATC airspace under consideration.
2) REQ-OPS-02: The Allocation Center shall have a high degree of automation, monitored by a human Allocator, while also allowing for human intervention in the system's decisions at any given time.
3) REQ-OPS-03: The Allocation Center shall allow for the automatic or human-initiated re-allocation of all aircraft already allocated and within the Flight Centric ATC area.
4) REQ-OPS-04: The re-allocation shall be clearly visualized for the controllers concerned and displayed on the radar HMI with a lead time.
5) REQ-OPS-05: The Allocation Center shall enable the automatic or human-initiated opening or closing of controller working positions at any time.
6) REQ-OPS-06: The allocation of aircraft to controllers shall be unambiguous at any time. Each aircraft must be allocated to a specific controller before entering the Flight Centric ATC area. Double allocation must be excluded under all circumstances.
7) REQ-OPS-07: The visualization of the allocation shall be clear for all controllers and the Supervisor on their respective radar/Supervisor HMI at any time.
8) REQ-OPS-08: The utilized allocation strategy shall enable the even distribution of all aircraft to air traffic controllers based on their individual workload.
9) REQ-OPS-09: The Allocation Center shall enable the implementation of new types of communication and also take into account the possibility of higher automation, in which the system has primary control over an aircraft under normal conditions.
10) REQ-OPS-10: The Allocation Center shall enable the Supervisor to execute shift rostering and react individually to the current traffic situation.
11) REQ-OPS-11: The Allocation Center shall provide the Supervisor with all relevant information on current and expected traffic volumes, abnormal situations, e.g., thunderstorms, and the available ATCOs

All in all, the issue of allocation has already been sufficiently investigated for application in a Flight Centric ATC airspace, with automatic, workload-based allocation in particular having been examined and deemed operationally feasible. Nevertheless, individual components such as the allocator workstation and efficient interaction between the allocation center and human allocators have not yet been fully analyzed (see Chapter V).

B. Team composition

In conventional operations, each sector is usually controlled by a pair consisting of one executive and one planning controller. While ultimately, their responsibility is to ensure safe separation between all aircraft inside their sector, the different tasks that come with that are divided between the two roles. Generally, the planning controller is responsible for coordination with adjacent sectors and ensuring that conflicts detected in the planning time horizon are resolved before entry into the sector. The executive controller mainly focusses on communication with the flight deck, resolving tactical conflicts (i.e. conflicts occurring within the next up to 15 minutes) and reacting to pilot requests for trajectory change. [45]

In Flight Centric ATC operations, an aircraft tends to be controlled by the same ATCO for a significantly longer time as sector boundaries within an FCA airspace are removed and the area of responsibility becomes larger than just one or two control sectors. This introduces an imbalance to the workload if the traditional controller team with their tasks is used; in particular, the need for coordination with upstream or downstream sectors is reduced. Furthermore, pre-tactical conflicts can, with appropriate tool support, be detected and resolved by the executive controller as well. Taking this into consideration, several options for team compositions in Flight Centric ATC have been explored:

- Traditional controller team (one planning controller paired with one executive controller): the approach of working in the conventional controller teams might be considered in the case of small FCA airspaces merging only few sectors. With larger FCA airspaces the workload imbalance between executive and

planning controller and thus inefficiencies grow to be more significant, as less coordination with surrounding units would be required. [45]

- Modified controller team (one planning controller or one Extended ATC Planner (EAP) paired with multiple executive controllers): the workload imbalances between planning and executive controller in FCA can be mitigated by pairing up one or several (depending on demand) planning controllers with multiple executive controllers. This coordination structure can follow either a fixed pairing – where specific planner and executive controllers are consistently linked – or a dynamic approach, allowing flexible allocation among several planners and executives. With the flexible configuration, a balanced workload for planner controllers can be maintained more easily, adapting to real-time operational demands. In contrast, fixed assignments, particularly in larger FCA airspaces, may result in periods of planner underutilization, especially when coordination needs at airspace boundaries are minimal or absent for the associated executive controllers. [46]

  In another approach of a modified controller team, multiple executive controllers are supported by one or more Extended ATC Planners, who execute the tasks of the conventional planner controller, but also manage traffic complexity, coordinating with the Local Traffic Manager and implementing restrictions if necessary. [47]
- Single-person operations: in this approach, the idea of differentiating between planning and executive controller is abandoned, and controllers work in single-person operations as FCA ATCOs. They take on tactical tasks as well as coordinating with adjacent ATC units and resolving conflicts in what would conventionally be considered planning time horizon. This added workload can be considered in the allocation of aircraft to controllers, allowing a flexible use of controller capacities.

C. Supervisor role

In any real-time simulations performed up to this point, the scope was limited to the ATCOs actively controlling aircraft. A crucial role in ATC operations is that of the Supervisor, who is supporting the controllers and managing and supervising operations. A fundamental change of airspace structure and working methods as brought on by the Flight Centric ATC approach naturally also impacts the Supervisor's tasks and responsibilities. This impact was investigated in a workshop conducted by the German Aerospace Center in 2024 as part of the DES HE SESAR FCA project, and a definition of the Supervisor role in FCA was drafted.

Workshop participants were seven air traffic controllers (some of which additionally held positions of supervisors, unit instructors or head of ACC) working for Ukrainian State Air Traffic Services Enterprise (UkSATSE) with professional experience ranging between 13 and 31 years.

During the workshop, the participants were asked to provide their expert judgement on how conventional supervisor tasks would have to be adapted in Flight Centric ATC and what tool support would be required or beneficial for the FCA supervisor. The outcomes are described in detail in [48]. As sector boundaries are dissolved in Flight Centric ATC, especially those tasks related to managing sectorization based on traffic flows are affected. Additionally, FCA introduces a new approach to allocation of aircraft to controllers, as detailed in section IV.A, which in the case of automatic allocation requires some degree of monitoring and perhaps modification by a dedicated allocator role or the FCA Supervisor. The new and modified tasks of the FCA supervisor are now defined as follows [48]:

- Analysis of traffic flows and airspace constraints in collaboration with local traffic manager (LTM) and flow management position (FMP).
- Coordination with the other concerned Supervisors if short-term planning changes are allowed by airspace management.
- Opening or closure of CWP according to expected traffic load after coordination with the LTM, if applicable.
- Coordination with the other concerned Supervisors on the activation and deactivation of special use airspace.
- Decision on staffing and manning of CWP according to ATCOs' training levels and individual competencies.
- Alerting search and rescue organization in case of an aircraft accident or aircraft uncertainty.
- Coordination with the concerned technical staff about the usability and availability of ATM system, radars, coordination tools, redundant ways of communication in case of different failures and degradations.
- Monitoring and, if required, modification of automatic allocation.

D. Training & Licensing

The transition from conventional sector-based operations to Flight Centric ATC introduces significant changes in working methods which consequently requires modifications to ATCO training and licensing in some regards. This shift was explored during a workshop conducted by DLR in cooperation with the Swedish ANSP LFV, as part of the SESAR project PJ.33-W3-FALCO. [49] During the workshop, the controllers were first familiarized with the operation characteristics and the different support tools using demonstrator work stations, before discussing the implications for ATCO training and licensing.

The training process is regulated by EU Commission Regulation 2015/340 and includes three main phases [50]:

- *Selection phase:* candidates undergo several tests, personal interviews, medical assessments, and security checks to determine their suitability for the role before being accepted for the actual ATCO training process.
- *Initial training:* Candidates that successfully passed the selection process proceed to initial training, typically conducted at an air traffic services academy such as Entry Point North. This phase includes a basic ATC course, covering theoretical knowledge and generic practical skills, followed by rating courses tailored to the type of ATC service (e.g., en-route or tower). Some ratings require additional endorsements to specify the type of service or equipment the controller is qualified for. Completion of this phase allows candidates to apply for a student ATCO license.
- Unit training: This training phase is conducted at the specific ATC unit where the candidate is designated to work. It includes transitional training on national procedures, pre-on-the-job training (pre-OJT) for complex units, and on-the-job training (OJT) under supervision. Student ATCOs successfully passing unit training and related exams are issued a full ATCO license with unit endorsements.

Although the fundamental structure of this training process – including selection, initial training, and unit training – may remain valid with the introduction of Flight Centric ATC, the content and focus of the phases will require some modifications:

With regards to the increase in automation and human-machine collaboration that allows the FCA approach to reach its full potential in terms of benefits, the *selection process* should increasingly assess psychological traits associated with the successful use of automation. In particular, high emotional stability and low neuroticism have been shown to correlate with higher trust in automated systems and should be emphasized in candidate screening.

With respect to *initial training*, the elimination of sector boundaries and the harmonization of systems across the FCA airspace suggest a shift away from generic environments towards FCA-specific content. Instead of practicing in abstract generic airspaces as is practice in today's initial training, students could be trained directly on simplified representations of the actual FCA environment. Moreover, theoretical instruction should emphasize a deep understanding of air traffic management systems, including the design of safety barriers and the interaction between automation and human operators.

In *unit training*, the current focus on sector-specific procedures becomes less relevant, as controllers in FCA work in an airspace larger than one or two sectors and the need for localized knowledge is reduced. Instead, unit training could evolve into a system-oriented module focused on the use, integration, and trust in highly automated support tools. Simulator hours would remain essential, but a stronger focus should be placed on system design, safety logic, and human-machine interaction in order to enable controllers to work collaboratively with the system and understand and evaluate the decisions made by it.

In terms of *licensing*, while existing area ratings such as Area Control Surveillance and Approach Control Surveillance may still be applicable within FCA, the current sector-based endorsements would need to be replaced or complemented by an FCA-specific endorsement. [49]

E. HMI

Current ATM Human-Machine Interfaces (HMIs) are equipped with a display designed to represent the entire airspace controlled by a pair of ATCOs, alongside the traffic passing through. The vertical and lateral dimensions of each sector are limited and can conveniently be displayed within one radar screen. As a consequence, ATCOs can constantly be aware of the traffic situation and effectively monitor the airspace they are responsible for and identify potential conflicts involving the aircraft under their control. However, with the introduction of the FCA concept the conventional HMI radar display is becoming impractical, because the significant expansion of the ATCOs' area of responsibility depending on the size and shape of the FCA airspace, can make it impossible to fit the full north-south and east-west dimensions onto a single radar display screen. To allow the implementation of FCA in airspaces of

different extents and shapes, current HMI radar displays must be redesigned or adapted to accommodate the specific features of the new environment. [42]

Since the initial experimental activities related to FCA, various studies have been conducted to identify suitable solutions for adapting the HMI radar display to new requirements. Early feasibility studies and validation experiments were carried out by DLR in 2008 [23]: for these simulations, performed with DLR's simulation platform TrafficSim featuring high-density traffic, the ATCO HMI consisted of one or more cloned situation displays, showing standard flight information such as position, altitude, speed, history, and flight plan, with an adjustable range; for each ATCO, the controlled aircraft was displayed in magenta, those at similar flight levels in white, and those that were considered less relevant in grey. During the debriefing sessions controllers declared that the HMI was a solid starting point; however, the need for a well-defined set of conflict-handling rules was manifested. The operational feasibility of FCA was further validated with a real-time simulation using an area covering the Budapest Area Control Centre (ACC) between FL325 and FL660. [26] To that aim, the HMI was modified to resemble the radar display and interaction style used by HungaroControl in daily operations, but a relatively large radar monitor was used to display the complete Flight Information Region (FIR), as the dimensions of the airspace allowed it. Generally, ATCOs agreed that conflict warnings were correctly triggered, responsibility for conflict resolution clearly assigned, and the responsible aircraft well identified. Nevertheless, a difficulty locating useful data for separation provision was reported, alongside the need to improve the filtering algorithm to display relevant aircraft. [28], [30]

Within the DES HE SESAR project FCA, initiated in 2023, two real-time simulations have been conducted to evaluate Flight Centric ATC operations using scenarios in Ukrainian and limited parts of Spanish airspace. Building onto the above-described tiled approach for FCA radar displays, the HMI was redesigned to support controllers in managing traffic distributed across wide areas. Specifically, ten radar screen tiles were arranged in a 4×3 grid positioned around the perimeter, while a task manager—containing a timeline of clearances, conflict alerts, and pilot requests, along with a list of assigned callsigns—was placed in the central cells. When the number of assigned aircraft exceeds the available radar tiles, controllers can select the ones to display based on position, flight plan, and timeline data; also, the simulation allowed the electronic transmission and processing of requests and clearances via data link directly through the HMI radar display. [40]

Another approach to a radar HMI tailored to FCA operations was designed as part of a study conducted by DLR and validated using a simulation game with subject-matter experts. To support scalability, the HMI interface described in [54] was expanded to eight sections, six basic radar tiles and two additional areas for advanced tools. A *Conflict Display* was set to continuously scan the airspace for medium-term conflicts and present both visual and tabular alerts, allowing ATCOs to manage resolution responsibilities effectively. At the same time, a *Situation Display* offered a consolidated view of all controlled aircraft, displaying proximity relationships and aiding in rapid conflict identification. As reported by the participants, these HMI components significantly enhanced situational awareness and decision-making; however, true scalability remained limited because the maximum number of controllable aircraft was still bound to the number of available tiles. [51]

F. Air-ground Communication

With regard to air-ground communication, two different issues were considered in the context of Flight Centric ATC. On the one hand, the DLR's internal DIAL project investigated different communication channels (radio telephony, CPDLC and LDACS) between controllers and pilots and their impact on the controller workload when used in the allocation of aircraft to controllers. [36] Further details can be found in Chapter IV.A.

Another key focus of the investigation, which was examined in the two real-time simulations conducted by the German Aerospace Centre in collaboration with Frequentis and HungaroControl as part of the two SESAR2020 projects, was the frequency coverage of large airspaces. [7][25] While the implementation of FCA in relatively small areas does not require any changes in terms of communication, the conventional concept of voice communication in airspaces with a diameter of more than 200 NM requires some adjustments due to the current VHF radio range of approximately 200 nautical miles. Since flight crews in the FCA concept should ideally use the same frequency throughout the entire flight and no longer have to switch between radio frequencies as frequently as before, the introduction of a so-called wide-area communication system is necessary. This requires the existing ground-based communication infrastructure to be adapted to enable flexible and automated allocation of frequencies to the responsible air traffic controllers and aircraft. [47]

Two options have been considered with regard to the use of the existing VHF infrastructure at FCA [52]:

1. *FCA with one VHF coverage*

In this setup, each air traffic controller is given his own VHF frequency, so neither the flight crew nor the controllers within the Flight Centric Area need to change frequencies. To cover large areas, several transmitters are usually used for one frequency. If these are part of the CLIMAX network, they work together to provide coverage for the entire area. If CLIMAX mode is not sufficient, the transmitters can be controlled individually. In this case, the VCS requires the current position of the aircraft in order to automatically switch between the individual transmitters during the flight. [52] The corresponding validations carried out as part of the above-mentioned projects have shown that this concept is applicable for air traffic controllers and that even in degraded mode scenarios, in which a failure between the controller HMI and the voice communication terminal (VCT) is simulated, no significant increase in workload for controllers results from the manual selection of aircraft on the VCT. The proposed concept for voice communication between controllers and pilots can be considered operationally feasible. [29]

2. FCA with more than one VHF coverage

In this case, each controller is assigned to at least two different frequencies. Each aircraft entering the FCA area gets its own frequency sequence. This means that the pilots might need to change frequencies during the flight. The frequencies and associated transmitters are controlled automatically via the VCS. To communicate with the aircraft, the controller selects the aircraft on the radar screen and communicates as usual. If the connection between the radar HMI and the voice communication terminal (VCT) is interrupted, the aircraft must be selected manually on the VCT. Although frequency changes are necessary with this type of implementation, they are fewer than the number of handovers in the current sectorized airspace. A study conducted for MUAC airspace shows that more than 3,500 handovers can be avoided each day, which, assuming that a handover takes approximately 30 seconds, corresponds to a time saving of 1,750 minutes per day. [52]

The Wide Area Communication framework and its associated tools are not limited to Flight Centric ATC alone. Although originally devised to support FCA operations, the WAC methodology can also be applied within traditional ATC settings, particularly in environments where very large horizontal sectors are established to boost capacity and decrease the total number of sectors. While additional operational trials are necessary to validate its effectiveness in these contexts, the approach is already deemed viable at its current maturity level. A voice communication system, which offers these possibilities needed by FCA is currently being implemented by NAV Canada. [53]

G. Performance & Cost Benefit Analysis

In addition to the general investigations mentioned above with regard to the operational feasibility of the overall concept and individual concept components, e.g. the design of the radar HMI, training and licenses, or allocation, another point to analyze are the expected benefits. Can these benefits, particularly in relation to cost efficiency (ATCO productivity) and fuel efficiency, actually be achieved, and what impact do the costs have on the expected benefits in terms of the cost-benefit analysis? Two different validations that carried out such an analysis of the overall concept must be considered here. Initial analyses of both the benefits and the expected costs were carried out as part of the SESAR 2020 PJ.10-W2-73 FCA project. As part of the project, eight different implementation scenarios were considered, which differed in terms of the type of implementation (static vs. dynamic), the airspace considered (fragmented (country-level) vs. consolidated (VAB-level)) and the tool support used (basic vs. advanced). [54] Both the fast-time simulations and the real-time simulations of the Hungarian and Spanish airspace were incorporated into the evaluation. Extrapolated to the entire ECAC airspace, this resulted in fuel savings depending on the scenario considered, ranging between 1.3 kg/flight and 46.67 kg/flight, although it should be noted that the savings varied considerably across the eight virtual airspace blocks covered. The same can be seen in terms of cost efficiency, where a benefit between 4.13 % and 17.94 % was achieved depending on the scenario. [54] Taking into account the implementation and transition costs, as well as the cost delta for operating costs, this results in a net present value (NPV) of €811.9 million to €2,834.4 million, depending on the scenario, assuming a discount rate of 8 % and normal traffic growth. [55]

Build on these initial cost-benefit analysis findings, [56] performed a study that considered the detailed workload formula for distributing aircraft among air traffic controllers described in Chapter IV.A and the radar HMI developed for Ukrainian airspace (Chapter IV.D). Using this formula, ATCO productivity can be significantly increased, assuming that up to ten aircraft can be allocated to each air traffic controller at the same time. This results in an ATCO productivity increase of 385 %, which, under the same assumptions for costs, traffic development and discount rate as in the previous results, leads to an NPV of €4,779 million, representing a significant increase compared to the initial assessments. [56]

V. Open Gaps

The following chapter highlights the gaps that have not been addressed, or only partially addressed, in the analysis of the Flight Centric ATC concept thus far. Some of these were already mentioned in Chapter IV, while others are being examined here for the first time within the scope of this paper.

A. Level of automation

Previous studies on flight-centric ATC have mainly used tools that are also used in today's air traffic control. In addition, only novel tools that are currently under development were considered, such as the Conflict Detection and Resolution Tool from current research on Trajectory Based Operations (TBO). All these tools, regardless of whether they are already in use or currently under development, do not exceed AL2 according to the current definition of the ATM Master Plan (Table 1]. [57] For future studies on the FCA concept and its implementation in high to very high complexity airspace, it is entirely appropriate to use tools with a higher level of automation, e.g. AL3, to automate routine tasks such as transfers at the FCA outer boundaries.

Table 1. Automation Level according to [57]

Automation level	**Definition**	**Authority of the human operator**
AL0 – Low automation	Automation gathers and exchanges data. It analyses and prepares all available information for the human operator. The human operator takes all decisions and implements them (with or without execution support).	Full
AL1 – Decision support	Automation supports the human operator in action selection by providing a solution space and/or multiple options. The human operator implements the actions (with or without execution support).	Full
AL2 – Resolution support	Automation proposes the optimal solution in the solution space. The human operator validates the optimal solution or comes up with a different solution. Automation implements the actions when due and if safe. Automation acts under direction	Full
AL3 – Conditional automation	Automation selects the optimal solution and implements the respective actions when due and if safe. The human operator supervises automation and overrides or improves decisions that are not deemed appropriate. Automation acts under human supervision.	Partial
AL4 – Confined automation	Automation takes all decisions and implements all actions silently within the confines of a predefined scope. Automation requests the human operator to supervise its operation if outside the predefined scope. Any human intervention results in a reversion to Level 3. Automation acts under human safeguarding	Limited

The use of artificial intelligence (AI), for example in connection with filtering for the different air controller positions or during allocation, would also be conceivable to optimize the overall system.

B. Integration with lower airspace/approach

The real-time simulations carried out for FCA primarily considered the upper airspace as a uniform Flight Centric ATC area, with the lower limit set at flight level (FL) 275 or higher. The only exception to this was the RTS carried out by DFS in the first SESAR2020 project investigating Bremen TMA. However, it should be noted that the working method in this case hardly differed from today's structures for arrivals and departures, as the aircraft were divided between an arrival, departure and overflight flow. What has not yet been covered in real-time simulations, however, is a real FCA in lower airspace below FL275, as well as the actual implementation of the FCA concept in the TMA in order to actually consider an aircraft in a flight-centric perspective throughout its entire flight. However, considerations of these airspaces also present new obstacles. If only the lower en-route airspace is taken into account and the TMAs are completely excluded from the Flight Centric Area, the question arises as to how separation is achieved at the entry

and exit points of the Standard Instrument Departure (SID) routes and the Standard Terminal Arrival Routes (STARs), which is currently ensured by the responsible sector controller. If the TMAs are integrated into the FCA area, however, such separation aspects arise over the entire length of the SIDs and STARs and also include the final approach separation. In particular during approach, where approach controllers currently simply vector aircraft depending on traffic density instead of letting them fly the entire STAR the whole concept needs to be changed if different controllers are responsible for the various aircraft on this STAR.

In addition to the pure integration of lower airspace/approach into the Flight Centric ATC concept, urban air mobility (UAM) is another topic that needs to be examined in more detail in relation to FCA if the area under consideration extends to areas that are also used by unmanned vehicles. Close cooperation between both research areas is necessary in order to combine the needs of both in a joint concept. However, as the field of UAM is still in its early stages of research, this issue should be clarified at a later stage, but must not be forgotten for the future implementation of the concept.

C. Cross-border implementation

Previous studies of the concept have primarily examined an FCA area covering no more than a single country. Although initial studies for the cross-border introduction of FCA have already been conducted as part of the DLR internal validation campaign within the DIAL project and the fast-time simulations within the SESAR2020 projects, these studies only focused on the technical implementation on the air traffic control side, such as the design of the HMI (see Chapter IV.D) and the expected benefits of a Europe-wide implementation. However, key aspects that currently prevent this kind of implementation have not yet been addressed. These aspects relate in particular to legal, regulatory, economic and political issues.

The primary question is how air navigation service providers could be restructured. Since, in an ECAC-wide Flight Centric ATC area, aircraft are monitored by the same air traffic controller throughout their entire flight in European airspace, ANSPs are no longer necessary at national level. Instead, it would be possible to control all flights within the European FCA area by a single centralized ANSP or to divide this task among three to five larger ANSPs. Another approach would be to completely liberalize the market so that anyone with the appropriate certification and licenses could control the airspace or a portion of the aircraft. However, such changes must also be politically desirable, as many of the ANSPs in Europe are still under national control. Eurocontrol, however, provides a good example of how this can be achieved.

Another aspect that must not be overlooked are the legal and liability issues that arise when implementing such an area. How are liability issues regulated in the event of incidents or accidents when air traffic controllers from different national ANSPs are responsible for an incident in the sovereign airspace of a third country? This liability issue is further exacerbated by the question mentioned in ChapterV.A regarding liability when using highly automated tools.

D. Civil-military coordination

As part of the current validation campaign for the SESAR DES FCA project, the interaction of military aircraft in the civil airspace of the FCA airspace was investigated for the first time. However, the focus was limited to the activation of multiple ARES and on flights between these. In addition, the SESAR Performance Framework defines the following further aspects that need to be examined in general [58]:

- Unrestricted access to airspace aimed at safeguarding the integrity of national airspace and the provision of support to civil authorities in connection with national security.
- Unconstrained training to ensure the readiness of military forces (as well as police and customs) to perform the activities required and to test systems or operational concepts.
- Accessibility to civil and military aerodromes
- Accessibility to common ATM information, data repositories and networks
- Light- and cost-efficient transit to operating and training areas.
- Ensuring that national airspace is unrestricted access for national armed forces including agreed cross-border operations and access to cross border ATM resources.
- Infrastructure sharing and rationalization.
- Processes and mechanisms supporting performance-based certification so that an equivalent level of performance of the military system against SESAR ATM/CNS requirements can be achieved.

An assessment of these questions should be carried out as soon as possible. Furthermore, military activities in a cross-border concept, as described in C, present additional implementation challenges. Today, many European

countries have special military air traffic controllers responsible for controlling their own military aircraft fleets. In an FCA area where national borders are not considered, this would mean that military activities could be taken over by controllers from other countries. This would be possible within NATO member states, but not all European countries are part of NATO. Appropriate analyses with military experts/controllers are needed to discuss these implementation issues in detail.

VI. Roadmap & Conclusion

One might think that 25 years of working on a new concept is more than enough time to either fully explore it or to come to the conclusion that it cannot be realized in the way it was conceived. This statement may be true for a large number of projects, but in the case of Flight Centric ATC one thing must be taken into account: It is not a single concept element that can be integrated into the existing airspace structure and the general structure of air traffic management. Rather, it is a completely new overall concept that entirely replaces the traditional structures of sectorized airspace that have evolved over decades. The history of the concept development from the first ideas in 2001 as sectorless ATM, to the first real-time simulations almost 10 years later, carried out by the German ANSP DFS and the German Aerospace Center, to the integration of the concept as Flight Centric ATC in the SESAR Programme and the intensified research at the German Aerospace Center, shows how complex the validation of such a revolutionary concept is.

However, this does not mean that nothing has been achieved over the years in terms of further developing the concept. From the initial idea, which already outlined a wide range of open questions, a concept applicable to low to medium-complex airspace was developed with the help of various simulations, in which the German Aerospace Centre played a leading role, even though research in this area has so far been limited to the national level. Nevertheless, with the achievement of TRL 6 (expected in mid-2026), the first cornerstone has been laid for establishing the concept in initial airspaces and gaining further experience from operational use, which can then be transferred to other more complex airspaces.

After the concept was recognized as a flagship project of the Single European Sky ATM Research Programme between 2017 and 2020, interest has now subsided somewhat. While the current calls for proposals are already discussing automation level 3 (conditional automation) and automation level 4 (confined automation) [57], one thing should not be forgotten: Flight Centric ATC can close precisely the gap between today's long-established sectorized airspace and automation at AL4, as one thing is clear, highly automated airspaces no longer need sectors. Another key point in favor of the concept for the future is that without FCA, the actual goal of the SESAR Programme cannot be achieved. A Single European Sky cannot be achieved simply by harmonizing and adapting systems, even if this naturally offers enormous added value. Rather, it is precisely what FCA delivers: a large airspace instead of national air navigation service providers, whose control is subject to one or more area control centers, which in turn divide the airspace into individual sectors. It should not be forgotten, of course, that the FCA concept has not yet reached the maturity level required for its use across Europe in airspaces of all degrees of complexity, as Chapter III and Chapter IV make clear. Extensive research is needed to achieve this. In particular, the issue of legal and liability aspects has not yet been clarified. On one hand, there is the question of responsibility when aircraft are controlled in another country, and on the other hand, there is the question of the use of highly automated tool support for air traffic controllers, which could well be considered, especially in high and very high complexity airspaces. The question of restructuring European air navigation service providers is also an open issue that has yet to be clarified, but must first be resolved at the political level, as it is a major obstacle to establishing a Single European Sky. A perfect example of such cross-border cooperation is the Maastricht Upper Control Area controlled by Eurocontrol, which covers the upper airspace of the Netherlands, Belgium, Luxembourg and the entire upper airspace of northern Germany.

All in all, it can be concluded that the Flight Centric ATC concept is well on its way to offering an alternative to conventional sectorized air traffic management in the future and, as a result, solving or significantly reducing problems such as air traffic controller shortages and airspace capacity bottlenecks, always with the understanding that parallel developed concepts such as trajectory-based operations, new air traffic control support tools and new communication methods between air traffic controllers and pilots (e.g. LDACS) can be integrated relatively easily into the concept and a mutual benefit can be achieved.

25 years of research will definitely not be the end of concept research for FCA, even if it is not expected that another 25 years of research will follow.

The further path towards implementation of the FCA concept should consist of many individual, partly parallel steps. In order to achieve the benefits of the concept in a timely manner and solve the existing problems at the same time, implementation in the designated airspaces should begin shortly after TRL6 is reached. Implementation should take place at least on the scale of an ACC, but may also directly encompass several ACCs of the same ANSP. The

lower boundary of the FCA area should be selected so that the resulting uniform airspace does not exceed the complexity and density of a medium airspace. Accordingly, no specific lower limit can be recommended, as this varies depending on the ACC. It should also be noted that there are no airspaces that are 'too small' to implement the concept. Parallel to this implementation, it is advisable to start working on the further realization of the concept across national borders, as the greater the overall airspace covered, the greater the benefits that can be achieved. Such implementation must be discussed in detail and coordinated at both the political level and in the area of legal and liability regulations

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