

An optimisation framework for aircraft operators dealing with capacity-demand imbalances in SESAR

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Abstract—This paper presents a framework for the negotiation phase that is foreseen in the new operational concept proposed in the Single European Sky Research (SESAR) program. In particular, this paper describes a possible strategy for the airspace users in order to deal with the Collaborative Decision Making (CDM) process that is expected in this future scenario. In the SESAR scenario, airspace users will become owners of their trajectories and they will be responsible to solve possible mismatches between capacity and demand in a particular airspace sector. The aim of this strategy is to improve the efficiency in the CDM process by computing the different operational costs associated to different solutions that may solve a particular demand-capacity imbalance in the airspace. This will allow them to optimise their operating costs while reducing fuel consumption and therefore being more environmentally friendly. Some suggestions have already been done for the CDM mechanism, for instance the use of auctions. However, the different options that aircraft operators might use have not yet been sufficiently investigated. In this paper, the authors propose an optimisation framework for aircraft operators aimed at computing 4D trajectories with time constraints to deal, in this way, with possible airspace regulations. Once a nominal flight plan and a potential regulation is known, it is suggested to compute several possible alternative flight plans (including re-routing, but also altitude and speed profiles) that may solve the capacity-demand problem. If more than one regulation is applied to the flight, a tree of options is subsequently computed. The cost of each optimised option is also calculated in order to allow the airspace users to initiate the negotiation process with other airlines. Finally, a preliminary example is given at the end of this paper in order to better illustrate the proposed methodology.

I. INTRODUCTION

As it is well known, the number of IFR flights is growing all around the world. The forecast of flight movements in the Eurocontrol Statistical Reference Area (ESRA) for 2030 is between 1.7 and 2.9 times the traffic of 2007 [1] and, according to [2], by 2030 the 11% of actual demand will not be accommodated, in the most-likely growth scenario. For example, during the period from 2003 to 2008, the European traffic has increased by 19.9% (average of 27818 flights per day in 2008), the total delay has increased by 60.7% (65138 minutes per day) and the total delay per flight has increased by 34% (2.3 minutes on average for all flights) [3]. This trend shows that capacity of the system is starting to get overpassed. To deal with capacity-demand imbalances, ground delay programs have been implemented. The ground holding problem has been thoroughly addressed in all its forms: as a deterministic process [4], probabilistic [5], [6], for a single airport [4] or for a multi-airport scenario [7]. For instance

in [7] the multi-airport ground holding problem is solved using integer programming techniques. The objective of these algorithms is to determine the ground delay that has to be assigned to flights in order to deal with capacity constraints. However, all these models need accurate information about the flights, and in particular, the costs associated to delay.

On the other hand, techniques as the one described in [8] allow to analyse the propagation of delay on a network of more than one airport. These techniques that are focused on the airport have been extended in order to deal with all the network constraint, including airspace capacity restrictions. In this manner the whole Air Traffic Flow Management (ATFM) problem, with ground delay, speed control during cruise and rerouting, has been solved (see for instance, [9], [10] or [11]). For a wider and excellent literature review of modelling and optimisation in traffic flow management, the reader is referred to [12].

Even if all previous approaches are able to compute the best route, the optimal amount of ground delays and even the optimal cruise speed for the different flights, these computations are done in a centralised system aimed at optimising the whole network. The main assumption for this system is that it is supposed to be fed with accurate data coming from the aircraft operators. Yet, some of the data are considered *critical* for the airlines, specially when dealing with cost figures, and they would be reluctant to release them. In other words, keeping the problem centralised, the above techniques are appropriated to solve it, but some effort has to be done to include airlines preferences while maintaining the privacy of some of their data. Nowadays, priority has been given to user-driven policies and therefore, as traffic is expected to continue growing, new concepts of operation are starting to be developed: SESAR project (in Europe) and NextGen (in the USA).

If the focus is given to Europe, two big changes arise from the SESAR guidelines: 4D trajectories should become a reality and the airspace users (i.e. the aircraft operators) will be the owners of their trajectories. The ownership of the trajectories leads to a situation where if a capacity-demand imbalance exists, a negotiation process among airlines should be done to solve the potential conflicts. The network managers are not longer in charge of solving the imbalance in a centralised manner but of coordinating the negotiation between the airspace users. The airspace users will be involved in the process of balancing demand and capacity and a Collaborative Decision

Making process (CDM) will become mandatory at strategic level [13]. During summer 2008, 14.1% of the traffic in Europe was delayed with an average delay of almost 20 minutes [14]. Furthermore, in 2008 the price of fuel reached values over \$100 per barrel and therefore, most airlines reported fuel costs to be between the 30 and 40 percent of their total expenses. Therefore, on one hand, the aircraft operator will be forced to deal with capacity-demand imbalance, while on the other hand, bearing in mind that the objective of the aircraft operator is to improve its benefits, optimise its 4D trajectories according to the cost of time and fuel burned. An optimisation is essential if they want to reduce their operational costs and therefore, be more competitive in front of other operators.

In the future SESAR scenario, it will be critical for airlines to know the associated cost of solving capacity-demand imbalances in the air transportation network. Therefore, if a negotiation process is established with concurrent airlines, those ones with more options, and with better information of the associated costs for each option, will be better placed [15]. In this context, the negotiation process has already been analysed in [16], where a market based mechanism is suggested to be used. However, the different options that the aircraft operators would have when facing this negotiation process have not been yet assessed and this is the main motivation of the proposed research by the authors.

Thus, this paper suggests an optimisation framework for aircraft operators that have to negotiate with other airlines in order to solve a capacity-demand imbalance problem in the airspace. In this negotiation process, different slots might be traded. In this case, it would be essential for the airline to compute the optimal vertical profiles and speeds to be used for each of the possible options, that will result in a different final costs. When a regulation is set, the affected airspace users will initiate the negotiation process acting in different ways, which represent different options, according to their own interests and to the associated costs of each solution. Therefore, the proposed methodology is intended to assess the different options that a particular aircraft operator would have and to compute the associate cost for each of them in order to better perform in the negotiation.

This paper is organised as follows: in Section II the current framework of operations used in Europe is presented, regarding both the the network manager and the airlines. Section III presents the operational framework in the SESAR scenario while taking into account the proposal of the authors for the aircraft operators. Section IV is devoted to show a preliminary example of the proposed methodology, considering the computations that a given airspace user would perform for a hypothetical regulation. Finally, in Section V the main concepts are summarised and further work on this research is explained.

II. CURRENT OPERATIONAL FRAMEWORK

Nowadays, in the operational concept, as implemented in Europe, the Air Navigation Service Providers (ANSP) submits the capacity of their airspace sectors to the Control Flow

Management Unit (CFMU). The CFMU acts as a network manager and has the responsibility of maintaining the demand below the capacity for each sector. In order to attain this objective, the airspace users must submit their intended flight plans to the CFMU well in advance. As it can be seen in Figure 1, the CFMU regulates the demand by imposing on-ground delays to some of the flights.

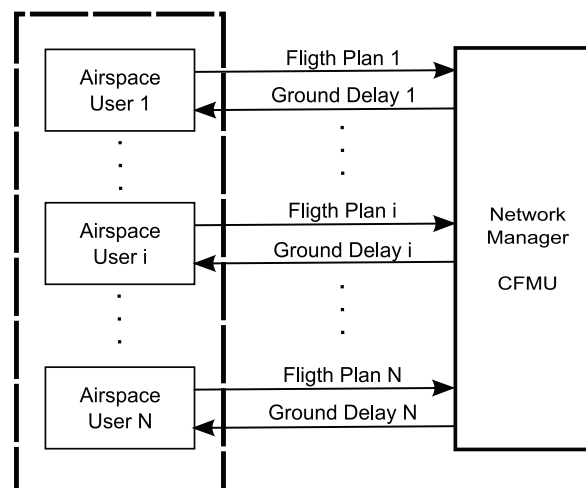


Fig. 1. Current concept of operations in Europe

On the other hand, airline operators optimise their flight plan with respect the cost of time and fuel. During this optimisation process different operational parameters are taken into consideration, such as crew and maintenance costs, number of transfer passengers, the type of the aircraft, weather conditions, available airspace routes, etc. However, airspace capacity information is hardly never taken into account. Next, current airspace network management and airline operation strategies are briefly described.

A. Network Manager

In Europe, the CFMU simulates the flight plans in order to identify those sectors where the capacity might be exceeded by the foreseen demand. In this case, the Computer Assisted Slot Allocation (CASA) algorithm is used to mitigate this mismatching by imposing on-ground delays to some flights. CASA implements a First Planned First Served (FPFS) algorithm to assign slots to flights while preserving fairness. Briefly, this slot allocation algorithm can be explained by the following simple example.

Let us set a regulated area with one available slot every five minutes (10:00, 10:05, 10:10...), and six planes that want to cross this regulated airspace with their Estimated Time of Over-fly (ETO) as shown in Table I. As it can be seen in Figure 2, the first plane (F1) will take slot number one while F2 will take slot number two. Without any regulation, the ETO of the third aircraft (F3) is 10:07, corresponding as well to slot number two (between 10:05 and 10:10). However, this slot has been already assigned to F2 that will keep it as its ETO is lower than the ETO of F3. Then, the third slot will be

TABLE I
EXAMPLE FLIGHTS

Flight	ETO
F1	10:00
F2	10:06
F3	10:07
F4	10:10
F5	10:12
F6	10:18

assigned to F3 and this flight will be delayed on ground by three minutes. In the event of having more than one regulation, the delay coming from the most penalising regulation will be imposed to the aircraft. Then, the over-flight time of the remaining regulations will be fixed to this most restrictive value [17].

The final result that is obtained with this assignation is shown in Figure 2. As it can be seen, flight F3 has been delayed for three minutes, and will arrive at the regulated area at the slot R1S3, flight F4 will be delayed for five minutes and will use slot R1S4. Finally, F5 would have arrived at the regulated area to take slot R1S3, but being the CASA algorithm FPFS, it must be delayed DGF5 minutes in order to arrive at the regulated area with slot R1S5. In Figure 2, the slot that F5 would have taken is presented along with the finally assigned one and the ground delay (GDF5) that consequently has been imposed to this flight. It is worth mentioning that besides the departure time, the flight plans of the delayed flights are not changed. This means that once the delay has been absorbed on ground, the flight will be operated at its initially planned cruise speed.

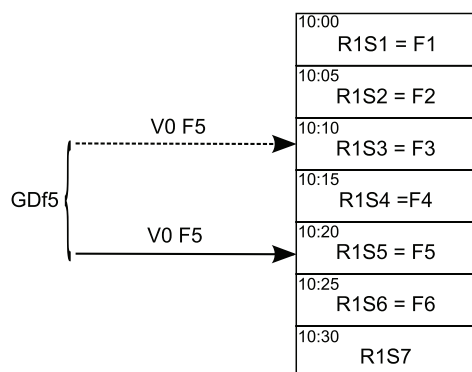


Fig. 2. Example of a regulation area with 5 slots every five minutes

The main advantages of this solution are that it is simple to find a robust solution, the algorithm can easily deal with real-time modifications and cancellations of flight plans and, being a FPFS algorithm, a minimisation of the total delay is achieved [16]. However, it does not take into account the cost for the operators and the repercussion of the imposed delay on that cost. In other words, the economical impact of the regulation is not minimised while the same amount of delay can indeed be more expensive for a given operator than for

another [16], [18].

Some effort has been done in order to try to improve this CASA algorithm using new techniques as constraint programming (see for instance [19]) or extending the ground delay to deal with conflict and not only with capacity-demand imbalances [20]. Moreover, other criterions rather than the FPFS algorithm have been analysed, like for instance the ratio-by-distance one [21]. Nevertheless, these modifications of the CASA algorithm present some issues that stop their practical implementation. Even if the computation time has been significantly reduced, they still have difficulties to deal with real time modifications and cancellations of flight plans. Moreover, some of them have problems with equity and fairness.

B. Airspace Users

The main objective of aircraft operators is to minimise their operating costs. Therefore they will try to compute and fly an efficient flight plan. In Figure 3 it is presented the optimisation process that the airline should do for each of its flights. Before this optimisation, the airline has computed the route planning and the fleet and crew assignment. The reader is referred to [22] and [23] for more details on these processes, which are out of the scope of this paper.

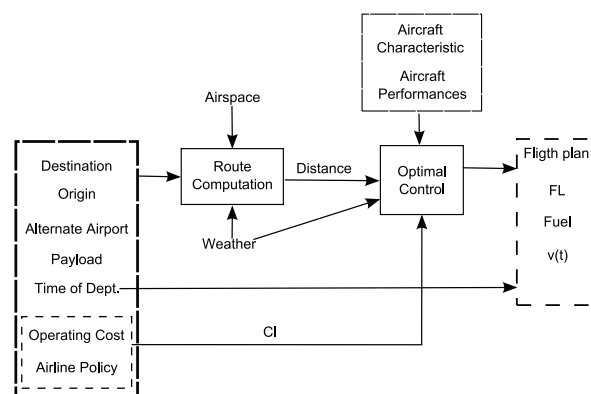


Fig. 3. Flight optimisation applied nowadays

In the flight plan optimisation, the input values are the route that the airline will fly (origin, destination and alternative airports), the intended payload and the time of departure. With the information of the airports and using the airspace configuration and the weather data, the route will be computed [24]. After this process, the distance to be flown will be obtained. A main aspect to take into account in this process is the airline policy regarding its operating costs. This will result on a given CI (Cost Index) for the intended flight. The Cost Index will be part of the optimisation function which will weight the cost of time against the cost of the fuel. Therefore, the optimisation function is to be $J = Fuel + CI \cdot Time$. As expected, changes on CI will impact on the profile of the flight, on the speeds and, as a result, on the fuel consumed and on the final take off weight [25]. It has been demonstrated how variations on CI might have a small impact on time but a great repercussion on fuel consumed [26].

Summing up, by using the aircraft characteristics and aerodynamic data, the payload, the distance, the weather and the CI, the optimiser computes the operational flight plan that is composed of speed and vertical profiles, as well as the fuel needed for that flight [27], [28].

During the flight, the CI is introduced in the Flight Management System (FMS) by the pilot. The management of the flight will be done by direct changes on the CI. This is the reason why it is not surprising that extensive research has been conducted to help airlines on the optimisation of their CIs. If a flight is delayed, but time is critical, which means that the cost of time is high, some time might be recovered during the flight. Nevertheless, as it has been analysed in [18], there is a compromise between the time recovered and the fuel burned. Therefore, to optimise the new value of CI becomes crucial [18], [29].

III. PROPOSED FRAMEWORK FOR SESAR

As mentioned before, the main change that SESAR introduces is that the airspace users become owners of their trajectories [13]. It means that in this new operational scenario, the network manager should not modify the intended flight plans of the aircraft, unless it is strictly necessary. In SESAR, as in NextGen too, the trajectories will be based on the 4D concept. A 4D trajectory is a precise description of the flight path of an aircraft as a 4 dimensional continuum, from its current position to the point at which it touches down at its destination. Thus, every point on a 4D Trajectory is precisely associated with a time [30]. Obviously, this will help on the predictability of the flights and some gain in efficiency is also expected. The airspace users will create their trajectories that in turn, will be shared using the network manager. With this information, along with the airspace related data, the airlines will have to negotiate among them to solve possible capacity-demand imbalances. In this case, the network manager will only act as a supervisor of the negotiation process that airspace users will do in case the demand excess the capacity (see Figure 4).

A. Network Manager

The task assigned to the network manager in the new operational context is the coordination of the different airspace users. As previously mentioned, in [16] a market mechanism aimed at assigning the air traffic flow management slots is proposed. In this case, after an initial First Planned First Served (FPFS) assignation (done by the network manager), an auction process is subsequently initiated. The airlines are owners of their initially assigned slots by the FPFS algorithm, but during the auction process they might keep or sell them according to their own interests.

In order to achieve an optimum from an economical point of view, the airspace users must have a good knowledge of the cost associated with a particular slot. This would help them to eventually choose a particular slot and sell their initial one, with regards to the other slots. In the work done by [16] and [18] a fixed cost is chosen for each minute of delay. In

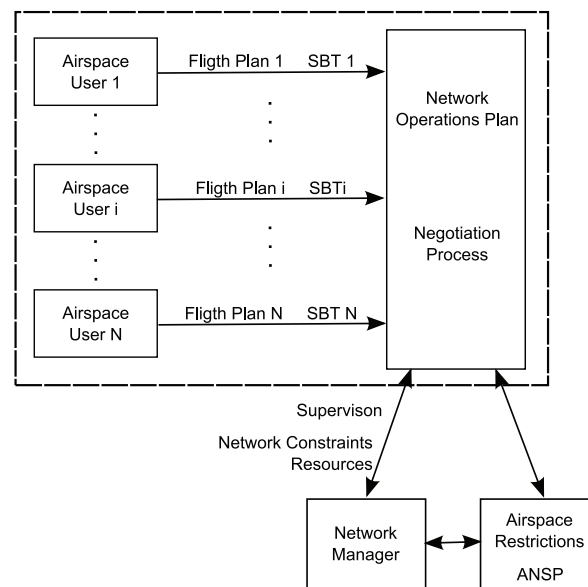


Fig. 4. SESAR concept of operations

these works, if the aircraft operator chooses a slot later than the initial one an extra on-ground delay must be performed (as shown in Figure 2) and no other options are left to the airlines. Moreover, in [16] the delay that the airline suffers at the take-off is supposed to be the same delay that the flight will experience at the arrival airport. This means that the airline is not allowed to change the original flight plan that was proposed before the regulation was known. In addition, the possibility of speeding up the flight before the regulation is also not considered and therefore only the slots with a higher time than the one the aircraft would have without regulation are taken into account. However, as it will be shown in next section, the authors propose that airlines might be more active during the negotiation process. The aircraft operator should change the initial flight plan (i.e. vertical and speed profiles, or even re-routing) in function of the chosen slot.

B. Airspace Users

In a complete 4D environment, where airspace users can fully optimise their trajectories, many options arise to deal with capacity-demand imbalance problems. First, a re-routing may be possible in order to avoid the regulated area.

In the case where the original route is kept, the aircraft might take off later (as it is done nowadays with the on-ground delay methodology [17]) but it would be also possible to fly slower. In this way the aircraft would be in the air earlier and if for some reason the regulation is cancelled it would be easier for the operator to recover the initial delay. Moreover, by flying slower, the cost of arriving to a later slot is also optimised [29]. Finally, the aircraft could increase the cruise speed in order to arrive to a previous slot. In fact, the optimisation algorithm used by the airspace user should compute an optimal solution for each possible slot taking into account a combination of all above strategies.

Once the regulation has been passed, some time might be recovered if the aircraft speeds up. Due to the fact that recovering time would have an impact on fuel consumption, in [18] an analysis has been done showing the amount of optimal time that should be recovered. As it could be expected, optimised solutions often do not recover all the possible delay due to the involved fuel consumption. On the other hand, even with high cost indexes, the time that is possible to be recovered is quite limited for short-haul routes. Thus, this technique may become more interesting for longer flights [18], [29].

The optimisation process that airspace users have to do will be enhanced to include time constraints, as shown in Figure 5. The authors propose the computation of the whole trajectory using an optimal control approach while meeting all possible constraints. Thus, the input of the optimiser will be, as in Figure 3, the distance computed, the weather conditions, the aircraft characteristics, but also the way-point time windows constraints for each slot and regulation.

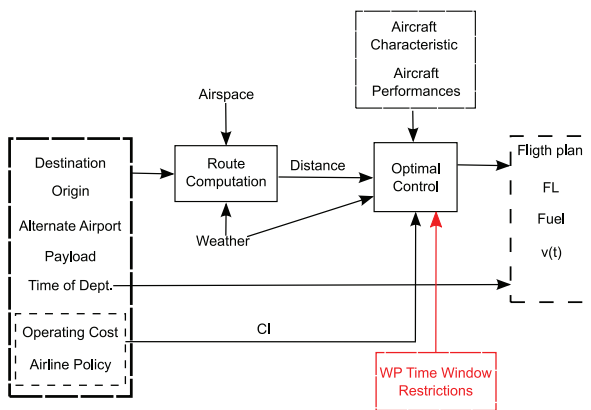


Fig. 5. Proposed flight optimisation

Therefore, each airline will compute for a given regulation a set of achievable slots. These sets will be bigger than other proposed approaches, such as [16], where all the delay is supposed to be absorbed on ground. The first valid slot will be determined by the aircraft taking off as soon as possible and flying to the regulated area at the maximum operational speed (or VMO). On the other hand, the last slot will be reached when flying at an optimal speed before the regulation to arrive at the slot ($V_{optBR_j S_i}$) and eventually doing some on-ground delay of GD_i . The last useful slot will be determined when the cost of the delay produced at the arrival airport due to the fact of using that slot becomes bigger than the economical profit that can be attained by using it.

After the regulation it will exist an optimal speed ($V_{optAR_j S_i}$) that will allow to eventually recover some time in order to minimise the cost of the delay at the destination airport. This optimal speed will take also into account the increase in fuel consumption due to the fact that the aircraft is flying faster than the initial intended speed [18]. The authors also suggest that the variable that should be taken into account in this optimisation process is the total delay at the destination

airport instead of the on-ground delay before take-off as it is usually done nowadays. In fact, the real cost for a minute of delay is due to the fact that the flight arrives late at the destination airport rather than because it has departed delayed.

In Figure 6, it can be seen that for each available slot, the airspace user will have a certain amount of ground delay (GD_i), an optimum speed to arrive to that particular slot ($V_{optAR1 S_j}$) and another optimum speed after the slot to eventually recover or lose some time if necessary ($V_{optAR1 S_j}$). These speeds should be computed with the optimisation mechanism proposed in Figure 5 by changing the time window associated to the way-point that define the entry of the regulated airspace. In Figure 6 it is shown that if the aircraft flies as initially planned, it will over-fly the regulated area at the slot achieved at V_0 . However, the aircraft operator has a set of alternative options, by using other slots with different associated costs on fuel and total delay. For each path (i.e. each different slot), the whole trajectory should be optimised by the aircraft operator. The optimal cost for each path will be computed in order to start the slot auction process described above. This optimisation might be done with an optimal control problem modelled with phases as the one described in [31], extended with time windows constraints.

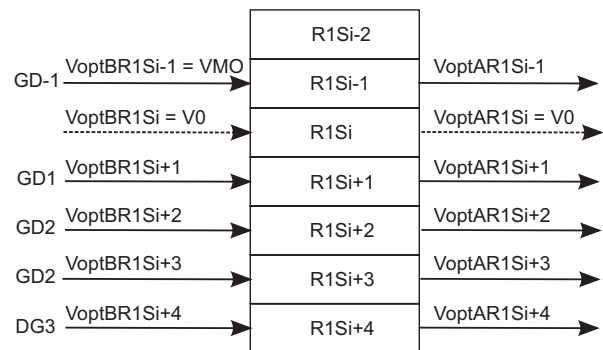


Fig. 6. One regulation with changes on flight plan

It is not surprising that the aircraft might fly through more than one regulated area. Actually in Europe 21% of the flights had two regulations in the AIRAC 311: 21st July 2008 to 27th August 2008 [16]. In this case, as can be seen in Figure 7, from one slot of the first regulation a set of slots on the second regulation can be reached flying from VMO to V_{min} . After the second regulation an optimum speed ($V_{optAR2 S_i}$) can be used to recover the optimal amount of time. Then, the optimiser has to be extended to include the possibility of having more than one restriction. This should not be difficult due to the fact that a narrow set of slots at the second regulation might be reached from one slot of the first one (see Figure 7).

Therefore, for each slot of the first regulation the airspace user have a set of slots of the second regulation that can be reached. With this definition a tree can be created (see Figure 8), and for each path different speeds will be used to minimise the operational cost (fuel and time). It is expected

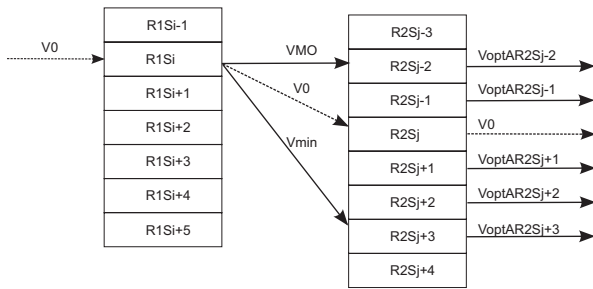


Fig. 7. Slots reachable from one slot of the first regulation

that this tree will not be too large, and therefore its creation should be computationally feasible. In this context, it has been presented in [18], [25] and [29] how time that can be saved or lost by changing cruise speed is quite reduced. Moreover, as it is distributed, each airline has to compute its own trees, reducing the computational cost that would involve solve this problem for all the traffic in a centralised system.

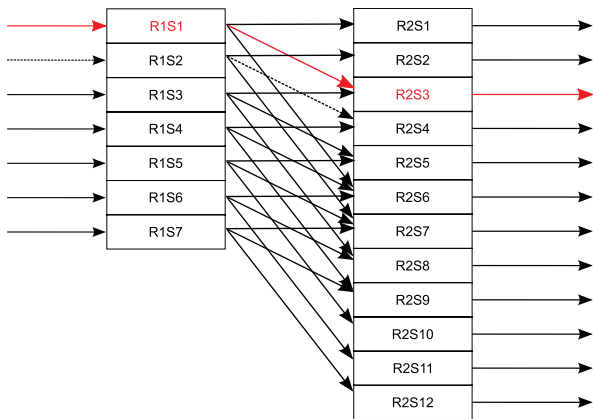


Fig. 8. Tree of reachable slots with two regulations in place

With this computation, the airspace user is able to determine which is the direct cost that it will have if a set of slots is chosen. If it is not possible to change the assigned slots, like in the current operational concept, the optimum speeds and vertical profiles to minimise the cost will be determined. If a negotiation process is possible with the network manager, the airspace user will be in a better position to choose between the options. Finally, if a market mechanism is established as the one described in [16] the airspace user that implements this solution will know the cost of each of the paths. Each path will be a set of slots, for example R1S1 and R2S3 which are shown in red in Figure 8. With the optimisation process, for each path the vertical profile and the optimum speeds will be computed. Therefore the airline that performs this optimisation has more information to decide at which price is worth to sell the original assigned slots and to buy a different path.

One advantage of this optimisation is that the objective functions for the airline can be easily modelled while the negotiation process supervised by the network manager ensures that the capacity is not exceeded. Moreover, the suggested

model allows to include different types of airlines, with different objectives and even airlines that do not optimise their trajectories with time constraints. The difference will be that those who did it will have more information and more optimal trajectories, being in a better situation to perform the negotiation [15].

The mechanism described in [16] might be easily extended to include re-routing. In this case, the airspace user will monitor the cost of different paths through different sectors while performing the negotiation.

IV. PRELIMINARY EXAMPLE

In this section, an illustrative example of the concept proposed above will be shown. The following preliminary results are based on a hypothetical situation where an Airbus A320 is scheduled to fly a route of 2000 NM with a payload of 15 tons. Let us suppose that the aircraft operator chooses a cost index (CI) of 40. For this aircraft and payload, this CI represents a cruise speed of M0.789 with a total flight time of 250 minutes (the climb and descent phases are neglected in this preliminary example) [32], [33]. On the other hand, let us have a regulation located at 800 NM ahead from the departing airport and where airspace slots are available at six minutes intervals. For the sake of simplicity, the time references are set to zero at the original intended take-off time.

Figure 9 shows the initial intended flight plan, where the CI is set to 40. In this case, the aircraft will enter the regulated area after flying 107 minutes and therefore, it will use the third available slot (R1S3) that spans from minute 106 to minute 112. Let us assume that another flight with a lower ETO has already been assigned to this slot R1S3. This means, that our aircraft will be delayed for five minutes on-ground in order to enter the regulated area by using the slot R1S4. If the flight plan is not changed, as it is done nowadays, the aircraft will always fly at CI 40 and therefore will arrive to the destination airport with a delay of five minutes.

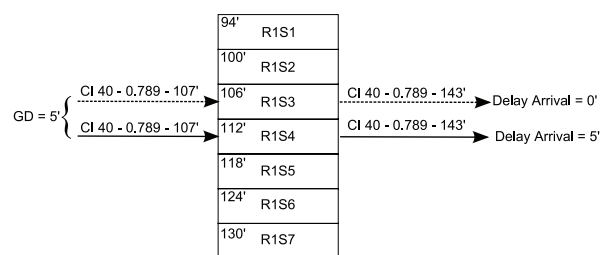


Fig. 9. Example of one regulated area without changes on the original flight plan

With the mechanism proposed in this paper, the aircraft operator can compute the cost of all available slots. For each slot a flight plan optimisation is performed in order to minimise their own policy of time and fuel consumption. Figure 10 shows the different available slots for this particular example. Even if the aircraft takes off at the original intended take-off time it is not possible to reach the regulation before 105 minutes, in order to arrive at slot R1S1, due to the

limitation on the maximum cruise speed. It turns that the first available slot for this example is the second one (R1S2), spanning from minute 100 to 106. To achieve this slot, no ground delay will be done and a CI of 150 will be used. For the studied aircraft this corresponds to a cruise speed of $M 0.80$ from the take-off to the regulated area. After the regulation it is possible to fly slower to save some fuel since the aircraft is two minutes ahead of the original schedule. In this case, the CI is changed to 25 and the flight will continue at $M 0.78$ during 145 minutes to the destination airport, where the plane will arrive on time.

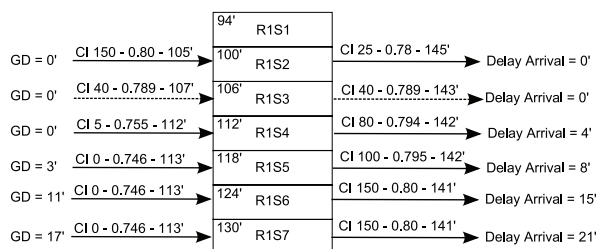


Fig. 10. Example of one regulated area allowing changes on the original flight plan

Obviously, for the third slot (R1S3) the flight is performed at the intended CI of 40 and any delay is experienced. If the slot R1S4 were to be used, it is worth mentioning that on the current operational scenario the aircraft would be delayed five minutes on ground (see Figure 9). However, with the proposed mechanism slot R1S4 can be reached with no delay on ground flying at a lower airspeed before reaching the regulation. In this case a CI of 5 would be used, corresponding to a cruise speed of $M 0.755$. Using this cost index, the plane will arrive to R1S4 consuming less fuel than initially planned, but with five minutes of delay. Moreover, once the regulation is passed, a speed up might be done by increasing the CI to 80. This will represent arriving with four minutes of delay instead of the initial five minutes expected with the current operational concept of operations. Finally, for the last three slots (R1S5, R1S6 and R1S7), the best that can be done is to fly at $CI=0$ to minimise the fuel consumption during the segment before the regulation while adding the needed ground delay in order to arrive to the regulated area at the appropriate slot. As it was done with slot R1S4, once the regulation is passed some time may be recovered speeding up the flight. In this case, the authors refer to the work presented in [18] where it is shown in which conditions it is worth to increase the airspeed by trading off fuel consumption and time recovered.

After this optimisation process, the aircraft operator knows exactly the cost associated to each slot, how much delay the flight would experience at the destination airport, how much fuel would be used and therefore the best sequence of CI depending of the flight segment. In this way, if a marked based mechanism is used, as described in [16], the airline will be on a better position to decide if it is worth to sell their initially assigned slot (in this example slot R1S4) and to buy another one.

V. CONCLUSION AND FURTHER WORK

This paper explains a framework for the optimisation of aircraft trajectories in the SESAR operational scenario, where airlines are expected to be more active in the resolution of demand-capacity imbalances in the airspace or airports. One possible concept of operations in the future Air Traffic Management (ATM) scenario is that if a congested airspace is declared, airspace users will have to agree with the final adopted solution. As airlines will have to negotiate the necessary delays or reroutings, a game from an economical point of view is set and the agent with most information is most likely to have advantage with respect to the others.

In this paper, the authors, suggest the idea of solving this kind of Air Traffic Flow Management (ATFM) problems in a distributed way, instead of using a centralised approach as it is often proposed in the literature. Therefore, airlines will accurately compute the cost of the different options that arise when the capacity-demand imbalance problem is solved (such as ground delays, speed reductions or reroutings). This optimisation will compute the optimal speed and altitude profiles for each possible alternative leading, in consequence, to different fuel consumptions and different delays at the destination airport. With the proposed methodology, this information will be kept by the operators without the necessity to publish sensible data to the network manager, as it is necessary with centralised based solutions. Thus, the main advantages of this method are that airliners can keep the secrecy on their data; the final solution is globally more efficient than with centralised methods, because airline data is expected to be more accurate; and being a distributed optimisation performed for each airline separately, no computational issues are expected when solving big real problems.

As part of on-going work, we are analysing the benefits of this solution with more than one restriction at the same time. In addition, results are being obtained for some practical cases using realistic data. Also, some simulations with the market mechanism are also foreseen including airlines with and without the optimiser in order to analyse the benefit for an airline of having this data available. Finally, as airlines work with the Cost Index (CI) parameter, a complete translation from this optimisation process to the CI values might be also interesting.

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