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Integrated design and allocation of optimal aircraft departure routes

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ABSTRACT

This paper presents a new multi-objective optimization formulation for the design and allocation of optimal aircraft departure routes. In the considered problem – besides two conventional objectives based on cumulative noise criteria and fuel burn – a new objective considering the flight frequency is introduced. Moreover, to take advantage of the combination of designing new routes and allocating flights to these routes, two different routes are considered simultaneously, and the distribution of flights over these two routes is addressed in parallel. Then, a new version of the so-called MOEA/D optimization algorithm is developed to solve the formulated optimization problem. Two different case studies, one at Rotterdam The Hague Airport and one at Amsterdam Airport Schiphol in The Netherlands, are carried out to evaluate the reliability and applicability of the proposed approach. The obtained results reveal that the proposed approach can provide solutions which can balance more effectively the concerned metrics such as the number of annoyed people, fuel burn, number of people exposed to certain noise levels, and number of aircraft movements which people are subjected to.

1. Introduction

With a significant impact on economic development, communication, tourism and job creation, aviation is predicted to grow quickly in the coming years (Boeing, 2016). In response to this trend, airports are forced to increase their operations, and hence a significantly increasing amount of aircraft movements needs to be handled every day. Nevertheless, the expansion of these activities often causes harmful effects on local communities such as noise and pollutant emissions (Hartjes et al., 2014). This leads to an adverse community reaction to authorities and policymakers, resulting in opposition to the extension of airport and aircraft operations. Thus, it is crucial to identify solutions to aid the sustainable development of the aviation industry, while minimizing its adverse impact as much as possible.

In an effort to overcome the above issues, a series of research initiatives has been launched in recent years, e.g. Clean Sky*, AIRE†, and ASPIRE‡. Apart from these research initiatives, a number of different approaches have also been proposed – and are currently being implemented – such as creating new criteria and regulations, advancing new engine/aircraft models and replaceable fuels, and

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* Clean Sky. http://www.cleansky.eu/#no-back. (accessed 23 October 2017).

† Atlantic Interoperability Initiative to Reduce Emissions (AIRE). https://ec.europa.eu/-transport/modes/air/environment/aire_en, (accessed 23 October 2017).

‡ Asia and South Pacific Initiative to Reduce Emissions (ASPIRE). http://www.aspire-green.com/, (accessed 23 October 2017).

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varying operational procedures of aircraft and airports (Marais et al., 2013). From a practical implementation point of view, it can be observed that the variation of aircraft/airport operational procedures emerges as a suitable option that can result in short term improvements and could be less costly in comparison with the other options. For this approach, the optimal design of routes for departures and arrivals, and the allocation of aircraft to these routes are considered as the most promising options (Green, 2005).

The literature shows that efforts to design optimal departure and arrival routes with less noise and fuel burn have been well studied over the past decades, and various strategies have been proposed. For example, the optimization tool NOISHHH, a combination of a dynamic trajectory optimization method, a noise model, an inventory model of emissions and a Geographic Information System (GIS), was developed by Visser and Wijnen (2003, 2001) to create environmentally optimal departure and arrival trajectories. This tool was extended over the years for amongst others the design of optimal terminal routes based on area navigation (Braakenburg et al., 2011; Hartjes et al., 2010; Hogenhuis et al., 2011). A lexicographic optimization approach was utilized by Prats et al. (2011, 2010a, 2010b) to optimize aircraft departure trajectories with noise annoyance criteria. In an effort to reduce noise impact, Khardi and Abdallah (2012) carried out a comparison study of direct and indirect approaches for solving the system of ordinary differential equations (ODEs) to generate optimal aircraft flight paths. Torres et al. (2011) applied a gradient-free optimization method called multi-objective mesh adaptive direct search (multi-MADS) to create optimal departure trajectories with less noise and NO_x-emissions at a single measurement point. Hartjes and Visser (2016) proposed a novel trajectory parameterization technique, and then applied the elitist non-dominated sorting genetic algorithm (NSGA-II) to design environmentally friendly departure trajectories. Later, this technique was also utilized to design departure routes at Manchester Airport by Zhang et al. (2016). Recently, a multi-objective evolutionary algorithm based on decomposition (MOEA/D) was developed by Ho-Huu et al. (2017, 2018a) to design optimal departure routes with less noise and fuel burn.

Besides the attempts to design environmentally friendly departure/arrival routes, the allocation of aircraft and operational procedures to specific routes could also help to considerably diminish the environmental impacts. For instance, Frair (1984) proposed a nonlinear integer programming model to minimize community annoyance at an airport by allocating aircraft to the existing arrival and departure trajectories. Zachary et al. (2010) investigated the optimization problem which aims at finding an optimal combination of approach and departure routes, operational procedures and fleet composition to optimize noise and pollutant emissions. Kuiper et al. (2012) developed an optimization tool for allocating and distributing the annual aircraft movements over available runways and routes to maximize the allowable number of flight operations into and out of an airport within a given annual noise budget. Kim et al. (2014) built an optimization model to minimize the total emissions on the airport surface and in the terminal area by allotting aircraft to runways and scheduling the arrival and departure operations on these runways concurrently.

Looking at the above literature review on the design of arrival and departure routes, the studies can be generally categorized into two different groups: those using single-event noise criteria (Hartjes et al., 2010; Ho-Huu et al., 2017; Hogenhuis et al., 2011; Prats et al., 2010a, 2010b; Torres et al., 2011; Visser and Wijnen, 2001, 2003) and those using multi-event or cumulative noise criteria (Braakenburg et al., 2011; Hartjes et al., 2014). For the first group, the most widely used criterion is to minimize the number of people awakened, which is derived from either the Federal Interagency Committee on Aviation Noise (FICAN, 1997) or later the American National Standards Institute (ANSI, 2008). Although results can be obtained for different types of aircraft, the resulting optimal routes are most likely only suitable for those specific aircraft. This is because the noise criteria are evaluated based on a specific aircraft model. From an airport operations or Air Traffic Control point of view, however, it is not feasible to manage individual routes for individual aircraft types. For the second group, the most broadly used criterion is to minimize the number of people annoyed, where dose-response relationships based on the day-evening-night noise level (L_{den}) or night noise level (L_{night}) are often employed (Braakenburg et al., 2011; Hartjes et al., 2014). Unlike the first approach, these noise criteria are determined based on the aggregation of noise caused by different aircraft types, where the number of aircraft movements is also taken into account. Therefore, the optimal routes obtained can be applied for different aircraft types and depend on an assumed fleet mix. Though the optimal solutions do not fully exploit the potential noise reduction for each individual aircraft type because of the requirements to follow a common path, from an operational perspective this approach is easier to implement.

From the studies using the second approach, it is also identified that all studies design only one optimal route at a time, and all aircraft movements have to follow the same common path. Although the multi-event noise metrics have already included the influence of the number of aircraft movements, they do not explicitly take into account the frequency of those events. Though noise levels will increase with increasing aircraft movements, and consequently the number of people highly annoyed will increase as well, it is conceivable that an increase in the number of movements above a certain level may lead to more resistance in local communities than the common dose-response relationships would predict. This issue has recently been recognized as one of the emerging concerns that should be investigated and taken into account in noise regulations and policies (Brown, 2014; Fields, 1984; Janssen et al., 2014). In addition, recent studies have also pointed out that despite playing an important role in noise assessment, the above metrics contain certain limitations (Porter et al., 2014; Southgate, 2011). Most importantly, these metrics do not represent the actual experience of communities who are not noise experts, and hence it is difficult for authorities and decision makers to communicate related policies to the local communities. As a consequence, they have been regularly considered as unhelpful and lacking transparency (Porter et al., 2014; Southgate, 2011). In order to address this issue, the Australian Government developed supplementary noise descriptor concepts that can help the general public to understand and communicate with the authorities (DOTARS, 2000). They include the numbers of events above certain noise levels (N70s, N65s), Person Event Index (PEI) and Average Individual Exposure (AIE), which are helpful to provide simple information on the location of flight paths, the number of aircraft movements and the time of day of the movements. Nowadays, these metrics have been recognized and widely used in many countries in the world such as Austria, Sweden and the United Kingdom (Porter et al., 2014). So far, these metrics are, however, rarely considered for designing new aircraft routes.

In an attempt to generate optimal departure routes which can balance the above concerns more effectively, in this paper we have