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Safety assessment method of performance-based navigation airspace planning

Yong Tian [a,b,*], Lili Wan [b,c], Chun-hung Chen [a], Ye Yang [b]

[a] Center for Air Transportation Systems Research, George Mason University, Fairfax, VA 22030, USA
[b] School of Civil Aviation, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China
[c] National Key Laboratory of Air Traffic Flow Management, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

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ABSTRACT

The paper introduces a computational model of airspace conflict risk in the hierarchy of performance-based navigation (PBN) airspace operation and combines it with air traffic controller (ATC) workload to propose a method for safety assessment of PBN airspace operational planning. Capacity probability distribution is employed to depict airspace capacity in uncertain weather, errors of deviating from nominal PBN track are taken into consideration, and the stochastic process based on Gaussian distribution is used to depict random aircraft motion according to airspace PBN specification, so as to build an airspace conflict risk computational model in corresponding capacity scenario. Guangzhou No. 15 sector is chosen for simulation validation. The analysis results suggest that 60% of ATC workload is corresponding to sector traffic flow of 31 aircraft/h and airspace risk of 0.018 conflict/h, while 70% of ATC workload is corresponding to sector traffic flow of 35 aircraft/h and airspace risk of 0.03 conflict/h. As air traffic flow increases, both airspace conflict risk value and ATC workload will increase, resulting in reduction of airspace safety, though their increasing magnitudes differ with different capacity scenarios. The safety assessment method enables effective quantization of safety with regard to airspace operational planning strategy, and benefits the development of optimal operational scheme that balances risk with capacity demand.

1. Introduction

In the time of increasingly busy air transportation today, conventional navigation based airspace structure is very difficult to meet the requirement of increasing flight volume. Flight delay occurs quite often indicating a desperate need of optimization design of current airspace in China. The performance-based navigation (PBN) is a novel operational concept proposed by the International Civil Aviation Organization

* *Corresponding author*. Center for Air Transportation Systems Research, George Mason University, Fairfax, VA 22030, USA. Tel.: +86 13601589681.
E-mail address: 138139@263.net (Y. Tian).

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(ICAO) on the basis of integrating operational practices and technical standards of country-specific area navigation (RNAV) and Required Navigation Performance (RNP), enabling effective improvements of airspace resource utilization, airspace capacity and safety. The international aviation community even regards PBN as one of the cornerstones of future air navigation system. According to China's strategy of reinvigorating the country through civil aviation, Civil Aviation Administration of China (CAAC) plans to implement PBN technology in en-route phase during the Twelfth Five-Year Plan period.

Safety is a critical issue as to whether an airspace planning scheme can be efficiently implemented or not. Safety assessment is capable of providing valid feedback information for planning, efficiently of preventing aircraft from having such hazards as conflict and collision. Therefore, airspace planning has to be built on the basis of safety assessment. Depending on different phases of air traffic management (ATM), airspace planning can be divided into strategic, tactical and operational hierarchies. Factors considered gradually increase with hierarchies and the corresponding safety assessment method varies somewhat, evaluation model has become more complicated. Safety assessment of airspace planning in various hierarchies is an important task to ensure air traffic safety.

In light of this, the scholars worldwide have conducted numerous researches. Reich (1966a, 1966b, 1966c) established the theory of aircraft collision model, firstly proposing the Reich collision risk model. Hsu (1981) put forward a concept of critical collision zone and studied aircraft collision risks on intersecting routes using conditional probability method, namely the modified Reich model. Cox et al. (1991), Harrison and Moek (1992), Moek et al. (1993) employed Reich model to study collision risks at places including North Atlantic Ocean, and analyzed probability of reducing safety separation. Brooker (2002a, 2002b) analyzed separation safety from perspective of accident analysis, studied current separation safety assessment and collision risk models, and proposed the event model (Brooker, 2003, 2004a, 2004b, 2006). Netjasov (2012a, 2012b, 2013) proposed a conflict risk evaluation model for airspace strategic planning with conflict probability and number of conflicts giving the minimum flight safety separation. Domestic studies in this field started later, Zhao (1998) studied number of dangerous conflicts occurring on aircraft at two intersecting air routes. Ying and Xu (2002) and Xu et al. (2008) employed Reich model to study the issue of safety assessment of separation criterion at parallel routes in oceanic area and built the event model based on collision cylinder. Han et al. (2006) improved the collision risk model under the condition of radar separation and proposed a computational model at radar control separation where it is necessary for air traffic controller to intervene any flight conflict with or without non-intrusion zone. The researches on airspace safety assessment worldwide primarily started from collision risk, focusing on collision risk model and safety separation determination, but there were only fewer studies focusing on conflict risk. Moreover, they mainly used two routes, not applying their researches to all airspace planning cases, such as ad-hoc sectorization (Zhang et al., 2007, 2009; Meng et al., 2010; Zhou et al., 2014).

In this paper, weather uncertainty factor and error of aircraft flight deviating from PBN nominal track are taken into account for airspace planning operational hierarchy. Actual track is simulated using stochastic method based on Gaussian distribution, thereby random airspace conflict risk in corresponding capacity scenario is studied. With ATC workload as an indicator to represent human factor impact, a method for safety assessment of PBN airspace operational planning is proposed, thereby different airspace design and organizational scenarios are compared and validated through computation of test cases.

2. Problem description

During actual aircraft operations, flight safety will be subject to such factors as complexity of air route structure and features of traffic flow in airspace. While the PBN specification is selected, weather change and human factor would further increase uncertainty of flight safety. If PBN specifications selected varies, then errors of deviating from nominal track would differ somewhat; occurrence of adverse weather would aggravate the difficulty of pilot operation, directly impairing the flight safety. Meanwhile, weather change leads to uncertainty of airspace capacity. Once airspace capacity decreases, congestion phenomenon would appear, resulting in increased ATC workload. If the load exceeds affordable ATC load limit, the response rate and air control efficiency of an air traffic controller would decrease dramatically, and it would be too late to control some aircraft in “potentially dangerous conflict state”, resulting in potential safety hazard.

What has bean considered in this paper is the safety assessment method in airspace operational planning hierarchy, such assessment usually lasts a week, so information about aircraft type and traffic flow in airspace is certain. This model mainly combines airspace conflict risk and ATC workload to compare various operational scenarios of airspace, so as to balance airspace conflict risk and traffic flow demand, which are beneficial to developing a flight plan with low risk and high traffic flow and to enabling air traffic flow assignment in case of uncertain weather. The model can be used in PBN airspace operational planning stages, such as discriminating the responsibilities of an air traffic controller from those of a pilot, ad-hoc adjustment of flight plan and dynamic sectorization. To simplify the model, the following assumptions are adopted.

(1) When an aircraft flies in a PBN airspace, its error of deviating from nominal track follows Gaussian distribution.
(2) Conflict risk value is not a constant, but is related to airspace structure and weather information, etc.
(3) Influences of on-board devices and others on conflict risk are disregarded.

3. Safety assessment model

The model proposed in this paper makes safety assessment from macroscopic perspective. With the combination of