Feasibility and Benefits of Implementing Flight Centric ATC in the Spanish upper airspace

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***Abstract*—The Flight Centric Air Traffic Control (Flight Centric ATC or FCA) concept introduces a new approach to airspace design and air traffic controller operations in en-route environment. By removing traditional sector boundaries and restructuring controller workflows, FCA aims to alleviate capacity constraints caused by the continuous growth of air traffic in Europe. This concept also enables a more balanced distribution of traffic among controllers within an Area Control Center (ACC), based on workload allocation. As a result, both airspace and overall controller capacity can be optimized. With FCA, it becomes possible to control the same number of aircraft with fewer controllers compared to sectorized airspace. In this paper, we present the latest research findings from the Single European Sky ATM Research Programme (SESAR2020 Wave 2 PJ.10-W2-73 FCA). Specifically, we discuss the Real Time Simulation (RTS) validation exercise conducted by the Spanish Air Navigation Service Provider (ANSP) ENAIRE in collaboration with INDRA, focusing on the upper Spanish airspace.**

***Keywords*—Flight Centric ATC, Real Time Simulation, Single European Sky ATM Research, Sectorless, Air Traffic Management.**

I. Introduction

Europe's Air Traffic Control (ATC) system is facing capacity limitations, as it reaches its maximum limit. Although air traffic decreased during the Covid-19 pandemic, since the restrictions on international travel have been lifted in 2022, there has been an increase again. According to Eurocontrol's annual traffic forecast and based on the experiences of previous global crisis such as the economic crisis in 2008/2009 and 09/11, the volume of traffic is expected to return to pre-crisis levels in 2025 [1; 2].

An increasing volume of air traffic is indicating an improvement in the European aviation industry. However, it is also leading to pre-crisis problems. The current airspace structure is coming under significant pressure, particularly in Central Europe, where the most significant traffic flows of the European air transport system exist. The capacity limits of the sectors and the maximum number of aircraft that each Air Traffic Control Officer (ATCO) can safely handle are being reached here. In contrast, in some regions of Europe, including the Scandinavian area, where population density is low, airspace utilization is also decreasing. Furthermore, political tensions, such as the Ukrainian crisis, are also adding significant pressure to the airspace's capacity and associated controller utilization in response to shifts in air traffic [2].

The efficiency of the overall air traffic control system is significantly impacted by both anticipated and unanticipated changes in air traffic. In 2022, the average delay per flight in Europe reached 1.74 minutes, returning to the pre-crisis level of 2018/2019, despite the traffic volume being at 83.3% of that level. This average delay per flight resulted in a total enroute Air Traffic Flow Management (ATFM) delay of 15.9 million minutes, showing a significant increase of 784% compared to 2021. Among these enroute ATFM delays, 36% were caused by ATC capacity limitations [3]. With increasing traffic demand and no adjustments to the airspace structure, average delays are expected to further increase, resulting in substantial financial losses for the aviation industry.

To address this issue, the Flight Centric ATC (FCA) concept has been introduced, which aims to eliminate traditional sector boundaries and distribute the workload evenly among all controllers in the airspace. First mentioned in 2001 [4], the FCA concept has continually evolved and was initially validated in 2008 through a cooperative research project between Deutsche Flugsicherung GmbH (DFS) and DLR, simulating the upper German airspace as an FCA airspace [5; 6]. Since then, it has been investigated further in the European research program "Single European Sky Air Traffic Management Research" (SESAR) since 2017 [7; 8].

The most recent project, conducted from January 2020 to April 2023, involved multiple ANSPs, including DFS, ANS CR, ENAIRE, ECTL, HungaroControl and NATS, along with industrial partners such as Frequentis and INDRA SISTEMAS S.A. (INDRA) and the research institution DLR. This project aimed to analyze the impact of the FCA concept on various aspects such as overall airspace capacity, workload distribution across ATCOs, predictability, fuel consumption, and the required number of ATCOs. Additionally, suitable radar displays and supporting tools were developed to facilitate the implementation of the FCA environment for air traffic controllers. Human performance assessment and evaluation of trust in automated tools were also key considerations due to the increased level of automation in FCA [9].

To study these aspects of the FCA concept, different exercises were conducted as part of the project. One of them, led by DFS, tested the concept's operational feasibility in Hungarian airspace [10]. The one analyzed in the following study was one carried out jointly by ENAIRE and INDRA, by means of which the aim was to evaluate the operational feasibility and benefits of a possible implementation of FCA in the upper Spanish airspace, a low-medium complexity operational environment [11].

II. Flight Centric ATC Concept

Flight Centric ATC concept presents a fundamental distinction from the current ATC approach concerning airspace configuration and the delegation of controller tasks.

Currently, the European airspace is divided into sectors delineated by horizontal and vertical geographical boundaries. Each controller pair, comprising an executive controller and a planner controller, have the responsibility for all the traffic within that sector, as well as coordinating its entry and exit. This arrangement enables the provision of air navigation services, ensuring the safe operation of aircraft flying through these sectors. This mode of operation will be referred as "sectorized" hereafter.

The proposed FCA operational mode transforms this sector division into a more uniform structure that covers a larger airspace, where the division is based not on geographical regions, but on the characteristics of the flights themselves. Within this airspace, several controller pairs are responsible for all flights within it. This implies that while a pair of controllers is responsible of a certain number of aircraft during their flight segment within the FCA airspace, other pair of controllers is responsible for a different set of aircraft within the same airspace.

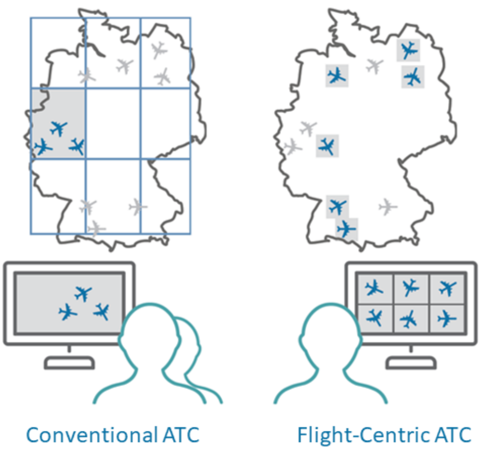


Figure 1. Comparison between sectorized and Flight Centric ATC

Consequently, a single pair of controllers would not have the responsibility for all the traffic entering a sector and coordinating all of them upon exit. Notably, they would need to coordinate with other controllers who also have another set of aircraft under their control within the same airspace. This introduces a new form of coordination and communication among controllers, as well as a different approach to traffic assignment. Although, this is compensated by a reduced necessity for frequent control transfers for the same flight due to fewer sector boundaries.

In contrast to the sectorized mode, FCA focuses on the needs of each individual aircraft as it moves through the airspace. Controllers can monitor the entire trajectory of an aircraft and make decisions based on its specific requirements, such as preferred route or altitude. This could lead to more direct and efficient routing, ultimately reducing delays.

III. Validation Exercise

A Real-Time Simulation (RTS) was conducted in October 2022 to assess the operational feasibility and benefits of a possible implementation of FCA in a low-medium complexity operational environment, such as the upper Spanish airspace. More concretely, the airspace selected corresponded to the south part of Madrid ACC (in purple in Figure 2), whose sectors will be detailed below.

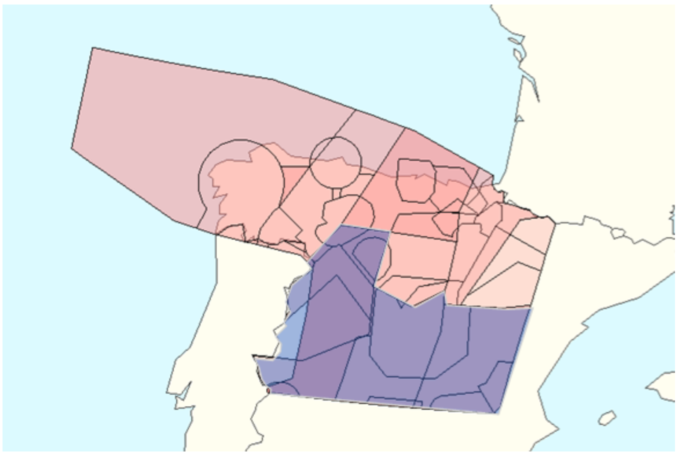
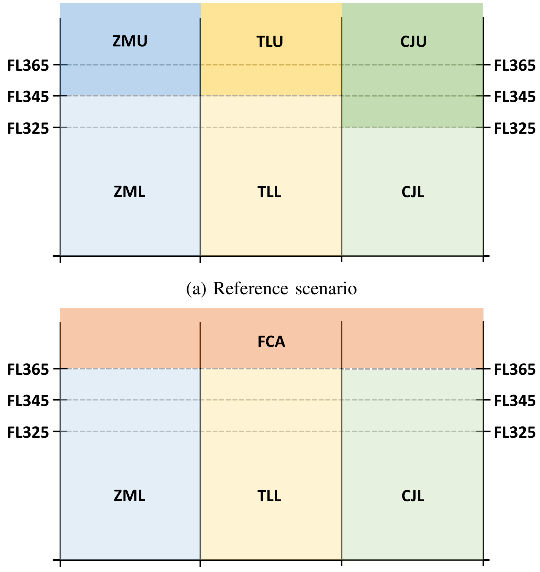


Figure 2. Horizontal profile of the airspace analyzed

In order to assess the obtained benefits, it was necessary to compare the measurements or observations taken between the reference scenario, where the sectorized operational mode was in use, and the solution scenario, where the FCA was implemented even if not continuously due to different use cases as it will be explained later. The details of both scenarios are the following:

- The reference scenario corresponded to the current operational environment applied to the volume occupied by the SWI sector (in purple in Figure 2), which is composed by the following elementary sectors: CJL, CJU, TLL, TLU, ZML and ZMU. Regarding ZMM elementary sector, it has been integrated in ZML due to system capabilities. In actual operation, these sectors are not always deployed individually, but depending on the traffic situation they can be integrated with each other, with their lower sectors or with other adjacent sectors creating bigger sectors. In the validation exercises, these sectors will be simulated individually deployed.
- The solution scenario implements a Flight Centric ATC approach in the airspace belonging to SWI at higher levels, from FL365 and above. Thus, below this level, sectorized control will be implemented, using the current lower sectors (CJL, TLL and ZML), but adjusting after different analysis their upper limit at FL365, where FCA airspace begins. The upper levels will, therefore, operate under the FCA mode, where controllers will share responsibility for flights within that area.

The following Figure 3b illustrates the vertical profile structure in each of the two scenarios, where the differences between how the airspace structure is deployed for each of the scenarios can be appreciated.



(a) Reference scenario

(b) Solution scenario

Figure 3. Vertical profile of the airspace analyzed

Twelve licensed air traffic controllers from ENAIRE participated in the RTS as the primary test subjects, who alternated their roles as executive and planner controller and also as sectorized or FCA controllers. Moreover, ten different participants assumed the roles of pseudo-pilot during the experiments creating a more realistic environment. The experiment was conducted over a two-weeks period. The first three days were used to introduce the participants to the proposed concept, airspace and platform through a series of short training sessions, while the rest of the days were focused purely on performing validation exercises.

These validation runs concerned to seven use cases previously identified to help at evaluating the main objective of assessing the operational feasibility and benefits of implementing FCA in a low-medium complexity operational environment. These use cases are shown in the following table.

TABLE I. USE CASES VALIDATED IN THE EXERCISE

UC Number	Description	Type
1	Conflict detection and resolution	Nominal
2	Opening of FCA position	Nominal
3	Closure of FCA position	Nominal
4	Switch from sectorized ATC to FCA	Nominal
5	Switch from FCA to sectorized ATC	Nominal
6	Loss of communications	Non-Nominal
7	Emergency descend	Non-Nominal

All use cases were carried out with the same traffic levels, corresponding to real traffic from July and August 2019 with slight modifications, and under the same conditions. In addition, each one of the mentioned use cases has been executed in reference and solution scenario conditions enabling the comparison between the results of both scenarios. The simulated traffic in both runs of the same use case was the same, being the controlling mode the only difference between both of them. As a result, 14 validation runs were carried out within the validation campaign, whose order was randomized to mitigate learning effects as much as possible.

A. *Roles and Responsibilities*

Within the validation campaign there were three distinct roles and each had different responsibilities.

1) *Flight Centric Executive Controller (FCEC):*

The FCEC, together with his planner, has the responsibility for the management of the aircraft assigned to him within the FCA area, while other pairs of controllers are responsible for the rest of the aircraft within the same space. His main tasks are the same as a current executive controller but adapted to FCA environment:

- Monitor traffic under control responsibility and those from areas ”of interest”, as well as flight plan compliance of them.
- Provide separation to flights under control responsibility.
- Coordinate the resolution of conflicts with aircraft controlled by another control team (this task corresponds mainly to the planner controller, but if the planner controller is busy with another task it is understood that the executive controller would perform the coordination).

2) *Flight Centric Planner Controller (FCPC):*

The FCPC is primarily responsible for the planning and coordination of traffic entering, flying into and out of the FCA area. Each FCPC is associated with a specific FCEC. His main tasks are the same as a current planner controller but adapted to FCA environment:

- Coordinate the entry of aircraft into the FCA area and monitor flight trajectory along the FCA area.
- Provide early detection and resolution of conflicts prior to aircraft entry into the FCA area, detecting conflicts early within the FCA area and providing the ECPC with early resolution proposals for conflicts within the FCA area on a medium to short term horizon.
- Flight Centric PC could apply level capping and rerouting in the FCA area to offload certain areas depending on the time horizon due to DCB needs.
- Input tactical trajectory changes into the flight data processing system assist in executive controller duties if requested by the corresponding FCEC.

3) *Allocator:*

The allocator is a completely new role designed for the FCA concept. This role does not require the need for a new controller as its functions can be performed by the supervisor or by an ATCO with the Extended ATC Planning role, in chanrge of planning responsibilities for all or portion of aircraft entering the FCA Area. However, if the traffic situation requires it, it could be a controller who takes over these functions, having to be one who knows the airspace covered by the FCA area.

Supported by its own allocation support tool, with its own dedicated Human-Machine Interface (HMI) and “what-if” functionality, it is primarily responsible for allocating incoming flights to different controller teams based on criteria that can be dynamic, such as workload, or static, such as aircraft routes or heading. This role does not act on flights once assigned and taken over by an FCEC, as its role covers only the assignment of flights outside the FCA Area. The working timeframe for the allocator is from 20 minutes to 5 minutes before the flight enters the FCA Area, but it can vary in line with airspace characteristics, air traffic situation or quality of prediction. His main tasks are:

- Assign traffic unambiguously to a given controller team (FCEC + FCPC) by applying an assignment strategy. The allocator will also monitor the workload distributions among different controller teams being able to update the initial allocation could be updated until 5 minutes before the flight enters the FCA Area.
- In coordination with other involved parties such as the Supervisor and FMP, assess traffic demand and controller workload, determining the need for additional flight centric positions in the event of forecast overload or, based on forecast lower demand, determining the need to close one or more FCA control positions. In addition, it also monitors transitions from sectorized ATC to FCA and vice versa.

B. *Allocation strategy*

As mentioned above, the allocator relies on a predefined allocation strategy, proposing how flights will be allocated to the different teams of controllers, so that their workload is as balanced as possible. The allocation strategy may be based on different factors such as aircraft heading, location of conflicts, airspace flows, balance of the workload of the controllers involved... [12] This allocation will be static throughout each run, and may be slightly modified by the allocator to adjust the workload by monitoring the traffic situation at any given time.

In the case of this project, it was decided that the strategy for assigning flights to different FCA controllers would be by inbound traffic heading. That is, while one pair of controllers will be responsible for all traffic with inbound heading between some margins, another pair (or pairs) of controllers will be responsible for traffic with the rest of the inbound headings.

For this purpose, a study was carried out before the RTS analyzing the entry heading of all traffic samples to be simulated in the RTS to the FCA and the distribution of traffic on them in each scenario. For each scenario, appropriate traffic assignments per entry heading were studied, so that the traffic was balanced between pairs of controllers. Moreover, the following criteria was taken into account:

- The minimum range of heading associated with aircraft that would be assigned to a pair of controllers is 15º, therefore, the maximum range is 345º.
- The range of headings associated with the aircrafts to be assigned to a pair of controllers must always be consecutive to facilitate situational awareness. For example, in the case of two FCA control positions, one pair might be able to control aircraft whose entry heading is between 0º and 119º and the other pair could control aircraft whose entry heading is between 120º and 359º. However, one pair could not control aircraft whose entry heading is between 0º and 44º along with aircraft whose entry heading is between 210º and 269º, while the other pair controls aircraft whose entry heading is between 45º and 209º along with aircraft whose entry heading is between 270º and 359º.

Once the study according to the number of flight per entry heading had been carried out for all the scenarios, the so-called elementary FCA sectors, i.e. slices into which these headings can be grouped, were defined. These FCA sectors corresponded to the minimum ranges to be assigned to a control pair and are shown in the following Figure 4 by different colors. It is true that these FCA sectors may seem a contradiction, since the FCA is a way to move away from sectorisation in search of larger air spaces and the elimination of borders. However, it should be noted that this designation is an analogy to the operational sectors. FCA sectors are not operational, they are only part of the allocation strategy and an analogy has been made with the operational sectors.

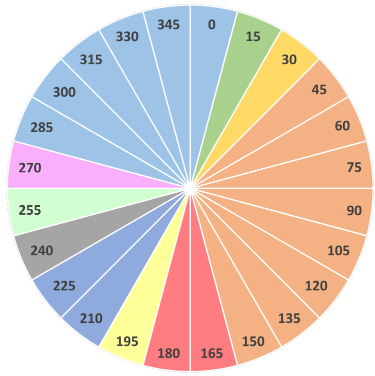


Figure 4. FCA elementary sectors defined according to traffic entry headings.

The elementary sectors presented were later grouped together to form only 2 or 3 portions, in the so called integrated FCA sectors, to ensure the number of combinations between different elementary sectors is limited.

Finally, FCA configurations were defined having as reference the integrated sectors. In these configurations, the compass rose was divided into 2 or 3 portions (depending on the active FCA positions) to balance the number of flights between the various positions by grouping the presented elementary sectors in different ways. Figure 7 shows an example of these configurations (for 2 FCA positions in the left side and for 3 in the right side), as well as how the workload would be balanced between the different pairs of controllers.

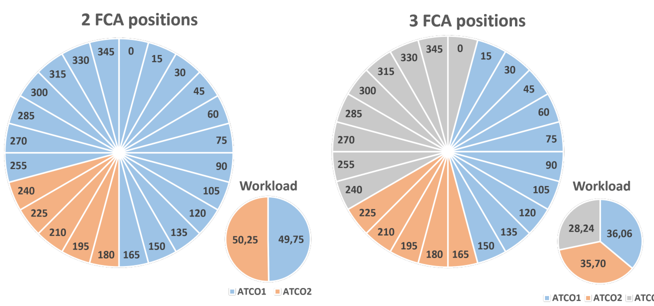


Figure 5. Examples of FCA configurations with corresponding workload balance for 2 (left) and 3 (right) FCA positions.

As mentioned above, the allocator is in charge of the distribution of flights, i.e. choosing the most appropriate FCA configuration for each scenario if needed to be changed, based on the proposals available on its own HMI.

C. Validation tools

In this subsection, the validation tools used to perform the validation campaign, as well as the new functionalities that have been designed for a correct implementation of the FCA concept are described.

1) iTEC SkyNex: It is an air traffic management system developed by INDRA in collaboration with different ANSPs. The system processes air traffic data and defines the routes followed by the aircraft. When totally deployed across Europe, this technology will strengthen safety, increase efficiency and improve environmental impact of flights. At the same time, it will enhance interoperability between control centres in Europe and will also make it possible for aircraft to optimise their routes [13].

The platform used for the validation exercise is based on iTEC SkyNex. This platform includes many technical components that are typically part of an operational platform, like the one deployed in air traffic control centers and a simulation engine that provides simulated surveillance and flight data to the system. The simulator allows the evaluation and validation of new functionalities of the iTEC SkyNex platform, as well as Air Traffic Management (ATM) solutions under research and development, as is the case with this project.

The main components of the iTEC SkyNex platform for performing a correct RTS are the following:

- Flight Data Processor (FDP). It is responsible for processing and managing flight plans of the flights involved in the simulation exercise. It provides real- time flight information and other processed ATM data to be used for different functions, allows flight correlation and flight path monitoring and enables automated coordination of the internal sectors to the exercises with simulated adjacent air traffic control centres.
- Control Working Position (CWP). It is the main working tool of the air traffic controller, from where he or she interacts with the flights under control. Apart from the radar screen, where the flights are displayed, it also contains different windows from which the ATCO can access to all the necessary data for the proper development of his tasks. The CWP can be configured to be adapted to executive, planner or Single Person Operation (SPO) ATCO roles for both sectorized and FCA operation mode. The Figure 6 illustrates the detail of the radar screen of iTEC SkyNex CWP.
- Pseudo-Pilot Working Position (PPL). It is the position where the pseudo-pilots manage the flights during the simulation. These pseudo-pilots emulate the actions that a pilot would perform in real operations, so this position allows to enter the flight level or heading indications given by the controllers. These actions will be automatically reflected in the CWPs of the ATCOs.
- Session Management Position (SMP). It is the position that allows to start the simulation exercises and to stop them when necessary. It also allows the exercise manager to make changes on the flights present in the simulation to improve the simulation fidelity.

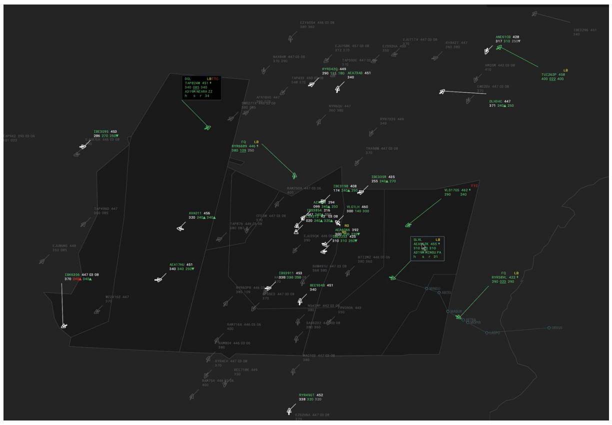


Figure 6. Detailof the radar screen of iTEC SkyNex CWP

On the other hand, there are certain functionalities that have been implemented and integrated into iTEC SkyNex to emulate and validate specific functions, which are key to provide safety ATC in FCA operations. These functionalities are the following:

- Conflict detection and resolution tools. Three different tools have been developed:
  - Planner Controller Tool (PMTCM). It is the tool for calculating three-dimensional planned conflicts based on the aircraft's planned trajectory. This tool presents pairs of aircraft whose protection volumes associated to planned trajectories cross below defined horizontal or vertical thresholds.
  - Tactical Controller Tool (TTM). It is the tactical conflict calculation tool. It warns controllers if aircraft are predicted to violate separation criteria with respect to any other aircraft. Its calculations are based on the aircraft cleared trajectory or tactical trajectory (planned trajectory updated with tactical clearances), both vertically and horizontally. The time until the start of the conflict and the minimum separation between flights are indicated. The severity of the conflict is indicated by different colors.
  - Short Term Conflict Alert (STCA). This tool is available to support executive controllers in detecting short-term conflicts. It is activated when there is less than 2 minutes to loss of separation.
- Filters. Thanks to the filters, the user is given the possibility to filter flights of interest. In addition, there is a filter that allows, when selecting a flight, to hide those flights that are outside a defined cylinder around the selected flight, being able to have a radius of 25 NM and ± 3 FL, or a radius of 50 NM and ± 5 FL.
- Monitoring Aids (MONA). This tool performs the compliance analysis of a flight, showing, on the flight label, alerts associated with lateral route deviation, lateral deviation on heading clearance, vertical unconformances or selected level in aircraft not consistent with CFL.

2) VOCALIST: It is the voice communications system developed by CRIDA, an Spanish R&D+i centre adhered to ENAIRE. It allows air-ground and ground-ground communications, following current frequency and telephone line management. Each CWP and PPL has a separated VOCALIST position which provides communication capabilities.

VOCALIST positions in CWPs have three parts. The first part is where the ATCOs choose the frequency they want to connect to in order to talk to the pseudopilots, the second part is the hot line where they communicate with other controllers in the room, and finally, the last part is where the ATCOs can communicate by telephone with controllers in other control centers. On the other hand, the VOCALIST screens of the PPLs part only have the function of connecting by frequency with the assigned controllers.

3) Allocator HMI: This is a tool designed to support allocator tasks. It allows the visualization of the distribution of flights to each of the CWPs in order to keep the workload well distributed among the different controllers. This tool is based on the entries to each of the FCA positions and automatically creates charts that illustrate flights distribution among the active controller teams (FCEC + FCPC) and how the evolution of air traffic situation, in terms of entries to the FCA area, will be for each pair of controllers. Likewise, allowing the monitoring of the temporal evolution of the balance of the number of flights assigned to each of the active controller teams, the HMI helps to identify workload peaks in order to select the right moment to close and open an FCA position, as well as the transition between the different control modes

D. Validation objectives

The impact of FCA was measured with the help of the data resulting from the simulations. This data was classified into two groups: quantitative data and qualitative data. The first one was composed by the recordings of iTEC SkyNex simulator data logs and Instantaneous Self-assessment (ISA) questionnaires, helping to analyze the flight performance and controllers workload. On the other hand, a lot of emphasis was placed on capturing subjective data from the participants, through post-experiment group debriefing sessions and individual questionnaires and interviews.

With this collected data in mind the following objectives were defined and later validated:

- Human Performance.
  - OBJ1. Asses if the role of the human is consistent with human capabilities and limitations in FCA, with the support of technical systems in performing their tasks.
- Operational Feasibility.
  - OBJ2. Demonstrate that FCA operation in Spanish upper airspace is acceptable and operationally feasible for different traffic density.
  - OBJ3. Demonstrate that the operational feasibility and acceptability of the allocation strategy and its system support, as well as the tasks assigned to the allocator are feasible and improve the efficiency of the FCA.
  - OBJ4. Validate the operational feasibility of the FCA operations in Spanish airspace in non-nominal situations: loss of communication and emergency descend.
  - OBJ5. Provide evidence of the operational feasibility and acceptability of the conflict detection and resolution coordination procedures and system functions in FCA.
  - OBJ6. Assess the operational feasibility and acceptability of transition/switch between sector-based and FCA mode of ATC operation and vice versa and of the FCA CWP opening/closing procedures.
- Performance Assessment.
  - OBJ7. Assess the impact of FCA operations on Cost Efficiency.
  - OBJ8. Assess the impact of FCA operations on Predictability.
  - OBJ9. Assess the benefits of FCA operations on Fuel Efficiency.

IV. RESULTS

This section evaluates the objectives defined to assess the results of the validation exercise described in the previous sections [11].

A. Human Performance

All the roles involved in the FCA concept (allocator, FCPC and FCEC) were considered necessary for its proper functioning. All participants were able to perform their tasks and consider that the definition of roles and associated responsibilities was correct.

The tasks to be performed by each of the actors were considered feasible within the workload levels found in the nominal situations. However, emphasis should be made to address the number of safety issues found in the non-nominal cases, as well as in the transition and opening/closing cases.

On the other hand, there is a need to work on further develop system support and trust. This resulted in the identification of additional research needs reviewing the operating method and system support in order to reduce potential human error, improve task timeliness, reduce coordination tasks and ensure clear allocation of conflict responsibility.

B. Operational Feasibility

This section shows the results obtained on the operational feasibility of the concept in the analysis environment from the questionnaires and individual and collective evaluation sessions of the results by the participants in the real-time simulation.

The FCA concept has proven to be operationally feasible in upper airspace, as stated in OBJ2. In this airspace, traffic usually crosses the entire airspace established at a certain flight level so traffic in evolving phases and high traffic density and complexity is avoided. The concept could be applied to any size of airspace taking into account the display limitations this may cause in the CWP. Moreover, under the conditions applied in the definition of the exercise, in very large airspace situational awareness could be affected and new conflict points may appear, since the coordination time between controllers increases.

It should be noted that this aspect was influenced by the lack of familiarization of the controllers involved in the exercise with both the Madrid Route 1 environment and the validation platform. They all concluded that with more knowledge about these two aspects, the applicability of the concept would have been positively affected.

In relation with OBJ3, the allocation strategy has been considered acceptable. However, it has not been considered entirely safe. A significant number of conflicts between flights associated with different executive controllers were identified leading to the need of coordination, increasing the workload and decreasing situational awareness. Participants considered acceptable the automatic pre-assignment of the traffic between the different FCA positions based on the entering heading, but they stated the importance of maintaining the possibility of re-allocating different flights when needed. These re-allocations, done by the allocator, would be aligned to minimise the number of conflicts and workload unbalances.

In addition, the introduction of the allocator role was welcomed by all participants and was considered key to achieving better capacity management, balancing the workload of the different controllers, optimizing the cost efficiency resulting from the implementation of FCA and managing the need for room configuration changes. Nevertheless, they highlighted the need to develop an improved visual interface to enable the allocator to perform its task properly, which offered to the allocator information about the workload foreseen per flight and further automated support for their tasks.

The FCA environment ensures operational viability in non-nominal cases of emergency descent or loss of communications, as long as the situations are correctly handled by the operational staff. But better results would have been obtained in relation with OBJ4, if more support and automation of the system would had been applied showing a much more conspicuous alert.

Regarding conflict detection and resolution, as stated in OBJ5, the main comment from the participants was that since many conflicts involved flights assigned to different FCA positions and different frequencies the number of coordinations between different controllers increased, as well as the time needed to solve conflicts. The safety of air operations was considered to be impacted, so more automatic support from the tool to avoid it is needed.

Despite these facts, controllers were able to correctly handle all conflicts and showed full confidence in the tools regarding the conflict detection: TC/PC Aid Tools. Moreover, it is important to highlight that coordination was also negatively affected by the trust in the resolution proposals of other air traffic controllers. Consequently, the need for a legal framework to clarify the responsibilities of each air traffic controller in conflict resolution was identified.

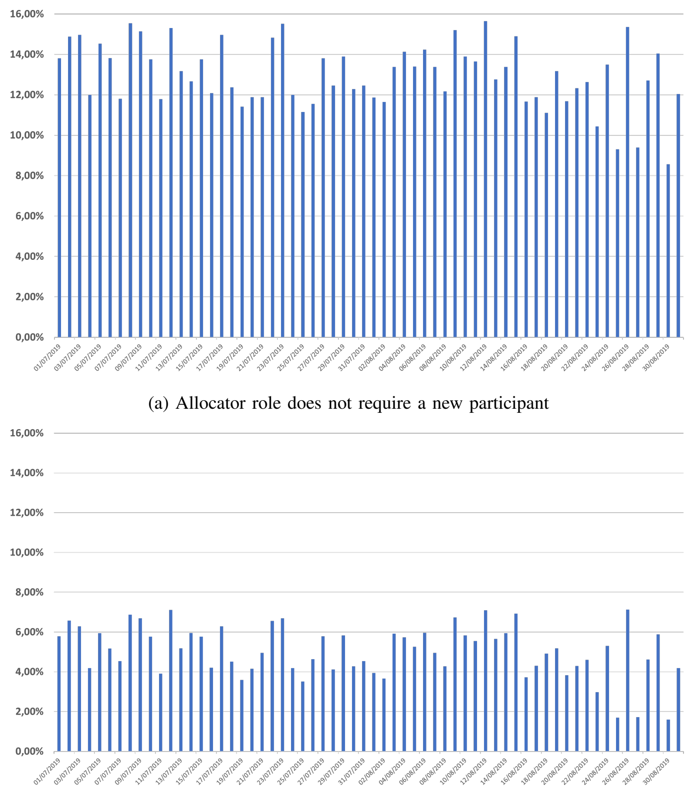
Both for cases of transition/switch between sector-based and FCA mode of ATC operation and vice versa and for those of closing or opening an FCA position the results were the same. The processes could be carried out correctly and they were considered acceptable, but the procedure defined for each of them, taking into account the limitations of the system, involved many manual actions. This made the duration of this process longer than convenient from the controllers' point of view, causing a slight loss of situational awareness. So according to the participants, OBJ6 could not be considered as completely achieved, as the procedures should be more automatic and should have more support from the system.

C. *Performance Assessment*

The benefits in terms of cost efficiency, to assess OBJ6, were analyzed based on the comparison of the behaviour of SESAR CEFF2 indicator [14] between solution and reference scenario, which is calculated as the division between the number of flights handled and the number of ATCOs hours of controllers on duty.

To carry out the study, it was determined that the minimum time of an established FCA configuration should be 40 minutes, considering it beneficial from this time on-wards. The period of time analyzed is between 01/07/2019 and 31/08/2019 due to the high traffic in the selected geographical area during these months. CEFF2 was calculated daily for the entire FCA area, both for the reference scenario and the solution scenario.

The scenario was considered beneficial when the total sum of operating control hours required when implementing the FCA concept was less than the total sum of operating control hours required in the reference scenario. This analysis has been done by considering the role of the allocator as independent participant or by having another existing position take over the role of the allocator.



(a) Allocator role does not require a new participant

(b) Allocator role requires a new participant

Figure 7. CEFF2 improvement

As can be seen in the Figure 7, taking into account the established criteria, cost efficiency benefits were obtained as solution scenario results provided better results for all the analyzed days and both cases. However, the savings are greater when the Allocator hours are not kept separate, i.e. if the function of this role is assumed by another person or position already existing in the system,

Regarding OBJ8, predictability was analyzed thorough the PRD1 indicator, defined as the average of the difference in actual and flight plan duration taking into account all flights analyzed [14].

The metric was calculated using the trajectories generated after the simulations for the period within the FCA area and the part of the flight plans introduced on the platform that were inside FCA area, for nominal use cases only.

It could be said that the predictability has been maintained, since the values estimated by the platform and the real values have not undergone significant changes, with all the mean variations being less than 20 seconds, as it can be seen in Figure 8. Therefore, it was concluded that the implementation of the FCA maintains good predictability levels.

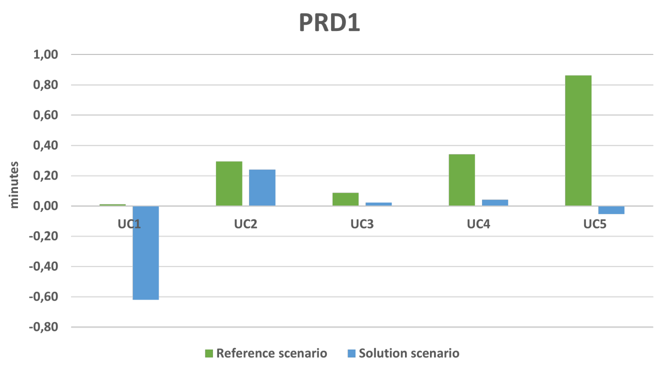


Figure 8. PRD1 indicator values for each nominal scenario performed both in solution and in reference

Finally, assessing OBJ9, fuel savings were studied based on the FEFF1 indicator, defined as actual average fuel consumption per flight [14].

The average fuel consumption per flight was calculated using the AEM model for consumption estimation which is fed by the trajectories generated by the simulations (only the part within the FCA area), both for the solution and reference scenarios. Again, as for PRD1, only nominal use cases were analyzed and traffic consistency in both scenarios was assured.

Observing the results for the defined FCA area, as seen in Figure 9, the fuel consumption was lower in solution scenarios in conflict detection and resolution (UC1), opening an FCA position (UC2) and switch from FCA to sectorized ATC (UC5) use cases. These results are remarkable but not conclusive at all. In deed, FCA is a new concept and the controllers are not so used to it, so during the simulations they did not feel so confident to give a direct contributing to fuel savings. However, the fuel savings would be greater once the concept is fully integrated.

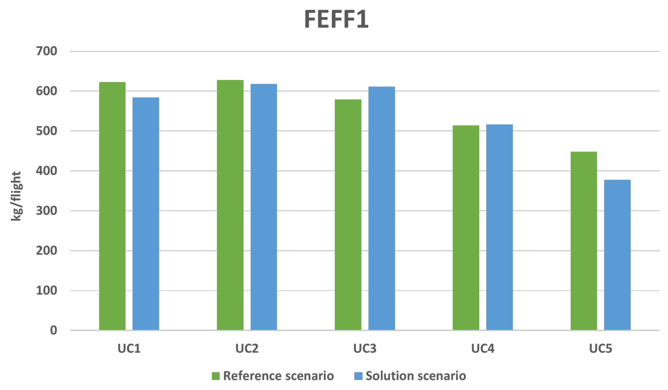


Figure 9. Values obtained for the FEEF1 indicator inside FCA region for each nominal scenario performed both in solution and in reference.

V. Conclusions and Step Forward

As main conclusion, the FCA concept can be considered operationally feasible in the Spanish upper airspace regarding the results obtained. However, it has not been fully accepted under the conditions and traffic characteristics in which it has been designed. Consequently, necessary modifications have been identified in order to be viable.

Firstly, the need to raise the flight level from which the FCA is designed has been identified to avoid traffic in evolution phases and high traffic densities. Secondly, airspace complexity should also be avoided trying to reduce conflict points, having been proved to be one of the major drawbacks of FCA application, since the coordination of them requires huge temporal and mental demand from the controller affecting situational awareness. Limiting the route network by studying the most necessary and efficient routes for aircraft and designing a simpler network with fewer conflicting points at the same level could reduce the complexity of the FCA space.

It is expected that FCA mode will allow traffic to be distributed more equitably and avoid loss of productivity in underutilized sectors, although workload has not been significantly reduced. Given this result and the impact on the situational awareness, the allocation strategy based on heading entries to the FCA area has resulted not very well accepted from the perspective of the exercise participants. Other strategies believed to be more appropriate, such as conflict-based assignment, ATCO workload, exit point or even a combination of them, have been proposed. Another aspect that may be taken into account for this assignment is the added complexity that the FCA may bring, as new co-ordinations may arise to resolve conflicts between aircraft. Taking this complexity into account, as a way of balancing the workload between different teams of controllers, is essential.

On the other hand, although the allocation strategy may not have been the most appropriate, the role of the allocator was shown to be essential to evaluate the situation and for decision-taking in order to evaluate the better FCA configuration and to achieve better capacity management, always supported by the system.

The system is something that should be looking for more automation. In a new control mode the system facilities are essential, as they help in the understanding of the concept and in the realization of the tasks. For example, in the more complex use cases, the controllers felt that they needed more automatic help from the system, as the large number of steps to be performed required a great deal of effort and caused a loss of situational awareness. The allocator HMI should also have new functionalities in order to facilitate the traffic reallocation between different FCA positions, the establishment of an appropriate allocation strategy, the evaluation for opening or closing FCA control positions and the selection of the optimal time for the transition between FCA and sectorized modes, avoiding occasional workload imbalances and potential future conflicts.

Another point from ATCOs' view was that FCA requires establishing new rules related to traffic assignment and coordination. In the event of a conflict, for example, it is important to establish which controller is responsible for its resolution. For high traffic densities, advanced conflict detection and resolution tools that can provide adequate lead time and help assign conflicts to controllers for then being solved are required. In fact, conflict detection and resolution tools were evaluated as very useful compared to the current tools and ATCOs showed high confidence in the TTM, but lacked clarification of responsibilities and resolution proposals.

In terms of aircraft performance-related aspects, cost efficiency results show the benefits that the FCA solution brings to the ATM in terms of control hours for medium complexity scenarios. On the other hand, predictability and fuel savings results are not as promising. Although there are improvements in these metrics focusing on the FCA area, no major impact has been seen. Moreover, this benefits can be offset by taking into account the need for adapting technology and procedures that the FCA concept. However, the benefit would be appreciated in the long term when all of the above is fully implemented. More research is needed to evaluate whether the FCA mode of operation could be a suitable solution to improve ATM network efficiency and reduce fuel emissions when a higher level of automation and participant's familiarization with the concept and platform is achieved.

As mentioned above, the lack of knowledge in the platform used during the execution of the exercise and the need for more automation and functionalities, could have a negative impact on the results. To mitigate this problem, it is important to further develop the tool itself and keep in mind that the training phase is essential in this type of validation campaigns to ensure that the controllers are familiar with the platform and the concept.

Moreover, it is important to note that the validation exercise has only covered the upper Spanish airspace. Nevertheless, it is plausible that the benefits from implementing FCA can be realized in bigger airspaces. This issue requires more examination, considering additional obstacles such as adapting the representation of the control area on the radar HMI, with the associated situational awareness, and the use of frequencies. There may also be legal and political hurdles associated with FCA areas involving different countries' airspaces [15] . Furthermore, in subsequent studies, weather-related non nominal scenarios and the activation of military restricted areas should be taken into account, irrespective of the size of the airspace being assessed, as real aspects present in actual ATC operations.

Finally, with this final idea in mind, the FCA concept is being further developed in the SESAR 3 FCA project, part of the HORIZON-SESAR-2022-DES-IR-01 call. In this project, the development of the concept for an ECAC-wide implementation in medium density traffic areas considering the existing national boundaries will be pursued towards industrialization phase trying to resolve those identified improvements.

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