

Flight Centric ATC – How to solve conflicts without communication and coordination overloads?

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Abstract

Flight Centric Air Traffic Control (FCA) removes fixed sector boundaries and allocates flights, rather than airspace volumes, to controllers. The concept promises a substantial reduction of handovers and a more flexible use of controller resources, but it also changes the operational problem of conflict resolution: two aircraft in conflict may be handled by two different controllers. This paper addresses that issue and describes how conflicts can be solved without creating a new coordination burden. To this end, the results of the real-time simulations of the Flight Centric ATC concept conducted at DLR over the past nine years will be examined, compared, and analyzed. The FCA approach combines medium-term conflict detection (20 to 5 minutes prior conflict), rule-based responsibility allocation and controller support functions, including DLR's Less Impacted Flight Algorithm (LIFA), to determine which aircraft shall maneuver and which controller is responsible for the resolution. Evidence from high-fidelity real-time simulations in the upper airspace indicates that conflict ownership can be separated from geographical airspace ownership without loss of operational clarity. Controllers were able to apply the priority rules, use the advisories pragmatically and retain tactical authority when adapting a suggested solution. The results suggest that conflict resolution is not a blocking issue for FCA, provided that the responsibility assignment is explicit, visible and supported by robust trajectory-based automation.

Keywords: Flight Centric ATC, sectorless ATM, conflict resolution.

1. Introduction

European airspace is experiencing increasing pressure due to the growing traffic demand; as a result, the current sector-based air traffic control (ATC) system is reaching its limits. Current en-route airspace in Europe is fragmented into many national flight information regions and smaller control sectors, which introduces inefficiencies and capacity bottlenecks. [1][2] When traffic in a sector becomes too dense, the usual workaround is to split it into smaller sectors and add more controllers; however, this approach has diminishing returns, as each sector boundary introduced requires additional coordination between controllers and more handovers of flights, which can offset the potential airspace capacity gain. Moreover, in some busy areas, sectors cannot be further subdivided without excessive workload overhead: for example, the LUXIE sector (MUAC, over Luxembourg) and WUR sector (Karlsruhe UAC, Germany) operate at maximum capacity, but they cannot be split further without greatly increasing radio communications and coordination, negating the benefit of a smaller sector. [3] As a result, delays are rising and airlines are forced to fly less efficient routes to avoid congested sectors. It is clear that new concepts are needed to safely increase en-route capacity and reduce fragmentation in Europe's skies: in this regard, the Single European Sky initiative and SESAR Programme have highlighted the need for innovative operational models to handle capacity on demand and more flexible use of airspace. [1] One promising concept emerging from this effort is Flight Centric Air Traffic Control (FCA), also known as sectorless ATM, which rethinks the traditional sector paradigm in order to unlock significant efficiency and capacity improvements. [4]

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2. Flight Centric ATC Concept Overview

Flight Centric ATC is an airspace design and control philosophy in which controllers are no longer allocated to fixed geographic sectors, but instead manage a set of flights anywhere in a large, consolidated airspace. [5][6][7] In other words, the airspace (for example, an entire country's upper airspace) is treated as a single volume without conventional sector boundaries. Controllers are each allocated a number of aircraft regardless of those aircrafts' positions, and remain responsible for guiding those flights from the entry point until they exit the airspace [5][8][9]; instead of handing over an aircraft every time it crosses an invisible sector boundary, each controller can supervise the flight throughout its en-route journey (Figure 1). [10][11][12][13]

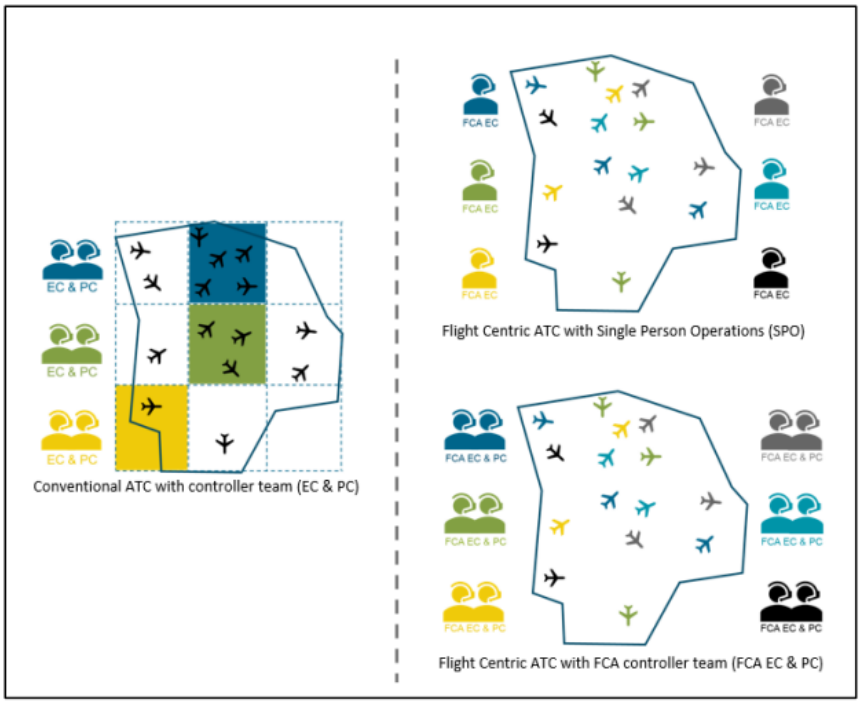


Figure 1 – conventional vs FCA concept.

The FCA concept yields several key benefits over the conventional sector-based system:

- Fewer Handoffs and Coordination: As flights are not forwarded between sector controllers, the number of controller-to-controller handovers drops significantly within the FCA area. This reduces coordination workload and communication errors, and allows pilots to deal with a single controller for a much longer portion of the route [14], pilots can fly more direct, user-preferred trajectories without the need to conform to sector boundaries or predefined hand-over waypoints. [5]
- Better Workload Distribution: A core principle of FCA is the ability to dynamically balance controller workload by adjusting the number of flights each controller is managing; in a few words, when traffic is busy some controllers can take on additional flights while others handle fewer, avoiding traffic bunching up unevenly in one sector while a neighboring sector is quiet. [15] To this aim, an allocation system automatically assigns incoming flights to controllers in a way that evens out the traffic load in real time, this means that, when working in FCA, the same number of controllers can monitor a significantly higher traffic. [16][17][18][19][20]
- Increased Capacity and Fewer Delays: By removing the sector bottlenecks, FCA promises a step-change in en-route capacity. Traffic can flow according to demand, with controllers added or removed dynamically rather than being capped by the fixed capacity of the busiest sector. Simultaneously, eliminating unnecessary path stretching and holding reduces delays and fuel consumption. Overall, the concept allows better use of available airspace, and can accommodate traffic growth without simply multiplying staff. [2] [21][22]

- Operational Flexibility: Without sector ownership, controllers and controller working positions can potentially be located remotely or pooled among multiple facilities (the virtual center idea). Therefore, it becomes easier for neighboring ANSPs to share airspace responsibility or delegate it to each other if needed, supporting a more unified European sky. Moreover, new types of air vehicles or high-altitude operations could be integrated more smoothly, since the system is focused on managing trajectories rather than segregating airspace into fixed blocks. [25]

To reach these benefits, the allocation of flights to controllers must be an active operational function. It cannot be based only on the number of aircraft, because two sets of flights with the same count may create very different workload. Relevant allocation parameters include the expected time on frequency, climb and descent phases, conflict potential, route complexity, weather deviations and the amount of pilot-controller communication anticipated for each flight. The aim is not to give every controller an identical number of aircraft, but to distribute the expected work in a way that remains stable over a useful planning horizon.

This dynamic distribution is one of the main advantages of the concept. In a sectorized system, workload peaks occur when traffic happens to concentrate in one geographical sector, even if neighboring sectors are comparatively quiet. FCA allows the system to allocate flights across a larger pool of controller working positions. When traffic demand changes, additional controllers can be inserted into the operation by assigning them flights rather than by opening a new sector with new coordination boundaries. Conversely, during periods of lower demand, flights can be consolidated without changing the structure of the airspace. [15][16]

The controller working method in FCA is still recognizably air traffic control. Controllers monitor their flights, communicate with pilots, issue clearances and solve conflicts. What changes is the context in which these tasks are performed. The controller must be able to observe the trajectories of owned and non-owned traffic in the surrounding area, as relevant conflicts may involve aircraft allocated to another controller. The human-machine interface therefore has to distinguish clearly between aircraft under the controller's responsibility, aircraft that are relevant for monitoring, and aircraft for which another controller has the current action responsibility.

This distinction is important as FCA would lose much of its benefit if every crossing situation required a negotiation between controllers. The working method must give controllers enough shared information to understand the traffic picture while preventing them from being drawn into unnecessary coordination. For this reason, conflict detection, responsibility assignment and resolution support are not optional add-ons to FCA; they form part of the operational concept.

FCA relies on a consistent trajectory picture. The Medium-term conflict detection (MTCD) tool uses planned and updated trajectories to identify future losses of separation early enough for strategic or pre-tactical intervention. In this regard, the look-ahead time applied in the DLR validation work was set to 20 minutes. This timeframe allows controllers to identify and resolve a conflict before it develops into a short-term tactical problem (up to two minutes before separation infringement), while accounting for the growing inaccuracy of trajectory prediction over longer time periods. [5][26][28] The longer and more stable the predicted trajectory segment is, the easier it becomes to decide which controller has to act and which maneuver causes the lowest operational disturbance.

Automation in this context is not intended to replace the controller. Its task is to remove ambiguity from recurring coordination problems. It detects potential conflicts, marks the aircraft that should give way, proposes maneuvers and monitors whether the chosen solution remains conflict-free. The controller remains responsible for assessing the advice, taking account of the actual operational situation and issuing the clearance. This division of labor is essential for acceptance, the system supports the controller, but the controller keeps the final operational authority.

3. Conflict Resolution in Flight Centric ATC

One of the most critical challenges when implementing an FCA environment is handling conflicts (losses of separation) between aircraft when the traditional notion of “ownership” of airspace is removed. In conventional ATC, a conflict is almost always solved by the controller responsible for the sector in which the two or more aircraft are flying: so, as all aircraft in a conflict are usually in the same sector at the moment of interaction, a single controller (or controller team) can detect and solve the conflict by his own. In a FCA scenario, however, conflicting aircraft might be assigned to different controllers, as the flights are no longer allocated based on a geographical region. This raises one important question: “Who is responsible for solving a conflict when each aircraft has a different

controller?". Without special provisions, this situation would demand a lot of coordination: the two controllers would have to communicate and agree on a resolution strategy for every conflict, which would be impractical and negate some of the efficiency gains of the FCA concept. [4][23][24]

To avoid this inefficiency, Flight Centric ATC introduces formal priority rules and automated decision support to streamline conflict resolution responsibilities. Essentially, a set of unambiguous right-of-way rules determine which aircraft in a conflict should maintain its trajectory and which one should maneuver to avoid the other. These priority rules can be based on factors like flight phase (e.g. climbing vs. cruising), heading, or an algorithmic assessment of which aircraft would be less impacted by a deviation. The German Aerospace Center has developed a Conflict Detection and Resolution (CD&R) tool integrated with what is called the Less Impacted Flight Algorithm (LIFA) to implement this logic. [4] When the medium-term conflict detection system predicts a potential loss of separation (typically with a look-ahead of 15-20 minutes), the LIFA algorithm automatically evaluates the aircraft involved (a pair or more) and determines which one should give way (take avoiding action) for each conflict. The aircraft deemed to have right-of-way will ideally continue its flight unaffected, while the other aircraft, the "less impacted" one, will be maneuvered; this means that the system clearly identifies one controller who is responsible to solve the conflict, without the need of any coordination/communication (see Figure 2). In addition, the system provides this controller with one or more possible avoidance maneuver to solve the conflict safely. The conflict-resolution suggestions are computed to not only solve the conflict itself but also to avoid creating new conflicts within the next 15 minutes, based on the current traffic situation. In essence, automation helps to coordinate the controllers' actions in advance, so that multi-controller conflicts are handled as smoothly as conflicts within a single sector are today. [5][14]



Figure 2 – Less Impacted Flight Algorithm

In summary, conflict resolution in FCA is "special", as it relies on predefined rules and decision support tools to allocate responsibility for conflict solving without geographical sectors. This prevents ambiguity and minimizes the need for inter-controller coordination, even when conflicting aircraft are handled by different controllers. By design, these procedures maintain safety equivalence with today's system: every potential conflict has a controller assigned to solve it, and all controllers have a clear picture of which aircraft under their responsibility have conflicts and what solutions are suggested. Early validation runs indicate that controllers can adapt to this, they follow the system's priority rules and resolution advisories, which allows FCA operations to run safely and smoothly. [16]

4. High-fidelity real-time simulations

The analysis presented in this paper is based on a series of high-fidelity real-time simulations conducted by the German Aerospace Center (DLR) and its operational partners, including HungaroControl, Frequentis and UkSATSE. These activities have been carried out over several research phases since 2017 and provide a broad empirical basis for assessing the feasibility of Flight

Centric ATC in operationally relevant environments. The focus of the carried-out analysis is especially the question of whether conflicts can be detected, assigned and solved without introducing a new layer of communication and coordination workload between controllers. The three simulation campaigns described below were examined in detail (Table 1).

Table 1 – Flight Centric ATC simulation campaigns

	Simulation campaign 2018	**Simulation campaign 2022**	**Simulation campaign 2024**
Partners	DLR Frequentis HungaroControl	DLR Frequentis ATCOs from 5 different ANSPs (PANSA, DFS, ON, ENAV, ENAIRE)	DLR UkSATSE
Airspace Under Consideration (horizontal/ vertical)	Hungary (whole country)	Hungary (whole country)	Ukraine (whole country)
	FL325 – FL660	FL325 – FL660	FL275 – FL660
Scenarios	2 Normal 2 Degraded-mode	3 Normal 4 Abnormal 3 Degraded-mode	2 Normal 2 Abnormal 3 Degraded-mode
Involved positions	10 FCA ATCOs 5 Feeder ATCOs 10 Pseudo pilots	10 FCA ATCOs 5 Feeder ATCOs 10 Pseudo pilots	5 FCA ATCOs 5 Pseudo pilots
Nb of ATCOs involved	15	15	11

Across these investigated simulations, medium-term conflict detection was used as the primary support function for identifying potential losses of separation. The look-ahead time was in the range of 20 to 5 minutes, allowing conflicts to be addressed before they became tactically urgent. This early detection window is particularly important in a Flight Centric ATC environment, as responsibility for aircraft is no longer linked to a defined geographical sector. Instead, conflicts may involve aircraft handled by different controllers, even though the aircraft are operating in the same physical airspace. The simulations therefore provide an appropriate environment for testing whether procedural rules and decision support tools can replace conventional sector-based coordination mechanisms.

The overall results indicate that the absence of sector boundaries does not, in itself, reduce the ability of controllers to maintain separation. On the contrary, the availability of a larger and less fragmented traffic picture can support earlier recognition of conflict situations and reduce the dependency on handover-related coordination. In the investigated scenarios, conflicts were detected by the system before they became critical, and the controllers were able to act on the information provided. This suggests that Flight Centric ATC does not shift conflict resolution into a more uncertain or less controlled environment, provided that conflict detection, responsibility assignment and resolution support are implemented as integrated functions. [26][27]

4.1 Conflict Resolution Responsibility Allocation

A key result concerns the allocation of responsibility for conflict resolution. In conventional sector-based ATC, the question of responsibility is usually answered by the sector structure itself. The controller responsible for the sector in which the aircraft are operating is also responsible for detecting and solving conflicts in that sector. In Flight Centric ATC, this automatic link between airspace ownership and conflict responsibility no longer exists. A conflict may involve two aircraft allocated to two different controllers, and without additional rules this could lead to uncertainty, duplicated actions or time-consuming verbal coordination.

The simulations showed that this problem can be addressed by introducing explicit priority rules and automated responsibility assignment. The conflict resolution logic, including the Less Impacted Flight Algorithm, was able to identify the aircraft that should be maneuvered and, by implication, the controller responsible for initiating the resolution. As a result, the conflict was not treated as a shared coordination problem, but as a clearly assigned operational task. Data from human-in-the-loop

simulations carried out by DLR in 2022 shows that in between 87 % and 100 % of conflict situations, the controller that was determined by the system to be responsible for a conflict also ended up solving the conflict, as presented in Figure 3. As controllers were instructed to coordinate and switch responsibility, if necessary, this indicates a high degree of approval with the system's suggestion.

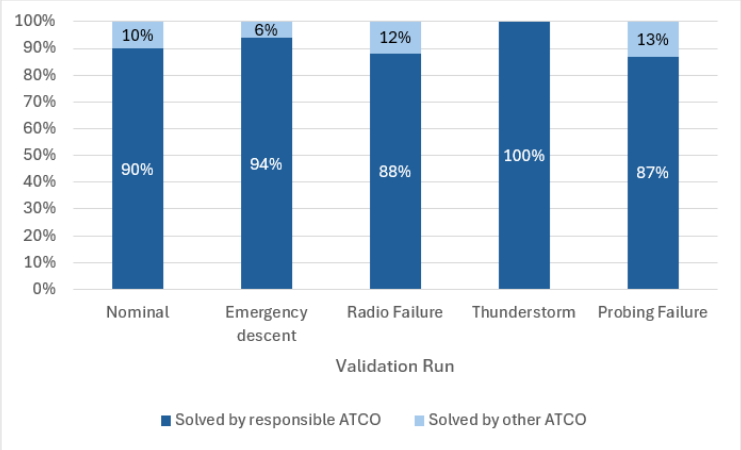


Figure 3 – Rate of conflicts solved by responsible vs. non-responsible controller

This finding is important as it demonstrates that conflict ownership can be separated from airspace ownership. In the simulated FCA environment, a controller did not need to own the geographical area in which the conflict occurred in order to solve it. What was required instead was an unambiguous assignment of the conflict to one controller, a clear indication of the aircraft to be maneuvered, and a shared understanding among all controllers that this assignment was binding for the operational handling of the situation.

Controllers reported that this clarity reduced ambiguity and avoided coordination deadlocks. No evidence was found that controllers routinely attempted to solve the same conflict independently. Likewise, there was no indication that conflicts were left unresolved because responsibility was unclear. This is a key result for the operational credibility of Flight Centric ATC. It shows that the concept does not require controllers to negotiate responsibility for each individual conflict, which would undermine the expected efficiency gains. Instead, responsibility can be allocated systematically and displayed directly within the controller working environment. [28][29]

4.2 Controller Workload and Cognitive Effects

From a human factors perspective, one of the main concerns regarding Flight Centric ATC is whether controllers can maintain situational awareness when their aircraft are distributed over a large airspace rather than grouped within a sector. The simulations indicate that this concern is valid but manageable. Controllers do not rely on sector boundaries alone to build a mental picture of the traffic situation; they also rely on conflict indications, trajectory information, labels, filtering functions and the consistency of task allocation. The removal of sector handovers had a positive effect on the temporal structure of the work. In conventional operations, conflicts close to sector boundaries can create additional pressure as the involved aircraft may soon be transferred to another controller. This can force controllers either to solve the conflict quickly before handover or to coordinate the situation with the next sector. In the FCA environment, this source of pressure was reduced. Since a controller remains responsible for an allocated aircraft over a longer portion of its route, the conflict can be handled without preparing an imminent handover at the same time. Controllers reported that this made several conflict situations easier to manage. Their attention could be directed toward the conflict geometry, the available solution options and the downstream effects of the maneuver, rather than toward coordination timing. This does not mean that FCA automatically reduces workload in all cases. Workload still depends on traffic density, the number of aircraft assigned to one controller, the number of simultaneous conflicts, and the quality of the support tools. However, the simulations showed that the type of workload changes. Less effort is spent on boundary-related coordination, while more importance is placed on monitoring a distributed set of flights and understanding system-generated support information. During peak traffic scenarios, the number of conflicts increased as expected. Nevertheless, the available results indicate that conflict resolution remained manageable when supported by medium-term detection, clear responsibility assignment and dynamic flight allocation.

No systematic safety-critical workload peaks were observed, which suggests that Flight Centric ATC can scale beyond the limitations of fixed sectors, provided that the number and complexity of aircraft allocated to each controller are actively managed. [28][29]

4.3 Communication and Coordination Effects

A major motivation for Flight Centric ATC is the reduction of coordination workload. In a sector-based system, each additional sector boundary creates potential coordination needs. Aircraft must be handed over, clearances must be coordinated, and conflicts close to a boundary may require discussion between controllers. This is especially problematic in highly fragmented airspace, where a flight may cross several sectors within a short period of time. The simulations support the assumption that FCA can reduce this type of workload. Since flights are not transferred from one sector controller to another at every boundary crossing, the number of routine handovers is reduced. More importantly, conflict resolution does not automatically become a coordination task between the controllers responsible for the aircraft involved. The responsibility assignment logic determines which aircraft is to be maneuvered and which controller has to act. As a result, the coordination process is shifted from verbal negotiation between controllers to rule-based support embedded in the system. This does not mean that communication disappears. Controllers still communicate with pilots, supervisors and, where necessary, other operational roles. However, the communication is less driven by artificial sector boundaries and more directly linked to operational needs. In this respect, FCA changes the character of coordination. It removes many routine coordination events and reserves explicit human coordination for cases where it is necessary, such as abnormal situations, unclear system states or strategic traffic management decisions. A certain need for coordination remains; for example, when controllers intend to issue a clearance that conflicts with other traffic, or when they disagree with the conflict responsibility assigned by the system, they may coordinate and reassign responsibility as needed. Table 2 shows that controllers rarely needed to coordinate in order to solve a conflict in the DLR-UkSATSE validation campaign of 2022.

Table 2 – Participant responses about the need of coordination for conflict resolution

Was there any occasion when you had to coordinate with another controller to solve a conflict?		
Validation Run	***No***	***Yes***
Nominal	82.1 %	17.9 %
Thunderstorm	90.9 %	9.1 %
STCA	100 %	-
Radio failure	92.9 %	7.1 %
Conflict resolution failure	100 %	-
Datalink failure	93.3 %	6.7 %

The reduction of routine coordination is one of the most relevant operational benefits observed in the simulations. It supports the argument that Flight Centric ATC should not simply be understood as “sectorless airspace”, but as a different way of organizing controller responsibility. The benefit is not only that sectors are removed, but that the work associated with maintaining sector boundaries is also reduced. [28][29]

4.4 Non-Nominal and Degraded Scenarios

The robustness of conflict resolution was further assessed under non-nominal and degraded conditions. These scenarios are essential as an operational concept cannot be considered viable if it only works under ideal technical and traffic conditions. In the investigated simulations, non-nominal situations included weather-related rerouting, unusual traffic patterns and reduced availability of automation support functions. The results indicate that FCA conflict resolution does not depend on automation as a single point of failure. When automated resolution support was reduced, controllers were still able to apply conventional ATC techniques, supported by the larger traffic picture and the remaining system functions. This is an important finding as it shows that the FCA concept can be designed with fallback possibilities. The automation improves clarity, speed and consistency, but the controller must still be able to understand the situation and intervene manually. However, degraded scenarios also show where future development is necessary. The more the concept relies on

automated assignment, trajectory prediction and conflict support, the more important it becomes to define clear degraded modes. Controllers need to know which functions are still available, which information can still be trusted, and which procedures apply when support is reduced. In this respect, degraded operations are not an exceptional add-on to the concept, but they are a core design requirement. The simulations suggest that controllers can handle degraded situations if the transition into the degraded mode is clear and if the human-machine interface continues to provide a coherent traffic picture. Ambiguous or partial degradation, where controllers are uncertain about the reliability of system indications, would be more problematic than a clearly declared fallback mode. [28][29]

4.5 Summary of Preliminary Findings

The results demonstrate that conflict resolution in Flight Centric ATC is operationally feasible when three conditions are met. First, conflicts must be detected early enough to allow planned rather than purely tactical intervention. Second, responsibility for each conflict must be assigned unambiguously to one controller. Third, the controller must receive resolution support that is transparent and understandable, operationally plausible and compatible with human tactical authority.

Under these conditions, the absence of sector boundaries does not create unacceptable ambiguity. On the contrary, the simulations indicate that conflict management can become more direct because it is no longer tied to sector ownership, handover timing or boundary coordination. Conflict responsibility is assigned by the system according to defined rules, and controllers can focus on solving the conflict rather than negotiating who should act. The findings also show that Flight Centric ATC should not be assessed only in terms of capacity or delay reduction. Its operational value also lies in the way it changes the structure of controller work. It reduces boundary-driven coordination, supports earlier conflict handling, and enables responsibility to follow flights rather than airspace fragments. These effects are central to the concept and provide the basis for the discussion in the following chapter.

5. Discussion: Conflict Resolution without Coordination Overload

The results presented in the previous chapter address one of the most critical questions for Flight Centric ATC, how conflicts can be solved when aircraft are no longer grouped by geographical sector responsibility. At first glance, the removal of sectors appears to create a responsibility problem. If two aircraft are in conflict but are handled by different controllers, it is not immediately obvious who should act. In a conventional environment, this question is usually answered by the sector structure. In FCA, it must be answered by the operating concept itself. The simulations show that this challenge is not a fundamental obstacle. Conflict resolution can be organized without excessive coordination if responsibility is assigned explicitly, consistently and transparently. The key point is that Flight Centric ATC does not remove responsibility, it relocates it. Responsibility is no longer derived from ownership of a piece of airspace, but from ownership of a flight and from the rule-based assignment of conflict resolution tasks. This distinction is key to understanding the concept. A sector-based system is built around territorial responsibility. A controller is responsible for all relevant aircraft within a defined volume of airspace. A flight centric system is built around trajectory responsibility. A controller is responsible for a set of aircraft, even if those aircraft are distributed across a larger airspace. Conflict resolution therefore becomes a relational task. The system has to identify which aircraft in a conflict should be maneuvered and which controller is responsible for that aircraft.

5.1 Decoupling Conflict Responsibility from Airspace Ownership

The most important conceptual implication of the results is, that conflict responsibility can be decoupled from airspace ownership. This is a substantial change in operational logic. In conventional ATC, sectors provide a simple and robust way to allocate responsibility, but they also create fragmentation. Every boundary introduces handovers, coordination tasks and potential inefficiencies. Flight Centric ATC removes these invisible boundaries, but must then on the other hand provide another mechanism to maintain operational clarity. The evaluated approach achieves this through rule-based responsibility assignment supported by automation. The Less Impacted Flight Algorithm plays a central role as it determines which aircraft should be maneuvered. Once that aircraft is identified, the responsible controller is also identified. This means that the conflict is not left open for negotiation between controllers. The system converts a potentially multi-controller situation into a clearly assigned task. This has two consequences. First, it reduces the risk of duplicated or contradictory actions. If two controllers independently solve the same conflict, they may create unnecessary deviations or even generate secondary conflicts. Second, it reduces the risk of delayed

action. If responsibility is unclear, controllers may first need to coordinate before issuing a clearance. In time-critical situations, this delay is undesirable. A rule-based assignment avoids both problems by making the expected action clear at an early stage. The findings therefore suggest that FCA can maintain the safety benefit of clear responsibility while reducing the inefficiencies associated with fixed sector boundaries. This is not a minor procedural change. It is a shift from geographically defined responsibility to conflict-specific responsibility.

5.2 Human-Machine Cooperation instead of Full Automation

The results also underline that automation in FCA should not be understood as a replacement of the controller. The system detects conflicts, assigns responsibility and proposes solutions, but the controller remains responsible for operational execution. This distinction is important for both safety and acceptance. A fully automated conflict resolution system would require a very high level of trust and certification. It would also risk moving controllers into a passive monitoring role, where they may lose detailed awareness of the traffic situation. The FCA approach evaluated in the simulations follows a different logic. Automation structures the task, but the controller remains part of the decision chain. The controller can assess the proposed solution, accept it, modify it or choose another resolution. While the resolution maneuvers suggested by the system are generally conflict-free, other clearances must be checked for conflicts with other trajectories with the help of probing tools or deactivating the filtering and assessing the traffic situation. All trajectory changes entered into the system by the controller are continuously checked by the system for conflicts which are then indicated on the Human-Machine Interface (HMI). This form of human-machine cooperation appears well suited to the current maturity of the concept. It allows the system to reduce complexity where automation is strong, for example in scanning trajectories and identifying possible conflicts. At the same time, it preserves human judgement where contextual interpretation is required, such as assessing pilot behavior, operational constraints, unusual traffic situations or the broader acceptability of a maneuver. The acceptance of resolution advisories depends strongly on whether they appear understandable and operationally reasonable to the controller. A technically correct solution may still be rejected if it does not match the controller’s perception of the situation or if it creates operational side effects that are not sufficiently visible. For this reason, future FCA tools should not only optimize conflict geometry. They should also explain, or at least make visible, why a particular aircraft has been selected and why a certain maneuver is recommended.

5.3 Workload, Situational Awareness and Trust

The simulations indicate that FCA changes controller workload rather than simply increasing or decreasing it. Some tasks become easier or less frequent, especially routine handovers and coordination at sector boundaries. Other tasks become more important, particularly monitoring a distributed set of aircraft, interpreting system-generated conflict information and maintaining awareness of aircraft outside a traditional sector frame. This has implications for training and system design. Controllers must learn to build situational awareness around assigned flights rather than around a geographical sector. This requires suitable HMIs, filtering mechanisms and conflict displays. The human-machine interface must help controllers understand which aircraft are their responsibility, which conflicts require action, and which aircraft are relevant for monitoring even if they are not directly assigned to them. Trust is another key factor. Controllers must trust the system enough to use its support, but not so much that they stop monitoring the situation critically. This balance is delicate. If the system produces too many irrelevant alerts or implausible advisories, controllers may ignore it. If the system appears too authoritative or opaque, controllers may become reluctant to challenge it. The most promising approach is therefore a transparent advisory system that supports controller expertise rather than competing with it. The results suggest that this balance is achievable. Controllers were able to work with the conflict resolution support and retained tactical authority. This is an encouraging finding, because acceptance by operational controllers is essential for any future implementation of FCA.

5.4 Limitations of the Present Assessment

The findings presented in this paper should be interpreted as strong evidence for feasibility, but not as a final proof of universal applicability. Currently the concept has reached technical readiness level 6 only for low and medium complex en-route airspaces. Other airspaces may present different challenges, especially if they include more complex climb and descent interactions, dense crossing flows, mixed civil-military structures or different communication constraints. The results are also

dependent on the quality of trajectory prediction and conflict detection. If trajectory data are inaccurate, conflict advisories may be delayed, unnecessary or incomplete. Similarly, the effectiveness of the Less Impacted Flight Algorithm depends on the operational assumptions embedded in the algorithm. These assumptions may need adaptation for different airspace structures or traffic patterns. Another limitation concerns long-term operational adaptation. Real-time simulations provide valuable insight into feasibility and controller behavior, but they cannot fully reproduce the organizational effects of long-term use. Training, procedures, staffing models and licensing would all need to be addressed in the deployment phase of the concept.

5.5 Overall Interpretation

The results support the conclusion that conflict resolution is not a limiting factor for Flight Centric ATC if it is designed as an integrated operational process. The decisive element is not the absence of sectors, but the presence of a clear alternative responsibility model. When conflicts are detected early, assigned unambiguously and supported by transparent advisories, controllers can solve them without creating the coordination overload that might otherwise be expected in a sectorless environment. This finding strengthens the case for FCA as a serious option for future en-route operations. The concept addresses one of the structural limitations of the current sector-based system: the fact that capacity is constrained not only by traffic volume, but also by the coordination burden created by sector fragmentation. By assigning responsibility to flights and by supporting conflict resolution through rule-based automation, FCA offers a way to reduce this burden while preserving clear operational accountability. At the same time, the concept should not be understood as a simple capacity solution. Its success depends on careful design of allocation logic, support tools, controller interfaces, training and fallback procedures. If these elements are weak, the removal of sectors could create new complexity. If they are well integrated, the results indicate that Flight Centric ATC can provide a safe, scalable and operationally acceptable method for managing future en-route traffic. The main contribution of the present work is therefore to show that conflict resolution in FCA can be organized without relying on continuous controller-to-controller coordination. This is a necessary condition for the concept to deliver its expected benefits. The simulations indicate that this condition can be met, making conflict resolution not an obstacle to Flight Centric ATC, but one of its central enabling mechanisms.

6. Conclusion

Flight Centric Air Traffic Control represents a fundamental shift in the way en-route air traffic can be managed. Instead of assigning controllers to fixed geographical sectors, the concept assigns responsibility for individual flights across a larger and less fragmented airspace. This approach directly addresses one of the main limitations of the current sector-based system: the increasing coordination workload caused by airspace fragmentation, handovers and sector-boundary constraints. The analysis shows that conflict resolution is not an obstacle for the implementation of Flight Centric ATC. The removal of sector boundaries does not remove responsibility; rather, responsibility must be assigned through explicit rules, reliable conflict detection and transparent decision support. In particular, automated responsibility assignment and tools such as the Less Impacted Flight Algorithm make it possible to determine which aircraft should maneuver and which controller should act, without requiring continuous coordination between controllers. The high-fidelity real-time simulations discussed in this paper indicate that controllers can manage conflicts safely and effectively in a flight-centric environment. Medium-term conflict detection (in a time range of 20 to 5 minutes prior to the conflict), unambiguous responsibility allocation and understandable resolution advisories allow conflicts to be handled before they become tactically urgent. At the same time, controllers retain operational authority, meaning that automation supports rather than replaces human decision-making. The findings also show that Flight Centric ATC changes the nature of controller workload. Routine handovers and boundary-related coordination are reduced, while greater importance is placed on trajectory monitoring, system-supported conflict management and maintaining situational awareness across a larger airspace. This makes the design of human-machine interfaces, training procedures and fallback modes essential for future implementation. Overall, Flight Centric ATC offers a promising operational model for increasing capacity, reducing fragmentation and improving the flexibility of European en-route airspace. However, its success depends on the careful integration of allocation logic, conflict detection, resolution support, controller interfaces and degraded-mode procedures. Further validation in more complex traffic environments will be necessary before operational deployment in those areas. Nevertheless, the simulations provide strong evidence that conflict

resolution in Flight Centric ATC can be organized without creating coordination overload, making it one of the key enabling mechanisms of the concept rather than a limiting factor.

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