Conflict avoidance: 0-1 linear models for conflict detection & resolution

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Abstract The Conflict Detection and Resolution Problem for Air Traffic Flow Management consists of deciding the best strategy for airborne aircraft so that there is guarantee that no conflict takes place, i.e., all aircraft maintain the minimum safety distance at every time instant. Two integer linear optimization models for conflict avoidance between any number of aircraft in the airspace are proposed, the first being a pure 0-1 linear which avoids conflicts by means of altitude changes, and the second a mixed 0-1 linear whose strategy is based on altitude and speed changes. Several objective functions are established. Due to the small elapsed time that is required for solving both problems, the approach can be used in real time by using state-of-the-art mixed integer linear optimization software.

Keywords Air traffic flow management · Conflict avoidance · Mixed 0-1 linear optimization · Pure 0-1 linear optimization · Conflict detection and resolution

Mathematics Subject Classification (2000) 90B20

1 Introduction. Brief state-of-the-art

Air traffic in Europe and the USA has undergone an astonishing growth during recent years, and a further 50% increase is expected by 2018 over the traffic in 1999, see Air
Traffic Action Group (ATAG) (1999). In this scenario, the aim of Air Traffic Flow Management consists of extending the airspace allowing the so called “Free Flight”, where the pilots and the airlines are able to decide freely the flight plan, keeping in touch with the air traffic controller. To maintain safety the air flow, the Conflict Detection and Resolution Problem (CDR) or Conflict Avoidance Problem (CA) is currently attracting the interest of air transportation service providers and has been studied extensively.

Unfortunately, the CDR has proven to be a hard problem to solve. To give some idea, the way in which to represent the actual trajectory of an aircraft is by means of a dynamic model that has to take into account, as an example, the following relationships: speed of the aircraft will depend on the wind direction and altitude on which it flies (such that the higher a aircraft flies, the lesser the air is around it and thus it needs to go faster to maintain its position); acceleration depends on the speed (e.g., at lower speeds, a plane can reach higher acceleration ratios) and altitude, and so on. Notice that the aircraft is losing mass throughout the flight as fuel burns, and this influences the speed and acceleration of the aircraft (and, vice versa, the speed influences the consumption of fuel and thus the mass loss), etc. Good introductions to flight dynamics modelization can be found in Etkin and Reid (1996), Hull (2007), Tewari (2007). Finally, CDR has to deal with the simultaneous trajectories of (possibly) many aircraft. Moreover, we must bear in mind that given the intended trajectories, captured in the flight plans, some uncertainty regarding the actual trajectories of the aircraft is unavoidable, which makes CDR harder to solve. Trying to address all these issues within a mathematical optimization model would lead today to an unmanageable problem (in terms of computing effort, i.e., elapsed time and memory requirements).

Different methods have appeared in the literature. What follows is a brief state-of-the-art on the subject. Magister (2002) presents two different models: The first applies to conflict detection. The second is related to conflict resolution to solving the conflict by lowering one of the two aircraft that are taken into consideration in the conflict. Magister (2004) describes the conflict resolution problem in great detail and makes a quantitative analysis of avoidance procedures.

One of the most recent works, see Jardin (2005), presents some algorithms for strategic conflict detection, based on the use of a 4-dimensional space and time grid to represent the airspace. This approach to compute conflict detection was previously introduced by Jardin (2003a, 2003b), where he uses a 3-dimensional grid (two horizontal spatial dimensions and time). Prandini and Hu (2008) present a stochastic approximation scheme to estimate the probability that a single aircraft will enter a forbidden area of the airspace within a finite time horizon. A numerical algorithm is also proposed for computing an estimate of the probability that the aircraft might enter an unsafe region of the airspace or come too close to another aircraft. Hu et al. (2005) introduce a model of a two-aircraft encounter with a random field term to address correlation of the wind perturbations to the aircraft motions. Based on this model, they estimate the probability of conflict by using a Markov chain approximation scheme. The same authors study in Hu et al. (2003) the problem that consists of evaluating whether the flight plan assigned to an aircraft is safe. They introduce a kinematic model of the aircraft motion in a three dimensional wind field with spatially correlated random perturbations.