# Meteorology and Air Transport Conference

Conflict and wind forecast

:

*How to best benefit from wind forecasting*

## Towards a more and more extensive automated assistance to air traffic controllers

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Personal Contribution

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# Abstract

At the present stage of air traffic automation, computers are presenting to controllers flight plans and Radar data in the most appropriate form ; they do not proceed to *conflicts resolution* and their participation to *conflict detection* remains of a marginal interest.

The present study aims at analysing the interrelations between *meteorological* causes and *human causes* which up to now were limiting automation, and at making better known how a new control process could permit to surround them.

- *Meteorology* intervenes due to the fact that flights are conducted in *air speed* which confers to a/c conflicts a random and evolutionary nature; moreover the statistical layout of wind forecast errors is not strictly Gaussian and could be affected by large "*distribution tails*".
- *Human sour*ce results namely from the fuzziness of controllers forecast as compared to the accuracy of computers' one taking wind into account. It results that a conflict resolution proposed by a computer has a poor probability to coincide with the solution that controllers had elaborated and intended to adopt in the framework of their *evolutionary strategy taking the whole traffic in consideration*. In practice, there is an incommunicability in real time between controllers and computers which are provided with different data and computation means.

It is shown that all these problems can be overcome by a *new automatic control process* that SESAR[2] has retained in its plan under the acronym TC-SA (Trajectory Control by minor Speed Adjustments).

It can be shown that minor (longitudinal, lateral and vertical) speed variations staying within the limits of the present flight plan tolerances permit to confer :

- to the ATTC computer a ***privative zone of action***
- to each aircraft a ***privative zone for adjustment*** of its flight parameters,

so that it can be proceed case by case with this new mode of automatic conflicts resolution *without any prior coordination* with controllers since it has no perceivable effect both on the *controllers' on-going work* and on the *rest of the traffic*.

This process opens a potential of increasing separations between a/c which is sufficient to *solve more than 80% of conflicts*, even in the presence of large "distributions tails" of wind forecast errors.

Already available wind forecast are sufficient to this effect.

ERASMUS project, "*a friendly way for breaking the capacity barrier*" published by the Institute of Air Transportation (J.Villiers, June 2004) has presented and justify this process and proposed specific devices for providing a more and more extensive automated assistance to controllers.

Up to now there is no competitive proposal for reaching such achievements.

Developments and experimentations conducted by ERASMUS Consortium have confirmed the feasibility and efficiency of this project which will be progressively deployed in the framework of SESAR Joint Undertaking which has considered it as one of its first priorities.

[2] Single European Sky Atm Research : a research program equivalent to Nextgen in the USA

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# FOREWORD

At the present stage of air traffic automation, computers are presenting to controllers flight plans and Radar data in the most appropriate form; they do not proceed to *conflicts resolution* and their participation to *conflict detection* remains of a marginal interest.

The present contribution aims at analysing the *interlaced meteorological* and *human* causes which prevent a more extensive assistance to air traffic controllers and at studying the means to surround them.

## 1-Conflict/ Potential Conflict

Two aircraft are said to be in *potential conflict* as long as one cannot be *certain* that their separation will be safely respected at their trajectories crossing point.

Because of decisions consequently to be taken, it is necessary to envisage this *possibility* with sufficient notice (T).

Aircraft flights are carried out by *air speed* control while their separation is defined by *reference to the ground*.

It follows that times of arrival forecast at the crossing point is affected by several error sources : air speeds and *average wind gradient* on the concerned trajectories parts.

The larger the anticipation of T is, the higher the margins must be taken. These latter must result from a compromise between:

- the *rate of undetected conflicts*
- the rate *of falsely detected conflicts*.

Conflicts have therefore to be qualified as “certain”, “probable”, “not very likely” or as “definitely non-conflicting”.

Whatever is this compromise, it is appropriate to carry out *monitoring* of the *situation evolution*.

As the moment of the conflict approaches, forecasting can be refined so that qualification of conflicts are both of *random* and *evolutionary* nature.

It will be noted that the system is protected by an automatic urgent avoidance device (TCAS) which, in the last resort, protects safety by acting in such a short ~~timescale~~ time scale that wind influence is negligible.

## 2- Fuzziness of the controllers' vision

To know the future position of an aircraft, controllers can only rely on flight plans, which describe projected aircraft trajectories, and Radar which gives ~~the a/c~~ the a/c accurate *current position* and *a very approximate indication of* ~~*their*~~ *its ground speed*.

Controllers forecast do not result from a true mental calculation but from an intuitive evaluation to which ~~the~~ they are brought by *long experience*.

The fuzziness of this evaluation is increased by uncertainties resulting from not taking wind in consideration.

In traditional air traffic control practice, controllers:

- take large margins, such that situations that they regard as conflicts are numerous,
- are led to solve in an anticipatory manner potential conflicts to avoid ~~:~~
  being later overwhelmed by several conflicts ~~simultaneously becoming urgent to be solved,~~ to solve simultaneously
- [~~- monitoring of a too numerous number of potential conflicts~~ ?]

It results that, in 3 out of 4 cases, potential conflicts are resolved which would not have resulted in a real conflict if controllers had not intervened.

To resolve conflicts, controllers do not have any other solution than to carry out large trajectory alterations: change of level or Radar avoidance. Preparation and control of these manoeuvres require time and attention.

## 3- Conflicts and ATC computer

A computer having access to on board available data and to the best sources of wind forecast can calculate future positions with a precision much higher than those estimated by controllers.

There are several data sources available concerning real time wind forecast, which at the present stage of air traffic control automation~~, are~~ are still only made very little use of.

MET services provide wind forecast, starting from models adjusted by actual wind knowledge (in particular by collection of wind measurements transmitted in real time by commercial aircraft[3]).

These forecasts are conducted with:

- a mesh "m" (3 km in the most modern US network)
- a renewal rate $\tau$ (one hour in the network above).

To estimate the future positions of a given aircraft, this model can be readjusted again and refined by the knowledge of :

- *current actual winds* as known *here and now* on board aircraft i.e. by direct access to data which are currently transmitted in real time by Airlines only to ~~meteorology~~ meteorological services,
- wind encountered by aircraft having preceded them on the same trajectories.

Very great progresses are thus possible in effective use of available real time wind forecast and consequently in forecasting future a/c positions.

How to use this invaluable further information?

Note- Future "business flight plans", basis of SESAR and NextGen programs, will not provide sufficient accuracy for being solely used for conflicts forecasting without taking into account local and real time wind forecast.

## 4- Controllers and ATC computer

### 4.1. Conflicts detection

How to allow controllers to benefit from the more accurate estimates carried out by the ATC computer?

This problem which appears simple is in fact of *particular complexity* because of incommunicability in real time between

- a controller under intense cognitive pressure in the face of a fuzzy universe in constant evolution, and
- a computer whose forecasts are themselves evolutionary and affected by a residual uncertainty.

Any all new information, and "a fortiori" any dialogue with the computer, introduces an intrusion penalising the cognitive controllers' processes of analysing, memorizing and surveying the interactions between all aircraft in charge.

[3] Airlines are remunerated for providing these data to Met Services

Many modern en route control centres are equipped with a list of conflicts, called MTCD, as perceived by the ATC computer. Experience has shown that effective use of such a list by controllers has only marginal interest because of the randomness and constant evolution of conflict probabilities.

### 4.2. Conflicts resolution

Based on more precise forecasts than those of controllers, a computer can elaborate proposals for *conflicts* resolution (choice of the mode of resolution, moment of its execution).

Many effective programs have been elaborated to this end. But what to do with them?

One could imagine that a computer is programmed according to "Artificial Intelligence" in order to behave like a real controller and thus be able to issue clearances proposals entering into the framework of the controllers' evolutionary strategy. This is still currently an unrealistic Utopia.

It follows that proposals carried out by computers based on data which are different from those available to controllers would have very little probability to fit the *evolutionary strategy* worked out by controllers; experience has shown that this would contribute more to distract them from their cognitive processes in progress rather than to bring them useful assistance.

### 4.3. What can be done ?

The fact that all ingredients have been available for a long time without finding an effective application, shows well that this is a highly complex problem : to the very great "complication" of the moving relationship of "n" aircraft between them is added the "complexity" of the human brain which remains in the ~~centre~~ center of the system!

There are however two types of action which computers can automatically undertake for the benefit of controllers without any disturbance of the course of their cognitive processes:

- "assurance of non-conflict"
- "subliminal control"

## 5- "Non-conflict" assurance

An ATC computer can detect among the doubtful cases as perceived by controllers, those which it can ensure that a given pair of a aircraft will indeed be separated at their intersection point by a distance higher than the safety separation (5 N.M.).

This apparently simple action poses in its turn a *very difficult problem* due to the fact that, even if uncertainties in wind estimation are taken into account with precaution (for example 4 $\sigma$), nothing makes it possible to neglect "*distribution tails*" in particular in the case of a not particularly stable atmosphere.

The "non conflict" assurance must have a probability of failure at the most equal to the probability commonly admitted for the setting off of TCAS alarm s ($10^{-4}$ or less ).

One will show below how it is possible to face this problem.

## 6- "Subliminal control"

### 6.1 Speed regulation

Since it is impossible to make computer and controllers *cooperate in real time* with significant benefit to the latter, the idea has come that, due the fuzzy ~~controllers~~ controller's vision, a *privative field of action* can be opened to computers.

A *minor adjustment of aircraft longitudinal speeds* staying within the limits of this fuzziness and initiated sufficiently in advance can make it possible to remove many conflicts while being *undetectable by controllers*.

Such an action is of *a subliminal* nature with respect to controllers and is not by any means likely to influence the course of their cognitive activity, to disturb their strategy or to interfere with the remainder of traffic as seen by controllers: it can thus be carried out *without previous coordination with controllers*.

In addition, this mode of avoidance has the advantage on any other mode of conflict resolution insofar as each conflict can be treated separately *without creating any interference with the whole of the traffic* (which has the further advantage to highly simplify conflicts resolution software as compared to classical ones[4]).

This original control *process* has been retained by SESAR under the acronym TC-SA (Trajectory control by minor Speed Adjustments).

It also constituted the heart of ERASMUS[5] project and is the object of one of the

4 Except the case of an aircraft involved in more than one conflict

5 "ERASMUS, a convivial way to break the capacity capacity barrier". J.Villiers in the Institute of Air

fundamental claims of a French patent in course of extension to Europe and USA.

### 6.2. Relation with controllers

To benefit from this process, one can first consider a version which could be named *minimalist* or passive, which consists in engaging subliminal control and leaving to controllers the care to appreciate, as they currently do, separations between aircraft which result of this action.

Controllers will thus directly note that the traffic is miraculously fluid.

This version has the considerable advantage of allowing a first operational stage for subliminal control implementation without requiring complementary devices on controllers desks. Moreover, Control Centers equipped with MTCD and thus with calculation of a/c separations are able to carry out subliminal control from the start.

In the following stages, ATC computers will take *responsibility* of guaranteeing to controllers the pairs of aircraft which separations are indeed safely assured and let it know to them.

Then is ~~raised,~~ raised the problem of wind gradient forecast *distribution tails* already analysed above.

This problem can be solved thanks to implementation of lateral speed control.

## 7- Lateral speed control

~~Just as potentialities~~Potentialities of minor longitudinal speed variations were unrecognised for a long time~~, it~~ . It is ~~much~~ still more the case for lateral control.

Without that being obvious at first sight, action on lateral separation is particularly interesting for several reasons:

- the data source consists of navigation means (in particular GPS) having a terrestrial reference, therefore *indifferent to wind*
- lateral guidance accuracy from now on can be of *an extreme precision* (0.02n.m.)
- *potentialities in terms of increasing separations* are much larger than those of longitudinal control.

On this last point, one notes with some surprise that displacement of each two aircraft on the port or starboard side of an airway (+/- 5 N.M wide) increases their separation since convergence point is then moved so that the distance to reach is increased for one of the aircraft and ~~decrease~~ decreased for the other one.

It results that the volume delimited by present Flight Plans can constitute for each aircraft a *privative domain* in which it can freely move without creating any interference:

- with the rest of the traffic,
- with on-going controllers' cognitive processes

It will be shown here under that such minor speed variations are sufficient for solving most of the conflicts.

This innovative process could be put in practice in two different ways :

- on a complementary basis to *clip "distribution tails*"
- as a basic tool for complementing longitudinal control in the form of "*composite control*".

Initiated 15 minutes in advance lateral control requires only a trajectory variation of less than 3 degrees for each aircraft with a ~~quasi-nul~~ quasi-null effect on overall flown distances ~~(each increase of one of flight trajectory is compensated by the decrease of the other one).~~

It will be noted that lateral control is not strictly subliminal: the controllers can become aware of it when an aircraft slightly moves away from its nominal trajectory, but they will be informed that this has not to be taken in consideration.

## 8- Potentialities of composite control

It is then possible to assess the potential offered by *weak variations of aircraft flight parameters* :

- the number of actual en route conflicts at a given crossing point is ~~naturally~~ genuinely very weak; in effect, if aircraft were regularly spaced, the capacity would be in the order of 180 aircraft per hour (speed of the aircraft 450kts, separation 5 N.M.)[6]
- longitudinal subliminal control makes it possible to increase natural a/c separations by 6 N.M., with, however a degree of uncertainty concerning wind gradients forecast (this capacity is limited in particularly unstable atmosphere)
- lateral control offers an additional possibility to increase natural separations independently of any wind influence by a supplementary number of miles all the

[6] Which shows that the sky en route is very far from being saturated and that the limits of the cognitive and mnemonic capacities of the human brain fix those of the capacity of the system!

more important as the angle of crossing trajectories are greater with a minimum of some 3N.M[7]. up to 7 N.M. (right angle) and more for obtuse angles.

A large *potential to increase natural separations* is thus opened which makes it possible to safely *guarantee* safety *even in the event of particularly unstable winds*.

The ATC computer has thus a large field for choosing the best solutions (taking into account the angle of trajectories, relative a/c speeds, wind forecast and the estimated degree of instability of winds) for solving conflicts by minor speed adjustment or to renounce solving some of the conflicts if it cannot find a sufficiently safe solution.

It must be recalled that

- the objective of this process is not to solve every conflict (as required in an automated system) but to reduce as much as feasible the number of residual ones,
- "non conflict" insurance for potential conflicts as seen by controllers will by itself highly reduce their task (surveillance + non necessary potential conflict resolutions),
- automated processes added to controllers vigilance will increase safety.

It consequently becomes possible to greatly increase the service rendered to controllers, beyond the minimalist solution above considered.

## 9- ERASMUS implementation

### 9.1. Controller's side

ERASMUS project includes many devices for assisting controllers, beyond the minimalist solution discussed above, which could be implemented gradually :

- a display of guaranteed "non-conflicts" (natural or under speed control)
- an automatic monitoring of the evolution of computed separations
- an innovative display called "Dynamic Separations Display": each *pair of aircraft* is represented by a point : X-coordinates representing the time before the moment of conflict and Y coordinates the computed separation. This tool of *vigilance* could bring an assistance to controllers as important as was the introduction of Radar compared to procedural control.
- transfer of responsibility to aircraft (ASAS) for speed control management.

7 In compensation, correlation of winds is greater on little angle trajectories crossings.

Note- Speed control process can be initiated on board of aircraft since it has no effect on the rest of the traffic and on controller's task. This opens the way to a future decentralized system that any other conflict resolution process would render impossible.

### 9.2. Aircraft side

Several processes for conflict forecast and regulation of longitudinal or vertical speeds can be considered:

- separations are calculated by ATC ground computers after taking into account wind gradients forecast and then clearing a new aircraft *air speed* ,
- idem but clearing an *hour of arrival* at the trajectories intersection point (RTA), the aircraft flight management system (FMS) ensuring then the necessary control.

The first solution, which one can describe as *minimalist*, has the advantage of not requiring FMS modifications to make them ready to control an RTA and of making thus possible to proceed rapidly to an operational service.

### 9.3. An easy transition

The association of *minimalist solutions* both aboard aircraft (air speed control) and for controllers (no new device added on their desk) makes it possible to proceed, as of now, to a first phase of implementation of ERASMUS process.

Controllers will thus be able to familiarize themselves with this innovation without change ~~of~~ in their working methods and to gradually participate in the development of the complementary means offered for a full implementation of ERASMUS potential; on their side, convinced that a new way is finally open, Airlines will be ~~incentivised~~ induced to equip gradually with FMS ready to include an RTA control.

The transition towards a more and more automated assistance to controllers will be thus progressive and will justify, one hopes, the acronym ERASMUS (towards "En Route Atc Software Management Ultimate System")

## 10 - Feasibility, effectiveness of ERASMUS

After the very favourable reception, even enthusiastic from controllers, of ERASMUS project published by the Institute of Air Transportation, an international entity called "ERASMUS Consortium" was quickly constituted in 2006 to study the feasibility and efficiency of this project.

This consortium :

- has demonstrated that +/- 3% longitudinal speed variations are undetectable by controllers
- has successfully developed a conflict resolution software by longitudinal speed control
- has shown that more than 80% of the conflicts can thus be solved (a residual conflict on each sector every 10 minutes !)
- has experimented in operational environment (Aix en Provence en route ATCC) solving conflict by longitudinal speed control. ~~Which~~ This experiment has been highly welcomed by controllers
- has shown that no specific controllers training was necessary but only a short familiarization
- has left pilots in the loop letting themselves modifying their air speed

ERASMUS Consortium has thus reached its *primary goal* of demonstrating the feasibility and the potential efficiency of ERASMUS process.

During the assigned time, it has not proceeded with all possible declination of all these process potentialities as above analysed. It has essentially concentrated its effort on :

- longitudinal speed control
- RTA control which requires FMS improvements
- *minimalist* solution for controllers (no addition to controllers' desk).

Replaced in the frame of the present study, ERASMUS Consortium findings produced the proof of the originality, the feasibility and the efficiency of ERASMUS project and of its ability to be introduced progressively without requiring special controllers new training, the first phase beginning shortly

## 11- SESAR and ERASMUS

ERASMUS project is the conclusion of a personal study of its author. Its approach is "*bottom up*", i.e. based as shown above, on a thorough analysis of the reasons for the blocking of any significant evolution of en route control and on the research of means for circumventing encountered difficulties.

On its side, the European Commission was worried, in its turn, by the lack of any innovative project allowing ~~facing~~ to face forecast traffic growth.

"SESAR Consortium", which was consequently inaugurated, was attached to this last task and decided to proceed on a "*top down*" approach. i.e. starting by laying down objectives in terms of capacity and safety, then proposing a way to achieve them.

Each of the two projects considered that controllers will remain the ~~centre~~ center of the system and will continue to assume full responsibility for safety.

Proceeding with two opposite approaches, these two projects were therefore *complementary*.

SESAR was most naturally interested in ERASMUS project, whose feasibility and effectiveness had previously been demonstrated within the framework of "ERASMUS Consortium".

So, SESAR report retained ERASMUS *process* in its own project and, as said above, named it TC-SA according to its functional contents (Trajectory Control by minor Speed Adjustments), and defined its substance (under reference CM0403) in the same terms as those of ERASMUS project:

> *"Conflict dilution by upstream action on speeds to dissolve conflicts by minor speed adjustments of flight parameters (vertical/horizontal, rate of climb/descent), not directly perceivable by the controller and not conflicting with their own action and responsibility".*
> *"This air-ground co-operative and human centred ATC automation allows transition towards further automation while respecting the operator cognitive process"*

In its final report SESAR Consortium did not explain this choice and did not describe its expected results. Moreover it did not consider the effects of wind forecast errors and did not propose the *devices* necessary to implement this *process*.

In addition, SESAR Consortium (as ~~ERASMUS)~~ ERASMUS Consortium) did not perceive lateral control potentialities.

SESAR report left then to SESAR Joint Undertaking (SJU) to perform the necessary studies in these fields in complement to ERASMUS Consortium findings.

TC-SA is a part of IP1 package which SESAR considered so important that " *any delay or failure to implement IP1 will impact the rest of the ATM deployment sequence*".

D4 part of SESAR report envisages to deploy longitudinal control by minor speed variations in the very near future (2012).

## 12-CONCLUSIONS

## 12.1 Meteorology

- Mean wind gradient forecast in the next 15 minutes is essential for accurate a/c separation computations
- Necessary data is already available (current Met forecast + real time measurements on board of the a/c) and can be complemented in Air Traffic Centres by the knowledge of winds encountered by preceding a/c on the same trajectories
- These available data are sufficient … if properly exploited
- Statistical wind forecast errors distribution is not strictly Gaussian, in particular under atmosphere instability : *distribution tails* are inevitable,
- The required degree of safety ~~imposed~~ impose to take into account these distribution tails in an ~~appropriated~~ appropriate manner
- It would be of great interest to better know the shape of the statistical distribution of mean wind gradients errors during the 15 minutes to come and namely the σ of the distribution core and the distribution tails as a result of real time evaluation of the degree of atmospheric instability.

## ~~1.2.~~ 12.2 Air Traffic Control

For many years, little progress has been made in using a/c separations forecast for developing improved automated assistance to controllers. Two interlaced main causes of this blockage are :

- a *meteorological* cause : these forecast are affected by "distribution tails"
- a *human cause* : classical conflicts resolution proposals (change of flight level, radar avoidance) established by computers ~~has~~ have an impact on the overall traffic (possible induced conflicts) and ~~has~~ have a weak probability to be compatible with controllers' intents and strategy,

It is why SESAR has retained an *innovative control process* which it called TC-SA (Trajectory Control by minor Speed Adjustments) ; this process :

- confers to ground computers a *privative domain of action* for automatically solving conflicts without interference with the rest of the traffic and without prior coordination with controllers,
- confers to each aircraft a *private volume of evolution* of its flight parameters ~~delimitated~~ delimited by the tolerances of current flight plans,

- is able to safely increase a/c separations even in presence of large *distribution tails* affecting mean wind gradients forecast,
- can ~~be first start to~~ be implemented in the very near future in its *minimalist* form,
- will progressively be able to automatically solve more than 80% of the conflicts (i.e. one conflict left every ten minutes on a sector).

ERASMUS is the first project having proposed this process and having described the devices for a progressive implementation of a more and more extensive assistance to controllers letting them the ~~master~~ masters of the situation, situation all the more easy to dominate in that:

- the number of residual conflicts will progressively become extremely weak and
- controllers will be provided with appropriated devices to be kept informed and to ensure a constant vigilance on the evolution of the situation.

This project fits all SESAR requirements.

There is no known competing project able to reach such objectives

Mr. Peter Sorensen, Director of IATA Europe will be able to see thus carried out his wish[8] to profit from a "quick return" from SESAR, after which the progressive completion of the project will be able to undoubtedly exceed his own hopes.

. The circumstances of this Conference are ~~felling particularly well~~ quite appropriate to wish… *favourable winds* for the SESAR Joint Undertaking !

[8] Bulletin of SESAR JU of December 2009