Fuel Planning Strategies considering Operational Uncertainties of Aircraft Wake-Surfing for Efficiency

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Abstract

The concept of aerodynamic formation flight, also known as aircraft wake-surfing for efficiency (AWSE), allows the follower aircraft to utilize the energy of the leader aircraft's wake vortex, which can result in rich benefits as long as the formation is perpetuated successfully along the segment between Rendezvous Start Point (RSP) and Separation End Point (SEP). The follower's mission fuel requirements therefore depend on the success of formation execution, increasing the level of fuel planning uncertainties.

A conventional fuel planning strategy, that does not take anticipated fuel savings due to AWSE into account, will ensure a follower to complete the mission in the case of a formation failure. From a long-term perspective however, this strategy might result in high amounts of excess fuel and unnecessary high fuel consumption. A fuel planning strategy, which takes the expected AWSE-induced fuel savings into account, might provide a significant potential of fuel savings due to a reduced take-off mass.

An analysis is presented in [1] that quantifies the savings potential regarding fuel and direct operating costs (DOC) of a flight planning procedure that fully includes the anticipated benefits induced by AWSE, balancing them with the additional expenses to be expected from a formation failure. These expenses essentially arise from a detour for a re-fueling stop along the route, which is optionally scheduled according to an AWSE-adapted variant of the established Decision Point Procedure (DPP) [2].

The optional re-fueling stop has been shown to be feasible at almost neutral cost regarding fuel consumption, but its DOC-wise assessment was found to be highly disadvantageous. This raised the question whether a flight planning according to AWSE-DPP might be conducted depending on the ratio of achievable values of profit and loss and the expected benefits from a long-term perspective. Furthermore, it was asked whether a slight adjustment in routing towards available ERAs along the track might affect this ratio favorably. We investigate these questions for a statistically significant meteorological setting and presumed levels of success probability regarding AWSE.

Decision Point Procedure adapted to AWSE

Subject of investigation are the two fuel components Trip Fuel (TF) and Contingency Fuel (CF). Further fuel components are added in form of an allowance. A conventional fuel planning instructs the operator to calculate the required TF and charge it with a minimum CF share of 5%. The application of DPP allows the operator to reduce the contingency share, presuming that the contingency fuel is not used along the mission segment before reaching the predefined Decision Point (DEC).

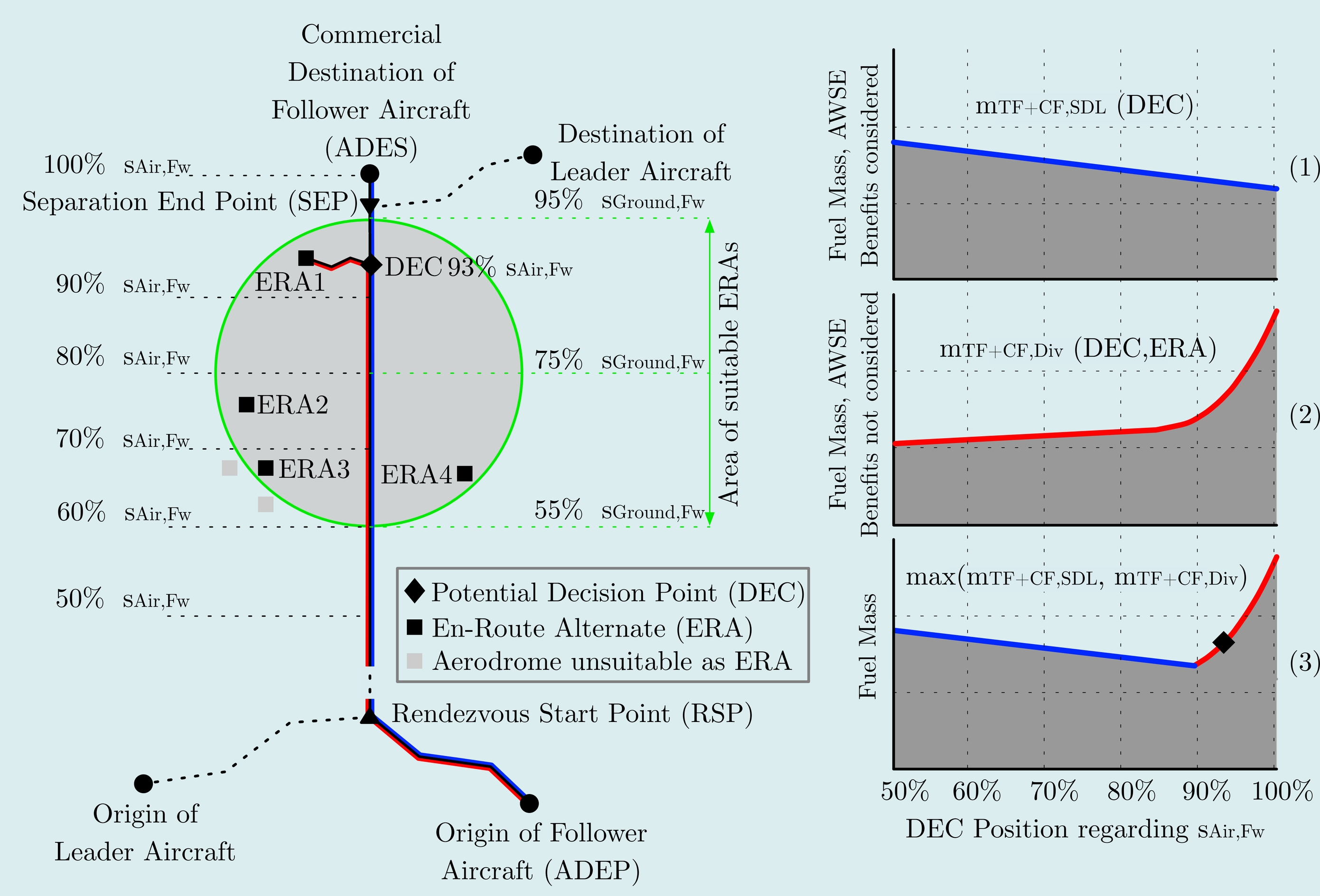
Initially, the mission is operated according to a flight plan heading to the En-Route-Alternate Airport (ERA). If the mission is going according to schedule until passing DEC, a second flight plan takes effect, which is heading to the commercial destination aerodrome. In the case of unexpected complications on the other hand, the commander will hold on to the initial flight plan, conducting a re-fueling stop at the predefined ERA, which has to be located along the track (see shaded circular area).

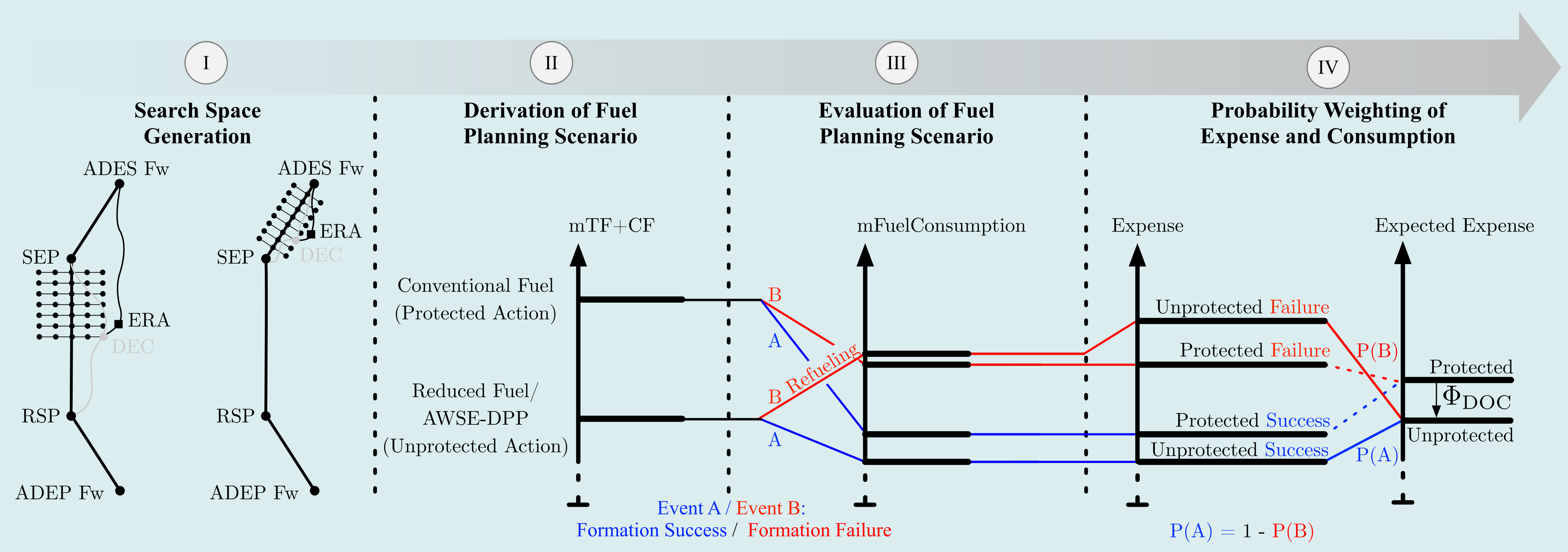
$$m_{TF+CF,SDL} = m_{TF}\,(ADEP \rightarrow DEC \rightarrow ADES) + 0.05 \cdot m_{TF}\,(DEC \rightarrow ADES) \quad (1)$$

$$m_{TF+CF,DIV} = 1.03 \cdot m_{TF}\,(ADEP \rightarrow DEC \rightarrow ERA) \quad (2)$$

$$m_{TF+CF} = \max\,(m_{TF+CF,DIV}, m_{TF+CF,SDL}) \quad (3)$$

Applying DPP, the required amount of TF and CF is determined according to Equations (1-3). For a set of DEC and corresponding ERA, the procedure instructs the operator to calculate TF according to Eq. (2), associated to the original flight plan heading to ERA. Subsequently, the amount TF+CF is calculated for a mission to the intended destination ADES, according to Eq. (1). Finally, the operator selects the respective higher value according to Eq. (3). The adaption of DPP includes a full consideration of anticipated AWSE-benefits by Eq. (1), referred to as schedule (SDL), and a full neglect of AWSE-benefits by Eq. (2), referred to as diversion (DIV).





Proposed Workflow

I. A reference route, based on a wind optimized formation geometry [3], is partitioned into percentual fragments of air distance $s_{Air,Fw}$, whereas each fragment is representing a DEC. Offside the track, additional DECs are derived and respectively connected to the two closest fixpoints RSP, SEP or ADES. Each combination of DEC and suitable ERA is a designated element of search space

II. Conventional and **AWSE-DPP** fuel scenarios are derived and assigned to each search space element, referred to as protected and **unprotected** action, respectively

III. Each protected and unprotected action is evaluated with regard to formation success and formation failure in terms of fuel consumption and flight time

IV. DOC are derived according to [4], the expected expense is derived by weighting with assumed values of formation success probability P(A) and failure probability P(B). The margin between unprotected and protected expected expense is denoted by Φ_{DOC}

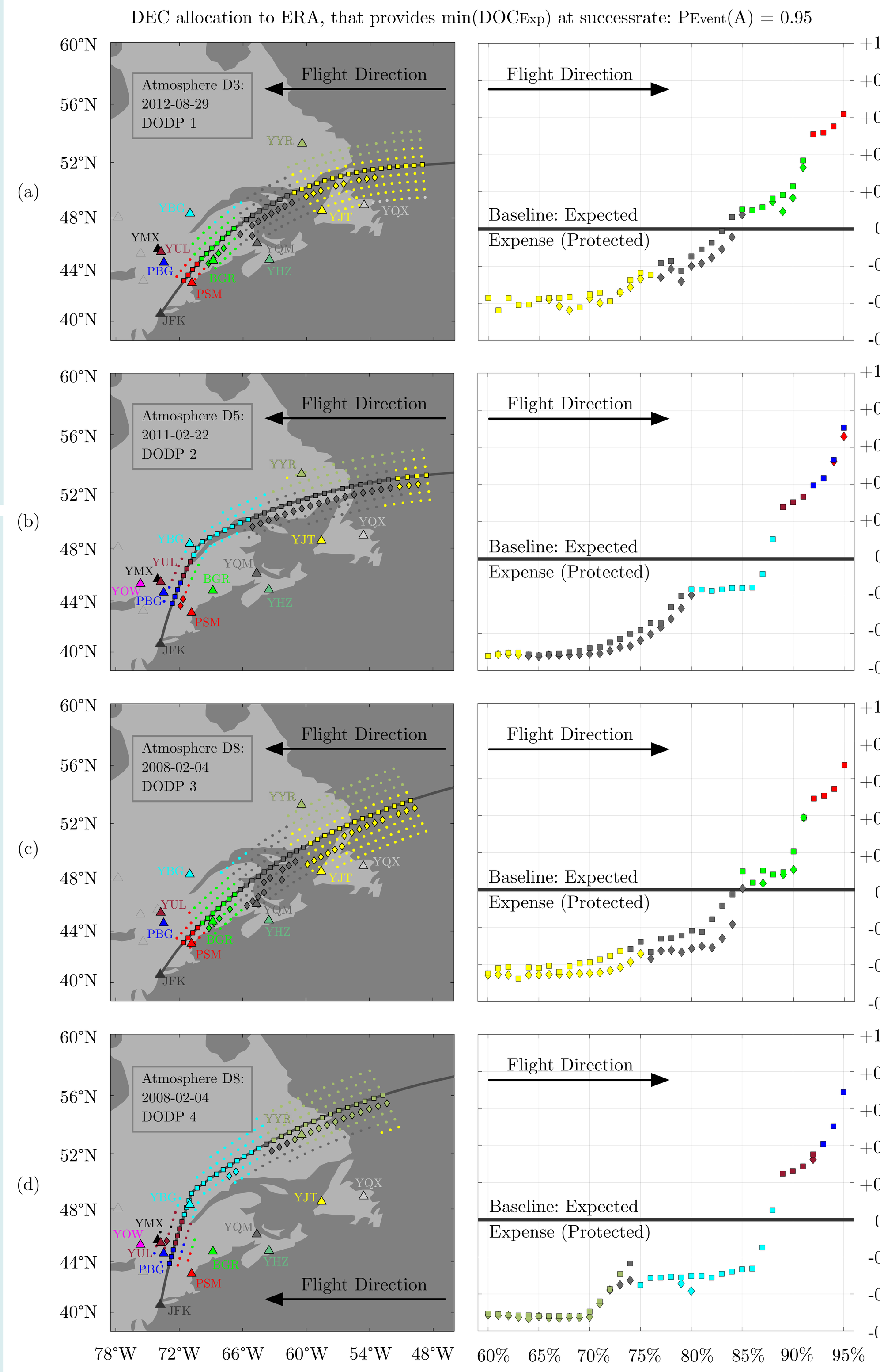
Methodology and Scope

- Fuel planning scenarios are generated and evaluated using MultiFly-TCM [5], based on a B777-200 flight performance model from BADA 4.0 [6]
- Four double-origin-destination-pairs (DODPs) are investigated, originating from London (LHR) and Paris (CDG) and heading to New York (JFK) and Chicago (ORD)
- A set of eight meteorological representative North Atlantic weather patterns is considered as presented in [7]. Atmosphere data are obtained from ECMWF ERA Interim archive [8]

Savings Potential Φ

- Potential Φ represents the margin between the probability weighted (expected) outcome of a protected action and its unprotected counterpart, the two possible options for a decision maker to pick according to the proposed method
- The potential quantifies the saving margin with regard to monetary expenses Φ_{DOC} or fuel consumption Φ_{FCon}
- The subscripts *On* and *Off* refer to the applied boundary condition of search space limitation. While $\Phi_{X,On}$ represents the potential of a DEC located on the reference track, $\Phi_{X,Off}$ refers to an offside DEC from the expanded search space
- Figures (a-d) show monetary savings of up to 0.5% for P(A) = 0.95 (i.e. 19 out of 20 formations would succeed) derived by application of AWSE-DPP (colorcode refers to depicted ERAs)
- Figures (e-h) show long-term saving potentials exceeding 1% in DOC and up to 4.5% in terms of fuel consumption for a probability value of P(A) = 0.99 (colorcode refers to P(A))
- The optimization potential ($\Phi_{X,Off}$ - $\Phi_{X,On}$) due to track shifting towards ERA locations is shown to be negligible

DEC allocation to ERA, that provides min(DOCExp) at successrate: PEvent(A) = 0.95



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