Airspace Complexity for Airborne Self Separation

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Abstract

This paper addresses a way how to profit from enhanced information sharing process envisioned in future Air Traffic Management (ATM) system (both SESAR and NextGen) and to help overcome some of the well-known ATM-related issues: the need for excessive tactical maneuvering resulting from poor strategic flow/trajectory management; and a lack of strategic information for user-preferred trajectory optimization onboard an aircraft. Satisfactory solution to both of these problems is crucial not only for ATM performance and flight efficiency, but also for overall air traffic safety. Related needs for new concepts and tools are even more urgent in envisioned ATM framework based on new separation modes and Self Separation environment. As shown in this paper, the revised notion of air traffic complexity and its applications may successfully answer some of these issues.

Our work shows how a measure of air traffic complexity can be used for dynamic flight optimization and re-planning, and for improvement of strategic flow/trajectory management. We start with a general discussion of the meaning of complexity, then elaborate a set of requirements for such a metric, and finally offer a specific definition of an air traffic complexity metric. A set of examples is used to demonstrate the usage and the expected benefits.

Introduction

The air traffic load is already reaching the capacity limits given by the current Air Traffic Management, which will not be able to accommodate the forecasted worldwide growth of air traffic without fundamental changes. One of the key challenges of such ATM evolution is to achieve an optimal balance between strategic and tactical actions needed for air traffic control.

From the flight performance perspective, a strategic intervention represents smaller variations from the optimal flight profile however applied for a longer time period, while a tactical action results in larger deviations but used for a shorter time. Nevertheless, the main difference lies in the ATM operational aspects. As a strategic action is usually taken well in advance of the detected threat it represents only moderate safety issue (subsequent safety nets still may be implemented). Moreover, more potential solutions can be assessed, which allows for better optimization of necessary trajectory changes. However, as an intervention is based on a long-term prediction of the behavior of a stochastic environment, the related uncertainty may results in unnecessary modifications of the flight (false alarms problem). On the contrary, a tactical maneuvering has typically worse impact on the passenger's comfort and aircraft load, but it is applied only when really needed. Therefore an effective use of strategic ATM requires an appropriate handling of air traffic prediction uncertainty.

The current system is based on strategic tasks that manage the load of ATC sectors and tactical tasks performed by air traffic controllers in order to solve conflicts within the sectors. In reality, most of the strategic tasks (flight planning and slots allocation process) are performed prior take-off (although a dynamic re-routing or slots update services during the flight are provided as well[1]). The core of the dynamic ATM is therefore formed by the controller's tactical actions within sectors. In order to face the capacity and performance problems, both the European SESAR (1) and the US NextGen (2) concept of operations envision an enhancement of the strategic ATM using Trajectory-Based Operations (TBO) to face the prediction uncertainty problem.

In these novel concepts, Trajectory-Based Operations are based on dynamical sharing of 4D (i.e., position and time) trajectory (during the flight the term Reference Business Trajectory (RBT) is used as it reflects airspace user's preferences) to reduce uncertainty in the aircraft position during its flight. The focus of ATM will be shifted from tactical interventions toward a management of RBTs which will be then flown using the advanced functions of airborne systems. Although, there will be still needs for tactical ATM due to the stochastic nature of air traffic environment and emergent events, it is anticipated that their usage will be considerably reduced.

In future, the tactical ATM may be provided by ATC as today, however, for a large part of airspace there are envisioned new separation modes where the responsibility for tactical ATM actions is fully or partially delegated to aircrew supported by airborne systems (so called Airborne Separation Assistance Systems (ASAS)). It is envisioned that an implementation of the new separation modes will result in more effective tactical maneuvering, as they will allow a straightforward application of user (aircrew, passengers, airlines) preferences and the ATM actions will be based on better knowledge of the local situation (available only onboard maneuvering aircraft).

There are two main enablers of the ATM changes described above, both being related to the availability of traffic information. The sharing of RBT information will be enabled by System Wide Information Management (SWIM) system which will incorporate ground infrastructure and air-ground data links network. Considering new separation modes, the main barrier is the unavailability of reliable and complete information about surrounding traffic onboard an aircraft. Except this, nowadays a commonly equipped aircraft with onboard sensors already has better information about local environment than ATC. The traffic information issue should be solved by progressive implementation of data link technologies, such as Automatic Dependent Surveillance – Broadcast (ADS-B) or Traffic Information Service – Broadcast (TIS-B), together with SWIM.

A design of the interface between strategic and tactical ATM tasks requires a suitable metric assessing the air traffic situation from ATM perspective. The term "air traffic complexity" is usually used for this characteristic, however as described in the following section, there is not a commonly accepted definition of this term. The purpose of the metric is basically twofold: avoid the overload of tactical ATM (safety aspects), and to avoid the need for excessive tactical maneuvering (performance aspects). Strategic ATM is then applied to reduce air traffic complexity and therefore to achieve these goals.

The present paper describes a possible use of shared RBTs to detect and avoid areas with high traffic complexity. For this purpose a new complexity metric is defined and analyzed, and two potential applications of the resulting complexity information are discussed. The first is based on the use of complexity information for trajectory optimization either onboard or in Flight Operating Centers (FOC) and the primary purpose of this application is to provide performance benefits for self separating aircraft (although its use may be more general). The second application is considered within a centralized flow management to manage the complexity of an air traffic complexity within a given part of airspace.

The work was performed within the FP6 project iFly (http://ifly.nlr.nl) which aims to provide safety and

[1] For example, the Central Flow Management Unit (CFMU) performs these tasks for the European airspace.

performance analysis of an advanced en-route self separation ATM system. In this context it continues in the theoretical work performed within the project HYBRIDGE (3) and the validation experiments in the Mediterranean Free Flight (MFF) project (4).

Air Traffic Complexity

Although "complexity" is a buzzword in current science and engineering, it is nearly impossible to find its commonly accepted definition. Paradoxically, it is probably simpler to start by specifying what is not complex. A system is not complex if it consists of independent parts, i.e., there are no internal interactions among its elements. On the contrary, "a complex structure uses interwoven components that introduce mutual dependencies and produce more than a sum of the parts." (5) A nice example of the latter is the butterfly effect in meteorology[2].

The main difficulties lie in the issue how to quantify and measure such a general quantity. Various definitions are used across physics, chemistry, computer science, psychology, and other scientific areas. For instance, Seth Lloyd (6) found forty two different definitions of complexity in literature, which he classified under four classes: measures of how hard it is to describe something; measures of how hard it is to do something; measures of organization in a system; and non-quantitative ideas associated with complexity (e.g., self-organization, complex adaptive systems). In summary, it can be stated that while there is a common agreement which factors contribute to complexity, a well-balanced metric providing an optimal trade-off among them is in general missing. On the other hand, there is a lot of specific metrics assessing the complexity in various scientific and technical areas but these metrics have only limited applicability outside the target application.

Now let us focus on the specific subject of air traffic system. The main part of the system is formed by aircraft that are not independent but are interacting with other traffic. The interactions are represented by ATM interventions to ensure a safe separation among the aircraft. In addition to these internal interactions there is also an external influence by the environment (e.g., weather) which brings a considerable stochastic character to the time evolution of the system. As it is the ATM that primarily determines the internal behavior of the system, the measure of air traffic complexity is naturally tightly connected with the applied ATM approach.

An important characteristic of the current ATM system is a conservative approach to the organization of traffic. Due to the use of navigation aids and the airways network, most of the traffic in a sector follows the same pre-defined patterns, which considerably simplifies both the conflict detection and conflict resolution. Furthermore, the structural complexity of airways may be taken into account in the definition of sectors keeping thus the organizational complexity within the sector at an acceptable level. The existing air traffic complexity metrics thus typically focus on the number of aircraft and on factors related to the controller's perception (that is, human-based perception related to the cognitive complexity used in psychology (7)) and resolution of conflicts.

While the pre-defined traffic structure significantly simplifies controller's work, it represents a limiting factor for the airspace capacity and also reduces the achievable flight performance. Current airborne systems have already used RNAV/RNP capabilities to navigate aircraft accurately out of airways network and this flexibility will be commonly used within the envisioned trajectory-based operations. Therefore, the traffic structure constraint will be relaxed within the future ATM systems, which will increase the need for an appropriate metric of air traffic complexity to avoid overloading of the system.

[2] *Butterfly effect* refers to a particular sensitivity of meteorological equations to small variations of input parameters (first observed by Lorentz). It is often illustrated by an example, that a butterfly flapping its wings in one part of world can cause a typhoon in the other part.

Another important change is related to the envisioned implementation of the new separation modes that will be based on distributed ATM (airborne separation and self separation). As the behavior of a distributed system is fundamentally different from today's centrally controlled system, a development of new adapted complexity metrics is indispensable.

Target Applications

Within the iFly Concept of Operations (8) three potential applications of air traffic complexity in a distributed ATM are proposed. Two of them are oriented mainly to tactical actions and focus on onboard separation management. In particular, they aim to prevent overloading of ASAS conflict resolution, and to compare possible conflict solutions (their impact to the air traffic complexity), respectively. The present paper focuses on the third application, which is related to the strategic trajectory planning.

One of the key limitations of the distributed (airborne) ATM is the availability of strategic traffic information onboard an aircraft. While an aircraft has typically very accurate information about its local environments due to onboard sensors and air-air data links, the availability of information for strategic planning would require a transmission of a big amount of data from a large area. For these reasons, some level of ground support is usually considered for strategic tasks.

Potential applications of complexity metric suggested in this paper are based on a ground-based service which uses the actual RBTs available via SWIM. The related process can be split into three phases:

1. The complexity metric is computed on a 4D (that is, space and time) grid in the airspace, so that a sequence of 3D complexity maps can be obtained.
2. The complexity maps are processed and areas with high complexity are extracted using segmentation techniques with predefined threshold(s).
3. High complexity areas are used to identify the parts in time and space that should be avoided (in the case of an aircraft seeking for optimized flight) or re-organized (in the case of strategic flow management). Based on this information suitable trajectory modifications are generated either onboard or by a ground application (FOC or centralized flow management).

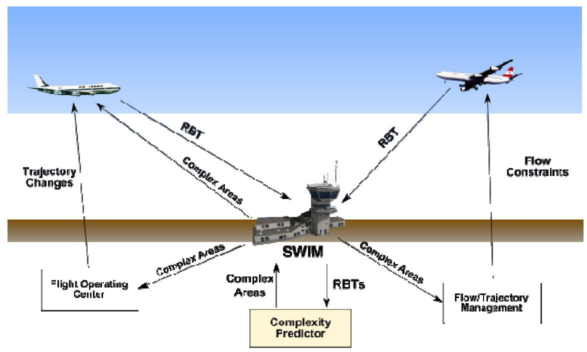

Figure 1: Communication overview.

Proposed applications aim to minimize the amount of strategic information that must be transmit to aircraft and at the same to delegate computationally demanding tasks (computing of complexity on a 4D grid, segmentation techniques) to ground systems where higher computational power is available. While the first two phases are essentially the same for all applications, the third phase in general differs. Following applications are considered in this context:

- Areas with the complexity higher than a predefined threshold are sent to aircraft and used as additional information for onboard trajectory optimization.
- Complexity areas (or whole maps) are used for a ground-based trajectory optimization (e.g., in Flight Operating Centers) and the suggested trajectory changes are sent to aircraft.
- Complexity areas (or whole maps) are used for a ground-based centralized flow

management and the corresponding flow or trajectory constraints are sent to all involved aircraft.

Schematic overview of potential applications and the related communication channels is shown in Figure 1.

Building the metric

The primary goal of this paper is to propose a complexity metric which could be used for strategic trajectory optimization within a distributed ATM system. It is built upon a simple idea: *to assess whether it would be convenient for an aircraft (from tactical maneuvering perspective) to be at specific place in specific time, or not.*

Existing metrics

So far large literature has presented many complexity metrics aimed at evaluating air traffic. However, under the term 'air traffic complexity' diverse concepts are described. They may be classified depending on how tightly are connected to a particular ATM system. As summarized in (9), most of the current metrics directly incorporate a measure of workload of an air traffic controller and are strongly dependent on the sector-based airspace structure. On the other hand, there is a class of metrics which aims to measure an "intrinsic" (i.e., ATM-independent) complexity of air traffic. However, as also discussed in (9) existing metrics typically provides only limited consideration of time dependence aspect and of trajectory uncertainty.

As described in the previous section, the applications proposed in this paper are based on a generation of complexity maps that may be used by different (both distributed and centralized) tools across the future ATM. In this context, the corresponding metric should be independent of ATM algorithms applied in various tools, and therefore it should be preferably a measure of local intrinsic complexity.

The intrinsic metrics already published in literature include: a geometrical approach taking into account relative positions and velocity of aircraft (9), Kolmogorov entropy of a dynamical system modeling air traffic (9), (10), (11), (12), interpolation of a velocity vector field (13) and Lyapunov exponents as a measure of order/ disorder of the dynamical system given by aircraft trajectories (14). They are therefore primarily focused on the assessment of the organization of air traffic or computational power needed for its modeling.

Unlike the above mentioned intrinsic metrics, the metric presented in this paper does not seek for a measure of organization of air traffic. The reason for the different approach lies in different understanding of the term 'air traffic complexity'. We believe that there are 'very organized' and 'well predictable' air traffic situations, which may at the same time be complex in the following sense: if something goes wrong, the solution may not exist, or may not be easily computed or performed. On the other hand, a completely disordered situation (for example, random flow of traffic) may be in some circumstances very favorable from ATM perspective.

General requirements

A definition of metric requires a good understanding of the applicable requirements and constraints. Although the following four requirements were developed for a complexity metric measuring a controller workload (15), they may be applicable also for our complexity:

1. Adding an aircraft should not reduce complexity.
2. Shrinking the geometry of the airspace, or increasing the speeds of all aircraft in the airspace, should not reduce complexity.
3. Repositioning one aircraft so that it is now farther from every other aircraft should not increase complexity.
4. The metric should be independent of the orientation and origin of the coordinate system.

These requirements are meant for one cumulative value of complexity for all the airspace under evaluation. Applying them on a complexity map requires modification of the statements in the following way: “Nowhere in the complexity should the complexity value be reduced/ increased…”

Moreover, symmetry of the problem should be taken into account when the fourth requirement is considered. In fact, the characteristics of horizontal and vertical movement are qualitatively different during the flight. This fact is also reflected in applicable separation standards (compare the minimum en route lateral separation of 5 NM, with the vertical separation of 2000 feet, or even 1000 feet in Reduced Vertical Separation Minima (RVSM)). This fundamental asymmetry must be therefore reflected in the metric definition. The fourth statement may be therefore adapted as follows:

4a. The metric should be independent of the origin of the coordinate system as well as of any rotation of it around the vertical axis.

On top of that we put additional requirements, tailored already for the applications considered in this paper. They may be formulated in the following way:

5. *The metric should express whether (generally speaking) it is acceptable for an aircraft to be at time t in place X (x,y,z).* For this purpose it should assess how probable is that an aircraft will be forced to tactically maneuver at that point.

6. *The metric should be a function of intended flight paths of concerned traffic.* It should not be a function of other airspace characteristics, such as forecasted weather. Nor should it be a function of aircraft types, as the scale is too large to consider such details.

7. *The metric should express a local property of the airspace.* This means that distant flights (be it in space or time) from the point *X* under evaluation have negligible effect on the decision formulated by 1. To extend this idea, the metric could be a function of a neighborhood O_x of the point $X=(x,y,z,t)$.

8. *The metric should be robust* (that is, not excessively sensitive) with respect to the uncertainty of processed trajectories (strategic applications are based on a long look-ahead time and therefore a considerable uncertainty should be expected).

9. *The metric should be simple* – for computer to process, and for people to understand, trust and certify.

10. The metric should consider the predicted positions of traffic as follows: *the closer the traffic is to X, the bigger impact it has on the complexity there* (the relation may not be linear, and the metric of proximity may not be Euclidean distance).

Countless numbers of metric definitions can be defined according to the given points. One such a metric will be presented in the next section, and its characteristics and potential applications will be discussed in the rest of this paper.

<u>Metric definition</u>

The local complexity at a point *C* takes into account all the aircraft inside a rotational ellipsoid *E(C)* centered at *C* and with axis of rotation in vertical direction. The vertical semi-axis (*c*) is much shorter than the horizontal one (*a*). The contributions of aircraft outside the ellipsoid *E(C)* are neglected in the computation of local complexity at the point *C* (see requirement 7).

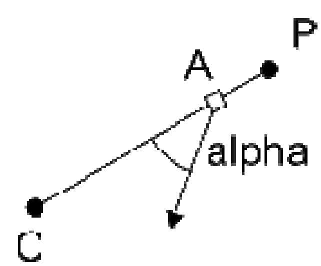

Figure 2: Metric definition schema.

The proposed metric is **additive** with respect to contributing aircraft, i.e., the value of the metric at point *C* and time *t* is computed as the sum of the contributions from all aircraft *(A)* whose intended positions *A(t)* at time *t* fall inside the ellipsoid E(C):

$$M(C,t) = \sum_{A(t) \in E(C)} m(A)$$

Contribution of each aircraft *A* is determined by its position and the actual direction of flight (track angle, inertial flight path angle). The contribution *m(A)* can then be computed with the help of an intersection of semi-axis *CA* with the boundary of the ellipsoid *E(C)* (the point *P* in Figure 2) as follows:

$$m(A) = \log_2\left(1 + \frac{|AP|}{|CP|}\frac{1}{1+e^{K(\alpha - 1/2)}}\right),$$

where α is the angle between the actual direction of flight and the vector *AC*.

In this formula, the distance based component $\frac{|AP|}{|CP|}$ aims to emphasize the influence of the aircraft that are closer to the ellipsoid centre *C* (see rule 10), while the angle based component $\frac{1}{1+e^{K(\alpha - 1/2)}}$ takes into account how much the aircraft is heading towards the point *C*. The direction of the flight is considered in a nonlinear way using the classic sigmoidal function. The range of both the distance based and angle based component, as well as of the function *m*, is .

A lateral view at the complexity map of one aircraft is shown in Figure 3. It illustrates well the contribution of the direction of the flight to the local complexity and the related added value with respect to the simple traffic density calculation.

<u>Complexity maps</u>

As already outlined, the proposed metric is used to generate complexity maps for a given airspace. For this purpose the metric is computed on a regular grid. For the sake of simplicity we decided to keep a "rectangular" grid, with lateral distances D_{lat} and vertical distances D_{ver}. The grid is computed using snapshots of (predicted) traffic throughout time, hence the fourth dimension is added by generating a sequence of 3D maps, with regular time steps of the length D_{time}.

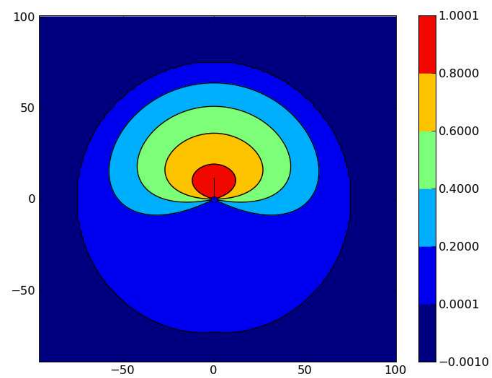

Figure 3: Complexity map of one aircraft (lateral view).

<u>Metric analysis</u>

The function *m* defining the metric has the following desirable properties:

- The contribution of an aircraft to the complexity (function *m*) is smooth in the space.
- The smoothness of the resulting 3D complexity maps can be easily controlled by a suitable choice of the ellipsoid E(C) and the parameters of the grid D_{lat} and D_{ver}.
- Due to the form of the function *m* and the additivity of the metric, the resulting complexity is relatively robust to the trajectory uncertainty. Furthermore, the robustness of the metric can be also influenced by the size of *E(C).*
- For each point of the grid, it has linear computational complexity with respect to the number of aircraft. In fact, it does not

require to evaluate the interaction of the aircraft (such as converging or diverging tendencies), which usually leads to exponential computational complexity. Nevertheless, the interaction of the aircraft is still inherently present: if two aircraft are converging, there is certainly a point in the grid close to both of them and in the direction of their flight, which will take high complexity values. In the same vein, diverging aircraft will not contribute together to high complexity values in any grid point.

- The precision of complexity maps (hand in hand with the computational load) increases with the decreasing tendency of D_{lat}, D_{ver} and D_{time}. From our preliminary estimations it follows that the values could be 5 NM for D_{lat}, 1600 ft for D_{ver} and 60 seconds for D_{time}.

- The curvature of the Earth can be typically neglected in the computation. In fact, this approximation is applied only within each ellipsoid E(C), so a potential impact should be verified based on the choice of the E(C) size.

- The metric is **additive** with respect to contributing aircraft. This is a key characteristic for the use of resulting complexity maps in different ATM tools. As the maps themselves are computed centrally involving all aircraft, the metric addictiveness allows a simple evaluation of the impact of potential trajectory changes by distributed ATM tools (by subtracting the original contribution of own aircraft and adding the new one based on the updated trajectory). Also in the centralized flow management this property may be useful, as it allows a simple assessment of the contributions of different aircraft which can be useful for a decision which aircraft should be re-planned.

Complexity map processing

The 4D rectangular grid is filtered using a threshold (or multiple thresholds, if desired). A segmentation algorithm is then applied so that it is clear how many components (that is, 4D areas of complexity) are there. Each component is then simplified as much as possible, so that clear and transparent objects are obtained. This process shall reflect the requirements of the applications: for computation of the optimal trajectories, communication, displaying to a pilot/controller, etc., it is necessary that the areas are easily represented. Components that are too small can be omitted; those that are close to each other can be merged; those with “holes” inside can be filled; those that are complicated can for example be made convex.

Numerical parameterization of the metric

The optimal choice of numerical parameters is of course tightly connected to the realistic parameters of the air traffic system and detailed operational requirements. So the values listed in this section are only preliminary and they are based on our initial estimation and first simple validation.

- The narrowness of the angle based component of the metric can be controlled using the parameter. Within our first modeling we adopted the value K=12.
- For the horizontal semi-axis of the ellipsoid *E(C)*, the value a=40 NM (about 5 minutes of the en-route flight) was used.
- For the vertical semi-axis of the ellipsoid *E(C)* the value of 10 000 ft was considered (10 Flight Levels).

Example of complexity maps

Figure 4 to Figure 7 show the evolution of a complexity of an air traffic situation at times 300 seconds, 600 seconds, 900 seconds and 1200 seconds after the ‘ownship’ (encircled in the figures) left from the position [0,0]. This example uses a random traffic with approximately 50 aircraft with two mild crossing flows.

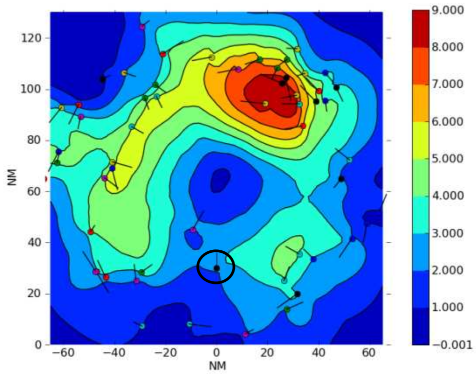

Figure 4: Complexity map of an air traffic example – time 300 s.

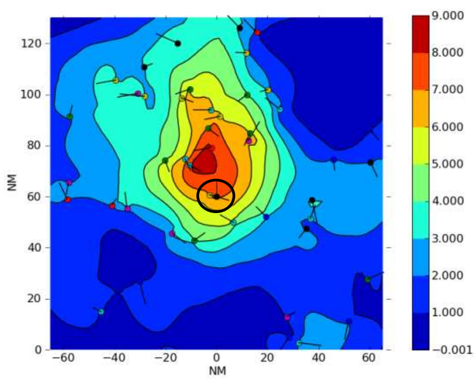

Figure 5: Complexity map of an air traffic example - time 600 s.

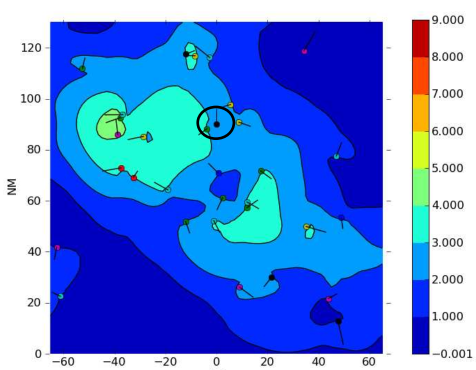

Figure 6: Complexity map of an air traffic example – time 900 s.

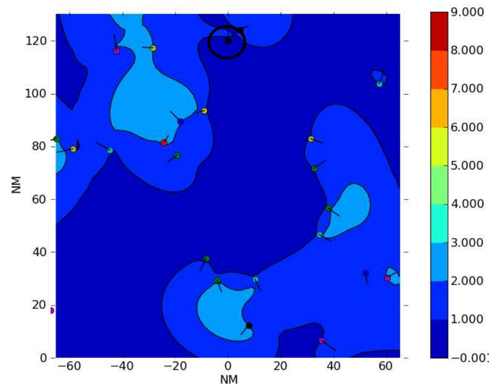

Figure 7: Complexity map of an air traffic example – time 1200 s.

Thresholds

The complexity map itself provides only relative information about the air traffic complexity: it shows areas with higher or lower complexity, but does not tell anything about feasibility of these places. In other words, we need threshold value(s) that would help us distinguish between areas with high and low complexity.

For a distributed trajectory optimization we propose application of two thresholds: a hard threshold and a soft threshold (see an example in Figure 8). Their intended use is as follows:

The hard limit is the complexity value that should not be exceeded. The soft limit is the hard limit decreased by 1. It can be ignored during an assessment of a planned path, however should be taken into account if re-planning takes place.

Note that the complexity is computed based on all the concerned aircraft. So if a pilot of one such aircraft finds out that his/her plane (ownship) is going to fly through a complexity area given by the soft limit, but not through an area given by the hard limit, he/she can expect that the complexity will not exceed the hard limit. On the other hand if a new trajectory is searched for (for example, a bypass around an area given by the hard limit), the new path should avoid the soft limit borders.

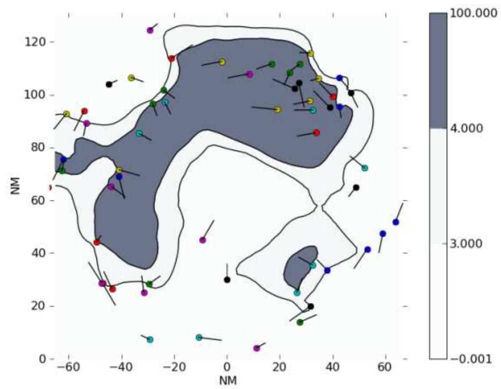

Figure 8: Complexity map of an air traffic example - time 300 s. Soft threshold (value 3) and hard threshold (value 4) are applied.

The reason is that the complexity far from the original flight path was computed with little or no contribution from the ownship, but after a flight path change, the contribution of the ownship would be equal to one exactly on the new path, and close to this number in the near neighborhood. So, if the new flight path is planned in the areas with complexity less than the soft limit, it is certain that after that change the complexity there will not exceed the hard limit.

<u>Threshold values setting</u>

As already suggested, the soft threshold for the onboard application of complexity metric should be one less than the hard threshold. But what is the right value of the hard threshold? This may depend mainly on the character, requirements and expectations of each user, and should be a result of deep analyses.

Here we describe only a little experiment in order to provide a glimpse into the complexity values meaning.

We simulated one thousand instances of a random traffic (with two main crossing flows of traffic of moderate intensity) at a square of 130 NM x 130 NM. The traffic was not de-conflicted in advance by any strategic flow management, and conflicts[3] occurred now and then. For a selected ownship travelling through the area, the ratio of discrete time instances with a conflict, to the total number of time instances, was evaluated for each complexity interval of length 1, that is, , , and so on.

The results are shown in Figure 9:

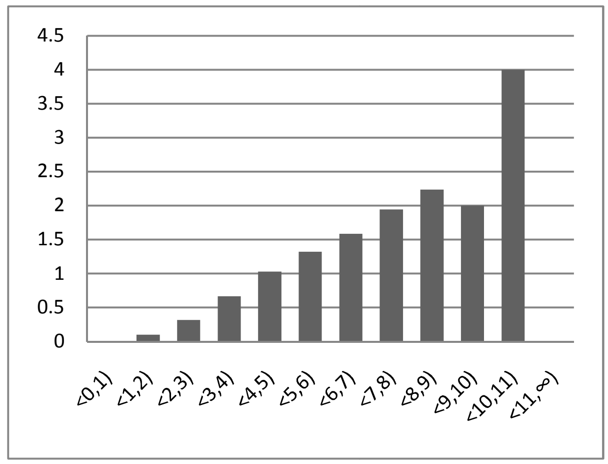

Figure 9: Conflict ratio (vertical axis) vs. complexity range (horizontal axis).

The first complexity interval is empty. This is due to the fact that the ownship itself increases the complexity value by one, as the complexity is measured exactly in the ownship’s position in this experiment. All measured complexity values were lower than 11, so the last column is also empty. The penultimate column represents only one case: a time instance when the ownship has conflicts with 4 other aircraft at once, but generally this is also a rare situation. The rest of the columns, however, can tell a little about the relation between the complexity measure and conflicts experienced at the same time: For example, if we want the probability of conflicts to be around 0.5, the aircraft should avoid areas

[3] Lateral loss of a separation, that is, proximity of aircraft less than 5 NM, was interpreted as a conflict in this simple 2D scenario.

with complexity higher than 3 or 4 (see the fourth most left column). Nevertheless, finer complexity categorization would be necessary in order to find the right balance between conflicts and complexity areas size (usually, the lower complexity threshold, the larger the area determined by the threshold value).

Potential onboard application

In the previous, we have already outlined how thresholds can be set and used for the trajectory optimization application. In the case of an onboard application only the resulting complex areas in time and space are sent to the aircraft. Still there can be many of them, and their predicted evolution in time can be rather complicated (see the example in the previous section). However, the relevant information for the crew or the trajectory planning system consist only of the information related to those times and places that can be reached by the aircraft. This means that current situation at distant place, or future situation at the place where the aircraft is now, is of no importance to it. Thus it would be waste of communication effort to transmit and process such information. Instead, according to the expected speed profile of the aircraft, only a 2D cross section (the complexity at different grid points is evaluated for the time when this point could be reached by own aircraft) through the 4D grid can be used, providing the subjective view of the expected complexity evolution to be experienced by the aircraft.

Such a subjective 2D view for the ownship from our example (see Figures Figure 4 to Figure 7) is shown in Figure 10. The main axis shows the intended flight path of the ownship.

Note that the subjective view not only reveals all the details of the evolution of complexity from the ownship's subjective perspective, but – if generated without the ownship's contribution (see Figure 11) – also helps to decide which way to go around an area of high complexity.

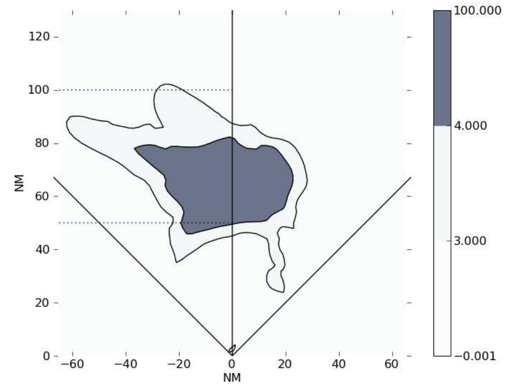

Figure 10: A subjective view on the traffic complexity from the ownship's perspective. The intended flight path goes through a hard threshold area, therefore re-planning is needed.

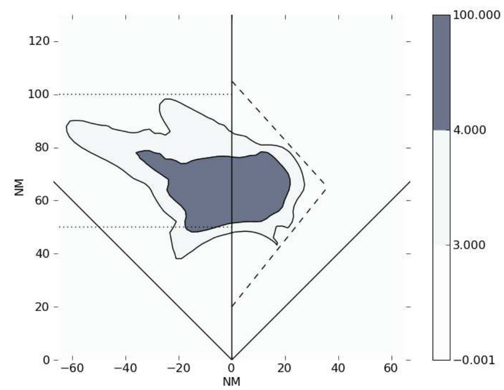

Figure 11: New trajectory (dashed line) avoiding the complex areas.

Conclusion and future work

One of the key challenges of the ongoing development of future ATM within SESAR and NextGen programs is careful balancing between strategic and tactical ATM tasks, which is indispensable to increase the overall ATM performance while maintaining safety and efficiency of air transportation. In this paper we try to take the advantage of some of the envisioned operational and technological changes (System Wide Information Management (SWIM), new separation modes, etc.) in order to respond to some of the known ATM issues. Namely, we present a way how trajectory information shared via SWIM together with a suitable definition of air traffic complexity metric can be used to reduce a need for excessive tactical maneuvering. For this purpose we considered the use of complexity in:

- Trajectory optimization (onboard or in Flight Operating Centers)
- A centralized flow management

Based on these envisioned applications, we postulated a set of requirements that such a metric should fulfill, and performed a review of existing metrics of air traffic complexity. After we realized that none of the existing metrics is suitable for our target applications, we developed such a metric in order to grasp an initial insight into its behavior. The main idea upon our metric is to assess whether it would be convenient (from tactical maneuvering perspective) for an aircraft to be at specific place in specific time, or not.

The metric is defined as a local quantity taking into account predicted states of all traffic within a local neighborhood. It is intended to be computed for each point of a regular grid in the time-space of interest in order that the corresponding complexity maps can be generated and used by different ATM tools.

The proposed metric has several advantageous properties, among which we mainly emphasize the additivity principle (it is expressed as a sum of independent contributions from near aircraft). This considerably simplifies the calculations of alternative trajectories, which is one of the most important tasks of the considered target applications. A special section was devoted to the setting of threshold(s) to determine the areas with a high risk of tactical ATM issues. In fact, proper threshold setting is crucial to achieve an effective balance between strategic and tactical ATM actions and therefore for a successful application of the metric.

Besides more thorough testing and validation, future work should focus on ways how this particular air traffic complexity metric could be used in various optimization algorithms (both onboard and on the ground).

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