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STUDY OF AUTOMATIC CONFLICT DETECTION AND RESOLUTION IN AIR TRAFFIC CONTROL PLANNING

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Summary

The paper presents an analysis of one possible method of planning the traffic flow based on the minimization of the state of potential conflict in a given traffic sample. The basic principles of the method include prediction of flight paths, definition of an instantaneous zone of protection assessed in terms of length and definition of a function characterizing the probable state of conflict of the traffic sample. It implies the definition of a detection logic which amounts to determining the intersection of pairs of zones of protection, and suggests a conflict resolution procedure based on possible flight plan amendments in order to minimize the state of conflict function.

Abstract

The procedures and quality of the planning function in Air Traffic Control have a major influence on the utilisation of available airspace and consequently on the efficiency of the whole control system.

The paper presents an analysis of one possible method of planning the traffic flow based on the minimization of the state of potential conflict in a given traffic sample.

The basic principles of the method essentially include the prediction of the flight path of all the aircraft in the sample, the definition of an instantaneous zone of protection whose components are assessed in terms of length and the definition of a function characterising quantitatively the probable state of conflict of the traffic sample.

In comparison with the position vector derived from inflight observation, the position vector calculated a priori presents a certain scatter. The factors responsible for this scatter are taken into account in the actual expressions representing the dimensions of the zone of protection, and this volume is therefore closely related to the accuracy of the flight path prediction and varies with time.

The detection logic consists of determining the instantaneous intersection of the areas of protection for each pair of aircraft in the traffic sample under consideration. When zones of protection intersect it follows that a conflict has arisen between the two aircraft involved, and the conflict configuration and its position in space and time are then determined.

The state of conflict in the traffic sample is characterized by the distribution of conflicts (number and duration) in time and possibly in space, by the configuration of the conflicts detected and their probability of occurrence. In this study, the aim has been to define a state of conflict function which takes these main parameters into account.

Finally, the paper suggests a method of conflict resolution based on the possibility of modifying the flight plans of the aircraft in the traffic sample. The problem here amounts to minimizing the state of conflict function by amendments (sequence, type and magnitude) to the flight plan.

Introduction

Current Air Traffic Control methods involve two distinct but closely related functions. Firstly, there is the planning function which implies some organisation of the proposed traffic flow. Secondly, there is the executive function, involving direct ground control of aircraft movements, which is necessitated by inability to plan certain phases of flight with sufficient accuracy. In the early

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days of civil aviation, traffic flow was organised on the basis of simple flight plans and flight paths were monitored and corrected by ground control on the basis of position reports passed from air to ground when over-flying specific route points. As the density of aircraft in the airways structure has increased radar has come to the aid of the ground controller enabling him to reduce relative separations between aircraft with no loss of safety. However, the increases in traffic have been accompanied by increases in the number of ground controllers and hence also the coordination work load between controllers. Increased coordination workload reduces useful control capacity and, although recent automation developments have delayed saturation, it does not appear that traffic can continue to increase without the efficiency of air traffic control systems showing a marked reduction.

As the accuracy, with which traffic flows can be planned increases, so separation standards can be reduced as also the requirements for executive control.

Therefore, the aim of the present study has been to reduce to a minimum the executive control requirements while at the same time increasing to a maximum the use of the available airspace, based on the minimisation of the state of potential conflict in a given traffic sample and increased accuracy in flight path prediction.

The problem is constrained in several ways. For the purpose of this article, it will be sufficient to mention three fundamental sources of constraint namely, safety, aircraft trajectories and ATC flight plan amendments.

Maximum safety must be maintained and will not be directly related to the prediction accuracy. Prediction is used for planning the traffic flow but continuous monitoring and updating by a surveillance system is assumed in order to ensure that aircraft remain within the prediction or planning tolerances. However, the more accurate the prediction achieved, so the reliability of the planning will increase and reduce the workload of replanning or executive control intervention. It is not intended to impose any restriction on the type of aircraft trajectory proposed by the aircraft manufacturers or recommended by airlines. The treatment of a given sample of traffic should keep the amendments of the original flight plans within reasonable limits.

In this study, initiated as a contribution to possible future requirements of air traffic control, it will be noticed that certain liberties have been taken with some recognized concepts (Ref.1).

For instance, a zone of protection, centered on the aircraft, is introduced having the general shape of a right angled parallelipiped whose three dimensions are expressed in units of length, and are time dependent. In particular, this includes a longitudinal distance separation which supersedes the usual longitudinal time separation. Based on these three-dimensional time-dependent zones of protection, a concept of conflict criteria is introduced. It amounts to saying that there will be a conflicting situation between a pair of aircraft when their respective zones of protection intersect and only then. Also, in a flight plan the commencement of vertical manoeuvres, changes of altitude such as climb or descent phases, are specified in terms of time rather than position.

The requirement for maximum use of available airspace combined with a reduction of executive control workload while maintaining safety calls for a detailed evaluation of the dispersion volume in which an aircraft is likely to appear at a given time. The relevant trajectory aspect will not be discussed in this paper. It is presently under investigation and the first results obtained have been reported in Ref.2. Such results concern the determination of spatial and temporal predictability of civil aircraft in flight, and assesses the effects of various parameters on this predictability.

The present study, while only partially applicable to current ATC environments, is intentionally related to foreseeable future environments incorporating a higher degree of automation and digital data transmission than is currently available. Thus, it is suggested that the full benefits of this study would be achieved in an environment where automatic monitoring of flight path is available together with air/ground data link, where computer/computer digital interchange is operating and where each element of the control system (i.e. Control Tower) has direct access to the air traffic computer.

Position of the aircraft

At the planning level, an aircraft will need to be given a volume of airspace, which differs in shape and size from that of the aircraft's physical volume. This is in fact to insure safety in the planning stage, in spite of our lack of control of the elements and ignorance of the future.

If, in accordance with the scale of the problem, the aircraft is identified with its center of gravity, our ignorance can be expressed in other, perhaps too familiar words which are likely to sound as follows. In general, it is possible to ascertain that at any given time t, there exists a probability p for the predicted position of an aircraft A to fall within a certain volume of airspace ΔV around P.

This anodyne looking assertion may raise appreciable difficulties when it comes to transpose it into analytical and numerical forms. In this section we shall formulate our approach and indicate how we overcome some of the difficulties.

Stated in such general terms, the problem of predicting the aircraft position exhibits several aspects which could be categorized under four main headings. First, the prediction of a nominal position of the aircraft. Second, the identification and choice of elementary sources of dispersion effecting the aircraft position. Third, the evaluation of the size of the airspace dispersion volume for given values of the elementary contributions. And finally, the probability aspects which imply knowledge of distribution functions for each elementary contribution and adequate rules for combining them.

This last aspect in itself could constitute a whole study whose applicability would probably raise numerous questions. In this article, it will be assumed that the basic dispersion components are given their maximal values, leading to near certainty of finding the aircraft in the associated dispersion volume.

The prediction of a nominal position of the aircraft amounts to computing the complete three-dimensional aircraft trajectory. This computation avoids introducing any restriction to the usual type of trajectory proposed by aircraft manufacturers or recommended by airlines to their pilots.

Generally speaking, the trajectory of an aircraft is obtained by integration of the equations of motion. In a particular route network and under given meteorological conditions (temperature profile and wind velocity vector), this method requires knowledge of the aerodynamics and power plant of the aircraft concerned. These characteristics are generally available in tabular form and usually represent a considerable quantity of numerical data. Although the programming of such computations on an electronic computer is routine, the use of the program requires an important quantity of storage and proves relatively slow in execution. In order to reduce both the quantity of data required and the integration time, we are contemplating using a very simple method for computing trajectories. The method has been described in Ref.2. The approximations essentially concern the vertical components of the velocity and position vectors. It requires only about 20 numerical coefficients per type of speed law and enables a climb phase calculation to be performed in a few seconds, printing of the results included. A hundred numerical tests on the trajectories of a dozen different aircraft types have been carried out altogether and in all of these the model proved to be relatively accurate. Taking different combinations of variations in the initial mass, temperature profile and calibrated airspeed, the difference between the approximate altitude and that given in the manufacturer's performance charts at a given moment in the climb phase from flight level 50 to flight level 220 generally remained within approximately 500 feet. In the case of the distance/time function, the upper limit of the corresponding error has been estimated at 0.1 nautical mile. By way of comparison, it may be noted that for a typical medium-range aircraft it would require an error of one ton in the take-off mass or a shift of 2°C in the temperature profile to produce an altitude error of the same magnitude. Additional details on this subject can be found in Ref.2.

Practically, the calculation of the trajectory assumes the knowledge of information not usually contained in today's flight plans available to Air Traffic Control. These are : the take-off mass and the proposed speed-altitude profile. Also, the specification of vertical manoeuvres includes time of initiation and final altitude to be achieved.

The following remarks suggest a convenient way to define the shape and determine the size of the dispersion volume, while at the same time indicating the basic sources of prediction inaccuracy.

The position of the aircraft can readily be referenced to the axis of the route to be followed, the three components of the position vector being : a vertical component h(t), a longitudinal component d(t), horizontal and measured along the elementary route axis, and a lateral component l(t), normal to the vertical plane containing the route axis. The vertical and longitudinal components result from the integration of the rate of change of altitude $\tau(t)$ and ground speed u(t) measured along the route axis, respectively, while the lateral component results from course deviation. Consequently, if we denote nominal quantities by subscript n and indicate by δ

prediction inaccuracies, namely possible differences between predicted and actual values, we have for the nominal position of the aircraft

$$h_n(t) = \int_0^t \tau_n(t),$$

$$d_n(t) = \int_0^t u_n(t)dt,$$

$$l_n(t) = o$$

and for the dispersion

$$\delta h(t) = \int_0^t \delta\tau(t)dt,$$

$$\delta d(t) = \int_0^t \delta u(t)dt,$$

$$\delta l(t),$$

where the lower limit appearing in the integrals will usually be replaced by the time of prediction.

Consequently, the sources of prediction inaccuracies are readily identified. For the vertical and longitudinal components they are included in the rate of climb and ground speed, respectively. Some of these effects are readily evaluated. This is the case for the influence of the take-off mass, indicated airspeed, temperature and wind. Others will actually need thorough analysis of inflight observation data. The dispersion resulting from the use of different aircraft of the same type, operated in the same way, by a given airline, is an example. To take account of lateral deviation, each elementary route segment is given an equivalent width, say $2w_e$, consistent with local navigational aids, and possibly aircraft type and equipment, such that at any time the inequality

$$|\delta l(t)| < w_e$$

remains satisfied.

Zone of protection

When organizing the traffic flow, the protection of the aircraft against prediction inaccuracies is achieved by reserving around the nominal predicted position of the aircraft, a zone of protection having the general shape of a right-angled parallelepiped in the system of coordinates defined in the previous section, whose vertical Δh, longitudinal Δd, and lateral Δl components should satisfy at any given time the inequalities

$$\Delta h > |\delta h|, \quad \Delta d > |\delta d|, \quad \Delta l > |\delta l|,$$

within the requirements of safety and system efficiency. This implies defining these components with the aim of minimum airspace expenditure. Moreover, the components of the zone of protection should be in a handy form and if necessary easily amended in the course of the development of the project.

There are obviously several possible manners of answering the question. At this stage, we propose the following which has the advantage of requiring only global estimations of spreading errors on speed, rate of change of altitude and time scheduled for initiation of vertical manoeuvres.

Let ϵ_u be the magnitude of the ground speed estimation error, grouping all the elementary contributions arising from prediction inaccuracies on aircraft performances, take-off mass, indicated airspeed, temperature and wind. The resulting effect on the longitudinal inaccuracy will be taken as proportional to the time elapsed between last updating t_u, and the time t for which prediction is made.

The inaccuracy ϵ_t on the time t_o at which a vertical manoeuvre from altitude h_i to altitude h_f, is initiated will cause dispersion on both longitudinal and vertical positions of the craft. Assuming that alterations of atmospheric conditions and aircraft mass variation during an interval of time equal to $2\epsilon_t$, can be neglected, the longitudinal inaccuracy built up at time t results from variations of ground speed with altitude. If u_m is a mean value of the ground speed on the interval of time $(t - \epsilon_t, t + \epsilon_t)$ and u_i the value taken just before starting the manoeuvre, this inaccuracy becomes proportional to the absolute value of the difference $u_m - u_i$. In particular, after completion of the manoeuvre, u_m becomes equal to the ground speed u_f reached at the final altitude. The effect of ϵ_t on the vertical inaccuracy is proportional to the value of the rate of change of altitude τ_m averaged on the same interval of time $(t - \epsilon_t, t + \epsilon_t)$, and disappears when final altitude is reached.

The next source of prediction inaccuracy introduced, ϵ_τ, accounts for possible errors affecting the rate of climb, causing a vertical spreading of the aircraft position around predicted position. This influence increases with the magnitude of the altitude change, and a linear dependency has been considered.

To protect the aircraft in the lateral direction, the zone of protection will be given a lateral component equal to w_e, half of the equivalent width of the route segment on which it is flying. This might be decreased if account is taken of individual aircraft capability.

Finally, even if the aircraft was likely to fly ideally according to prediction, it should be assured that all aircraft in the system maintain a separation acceptable and safe to both pilots and ground control. Therefore, minimum vertical $(\Delta h)_o$, and longitudinal $(\Delta d)_o$, separation standards will be incorporated in the zone of protection components. The latter will be taken as a constant while, as usual, the former will be a discontinuous function of altitude.

Consequently, for an aircraft a, the components of the zone of protection will be, for one single manoeuvre

$$\Delta d(a,t) = (\Delta d)_o + \epsilon_u(a)(t-t_u(a)) + \epsilon_t|u_m(a,t) - u(a,t-\epsilon_t)|$$

$$\Delta h(a,t) = (\Delta h)_o + \epsilon_t|\tau_m(a,t)| + \epsilon_\tau(a)|h_f(a) - h_i(a)|$$

$$\Delta l(a,t) = w_e(r(a))$$

If several manoeuvres have taken place since last updating, the last term in the expression of the longitudinal component is replaced by a summation extended to all these manoeuvres. It is worth noting that the two components $\Delta d(a,t)$ and $\Delta h(a,t)$, and consequently the relevant volume of the zone of protection $Z(a,t)$, are kept within limits through the updating process. Indeed, when updating takes place, they are set back to their minimum values $(\Delta d)_o$ and $(\Delta h)_o$, respectively, and reach their peak values just before the next updating is performed.

Conflict Criterion

When planning the traffic flow, it will be considered that a pair of aircraft, say a and b, create a conflicting situation when, and only when, their respective zones of protection $Z(a,t)$ and $Z(b,t)$ intersect.

For convenience, this criterion will be separated into two components, namely a "lateral" and a planar component for each aircraft, the latter component referred to the vertical plane containing the route segment r(a) or r(b). Then, the two aircraft will be in conflicting situation when, and only when, both lateral and planar conflicts exist.

To determine whether a lateral conflict exists or not, the concept of a zone of potential lateral conflict, say $A(r(a),r(b))$, associated with the two route segments r(a) and r(b) along which the two aircraft a and b are flying, respectively, is introduced. Then the lateral component of the conflict criterion becomes : the two aircraft a and b are in a lateral conflict situation in relation to the pair of route segments r(a) and r(b) when, and only when, they are simultaneously in the potential lateral conflict zone.

$A(r(a),r(b))$ is the overlap of the horizontal projections of the two tracks defined by the route r(a) and r(b) of equivalent width $w_e(r(a))$ and $w_e(r(b))$. It is centered at the intersection $I(r(a),R(b))$ of the two geodesics $g(R(a))$ and $g(R(b))$, containing the horizontal projections R(a) and R(b) of the route segments r(a) and r(b), respectively.

For the numerical treatment, it is convenient to characterise this zone by the distance $z(R(a),R(b))$ from $I(R(a),R(b))$ to the remotest point of $A(r(a),r(b))$. This distance $z(R(a),R(b))$ is a function of the equivalent widths $w_e(r(a))$ and $w_e(r(b))$, the dihedral angle formed by the two geodesics $g(R(a))$ and $g(R(b))$, and the relative configuration of the horizontal projections R(a) and R(b) of the two route segments r(a) and r(b).

The planar components of the criterion are readily expressed. We designate by $D(a,b,t)$ and $H(a,b,t)$ the longitudinal and vertical components respectively, in the vertical plane containing r(a) for instance, of the distance between aircraft a and b. Then, there will be a planar conflict between the two aircraft when, and only when,

$$D(a,b,t) < \Delta d(a,t) + \Delta d(b,t)$$

and

$$H(a,b,t) < \Delta h(a,t) + \Delta h(b,t)$$

Conflict Detection Procedure

When the detection of conflicts is initiated for a particular sample of traffic, efficiency demands the sorting of traffic starting with the most drastic elimination and continuing with more and more refined sorting up to the determination of the conflicting aircraft.

Consequently, the conflict search may generally be drastically reduced for parts of the traffic. If we call 'a' the test aircraft, then this is the case for aircraft flying on other routes or during another period of time than the aircraft 'a' under investigation.

The detection proceeds further with the search for lateral conflicts. First, the existence of a potential lateral conflict zone is investigated. When one is found, the next step in the detection logics consists in the determination of the temporal position of the two aircraft in this particular zone. Only when both aircraft are found to be simultaneously in this zone will the planar criterion be applied to this particular pair.

To conclude, in practice, the procedure followed for the detection of conflicts aims at reducing the computer time whenever possible. For this, the structure of logic is such that it allows us to ascertain that there will be no conflict between a given pair of aircraft of the traffic sample, if only one condition of conflict is not satisfied, and therefore, to set aside the corresponding pair of aircraft as early as possible in the detection procedure if no conflict exists.

State of Conflict

The conflict state for a given traffic sample can be represented by the distribution of conflicts, as regards both number and duration, in time and possibly in space. The importance of a conflict may depend on its configuration. Also, the probability that a conflict detected at the planning level will actually occur, may have an effect on the type of action which it may initiate.

At this stage, for each type of conflict, we have assigned a weighting factor μ. Also, we have chosen to express conflict probability in terms of the ratio ν, of the horizontal standard separation minimum to the instantaneous horizontal separation. Finally, we have defined the state of conflict by a single function C, which is the time integral

$$C = \int_T \left(\sum_c n_c(t)\ \mu_c\ \nu_c(t)\right)dt$$

over the period of time T of the summation of the weighted number n of conflicts in respect of the volume of traffic being considered in the detection and resolution in progress.

In other words, so far we have caracterized the state of conflict by a single function, namely the summation of the weighted durations of all conflicts arising in the traffic sample under consideration. This function has the advantage of being unique and simple, but in the future, it might appear desirable to separate the components representing number and duration.

Resolution Criteria and Procedure

If we use the integral C defined in the previous section as a measure of the state of conflict, we can say that for a given sample of traffic, the optimum planning has been achieved when the state of conflict function is minimum.

In practice, the flight plans are introduced in the system one after each other and consequently, it appears logical to organize the flight of the last entry in terms of the traffic already treated and cleared.

Also, for all sorts of practical, operational and economic reasons, the alterations of the proposed flight plans should remain within reasonable limits. When this "reasonable" aspect is further investigated, it turns out that the possible amendments should be restricted as regards type, magnitude and sequence.

Clearly, there may be several ways of meeting these requirements. For our preliminary investigation, we have limited ourselves to flight plan amendments related to the following changes

- a change of one or several cruise levels
- the interruption of a climb or descent by a phase of horizontal flight
- a delay in the start of a manoeuvre
- holding the aircraft at a determined position
- a delay in take-off.

This list is certainly not exhaustive, for instance, speed control could easily be introduced, but at this stage of the project, we feel that it constitutes a representative sample of possible and acceptable flight plan amendments.

Each type of amendment is limited in magnitude. For instance, the modification of cruise level is limited to a maximum variation of the order of 2000 ft or 4000 ft depending on the initially proposed cruise altitude. Also, when the interruption of a manoeuvre by a phase of horizontal flight is considered to solve a conflict generated during a climb or descent, the intermediate level should obviously remain within the altitude band defined by initial and final altitudes of the manoeuvre. The duration of the intermediate horizontal flight has been taken equal to the smallest integer number of minutes such that the longitudinal

Flight Number	Type	TOM	Entry Time	Route
X1	CA 6N	48	09.52	BRY.ATN.LYN.NIZ.ELB.
X2	B 707	140	09.52	LMG.XQW.MTL.NIZ.ELB.
X3	B 727	72	09.55	LMG.MOU.DIJ.LUL.STR.
X4	B 707	135	09.58	BRY.MOU.LYN.NIZ.ELB.
X5	CA 3	42	10.01	ELB.NIZ.LYN.ATN.BRY.
X6	CA 3	42	10.02	BRY.ATN.LYN.NIZ.ELB.
X7	TRI 1	40	10.03	BRY.ATN.LYN.NIZ.
X8	DC 9	50	10.08	BER.GLA.LYN.XQW.TOU.
X9	B 727	74	10.14	LXU.LUL.GLA.NIZ.ELB.
X10	CA 3	42	10.20	AJO.NIZ.LYN.MOU.BRY.
X11	DC 8	130	10.26	BER.GLA.LYN.XQW.TOU.
X2	B 707	140	10.51	LMG.XQW.MTL.NIZ.ELB.

TABLE 1 ILLUSTRATIVE SAMPLE ROUTES

conflict component ceases to be **infringed.** Moreover, the duration of the intermediate flight should not exceed a given fixed maximum value. Similarly, the other amendments, namely delay in starting a manoeuvre, holding of an aircraft over a given point and take-off delay are also limited in magnitude and restricted as regards applicability.

The resolution procedure aims at reducing the number and duration of conflicts existing in the traffic sample. It comes into action on each occasion that the introduction of a new aircraft into the system generates at least one conflict for which the function ν, defined in the previous section, has a value above a minimum threshold ν_{min}, specified in advance. When this new aircraft generates several conflicts with the aircraft which are already in the system, and for which the condition $\nu > \nu_{min}$ is satisfied, the resolution procedure is applied to the conflict which is the first, chronologically, to occur, for each pair of aircraft composed of the new aircraft and any one of all the aircraft already in the system.

In the absolute sense, a conflict is resolved when it ceases to exist. In practice, however, we shall say that a conflict is resolved when it ceases to exist, or when at the start of the conflict the function has become less than the minimum value ν_{min}, or when the start of the residual conflict is postponed for a sufficient length of time. Several amendments may resolve the conflict. The selection is then made by attributing a priority level to each amendment, i.e. a change of cruise level has been given the highest priority, then follows the interruption of a vertical manoeuvre by a phase of horizontal flight, then a delay in starting a manoeuvre, next the holding of the aircraft and finally, we kept the lowest priority for delaying the take-off. These amendments and their priorities are used experimentally at this stage of the study and represent only a selection of amendments currently in use.

When the traffic conditions are such that the conflicting situation cannot be resolved in the above sense, we retain the amendment which results in the smallest value of the state of conflict function.

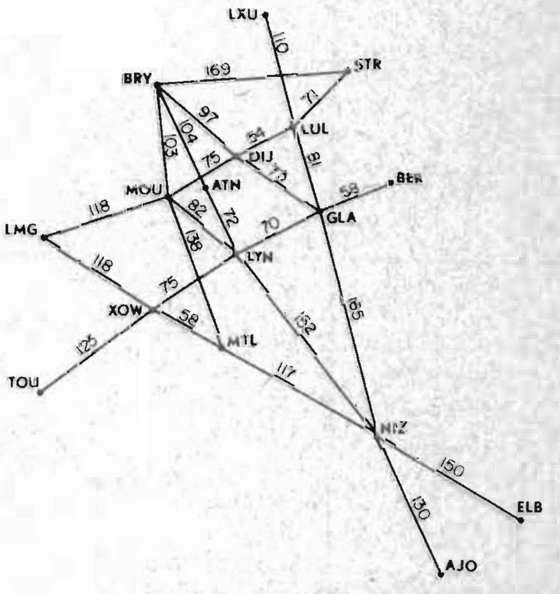

Fig. 1 — ILLUSTRATIVE EXAMPLE NETWORK

A \ B	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X2
X1					FLO FLO							
X2												
X3									FLO FCO			
X4	BLS FLS		FLO FLS									
X5	FLO FLO	FLO FLO		FLO FLO		FLO FLO	FLO FLO					
X6			FCO FLO		FLO FLO						FLO FCO	
X7	BLS FLS			BLS FLS	FLO FLO							
X8				FLO FLO			FLO FLO					
X9			FCO FLO									
X10				BCO BLO		FCO FLO						
X11					FLS BLO							
X2												

State of conflict in treated sample

State of conflict in initial sample

TABLE 2a CONFLICTS IN TRAFFIC SAMPLE

A blank indication absence of conflict

Type of conflict No.1 between a/c A & B

Upper line : relates to a/c B

Lower line : relates to a/c A

First letter : Indicates relative position at start of conflict

F : in front

B : behind

Second letter : Indicates type of phase

L : level flight

D : descent

C : climb

Third letter : Indicates relative movement

S : in same direction

O : in opposite direction

TABLE 2b NOMENCLATURE FOR TABLE 2a

If we designate by C the conflict state, for the initial sample of flight plans, and by C_r the corresponding value in respect of the sample of amended flight plans, the overall efficiency of the resolution procedure can be represented by the ratio

$$\eta = (C - C_r)/C$$

Illustrative Example

In order to illustrate the use of the concepts developed in this paper, the following very simple example has been treated.

The route network used for this illustration is shown in Fig. 1. It comprises 17 nodes and 25 elementary route segments and extends roughly from Luxembourg to Ajaccio as indicated in the figure. Each route segment comes within a meteorological area, and for this sample we have considered three distinct meteorological areas. Into this network, we have introduced 11 aircraft, X1 to X11, whose routes, generated in a near-random manner, are summarized in Table 1. The detection procedure applied to this traffic sample of 11 aircraft or 65 different pairs of aircraft, has revealed the conflict state summarized in the lower part of Table 2a, Table 2b giving the meaning of the symbols used. These tables indicate the existence and the initial configuration of the first conflict arising in respect of each of the 65 pairs in the sample. However, this is only a summary, the detection programme in addition giving in respect of each conflict which may arise between each pair of aircraft, the conflict duration, warning time and conflict area, and for each aircraft, its type, position at the start and position at the end of the conflict which are produced directly by the computer. Curve a of Fig. 2 shows the evolution of the conflict state for the whole of the traffic sample. This diagram gives the number of conflicts as a function of time for the network, traffic sample, and period of time considered.

Flight plans are introduced into the system in the order indicated in Table 1. When a new aircraft enters, the detection procedure is initiated for the aircraft pairs formed by this aircraft and the totality of the aircraft already within the system. When a conflict for which $\nu > \nu_{min}$ is detected, resolution procedure is initiated and if an amendment to flight plan is required, it is the last flight introduced into the system which is altered. Table 3 (in this table, CCL stands for change of cruise level) summarises the amendments

X1	Unchanged
X2	Unchanged
X3	Unchanged
X4	CCL from FL 320 to FL 340 at 10 hr 0 mn
X5	CCL from FL 330 to FL 310 at 10 hr 3 mn
X6	Manoeuvre delay = 3 mn from 10 hr 2 mn
X7	CCL from FL 360 to FL 300 at 10 hr 16 mn
X8	Holding delay = 5 mn from 10 hr 16 mn
X9	Unchanged
X10	Unchanged
X11	CCL from FL 320 to FL 340 at 10 hr 34 mn
X2	Unchanged

TABLE 3 MODIFICATION TO FLIGHT PLANS FOLLOWING RESOLUTION

which were made to the flight plans of each of the aircraft, following resolution. The residual conflict state is shown in diagrammatic form in the same way as previously, in the upper part of Table 2a and in Figure 2, curve b.

The detection procedure reveals 16 conflicts in the sample presented. The conflict state, namely the time integral of the instantaneous number of conflicts (all conflicts being given the same weight), is characterized by the value 227. When the resolution procedure has been applied, the conflict number is

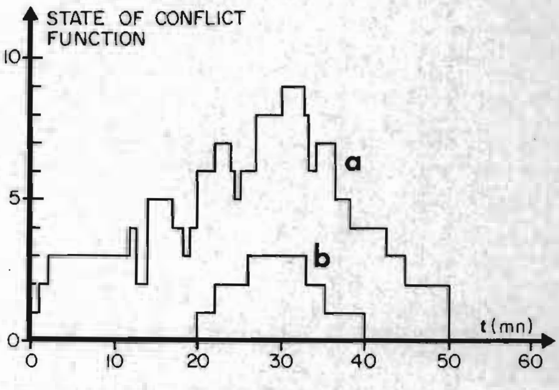

Fig. 2 – STATE OF CONFLICT
a) in proposed sample
b) in treated sample

reduced to 5 and the conflict state is reduced to 39, which corresponds to an improvement of the conflict state of about 83%.

It is not possible to assess, at this stage, whether such an improvement is representative or how it compares with current planning procedures. However, it will be necessary to demonstrate that the results of this work, as one component of automation in future ATC systems, offers effective improvements to airspace utilisation and ATC system efficiency.

Conclusions

This paper contains a summary of a preliminary study of the method of conflict resolution. The principle behind this method has three fundamental ideas :

a) the determination a priori of the changes occurring with time in the positions (in all three dimensions) of the whole of the aircraft in the traffic sample considered;

b) a definition of a conflict criterion which is a function of time and of the systems parameters which characterise the various sources of errors adversely affecting the position/time function;

c) an efficient resolution procedure which, from the digital view-point, is easy to use.

The determination of trajectories by the integration of the equations of movement, starting from the fundamental characteristics of the aerodynamic design and the powerplant of the aircraft, is a relatively slow process and demands a considerable amount of data storage. We have therefore developed an extremely simple model for reconstructing trajectories. This model utilizes only a small amount of data and enables the climb phase calculation to be performed with reasonable speed and accuracy.

The conflict criterion which has been introduced is based on the definition of a zone of protection around each aircraft. The dimensions of this zone are expressed in units of length. These dimensions vary during the period of time considered, under the influence of the various sources of error affecting the computed aircraft position. When the intersection of the zones of protection of the two aircraft overlap, we shall say that these two aircraft are in conflict. An automatic conflict detection programme has been developed which will determine the conflicts existing between each pair of aircraft in any traffic sample which it has to handle. It also defines each conflict in time, and gives amongst other things the aircraft positions in three dimensions and the conflict configuration at the start and end of conflict.

The resolution procedure is intended to reduce the number and duration of the conflicts in any traffic sample that is presented. It is based on the possibility of amending the flight plans within previously defined limits. The method implies the quantitative definition of the conflict state and of a resolution criterion (the initiation and end of the resolution procedure, and the selection of the particular flight plan amendments which are to be employed). The method described in this paper has been applied to a traffic sample consisting of 65 pairs of aircraft, generated in a near-random manner. The detection procedure detects 16 conflicts in the sample presented; the conflict state (simplified version : the time integral of the instantaneous number of conflicts) is characterized by the value 227. When the resolution procedure has been applied, the conflict number is reduced to 5, and the conflict state is reduced to 39, which corresponds to an improvement in the conflict state of 83%.

Much further study and experimentation is necessary before operational trials and simulations can be undertaken to assess fully the potential of this work. Results achieved so far indicate that such procedures may make a significant contribution to future automation in Air Traffic Control; particularly in the important stage of ATC flight planning.

These studies are likely to show maximum benefit when allied to other current technical developments, particularly in the fields of automatic flight path monitoring and digital communications.

References

1. "Procédures pour les services de la navigation aérienne. Règles de l'air et services de la circulation aérienne". Organisation de l'Aviation Civile Internationale, Doc. 4444-RAC/501/8, 8e Ed. 1966.
2. A. Benoit, Y.Charvet, P.Kuypers, R.H.G. Martin
"An Approach to the calculation of aircraft trajectories for possible application in air traffic control" Eurocontrol Review, Vol.2, no.2, 1970

Note
The views expressed in this paper are those of the authors and do not necessarily represent those of the Organisations to which they belong.