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# Modeling flight pairing strategies for formation flights in continental airspace.

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## Abstract

Formation flights has shown important environmental improvement in oceanic flights, but there is a lack of knowledge about the scalability in continental flights can be of great help for sustainable development of the airline industry. In this article, the implementation of an opportunistic pairing model supported by a Spatial Matrix Database is described to estimate potential candidates that could share a trajectory in formation flight. The results indicate the degradation of pairing candidates based on the application of heuristics. Out of the total number of flights analyzed, 5,83% of actual flights in Europe airspace could be used for conducting formation flights.

**Keywords:** Formation flight; Spatial database; Airspace optimization

## 1. Introduction

The ICAO and the United Nations Sustainable Development Goals (ICAO, nd.) are certainly linked, these goals provide a framework for sustainable development of the future aviation industry, reducing CO2 emissions, and enhancing global connectivity while maintaining safety in air operations.

One of the principal problems of air transport is the environmental impact generated by all daily flights. Some articles report that the aviation industry is responsible for 12% of worldwide CO2 emissions (Al-Rabeei et al., 2021; Harrison et al., 2015). Additionally, with the increasing use of air transport in recent years, these emissions continue to grow constantly, so a simulation model to experiment with new procedures to mitigate CO2 emissions would be helpful to identify the most prominent opportunities.

In a context where the amount of flight is expected to increase (EUROCONTROL, nd.), the development of simulation models tools that promote predict a reduction of costs, pollution, and air traffic congestion, while maintaining safety, is of great importance to envisage the changes to be introduced in present Air Traffic Management (ATM) rules. The actual application of Free route airspace (FRA) as a part of the Single European Sky Air Traffic Management Research (SESAR) program is an example, the goal is to minimize and simplify operations in the European air space. In consequence, the efficiency of the flights is increased, due to point-to-point routes. Furthermore, there is a considerable reduction in the ATM workload and air traffic capacity optimization. Some authors conclude that utilization of FRA can represent savings of approximately 39 000 kilometers in distance, which means 26 km saved per flight on average or 85 kilograms of fuel (Majka & Pasich, 2022).

Recents experiments of Fello'fly project (Airbus, nd.) in the Atlantic area shows a reduction of fuel consumption through the implementation of formation flights (FF). It has been shown that the use of this type of flight significantly reduces induced drag, resulting in considerable savings of fuel and a lower environmental impact (Phale et al., 2012). According to certain articles (Bower et al., 2019; Dahlmann et al., 2020), the utilization of formation flight in en-route traffic can represent a 5 to 10% fuel saving during flight, and in consequence an important reduction of harmful emissions. Inspired by the formation flights of migratory birds (Lissaman & shollenberger, 1970), where they use the V formation to increase aerodynamic efficiency, they can increase their flight distance by up to 70% compared to a single bird flight. Formation flight can be planned before departure, establishing the optimal route (Kent & Richards, 2013), taking into account departure times, as well as meeting and diversion points. However, planning efficient meeting waypoints among aircraft for FF requires a perfect coordination among departure times at the origin airports and mechanisms to mitigate any perturbation to the planned trajectory. This is an important drawback since not all the airports can ensure a planned departure time. An alternative to strategic planning FF, is an operational approach in which potential FF couple candidates must be identified once the aircraft are enroute. This operational approach is known as opportunistic FF, where two flights can meet during the route casually to perform the formation. In this paper the main requirements for an efficient FF between enroute aircraft are analyzed, such as the ammendments to the original trajectory and the length of the shared trajectory that can be achieved.

This article analyses the flight pairs detection between aircraft that can be capable of performing opportunistic formation flight, through the vertical and horizontal search radius between aircraft. In this way, as the search radius distances are increased both vertically and horizontally, we can observe an exponential increase in the total number of flight pairs capable of formation flight.

The paper is organized as follows. In section 2, a review of related work is made. Section 3 describes the methodology and materials used to find flight pairs. Section 4 discusses and summarizes the obtained results. Section 5 concludes the paper

## 2. State of the art / Related work

Various articles conclude that formation flight represents a significant improvement for general aviation, generating a great saving in fuel and as a result, a reduction in CO2 emissions (Tait et al., 2022; Wagner et al., 2002). Regarding safety, in (Economon, 2008) a safety analysis provides how certain parameters affect the strength of the vortex generated by the leading aircraft on the aircraft behind it. The wing span, if similar to the wake span, reduces the coefficient of roll. Therefore, the size of the aircraft is a factor to consider. Not only the size of the aircraft and its wings should be considered, but also its shape. A vortex produced by an aircraft with more rectangular wings generates a greater vortex force. All these are factors to consider, so when applying policies to search for flight pairings, not only space-time and cost-benefit should be taken into account, but also the physics of each aircraft must be evaluated.

Airbus, with the tests carried out in its Fello'fly project (Airbus, nd.), where two A350s performed an oceanic test formation flight on November 9, 2021, from Toulouse, France to Montreal, Canada, achieved a savings of between 5-10% of fuel compared to a conventional flight. The Fello`fly project accounts for 1,200 potential flight pairs per day, as well as a significant reduction in emissions and fuel savings. Although this proposal presented by Airbus is mainly focused on transoceanic flights and needing pre-flight planning.

Another case of application of formation flight was carried out by Boeing along with the company FedEx (Flanzer et al., 2020), who performed formation flights between different bases of the company in the United States. These tests concluded in a substantial saving of fuel, which generated a significant economic saving.

For the application of opportunistic formation flight in European airspace, there is less research. All these studies point to a potential use in commercial aviation in continental airspace, although there is little research on the viability and application of these types of flights. This research should establish potential numbers of usable flight pairs per day.

To achieve formation flight, an airspace with minimal flight restrictions is necessary. Currently, Eurocontrol is searching for measures to develop and improve the European airspace, an example is the Single European Sky Air Traffic Management Research (SESAR) program (Bolić & Ravenhill, 2021), which aims to unify European airspace, with the objective of improving capacity, efficiency, safety, and environmental impact, which translates into a substantial improvement in Key performance areas (KPA). On a small scale, Free Route Airspace (FRA) sectors are found, which allow point-to-point routes avoiding airways. All these measures optimize operations and simplify the use of the airspace, and paves de way for the implementation of the opportunistic FF in continental airspace.

Regarding the search for potential airplane pairs to perform formation flight, there is not much research either. The technique used in this article to find these pairs is based on the analysis of spatio-temporal interdependencies among aircraft candidates where two trajectories coincide in space and time, which can perform a formation flight. There are many studies that address the problem of conflict detection (CD) based on different search techniques and algorithms (Kuchar & Yang, 2000; De Homdedeu et al., 2017), and airspace complexity (Isufaj et al., 2022) each with a different motivation but useful as a baseline for identifying potential FF candidates. Thus, parametrizable CD algorithms are useful to identify aircraft in the surrounding area, while hotspots and complex airspace volumes are useful to identify areas with potential FF candidates. There is very little research on the use of CD and/or airspace complexity methods to find flight pairs that could implement a FF.

Mostly, studies on formation flight analyze and investigate the technical application of formation flight, fuel efficiency, and the reduction of harmful gas emissions. Similarly, there are various studies on the optimization of routes, geometries, and parameters to consider when performing formation flight (Antczak et al., 2022). On the other hand, there is little research on the search for airplane pairs for opportunistic formation flight. Authors consider that an application analyzing air traffic at real time could be of great interest to visualize different FF opportunities to improve ATM KPI's.

This article aims to fill some gaps on the potential applicability of formation flight in European airspace, showing how many pairs of aircraft are capable of doing formation flight, modeling different scenarios of flight pairs detection to visualize different results, which in the future and for further research could be very useful.

## 3. Methodology

### 3.1. Spatial Database

To find flight pairs, a Spatial Database (SDB) (Nosedal et al., 2015) has been implemented in Python, which consists of dividing the entire airspace into different cells for a given flight level (FL). Analyzing real historical flight trajectories in the European airspace, for each flight, it can be obtained: the flight's Callsign, the latitude and longitude of the entire flight trajectory, the altitude for each moment of the flight, and the time of recording of these data. With this data set, by dumping it into the spatial database, a model has been implemented to identify potential FF candidates.

Is important to take into account, that depending on the cell size, the loading time of counting flights per cell will oscillate, the smaller the cell size, the longer the charging time. On the other hand, the search for spatio-temporal coexistences in each cell will take more time as the size of the cell increases, since the number of flights to compare will increment.

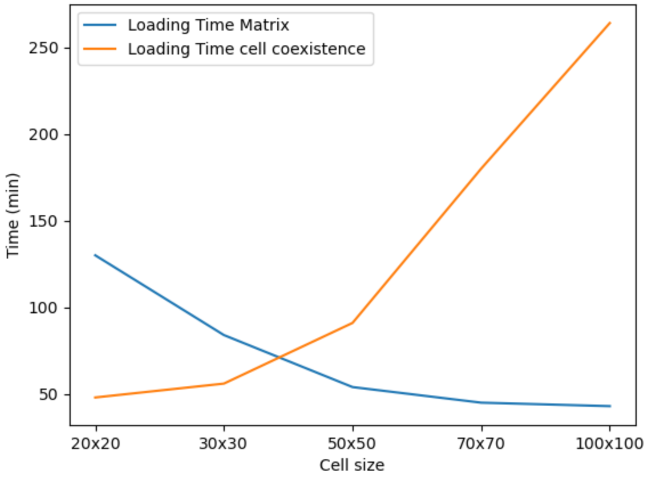

**Figure 1.** Spatial Database (blue) vs Spatio-temporal coexistence loading time (orange), depending on the cell size.

Although the 20nm x 20nm matrix is not the fastest one (see Figure 1) loading the matrix, this configuration allows limiting the distances between coexisting aircraft, since the maximum will not be superior to the diagonal of the cell, considering this distance reduced enough to become potentially usable for formation flight. Contrarily this 20nm x 20nm matrix results in the fastest cell coexistence runtime.

The spatial database has been implemented by a matrix (see Figure 2) with a resolution of 20 nm x 20 nm per cell, supporting the full European airspace, with the corners of the quadrant that forms Europe (lat = 35, long = -15) and (lat = 72, long = 35) representing a search quadrant of 1000nm x 2220nm. This way, the corners of the matrix, as well as the interior space where we will perform the search for flight pairs, are defined.

In this study, the Spatial Database resolutions consists of 5500 quadrants, which a matrix of 110 x 50 cells. For each cell, it is recorded the callsign of the aircraft trajectory together with the entry time and the exit time of the aircraft in the cell. This way, the search areas to identify FF candidates are reduced only to the interior space of each square and the adjacent squares, which significantly reduces the computational effort when searching for flight pairs.

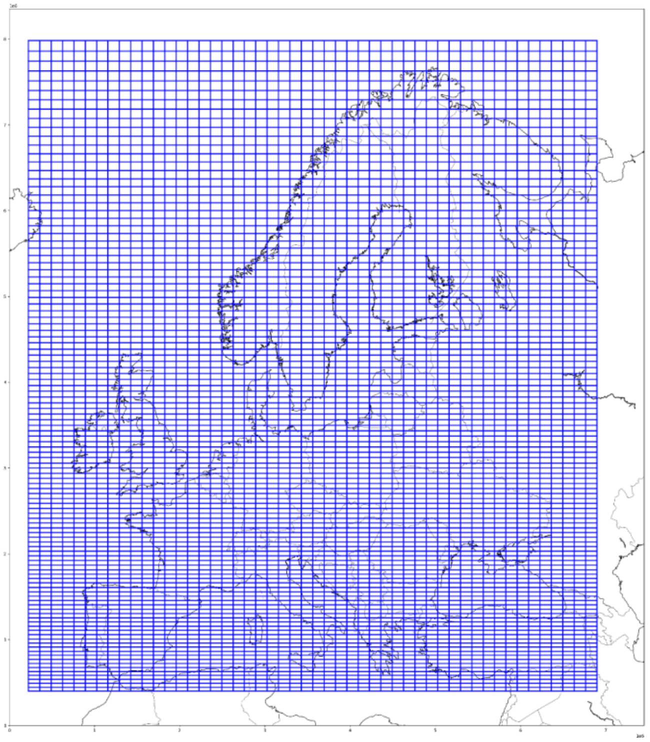

**Figure 2.** Matrix cells (blue) over Europe.

## 3.2. Interpolation

One of the problems when implementing an SDB is the trajectory data, which can be described by sequences of segments defined by the coordinates of the segment's endpoints. In cases where these segments or jumps between coordinates are greater in distance than the size of the matrix cells, a trajectory might pass through a cell, but since the starting and ending points of the segment are outside of it, its passage is not counted.

To avoid this, before processing the trajectories in the matrix, interpolation should be performed on segments where the jump between coordinates is greater than the size of the cell. By doing so, additional intermediate points are added to the trajectories.

To specify the data within the cell, it is useful to interpolate the exact intersection points with the matrix's endpoints. This way, the total time inside the cell can be determined, as well as the exact entry and exit points.

By using interpolation, more detailed trajectories and a greater amount of data are achieved, which enhances accuracy when performing calculations between aircraft.

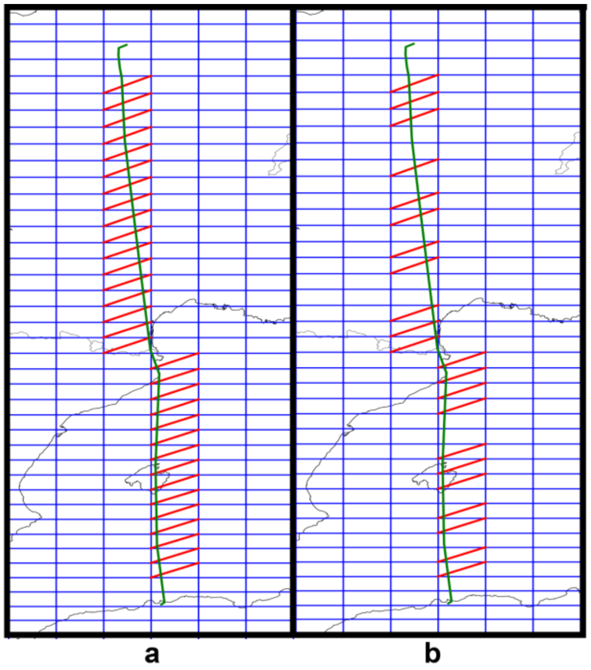

**Figure 3.** Interpolated trajectory (a) vs no interpolated (b). In red the counted cells.

In Figure 3 can be seen the difference between an interpolated trajectory in which all the cells are counted, and the same trajectory without interpolation where some cells are not counted.

## 3.3. Implementation

With the established matrix, a loop can be started to check the temporal coexistence of aircraft inside the cell, since the spatial coexistence is already ensured by the structure of the spatial database. A document can also be generated to store the data for further faster analysis. The information to be saved includes the date and time of entry into the cell, entry and exit coordinates, flight level, and cell identifier ranging from 0 to 5499. Only flight information will be considered where the aircraft is at an altitude of more than 180fl and the distance of the route is more than 1000 nm. In order to analyze the angle of conflict, it will also be necessary to calculate the azimuth (using the Vicenty formula (Thomas & Featherstone, 2005)) of the aircraft with the entry and exit coordinates to obtain its heading.

## 3.4. Shifted Matrix

One of the problems with the spatial database is that there may be pairs that are not counted since they may be feasible for performing a formation flight but are in different cells and thus not counted. Figure 2 represents 2 examples of potential pairing candidates located in adjacent cells.

To avoid this problem, two new matrices must be generated, shifted vertically and horizontally by half the size of the cells in the initial matrix. This way, we ensure that all possible pairs that were initially not counted are stored.

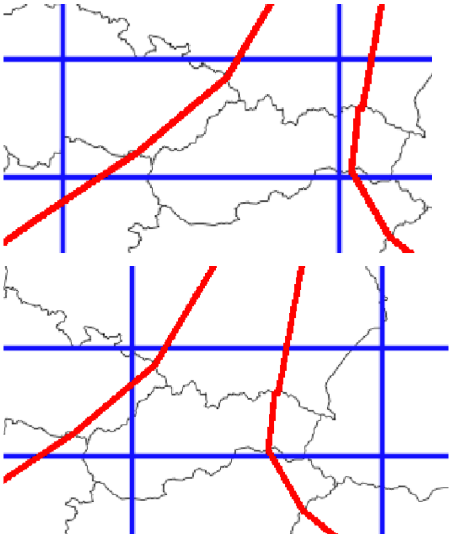

**Figure 4**. Difference between trajectory pairing, with initial (above) and shifted matrix (Below). Trajectory (red), cell (blue).

Therefore, when searching for pairs, the same process is used, although it must be established as a condition that if that pair has already been added, it cannot be repeated. The resulting matrices can be visualized in Figure 4.

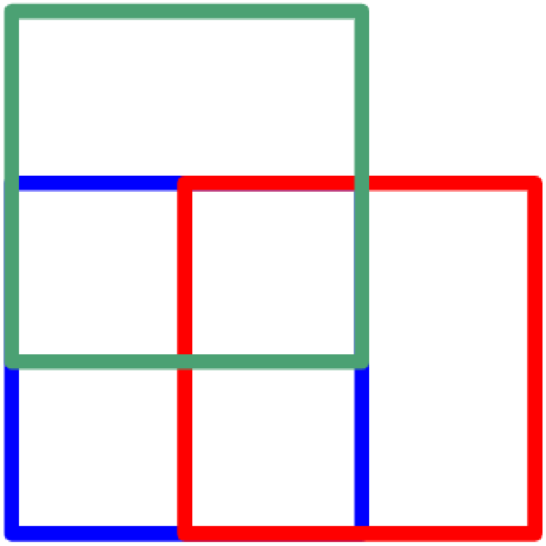

**Figure 5**. Shifted matrix scheme, initial (blue), shifted horizontally (red), shifted vertically (green).

## 3.5. Spatio-Temporal coexistence

Once the information is available, the entry and exit times between the aircraft that have passed through each cell are compared to identify the flight pairs that have coexisted in time and space within the cell. Next, the intersection angle between both trajectories and the third of the trajectory in which each aircraft is located will be calculated.

## 3.6. Heuristic

Once all the potential candidates for pairing have been identified, we need to process the results, applying and shaping the desired heuristics. A single aircraft may have several candidates for a FF, however, it is important to choose the best one according to particular metrics. In this paper, the main criteria used have been to choose pairs that can share the maximum amount of time in formation. A heuristic has been designed that is summarized in these equations:

$$|Af1 - Af2| \leq 45º \quad (1)$$

$$\sum Pf1f2 \leq 1 \quad (2)$$

$$\frac{Dist\ a}{Dist\ T} \leq \frac{1}{3} \quad (3)$$

$$ATf1 = ATf2 \quad (4)$$

$$\sum Sc\ f1f2 \geq 10 \quad (5)$$

$$\sum f \leq 1 \quad (6)$$

Where:

A = Azimuth

f = Flight

P = Pair

Dist = Distance

a = actual

T = total

AT = Aircraft Type

Sc = Shared cells

So, the criterion for choosing the best pair will be those with the six specified equations fulfilled. Eq (1) an intersection angle lower than 45°, in this way, trajectories with opposite headings can be discarded. Eq (2) The count of the same pair cannot exceed one, thus only one pair will be taken into account, storing the one with the earliest contact time. Eq (3) The intersection of trajectories must occur within the first third of their route, thus eliminating pairs that come together in the final sections of their route, and cannot share a significant portion of their trajectory. Eq (4) Currently, there is no research on the compatibility between aircraft types when performing formation flights. To avoid pairing different-sized aircraft, it is established that they must be of the same aircraft model. Eq (5) The total number of cells that the aircraft pair must have shared should be greater than 10 cells. This ensures that the resulting pairs have shared a significant portion of space and time. Eq (6) Finally, to obtain a real number of flight pairs, it is established that each aircraft can only have one pair.

This allows the resulting number of formation flights to be carried out simultaneously, and the pair with the highest number of shared cells will be chosen.

## 4. Results and discussion

Traffic on October 5th 2022, has been used, with 27.823 flights on European airspace. Once the initial data is loaded and the heuristic is applied, we obtain a result of 481.816 potential pairs. By applying heuristics 1),2),3),4),5) and 6) we obtain a total of 811 pairs. This represents a decrease of 99,83% compared to the initial number of pairs. Considering that the heuristic is applied and each aircraft can only have one conflict, with a total of 27.823 aircraft flying over European airspace, this means that 5,83% of current flights in European airspace could potentially fly in formation, without taking into account possible pairs that could arise from prior planning. Regarding these results with the heuristics, we can observe in Figure 6 their growth according to the vertical and horizontal filtering distance between the aircraft.

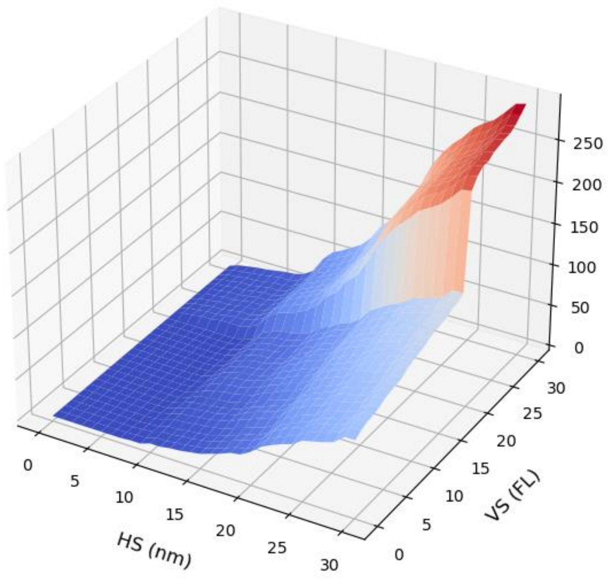

**Figure 6.** Total number increase of flight pairs with heuristic depending on horizontal and vertical separation.

In this graph (see Figure 6), we can observe how the total number of pairs grows more sharply in the search for vertical distance than in horizontal distance. This information gives us an approximation of where the large quantity of pairs is located and which criterion could be more effective in further analytics. The majority of spatio-temporal interdependencies feasible for a FF are concentrated between 20fl and 30fl of vertical separation and 25nm and 30 nm of horizontal separation. However, there is still fairly uniform growth throughout all the values on the graph. This result could be due to the use of airways where aircraft are separated vertically on the same route.

In the heuristics application, we can observe the degradation when applying each of the constraint equations:

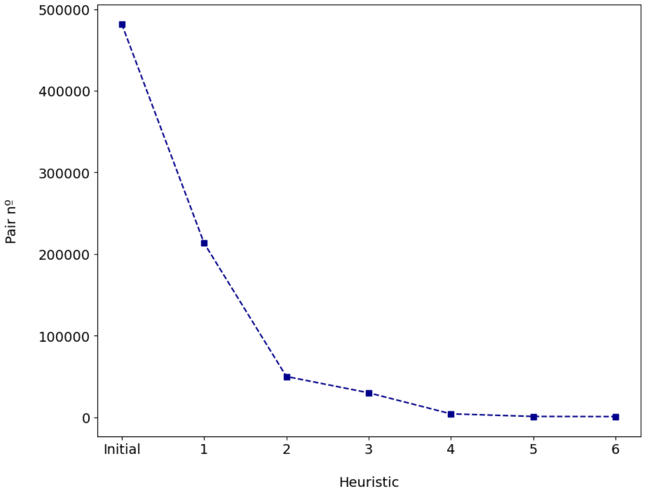

**Figure 7.** Total number decrease of flight pairs caused by equations application.

We can appreciate in Figure 7, how every equation has a significant impact on the number of pairs reduction. Equation 1) reduces the total number by a -55,71%, Equation 2) by a -76,63%, Equation 3) by a -40,07%, Equation 4) by a -86,24%, Equation 5) by a -77,09%, Equation 6) by a -13,94%. With these results, we can observe how the application of the heuristics affects the total outcome, and which are the most restrictive conditions. Although they are quite similar, the Aircraft Type constraint (Eq 4) is the one that eliminates the most pairs. This could change with the application of an aircraft compatibility study.

### 4.1. Modeling a formation flight.

Within the pairs obtained after applying the heuristics, we randomly select a result to analyze its potential use in formation flight. To see how they could perform the formation, we will use the BlueSky tool (BlueSky, nd). This is an open-source air traffic simulator where real air traffic trajectories can be visualized, simulated, and modeled. This tool is based on Python and allows running various simulation scenarios and different functions within the simulator to extract data and results.

Within the pairs obtained after applying the heuristics, a pair was chosen to improve its potential use in formation flight by modeling its trajectory. The selected pair is:

**Table 1.** Flight pair information.

| Flight | Callsign | Departure | Arrival | Departure Time |
|---|---|---|---|---|
| 1 | TRA11C | LEMG | EHAM | 18.23 |
| 2 | RYR1259 | LEAM | EBCI | 18.23 |
| Flight | Aircraft Type | Intersection Time | VS | HS |
| 1<br>2 | B738 | 20.01 | 20 FL | 1.46 nm |

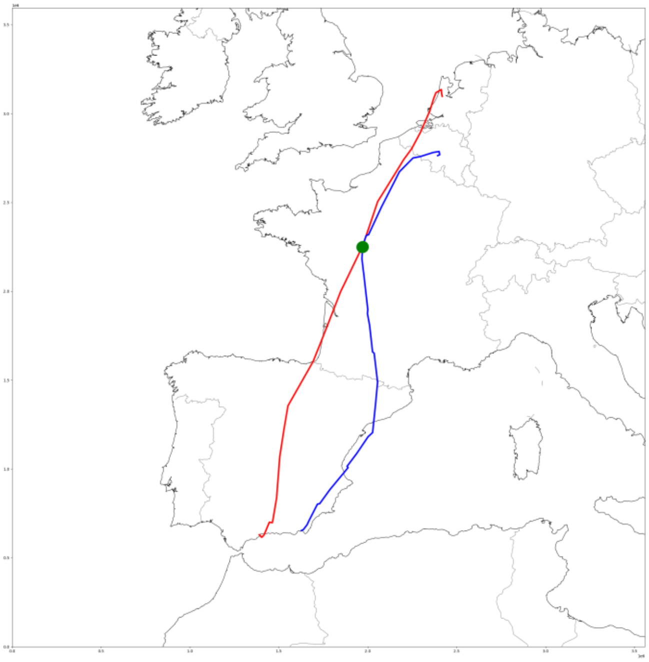

**Figure 8.** Flight pair initial route, flight 1 (red), flight 2 (blue), intersection point in green.

It can be observed (see Figure 8) that for a significant portion of the route, both aircraft have been flying in parallel, sharing a considerable time of their trajectory. To enhance the potential of the pair, we will model a deviation to facilitate trajectory sharing. In this case, a scenario in BlueSky has been parametrized using the available data to modify the heading of Flight 2 so that it deviates toward the trajectory of Flight 1. Speed restrictions should be applied to the aircraft to ensure they can converge at a distance between 1.5nm to 2nm, as specified in the Fello'Fly maneuver. Two aircraft must have the same FL.

The moment when aircraft 2 will make the deviation needs to be determined using Python. In this case, the deviation occurs at the beginning since they can share a significant part of the trajectory from the start. It should be established that depending on the distance between the aircraft, CD and Conflict Resolution (CR) should be disabled to avoid automatic deviations or FL changes by the BlueSky algorithm.

Once the restrictions are made, and the scenario file is created, the simulation can be initiated.

**Figure 9.** Flight pair with a simulated trajectory of formation flight in BlueSky.

The modified trajectory (see Figure 9), can share much more distance the the initial one. The diverted aircraft will have to move towards the new trajectory where it will meet its flight pair.

```
dist 39.143759,-3.528154 39.173417,-3.525646
QDR = 3.75 deg, Dist = 1.784 nm
```

**Figure 10.** Flight pair intersection point, and distance between them.

The intersection point where both aircraft meet (Figure 10) can be observed using the "dist" function provided by BlueSky. It can be observed that the distance between the two aircraft is within the range of 1.5nm to 2nm, which allows them to establish the formation. By maintaining a consistent velocity and flight level until the separation point, the aircraft can sustain the formation for an extended period of flight.

**Figure 11.** Flight pair intersection point on a modeled trajectory, flight 1 (red), flight 2 (blue).

In the new trajectory, the intersection point is located 635nm earlier (see Figure 11), which represents a 240% increase in the shared distance.

Once the trajectory of the resulting flight pair is modeled, it would appear as follows:

**Table 2.** Modeled Flight pair information.

| Flight | Callsign | Departure | Arrival | Departure Time |
|---|---|---|---|---|
| 1 | TRA11C | LEMG | EHAM | 18.23 |
| 2 | RYR1259 | LEAM | EBCI | 18.23 |
| Flight | Aircraft Type | Intersection Time | VS | HS |
| 1 | B738 | 18.48 | 0 FL | 1.78 nm |
| 2 | | | | |

In Table 2, it can be observed that the flight pair initiates the formation flight approximately 1 hour earlier, and at that moment, the vertical distance is 0 and the horizontal distance is 1.78. This indicates that a formation flight can be conducted. This increases the shared flown distance from 265nm to 900nm. This means that the aircraft can share approximately 85% of its total trajectory.

## 4.2. Limitations

This model allows for performing a matching search on real trajectory data, although it has certain limitations to consider in future research or implementations of it. These limitations are: conflict-free routes have not been considered in the FF approach.

- **Error margin interpolation:** When interpolating, a linear method has been used, which can result in a difference of approximately 0.5 nm depending on the flight level and segment distance.
- **Matrix Coverage:** As this study focuses on analyzing trajectories within the European airspace, it is important to note that some potential pairs may not be counted, since the SDB matrix only covers the European airspace, so potential flight pairs with origins, destinations, or significant portions of their trajectories outside this territory may not be accounted for.
- **Runtime:** The implementation and execution of this system have considered the processing time as a key factor. The system's dependency on its execution and processing time is an important factor to consider for future scalability.
- **Business Strategy Modeled Pairs search:** The implemented algorithm focuses on finding potential pairs that meet specific criteria to consider them as opportunistic formation flights with actual data. This algorithm does not detect potential pairs that could be part of a business strategy involving aircraft strategic deviation.
- **Flight Safety:** Formation flights involve critical processes in aircraft safety as the maneuvers performed have little margin for error. This represents a key factor in their implementation, and future research should consider emergency procedures, the treatment of aircraft by air traffic control (ATC), as well as the study of pilots' capacity to handle high workload situations without exceeding their limits.
- **Conflict-Free Routes:** As mentioned in the previous point, formation flights have little margin for error. Therefore, it is necessary to consider potential conflicts that aircraft may encounter, as evasion maneuvers can complicate formation flight procedures. In future research and refinements of this tool, it will be important to take into account potential conflicts encountered by the aircraft. Although, a CD could be implemented using the same SDB.

## 4.3. Environmental improvement

To estimate the potential impact of formation flights in European airspace, the following average values have been assumed:

- Aircraft: Airbus A320
    - Average Jet Fuel burn: 2.500 kg/h
    - $CO_2$ Emissions (IATA, nd): 3,16 kg $CO_2$ /Kg Jet Fuel
    - Jet Fuel Price (IATA, nd): 0,68 €/L
    - Average Flight time: 2h15
- Total number of daily aircraft performing formation flights (on trailing position): 811
- Total number of daily aircraft performing conventional flights: 27.012

- Fuel savings per formation flight= 7,5%

As a result of the aircraft that potentially can perform a formation flight, this could mean a daily saving of approximately 1.081 tons of CO2 and 232.655,63€ in fuel costs. This could mean an annual saving of 394.624 tons of CO2 and more than 84M €. This represents a significant reduction in both cost and CO2 emissions, and it is divided for each aircraft that performs a formation flight.

By implementing additional measures such as strategic negotiation models to search for flight pairs, it could increase the number of pairs performing formation flights. This, in turn, could lead to even greater savings.

## 5. Conclusions

Although formation flights may become a reality in the future, and their scalability can offer great benefits, there are still several gaps to consider. Formation flights present some challenges in planning and execution. Adequate aircraft, procedures, and trained pilots must be available. At the ATM level, new procedures will need to be established to carry out formation flights globally and ensure safety at all times.

The results found in this study demonstrate that there is significant potential for the application of formation flights in Europe, which can lead to significant savings in CO2 emissions and economic costs. Therefore, the development of flight pairing techniques can be of great importance in the future, as well as the application of Machine Learning tools for decision-making. This could increase the number of pairs found compared to the current state.

In terms of research, the study of economic viability and business application is of great interest. It should be noted that there may be pairs of flights that are at a great distance from each other and do not share practically any moment of the route, but could deviate to perform the formation flight. Therefore, studying the cost-benefit of flight deviations to perform the training would be useful, as finding the trade-off guarantees flight pairs that are not only feasible in space and time, but also in cost-benefit. Therefore, being able to establish a specific and accurate heuristic can also help obtain better results.

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