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Estimating separation distance loss probability between aircraft in uncontrolled airspace in simulation

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ABSTRACT

In this article, collision probability between aircraft in uncontrolled airspace is estimated. For that purpose, a large database of aircraft trajectories in the vicinity of Saint-Cyr-l'Ecole airfield (France) is considered and maps of probability collision from simulated aircraft are then estimated. Since the collision between aircraft is a rare event, we applied an importance splitting estimation technique rather than crude Monte Carlo simulations to reduce the variance of the probability estimation. In this study, we demonstrate the high local variability of collision probability in uncontrolled airspace and conclude on the difficulty to set general probability requirements.

1. Introduction

Maintaining a specific minimum separation distance between two aircraft to avoid collisions is mandatory in air traffic management (ATM). This safety rule is generally guaranteed by the air traffic control (ATC) that demands aircraft to fly at set levels or level bands, on defined routes or in certain directions. The aircraft positions are also well-known thanks to transponder and radar. Collision or separation loss statistics are consequently easily evaluated. The collection and analysis of data on hazardous air traffic management incidents have also been an important task to determine issues and improve ATM (Brooker, 2005; Leva et al., 2009). ATM modelling and simulation in controlled airspace (Kirkland et al., 2004; Shangwen and Ming-hua, 2010; Wang et al., 2010; Irvine, 2001) have been widely discussed in the literature. Based on these results, regulations have been set. On the contrary, when one considers uncontrolled airspace, it is difficult to evaluate the collision or separation loss risk with confidence. Indeed, the aircraft number, position and routes are neither known nor recorded. There is thus currently a specific need to estimate the probability of collision or separation loss in uncontrolled airspace.

For that purpose, we have obtained a 170 trajectory database of aircraft in uncontrolled airspace (class G airspace) over Saint-Cyr-l'Ecole, France, airfield. In this article, our objective is thus to estimate collision or separation loss probability with this trajectory database over the region of Saint-Cyr-l'Ecole in simulation. It will provide an overview of the mean collision risk in the general case and of its local variability. This type of study could be interesting for regulatory purposes about the integration of unmanned aircraft into uncontrolled airspace (Allouche, 2000; Ostwald and Hershey, 2007; Asmat et al., 2006; Kochenderfer et al., 2008b; Kochenderfer et al., 2008a). The effect of their integration on aircraft safety is a hard question to answer since the current safety conditions in uncontrolled airspace is not well characterized.

This paper presents the general context of airspace class and then details the aeronautical issue near Saint-Cyr-l'Ecole airfield. It describes the trajectory database that will be used in simulation and how collision probabilities are derived. As Monte Carlo (Mikhailov, 1999; Sobol, 1994; Robert and Casella, 2005) simulations are not accurate enough to estimate rare event probabilities with an affordable simulation, using importance splitting algorithm (Cerou et al., 2008; Cerou and Guyader, 2007; L'Ecuyer et al., 2006; Glasserman et al., 1996; Morio et al., 2010) is suggested and based on the recursive estimation of conditional probabilities. The final section of this article is dedicated to collision probability analysis over Saint-Cyr-l'Ecole.

2. Context

This section describes airspace class and flight rules that are followed by the aircraft in the trajectory database. The flight situation in the vicinity of Saint-Cyr-l'Ecole airfield is then presented.

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2.1. Flight rules and airspace class

2.1.1. Flight rules

Two different flight rule sets coexist currently in airspace (Thom and Godwin, 2007): the visual flight rules (VFR) and the instrumental flight rules (IFR). VFR are a set of regulations which allow a pilot to operate an aircraft in weather conditions generally clear enough to allow the pilot to maintain ground in sight and see where the aircraft is going. The weather conditions are supposed to be sufficient to sense and avoid potential collisions with other aircraft. IFR permit an aircraft to operate in instrument meteorological conditions (IMC), which have much lower weather minimums than VFR. In this article, all the aircraft trajectories that are considered in the database follow the VFR rules. VFR flights are operated in the case of visual weather conditions (VMC). VMC are characterized by an horizontal visibility above 5–8 km depending on the flight height and down to 1.5 km in uncontrolled airspace at altitude below 3000 feet. The distance to the clouds in VMC conditions is equal or greater than 1500 m in horizontal plan and 300 m vertically. Flight is also permitted in uncontrolled airspace below 3000 feet just outside the clouds.

2.1.2. Airspace class

There are two different types of airspace: controlled and uncontrolled airspace. In controlled airspace, ATC has the authority to control air traffic, the level of which varies with the different airspace classes. Controlled airspace is established mainly for two different reasons:

- high traffic density areas (for instance, near airfields)
- IFR traffic under ATC guidance

Controlled airspace (class A–E airspace) usually exists in the immediate vicinity of major airfields, where aircraft are carrying out procedures for departures, approaches and transit routes.

In uncontrolled airspace (class F, G airspace), ATC service is unnecessary or cannot be provided for practical reasons. ATC does not exercise any executive authority in uncontrolled airspace, but may provide basic information services to aircraft in radio contact. Flight in uncontrolled airspace will typically be under VFR in the studied case. Aircraft operating under IFR should not expect separation from other traffic. In most countries, it is common to provide uncontrolled airspace in areas where significant air transport or military activity is not expected. Each national aviation authority determines how it uses the airspace classifications in its airspace design. Indeed, Fig. 1 presents the different kinds of airspace class in France.

All the aircraft in the trajectory database operate in a class G airspace. More precisely, a class G airspace is an uncontrolled airspace where the ATC clearance is not required, the separation is not provided, and traffic information is provided if possible. In France, class G airspaces are either located below flight level 115 and above flight level 660.

2.2. Saint-Cyr-l'Ecole airfield

Saint-Cyr-l'Ecole airfield is a French airfield located at 21 km southwest from Paris, France in the territory of Saint-Cyr-l'Ecole town (Yvelines). International Civil Aviation Organization (ICAO) code of this airfield is LFPZ. Its geographic coordinates are 48°48′37″ North, 2°04′24″ East. Its elevation above mean sea level is 113 m and the airfield area is 80 ha. The airfield has two runways in grass of direction 11*L*/29*R* and 11*R*/29*L* and with respective dimensions $890 \times 100\,m^2$ and $867 \times 60\,m^2$. Fig. 2a and b shows Saint-Cyr-l'Ecole location on a France map and an aerial photography of Saint-Cyr-l'Ecole airfield. Visual Approach Charts (VAC) maps for visual landing and visual approach at Saint-Cyr-l'Ecole airfield are provided in Figs. 3 and 4.

Fig. 5 presents the public airfields (plane icons) in Saint-Cyr-l'Ecole airfield surroundings. The different ICAO codes correspond to Toussus-le-Noble (LFPN), Velizy-Villacoublay (LFPV), Chavenay-Villepreux (LFPX) and Beynes-Thivernal (LFPF). This airfield network is located at less than 5 flight minutes away from Saint-Cyr-l'Ecole airfield with significant traffic from one airfield to another. Green tags with ICAO code LFPZSNOR, LFPZSER, LFPZSNL, and LFPZWES describe the entry and the exit points of Saint-Cyr-l'Ecole airfield. The entry point of the airfield is located at 1100 feet and the exit points at 1500 feet. One can also notice that a VOR (VHF Omnidirectional Radio range) station is located near Toussus-le-Noble airfield and implies a locally higher traffic density.

The following section focuses more precisely on the description of the aircraft database and details how the probability estimates are computed by simulation.

3. Flight simulation and collision probability estimation

In this section, we propose to present the aircraft trajectory database that will be used extensively in this article and then we present a specific statistical technique to estimate collision probabilities.

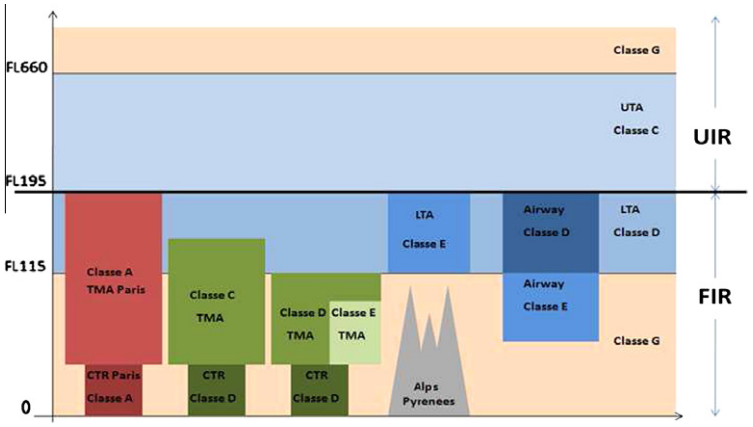

Fig. 1. French airspace description (Flight information region (FIR), Upper flight information region (UIR), TMA (Terminal Maneuvring Area), LTA (Lower Traffic Area), UTA (Upper Traffic Area), CTR (Contol Traffic Region) and FL (Flight Level)).