STREAM – Strategic Trajectory de-confliction to Enable seamless Aircraft conflict Management

Concept, methodology and tools

Andrea Ranieri, Rubén Martinez
Advanced Logistics Group - Indra
Barcelona, Spain
[aranieri, rmartinez]@alg-global.com

Miquel Angel Piera
Universitat Autònoma de Barcelona
Bellaterra - Barcelona, Spain

Javier Lopez, Miguel Vilaplana
Boeing Research & Technology
Madrid, Spain

Abstract— **The STREAM project aims to investigate innovative strategic trajectory de-confliction algorithms that can reduce the conflict management automation gap between the pre-departure and flight execution phases. The underlying concept is that of extending the Network Operations Plan (NOP) concept to separation management by means of a seamless conflict-management process that would run continuously from the strategic phase (pre-departure, collaborative design of the NOP) up to the execution one (automation-assisted, controller-driven conflict resolution). The project will define new metrics to evaluate the performance of such algorithms. In particular, a metric to measure the fairness of a trajectory de-confliction solution will be defined, in order to evaluate how fairly the cost penalties associated to the deviations from the original Shared Business Trajectories (SBTs) proposed by the de-confliction algorithms are distributed among airspace users.**

Foreword - This paper describes a project that is part of SESAR Workpackage E, which is addressing long-term and innovative research. The project was started early 2011 so this description is limited to an outline of the project objectives augmented by some early findings.

Keywords-Conflict detection, Conflict resolution, Spatial Data Structure, 4D Trajectory

I. PROBLEM DESCRIPTION

Conflict Detection and Resolution (CD/CR) tools are currently used to allow the controller to timely react to potentially dangerous situations by detecting conflicts and facilitating the identification of a resolution maneuver by the operator. These tools typically provide automated early detection and filtering of potential conflicts, based on trajectories with different look-ahead times depending on the considered controller role, typically from 5 to 20/30 minutes in advance to the conflict. They are not currently used at a pre-operational phase to proactively de-conflict traffic by imposing trajectory constraints. This is mainly due to the following reasons:

- the quality of pre-departure information available nowadays from Airspace Users (AUs) flight plans is rather poor and would not allow detecting conflicts within meaningful predictability margins;

- the computational complexity implied by the pairwise approach employed in current CD/CR algorithms impose that only a reduced number of trajectories (i.e. less than 60) can be easily managed under tight computational time constraints.

This implies that the demand/capacity balancing and tactical separation functions are two different and decoupled processes with few or no integration nowadays. As a consequence of this lack of integration between strategic and tactical traffic management, the declared capacity of airspace sectors is always kept below its real capacity, in order to avoid sector overload and to allow Air Traffic Control (ATC) and aircrews to safely respond to unexpected levels of traffic at a tactical phase.

II. STATE OF THE ART

The current management of air traffic is structured according to different layers of traffic organization and de-confliction, according to the phase of flight [1]. From the strategic predictive measures enforced by the Central Flow Management Unit (CFMU) the aircraft management evolves to the tactical and mainly reactive separation function, under the responsibility of Air Traffic Controllers. Several algorithms and tools have been proposed in literature to support controllers in deciding upon the best strategies and actions to solve conflicts (see e.g. [2,3,4]). Optimal models (e.g. [5,6]) as well as heuristics [3] have been investigated for solving CD/CR problems in real-time; however only few of them have been successfully integrated into operational tools, due to the complexity and safety criticality of these functions. The STREAM approach instead is to strategically move CD/CR functions to the pre-departure phase, in order to deliver traffic to the controllers already partially de-conflicted. This concept is enabled by the Shared Business Trajectory (SBT) element proposed by the SESAR, i.e. the 4D trajectory that is shared by the Airspace Users for planning and negotiation purposes [7]. The SBT evolves out of a collaborative layered planning process among the involved stakeholders and its ultimate instantiation corresponds with the Reference Business Trajectory (RBT), which the Airspace User agrees to fly and the Airport and ANSP agree to facilitate. The metrics currently available to assess the performances of ATM tools and

procedures ([8,9]) will be extended in STREAM and new metrics will be defined according to the work of [10,11], in order to take into account impacts such as fairness and equity of the proposed solution.

III. THE STREAM SOLUTION

STREAM solution relies on one of the fundamental elements of the SESAR Target Concept: the 4D Business Trajectory. It describes for each flight its intended trajectory in space and time and evolves out of a collaborative layered planning through 3 main different phases: the Business Development Trajectory - BDT (internal to the airspace user and not shared with the rest of ATM community), the Shared Business Trajectory – SBT (shared for planning and negotiation purposes with the stakeholders) and the Reference Business Trajectory - RBT.

The RBT constitutes the ultimate reference Business Trajectory that the Airspace user agrees to fly and the Airport and ANSP agrees to facilitate. Changes to the RBT must be kept to a minimum, altering it only for reasons of separation and/or safety or in case the Airspace Users' and ATM network goals prevail on the optimisation of an individual flight.

The STREAM project investigates innovative algorithms that can make use of the information contained into the SBTs to perform conflict detection at pre-departure phase, thus allowing the integration of appropriate conflict resolution manoeuvres into the first RBT instantiation. It is foreseen that at pre-departure phase the agreement on the best trajectory amendments which provide conflict resolution can be reached through an iterative and collaborative process between Airspace Users and the Network Manager (NM). This should enhance the overall process of conflict management by closing the gap that exists nowadays between the long-term predictive part of the ATM system, represented by central flow management measures, and the short-term adaptive actions locally performed by tactical controllers. In an ideal scenario (i.e. lack of perturbations) RBT revisions during the tactical phase would be maintained to the minimum and consequently the predictability of the entire system would increase.

To achieve this objective the STREAM project will develop time-efficient algorithms for strategic CD/CR, capable of adopting a combination of different resolution strategies (route, speed and flight level modifications to the involved SBTs); These algorithms will run in linear time with respect to the number of trajectories considered, thus allowing to take into account the whole European air traffic in order to ensure that resolutions of conflicts are effective. This implies that traffic complexity is maintained under control — at local (ACC), regional (FAB) and even global (ECAC) levels – and that resolutions do not generate secondary reactive conflicts on other zones of the network.

Furthermore the requirements on the reliability and robustness of traffic predictions to perform strategic CD/CR will be developed, based on a series of simulations run in a common environment to validate the proposed algorithms and metrics.

IV. TOOLS DEVELOPMENT APPROACH

The strategic trajectory de-confliction tool will be developed in two successive phases, basic and advanced solution, and will be based on the following techniques:

A. Distributed Spatial Data Structures (SDS)

To allow linear time conflict detection a Spatial Data Structure (SDS) will be used, which will constitute the core of the technical solution proposed in STREAM for CD/CR. An SDS can be thought as a mesh of discrete points distributed along the space representing the airspace under analysis. Inside this three-dimensional SDS (the cube) it is possible to store a discrete representation for each of the 4D trajectories inserted (different 3D positions of an aircraft in different discrete time steps). This permits to detect conflicts as soon as the reservation is attempted and to pass the information to the Conflict Resolution module. This latter relies on the same SDS information to calculate the best SBT amendments guaranteeing a trade-off between fairness, equity, efficiency and robustness of the suggested resolution. To support different airspace organisations, a scalable distributed SDS must be properly designed and implemented.

B. Discrete Event Models

The management of a considerable amount of 4D trajectories will require the development of efficient models for decision making. A discrete event specification of aircraft trajectories will avoid the computational burden of a continuous approach, therefore focusing the modelling target in the causal analysis of the decision variables (i.e. route, speed and flight level modifications). The key aspects and information of SBT must be analysed during the abstraction modelling tasks in order to guarantee efficiency, user flexibility and completeness for the conflict detection algorithm

The Coloured Petri Net (CPN) formalism will be used to develop the discrete event system (DES) models. This will be done under a causal modelling approach, since the resolution of a certain conflict can spread over new potential conflicts. State Space (SS) Analysis is a rigorous approach that can be supported by causal models developed through Coloured Timed Petri Net formalism

C. Scenario Design

Scenario planning will be considered as a framework of support for decision-makings based on clarifying cause-effect factors in a target business, which are mostly achieved by using a causal structural graph model. A Constraint Logic Programming approach will be implemented based on an automatic propagation of time constraints generated by the causal CPN models developed, avoiding in this way the exploration of non feasible solutions. These scenario results will allow the comparison of ATM characteristics: with or without ADS-B technology, convergent or divergent traffic, etc. Specific metrics for fairness, equity, robustness and efficiency will be developed to assess the impact of the

proposed solution on the system and in particular on the Airspace Users.

D. Trajectory prediction

The computation of precise trajectory predictions is fundamental for reliable CD/CR. To that end, an experimental Trajectory Prediction Infrastructure based on BADA4.0 aircrfat performance model will be used to synthesize flyable, realistic detailed trajectories serving as reference data set to test and evaluate the STREAM CD and CR algorithms. The trajectories will be synthesized integrating an atmospheric model (4-dimensional wind and temperature fields) based, if possible, on data from actual meteorological forecasts for the volume of airspace considered and the time interval of the sample.

These trajectories will represent the hypothetical "truth" trajectories that would be flown if the aircraft were left to fly according to their current SBT without ATC intervention during the execution phase. Different possible values of the trajectory prediction error (due to the aggregation of wind forecast errors, aircraft modeling errors, etc.) will be considered in the analysis, so as to conduct a study on the sensitivity of the performance of the algorithms with respect to this error. To establish a performance baseline, i.e. to define the maximum achievable performance, we will assume that the CD & CR algorithms use a "perfect" trajectory predictor, which reproduces exactly the synthesized trajectories.

V. Concept of Operation

A. Area of application

The final goal of STREAM concept is the early detection of conflicts at a pre-departure phase, when 4D trajectories are shared as SBTs with a high degree of precision, and the identification of appropriate de-confliction manoeuvres to be integrated into the final RBT.

In order for the conflict resolution manoeuvres to be effective, the complex interactions among different traffic flows must be taken into account which may imply the reactive creation of a new conflict when another one is resolved. Due to the high degree of connectivity of the European ATM Network it is foreseen that only by considering the whole ECAC Airspace one could ensure that all potential interactions are identified.

The average daily number of flights in 2010 in Europe was around 26000 [12] with peak days of up to 36800 as on July 1st. Considering the typical distribution of take-offs in Europe, as showed in Figure 1 below, and taking into account that the average flight duration is 1h23' (according to [9]), it means that a two-hour sliding time window could be employed to filter insertion into the SDS, which will imply to easily have between 5000 and 6000 flights active at the same time. This amount of flights will have to be managed in real time by the algorithms, and this represents a very demanding technical requirement on the performances of the algorithms and of the SDS.
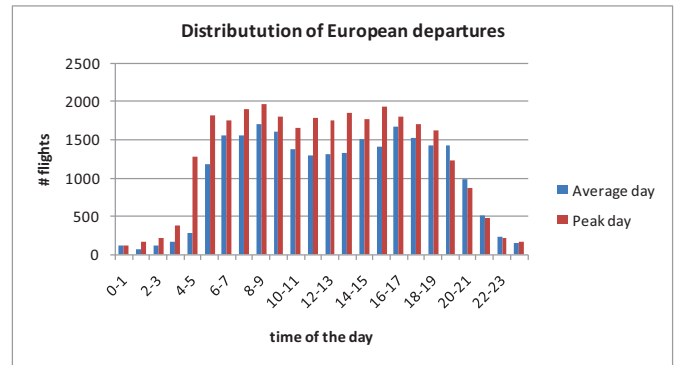

Figure 1: Daily distribution of take offs in Europe (Average day: 09/11/2010, Peak day: 01/07/2010). Source: EUROCONTROL ALL_FT data.

Hence the most appropriate solutions will be investigated by the project to comply with the computational burden required by the STREAM operational solution. These will include:

- The application of advanced techniques for the reduction of quantity of data stored in the SDS (temporal filtering, relational data bases, etc.);

- The design and implementation of a scalable distributed SDS, capable of supporting different airspace configurations (ACC, FAB, Sectors);

- The identification of disconnected clusters of interfering traffic allowing the separation of the general problem into several smaller sub-problems.

B. Operational application

The STREAM solution will mainly apply on the day of operations, during the time horizon that extends from a few hours before take-off to the final agreement of the RBT (i.e. few minutes before push back). Within this time frame in fact the most reliable information will be available regarding the main factors contributing to uncertainty in traffic evolution. The STREAM algorithms will reside within the NM function. The NM will be in charge of collecting SBTs from AUs, checking their validity and processing them (adding appropriate uncertainty buffers to estimates) in order to store in the SDS reflecting the uncertainty in data. This task will allow the 4D representation of traffic in the network at European level for the next 2-3 hours padded with uncertainty. Consequently it will be possible to:

a.   Identify potential conflicts, likely violations of separation minima, e.g. two aircraft at the same level over the same geographical area at the same time.

b.   Identify hot spots and congested areas.

c.   Determine those trajectories which are more sensitive to be involved in a conflict in case of perturbations.

The Airline Operational Center (AOC) will be in charge of providing the requested SBT to the NM and of implementing

the modifications required by the NM according to the strategic conflict resolution process. 4D trajectories will be provided in the form of flight 4D position estimates with attached confidence intervals on specific points along the trajectory (identified as hot-spots by the NM). A natural incentive for AUs to provide good estimates will be to receive targeted constraints for their flights causing fewer disruptions to schedules. Transparency will play also an important role for AUs to accept conflict free proposed trajectories. The AOC will constitute the AU interface and unique "spokesman" with the NM during the negotiation processes that may instantiate following the revisions of submitted SBT.

The Airport Operations Centre (APOC) and the local flow managers will be in charge of maintaining updated the information regarding local constraints and availability of resources in order for the NM to have a reliable picture of the system.

Figure 2: Main components of the STREAM solution

The AUs will have the possibility to express their preferences over different solutions to comply with constraints, thus engaging in a sort of iterative negotiation process, according to which the AUs communicates their preferences and the NM calculates the most preferred maneuvers, associated with specific constraints.

Since each detected conflict may have several possible trajectory amendments to be solved, each one implying in general a different impact on users, there two main mechanisms that can be used to collaboratively agree on the best solution:

1. The AUs communicates their priorities (e.g. in terms of cost index for each flight) to the NM who can then assess and impose the best solution

2. The NM proposes a set of possible resolutions to the users which then will have to provide the ranked order of preferred ones to the NM. This will allow NM to calculate the general preferred solution and to impose it.

VI. LOGICAL ARCHITECTURE

A. Data pre-processing module

The data pre-processing module will constitute the interface between raw SBT data as transmitted by AUs and the CD/CR tools within the NM system. It will be in charge of reading the information included in the SBT and to make it usable for being stored in the SDS by:

- receiving SBT from the AUs systems and generate accurate trajectory predictions from the information contained in it. Predictions will be based on the information included in the SBT, e.g. the flight script (intent) and will be complemented with trajectory prediction uncertainty bounds around the 4D estimates. These bounds will be used by the CD/CR algorithms to identify potential conflicts.

- Identifying which intent information can be amended to resolve potential conflicts (what-if probing), such as 2D route, speed/altitude constraints, etc

The trajectory data derived from the SBTs will be filtered according to the estimated take-off time and only those complying with the active time horizon of the SDS will be passed on and immediately stored into SDS, while others will be automatically pre-filtered and introduced at the right time. At a certain time t, the flights that will be inserted into the SDS will be the ones taking-off in the time interval [t; t+120minutes], with appropriate refreshing time (i.e. rolling base), to guarantee effective catching of updates. As soon as a flight lands, its trajectory data are eliminated from the SDS and possibly passed to the NOP for post-flight analysis. This rolling horizon thus constitutes a temporal filter to limit the amount of stored data only to flights which are at the final stage of SBT negotiation and whose 4D trajectory can be precisely described. The RBT of flights already in execution phase will be maintained continuously updated in the SDS through the NOP.

The specific architecture of the data pre-processing module and of its functional sub-blocks is out of the scope of STREAM project.

B. Conflict detection module

All SBT-derived predicted trajectories are sequentially inserted into the SDS according to their space and time evolution. This implies a formal booking of a series of discrete space/time volumes into the data base, corresponding with the samplings of 4D envelope that can be built around the aircraft, which takes into account the estimated aircraft path plus the applicable uncertainty bounds . Applicable separation minima for conflict detection will be included in the uncertainty bounds, so that their intersection (4D envelope) around two

trajectories would imply that a potential conflict has been detected.

The radius of the tube will then depend on the uncertainty attached to the trajectory prediction (which depends on the wind forecast, quality of the SBT data, knowledge of the applicable ATM constraints, etc) and on the applicable separation minima, which are considered as additional buffers around the predicted trajectory (for example to represent wake vortex separation requirements). In principle, different separation minima can be considered in the study. The sampling rate of the 4D-tube will in turn define the granularity of the information stored, while the spatial distance between successive reserved positions in the SDS depends on the speed of the aircraft, whereas the relative positions of the waypoints depend on the direction of the aircraft.

The resolution of the SDS is the distance between discrete points of the SDS. Several factors are considered to determine the granularity of the SDS, such as the modeled objects (size of the physical airspace to model, of the tubes to be stored in the database, of the aircraft speed), technological factors (available memory, speed of execution of the algorithms) and operational needs (the expected congestion levels and required accuracy)

Note that the excess of resolution may lead to a loss of computer performance as well as to an inoperable amount of memory requirements, whereas a lack of resolution may lead to lose some important objects of the space. Hence the right trade-off needs to be evaluated, depending on the specific operational needs and technical capability levels.

At the moment of storing a tube-point in the SDS, a conflict is detected. In the case that no other flight has reserved the same space volume, no conflict is detected so the spatial resource can be booked without conflict. In the case of detecting a previous booking of the same space volume by another flight, then the algorithm compares their time windows. If their time-windows are overlapping, then a conflict is detected and the CR system is informed. If the time windows are not in conflicting, it means that the coordinate might be booked for a different time window.

Therefore, the number of actual comparisons performed by the algorithm is considerably limited only to aircraft reserving the same spatial volumes, thus acting like a natural "spatial prune" avoiding the pairwise strategy and linearizing the temporal performance of the algorithm.

Additionally all relevant information to be successively exploited by the CR module, can be stored in the SDS and attached to the flight, such as state space information, times, type of aircraft involved, priorities, etc.

A conflict can be detected either between different SBTs or between an SBT and an RBT already on execution. In this latter case there might be situations in which it could be more beneficial to modify an already agreed RBT than a number of different SBTs, even if this may imply a stronger coordination effort to be achieved. In fact the change proposal should be triggered by the NM, channeled through the Flow Manager, to the Local Traffic Manager and then the RBT revision executed by the responsible ATCO. A specific case might be a congested TMA around a hub airport in which a predominant carrier operates and one of its RBTs is in conflict with several SBTs. It would be in the very interest of the carrier to slightly modify the one RBT to leave all other SBTs unchanged. This case should be assessed by simulations to derive feasibility and benefits.

C. Conflict resolution module

The maneuvers calculated and suggested by the CR module [14] will be based on the impact of the maneuver on the user preferred profiles, measured according to specific indicators for

- Fairness: balancing conflicting interests by means of a just procedure that takes into account the acceptance levels of the users and their individual satisfaction.

- Equity: Treating all users equally without taking into account their specific identity, but rather their ability to facilitate trajectory management process.

- Robustness: taking into account the ability of the aircraft to keep its planned trajectory in response to the occurrence of a disturbance. In relation to the solution proposed by the CR module it means that the amended trajectories are likely to resolve the conflicts even in the presence of disturbances, e.g. assigning different Flight Levels to resolve a conflict may be more robust than changing intended airspeeds (although the former solution may be more inefficient from the fuel point of view).

- Efficiency: including
  o time efficiency: additional flight duration implied by the trajectory change;
  o fuel efficiency: additional fuel consumption implied by the trajectory change;
  o overall flow efficiency: considering the number of impacted flights in the traffic flow;

The relevant indicators will be developed during the course of the project and they will be weighted in order to evaluate the overall impact of conflict resolution maneuvers on individual users as well as on the system. This implies that the best trade-off will be searched between local impact and global impact imposed by the maneuver.

A set of possible resolution scenarios could be available for each conflict. In this case the tool would clearly indicate the different options which should made available, together with the causing constraints to AUs for selecting the preferred one. Under all circumstances the final agreement between the involved service providers and the impacted Airspace Users will be necessary in order to close the SBT negotiation and to instantiate an RBT for each flight. This agreement may be achieved immediately upon AU request of its desired trajectory, in case that no ATM constraints are violated and no

conflict are detected, or may be the result of several proposals and negotiation iterations.

In the cases when negotiation process does not converge to a feasible solution within a certain time limit, the ATM authority (i.e. the NM at the strategic phase or ATCO during the execution phase) will have the right to impose the most indicated conflict resolution measure.

D. Final Agreement

Since each detected conflict may have several possible trajectory amendments to be solved, each one implying in general a different impact on users, either the AUs are able to attach a specific priority coefficient to each trajectory, in order for the NM to assess and impose the best solution, or the NM communicates to the users the set of possible resolutions suggested by CR module and they in turn respond with the ranked order. The NM will be then be able to select the preferred solution, i.e. the one whose sum of individual rankings is the higher. The trajectory amendments communicated to users shall just specify the actions on the aircraft operated by them, in order not to leave possibility of a ranking conceived just to penalize a competitor airline. This method could be more complicated to be implemented but could guarantee the collaborative agreement of a fair solution, without requiring AUs to explicitly declare aircraft priorities.

The result of this process will be to have pre-synchronized traffic in the regions that are foreseen to be more congested. This synchronization will be agreed by involved actors (AUs, ANSPs and Airports) and formalized through the RBT, which will include the constraints in path and time derived by the strategic de-confliction measures. Different types of constraints will need to be defined to better cope with the flexibility required by the system:

1.   Soft constraints: those constraints that admit certain flexibility since they are coupled with other constraints along the trajectory.

2.   Hard constraints: those constraints that must be rigorously respected since they have an impact on other constraints imposed along the trajectory in different areas.

These constraints will be clearly identified in the RBT and will provide a commitment from the stakeholders to conduct/facilitate the flight accordingly. This means that the aircraft will not be automatically cleared through these constraints, since unexpected events could still occur imposing tactical interventions and the explicit ATCO clearance will continue to be needed. However the overall predictability of the system will be enhanced, thus implying less tactical interventions and more stable plans.

The constraints resulting from STREAM early de-confliction maneuvers should be diversified from other type of constraints resulting from other interventions (e.g. sequencing through SESAR controlled times CTO/CTA). The concept of Target Window proposed by CATS project [13] represents a good candidate to easily represent the resulting constraints and their degree of looseness: they are 4D windows (i.e. in space

and time) located on sensitive points along the trajectory, depending on airspace configuration and ATM needs.

The size of the window inherently represents the tightness of the constraint in space and time to be respected in order to avoid the conflict. The sizes and location of the windows could be negotiated and changed until the final RBT agreement, when they are frozen. This allows to build an overall stable plan for aircraft already in the air and to take this plan as reference to negotiate and agree trajectories with aircraft still on the ground (i.e. during the SBT phase).

On the other hand the flexibility of the system will be guaranteed by allowing a tactical revision of the RBT in whatever moment and for whatever reason during flight execution. This implies a formal RBT change, thus causing a new or modified aircraft booking volume in the SDS to maintain the picture updated and at the same time to detect new potential conflicts as well as the corresponding resolving maneuvers by the CR. Due to the time constraints on the computational time that can exist in the execution phase the CD/CR processes need to be fast and reliable and this will be ensured by the specific design of STREAM algorithms.

VII.   Experiments

A. Assessment strategy

An existing experimental fast time air traffic simulation infrastructure developed by Boeing Research & Technology will be used to model the trajectories that result from the STREAM CD/CR algorithms and to assess a set of metrics that will allow understanding the potential impact of the proposed concept. The outputs of the STREAM CD/CR algorithms will be used as input to define the trajectories to be simulated. The simulation is based on a high fidelity 3 Degrees-of Freedom aircraft model based on BADA 4 (latest generation of EUROCONTROL's aircraft performance model) and allows reproducing the trajectories flown by current generation Flight Management Systems with a high degree of fidelity. The simulated trajectories include information on aircraft position, speed, time and weight, among other state variables.

The metrics to be considered will allow measuring the impact of the STREAM solution from different perspectives, such as ATM efficiency, fuel consumption and environmental impact, robustness and fairness.

Based on the high fidelity simulated trajectory data, estimates of fuel consumption and arrival times for each flight will be obtained. This information will allow analyzing the impact of the STREAM solution on the airlines' costs. In addition, the level of emissions derived from the fuel consumption obtained could be estimated to conduct a preliminary assessment of the environmental impact of the proposed concept.

The ATM efficiency analysis will focus on demonstrating the usefulness and benefit of the proposed tool for strategic de-confliction, whilst reducing the tactical interventions required

by the ATCO. A potential reduction of tactical interventions would in turn result in additional capacity.

The robustness assessment will focus on the impact of accurate and imprecise information on the strategic trajectory de-confliction tool. Case studies with and without wind will be key for the analysis as well as the trajectory modeling tools.

A special focus will be placed on fairness, as little research has been conducted to date on applying and measuring these concepts in the context of ATM. Specifically, tailored definitions of the concepts of fairness and equity adapted to the context of applicability of the STREAM solution will be proposed. These metrics will be based on cost penalty models that will capture the impact of the trajectory modifications by the STREAM algorithms on the flight costs and, ultimately, on the airlines' business strategy.

Recorded operational trajectory data will be used to calibrate the STREAM algorithms (e.g. to check whether tactical deviations from the flight plan found in the data could have been detected and avoided by the algorithm in the presence of a certain level of uncertainty), as well as to derive a baseline for the metrics to be evaluated (e.g. estimate the value of the metrics for a real scenario without STREAM).

Simulations will be run based on current real traffic scenarios as well as on scenarios assuming expected future traffic demand. For each traffic scenario considered, an ideal baseline will be defined by running the simulation without any ATM intervention, assuming all flights are hypothetically conducted as user-preferred Business Trajectories subject only to the applicable static airspace constraints. This will help understand the maximum level of efficiency achievable from the users' perspective. Then, each of the scenarios will be run with the STREAM solution in place, resulting in amendment to the user-preferred SBTs aimed at avoiding potential conflicts. A stochastic analysis will be conducted to estimate the probability of the need of tactical interventions to solve the conflicts assumed avoided by the STREAM solution at the planning level.

B. Expected benefits

The main benefits for which STREAM solution is conceived and the tools are developed can be resumed according to 3 ICAO Key Performance Areas: Predictability, Capacity and Environmental Impact.

In the following a rational is provided that justify the performance expectations in each area.

1) Improved Predictability

Higher predictability will be induced by closer integration between the global predictive part of the ATM, performed by ATFCM function previously to flight take-off, and the local reactive part, performed by tactical controllers. These 2 phases are currently poorly synchronized due to the scarcity of information on precise desired 4D profiles at the strategic phase and to the lack of computationally efficient tools to tackle complex CD/CR problems involving up to several

thousands of flights. STREAM solution will develop algorithms and models that can perform Conflict Detection and Resolution in the pre-departure phase, i.e. based on the richer information available in the SBT and on the contractual leverage offered by the RBT to integrate appropriate de-confliction measures.

Moreover the constraints imposed on the strategically de-conflicted RBTs will give visibility to the different involved actors of the level of sensitivity of each trajectory to tactical modifications. This will help controllers in assigning priorities to different flights when it comes to tactically vectoring traffic (for whatever need), in order to minimize network impact by picking the less constrained trajectories.

At the same time the traffic stored in the SDS will represent a reliable picture of the traffic in the next 2-3 hours, thus allowing the NM to identify congested areas and hot spots and to plan necessary actions.

2) Capacity Increase

The early de-confliction of flights will allow to reduce tactical interventions by controllers and thus to decrease the workload. This will allow them to handle more flights at the same time, while guaranteeing the same situational awareness and thus safety. This in turn implies an increase of the real sector capacity.

At the same time the fact of knowing in advance that part of the traffic will arrive to the airspace sector already de-conflicted, will help reduce the "safety buffer" which today is applied by local traffic managers when declaring capacity. This implies that the declared capacity will increase more than the true capacity, as indicated in the following diagram.

3) Environmental Impact

Thanks to the enhanced efficiency of ATM operations and the opportunity for airspace users to fly trajectories which are as close as it is possible to their optimal ones, while minimising the need for tactical modifications due to conflict resolution tasks, the STREAM solution will reduce fuel consumption and hence gaseous emissions.

VIII. CONCLUSIONS

This paper has provided some insights into the concept, methodology and tools at the base of the STREAM WP-E project, whose final objective is to preliminarily assess the impact of pre-departure trajectory de-confliction tools applyed on the aircraft SBTs. Based on the STREAM Concept of Operations described in Chapter V, the development of CD/CR algorithms is currently ongoing at the time of writing this paper. It is foreseen that the specific architecture of the solution, based on a Spatial Data Structure, will allow the algorithms to process several thousands of aircraft at the same time. This in turn implies that wider portions of airspaces can be taken into account than today, with look-ahead times of several hours, ensuring that the trajectory amendments are more effective. A series of experiments will be run with the purpose of assessing the operational application of the STREAM solution on stakeholders. This will imply the ad-hoc

development of a series of metrics to include a measure of fairness and equity of the solution, besides its efficiency and robustness to uncertainty.

ACKNOWLEDGMENT

LIST OF ACRONYMS

ACC	Area Control Centre
ANSP	Air Navigation Service Provider
APOC	Airport Operations Centre
ATC	Air Traffic Control
ATCO	Air Traffic Controller
AU	Airspace User
BADA	Base of Aircraft Data
BDT	Business Development Trajectory
CD	Conflict Detection
CFMU	Central Flow Management Unit
CPN	Coloured Petri Net
CR	Conflict Resolution
DES	Discrete Event System
ECAC	European Civil Aviation Conference
FAB	Functional Airspace Block
NM	Network Manager
NOP	Network Operations Plan
RBT	Reference Business Trajectory
SBT	Shared Business Trajectory
SDS	Spatial Data Structure
TMA	Terminal Manoeuvring Area

REFERENCES

[1] G. Gawinowski, V. Duong, J. Nobel, J.Y. Grau, J.Y. Grau: "Bridging the predictive and adaptive issues in traffic management: the synchronous paradigm", Digital Avionics Systems Conference, 12-16/10/2003

[2] H. Erzberger. "Automated Conflict Resolution for Air Traffic Control". International Congress of the Aeronautical Sciences, 2006.

[3] Nicolas Durand, Jean-Marc Alliot, "Ant Colony Optimization for Air Traffic Conflict Resolution", 8th USA/Europe Air Traffic Management Research and Development Seminar , Napa – California 2009

[4] James K. Kuchar and Lee C. Yang, "A Review of Conflict Detection and Resolution Modeling Methods", IEEE Transactions on Intelligent Transportation Systems, Volume 1, 2000, pages 179-189.

[5] Adan E. Vela, Senay Solak, John-Paul B. Clarke, William E. Singhose, Earl R. Barnes, and Ellis L. Johnson, "Near Real-Time Fuel-Optimal En Route Conflict Resolution", intelligent Transportation Systems, IEEE Transactions on , vol.11, no.4, pp.826-837, Dec. 2010.

[6] Pallottino, L.; Feron, E.M.; Bicchi, A.; , "Conflict resolution problems for air traffic management systems solved with mixed integer programming" Intelligent Transportation Systems, IEEE Transactions, vol.3, no.1, pp.3-11, Mar. 2002.

[7] SESAR Consortium, "The ATM target concept, milestone deliverable 3", Version 1.0, 2007;

[8] Breunig, T., Bradford, S., Liang, Diana, "Standardizing Performance Metrics", 5th USA/Europe ATM R&D Seminar, Napoli, 2003.

[9] EUROCONTROL PRU, "Performance Review Report 2010, Assessment of the performance of the European Air Traffic management Systems for the calendar year 2010".

[10] Del Pozo, I., Vilaplana, M. Goodchild, C, "Assessing Fairness and Equity in Trajectory Based Operations", 9th AIAA ATIO Conference, South Carolina, 2009.

[11] Jonker, G., Meyer, J., Dignum, F., "Efficiency and Fairness in Air Traffic Control", Utrecht University, Research supported by the Technology Foundation STW, applied science division of NOW and the technology programme of the Ministry of Economic Affairs, Project DIT5780

[12] EUROCONTROL Medium-Term Forecast Flight Movements 2011 - 2017, February 2011.

[13] CATS consortium: "CATS Concept of Operation Document", v.3.0, 30/09/2010.

[14] Zuñiga, Piera, Ruiz, del Pozo. "A TMA 4DT CD/CR causal model based in path shortening/path stretching techniques" ,4th Internatiobal Conference on Research in Air Transportation (ICRAT'10)