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POTENTIAL FUEL CONSUMPTION SAVINGS IN MEDIUM-TO HIGH DENSITY EXTENDED TERMINAL AREAS

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SUMMARY

With a view to more cost-effective control of inbound traffic every endeavour was made to (a) obtain reliable fuel consumption estimates for actual flights as observed by ground-based surveillance systems and (b) investigate the potential effect of alternative control procedures.

The work fell into four parts:

(a) comparison of cruise/descent speed profile control with the usual delay control techniques;

(b) real time application of cruise/descent speed profile control in the case of a flight path extending over some 200 nm;

(c) development of a method to derive information on consumption under actual operating conditions from data available to the ATC authorities and validation of the model using airline flight simulators;

(d) estimates of realistic fuel savings in actual extended terminals including and surrounding medium and high-density airports on the basis of real traffic data collected in the Brussels and London areas in cooperation with the national authorities.

This paper summarises these developments, investigations and conclusions and refers to the detailed reports for further information.

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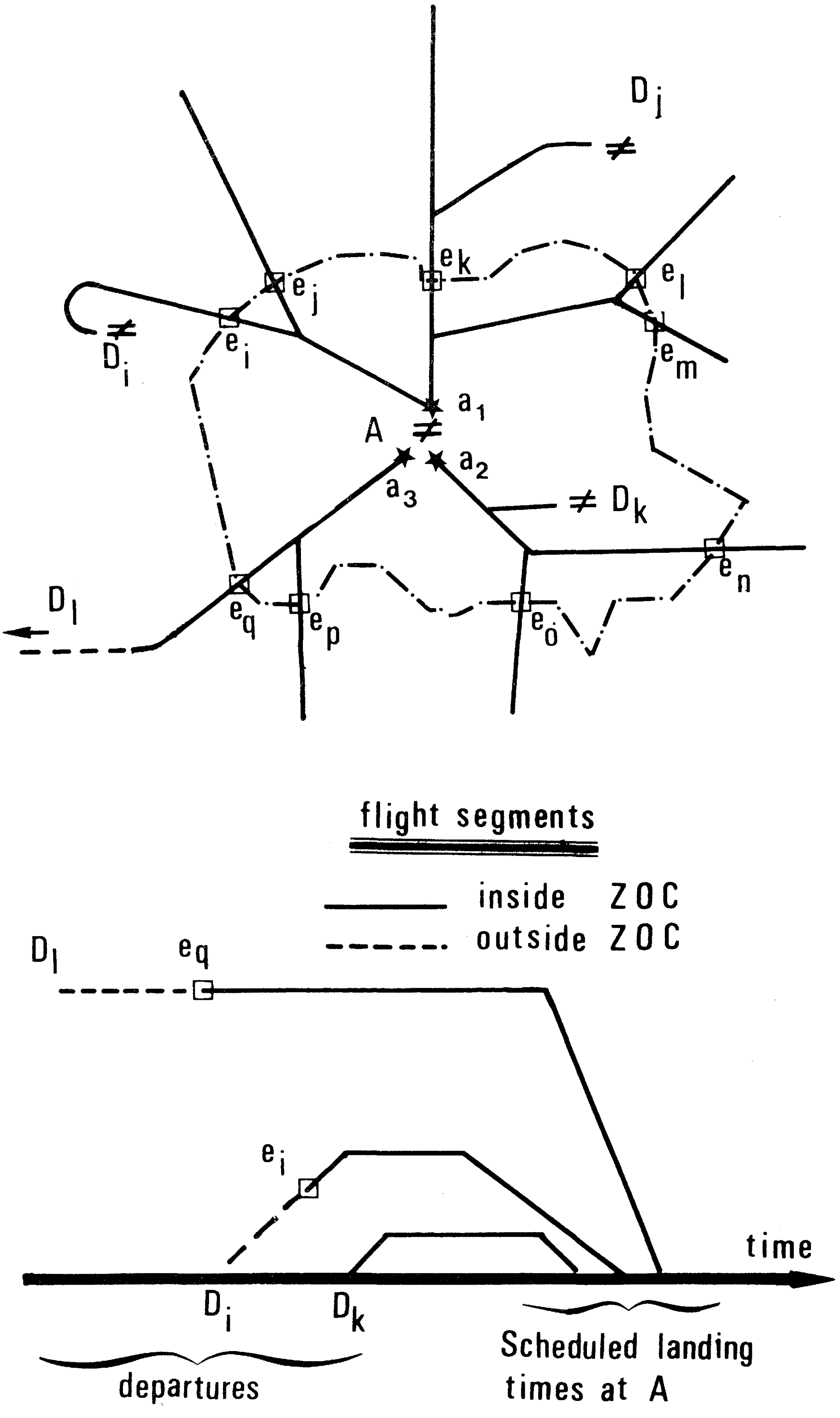
1. INTRODUCTION

A comprehensive survey of the potential contributions of Air Traffic Control to air transport economy was carried out recently by the General Directorate of EUROCONTROL at the request of the Commission of the European Communities (Reference 1). At virtually the same time, an independent investigation, more specifically orientated towards United Kingdom applications, was undertaken by the Civil Aviation Authority (Reference 2).

These surveys, certainly the most exhaustive available to date in Western Europe, clearly indicate the lack of adequate tools to measure the economy aspects of air traffic and more specifically the impact of the introduction of new control procedures on fuel consumption and the cost of air transport. In this short report, it is intended to indicate the efforts that have been made in order to determine reliably the potential improvements in flight economy which could and should result from the introduction of adequate cruise/descent profile control in an extended area including and surrounding a medium or high-density terminal (Figure 1 from Reference 3).

In such an area, which is referred to as a zone of convergence (ZOC), the inbound flights, except for a few connections from secondary airports, will essentially be made up of all or part of the cruise phase, the en-route descent and the final descent and landing phases. For a given cruise altitude, the consumption and cost of a flight will greatly depend on the ATC control procedure, which affects the speed history of the aircraft throughout the zone. It is of interest to measure this impact in a comparative manner, within a realistic framework of assumptions.



Schematic structure of a zone of convergence (ZOC)

Figure 1

This was done in several steps as outlined below.
The results presented do not presuppose any particular scheduling/sequencing technique other than ensuring proper use of the available runway capacity consistent with what is achieved today . The effect of optimising the sequence of arrival times will be discussed only briefly.

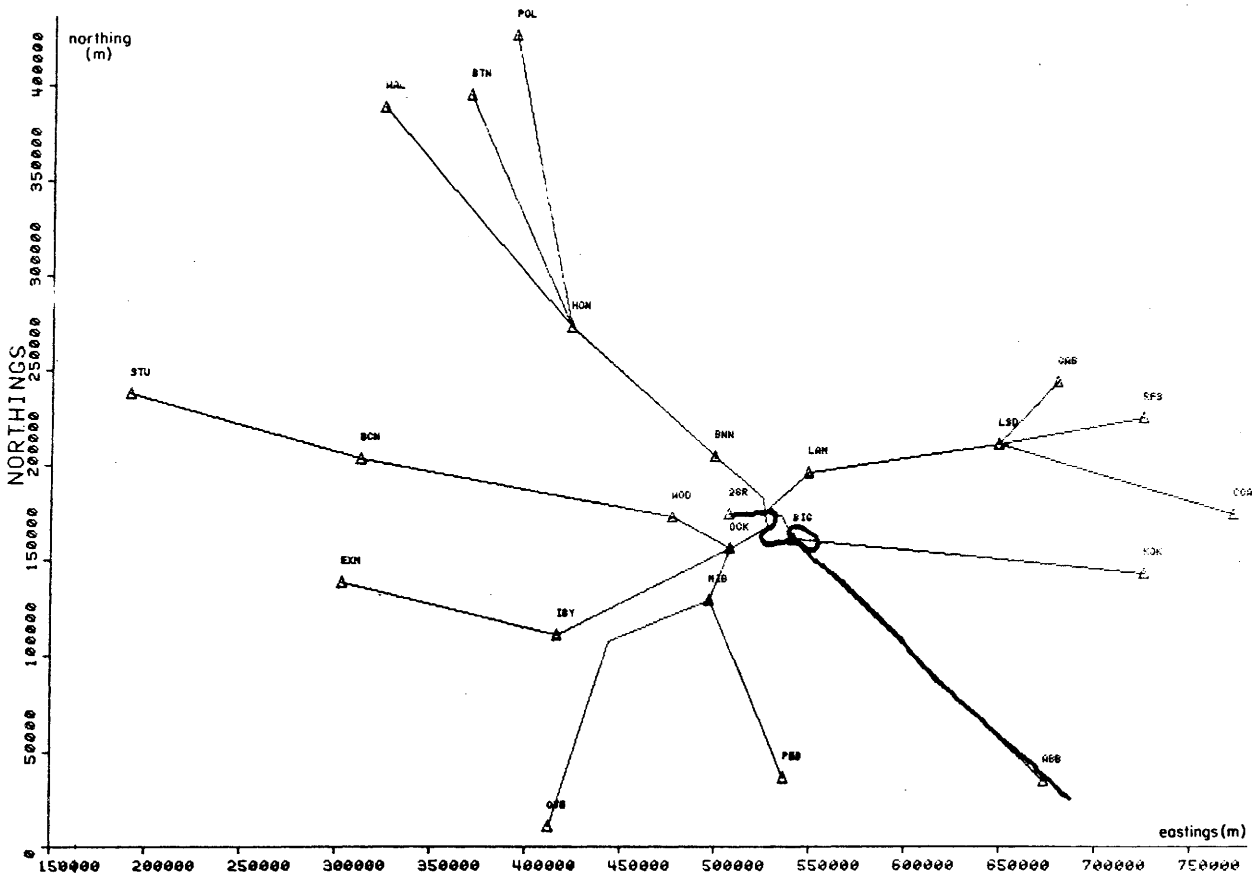
However, the savings in fuel which should result from the introduction of a flight control procedure integrating both en-route and approach phases will, in view of their importance, be discussed in detail.

2. CONTROL OF INBOUND FLIGHTS

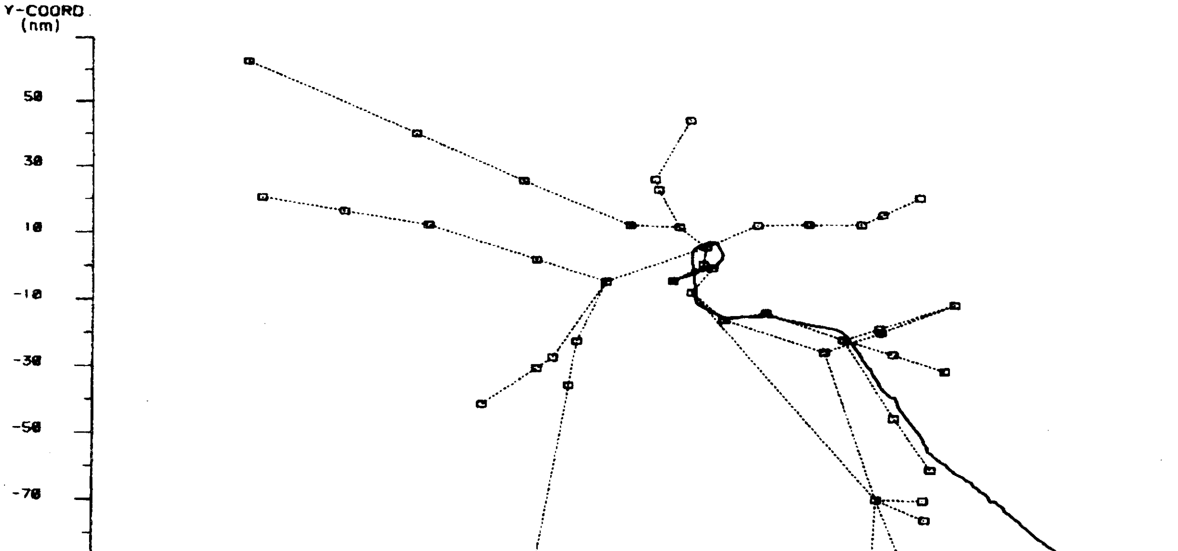
Each individual aircraft in the traffic inbound to a given airport is sooner or later assigned a particular landing slot which will depend on a number of factors such as traffic configurations and densities, local policies, level of automation and type of coordination between en-route and approach control functions.

The result is that each aircraft takes a specific time to transit from entry into the zone (point 'e' in Fig. 1) to landing. The transit can then be made up of a rather complicated profile including preferential speed for a period of time in the en-route phase, deceleration, level-off during descent, holding and possibly path-stretching, as trajectory records show (see illustration for two flights inbound to Brussels and London Heathrow in Figures 2a and 2b from References 4 and 5 respectively.

There are accordingly a number of ways to control the aircraft from entry to touch down. Nevertheless, as regards both economy and traffic control efficency, it would appear that proper control should be made up of two essential components :



STRUCTURE OF INBOUND ROUTES TO LONDON-HEATHROW
Illustration of a typical arrival
Figure 2(a)



STRUCTURE OF INBOUND ROUTES TO BRUSSELS-NATIONAL
Illustration of a typical arrival
Figure 2 (b)

a) a scheduler/sequencer to determine the transit speed profiles and the sequence of landing times for the traffic concerned;

b) a duly coordinated ground/air control procedure for the cruise/descent speed profile control of each individual aircraft in order to meet the corresponding landing slot in a realistic and reliable manner in the face of all possible perturbations.

In the following section, the impact of cruise/descent speed control on consumption and, as a result, on economy will be discussed in terms of present practice.

3. CRUISE/DESCENT SPEED PROFILE CONTROL COMPARED WITH PRESENT PRACTICE

3.1. Scope of the investigation

Under the present procedure, an aircraft may, on arrival at an assembly point, i.e. the point of entry in the terminal area, have to wait before being offered a landing time. The excess time may be spent in a number of ways, including diversion at cruise level, holding at cruise or high altitude and path-stretching at low altitude, e.g. FL 50. Of these, holding at high altitude is the least costly. Accordingly, the comparison between speed profile control and present practice will only be made for holding at high altitude, which offers the advantage of providing lower-bound estimates of potential savings.

It should also be noted that if the actual transit time of an aircraft through the zone is restricted by the overall traffic situation, the minimum-cost transit is determined by the speed profile which gives minimum fuel consumption for the relevant transit time.

The maximum delay or advance which can be accommodated through cruise/descent speed profile control is governed firstly by the aircraft's operational speed range and secondly by the flight distance over which speed control can be exercised. Obviously, if the delay required is outside the available range, the excess period will need to be absorbed by means of one of the four delaying techniques mentioned above.

The distance over which cruise/descent speed profile control is possible is related to the flight segment, as indicated in Figure 3.

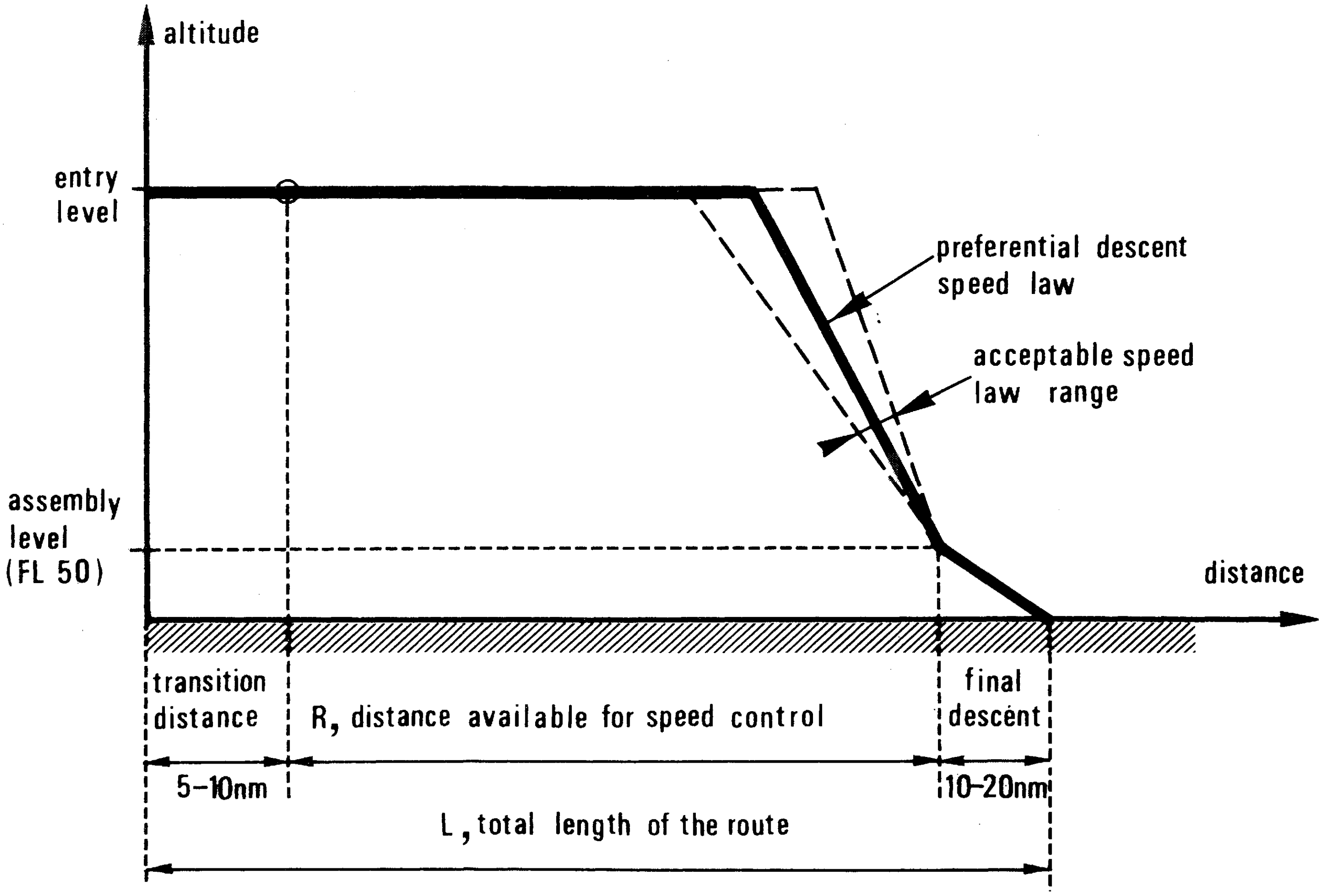
An analysis carried out in 1979 (Reference 6) provided detailed results for a wide range of flight configurations, covering

- five types of aircraft similar to the F-28, B-737, Trident 3B, DC-10 and B-747;
- three different cruise altitudes, namely FL 200, 250 and 300 for the first three aircraft and FL 250 and 350 for the other two;
- segment lengths (entry to landing) of 100, 150 and 200 nm;
- a range of delays covering the complete operational speed range for each aircraft/cruise altitude configuration.

The next paragraph summarises briefly the results obtained for some typical segment lengths.

3.2. Comparison and results

The results presented below cover a typical case representative of total flight distances of 100, 150 and 200 nm.



CONTROL DISTANCE VERSUS SEGMENT LENGTH

Figure 3

The cruise/descent speed profile selected to accommodate the delays imposed by the air traffic control authorities is characterized by a smooth cruise-to-descent transition, that is to say a profile for which cruise and descent speeds are defined by the same Mach/CAS values (Reference 7).

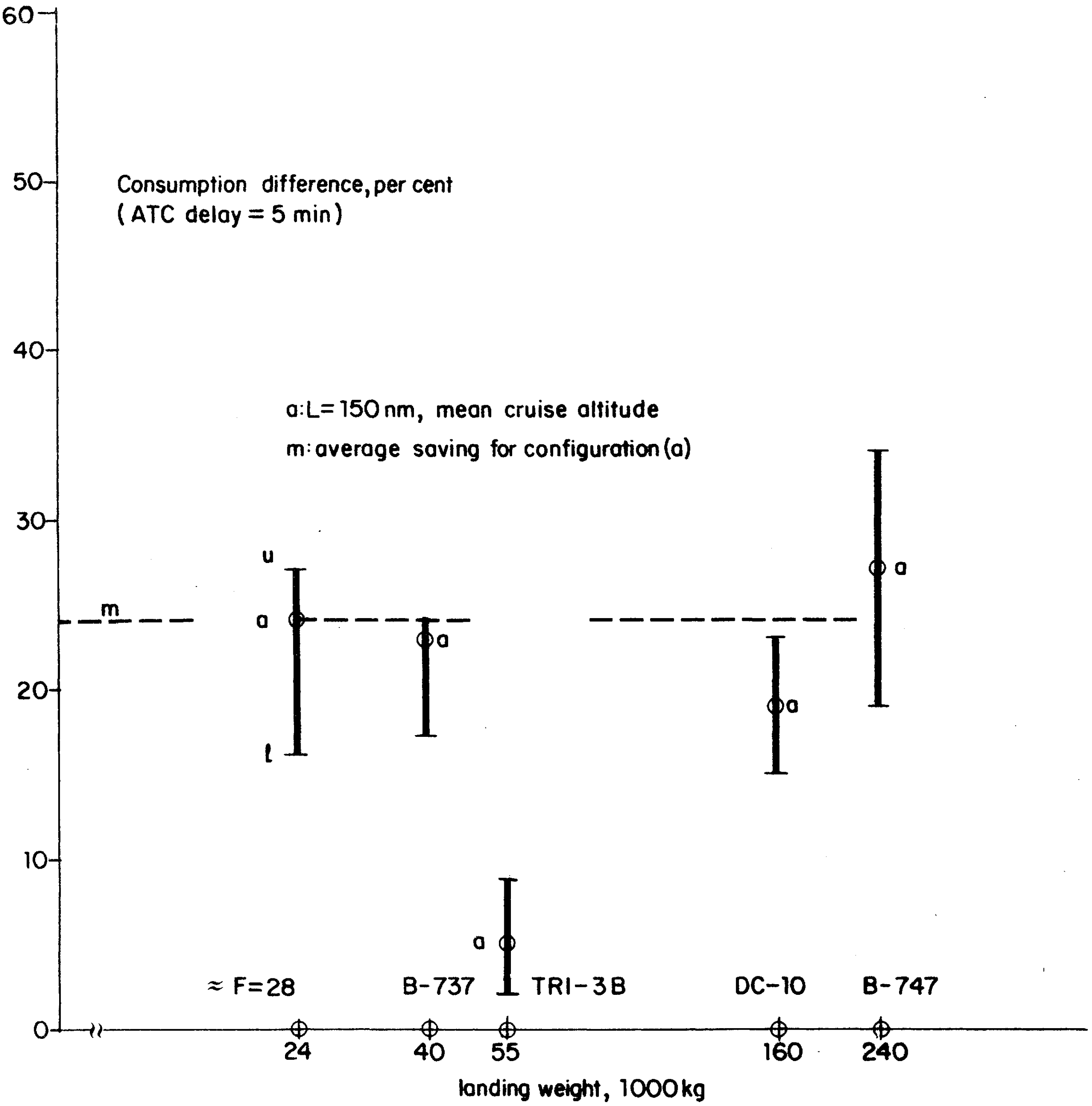
Figure 4 summarises the results obtained for a 5-minute ATC delay.

The points marked "a" refer to a total flight distance of 150 nm at the mean cruise altitude. The values obtained for other configurations fall within the range "l-u" as indicated. These include segment lengths of 100, 150 and 200 nm combined with the three cruise altitudes considered.

With the exception of aircraft represented by the Trident 3B (*), the advantage of cruise/descent speed profile over holding at high altitude to absorb an ATC delay of 5 minutes varies from 15 % to 34 % within the range of flight configurations envisaged. These values are referred to the corresponding amounts of fuel required to transit from entry to landing, with the ATC delay included.

If the savings noted for configuration (a), namely a segment length of 150 nm and mean cruise altitude, are averaged over the sample of aircraft, Trident 3B excluded, a mean value of 24 % is obtained.

(*) The particular results obtained for aircraft similar to the Trident 3B are due to the specific characteristics of this aircraft. It is a representative of an older generation of aircraft which was designed for high-speed operation. It is consequently most fuel efficient at higher descent speeds and as a result speed control using the smooth cruise-to-descent transition technique is less effective for such an aircraft type.



ADVANTAGE OF CRUISE / DESCENT SPEED CONTROL
OVER HOLDING AT HIGH ALTITUDE
(Fuel difference referred to delayed transit consumption)
Figure 4

3.3. Illustration : Flight conducted on the DC-10 simulator

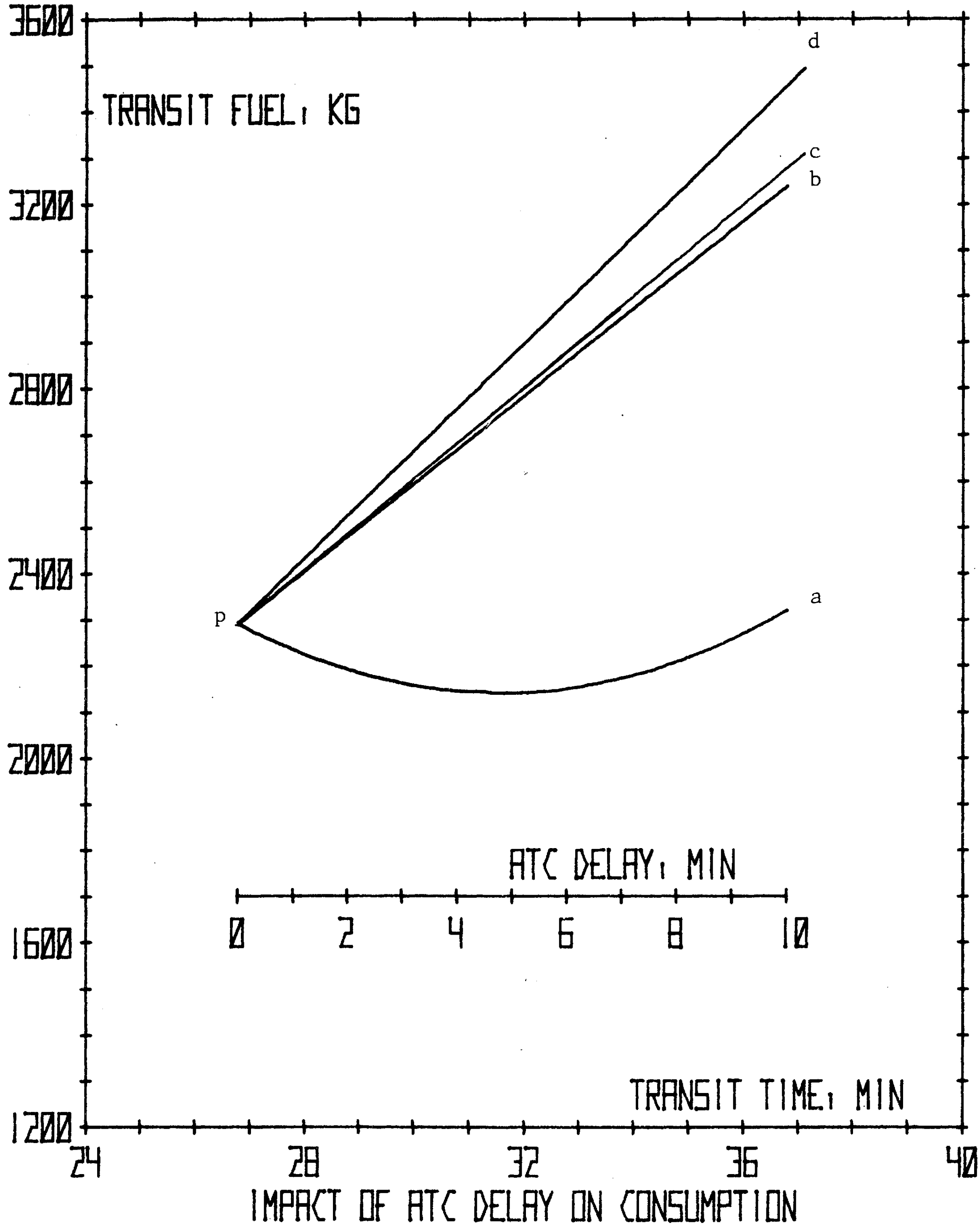
The flight was performed from Pampus to Frankfurt, along the route PAM - DOM - GMH - LIM - MTR, cruising at FL 300. The preferential speed recommended by the airline corresponds to the points marked "p" in Figure 5. This is the speed at which the pilot would proceed if no other directive were given by ATC. If the aircraft then had to wait for a landing slot, the consumption would increase with the delay, as indicated by the line "pb" for an aircraft holding at high altitude.

If, however, the same landing slot were assigned when the aircraft entered the zone, cruise/descent speed profile control would be possible and the consumption would vary as indicated by the curve "pa". Under such flight conditions, the difference between the absorption of delays by cruise/descent speed profile control or by holding, say at cruise altitude is, in terms of fuel consumption, as follows:

- about 500 kg of fuel for a 5 minute delay (23 %);

- almost 1 ton of fuel for a 10 minute delay (44 %).

With a fuel/time cost ratio of the order of 0.016 min/kg, the differences in extra cost resulting from such delays absorbed through cruise/descent speed control instead of holding is even higher. (Reference 3).



IMPACT OF ATC DELAY ON CONSUMPTION

a. Control of cruise-descent speed
b, c. Holding at cruise and low altitude, respectively
d. Path stretching at cruise conditions

4. ESTIMATES OF NUGATORY FUEL CONSUMPTION UNDER ACTUAL OPERATING CONDITIONS

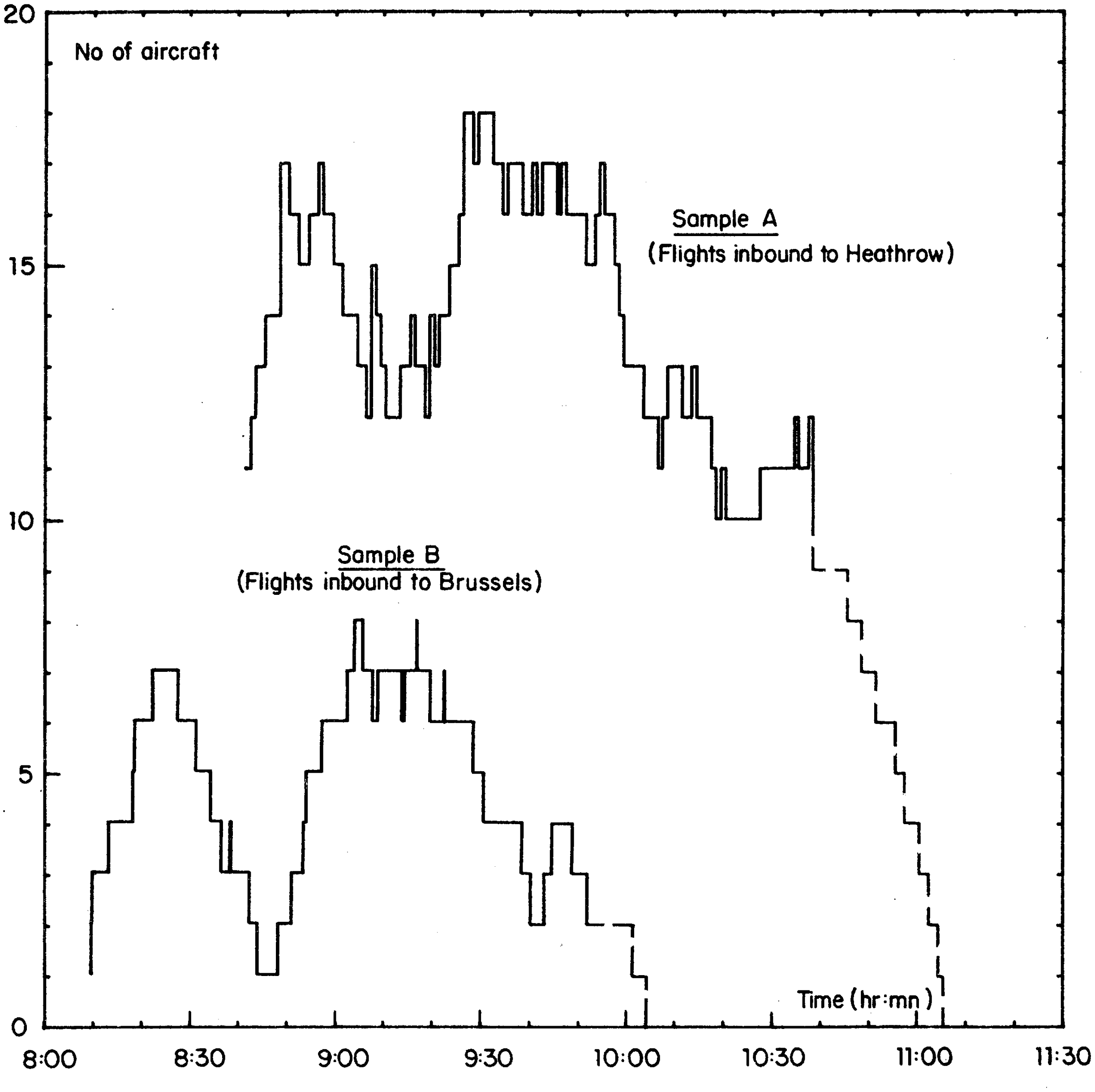
The aim of the investigation summarised in this section, was to obtain preliminary estimates of the potential savings which could be made under actual operating conditions if the control of the inbound traffic covered the final approach phase, the en-route descent and part of the cruise. Two typical traffic configurations where selected, namely one representative of a European medium-density traffic terminal, based on the Brussels area, the other typical of an area including one or several high-density traffic airports, based on the London zone. The specific objective of the exercise was to determine an upper bound for the possible consumption savings and an estimate of realistic savings, taking into account the existing traffic structure and the available runway capacity.

4.1. Actual traffic samples

The geographical areas covered are shown in Figures 2a and 2b for the Brussels and London zones respectively. In both cases, the extent of the zone was essentially dictated by radar coverage, that is around 130 nm. However, where feasible, it was extended to include a larger part of the cruise. In both cases, the sample of traffic covered a period of about 24 hours. It included a maximum number of 18 aircraft heading simultaneously towards Heathrow and 8 towards Brussels National. The distribution of aircraft in time is given in Figure 6. The information collected included :

- radar information,
- flight plan data,
- runway log of arrivals,
- atmospheric wind and temperature versus altitude.

Detailed accounts of the information collected in order to constitute the two traffic samples are given in Refrences 9 and 10 for Brussels and London respectively.



EVOLUTION OF DENSITY OF INBOUND TRAFFIC

4.2. Estimates of fuel consumption

Using methods developed previously (References 11 to 13), it was possible to determine estimates of instantaneous fuel flow on the basis of the aircraft speed history, an average landing mass being assumed for each type of aircraft.

The fuel burnt by the aircraft inbound to the airport considered and which actually landed during the survey period is represented by curves (a) in Figure 7. This figure shows the evolution of the amount of fuel actually consumed in the area as the traffic in this limited sample built up.

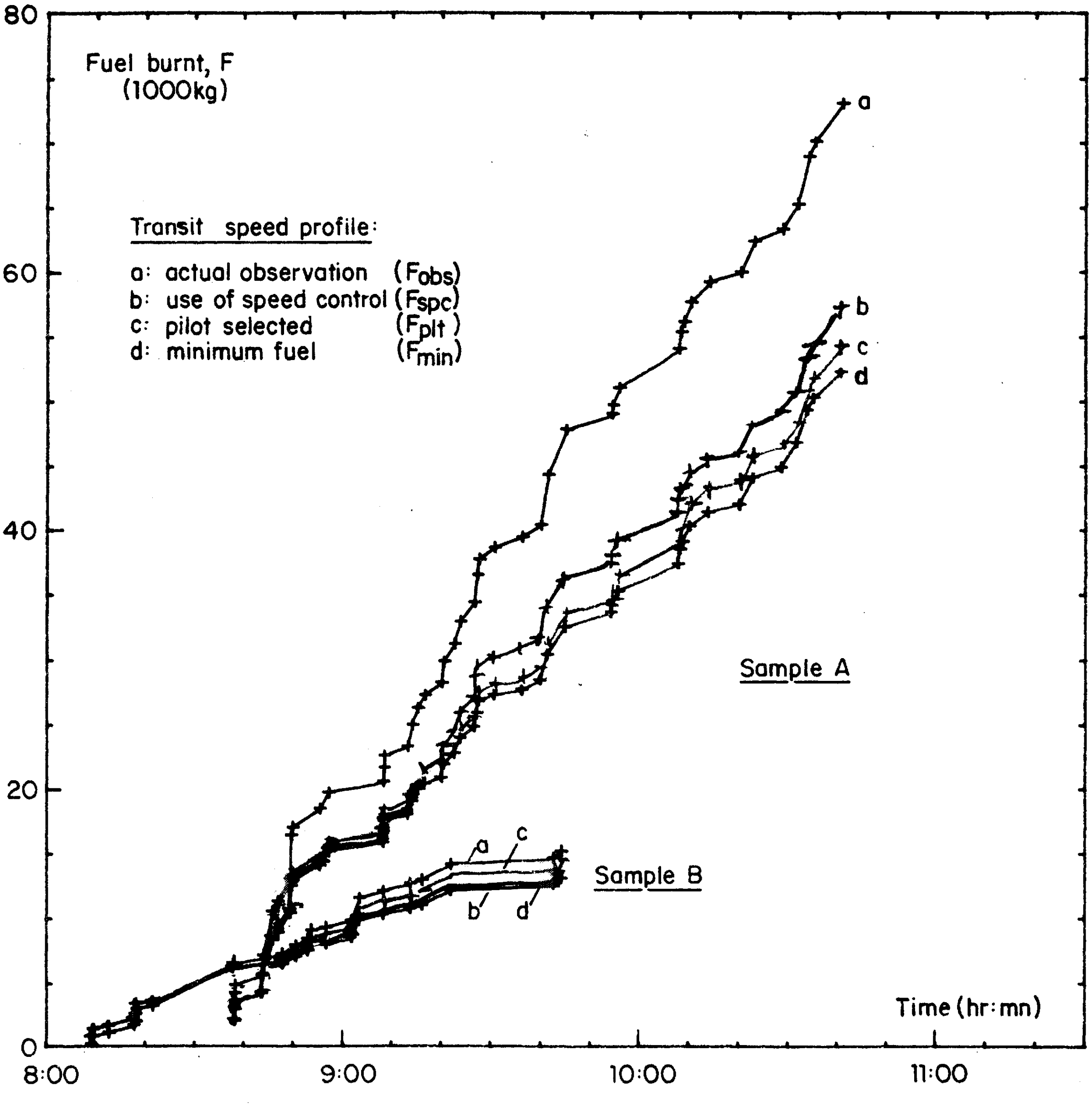
Over an approximately two-hour period, some 75 tons of fuel was actually burnt in the London area by the traffic inbound to London Heathrow alone. The corresponding amount was of the order of 15 tons in the Brussels area.

The obvious question that arises concerns the fraction of this quantity which could feasibly be saved. To clarify the matter, several typical control scenarios were envisaged.

4.3. Cruise-descent transit scenarios

4.3.1. Actual (observed) transit procedure

Depending on local practice and traffic conditions, the trajectory flown by an aircraft from entry into an area until it lands is determined by a number of factors controlled partly by the pilot and partly by the ATC authorities. The relevant time of transit and the consumption are referred to as actual observations. The evaluation of the amount of fuel burnt in the area is illustrated in Figure 7 by curves (a), as discussed in Section 4.2. The aim of the exercise was to determine what benefits might possibly have been achieved if other cruise/descent speed profiles had been used instead of the observed ones. To this end three different typical transit procedures were considered, as described in the following paragraphs.



FUEL BURNT IN EXTENDED TERMINAL AREAS
Sample A: Traffic inbound to London-Heathrow
Sample B: Traffic inbound to Brussels-National

4.3.2. Minimum fuel consumption

For an aircraft entering an area at a given altitude and flying a given air route segment, there is one specific cruise/descent profile which will minimise the fuel consumption. If all aircraft flew in accordance with such a profile, the total amount of fuel burnt by the aircraft in the sample would be minimum. Obviously, various factors, in particular the traffic situation, make such an ideal procedure difficult or even impossible to implement. Nevertheless, the difference between the actual and minimum consumptions provides an upper bound for the savings which could possibly be achieved.

The estimates of consumption which would result from such a hypothetical procedure are presented as curves (d) in Figure 7.

4.3.3. Pilot's preferred transit procedure

Generally a pilot would aim to fly in accordance with the airline's recommended cruise/descent speed profile that would ensure execution of the flight at minimum cost. In the exercise, the preferential profile was considered to be the observed profile until this was clearly affected by ATC intervention.

The fuel consumption which would result from such a transit is shown as curves (e) in Figure 7.

4.3.4. Minimum consumption under ATC constraints

The actual transit time from entry to landing is known from the data collected. Keeping this transit time unchanged, the cruise/descent profile is selected to achieve the minimum consumption for this time constraint (Reference 14). This consumption also corresponds to the minimum cost for the particular transit time considered. Obviously, control of the profile is limited to the range that is operationally acceptable for the individual aircraft, the remaining time being spent, whenever necessary, in holding patterns.

In conducting the flight at minimum-consumption operating speeds, whether constrained or not by ATC, two possibilities were considered whenever the actual route differed from the planned route. The differences may result from specific control directives, which may or may not be in response to a pilot's request. In such cases both planned and actual routes were considered. However, no distinction is made in the present abstract, the relevant details being available in the relevant reports (References 4 and 5).

4.4. Comparative assessment of transit control procedures

A comparative assessment was made of the various procedures presented above. The differences are shown in Figure 7.

In order to effect this comparison, the following assumptions were made. Firstly, the order of arrival of the aircraft as defined in the sample (Figure 6) and the evolution of the fuel burnt in the area (Figure 4) correspond to the actual order of entry into the zone.

Secondly, when an observed route was found to be appreciably shorter than the planned one, it was assumed that the corresponding short-cut had been agreed by ATC and the corresponding consumption was accordingly used.

The following comparisons were made :

(1) minimum consumption against actual fuel burnt (curves (d));
(2) pilot's preferential profile against observation (curves (c));
(3) control of descent and/or cruise profile components against observations (curves (b)).

In these three cases, the differences obtained were compared with both the actual consumption figures and the results expressed in percentages for both the London (Figure 8a) and Brussels (Figure 8b) areas.

4.5. Concluding remarks on the analysis

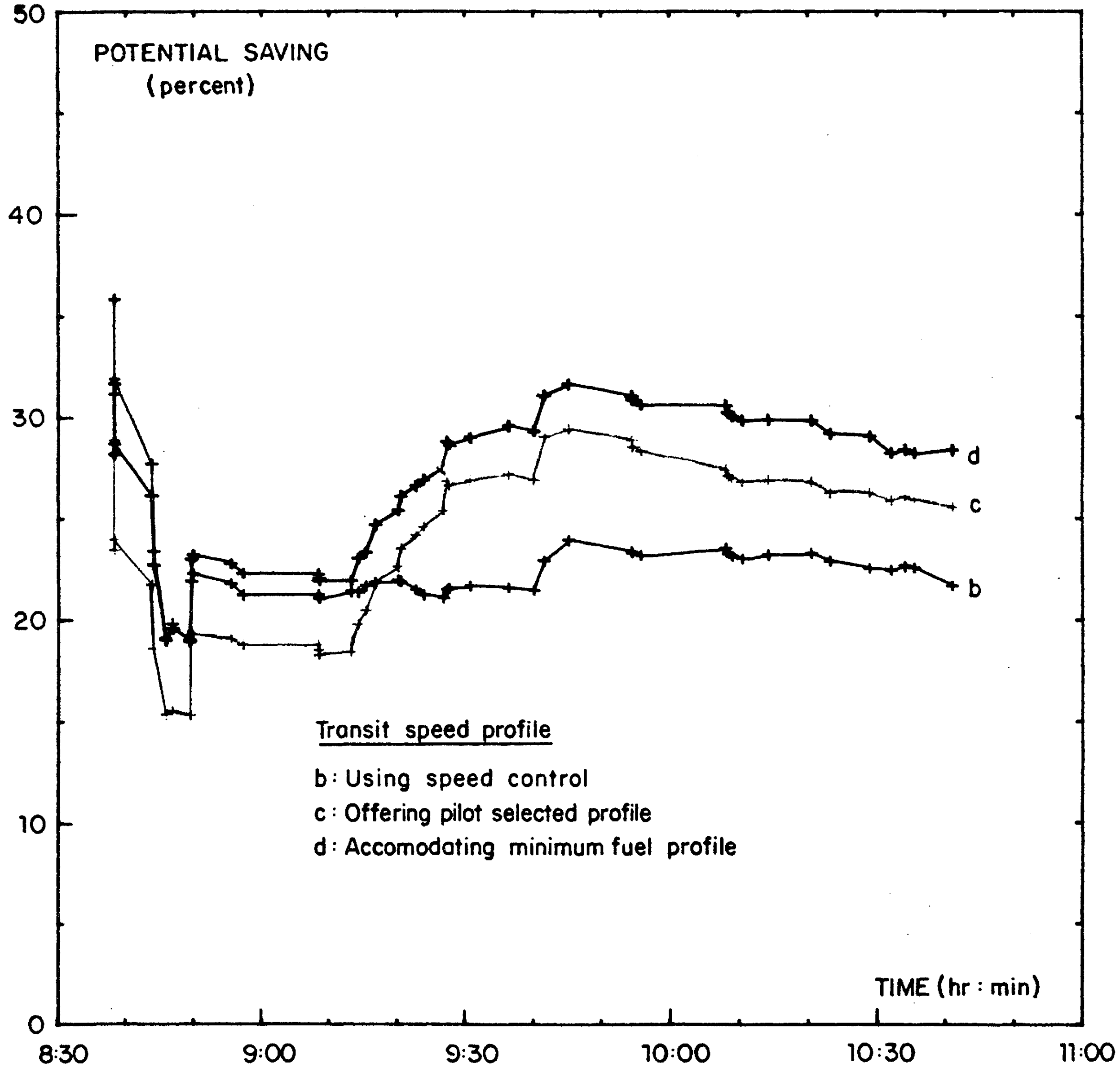
The following general conclusions can be drawn from the analysis carried out.

(a) For the two limited samples considered, namely

London area
- period of slightly more than two hours;
- 08.20 to 10.30 hrs one morning in July 1980;
- 46 flights inbound to London Heathrow;
- maximum of 18 aircraft simultaneously present in the zone;

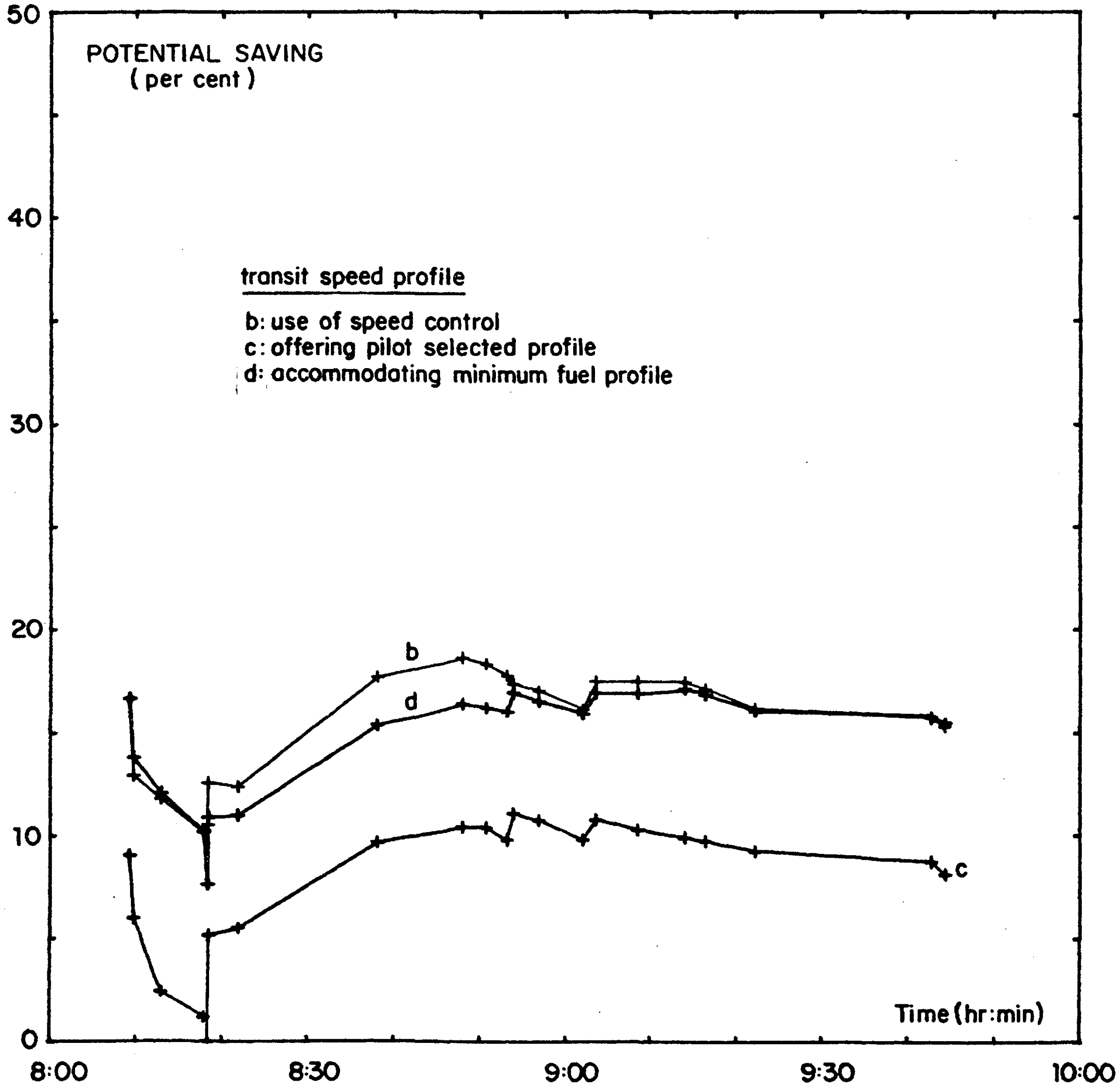
Brussels area
- period of slightly less than two hours;
- 08.00 to 10.00 hrs one morning in April 1981;
- 21 flights inbound to Brussels National;
- maximum of 8 aircraft simultaneously present in the zone;

the total amounts of fuel burnt in the areas were estimated to be 75 and 15 tons respectively.



POTENTIAL FUEL SAVING IN AN EXTENDED TERMINAL AREA
(Traffic inbound to Heathrow)

Figure 8(a)



POTENTIAL FUEL SAVING IN AN EXTENDED TERMINAL AREA
(Traffic inbound to Brussels)
Figure 8(b)

(b) Control procedure scenarios

Besides the actual transit procedures observed, three different control scenarios were considered namely minimum fuel consumption given the entry conditions, pilot's (airline's) preferential profile as derived from initial ob servations, and realistic control of the cruise/descent speed profile.

- The minimum consumption procedure provides a lower bound for the quantity of fuel required to bring the aircraft from entry to touch-down. It is obtained when each aircraft is considered to be alone in the system and operating in accordance with the minimum consumption cruise/descent profile.

  The difference with respect to the actual consumption constitutes an upper bound for the potential fuel savings for such a traffic configuration. Expressed as a percentage of the actual consumption, this difference is of the order of 30% for the London sample and about 20% for the Brussels sample (curves (d) in Figure 8).

- On the basis of the observations made before any noticeable ATC intervention occurred (that is to say during the cruise or initial phase(s) of cruise and/or descent), an estimate of the airline's preferential profile was made. As expected, this consumption is slightly higher than the minimum consumption, since it is based on cost criteria which include a time component. The associated average transit time was consequently shorter than that for the minimum consumption procedure. This situation may nevertheless require a high level of control and the result constitutes only an indication of the upper bound for the difference, expressed in terms of fuel consumption between the airline's require ments and the actual service provided.

- The sequence of landing times as observed was determined by the ATC controllers. Keeping this sequence as a reference, but assuming that it was determined at an earlier stage and that the relevant information was used to control an aircraft as soon as it arrived at the entry point into zone rather than the assembly point (see Figures 2a and 2b), the consumption would correspond to curves (b) in Figure 7. In other words, *control of the aircraft speed in conjunction with a simple landing-slot scheduler* (for instance, one that maximises the available landing capacity) would yield an appreciable part of the potential savings. These would amount to 20-25% and about 15% of the estimated actual consumption in the London and Brussels areas respectively.

  The control of the cruise/descent speed profile proved to be extremely efficient in terms of fuel and, consequently cost savings.

It is concluded, on the basis of such results that the impact of the introduction of a simple scheduler on flight economy and the consequent advantages for the environment would be appreciable and these findings would appear to warrant further investigation.

In order to obtain an idea of the accuracy of the estimates of actual consumption derived from ground-based surveillance observations (Reference 13) a limited test was conducted using an airline flight simulator. The results are presented briefly in Section 5.

During this exercise, it was noted that the influence of optimum sequencing was of secondary importance, once proper cruise/descent speed control was executed in terms of maximum available capacity. To investigate this, a limited analysis was carried out using the PARZOC performance approach (References 11 and 12). The results are outlined quantitatively in Section 6.

5. ESTIMATES OF ACTUAL FUEL CONSUMPTION FROM GROUND OBSERVATIONS

5.1. Fuel consumption estimates in a Zone of Convergence

A method has been developed (Reference 13) for the assessment of the actual fuel consumption of an aircraft on the basis of the observed trajectory (position and altitude), meteorological data (temperature and wind profiles) and PARZOC performance coefficients (References 11, 12 and 15). The method covers the en-route climb, cruise and descent, acceleration and deceleration phases included, and takes into account particular effects such as airframe configuration changes.

In addition to estimates of actual fuel consumption based on observations, the program developed also provides estimates of consumption for six different transit procedures which could possibly be considered either as references or as practical control approaches.

The set of relevant FORTRAN programs is referred to as the FUCOZOC system (Fuel Consumption Estimates in a Zone of Convergence).

5.2. Validation results using airline flight simulators

In order to assess the quality of the FUCOZOC approach a number of flights conducted on airline flight simulators were used. A description of these is given in the following paragraphs.

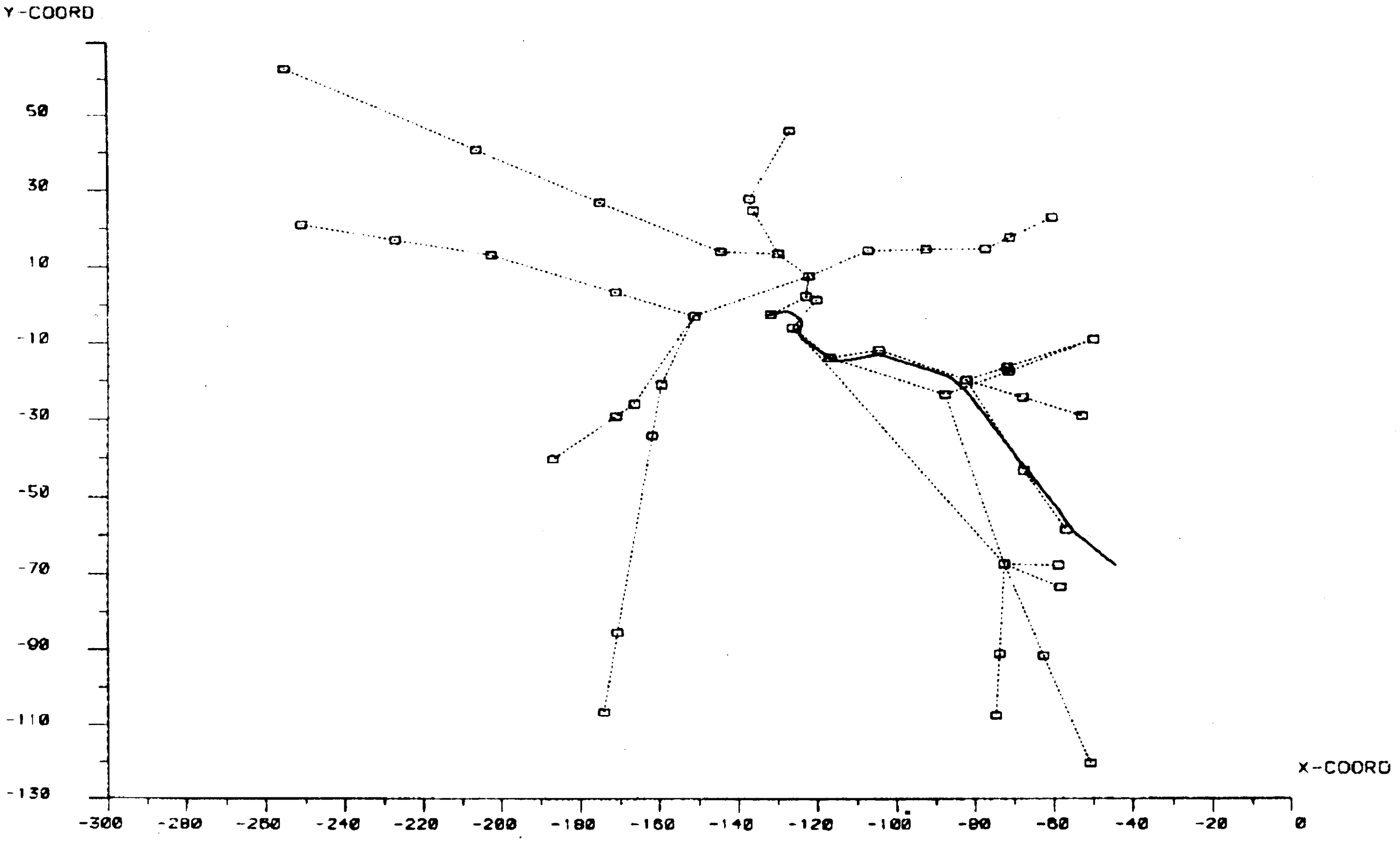
A given flight inbound to Brussels National enters at Nattenheim as depicted in Figure 9. The flight parameters, including in particular, position, speed and fuel flow are recorded automatically. They are as shown in Figures 9 and 10. The cumulative fuel consumption results from the integration of the fuel flow with respect to time.

The position (x, y and altitude) are then entered in the FUCOZOC system together with the aircraft identification. The fuel consumption estimate based on these observations is then calculated. A comparison of the estimate and the measurements made in the cockpit is presented in Figure 11. As can be seen from the diagram, the quality of the estimate appears satisfactory. Nevertheless, it is intended to extend the validation to incorporate measurements made during actual flights

6. RELATIVE INFLUENCE OF OPTIMUM SEQUENCING ON CONSUMPTION AND COST

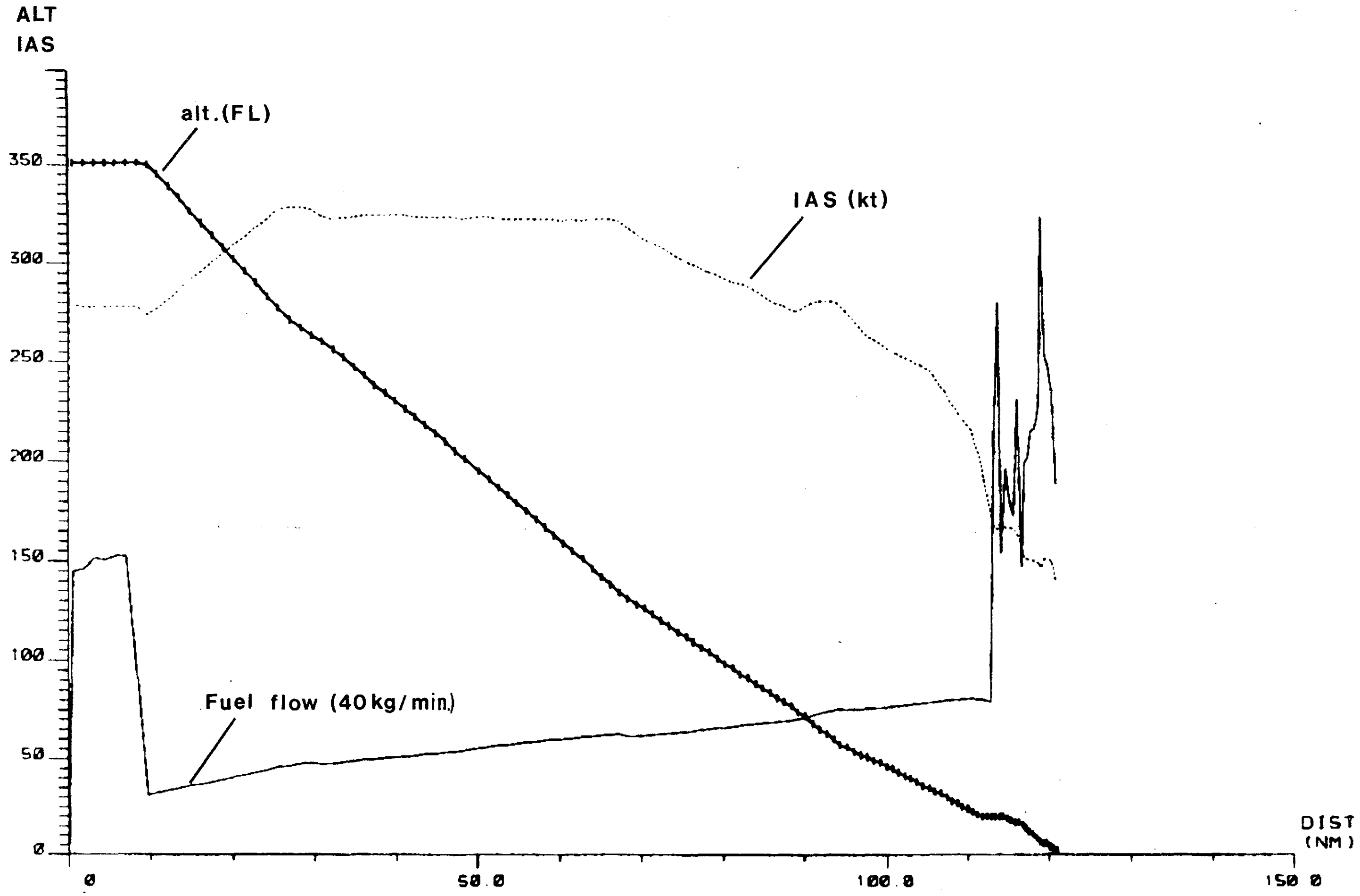
6.1. Cruise/descent speed profile control

In the exercises dealing with traffic observed in the Brussels and London areas (see Section 4), it was noted that cruise/descent speed profile control associated with simple sequencing by the air traffic controllers to ensure use of the maximum runway capacity available would yield a large part of the potential savings, perhaps of the order of 90 %.



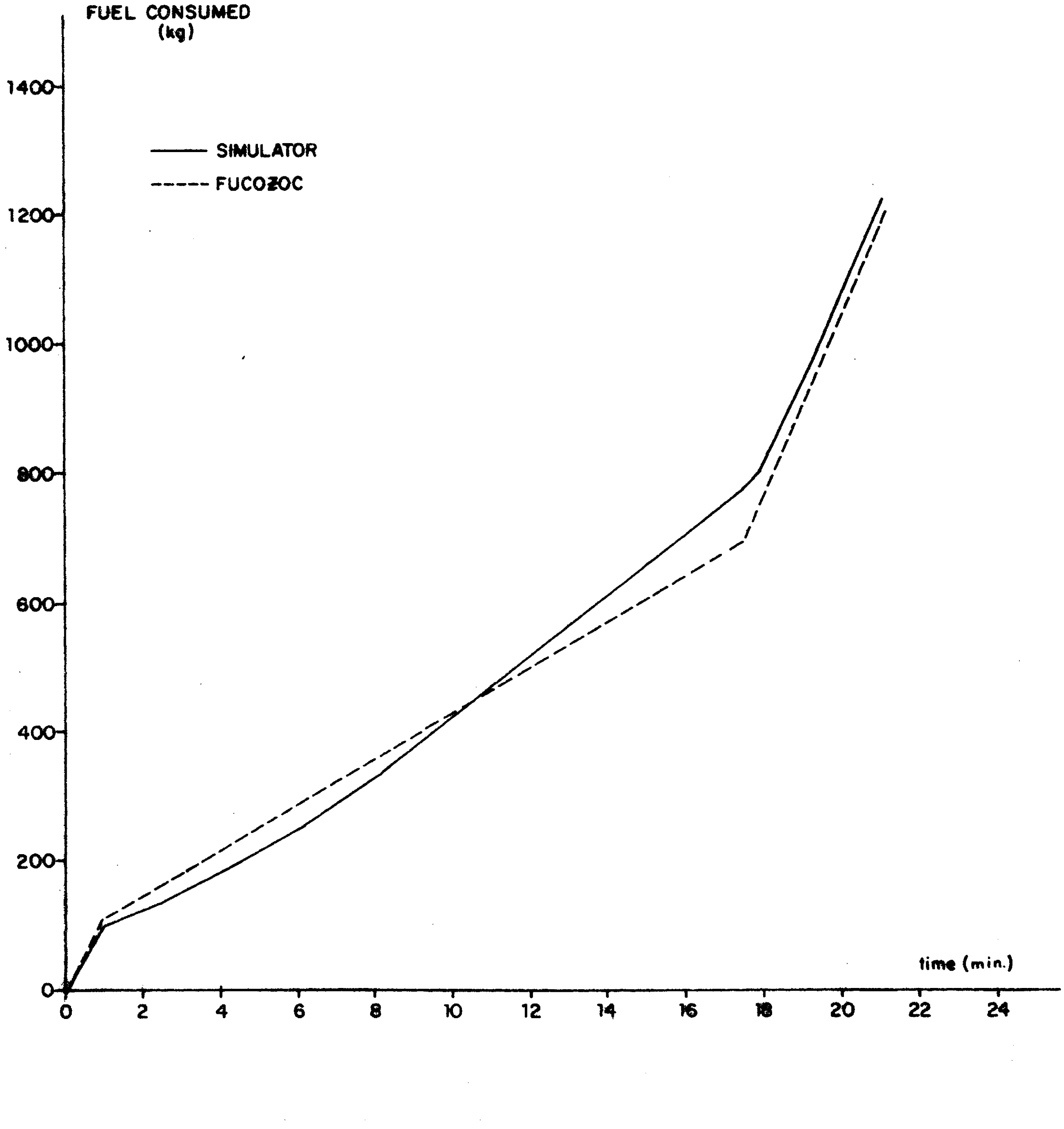
SABENA SIMULATOR EXERCISE ENTRY NATTENHEIM

Figure 9



SABENA SIMULATOR EXERCISE ENTRY NATTENHEIM

Figure 10



VALIDATION OF FUEL CONSUMPTION MODEL

Figure 11

In previous experiments (Reference 14), the expected benefits were not separated into components resulting from scheduling and sequencing. Accordingly, it was of interest to use the tools available in order to assess this particular aspect.

6.2. Traffic conditions

To this end, three sets of 4 aircraft were considered, entering a zone at various altitudes and speeds as detailed in Table 1. Firstly, a flight distance of 200 nm was considered. Cruise/descent profile control was systematically applied. For the purposes of the investigation, it was assumed that a landing window was available to accommodate the 4 aircraft, including adequate separation regardless of their landing order.

Obviously, within the operational speed ranges, there is a sequence which minimises the total transit cost for the four aircraft. The relevant cost expressed in equivalent mass of fuel terms was used as a reference. Now, since there are only 24 different landing sequences for a set of 4 aircraft, it is easy to compare them under the constraint of quasi-maximum use of the runway.

6.3. Effect of sequencing on global transit cost

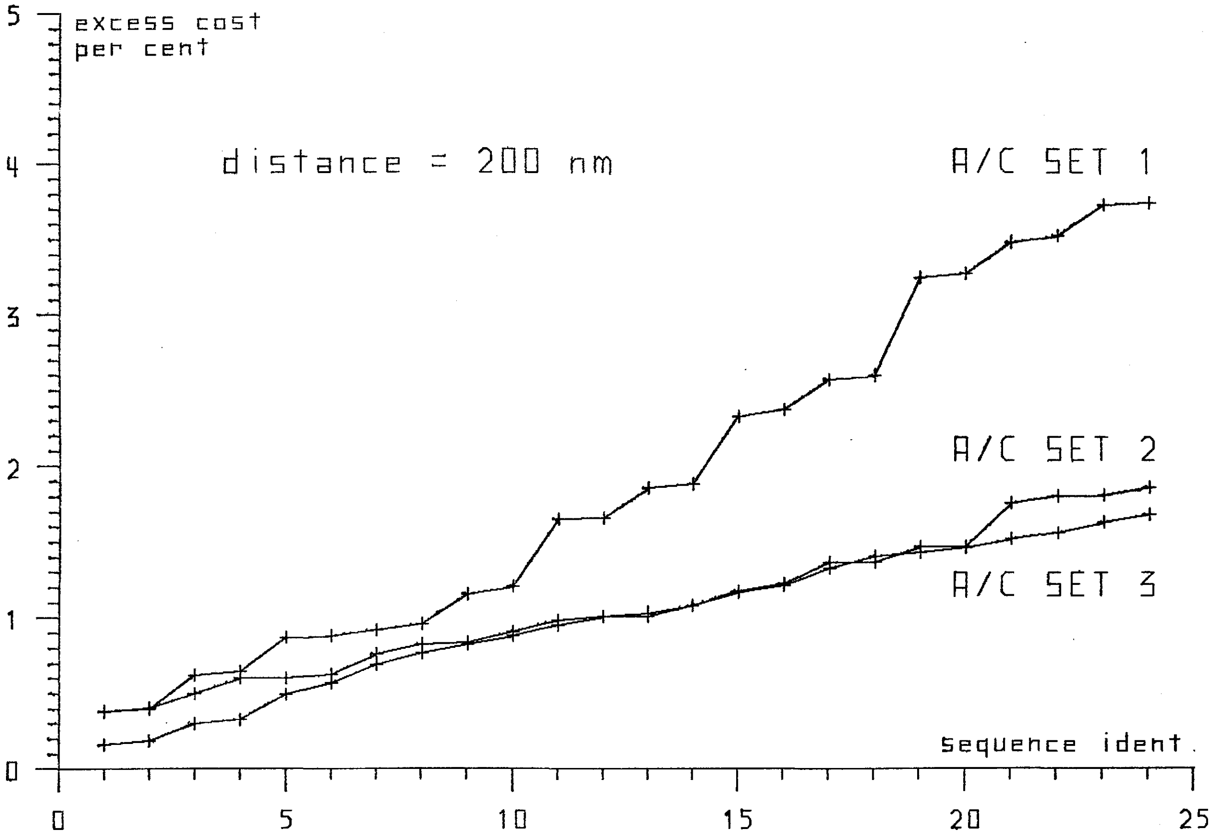
For each of the 24 possible sequences for the 3 sets of aircraft considered the total cost, combining the fuel and time components, was computed. The relative difference referred to the minimum cost sequence is presented in Figure 12a for a flight distance of 200 nm.

For the aircraft of set 1, which comprises 4 appreciably different types ranging from a short-haul light-weight aircraft such as the Fokker F-28 to a long-range wide-bodied aircraft such as the Boeing B-747, the effect of the sequencing may reach a maximum of about 4 %.

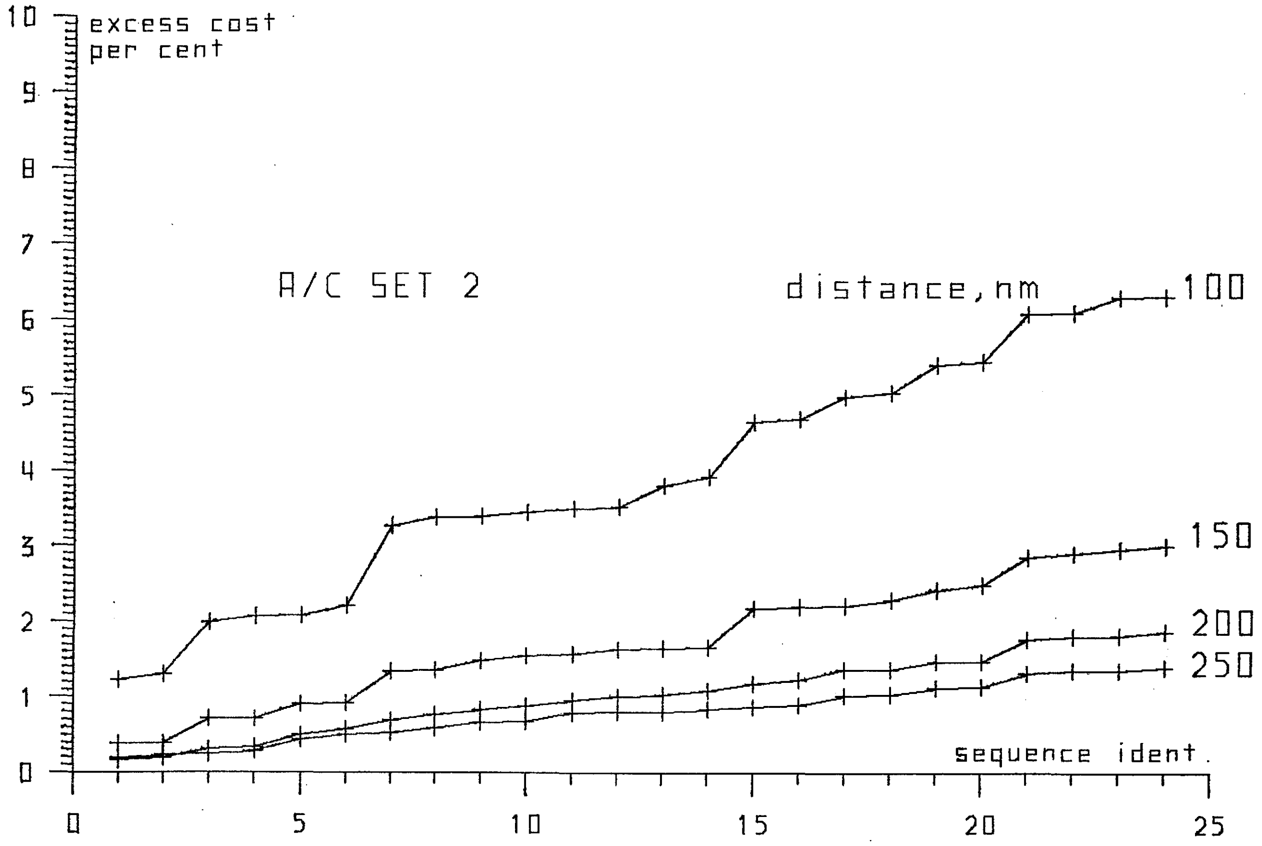
	TYPE	FL	CAS(KT)
A/C SET 1	FK28	311	276
	DC 9	233	306
	B737	230	311
	B747	251	336
A/C SET 2	DC 9	233	306
	TRI3	211	323
	DC 8	275	320
	B737	230	311
A/C SET 3	DC 9	310	291
	B737	310	272
	B737	240	305
	B737	160	305

SETS OF AIRCRAFT AND ENTRY CONDITIONS

Table 1



(a) Effect of various sets of aircraft



(b) Effect of flight distance (from entry to touch-down)

SEQUENCING WITHIN A GIVEN LANDING TIME WINDOW AND ITS EFFECT ON TRANSIT COST

Fig. 12

For sets 2 and 3, the influence of the sequence is even appreciably less important, remaining within 1.5 %.

6.4. Influence of flight distance on the relative importance of sequencing

In order to obtain an idea of the influence of sequencing on various flight configurations, the second set of aircraft (see Table 1) was considered over flight distances ranging from 100 to 250 nm.

The results are presented in Figure 12-b. It is clear that the importance of selecting the optimum sequence increases as the available control distance decreases. Indeed, for a given variation in the time of arrival, the deviation from the optimum speed profiles increases, resulting in higher total consumption and, consequently, higher total transit cost.

For flight distances greather than 150 nm, the excess cost remains within 3 % to the optimum sequence; for a 100 nm flight distance the excess cost as between the worst and the best sequences is approximately 5 %.

6.5. Variation in transit cost due to sequencing : Conclusion

When a given time slot is available to accommodate a set of, for example, four aircraft, the question arises whether the landing sequence of those four aircraft has any great influence on the corresponding transit cost. In order to answer this question, several sample configurations were considered. The results obtained as described above are summarised in Table 2.

It is essential to note that in the case of the results presented here, appropriate cruise/descent speed profile control was effected to meet any specific sequence.

Flight distance (nm)	A/C Set	Transit cost Minimum (1) (kg)	Excess (2) (%)
200	1	11,252	3.3
100	2	5,231	5.0
150	2	7,363	2.6
200	2	10,512	1.7
250	2	13,181	1.2
200	3	7,355	1.3

(1) : optimum landing sequence
(2) : worst landing sequence

TABLE 2

VARIATION IN TRANSIT COST DUE TO SEQUENCING
(Given overall time slot)

Additional information will be forthcoming, but from this limited investigation it might be concluded that optimum sequencing within adequate controlled scheduling would be conducive to a maximum reduction of only 5 % of the relevant transit cost.

7. CONCLUSIONS

A preliminary investigation was made of the benefits which should result from the introduction of a control method integrating all or part of the cruise phase, the descent and the approach and landing phases.

This covered two main aspects :

(a) the development of tools, in particular the development of methods suitable for analysing the effect of scheduling and sequencing taking into account aircraft trajectory, fuel consumption and operational speed range, as well as the production of computer programs for deriving consumption estimates from ground-based information ;

(b) the application of such a control method to actual traffic configurations in order to derive realistic estimates of potential savings in actual geographical areas.

From the analysis conducted and tests made, it appears that

(i) the use of cruise/descent speed control to absorb delays proves to be extremely efficient when compared with current practice or even holding at high altitude. For instance in the case of a 5-minute delay on a segment length of 150 nm, with representative aircraft operating at mean cruise altitudes, such a technique would lead to a saving of fuel of the order of 24 %.

(ii) When systematically used in an area including and surrounding a medium density terminal, such as Brussels, the control of cruise/descent speed profiles could result in an approximately 15 % reduction in consumption in the case of traffic such as actually observed during a preliminary 2 hour test period.

(iii) For an extended area including a surrounding a high-density airport (London Heathrow) the corresponding savings were estimated at 20-25 % in the case of the traffic observed during the 2 hour test period.

(iv) The scheduling of aircraft with a view to making optimum use of the available runway capacity through cruise/descent speed profile control yields the major part of the potential benefits.

(v) The additional sequencing of the landing order would only reduce further the flight cost/consumption by some 5 % at the most.

In conclusion, the results obtained so far clearly indicate that an appreciable fraction of the fuel burnt in an extended terminal area (15 - 25 %) could be saved through adequate control of cruise/descent speed profile, for the introduction of which ground/air coordinated procedures are currently being developed and tested.

8. REFERENCES

1. "Fuel savings in air transport. Possible contributions of Air Traffic Services in Europe". by J.L. Renteux and H. Schröter. EUROCONTROL Doc. 812007, February 1982.

2. "Report of the Air Traffic Management Fuel Consumption Working Group", CARDPB/P (81) 165. Civil Avaiation Research and Development Program Board, October 1981.

3. "Integrated dynamic control for flight economy" by A. Benoît and S. Swierstra, EUROCONTROL Doc. 822042, December 1982.

4. "Estimates of nugatory fuel consumption in an extended terminal area (Traffic inbound to Brussels National)" by A. Benoît, P. Sauer and S. Swierstra, EUROCONTROL, Doc. 812038, March 1983.

5. "Estimates of nugatory fuel consumption in an extended terminal area (Traffic inbound to London Heathrow)" by A. Benoît, P. Sauer and S. Swierstra, EUROCONTROL, Doc. 812021, March 1983.

6. "A minimum fuel transit procedure for the control of inbound flights" by A. Benoît and S. Swierstra, EUROCONTROL Doc. 802007, April 1980.

7. "Introduction of smooth cruise-to-descent transition for application in a zone of convergence" by A. Benoît and S. Swierstra, EUROCONTROL Doc. 812019, July 1981.

8. "The dynamic control of inbound flights. Experiments conducted on the SABENA DC-10 flight simulator", by A. Benoît and S. Swierstra, EUROCONTROL Doc. 822028, June 1982.

9. "Sample of actual inbound traffic for evaluating control aspects in a medium-density terminal (Brussels area)", by A. Benoît and S. Swierstra, EUROCONTROL Doc. 83200, March 1983.

10. "Sample of actual inbound traffic observed in a high density terminal (London Heathrow)", by A. Benoît and S. Swierstra, EUROCONTROL Doc. 832008, March 1983.

11. "Basic fuel and trajectory data to investigate economy aspects of cruise-descent profiles", by A. Benoît and S. Swierstra, EUROCONTROL Doc. 802019, September 1980.

12. "Aircraft (PARZOC) performance data", by A. Benoît and S. Swierstra, EUROCONTROL Doc. 812031-2, April 1982.

13. "A method for estimating actual fuel consumption from ground observations", by P. Sauer, H.U. Schünemann and S. Swierstra, EUROCONTROL Doc. 832006, March 1983.

14. "Optimum use of cruise/descent control for the scheduling of inbound traffic", A. Benoît and S. Swierstra, EUROCONTROL Doc. 802013, February 1980.

15. "Available tools for the prediction, control and economy assessment of flight profiles", by A. Benoît and S. Swierstra, EUROCONTROL Doc. 822033, September 1982.