'Free Flight' for Air Traffic in Europe

S. Ratcliffe

(*Private Consultant*)

In an earlier study, the author attempted to give some quantitative estimates of the problems that *free flow* might face in Europe. The study was based on a traffic sample from the Eurocontrol Route Charges Office for a busy day in 1991. More recently, they generously made available a similar sample for a day in 1997. Using this new data, the study has been extended to cover wider aspects of the free flow problem. The central problem is that of ensuring safety. This will require a mechanism to detect collision threats and safely to resolve the problems. Possible tools are ground-based surveillance and/or airborne systems. This paper will use computer modelling to predict the loads that these detection and resolution systems must face.

1. INTRODUCTION. *Free flight* is the name given to a variety of proposals for alternative ways of managing future air traffic. It is perhaps better thought of not as a specific system, but as an evolutionary process, beginning with a tendency to allow aircraft more freedom to depart from the present airways structure and eventually leading to the liberation of airlines from the *tyranny of ATC*. There is a school of thought in the USA that present-day ATC is based on civil servants in ATC centres dictating to airlines the way in which they should run their business. Such a system, it is argued, is clearly 'Un-American'.

There are many published papers claiming the advantages of *free flight*. These are, almost without exception, purely qualitative. The problems of evolving from the present system to some *laissez-faire* environment are, no doubt, considerable, and are the subject of much study by the FAA and others.

Since the case for *free flight* is usually based on claims that it is cheaper and more efficient than present-day ATC, the present paper will be devoted to a quantitative examination of the end-product of the evolutionary process. Emphasis will be on the problems that would be faced in European airspace.

2. THE COMPUTER MODEL. An earlier paper[1] described the model and its many over-simplifications in some detail. Using the 1997 traffic data, the study has been extended to look at some *free flight* problems in greater detail. Since we are discussing a situation that may not arise for less than about 20 years, the limitations on the accuracy with which the future can be forecast may provide some justification for adopting methods which can give only limited accuracy.

To summarise, a computer map of Europe is drawn to Mercator's projection, and all flights are assumed to follow rhumb lines; straight lines in the computer. It is difficult to envisage a free flight TMA, with aircraft jostling for access to the runway. The model assumes that each airport has a circular terminal area, 20 nm in radius, and that flights begin and end at the area boundary. There is a semicircular height rule, and aircraft enter or leave the boundary at 4000 or 5000 ft depending on the

https://doi.org/10.1017/S0373463399008358 Published online by Cambridge University Press

flight direction. Each route is parallel to the straight line from origin to destination, but displaced 5 nm to starboard. Flights on a given route are all given the same cruising level. All aircraft are assumed to fly at the same uniform rate of climb and at another uniform rate of descent.

Long-haul flights on a given route are all given the same cruising level. In real life, these would be chosen by the airline, but here they are allocated by the computer's random number generator. Short-haul flights are given the highest level which satisfies the semicircular rule and which their rates of climb and descent permit. Routes, such as positioning flights, which are not capable of achieving FL 80, are deleted from the sample. Traffic to and from airfields west of the Azores, east of Moscow or south of the Mediterranian coast of Africa are also eliminated. In all, this censorship has deleted less than 9% of the original routes, leaving 7625 remaining.

Possible systems for the resolution of conflicts involve a ground-based system resembling ATC (acting to intervene rather than to control), or an airborne system which gives a direct warning to the pilot, or a combination of the two. For study of these possible systems, different parameters are relevant. Given a centralised ATC-like system, any controller can, in principle, deal with any collision threat. The quantity that measures the load on this system will hereafter be termed the *conflict rate*: the average number of conflicts arising in a given time (a 15-hour day in the present paper). To the crew of a given aircraft, a more relevant factor is the probability, during flights along a given route, that they will need to avoid some crossing flight. There is no simple relationship between these two quantities. It can be shown,[2] that *conflict rate* is proportional to the square of movement rate, whilst *crossing rate* is directly proportional to movements. If traffic is doubled, for example, there will be four times the number of conflicts, but these will be dealt with by twice the number of pilots. This paper does not directly discuss collision risks.

ATC practice is to set some target level of safe separation. Controllers must use their discretion to choose the point at which they intervene to meet this target. The present paper is concerned with the frequency with which either controllers or pilots must take remedial action. Time to closest approach will be used as the alarm criterion. If two paths intersect at a given point, an alarm is raised if, for instance, there is less than 1000 ft height difference and times of arrival at the intersection differ by less than 30 secs. Since either aircraft may be in front of the other, this will be termed, in what follows, a one-minute time window. The one-minute window marks the lowest conceivable time at which a safe escape manoeuvre might be attempted. It corresponds, more or less, to that used in TCAS[3,4] which, of course, is designed only as a last minute back-up to ATC. TCAS warnings are preceded by an earlier *alert* message. It is not claimed that TCAS is an alternative to warning or intervention systems based on more adequate data. It can be shown that conflict counts and crossing rates are both directly proportional to the width of the time window.

Without data on aircraft departure times, the model makes the convenient but inaccurate assumption that any aircraft on a given route during a 15-hour day is equally likely to fall within a given time window, regardless of the position of the window on its route. This position may, for example, be defined as the time at which a conflicting aircraft crosses its track. We are neglecting any curfews that may be imposed by airports on departure or arrival times.

Table 1 shows the conflict pairs predicted by the model for time windows of one to three minutes. Results are based on the 1997 data; those in brackets are for the

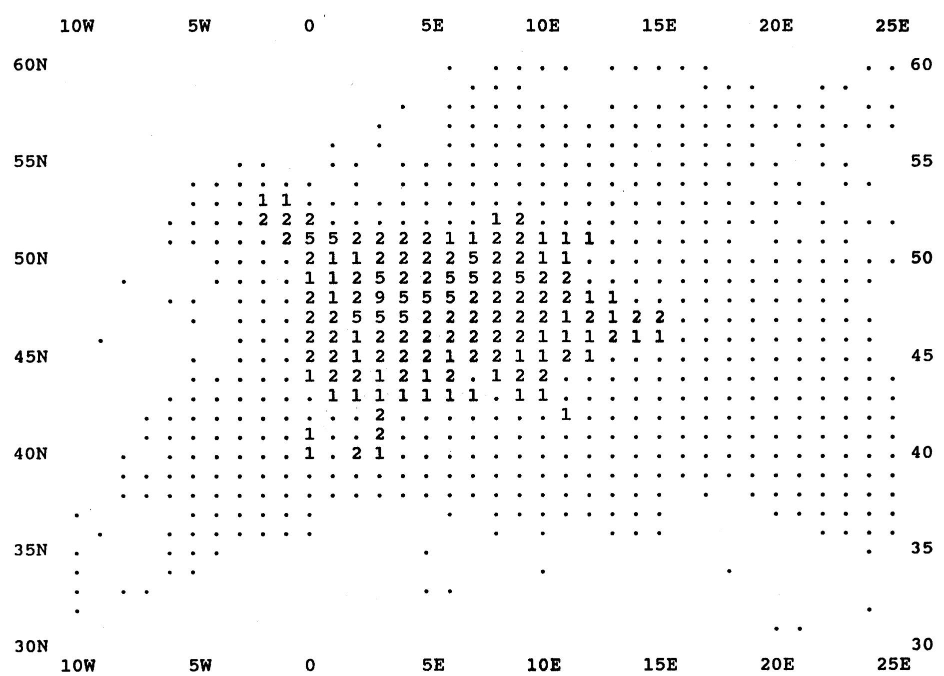
Table 1. Predicted Number of Conflict Pairs in a 15 hr Day.

Moves	Traffic in 1997 (1991) 1 min	Movements 19 284 (10 527) 2 min	3 min
20 000	863 (1153)	1727 (2306)	2 590 (3 459)
30 000	1942 (2594)	3886 (5188)	5 850 (7 783)
40 000	3452 (4612)	6908 (9224)	10 360 (13 836)

1991 data used in Reference 1. To simplify comparisons, both sets of results are scaled to predict conflicts pairs for 20 000, 30 000 and 40 000 movements per day.

In the period 1991–1997, there have been considerable political changes in Europe. These are reflected in the traffic pattern. For example, there are many more flights across the former Iron Curtain, and political upheaval in the Balkans and elsewhere may well have modified the pattern of tourist traffic. Probably as a result of these changes, European traffic is more widely dispersed, and the conflict rate has grown less rapidly than suggested in the earlier paper.

It may be of interest to see the geographical distribution of the points at which conflicts arise. Figure 1 shows the Mercator map of Europe divided into cells one



max conflicts 3286 (taken as 100% in what follows.)

%age ct. in cell	>90%	>50%	>20%	>10%	<10%	zero
Symbol on map	9	5	2	1	•	blank

Cell size 1 deg. latitude × 1 deg. longitude

Figure 1. Conflict density map.

https://doi.org/10.1017/S0373463399008358 Published online by Cambridge University Press

degree of longitude by one degree of latitude. Potential conflicts are each converted into geographical units and used to add to the count in the appropriate cell. Taking the highest score as 100 %, the scores are classified and represented on the map by single character symbols. Scores between 100 % and 90 % are denoted '9', '5' denotes cells between 90 % and 50 %, and so on. Dots denote cells where the count is less than 10 % of the maximum, and clear areas have zero conflicts. The diagram illustrates one of the weaknesses of the traffic sample. Flights which do not enter the Eurocontrol route charges region, Scandinavia or Eastern Europe are not included, hence the low conflict counts in right-hand regions of the map.

Table 2. Expected Crossing Encounters per Day and Route.

	Time window		
Moves	1 min	2 min	3 min
20000	0·11 (0·62)	0·22 (1·24)	0·33 (1·86)
30000	0·16 (0·93)	0·32 (1·86)	0·48 (2·79)
40000	0·22 (1·24)	0·44 (2·48)	0·66 (3·92)

Table 2 shows the expected crossing encounters for the aircraft spending, in total, 15 hrs in flight on a given route. They have been averaged over all routes. The *worst case* route is Estonia (EETN) to Spain (LERT). As explained earlier, *crossing rate* increases only linearly with traffic rate. The *average* figures have, perhaps, a rather limited meaning. They include, for example, 1492 routes which are immune from conflicts. Whatever the average *crossing rate*, there should be some upper limit to the crossings to be expected on the worst-case route. It may be remembered that the flight levels flown on each route were chosen by a random number generator, simulating – not very accurately, perhaps – the choices made by the airline planners. An attempt was therefore made to construct an *optimisation* program that would find a better method of assigning flight levels.

Optimisation opens several cans of worms. Obviously, if we reduce the number of crossings experienced by an aircraft on the above *worst-case* route, we have also reduced the crossing count for other traffic involved in the crossings under discussion, but by allocating a new flight level to any aircraft we will increase, hopefully to a lesser degree, the crossings to which some other aircraft will be exposed. By choosing to reduce the number of worst-case encounters, we may be ignoring the fact that an improvement on a route carrying many moves per day might be regarded as more important than one flight from Estonia to Spain. For that matter, we might have chosen to measure crossings per flight, rather than crossings in a given time, thus giving more emphasis to long-haul flights. There can be more subtle bias in the optimisation process. For example, routes are listed in the computer program in lexicographic order of the ICAO location codes of origin+destination, so the first choice of flight level might go to an Antwerp departure whilst Moscow came last.

The optimiser was given the task of halving the worst-case crossing, (rather than conflict), count. Results are given in Table 3 for the actual movement rate in the 1997 sample, and a one-minute time window, though neither of these parameters would influence the optimiser. The worst-case route is now that from Gatwick to Larnaca.

Apart from some of the difficulties listed earlier, it may be pointed out that the

Table 3. Experiment in Optimising Flight Levels.

Pairs of A/c in conflict in 15 hr period 619 (878)
Expected crossings in day's traffic
Average route 0·072 (0·11)
Worst-case route 0·31 (0·6)
Number of routes escaping crossings 1406 (1492)
Figures in brackets give results prior to optimisation
The process required changes to the flight levels of 600 aircraft
None of them were forced down below Flight Level 220

process, as described, implies the existence of some central authority allocating flight levels, and is therefore contrary to the *free flight* philosophy. There is, perhaps, at least one escape from this dilemma. No matter how fierce the competition between rival users of the airspace, they have a common interest in limiting the need for dangerous escape manoeuvres. Suppose that there were a database containing, for example, a greatly enlarged version of that from which were derived results quoted in this paper. It should certainly not be confined to rhumb-line routes, nor to climb and descent at constant rates, and should allow for aircraft using cruise-climb. It would also be desirable to take account of the approximate time of departure. This database might be controlled by some central authority serving terminals available to interested parties. Airlines owning such a terminal could then, using their own definition of *optimum*, explore the implications of alternative strategies using estimates from the central data base of *crossing* and *conflict rates*.

Encryption and/or other techniques should make it impossible to use the terminal to extract data on the strategies of rival operators. There should be the option of providing the central database with the operators' intentions for future traffic. This information, and/or historical data should provide the basis for conflict predictions. These would be purely advisory; there is no question of a conflict-free *Tube of Flight*.

3. MULTI-AIRCRAFT PROBLEMS. There is little risk of a near-simultaneous collision involving three aircraft. It will now be shown, however, that there is a distinct risk that the problem of resolving a conflict will be complicated by the presence of a third aircraft in the vicinity. This third aircraft will here be termed an *intruder*. Intrusion, here, will be defined as a situation when the third flight passes within 10 nm of the intersection of the conflicting routes, the vertical separation is less than 2000 ft from the predicted height of conflict, and time of closest approach to the predicted conflict is within plus or minus one minute of that predicted for the collision. These numbers are necessarily rather arbitrary, the mechanisms for the detection and resolution of conflicts are not defined, and *intrusion*, as defined above, covers a wide variety of problems. Table 4 is intended to give, at least, an indication of situations which may arise. Intrusion tests are based on a 10% sample of about one million potential conflicts arising in the simulation on which the earlier tables were based. Given the map coordinates of each conflict in turn, they were then tested for *intrusion* using the known movement rate and track for each route.

The number of intruders to be expected given the results in Table 4, is high enough to suggest the possibility of more than one intruder in a given conflict. Given the assumptions on which the model is based, intrusions qualify for treatment as a Poisson process.[5,6] From this, it follows that there is, at the 20000 movements per day

Table 4. Conflicts Having an Intruder Present
(as percentage of total conflicts expected.)

	Intruder		
Conflict pair	Climbing (%)	Level (%)	Descending (%)
Both Climb	0·002	0·03	0·0065
Both Level	0·031	7·97	0·99
Both Descend	0·10	0·0017	0·053
Climb + Level	0·134	0·83	0·052
Climb + Descent	0·037	0·34	0·34
Level + Descent	0·0065	0·57	0·007

traffic level here assumed, a 2·2% probability that a conflict will have to be resolved in face of two intruders and a 0·16% probability that three intruders will be present.

Some of these probabilities are small, but none of them are negligible. Table 4 quotes intrusion probability as a percentage of the *conflict rate*. Doubling the traffic will quadruple the conflicts. Since the probability of an intrusion is proportional to traffic cubed, it will also double the percentage probabilities of intrusion shown in Table 4.

Throughout the paper, many problems have been ignored; for example, those arising when two aircraft on the same route overtake each other, or when, for whatever reason, an aircraft deviates from a planned straight-line path. It would seem that there is inadequate certainty of selecting and executing suitable escape manoeuvres in the 30-second escape time frequently assumed in this paper. If the windows allowed for collision warning and intrusion are both doubled, there will be twice as many warnings and double the probability that there is an intruder in the vicinity of any of the increased number.

This paper has given some numerical estimates of the conflict problems that may be expected, but there is a need for work on the mechanisms by which these conflicts may be resolved. It remains possible that *free flight*, as outlined earlier in this paper, cannot be achieved in European airspace.

ACKNOWLEDGEMENT

The author thanks M. Chr. Vandenberghe, of Eurocontrol's Central Route Charges Organisation for his generous provision of the traffic samples on which this work is based. He is also indebted to Howagent Ltd. for assistance with some computing tasks.

REFERENCES

1 Ratcliffe, S. (1998). Assessing the benefits of innovations in ATC. This *Journal*, **51**, 312.
2 Ratcliffe, S. and Ford, R. L. (1982). Conflicts between random flights in a given area. This *Journal*, **35**, 47. (This paper contains numerous printers' errors in the algebra. Author's original proof corrections were finally published in Vol. 35, p. 516).
3 Carpenter, K. (1977). TCAS v. 7.00. A new generation. *Transmit*, Summer issue. Guild of Air Traffic Control Officers, London.
4 Foreman, P. K. (1998). Free Flight and the pilot. *Prospects for Free Flight Conference*, SMi, London, January.

[5] Ashby, W. R. (1956). Self-regulation and requisite variety. Reprinted in F. E. Emery (Ed.), *Systems Thinking*. Harmondsworth, Penguin Books, 1970, pp. 105–124.

[6] Weatherburn, C. E. (1949). *Mathematical Statistics*. Chapter III, pp. 47–49. Cambridge University Press.

KEY WORDS

1. Air Traffic Control. 2. Safety. 3. Modelling.