Air Traffic Restructuring with Airstreams

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1 INTRODUCTION

In recent decades, free-flight has been adopted by airlines where aircraft are freed from flying along a network of airways and waypoints to follow a more direct optimized trajectory. At the stage of carrying out these free-flights, the blind superposition of such types of trajectories leads to the generation of a large number of potential conflicts which need the intervention of traffic control to prevent their realization, de-characterizing the computed free-flight trajectories (Bucuroiu, 2015). This situation contributes to increase the complexity of air traffic and limit its performance (diminished capacity, new delays, extra costs, and increased risk). Then the recently introduced concept of airstream which can concentrate safely large volumes of traffic appears of interest to diminish the demand for free flight and reducing the resulting traffic complexity. In an airstream, the flow of traffic will be organized in different lanes according to aircraft performances and traffic volume, while the aircraft will present new enhanced guidance, anticollision and navigation functions (Ab-Wahid, *et al*., 2014).

In this paper, after presenting broadly the concept of airstream, a method based on ad-hoc clustering techniques is proposed to build a structure of airstreams to efficiently channel a large part of the air traffic of a given region. Then the problem of assigning air traffic to airstreams is considered. The proposed approach to perform traffic assignment to the airstream network introduces a new tactical parameter for air traffic management, the airstream distance discount factor to enforce, and regulate in the case of saturation, the use of sections of airstreams instead of direct flights. This paper is based on the recent European project Flight Centric Air Traffic Control with Airstreams (FC2A), funded by SESAR in 2020 (Dohy, *et al*., 2020).

2 AIR LINK CLUSTERING

A possible first step for generating, from a given prediction of air traffic demand, an airstream network is to perform a bundling of the air-links which are the pairs of airports connected by flights. The goal of the bundling mechanism is to partition the traffic into groups/aggregates geometrically as close as possible with respect to and separated one to another as much as possible. Two classes of traffic demand are then generated: bundled air-links associated to a bundle and outliers. The flight aggregates, or bundles, define the backbone (main flows) of the airstream network. Each cluster is allocated to an airstream which is built using the intrinsic characteristics of the aggregated traffic. Figure 1 describes the stages of the design process.

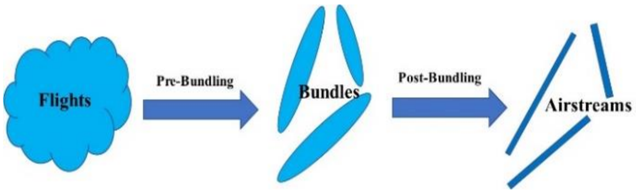

Figure 1 – *Airstream Generation Process*

The proposed approach considers that the ultimate desire of airlines would be to deliver more direct flights between departure and arrival airports so that travel distances and durations are minimum, optimizing the transportation service offered to costumers, contributing to the minimization of operational costs and to a more efficient aircraft fleet management. Considering that from the point of view of Air Traffic Management, there is no difference of treatment between flights of different airlines realized between the same airports, the focus is given here on air-links between each pair of considered airports, rather than in individual flights. An air-link will be characterized by the pair of arrival and destination airports (no order), the free flight trajectory between them and its length, the number of flights using this air-link during a day period. Then, the number of air-links is much smaller than the number of flights, limiting already the computational burden. A perfect direct flight trajectory is associated to the orthodromic curve between the two airports defining an air-link, it is characterized by two parameters, its route angle and root position. The clustering approach which progressively builds each cluster by inspection of the air-link list and on-line adaptation is described below. This method applied to the air-link set in a sequential way should reduce the computational burden compared with optimizing approaches or global approaches. Two parameters can be tuned for generating the clustering: the Maximum route deviation and the Maximum root deviation.

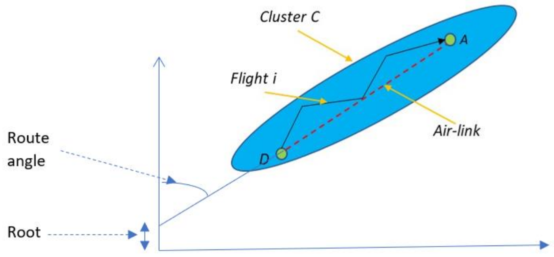

Figure 1– *Air-link and flight in a cluster*

The steps of the heuristic are: Rank air-links by traffic volume and select the first one as a seed for the first cluster and airstream, compare routes then roots and gather or not in the current cluster according to the size of their differences; update the current cluster and check the next air-link; if all air-links have been checked and no more air-links, the search ends; otherwise initialize a new cluster and start again the process with the remaining air-links.

3 FLIGHT ASSIGNMENT TO AIRSTREAMS

Once a set of airstreams has been defined to cover a large proportion of flights, it is necessary to predict the way in which the flights will use these airstreams. How to design for each flight a best trajectory using portions of the airstreams? Here the main considered objectives are: to ease the traffic control workload by minimizing cross conflicts through the use of airstreams, a simple way to contribute to this objective is to minimize the portions of flights which are not flown inside airstreams where traffic control acquires an automatic character, and to minimize the length of flights, this second objective is related to the operational costs supported by airlines and the travel time of passengers. It is obvious that the minimum distance flight between a departure airport D and an arrival airport A is the portion of the great circle linking them and assimilated here to a straight segment. So, to force traffic to deviate and use the airstreams, some attractiveness must be given to them. This can be done through the adoption of a discount factor to each airstream where the equivalent distance used in the computation of the flight path in airstream *i* is given by: $d_i^e = \lambda_i \, d_i$ where d_i is the real flown distance in the airstream and λ_i is the discount factor associated to airstream *i*. The adoption of this discount factor to compute flight paths may be turned mandatory by ATM but may also correspond to a reduction of air traffic control fees in airstreams. The discount factor can be associated to a given flight, to a given air-link, to a given bundle or to the whole traffic demand. Here two cases should be considered: the case in which a flight is part of the bundle associated to an airstream and the case of an outlier flight. Only the first case will be developed here, the second case can be tackled using a Dynamic Programming approach. Figure 3 represents the relative position of an air-link with respect to an airstream and a possible flight path using part of this airstream.

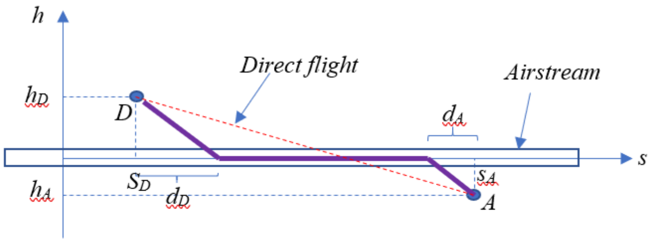

Figure 3 – *Airstream section of a bundled air-link*

The pseudo-length of the flight path is given by:

$$l(d_D, d_A, \lambda) = \sqrt{h_D^2 + d_D^2} + \lambda\big(s_A - s_D - (d_D + d_A)\big) + \sqrt{h_A^2 + d_A^2} \qquad (1)$$

This is a convex function of d_D and d_A and its minimum is given by:

$$l_{min}(\lambda) = s_A - s_D + \sqrt{\frac{1-\lambda}{1+\lambda}}(|h_D| + |h_A|) \;\; with \quad d_D^* = \frac{\lambda}{\sqrt{1-\lambda^2}}|h_D| \quad and \quad d_A^* = \frac{\lambda}{\sqrt{1-\lambda^2}}|h_A| \qquad (2)$$

$$and \quad 0 \leq \lambda \leq \lambda_{max} \;\; where \; \lambda_{max} = \sigma_{DA}/\sqrt{1+\sigma_{DA}^2} \quad with \quad \sigma_{DA} = |s_A - s_D|/(|h_D| + |h_A|) \qquad (3)$$

If $\lambda_{max} \leq \lambda < 1$ the airstream is not used by the considered air-link and the direct flight between airports *D* and *A* minimizes the above pseudo length. Possible KPIs associated with the chosen path and parametrized by λ with $0 \leq \lambda \leq \lambda_{max}$ are the ratio p_{DA} of the flight lengths associated to that air-link which will be outside the airstream, the ratio π_{DA} between these outside sections of flight and the length of the direct flight, the path length increase ratio ρ_{DA}, all given by analytical expressions depending of λ. It can be seen easily that when λ increases, p_{DA} and π_{DA} increase while ρ_{DA} decreases. If a performance level is attached to these KPIs, those air-links which do not comply with the required performance can be reclassified as outliers. If the number of these new outliers is significant, they can be excluded from the computation of the corresponding airstream. Mean ratios can also be computed for the whole air-links associated to a given bundle and airstream. If the flight path design process is performed centrally on a chronological basis (planned departure time of a flight), assigning momentarily a value equal or superior to one to the discount factor will avoid considering an airstream which is currently saturated. The proposed approach has been applied to a medium size hypothetical case displayed in Figure 4 where on the left is the original demand with three airstreams and on the right is the resulting assignment of traffic to these airstreams in the case in which λ=0.5. Only four air-links (13%) do not use the three available airstreams.

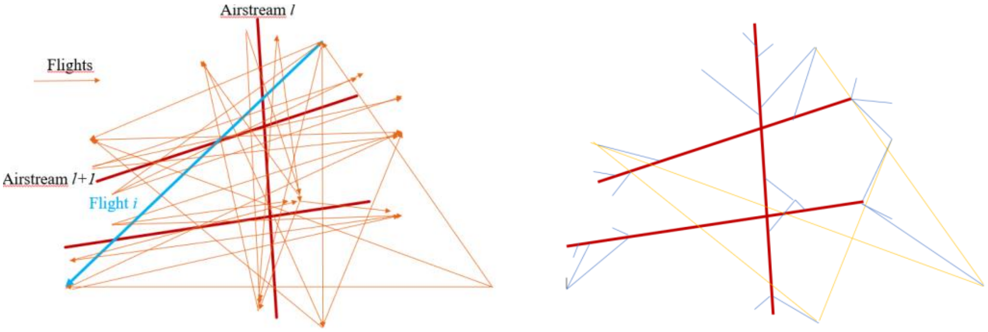

Figure 4 -*Assignment of flights to airstreams*

4 4 CONCLUSION

In this communication, the problem of designing airstream networks to efficiently channel a large part of the air traffic of a given geographic area has been considered. The proposed design techniques have avoided unnecessary complexity so that real size problems can be quickly processed. The proposed approach to perform traffic assignment to the airstream networks introduces a new tactical parameter for air traffic management, the airstream distance discount factor. From the obtained results it appears that there is an increased concentration of flight sections connecting airports and airstreams. So, it is of interest, with the objective of reducing further traffic complexity, to extent the airstream concept to departing and arriving traffic at airports. Then it will be possible to assign each aircraft to a unique dynamic slot leading it safely and efficiently through airstreams from the departure airport to the arrival airport of the considered flight. The introduced discount factor should be an input for the computation of air traffic control charges so that airlines comply with the proposed traffic assignment. Then it is possible to compute for different values of this discount factor the resulting traffic complexity and the environmental impact of the resulting traffic pattern for a given demand of traffic during a day over a given region. It is expected that, whatever the adopted complexity metric (Zhou, *et al*., 2017), a drastic diminution of the complexity of the resulting traffic pattern will be observed.

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