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Optimization of noise abatement aircraft terminal routes using a multi-objective evolutionary algorithm based on decomposition

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Abstract

Recently, a multi-objective evolutionary algorithm based on decomposition (MOEA/D) has emerged as a potential method for solving multi-objective optimization problems (MOPs) and attracted much attention from researchers. In MOEA/D, the MOPs are decomposed into a number of scalar optimization sub-problems, and these sub-problems are optimized concurrently by only utilizing the information from their neighboring sub-problems. Thanks to these advantages, MOEA/D has demonstrated to be more efficient than the non-dominated sorting genetic algorithm II (NSGA-II) and other methods. However, its applications to practical problems are still limited, especially in the domain of aerospace engineering. Therefore, this paper aims to present a new application of MOEA/D for the optimal design of noise abatement aircraft terminal routes. First, in order to optimize aircraft noise for aircraft terminal routes while taking into account the interests of various stakeholders, bi-objective optimization problems including noise and fuel consumption are formulated, in which both the ground track and vertical profile of a terminal route are optimized simultaneously. Then, MOEA/D is applied to solve these problems. Furthermore, to ensure the design space of vertical profiles is always feasible during the optimization process, a trajectory parameterization technique recently proposed is also used. This technique aims at reducing the number of model evaluations of MOEA/D and hence the computational cost will decrease significantly. The efficiency and reliability of the developed method are evaluated through case studies for departure and arrival routes at Rotterdam The Hague Airport in the Netherlands.

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Keywords: Terminal routes; trajectory optimization; noise abatement; fuel consumption; MOEA/D.

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1. Introduction

With the substantial contribution of aviation to the development of business, communication and tourism globally, the air transport industry is expected to grow rapidly in the coming years. However, one of the considerable concerns which policymakers are facing with the extension of aircraft and airport operations is the protest of near-airport communities. This is because of the significant increase in negative impacts on the environment such as noise and pollutant emissions (Hartjes et al., 2014), which directly affect the daily life of communities surrounding airports. Therefore, to grow the air transport sustainably, it is crucial to figure out feasible solutions for decreasing its adverse influences. One of the potential options is the optimal design of new terminal routes (i.e. departure and arrival routes), which has been widely studied during the past few years (Visser and Wijnen, 2001).

Research on optimization of environmentally friendly terminal routes has obtained significant achievements, and different approaches have been proposed in recent years. Hartjes et al. (2010) developed a trajectory optimisation tool NOISHHH including a noise model, an emissions inventory model, a geographic information system and a dynamic trajectory optimisation algorithm to generate environmentally optimal departure trajectories based on area navigation. Later, this tool was also used for the optimal design of area navigation noise abatement approach trajectories (Braakenburg et al., 2011; Hogenhuis et al., 2011). Prats et al. (2010a, 2010b) applied a lexicographic optimization technique to deal with aircraft departure trajectories for minimizing noise annoyance. Torres et al. (2011) proposed a non-gradient optimizer called multi-objective mesh adaptive direct search (multi-MADS) to optimize departure trajectories for NOx emissions and noise at a single measurement point. Recently, Hartjes and Visser (2016) employed an elitist non-dominated sorting genetic algorithm (NSGA-II) combined with a novel trajectory parameterization technique for the optimal design of departure trajectories with environmental criteria.

Based on the obtained results from Hartjes and Visser (2016); and Torres et al. (2011), it is evident that the use of non-gradient multi-objective optimization methods is one of the efficient approaches for the optimal design of terminal routes. These methods do not only help find out a set of non-dominate optimal solutions, but also help avoid the limitations of gradient methods in coping with discontinuous problems and integer or/and discrete design variables. Up to now, besides multi-MADS and NSGA-II, there are various multi-objective optimization algorithms available in literature, which may also be potential candidates for solving these kinds of problems. However, as yet, they have not been properly investigated. Among them, MOEA/D recently emerged as a powerful method, and has received much attention from researchers. Compared to NSGA-II, MOEA/D is better in terms of both the quality of solutions and the convergence rate (Li and Zhang, 2009), which are promising features for solving large-scale real-world problems. Nevertheless, the application of MOEA/D for real engineering problems is still limited, especially in the domain of aerospace engineering. This paper, therefore, aims to apply MOEA/D to the optimization of noise abatement aircraft terminal routes. In order to make the applied algorithm more efficient, advantageous features recently developed for MOEA/D are also integrated into the proposed version. They include an adaptive replacement strategy (Wang et al., 2016), a stopping condition criterion (Abdul Kadhar and Baskar, 2016), and a constraint-handling technique (Jan and Khanum, 2013). Moreover, to reduce redundant evaluations of infeasible solutions derived from operational constraints during different flight phases, the new trajectory parameterization technique in Hartjes and Visser (2016) is also employed. The robustness and reliability of the proposed approach are validated through two numerical examples comprising of a departure route and an arrival route at Rotterdam The Hague Airport.

Nomenclature

D	drag force
ff	fuel flow
g_0	gravitational acceleration
h	altitude
s	along-track distance
T	thrust
V_{EAS}	equivalent airspeed
V_{TAS}	true airspeed

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