Deconflicted Air-Traffic Planning With Speed-Dependent Fuel-Consumption Formulation

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***Abstract*— This paper discusses a unique formulation for the en-route flight planning problem in a constrained airspace with the objective to minimize costs incurred from earliness, lateness, and fuel-consumption, and to ensure flight safety. Mid-air conflict and collision avoidance, and also minimum separation distance between aircraft and speed-dependent fuel-consumption-rate, are explicitly formulated. A 3D mesh network consisting of waypoints is used to provide alternative routing options for aircraft. The formulation of fuel-consumption-rate as a function of speed as part of the air-traffic planning (ATP) problem is unique in the literature. Moreover, this paper is the first attempt to model the mid-air conflict and collision avoidance as part of the ATP problem. In order to demonstrate the capabilities of the mathematical model, test instances were generated and solved by three different solution strategies. The proposed centralized solution strategy can optimally solve small size instances, similar to the air-traffic around airports to help air-traffic control authorities to manage arrival and departure sequences. Larger networks that include several airports can be solved by the proposed two sequential solution strategies (decentralized and hybrid solution strategies) to help air-traffic planning authorities to manage air-traffic safely and more economically.**

***Index Terms*— Air-traffic control, air-traffic flow management, fuel optimal control, conflict and collision avoidance, speed-dependent fuel-consumption.**

I. Introduction

DEMAND for airline services has been steadily increasing around the world. Around the world, both the seat capacity and the number of airline companies have increased significantly. While long-haul routes are still dominated by the major carriers such as United Airlines, Lufthansa or Singapore Airlines, relatively smaller airline companies have gained important market shares in the short-flight markets. These new market conditions have brought many challenges as well as benefits for the industry. Crowded airports and airspace, volatile fuel prices, increasing environmental awareness and labor costs, and unpredictable weather conditions in most parts of the world are challenging many airline companies. The transportation authorities, in particular Air-Traffic COntrollers (ATCOs) are also impacted from the current market conditions. From taxing to facilitating safe navigation in open skies, ATCOs play a crucial role in delivering on-time services and ensuring the safety of aircraft and passengers. During an aircraft's journey, its speed and route are planned by the airline, and approved and monitored by the responsible Air-Traffic Control (ATC) authorities. Pilot's discretion in the en-route flight planning process is rarely an option (pilots make real-time decisions in emergency situations). FAA anticipates an increase of 56.9% in control tower operations and over 100% in en-route (high altitude flights) traffic-control operations by 2030 [1]. It is clear that increasing air-traffic is undermining ATCOs' ability to effectively manage the given flight plans. Long working hours, stressful working conditions and continuously increasing air-traffic volume may lead to poor decision making by ATCOs, necessitating an increasing reliance on tactical collision avoidance systems embedded in airplanes to avoid mid-air collisions [23]. Furthermore, due to high air-traffic volume, safety issues must be addressed before the lower priority issues like economic and service objectives of airlines can be accommodated.

Recently, an alternative Air-Traffic Flow Management (ATFM) strategy, namely Free Flight Concept (FFC) has been proposed to reduce the workload of ATCOs and improve the air-traffic flow. FFC aims at transferring the en-route flight planning task to individual aircraft ([14], [19], and [32]). The motivation for the mathematical model introduced in this paper came from the FFC philosophy. The goal is to assist both pilots and airline companies to create safe and economic flight plans and assist ATCOs to make real-time decisions for rerouting aircraft safely and at the same time still considering the business objective of the companies. In today's air-traffic planning, an aircraft completes its journey from an origin to a destination by visiting a set of waypoints which are geographical coordinates in the sky. Hence, we propose a mathematical model that navigates aircraft through these waypoints between origin and destination airports. The waypoint based mixed-integer linear programming (MILP) model takes all meaningful airport and flight characteristics into consideration to provide a comprehensive and thorough model of the situation. The produced flight plan for each aircraft includes the sequence of waypoints to be visited, the aircraft's exact arrival and departures times at these waypoints, the average speed between consecutive

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