Pattern Based Priority Assignment for Multi Aircraft Conflicts in Autonomous ATM

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ABSTRACT
Priority rules are one of the most promising approaches to aircraft conflict resolution. This paper deals with the problem of priority assignment in autonomous Air Traffic Management with imperfect trajectory prediction. A robust solution is presented that relies on onboard traffic pattern classification using a data base common to all aircraft. The method allows reaching a common consensus in situation assessment in a timely and reliable manner and can also lead to conflict resolution improvement.

Keywords
Autonomous aircraft, air traffic management, priority rules, multi aircraft conflicts

INTRODUCTION
The concept of an autonomous aircraft is one of the promising concepts aiming at increasing the capacity and efficiency of the current Air Traffic Management (ATM) system. The concept is considered in both SESAR [1] and NextGen [2] and is based on using advanced onboard Airborne Separation Assistance Systems (ASAS).

An indispensable part of ASAS is reliable conflict detection and resolution (CD&R). Large literature (e.g. [3], [4], [5], [6]) considers application of priority rules for coordination among aircraft if a medium term conflict is predicted (8-10 minutes). Priority rules determine which aircraft are given way and which ones have to give way. For shorter terms, cooperative maneuvering (3-5 minutes) and Airborne Collision Avoidance System (ACAS) (tens of seconds) would be applied.

The solution in which not all the aircraft involved in a conflict are required to maneuver is attractive for several reasons: first, the overall stability of ATM is better if fewer flights have to re-plan their trajectory due to a conflict. Moreover, for an individual flight it is better to perform as few maneuvers as possible with respect to fuel and time efficiency and passenger comfort.

In this paper we describe the problem of priority rules assignment based on conflict detection in a distributed environment with imperfect trajectory prediction. We explain potential consequences of situation assessment discrepancy. Then, we propose a solution suitable for ASAS that is robust to the evaluation errors and that enables the autonomous aircraft to arrive at a common consensus within short time and using minimum communication. The safety of the approach can be guaranteed given that the reliability and precision of the onboard functions are within required tolerance limits.

Assumptions and environment description
We consider segregated airspace where only ASAS equipped aircraft without direct involvement of Air Traffic Controller (ATCo) operate in a self separation mode. The aircraft can communicate with each other via Air-to-Air data link. Some information, e.g. about weather, can be retrieved from System Wide Information Management (SWIM).

We also assume that the aircraft are flying its RBTs that are a priori conflict free, but due to the stochastic nature of the environment conflicts can occur. However, we assume that a cluster of conflicts (e.g. conflicts that occur close to each other both in time and space) are reasonably small (in [3] only encounters up to 4 aircraft are considered for ASAS) and do not span across more than a given time and distance. These goals are achieved by a high level strategic means that is out of scope of this paper.

Centralized and distributed priority assignment
In a centralized ATM system, the ATCo assigns priority to aircraft based on the perceived situation. The priority assignment results in issuing a clearance (e.g. to vector or change altitude) to the aircraft with lower priority. The priority assignment is valid only for given conflict situation. No history records are made in order to achieve fairness among aircraft.

The main factor in this centralized human-based assignment is geometry of the predicted flights. What also plays crucial role is the proximity of neighbouring flights and other airspace-related or weather-related constraints. Aircraft performance limits have to be obeyed as well, but usually the ATCo can roughly estimate these limits and thus generates resolution manoeuvres that are safely inside these limits.
When designing a distributed system where aircraft are self separating without a central authority, each aircraft involved in a predicted conflict must

1. Be aware of the fact that it is part of a conflicting situation;
2. Know which aircraft should perform the avoidance manoeuvre.

**Situation assessment discrepancy**

When two (or more) aircraft are regularly performing conflict detection onboard, the results may slightly or considerably differ. Namely,

- The time of conflict detection and
- the predicted time and position of the detected Loss of Separation (LoS)
can differ among the participating aircraft. Moreover,

- Conflicts detected by some aircraft may remain undetected by some other participating aircraft (for some time or forever).

These issues stem from the inevitable imperfection of the onboard functions. The conflict detection algorithms depend on a trajectory prediction of the ownership and the other aircraft. The trajectory prediction error, which depends on multiple contributing components (sensor errors, navigation error, flight technical error, a system latency etc., see [7] for details) is a well known issue in ATM. Even if this error is minimized by using advanced and highly reliable technologies, its impact on conflict detection can hardly be excluded.

**PROPOSED SOLUTION**

Priority can be assigned taking into account plentiful of parameters. Usually, higher priority is reserved for emergency situations, VIP flights etc. but our contribution focuses on prioritization of normal operations with fully functioning ASAS functions.

In the proposed solution, every detected conflict situation is classified by each involved aircraft (step 1). Next, consensus must be achieved so that the classification is consistent among all the involved aircraft (step 2). Each aircraft then derives its priority from the situation class (step 3).

**Step 1: Conflict detection and classification**

All the autonomous aircraft regularly perform traffic surveillance and conflict detection. Once a conflict is identified, the predicted situation is classified. Not only the aircraft involved in the conflict is/are taken into account, but also all the surrounding traffic within a predefined neighbourhood of the detected conflict(s). This information is important in order to take into account manoeuvring possibilities.

The situation at the time of conflict is input into a classification function. This function compares the situation with the class representatives stored in a data base, and finds the most similar one according to a suitable similarity (or closeness) metric. In such a way, the most important features of the situation are captured but the complex situation can now be communicated in a very efficient manner: only data related to the predicted LoS and the class identification (CID) are transmitted. The data base of classes including the unique CID is common to all autonomous aircraft.

**Step 2: Consensus achievement**

Once an aircraft identifies conflict(s), classification is performed and the relevant information is automatically sent to all the aircraft involved in the conflict(s). This is done by all aircraft that detect a conflict so in an ideal case each aircraft sends a message to all the other involved ones (but not to the surrounding traffic, although the traffic is incorporated in the situation classification). If there is an aircraft that detects no conflict and this aircraft is identified by at least one other aircraft as a potential threat, it receives a message from another aircraft after which it is aware if the perceived conflict as well. The received message content (i.e. LoS) and the identity of the message sender help each recipient to identify what encounter is the one perceived as a conflict by the other aircraft.

Due to the trajectory imperfection, it may happen that the CIDs sent by different aircraft do not correspond. Now a consensus must be reached.

The consensus problem [8] is generally a difficult problem, but in our case several simplifications can be made. First, we assume that the last message concerning given conflict situation is delivered within a fixed time interval from the first message concerning the same conflict situation.

We also assume that the number of aircraft participating in a single conflict is not high (up to four). Since the classification process does not capture all the details, some imprecision is tolerated unlike in the case of the general consensus problem.

Therefore, if different classes are identified, it is not such an issue given that the classes are similar (according given metric). The similarity on classes does not have to be computed, it is already stored in the data base. And the fact that only mutually similar classes are proposed by different aircraft can be guaranteed by suitable class definition (see the example of two aircraft encounters below). In short, similar classes should be those that are based on close values of base parameters.

If different aircraft select different but similar classes, any of these classes can be used as the final class. Reaching such a consensus can be done in a simple way: for example, the data suggested by the aircraft with the oldest message time stamp can be used. The aircraft that do not detect the conflict situation at all do not send their CIDs. They only select the suitable CID from the received messages.

**Step 3: Priority assignment**

Once all the conflicting aircraft agree on a common class of the perceived conflict situation, the priorities are retrieved from the data base. Specifically, each class in the data base
uniquely defines how the priorities are assigned. For example, if a situation is classified as “an isolated aircraft crossing flow of aircraft” (see Figures 1 and 2), the isolated aircraft is given the lowest priority.

Figure 1: An isolated aircraft A is crossing a flow of aircraft.

In case of a symmetric situation, such as a head-on encounter, external parameters (such as geographical parameters) can be used in order to uniquely match the perceived situation with the pattern from the data base. Consequently, aircraft can be assigned priority according to these external parameters. For example, the aircraft heading from the north or west is prioritized.

**Conflict resolution simplification**

Effective priority assignments have to result in efficient and safe resolution manoeuvring possibilities for the low priority aircraft.

Many conflict resolution algorithms [9] explore large and complex solution spaces with many local extrema. This requires application of advanced optimization methods that are either too demanding to be run onboard of an aircraft, or too unreliable to be run in such a safety critical application (stochastic algorithms).

Obviously, many parameters that are suitable for priority assignment have to be taken into account for conflict resolution as well. In our concept, the conflict resolution function can therefore benefit from the pre-assessment done within situation classification and priority assignment. As a consequence, only part of the solution space can be searched for when looking for the optimum resolution manoeuvre. The idea is that for a given situation only certain manoeuvres make sense for the low priority aircraft. For example, if priority is assigned based on the order in which aircraft pass the geometric intersection of the trajectories and the aircraft that arrives to that point as the second one has low priority, all the resolution manoeuvres based on speeding up are excluded from consideration and the solution space is thus limited. It is also desired that priority assignment (together with the resulting type of resolution manoeuvre) based on data base patterns respects existing [10] or future flight rules. This would enable easier integration of ASAS equipped and unequipped traffic.

**CASE STUDY – TWO AIRCRAFT CONFLICTS IN 2D**

Let us demonstrate the approach on the simplest case possible: two-aircraft conflicts with no surrounding traffic (i.e. traffic with an impact on conflict resolution) in 2D.

Let us consider classification based on two parameters: Flight directions and time difference between the times at which the two aircraft are predicted to pass through the geometric intersection of their trajectories.

The space of all situations can be depicted in the following way using a cylinder surface: every potential situation is determined by the angle between the ownship direction and the conflicting aircraft direction at the time of the conflict (depicted as the azimuth) and by the time difference on passing the geometric intersection. The space is divided into twelve zones that determine the classes. Classes A, B, C and D include all the situations in which the ownship passes the geometrical intersection first and the time difference is higher than a predefined threshold. Class A includes all the cases in which the two aircraft have approximately the same direction, B and D include the perpendicular cases (approx. 90 degrees and 270 degrees) and class C consists of cases with opposite directions (approx. 180 degrees). Similarly, classes E to H include the cases in which both aircraft pass the intersection approximately at the same time (the time difference is below the threshold) and classes I to L include the situations in which the ownship passes the intersection after the conflicting aircraft and the absolute time difference is higher than the threshold.

Figure 3 presents the cylinder with two zones depicted: the green zone depicts class E and the blue zone depicts class L. The topology of the zones in the cylinder determines the closeness relation on the classes: two classes are said to be close if they are neighbours, that is, if they have a common edge or a vertex. For example, classes E and L are neighbours since they have a common vertex. If different conflict detection systems evaluate the conflict differently, the differences in estimated angle and/or time difference are acceptably small since the trajectory prediction errors are within limits given by the performance requirements. Therefore, the classes determined by different aircraft may be different, but they are close given that the onboard trajectory prediction systems are functioning within given performance limits. For example, in the nominal case it is not possible that one aircraft identifies the conflict as two flights in the same direction while the other aircraft identifies the same conflict as two flights in the opposite direction: the angle estimation error would be unacceptably high here. On the other hand, it is possible that one system
estimates the direction difference as 44 degrees and the other one as 46 degrees. In such a case any of the candidate classes is acceptable, no matter what the real angle will be.

The work is in its initial stage (this is the first publication of the concept). In the following work the data base of situation classes (including priority assignment) should be built for the whole space of traffic patterns (including multiple conflicting aircraft and three-dimensional trajectories). Special attention must be paid to the closeness relation: it must be shown that whenever different classes can be identified by different aircraft, those classes are close in the sense that any of them can be chosen for a reasonable priority assignment. Moreover, the role of the crew and the human machine interaction aspects as well as potential integration of ASAS unequipped traffic should be investigated.

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REFERENCES
1. SESAR programme web page, URL: http://www.eurocontrol.int/esar/.