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Introduction

For a short flight, say between London and Edinburgh, the route taken by the aircraft will be determined by the location of navigation beacons. In addition, except for variations at the ends of the route, due to the direction of landing depending on wind direction, and other factors, the route will be largely the same from one day to the next. For longer flights over Europe, different routes can be chosen depending on the wind patterns on the day in question. For a number of city pairs straddling the North Atlantic, an operator can chose a route more or less freely, subject to constraints in the domestic airspace at both ends of the route. However, for a portion of the oceanic airspace a route structure is imposed - the North Atlantic Organised Track System (NAOTS) (see, for example, Nolan (1990)). This is necessary because of the combination of high traffic density and procedural air traffic control, the latter being required due to limited Communication, Navigation and Surveillance (CNS). The track system forces those aircraft that use it to fly along tracks which are collocated in the vertical and fixed for finite periods of time - up to 24 hours. A track system could be devised which is fixed for shorter periods of time and in which different routes are allowed at different levels. The purpose of this study is to quantify the time (and hence, cost) saving that would arise from allowing a more flexible system. In 1997 the minimum vertical separation of aircraft at certain levels in the NAOTS was reduced from 2000 feet to 1000 feet, so greater flexibility is possible now than was possible two years ago.

This study was performed with the UKMO minimum time track (MTT) derivation model, which is essentially as described in Lunnon and Marklow (1992). It was considered highly desirable to do a comparison of that model with that used by NATS as a research tool to study costs of air traffic control scenarios in the North Atlantic (NATSIM). This comparison forms the first part of the study.

Optimum route model intercomparison

Experimental set-up

The model comparison consisted of choosing a day, a set of city pairs, and, with both models, calculating the times to fly both great circle routes and MTTs. In addition the times to fly the NATS MTTs using the UKMO algorithm were calculated.

The day chosen (by NATS) was 4th January 1996. This was a date used as part of the NICE (North Atlantic Implementation Management Group Cost Effectiveness) study. The city pairs chosen (again by NATS) were KJFK (New York JFK) - EGLL (London Heathrow), KLAX (Los Angeles) - EGLL, KORD (Chicago O'Hare) - EGLL, TFFR (Guadelope Le Reizet) - LFPO (Paris Orly), KJFK - LFPO and CYMX (Montreal) - LFPG (Paris Charles de Gaule). Both eastbound and westbound flights were considered. These were all flights flown on the day in question, and can be considered broadly representative of the range of flights across the North Atlantic on a particular day. The specific aircraft types used on that day were assumed in the simulations, although the only effect of this was in the assumed airspeeds. It was assumed that B747s fly at M0.84, B767s fly at M0.80, and L101s fly at M0.83. The aircraft types and the call signs (which are used later) are given in table 1 (in next section). For the comparison an identical wind field was used by both models, this being a 24 hour forecast valid at 12GMT on 4th, specified on a grid which was 0.833 degrees (latitude)* 1.25 degrees (longitude) *50hPa.

Results of comparison

The times taken to fly the various routes are given in table 2.

Whilst clearly the optimum routes derived by the two systems may be different, and thus the times taken to fly them are different, it might superficially be surprising that the times taken to fly the great circle routes are different. These differences can arise from a number of factors including

(a) Different calculation of the times to fly the ascent and descent
(b) Flight at different level in cruise phase. NATS assumed a flight level 350 while UKMO assumed a pressure of 250hPa (33999 feet).
(c) Different algorithm used to calculate flight time for a sector. In the UKMO system the times for sub-sectors each 1.25 degrees of longitude long are calculated and these times added. The use of a different algorithm would give different answers.

The average time savings (great circle time minus MTT) of the UKMO system (23.7 minutes) were 20% higher than those from the NATS system (19.7 minutes). However the time saving was not greater in all cases.

Figure 1 shows the MTTs from both systems for both eastbound and westbound flights. For the UKMO tracks, the algorithm returns a latitude for every point with a longitudinal separation of 1.25 degrees, and straight lines are used to connect these points. For the NATS system, the output used was in the form of flight strips which specify the latitude for points with a longitudinal separation of 5 degrees whilst in the North Atlantic Track System, but the route is unspecified across Canadian and US domestic airspace. For this portion of the flight it was assumed that latitude was a linear function of longitude: because figure 1 is a mercator projection these portions of the route appear curved. This is particularly the case for the westbound routes. Assuming a great circle route for these portions of the flight would have produced a more realistic route but this would have added computational complexity.

Apart from this difference, and apart from
(a) the flights to and from TFFR (Guadelope)
(b) the flight from KLAX to EGLL
the routes derived by the two systems are very similar.

It was desirable to understand why the time saving in the UKMO system was not always greater than that in the NATS system. . Therefore the times taken to fly the NATS MTTs were calculated using the UKMO algorithm.

These times agreed well (to within 2 minutes) with the times taken to fly the UKMO MTTs for all eastbound flights except KLAX - EGLL. The westbound flights did not agree so well because of uncertainty about the route taken across domestic US airspace, as discussed earlier. The differences were such that the UKMO MTTs took less time to fly in all cases.

The difference between the KLAX - EGLL times were significant - a difference in time saving of nearly half an hour. This arose essentially because a different entry point was used into North Atlantic airspace. The UKMO MTT overflew New York and then flew well to the south of Newfoundland, while the NATS MTT overflew Chicago and then only overflew the northern tip of Newfoundland.

In conclusion, the two systems broadly agree except for the KLAX - EGLL flight, although the routes chosen by the UKMO system were slightly superior.

Table 1. Specification of 12 city pairs					
CallSign	Time	Type	Direction	Origin	Destination
BAW176	0612	B747	E	KJFK	EGLL
BAW177	1524	B747	W	EGLL	KJFK
AAL136	0924	B767	E	KLAX	EGLL
AAL137	1248	B767	W	EGLL	KLAX
UAL928	0439	B767	E	KORD	EGLL
UAL929	1224	B767	W	EGLL	KORD
AFR521	0449	B747	E	TFFR	LFPO
AFR520	1321	B747	W	LFPO	TFFR
DAL118	0316	L101	E	KJFK	LFPO
DAL119	1348	L101	W	LFPO	KJFK
ACA870	0419	B747	E	CYMX	LFPG
ACA871	1226	B747	W	LFPG	CYMX

Table 2. Times for the 12 city pairs calculated different ways					
CallSign	NATS GC	NATS MT	UKMO GC	UKMO MT	NATS route, UKMO time algorithm
BAW176	336.4	323.1	339.3	323.6	324.9
BAW177	414.4	389.2	426.2	388.4	391.7
AAL136	628.9	596.2	638.1	582.1	603.5
AAL137	596.0	587.6	609.8	604.8	635.7
UAL928	435.7	405.1	439.7	405.9	407.2
UAL929	457.9	433.4	461.0	446.3	456.0
AFR521	426.7	414.4	435.2	426.7	426.9
AFR520	487.9	475.1	491.3	475.9	479.5
DAL118	354.3	341.7	358.1	342.2	343.2
DAL119	450.4	417.6	464.3	416.9	420.4
ACA870	354.4	334.0	358.0	334.9	335.5
ACA871	389.2	378.4	390.5	377.7	378.2

Costs (in time) of fixed track structure

Experimental set-up

A single study addressed both the cost of having a fixed track structure for a 24 hour period and the cost of having a fixed track structure in which the tracks were collocated in the vertical. The approach was to consider 12 routes (as used in previous study) and 12 dates (4th of each month in 1996). For each of the above a base route was calculated which was the optimum route at 250hPa and T+0. In addition to the base route, optimum routes were calculated at 200hPa, 250hPa and 300hPa, and for T+0, T+12 and T+24. Then we compared the time to fly the base route with the times to fly the optimum route through the winds which were used to calculate the optimum route.

Note that the track structure considered does not allow for aircraft to choose different levels for different parts of the route. This is of course possible and the value of this flexibility can be assessed separately.

Results

The average time differences (optimum route - base route) are shown in table 3.

Table 3. Average time differences (optimum route - base route) (in minutes) as defined above.

	T+0	T+12	T+24
200hPa	1.08	2.96	9.59
250hPa	0.16	3.44	10.90
300hPa	0.38	4.12	8.75

The figure in table 3 for 250hPa and T+0 should be zero. It is not because a three stage calculation is performed - the optimum route is calculated, this route is stored (with finite resolution) and then the time to fly the route is calculated later - this is not the same time as would be calculated at the time the original route was derived because of truncation errors in the specification of the route. Intuitively one would expect the figures for 250hPa to be lower than those for 200hPa and 300hPa at the same time, but clearly it is possible for a forecast for, say, 300hPa at T+24 to more closely resemble the analysis at 250hPa than does the forecast for 250hPa at T+24. The conclusion from table 3 is that the costs of a track structure in which the routes are collocated in the vertical is relatively small (of the order of or less than one minute) whilst the cost of applying a track structure to flights 24 hours after the time for which the structure was optimal is large (of the order of or less than ten minutes). If a track structure is fixed for a period of 24 hours, and is optimal for the central time in the period, then the cost is less than the T+12 cost. However the practical method of determining the track structure has a considerable subjective element so it is not clear that it is "optimal for the central time".

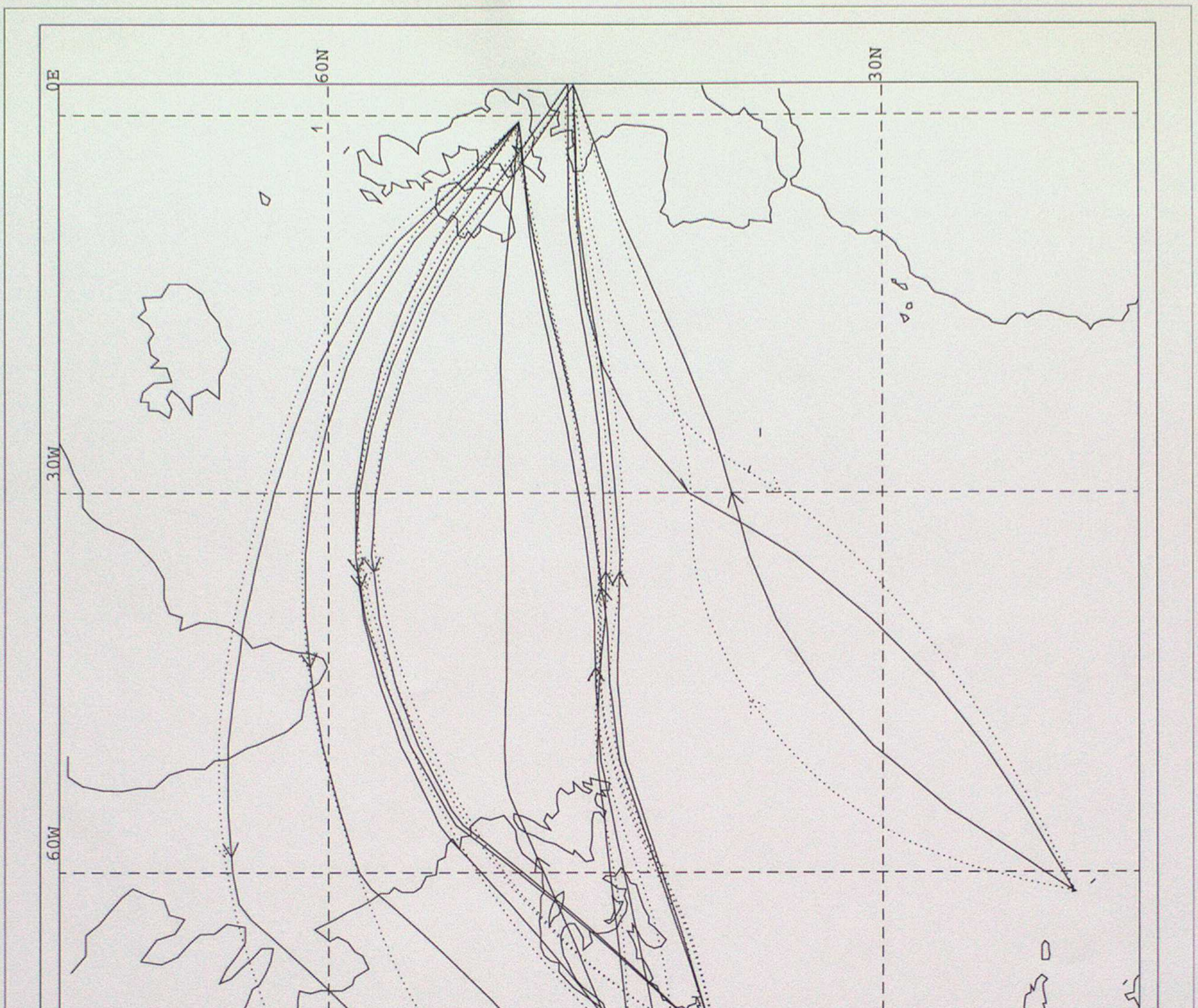
In the above, we are assuming that the difference between an analysed wind field and a 12 hour forecast based on that analysis is broadly similar to the difference between two analyses 12 hours apart.

Overall Conclusions

The two MTT models agree sufficiently well for the conclusions of the cost saving calculation to be considered valid (to the nearest minute or so). These conclusions are that the cost associated with having tracks collocated in the vertical is small while the costs of keeping the track structure fixed for 24 hour periods is larger, the actual size depending on how the track structure is determined.

A subsidiary conclusion of the model intercomparison is that, for long flights, if there is a constraint on the route part way along, then the maximum time saving may not be achieved.

Figure 1. Shows MTTs between city pairs identified in table 1, with NATS MTTs shown as continuous lines, and UKMO MTTs shown as dotted lines.



0E
60N
30N
30W
60W
90W