Efficiency/Predictability of 4D Trajectories at Tactical Level considering Meteorological Uncertainty

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TBO-Met Consortium

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Abstract

A major challenge for Trajectory-Based Operations (TBO) is the existence of significant uncertainties in the models and systems required for trajectory prediction. In particular, weather uncertainty has been acknowledged as one of the most (if not the most) relevant one. Here we present results on robust trajectory planning at the tactical level (short-term planning and execution) considering uncertainty associated to the evolution of thunderstorms. Short-term forecasts (Nowcasts) are used as input data for the uncertain evolution of thunderstorms. The main goal is to re-plan trajectories (computed at the pre-tactical phase) that are efficient, yet safe in avoiding the storms (modelled as stochastic high risk areas) considering that its evolution is uncertain. A case study with a set of simulations is presented herein.

Introduction

A better understanding of the elements introducing uncertainty in traffic management is key when optimizing, planning, executing, monitoring and synchronizing trajectories with ground systems and aircrafts. In TBO-Met (call H2020-SESAR-2015-1), the focus is on meteorological uncertainty for trajectory based operations in ATM. TBO-Met consists of the above mentioned institutions from research and industry.
We ambition to develop algorithms capable of improving the predictability of aircraft trajectories when subject to meteorological uncertainty while keeping acceptable levels of efficiency.

Main Objectives

1. Trajectories calculated using the algorithms presented in [1] will be used as input for the simulations (acting as business developed 4D trajectories (BDT)). See [1] .
2. Nowcast information ([2]) is treated and modelled stochastically (as stochastic storms), and, together with the trajectories (BDT), included into the DIVMET infrastructure for simulation.
3. The DIVMET algorithm [3] is used to calculate an updated trajectory (which eventually becomes the revised reference business trajectory (revised RBT) capable of avoiding the storms (modeled as stochastic high risk areas).
4. A set of simulations is conducted and results analyzed in order to estimate the effect of uncertainty on predictability and efficiency of the predicted trajectories under uncertain storms. For further details refer to [4]

Methodology

Modelling Uncertainty in DIVMET

Predictability of trajectories depends on the uncertainty of the adverse weather field. So we have to investigate the related nowcast model uncertainty to find out more about route predictability. Five different curve shapes were chosen (figure 1), derived from functions F1, F2, F3 with slopes of 0.25, 0.5, 0.75 resprectively. F4 was found by [5] and F5 was derived from AEMET Nowcast data.

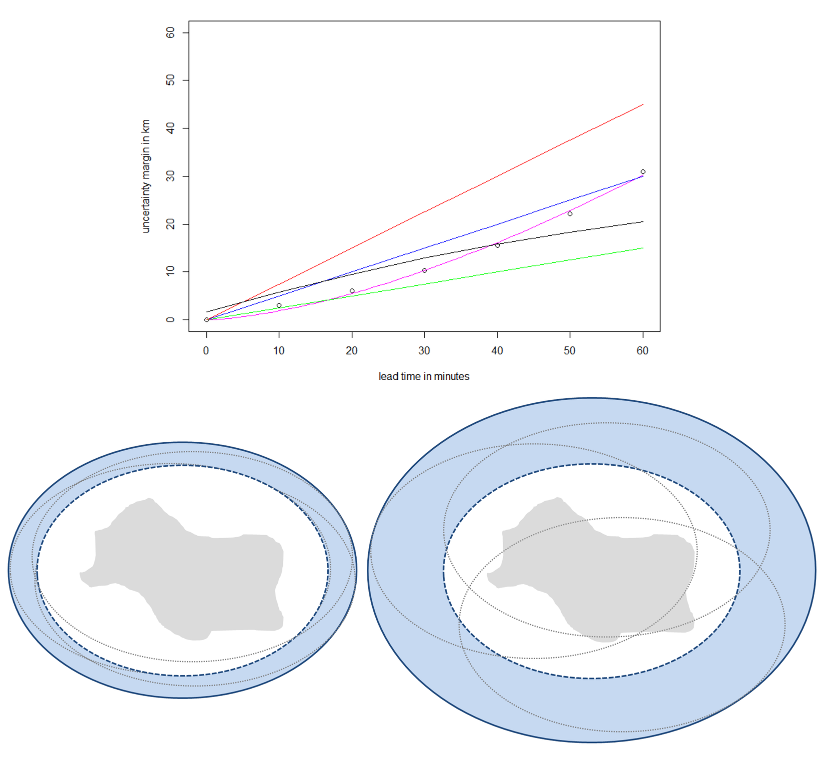

Figure 1: Above: Functions to quantify the lead time dependent uncertainty margin: F1 (green), F2 (blue), F3 (red), F4 (black) and F5 (magenta). Below: Illustration of the stochastic variation of the location of the convective cells (dotted grey) within a small (left) and a big (right) uncertainty margin (light blue area) for a low and high lead time respectively. Original ellipse from the input data is dashed blue. Shape of the original storm is filled in grey.

DIVMET performs a dynamic deterministic trajectory prediction according to the field of existing and forecasted high-risk areas [3] (see figure 2). In this context, high risk areas are defined by the limits of convective cells (derived from AEMET Nowcast data), which are modelled as ellipses and are further extended by a safety margin.
DIVMET is applied to three BDTs and 30 varied adverse weather fields. While the A/C is moved along the track of the BDT, the algorithm is applied every ten minutes. This results in 30 RBTs for each A/C position along the track.

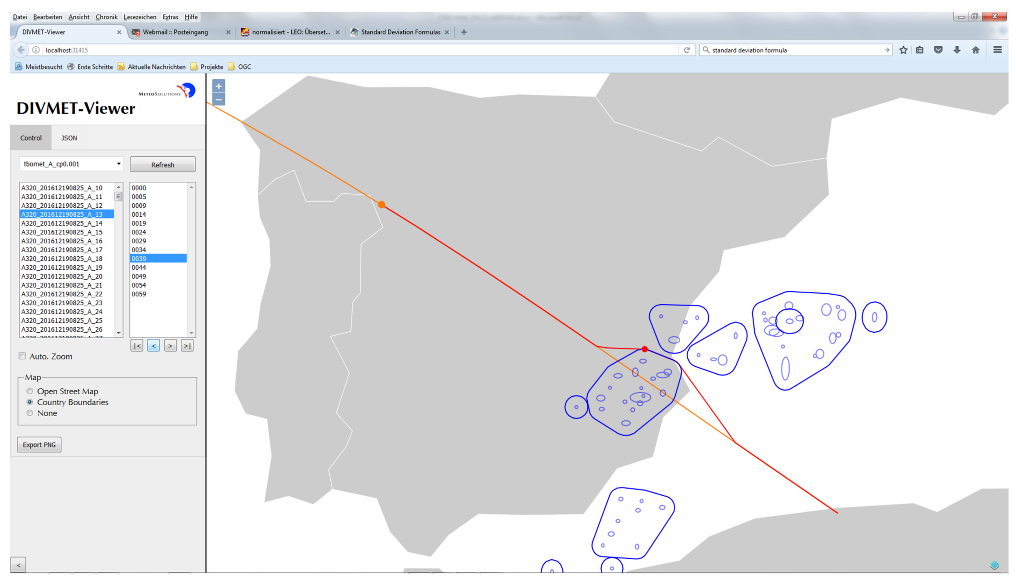

Figure 2: Example of one DIVMET simulation for BDT at 2016/12/19, 8:25 UTC. The orange dot marks the real position of the aircraft. The red dot marks the virtual position of the aircraft at 39 minutes forecast lead-time. The orange line to the aircraft position is still the BDT, followed by the RBT in red.

Analyses of Simulations

For the analysis of the predicted trajectories we put our focus on efficiency and predictability of the trajectories. For each RBT we determine the length and related arrival time. The arrival time distribution is shown in figure 3. If the arrival times are close to each other, respectively the dispersion of arrival time distribution is low, the enforced route deviations are of little impact and predictability of arrival times is high. Vice versa, if arrival times are highly scattered, the enforced route deviations have a strong impact. The arrival time distribution may thus serve as a measure of route predictability. Similarly, the route length distribution can be considered as a measure of efficiency. Please, refer to [4] for further information.

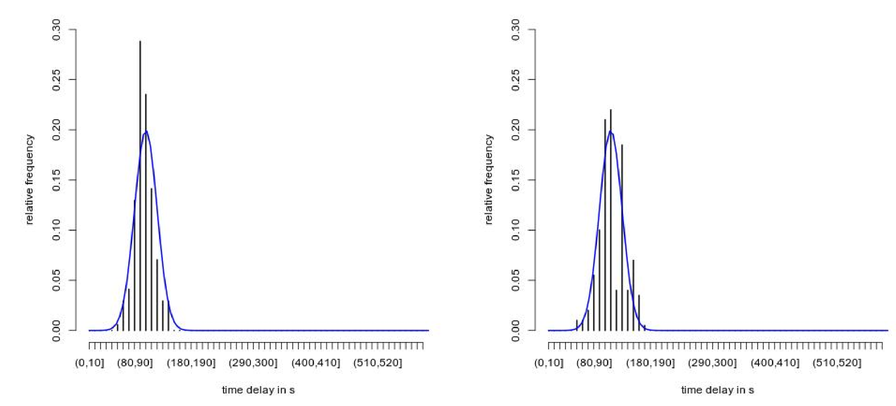

Figure 3: Examples of frequency distributions of delay times for various uncertainty margin functions F1 (left) and F5 (right).

Mean delay is an inverse measure of efficiency as we do not consider wind here. Comparing the lines connected to the uncertainty functions F1 to F5 with the line without uncertainty, it can be seen that any uncertainty, which is put into the trajectory prediction algorithm, will result in an increase of the mean delay. That means that efficiency is decreasing.

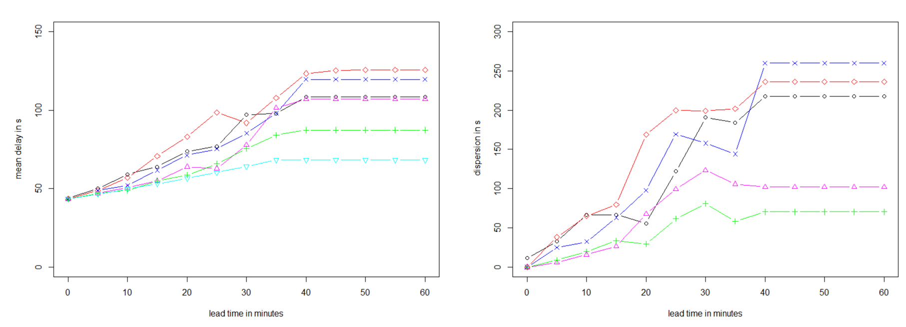

Figure 4: Delay over lead time (left) and dispersion over lead time (right) for one BDT with different uncertainty margins as a function of lead-time: F1 (green), F2 (blue), F3 (red), F4 (black) and F5 (magenta).

Dispersion of the distributions (figure 3) is an inverse measure of predictability of trajectories. This means that a low dispersion among predicted trajectories can be viewed as high predictability. The dispersion is expected to increase with growing uncertainty. As uncertainty increases with growing lead-time, the dispersion lines in figure 4 show this.

Conclusions

1. We introduced an approach for a methodology for short-term trajectory prediction which is capable of taking uncertainties of thunderstorm cells into account on the tactical planning level (short-term planning and execution).
2. We derived statistical parameters from the multiple trajectory predictions in order to estimate the effect of uncertainty on predictability and efficiency of the predicted trajectories. The case studies confirmed the working hypothesis that with growing uncertainty the predictability and the efficiency of the predicted trajectories decrease.
3. The case studies contained also the comparison of results between differently effective uncertainty functions. We found here an apparent dependency of predictability and efficiency under the different uncertainty conditions.
4. By the detailed analyses of intermediate results of single trajectory predictions we showed that predictability and efficiency are affected strongly by the course of the BDT in context of the thunderstorm cells. Additionally, the safety distance that represents the risk awareness of the pilot plays a major role.

Forthcoming Research

Different scenarios will be validated via simulation. The algorithms presented here will be used to calculate 4D trajectories on tactical level (short-term planning and execution) in real time simulations.
Different 4D trajectories, including its associated uncertainty, will be used as input to analyze sector capacity issues under trajectory prediction uncertainty.

References

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