Probabilistic versus Geometric Conflict Probing

by

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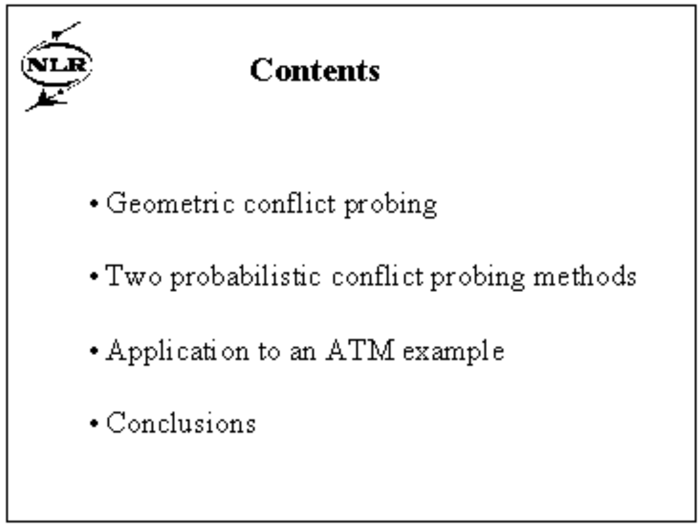
ABSTRACT

In this paper we consider three methods concerning conflict probing. The first method is the classical geometric approach, the second method is the probabilistic approach described by Paielli & Erzberger [1] and the third method is the NLR probabilistic approach [2]. In the classical geometric approach, separations between a pair of aircraft are compared with minimum separation criteria. The probabilistic method described by Paielli & Erzberger estimates the probability of two aircraft violating minimum geometric separations and the NLR probabilistic method estimates the probability of a collision between two aircraft. Both probabilistic approaches use predicted trajectories together with their levels of uncertainty, where the classical geometric method falls short in taking the level of uncertainty into account. Through simulations the three methods are compared with each other for some typical types of encounters and geometrics.

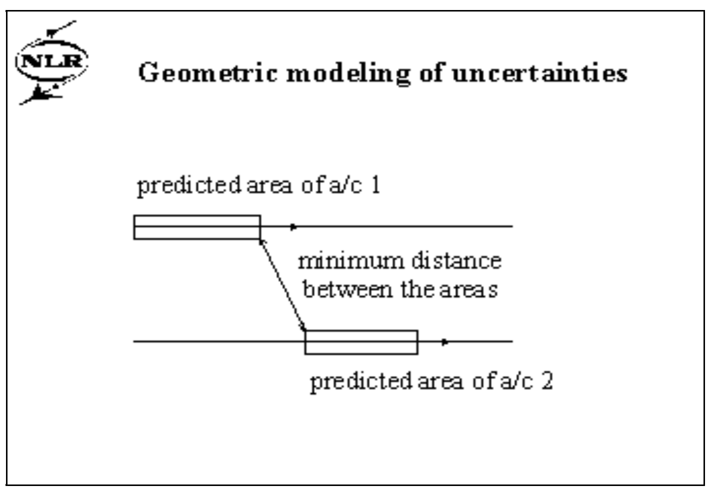
Given the air traffic density of today, some geometric conflict probing approaches exist, which have proven to perform well. For example the precursor of MTCD (Vink, de Jong & Beers, 1997) is already performing well for Schiphol. However, air traffic is getting more dense every year, so we need conflict probing approaches which accommodate increasing traffic density, while maintaining safety. Examples where geometrical approaches fall short are :

1. aircraft that level off need more move space than level flying aircraft
2. safely reducing lateral/longitudinal separations

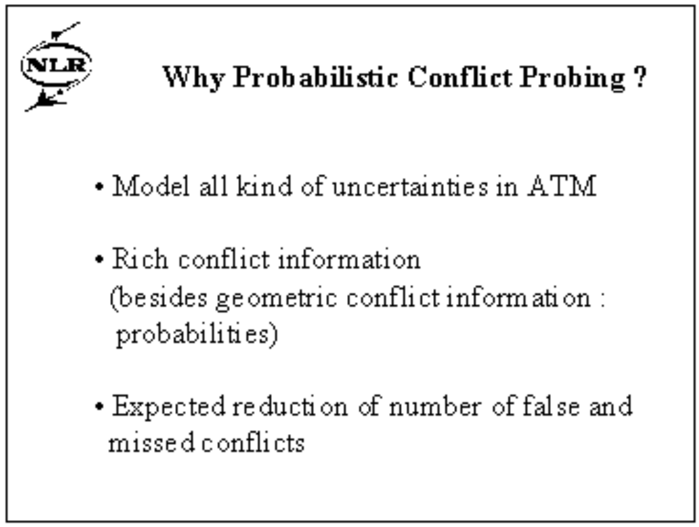
Goal of this presentation is to review two probabilistic conflict probing approaches and to compare them with a geometric approach. The two probabilistic conflict probing approaches considered, are from Paielli & Erzberger and from NLR respectively.



Geometric conflict probing will be considered first. The advantages of using probabilistic conflict probing approaches will be highlighted. Then two probabilistic conflict probing approaches will be presented. One of Paielli & Erzberger and one of NLR. It will be explained how the approaches apply to conflict probing and which restrictions they have. Both probabilistic approaches as well as a geometric approach will be compared through numerical application to an example. Following this, some concluding remarks will be given and the specific ATM applications at NLR will be mentioned.



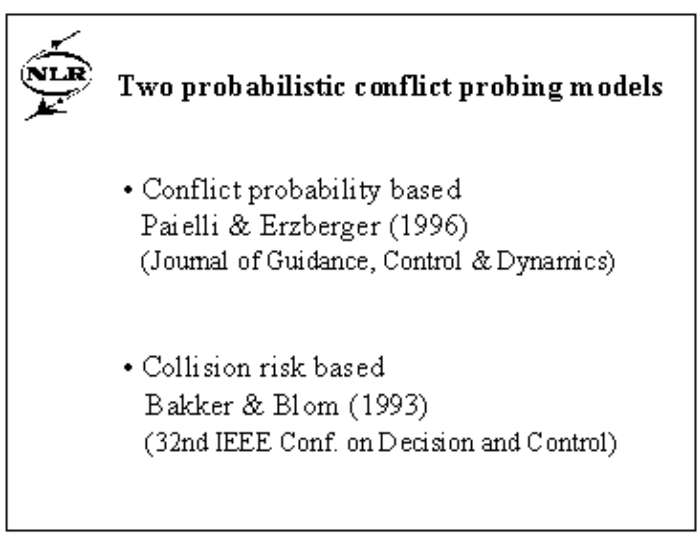
For geometric conflict probing it is necessary to predict the expected aircraft positions in time and to translate uncertainties into areas around these predicted aircraft positions. The size of these areas may vary with time. Two aircraft are said to be in "geometric" conflict when the distance between the areas of those aircraft becomes smaller than the minimum allowed distance between them. The advantage of the geometric approach is its proven applicability (ACOD/MTCD). Based on the distances between the areas, which may vary with time, information as the duration (e.g. time interval in which two aircraft are in "geometric" conflict) and minimum distance between the areas can be generated.



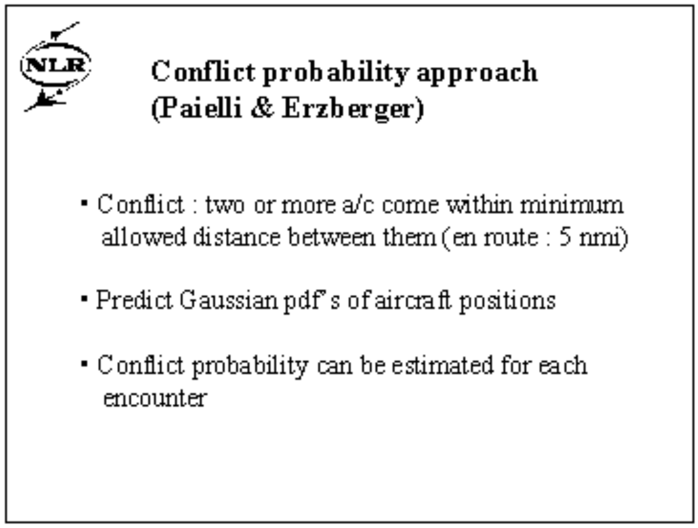
The main limitation of the geometric approach is its tendency to be overly conservative in handling uncertainties in aircraft behaviour. The idea is that this limitation can be overcome by a probabilistic approach.

For example one can model all kind of uncertainties in ATM, such as :

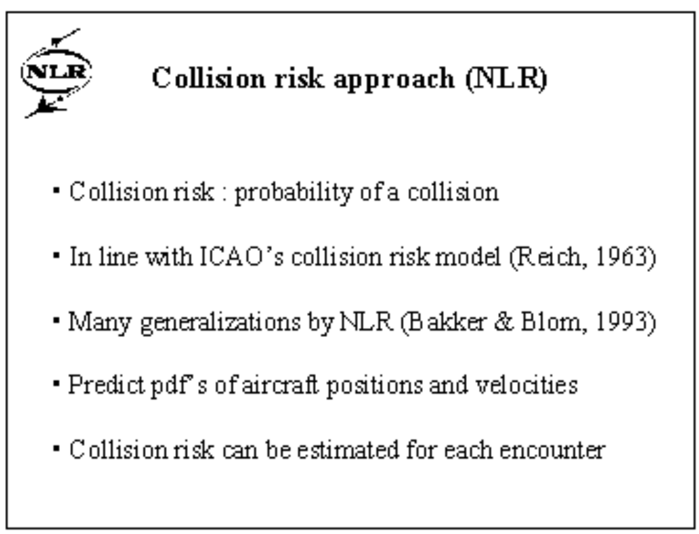
− wind modeling and prediction errors,
− tracking, navigation and control errors,
− human errors
− system errors Furthermore, using probabilistic conflict probing, more information about conflicts or encounters can be generated (e.g. probabilities, collision risks). This is good, because decisions which are based on more information can only improve. Based on the improved quality of the decision whether there is a conflict of not, one might expect the number of false and missed conflicts to reduce. So there is a clear reason to study probabilistic approaches to conflict probing.



The two probabilistic conflict probing approaches to be considered are from Paielli & Erzberger (1996) and from Bakker & Blom (1993). The first approach is based on conflict probabilities. The second approach is based on collision risk. These two methods will be compared with each other and with the geometric approach described.

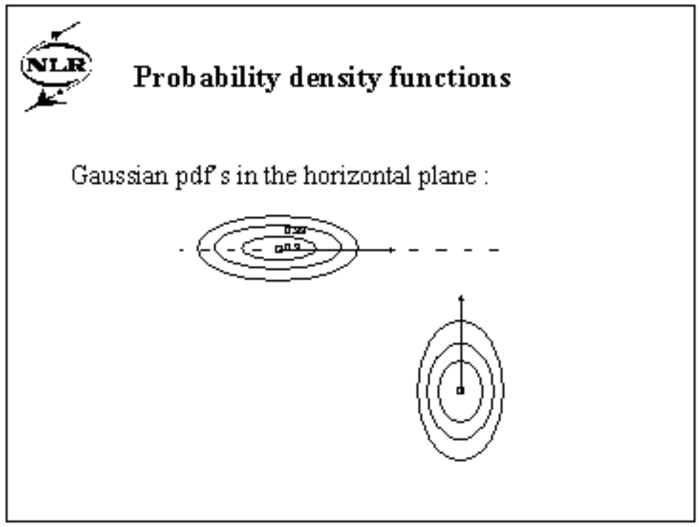


The first probabilistic conflict probing model following Paielli & Erzberger aims to predict the probability that two aircraft are in conflict with each other; i.e. the probability that they come within the minimum allowed distance between them. In order to calculate this conflict probability, first the aircraft postions are modeled by probability density functions. Then, using the direction of the relative velocity, some transformations and the pdf's, the conflict probability can be estimated by evaluating an analytical expression. Note that the conflict probability is estimated for the whole encounter of an aircraft pair.

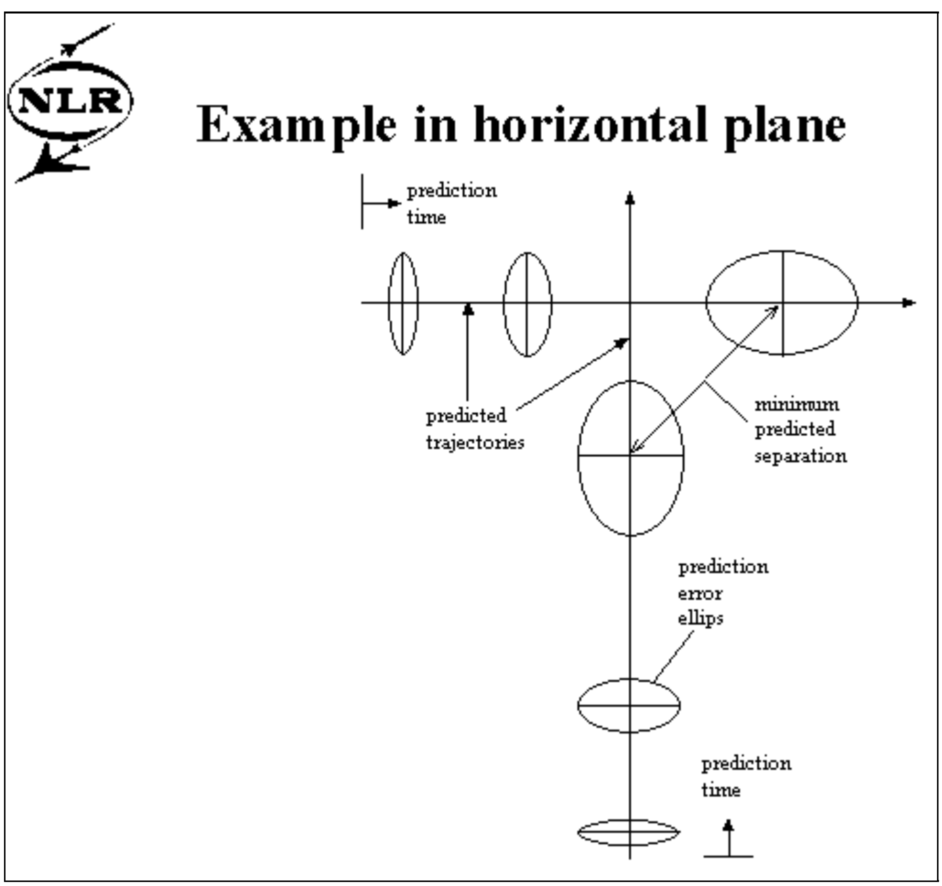


The conflict probing model at NLR is based on a generalized version of ICAO's collision risk (probability) approach. The generalizations were required since the Reich model had been derived under rather restrictive assumptions.
The generalised Reich model needs a characterization of the joint probability density function of position and velocity as input. As output of the model, the collision risk for an aircraft pair is generated.
Collision risk is a measure for the probability that two aircraft collide. For a probabilistic conflict probing approach, first joint pdf's of aircraft positions and velocities are predicted, then the collision risk for each

encounter is calculated using the generalised Reich model.



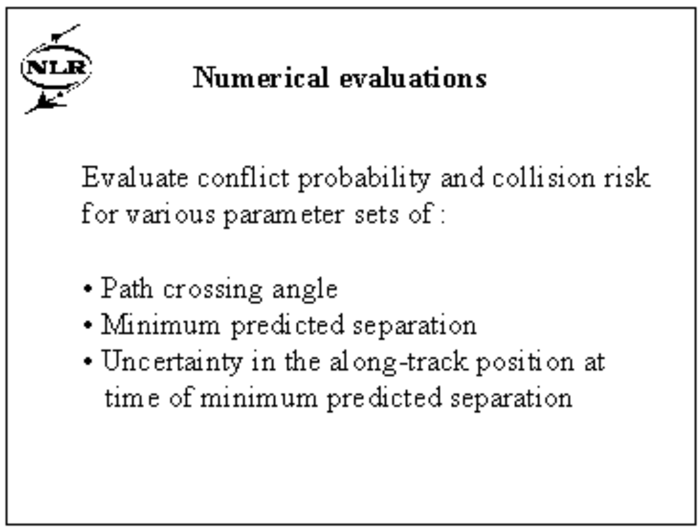
Since probability density functions play a crucial role in probabilistic conflict probing, we look at an example. In the figure, two predicted aircraft positions are drawn in the horizontal plane. They are drawn in the horizontal plane only for reasons of simplicity. The squares represent the expected aircraft position and the ellipses represent position probabilities. The probability that the aircraft position will be within the inner ellips is (in this case) 0.9. The probability that the aircraft position will be within the next ellips is (in this case) 0.99, etc. In the verical plane, the idea is the same. Also the joint probability density function of position and velocity is just an extension of the same idea.



Now the three approaches will be compared by applying them to an example described by Paielli & Erzberger (1996).

In the example, the pdf's of the positions of the a/c at a certain time are characterised by the expected positions and the prediction uncertainties in the across−track and the along−track direction. The expected positions of both a/c in time are predicted. The expected groundspeed is predicted to be the same for both a/c. Also the predicted cross−track uncertainty in position is the same for both a/c. The predicted along−track uncertainty in position is for both a/c linearly increasing in time The paths which can be formed by connecting the predicted aircraft positions, are straight lines in the horizontal plane which cross eachother. They are characterised by a path crossing angle, a minimum predicted separation and the starting points of the two a/c.

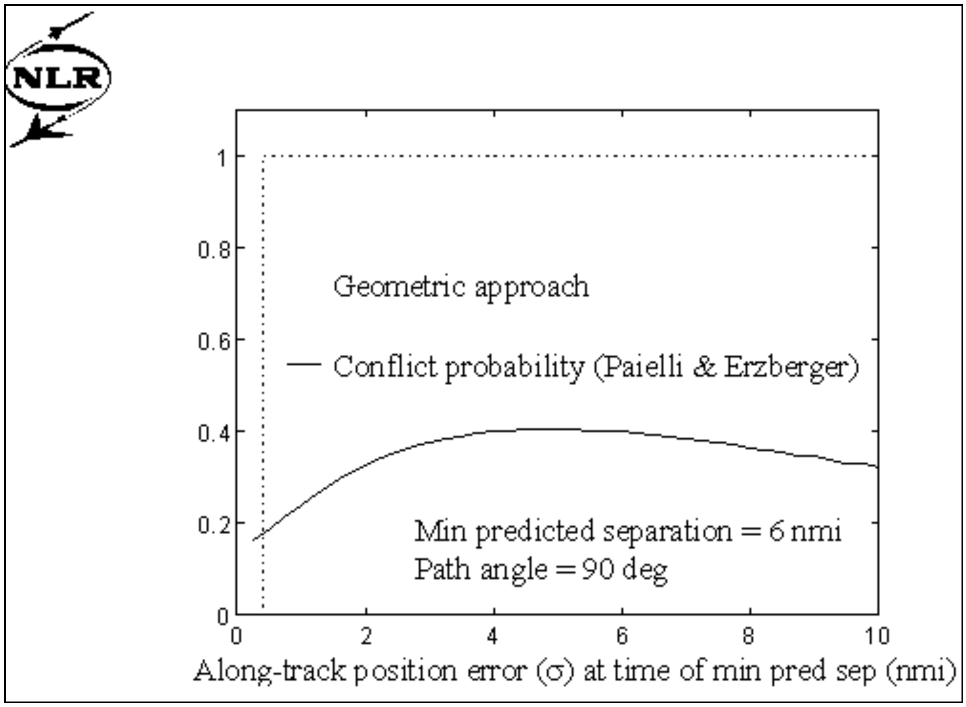
For the above described predicted pdf's of aircraft positions, we evaluate the predicted minimum distance between the assumed areas for the aircraft (geometric approach), the conflict probability during the encounter (Paielli & Erzbergers approach) and the collision risk during the encounter (NLR approach).

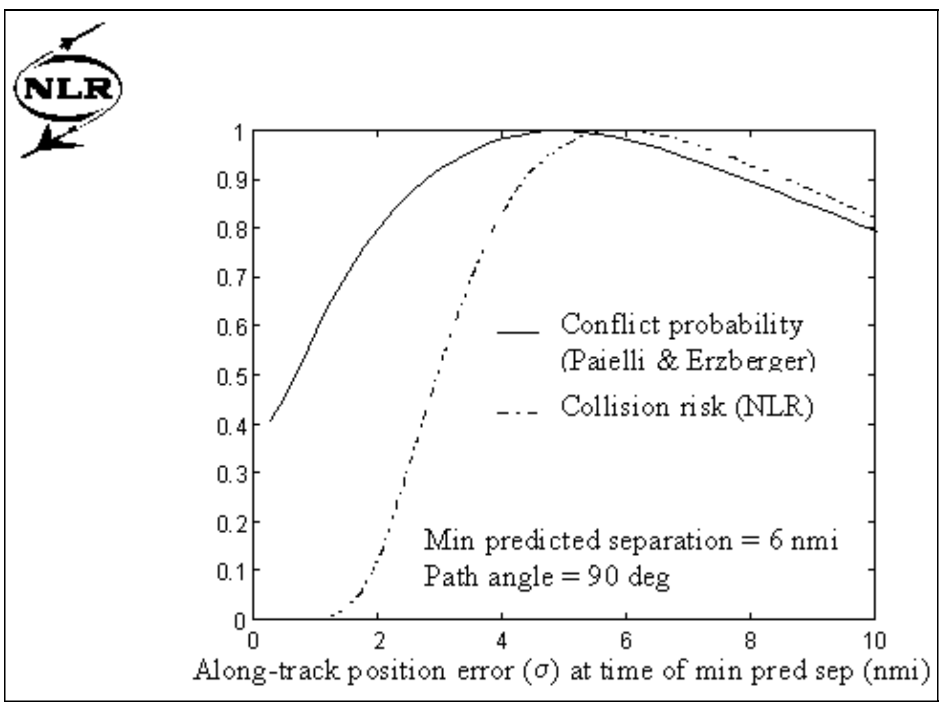


Note that the NLR model needs extra input parameters; the cross−track RMS error of the velocity, the along−track RMS error of the velocity and the size of the boxes which represent the aircraft. For these parameters, some reasonable values where used (RMS errors of the velocity is taken 5 m/s in all directions (approx. 2 % of the groundspeed) and the size of a box is taken 50 x 50 m).

In the geometric method, the size of the area around an aircraft position is defined to be a box whose length is equal to the along−track RMS error and whose width is equal to the across−track RMS error. The length of the box lays in the expected velocity direction.

The evaluation of the minimum predicted distances between the assumed areas of aircraft, the conflict probability following Paielli & Erzberger and the collision risk following Bakker & Blom can be done for various pairs of minimum predicted separation, path crossing angles and starting positions of both a/c. Varying the starting position of both a/c will result in different uncertainties of the along−track position of both a/c at the time in which they reach their minimum predicted separation.

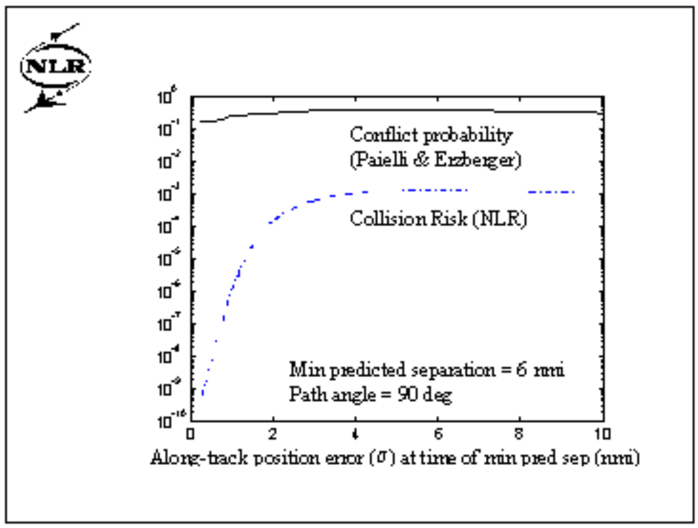




Example : Path angle is 90 degrees, minimum predicted separation is 6 nmi and the along−track rms position error at time of minimum predicted separation is varied (by changing the starting positions of both a/c) from 0.25 to 10 nmi.

In the above figure all curves are normalized (in order to fit within a linear scale figure). In the geometric approach, the minimum predicted distances between the areas of the aircraft are calculated. If a "geometric" conflict is detected, the probability of a conflict is taken 1, otherwise it is taken 0. The geometric approach was used with a one−sigma value for the assumed area of aircraft; the length and width of the area is equal to the along−track resp across−track RMS error. In the first probabilistic approach, conflict probabilities are calculated following Paielli & Erzberger (and normalized in above figure). In the second probabilistic approach, collision risk is calculated following Bakker & Blom (and normalized in above figure).

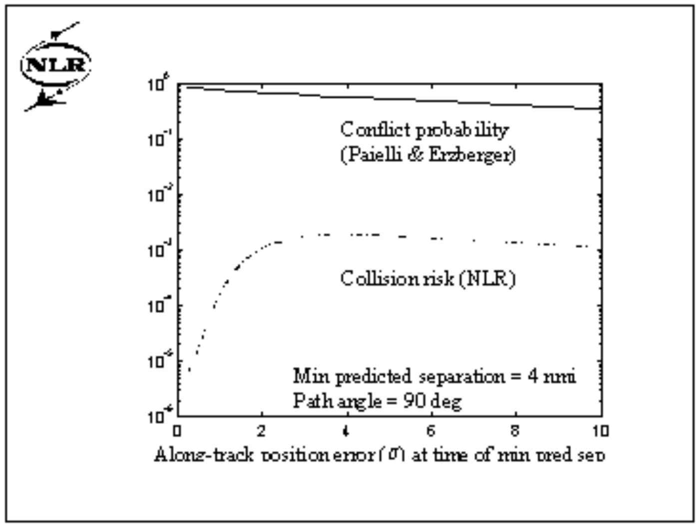
Conclusions : Even with an uncertainty area of one−sigma only (70 % containment), the geometric approach does not show flexibility in its usage. It can be seen from the figure that the probabilistic approaches show more flexibility to changes in along−track rms position error. So let us next zoom more into both probabilistic approaches.



In order to show the difference between the two probabilistic approaches, we use a log scale to plot the results of the example.

It can be seen that for large uncertainties in the along−track position the conflict probability (Paielli & Erzberger) and the collision risk (Bakker & Blom) are approximately equal sensitive to changes in the uncertainty (this can also be seen in the figure on the previous slide). Thus for tools which concentrate on situations in which large uncertainties are common, both methods can be used. A good example is a flow management tool.

However, if the uncertainties in along−track position become smaller, collision risk is much more sensitive to changes in along−track uncertainty than conflict probability. Suppose the uncertainty in the along−track position decreases. Collision risk values decrease very fast to very small values, where conflict probability values decrease very slow. So for small uncertainties, it is easier to separate safe situations from unsafe situations by using collision risk than conflict probability. An environment where small uncertainties are common, is 4D ATM. So in a 4D ATM environment, collision risk based conflict probing is preferable over conflict probability based conflict probing.

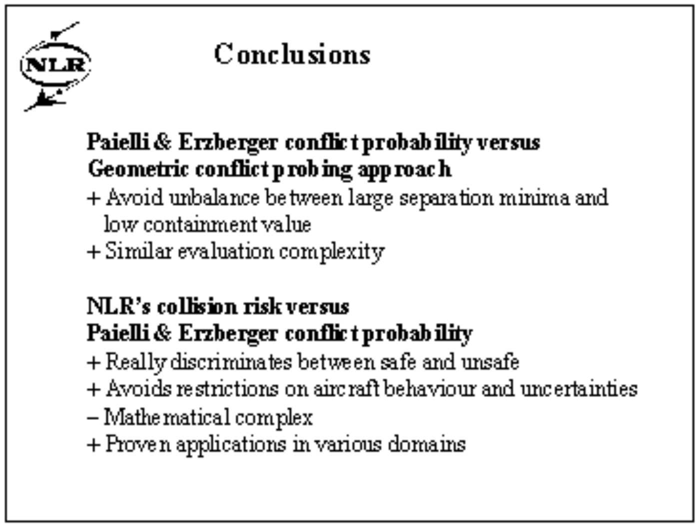


Example : Path angle is 90 degrees, minimum predicted separation is 4 nmi and the along−track rms position error at time of minimum predicted separation is varied (by changing the starting positions of both a/c) from 0.25 to 10 nmi.

In the above figure both curves are plotted using a log scale. Conflict probabilities are calculated following Paielli & Erzberger and collision risk is calculated following Bakker & Blom.

Conclusion : Paielli & Erzberger already explained that conflict probabilities for minimum predicted separations below 5 nmi have a different shape than for minimum predicted separations above 5 nmi. If the minimum predicted separation is larger than 5 nmi, the shape of the conflict probabilities is as plotted in the figure on the previous slide; first conflict probability increases from zero to a maximum and then it decreases towards zero. If the minimum predicted separation is smaller than 5 nmi, the conflict probability decreases from its maximum monotonically towards zero. For collision risk such a distinction is not necessary as can be seen in the above figure. For a minimum predicted separation smaller than 5 nmi, collision risk still decreases with small along−track position uncertainties.

As result of the above we see that conflict probabilities can give no information regarding the reduction of standard (ICAO) separation criteria, where collision risk can.

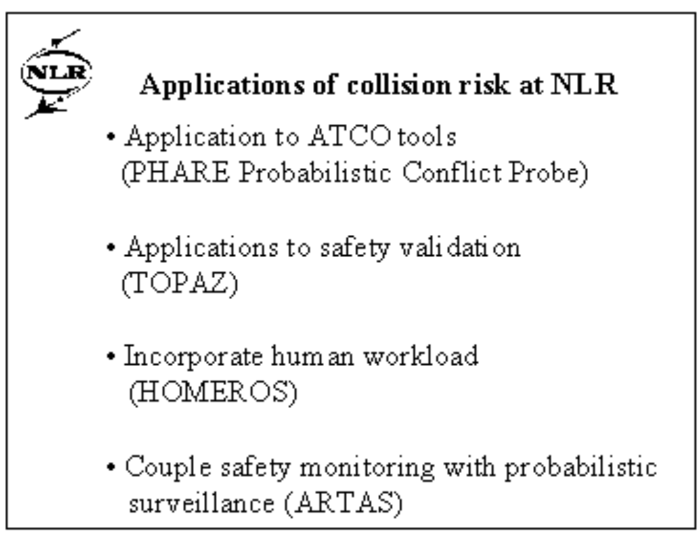


The main limitation of the geometric approach is its tendency to be overly conservative in handling uncertainties in aircraft behaviour.

In the probabilistic conflict probing models, the modeling of the uncertainties can be made less conservative by using pdf's.

The conflict probability approach following Paielli & Erzberger has some restrictions for the aircaft behaviour. Furthermore, the conflict probabilities are not as sensitive to changes in the pdf's as collision risk.

The collision risk approach following Bakker & Blom is mathematical complex. However, the approach incorporates all aircraft behaviour. In the shown examples, collision risk is the most sensitive to changes in the pdf's. Especially in 4D ATM (where small uncertainties in position are common), the collision risk approach is at its best. Collision risk modeling is very generic. It can be used for various applications and adapted to different environments.



At NLR several applications of the collision risk approach are under development.

1. Apply collision risk modeling to ATCO tools. A probabilistic conflict probe, based on collision risk, is currently being developed in the PHARE project (Kremer & Bakker, 1997). This project concentrates on 4D ATM. Initial evaluations will be done during the PHARE demonstrations in 1998.
2. Apply collision risk modeling to safety validation. Collision risk modeling is used for the development of an analysis tool set, TOPAZ (Traffic Organization and Perturbation AnalyZer), for designing advanced ATM inherently safe (Everdij et.al., 1997).
3. Develop human workload models (HOMEROS) which make part of TOPAZ. This work is done in collaboration between mathematicians and psychologists (Biemans & Daams, 1997).
4. Apply collision risk modeling to safety monitoring. At NLR we are considering the ways in which collision risk modeling can be used for this kind of applications (e.g. how to couple it to surveillance).

References

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