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# Nominal flight time optimization for arrival time scheduling through estimation/resolution of delay accumulation

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A B S T R A C T

In the arrival air traffic management, aircraft are provided with each one's scheduled time of arrival to satisfy the required time interval from the preceding one at a specific point, e.g. runway threshold, metering and merging points, etc. In general, the interval between aircraft in a traffic stream is controlled by delaying the following one, which inevitably results in delay accumulation and operational inefficiency. Because the scheduled time of arrival also depends on the nominal flight time toward specific points, it is considered possible to optimize the nominal flight time to minimize the operational cost of whole traffic stream. In this study, the nominal flight time optimization strategies through the estimation/resolution of the delay accumulation are proposed, and its feasibility is discussed. Through mathematical delay analyses, it is proven possible to estimate the delay accumulation by using the statistics of the traffic arriving at the initial point of the arrival scheduling. The feasibility to optimize the nominal flight time is then clearly demonstrated through the numerical traffic simulation. When the nominal flight time is longer than the minimum one, it is possible to reduce the flight time. When the traffic control with the flight time reduction is applied, it becomes possible to resolve the delay accumulation. It is further clarified that the optimum scheduled time of arrival can be directly estimated from the cost function of a single aircraft in the case of such a traffic free of delay accumulation. In addition, the maximum runway use and the equality of the operation performance are simultaneously achieved.

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## 1. Introduction

Continuous descent operation (CDO) (ICAO 2010) has been recognized as one of the most promising operational concepts in several future air traffic plans (Joint Planning and Development Office, 2010; SESAR Consortium, 2012; Japan Civil Aviation Bureau, 2010). A lot of researches and developments to realize CDO have been carried out (Clarke et al., 2004; Boursier et al., 2007; Barmore et al., 2008; Coppenbarger et al., 2010; Erzberger et al., 2010; Johnson et al., 2010; Kupfer et al., 2011; Clarke et al., 2013), and a trial of CDO has also been demonstrated at some airports (Meserole, 2009). The basic CDO concept can be summarized as follows: an aircraft descends from the top of descent (TOD) to reach the metering fix at a required time, and maintains an appropriate interval with the preceding aircraft by airborne separation (Weitz, Aug. 2013; Weitz et al., 2013) as shown in Fig. 1. The descent from TOD to the metering fix is operated using a time-based traffic control. This operation strategy is expected to enable every aircraft to reach the metering fix at the required time while maintaining minimum possible thrust without any conflict. In the arrival time scheduling, the estimated time of arrival (ETA) and scheduled time of arrival

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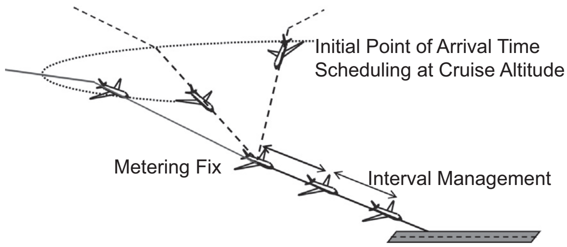


**Fig. 1.** Basic CDO concept.

(STA) are often referred to determine the flight time of aircraft for interval management (Erzberger, 1995). At the beginning of the arrival time scheduling, the ETA of an aircraft is determined assuming that it follows a nominal flight trajectory. Then the STA is determined so as to satisfy the required time interval from the preceding aircraft. Fig. 2 shows the typical nominal flight trajectories of representative types of aircraft (Nuic, 2010). The flight speeds during descent are near their upper limits, which are typically given around 300 kt in calibrated air speed (CAS). From this figure, it is considered that the nominal flight times used in actual operations are also near the minimum ones. The application of such near-minimum flight time profiles to the nominal flight profiles is considered effective to facilitate the traffic control by delay. As mentioned above, the delay accumulation is inevitable due to the traffic control by delay, and it increases around the latter part of the traffic stream. This results in the operational inefficiency.

Among numerous previous studies on the arrival traffic scheduling, a concept to advance the STA of the aircraft around the front of the dense traffic stream, has been investigated in several studies. It was shown to be possible to reduce the delay and the fuel consumption of the whole traffic (Lee and Balakrishnan, 2008; Sewnson et al., 2011). It is also clarified that the extra fuel consumption reduces as the reducible time of arrival becomes larger (Erzberger and Nedell, 1989). It is also shown that the advance of the STA can also minimize the operational cost by reducing the flight time of specific aircraft in traffic stream (Wu and Swenson, 2015).

The operational cost is generally defined as a function of flight time and fuel consumption (Robertson, 2007). Therefore, it becomes a function of flight time because the fuel consumption also depends on the required flight time. In addition, the required flight times are subject to the delay accumulation behavior. Therefore, it is expected possible to minimize the operational cost if it is possible to estimate the delay accumulation in advance. In this study, therefore, the feasibility of the delay accumulation estimation and its application to optimize the nominal flight time to minimize the operational cost are firstly discussed through numerical traffic simulations and theoretical analyses. In addition, if the nominal flight time is longer than the minimum flight time, it is possible to reduce the flight time. The author has clarified that the flight time reduction is able to minimize and resolve the delay accumulation of the whole traffic when an intentionally long flight time is applied for the nominal flight time (Takeichi et al., 2013). The effectiveness to minimize and resolve the delay accumulation by the flight time reduction in the arrival time scheduling on the operational performance is also investigated.

## 2. Air traffic analysis model

### 2.1. Traffic flow and CDO scheduling model

In this study, it is assumed that aircraft arrive at the metering fix from various directions. The highest density traffic stream is considered; aircraft are originally scheduled to arrive the metering fix with a nominal time interval throughout one day. It is assumed that disturbances such as wind, navigation and control error, etc. cause the arrival time error at the initial point of arrival time scheduling which is introduced at the same distance from the metering fix as shown in Fig. 1. At the initial point, the ETA at the metering fix is estimated based on the nominal flight time to arrive at the metering

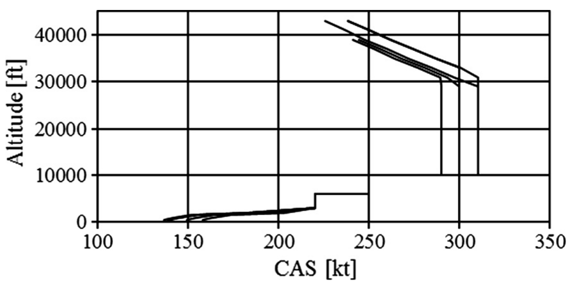


**Fig. 2.** Typical descent profiles.

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