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ESTIMATES OF NUGATORY FUEL CONSUMPTION IN AN EXTENDED TERMINAL AREA

(Inbound traffic to London Heathrow)

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SUMMARY

In order to estimate the amount of fuel burnt in an extended area surrounding and including a main terminal an investigation was undertaken. The main objectives were as follows :

(a) development of a method to derive sufficiently accurate consumption information from ground observation;

(b) collection of a sample of actual data convering all flights inbound to a high density airport over a sufficiently long period;

(c) comparison of several control approaches for the transit of the inbound trafic through the area;

(d) preparation of estimates of the potential fuel savings in an extended area (Zone of Convergence) where the control integrates both the approach phase and part of the en-route phase.

The results presented in this document pertain to the London zne and cover the traffic inbound to Heathrow during a two-hour period one morning in July 1980.

ACKNOWLEDGEMENT

The data used to conduct this investigation were received from the Civil Aviation Authority, United Kingdom.
The authors would like to express their appreciation to those who contributed to the relevant exercises, in particular the CAA Liaison Officer to the EUROCONTROL Specialist Panel for Automatic Conflict Detection and Resolution, who ensured the necessary coordination, the London Air Traffic Control Centre (West Drayton) and the Air Traffic Control Experimental Unit (Hurn Airport), which recorded the necessary data.

The meteorological information were obtained from the Meteorological Office, Bracknell, under a contract with the EUROCONTROL Agency.

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1. OBJECTIVES

The main objective of this investigation was to obtain a preliminary estimate of the potential savings which could be made if the control of the inbound traffic convered the final approach phase, the en-route descent and part of the cruise.

The aim was to determine two typical quantities, namely 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.

2. TRAFFIC SAMPLE

2.1. Area convered

The area convered is shown in Figure 1. This diagram also shows the trajectory of a typical flight inbound to Heathrow from Abbeville. The aircraft is kept in a holding pattern over the entry gate to the terminal (Biggin) and then routed to intercept the glide path along an S-shaped grand path.

The network presented in this figure constitutes the equivalent of a Zone of Convergence and shows the routes relevant to the inbound traffic. The area considered was essentially dictated by the London radar coverage, say 130 nm. However, where feasible, it was extended to include a larger part of the cruise.

To illustrate the general pattern of the trajectories collected, a subsample is presented in Figure 2.

2.2. Traffic density

The distribution of aircraft in time is given in Figure 3 (The traffic sample extends over a period of about 2 hours, from 8.30 to 10.30 a.m., one morning in July 1980).

The sample includes a maximum number of 18 aircraft simultaneously heading towards Hearthrow, the minimum number being 12. A summary of the sample characteristics is presented in Table 1. The detailed characteristics of the traffic are given in Ref. 1. The information available includes the individual trajectories (flight plan and radar data) and the actual meteorological observations briefly outlined in the next paragraph.

3. SOURCES AND NATURE OF INFORMATION

3.1. Radar information

The radar information was provided by the Air Traffic Control Experimental Unit on magnetic tape. This comprised essentially :

- aircraft identity (SSR code);
- aircraft position in the horizontal plan (x,y);
- aircraft altitude (Mode C data).

3.2. Flight plan data

The flight plan information included the following:

- aircraft information (type and identity);
- planned route and destination;
- additional information available as FPD summary on the LATCC High Speed Printer during the exercise period.

It can be seen from Table 1 that, due to a time synchronisation problem, the relevant flight plan data were not available for all the aircraft in the sample.

The data were provided by the London Air Traffic Control Centre in the form of listings.

3.3. Heathrow arrivals

The runway log for Heathrow arrivals was provided in a handwritten form. It included the aircraft flight number, the aircraft type and the landing time.

3.4. Atmospheric data

The meteorological information was obtained from the Bracknell Meteorological Office. For the London area it included the actual wind and temperature versus altitude profiles.

3.5. Aircraft performance

In order to obtain consumption estimates, the speed and acceleration data were derived from the radar and meteorological information collected, using the methods presented in Reference 2.

The specific consumption information used was in the PARZOC form as described in References 3 and 4. On the basis of the speed history, estimates of instantaneous fuel flow can be made an average landing mass being assumed for each type of aircraft. The fuel burnt by the aircraft considered, that is to say those aircraft inbound to Heathrow, during the exercise which actually landed during the survey period is represented by curve (a) in Figure 4. This figure shows the evolution of the amount of fuel actually consumed in the area when the traffic builds up. Over a two-hour period, some 75 tons of fuel was actually burnt in this area by the traffic inbound to London Heathrow alone. 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. CRUISE/DESCENT TRANSIT PROCEDURE

4.1. 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 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, five typical transit procedures were considered, as described in the following paragraphs.

4.2. Minimum fuel consumption (absolute minimum)

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.

In conducting the flight at minimum-consumption operating speeds, two possibilities were considered whenever the actual route differed from the planned route. The difference 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.

4.3. Minimum consumption under ATC constraints

The transit time from entry to landing is known from the data collected. Keeping the transit time unchanged, the cruise/descent profile is selected to achieve the minimum consumption for this time constraint (See Ref. 5). 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. As for the minimum (minimorum) consumption, both the actual and planned routes were considered when these differed.

4.4. Pilot's preferred transit procedure

Generally, a pilot would aim to fly in accordance with the airline's recommanded cruise/descent speed profile ensuring 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.

4.5. Notation

For ease of reference, the following notation system is used for the above procedures:

Actual (observed) transit procedure:	A
Minimum (minimorum) fuel consumption	
(a) along planned route:	F
(b) along actual route:	E
Minimum consumption under ATC constraints:	
(a) along planned route:	D
(b) along actual route:	C
Pilot's preferred transit procedure:	B

5. TRANSIT CRUISE/DESCENT SPEED PROFILES

Table 2 summarises the speed characteristics, as derived from the position observations. Columns 1 to 4 provide general information: type of aircraft, SSR-code, entry position, i.e. altitude and beacon.

5.1. Preferential speed profiles

The pilot's preferential speed profile as defined in 4.4. is given in columns 5 to 7 for each flight as CAS and related Mach number for the cruise phase and CAS for the descent.

5.2. Minimum-consumption profiles

The minimum-consumption speed profile is given for each flight in columns 8 to 10. Columns 8 and 9 give the CAS and related Mach number for the cruise and column 10 gives the en-route descent CAS.

5.3. Smooth cruise-to-descent speed transition

For the sake of completeness, the differences between minimum-consumption and pilot's preferential profiles are listed in columns 11 to 13.

This information provides an idea of the relative impact of the consumption and time of transit components on the flight cost. In general, the preferred speed is still appreciably higher than that corresponding to minimum consumption.

However, when the cruise and descent components of the preferential profiles are compared, it appears that the difference is small for an appreciable proportion of the flights, which indicates that the introduction of a smooth cruise-to-descent speed transition procedure should be compatible with present operation (Ref. 8).

5.4. True airspeed, distances and transit times

On the basis of the CAS derived from the actual observations and the available temperature data, the true airspace throughout the flight was computed. This and the wind data enable the actual air distance to be determined. The air distance to ground distance ratio (F) is given in column 14, while the true airspeed at entry, the ground distance actually flown and the transit time measured from entry to touch-down are given in columns 15 to 17.

6. ACTUAL, PREFERENTIAL AND MINIMUM-CONSUMPTION TRANSIT CHARACTERISTICS

Table 3 summarises the basic transit characteristics for each flight. These include:

- distance,
- time, and
- fuel consumption

for the actual, preferential and minimum-consumption transit procedures. Columns 1 to 3 give the aircraft type, flight SSR-code and entry point into the zone. The procedures considered are indicated by means of the notation system defined in Section 4.5. which, for convenience, is repeated at the top of the table for both transit times and consumption.

In columns 4 and 5, the distance is given for each flight, firstly as planned and measured along the network, and secondly as actually observed. The transit time is given for each flight and for procedures F, E, B and A in columns 6 through 9. SImilarly, the transit consumption for the corresponding procedures is presented in columns 10 to 13.

7. MINIMUM CONSUMPTION UNDER ATC CONSTRAINTS

The characteristics of the transit performed to achieve minimum consumption and cost while meeting ATC schedule constraints are given in Table 4 for each flight. For convenience the level at entry is also indicated and the distances shown in the previous table, (both as measured along the network and observed) are included again.

The time of transit corresponds to the actual transit, but the profile is controlled from entry into the zone to comply with the landing slot. Two variants are considered, corresponding to the planned and actual routes respectively. The speeds during such transits are given in Columns 9 and 10 of Table 4.

8. EVOLUTION OF FUEL CONSUMPTION DURING THE SURVEY PERIOD

To ascertain the total amount of fuel burnt in the area by the aircraft constituting the sample of inbound flights, the consumption was totalled as time proceeded. The sample of aircraft evolved as shown in Figure 3. The cumulated consumption is given in Table 5. This table shows, in particular, that the total amount of fuel consumed in the area by the inbound traffic constituting this limited sample amounts to some 75 tons. This is presented graphically in Figure 4.

9. COMPARATIVE ASSESSMENT OF TRANSIT CONTROL PROCEDURES

A comparative assessment of the various procedures was made. The differences shown in Figures 5 and 6 are expressed as percentages of the actual and minimum consumption (procedures F and A respectively) for the flights in the sample.

In order to effect this comparison, the following assumtpions were made. Firstly, the order of arrival of the aircraft as defined in the sample (Figure 3) and the evolution of the fuel burnt in the area (Figure 4) correspond to the actual order of entry into the zone (in contrast to what appears in the Tables, where the order corrsponds to the sequences of acquisition by the radar system).

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 Air Traffic Control and the corresponding consumption was accordingly used.

The following comparisons were made:

(1) minimum consumption against actual fuel burnt (curve (d));

(2) pilot's preferential profile against observation (curve (c));

(3) control of descent and/or cruise profile components against observations (curve (b)).

In these three cases, the differences obtained were compared with both the actual (Figure 5) and the minimum (Figure 6) consumption figures and the results expressed in percentages.

10. CONCLUSION

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

10.1. Sample size

The sample is rather limited in time (from 8.30 to 10.30 a.m. one morning in July 1980). It comprises a total of 46 aircraft, inbound to Heathrow, over a period of slightly more than two hours, with a maximum of 18 aircraft simultaneously present in the zone. The area is essentially limited to the London radar coverage, say 130 nm. However, wherever feasible, it was extended to cover a larger part of the cruise.

10.2. Control procedure scenarios

Three basic transit control scenarios were considered and compared in terms of fuel consumption. These are summarised below.

10.2.1. Present practice

For the sample considered, an estimate was made of the actual fuel burnt in the zone. The total amount was found to be of the order of 75 tons; the evolution is shown in Figure 4 (curve (a)).

10.2.2. Minimum consumption procedure

A lower bound for the quantity of fuel required to bring the aircraft from entry to touch-down is obtained when each aircraft is considered to be alone in the system and operating in accordance with the minimum consumption cruise/descent profile (regime status).

Where this is the case, the evolution of the consumption is as shown by curve (d) in Figure 4. 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 % (curve (d) in Figure 5).

10.2.3. Pilot's selected profile

On the basis of the observations made before any noticeable ATC intervention occurred (that is to say during the cruise of initial phase(s) of cruise and/or descent), an estimate of the airline's preferential profile was made. The corresponding consumption is given as curve (c) in Figure 4. As expected, this consumption is slightly higher than the minimum consumption, since it is based on cost criteria which include a time component. Accordingly, the associated average transit time was appreciably shorter than that for the minimum consumption procedure. Nevertheless, this situation may require a high level of control and constitutes only an indication of the upper bound for the difference, expressed in fuel consumption terms between the airline's requirements and the actual service provided. In terms of present consumption, this difference is slightly over 25 % (curve (f) in Figure 5), which is practically halfway between the absolute minimum consumption and that obtained by application of cruise/descent speed

10.2.4. Control of cruise/descent speed profile

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 the aircraft as soon as it arrived, not at the assembly point but at the entry into the zone (see Figure 1), the consumption which would result corresponds to curve (b) in Figure 4. In other words, control of the aircraft spped 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 saving.

  The possible saving amounts to 20-25 % of the estimated actual consumption in the area.

11. REFERENCES

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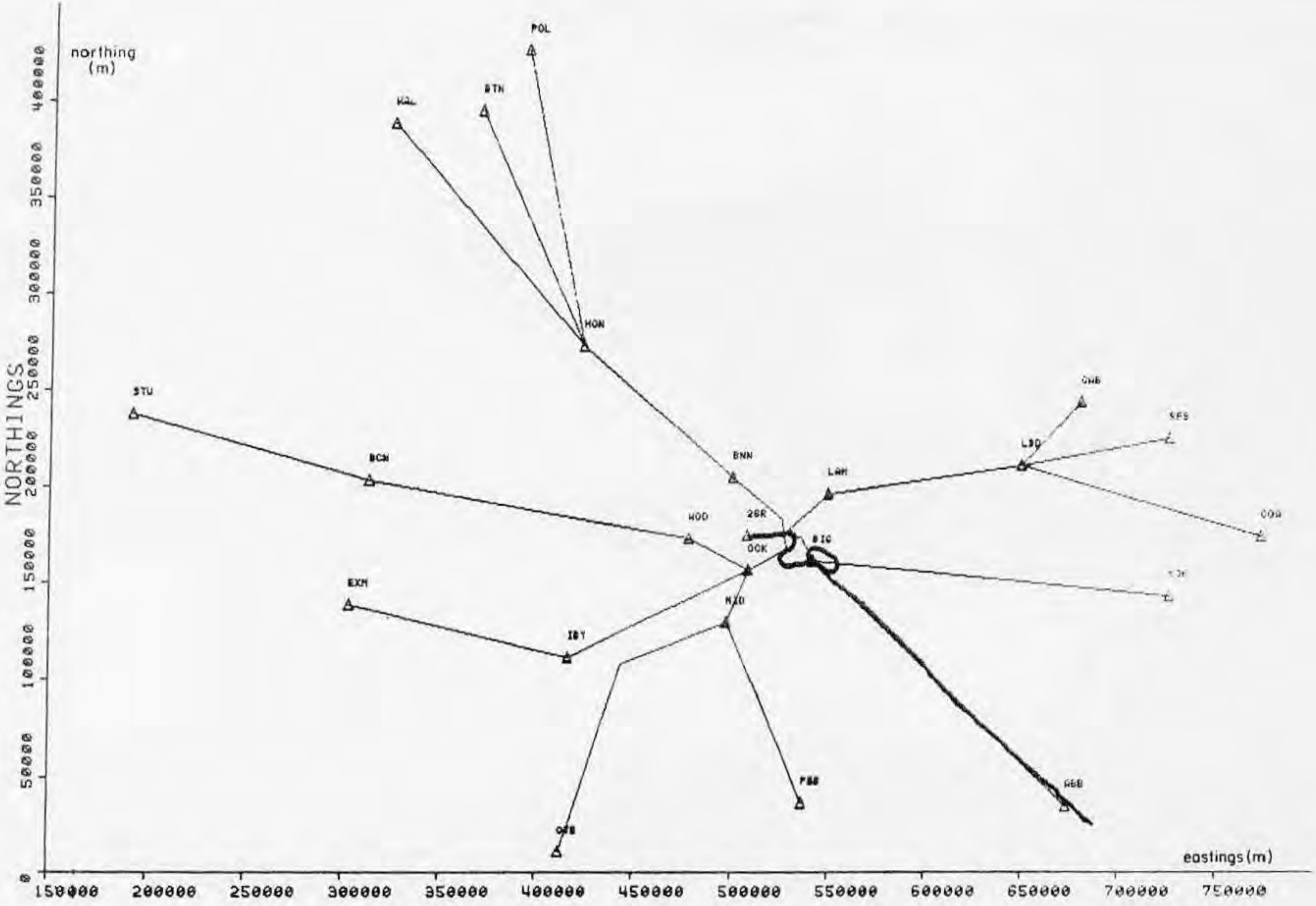


STRUCTURE OF INBOUND ROUTES TO LONDON-HEATHROW

Illustration of a typical arrival

Figure 1

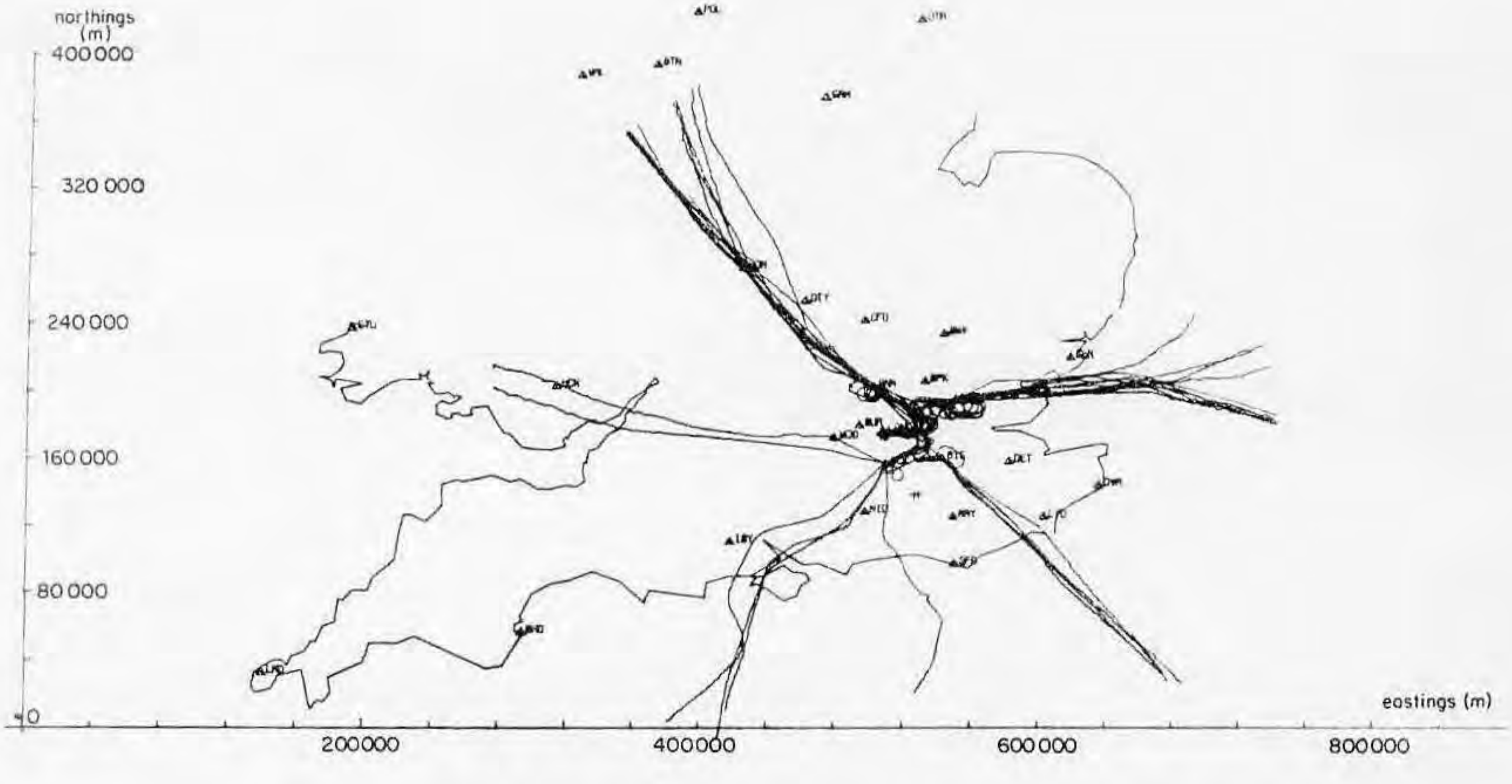
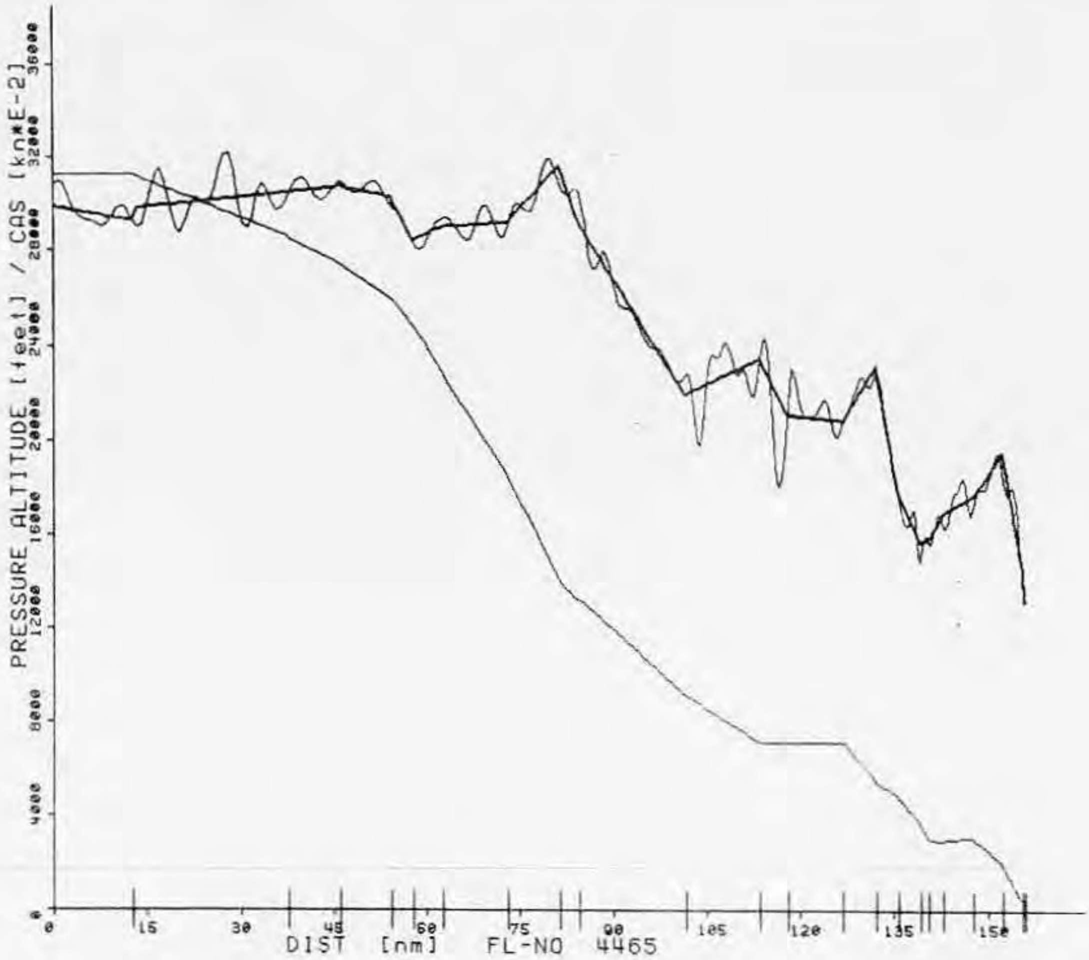


ILLUSTRATION OF SOME INBOUND FLIGHTS AS OBSERVED BY RADAR
(Inbound traffic to Heathrow)
Figure 2(a)



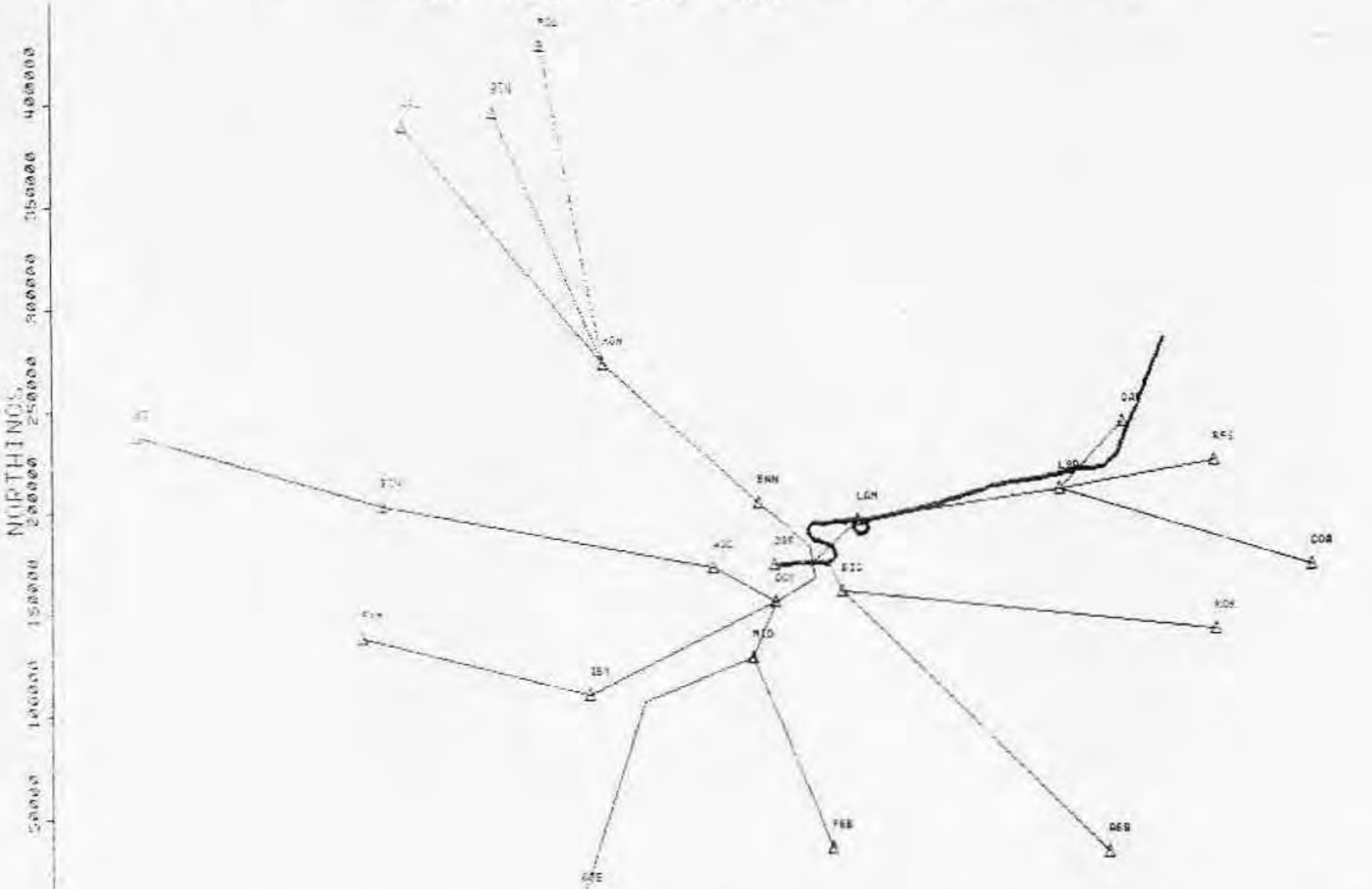
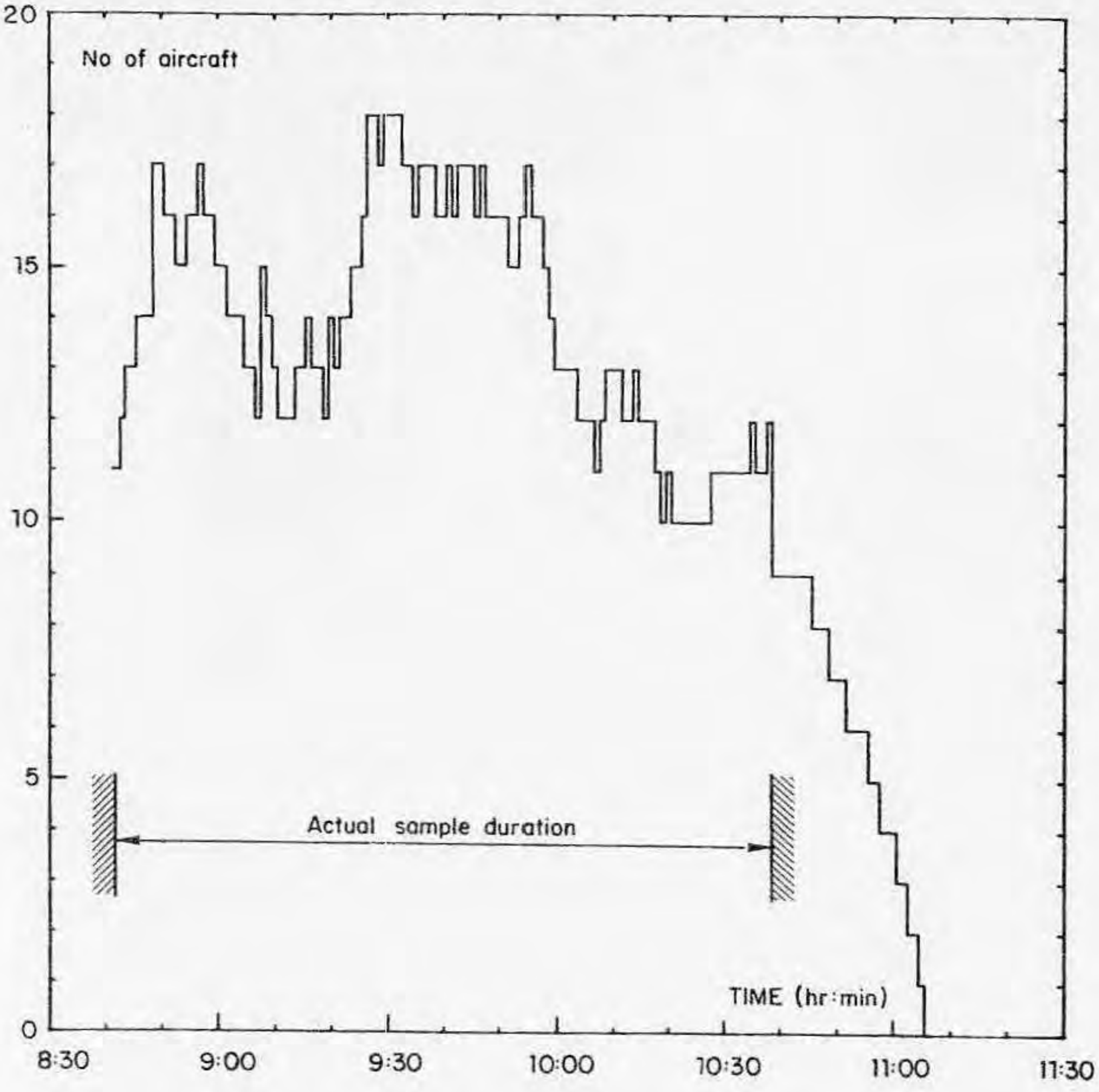


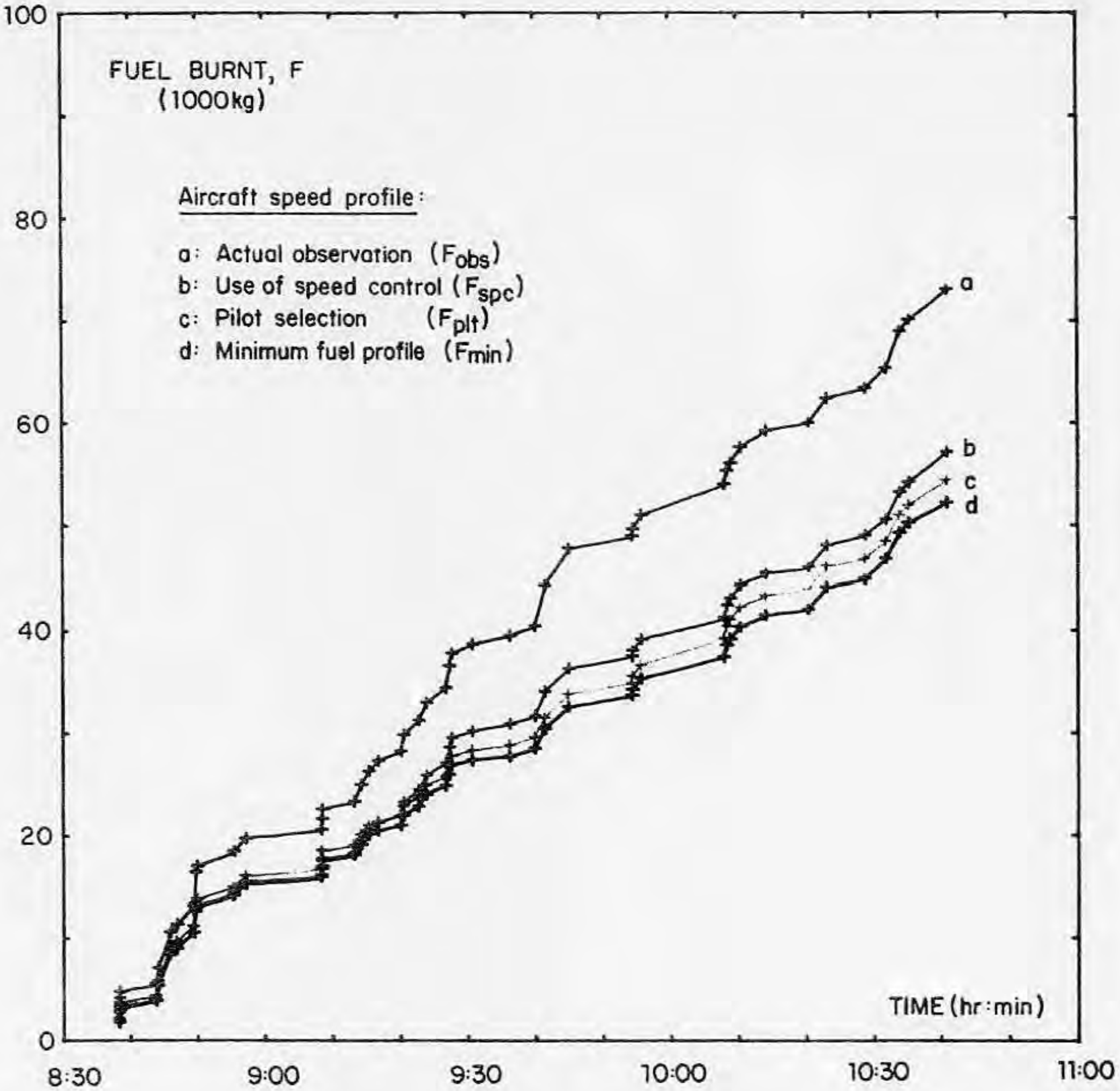
ILLUSTRATION OF TYPICAL ARRIVAL

Figure 2(b)



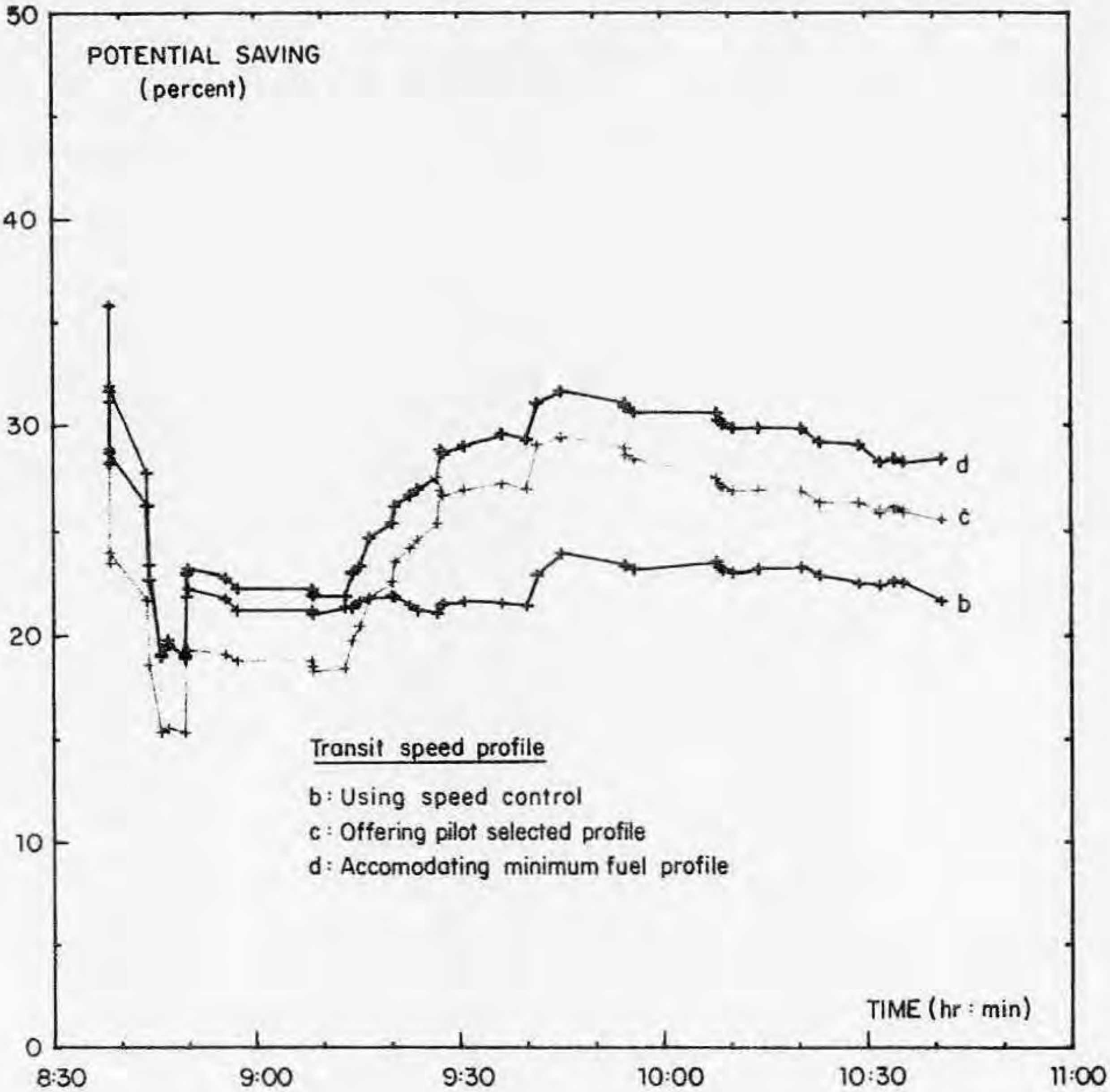
EVOLUTION OF INBOUND TRAFFIC
(Traffic inbound to Heathrow)

Figure 3



EVOLUTION OF FUEL BURNT BY INBOUND TRAFFIC IN AN EXTENDED TERMINAL AREA
(Traffic inbound to Heathrow)

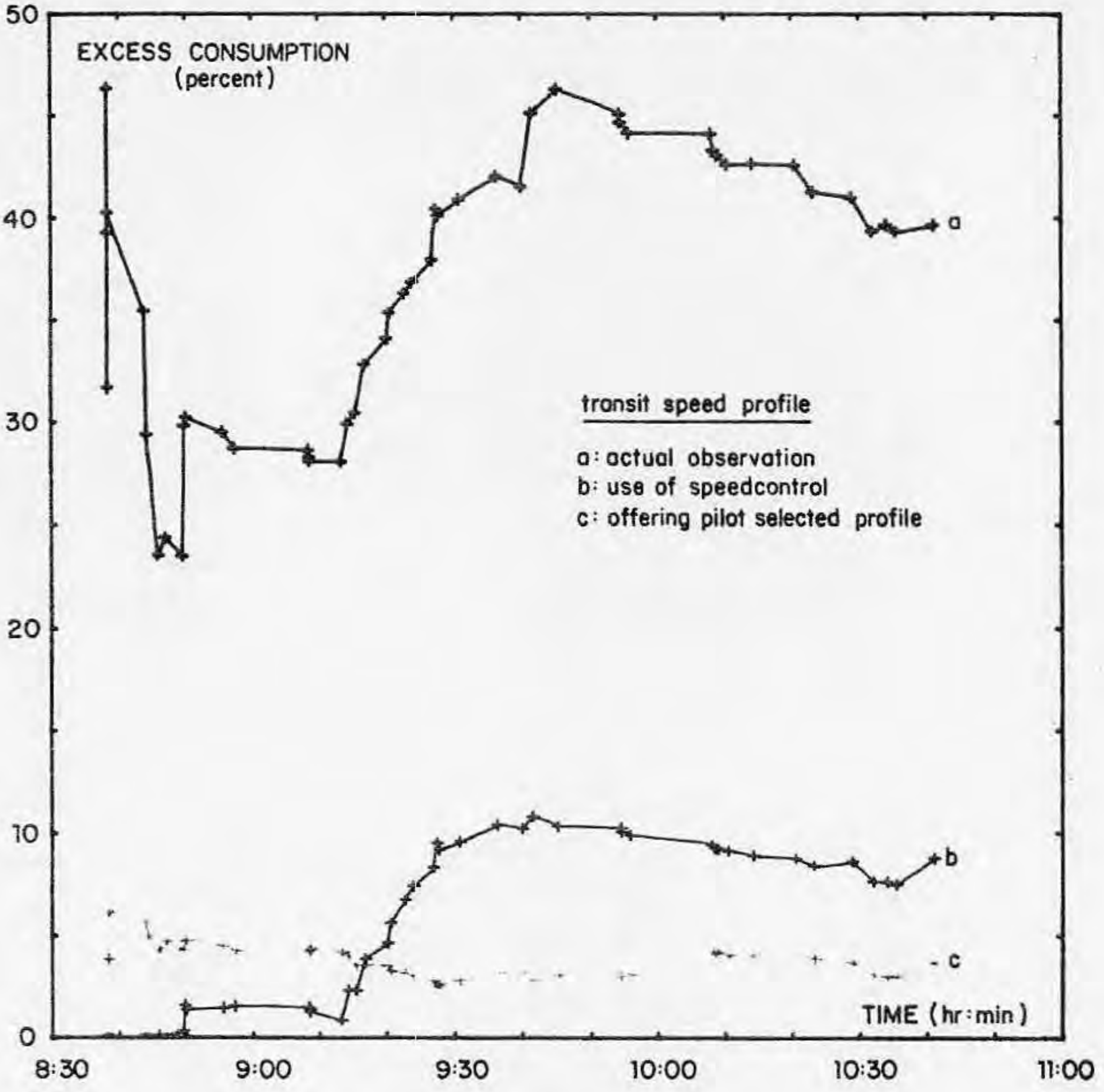
Figure 4



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

Figure 5

Fig. 6



EXCESS CONSUMPTION W.R.T. MINIMUM TRANSIT FUEL
(Traffic inbound to Heathrow)

Figure 6

SEQ NO	TYPE	ENTRY TIME	ENT BEAC	ENT FL	FROM	LAND TIME	SSR CODE
1	DC9	8 : 38	GAB	305		9 : 01	7463
2	B747	8 : 34	EXM	321		9 : 02	2004
3	B737	8 : 30	STU	253		9 : 05	105
4	TRI3	8 : 40	BTN	153		9 : 07	7464
5	BAC1	8 : 40	WAL	292		9 : 08	4457
6	B747	8 : 38	STU	332		9 : 09	2007
7	DC9	8 : 49	ABB	262		9 : 13	5421
8	TRI3	8 : 46	POL	253		9 : 15	4440
9	B747	8 : 48	ABB	253		9 : 17	4462
10	DC9	8 : 57	GAB	312		9 : 19	4471
11	TRI3	8 : 53	BTN	272		9 : 21	5034
12	B737	9 : 06	COA	242	EBBR	9 : 35	2762
13	DC9	9 : 04	WAL	212	EGCP	9 : 39	4460
14	BAC1	9 : 11	OTE	193	EGJJ	9 : 40	6333
15	B737	9 : 14	ABB	352	LSZH	9 : 43	5466
16	TRI3	9 : 17	ABB	312	LSZH	9 : 45	5413
17	DC9	9 : 12	GAB	312		9 : 46	4465
18	TRI3	9 : 13	BTN	292		9 : 48	5036
19	B737	9 : 21	RFS	312	EHAM	9 : 53	2153
20	TRI3	9 : 19	BTN	332		9 : 54	5165
21	TRI3	9 : 19	WAL	272		9 : 56	4430
22	B727	9 : 21	COA	352	EDDM	9 : 57	2504
23	TRI3	9 : 25	ABB	292	LSGC	9 : 58	6453

TABLE 1a : SUMMARY OF THE SAMPLE CONTENTS

(Flights inbound to London - Heathrow)

SEQ NO	TYPE	ENTRY TIME	ENT BEAC	ENT FL	FROM	LAND TIME	SSR CODE
24	B737	9 : 22	STU	292	EIDW	10 : 01	5470
25	B707	9 : 25	COA	332	LCLK	10 : 04	2515
26	FK28	9 : 30	RFS	222	EHRD	10 : 07	2157
27	DC9	9 : 37	GAB	352		10 : 09	4434
28	DC9	9 : 36	POL	292	EGNV	10 : 10	5416
29	B747	9 : 40	OTE	312	KMIA	10 : 12	5414
30	B747	9 : 42	POL	372	KSEA	10 : 14	5116
31	TRI3	9 : 51	WAL	293	EGAA	10 : 18	4464
32	DC9	9 : 55	OTE	272	LEMD	10 : 20	5443
33	TRI3	9 : 54	BTN	273	EGPF	10 : 23	5001
34	TRI3	10 : 07	COA	243	EDNK	10 : 32	774
35	B747	10 : 05	WAL	373	KSFO	10 : 34	5120
36	DC9	10 : 06	COA	353	LOWS	10 : 38	3132
37	TRI3	10 : 07	WAL	252	EGAA	10 : 39	5411
38	B707	10 : 13	COA	312	OJAM	10 : 42	3136
39	B747	10 : 18	WAL	372	KLAX	10 : 46	5122
40	DC9	10 : 23	RFS	262	EHAM	10 : 49	2104
41	B727	10 : 28	OTE	352	LEBL	10 : 52	7454
42	B747	10 : 32	ABB	332	LLBG	10 : 56	6473
43	TRI3	10 : 26	STU	252	EICK	11 : 02	121
44	BAC1	10 : 27	WAL	151	EGCC	11 : 03	7416
45	B747	10 : 32	COA	282	EDDF	11 : 05	2754
46	B747	10 : 38	WAL	393	KLAX	11 : 06	5127

TABLE 1b : SUMMARY OF THE SAMPLE CONTENTS

(Flights inbound to London - Heathrow)

FLIGHT		ENTRY		CRUISE/DESCENT SPEED PROFILES													
TYPE	SSR	ALT.	BEAC	PREFERENTIAL CRUISE CAS	PREFERENTIAL CRUISE MA	PREFERENTIAL DESC CAS	MIN CONSUMPTION CRUISE CAS	MIN CONSUMPTION CRUISE MA	MIN CONSUMPTION DESC CAS	DIFFERENCES CRUISE CAS	DIFFERENCES CRUISE MA	DIFFERENCES DESC CAS	AIR/GR DIST FACT	ENTRY TAS	TRANSIT GR.DIST	TRANSIT TIME
DC_9	7463	30535.	GAB	308.	0.82	304.	247.	0.67	237.	61.	0.15	67.	0.999	462.	116.5	22.6
B747	2004	32081.	EXM	318.	0.87	330.	267.	0.74	308.	51.	0.13	22.	1.003	510.	125.0	24.0
B737	105	25338.	STU	319.	0.76	332.	248.	0.60	260.	71.	0.16	72.	0.990	460.	145.8	26.5
TRI3	7464	15338.	BTN	335.	0.66	341.	282.	0.56	350.	53.	0.10	-9.	0.970	417.	94.7	17.7
BAC1	4457	29208.	WAL	265.	0.69	270.	235.	0.62	279.	30.	0.07	-9.	0.959	410.	136.8	24.3
B747	2007	33238.	STU	308.	0.86	301.	266.	0.75	300.	42.	0.11	1.	0.982	500.	151.2	25.3
DC_9	5421	26238.	ABB	321.	0.78	324.	250.	0.62	230.	71.	0.16	94.	1.044	471.	137.3	22.9
TRI3	4440	25338.	POL	311.	0.75	347.	275.	0.66	350.	36.	0.08	-3.	0.959	433.	146.3	25.0
B747	4462	25338.	ABB	354.	0.84	320.	276.	0.67	230.	78.	0.17	90.	1.044	512.	141.2	27.2
DC_9	4471	31238.	GAB	301.	0.81	308.	246.	0.68	238.	55.	0.14	70.	1.001	471.	114.3	21.7
TRI3	5234	27232.	BTN	309.	0.77	317.	273.	0.69	341.	36.	0.08	-24.	0.962	455.	143.9	25.5
B737	2762	24238.	COA	310.	0.73	329.	249.	0.59	257.	61.	0.14	72.	1.016	439.	141.7	25.9
DC_9	4460	21238.	WAL	293.	0.65	251.	253.	0.57	230.	40.	0.08	21.	0.968	409.	109.3	23.9
BAC1	6333	19338.	OTE	321.	0.65	305.	241.	0.52	274.	60.	0.12	31.	1.023	388.	136.6	27.4
B737	5466	35238.	ABB	232.	0.70	265.	230.	0.69	264.	2.	0.01	1.	1.043	411.	149.3	28.5
TRI3	5413	31238.	ABB	302.	0.82	324.	266.	0.73	314.	34.	0.08	10.	1.039	474.	145.3	27.2
DC_9	4465	31238.	GAB	295.	0.80	298.	246.	0.68	239.	49.	0.12	60.	0.991	474.	156.2	30.3
TRI3	5035	29228.	BTN	273.	0.71	300.	271.	0.71	327.	2.	0.01	-27.	0.964	416.	168.0	33.0
B737	2153	31238.	RFS	272.	0.74	300.	238.	0.66	269.	34.	0.09	31.	1.004	440.	154.4	30.3
TRI3	5165	33238.	BTN	272.	0.77	326.	266.	0.76	301.	6.	0.02	25.	0.968	447.	177.1	33.1
TRI3	4430	27238.	WAL	274.	0.69	295.	273.	0.69	341.	1.	0.00	-46.	0.968	409.	163.3	32.7
B727	2504	35238.	COA	255.	0.76	261.	252.	0.75	287.	3.	0.01	-26.	1.016	444.	167.4	33.2
TRI3	6453	29238.	ABB	295.	0.77	312.	271.	0.71	327.	24.	0.06	-15.	1.036	463.	167.7	31.8
B737	5470	29238.	STU	287.	0.75	291.	242.	0.64	268.	45.	0.11	23.	0.986	448.	173.1	32.1
B707	2515	33238.	COA	282.	0.80	319.	245.	0.70	300.	37.	0.10	19.	1.011	468.	187.5	36.1
FK28	2157	22238.	RFS	296.	0.67	289.	224.	0.51	222.	72.	0.16	67.	1.009	423.	173.9	35.4
DC_9	4434	35236.	GAB	250.	0.74	292.	244.	0.73	240.	6.	0.02	52.	0.999	433.	158.3	31.0
DC_9	5416	29231.	POL	263.	0.69	274.	247.	0.65	234.	16.	0.04	40.	0.957	410.	144.0	28.6
B747	5414	31238.	OTE	317.	0.85	334.	268.	0.73	313.	49.	0.12	21.	1.022	509.	163.4	29.8
B747	5116	37240.	POL	261.	0.81	298.	260.	0.81	274.	1.	0.00	24.	0.963	457.	152.5	29.2
TRI3	4464	29315.	WAL	282.	0.74	308.	271.	0.71	327.	11.	0.03	-19.	0.964	435.	138.2	23.1
DC_9	5443	27238.	OTE	322.	0.80	322.	249.	0.63	230.	73.	0.17	92.	1.023	478.	127.1	24.3
TRI3	5001	27338.	BTN	299.	0.75	328.	273.	0.69	340.	26.	0.06	-12.	0.965	446.	144.0	26.5
TRI3	774	24338.	COA	314.	0.74	338.	276.	0.65	350.	38.	0.09	-12.	1.020	451.	134.6	22.5
B747	5120	37321.	WAL	262.	0.81	308.	260.	0.81	273.	2.	0.00	35.	0.965	464.	140.6	25.5
DC_9	3132	35338.	COA	262.	0.78	248.	244.	0.73	240.	18.	0.05	8.	1.020	456.	144.0	29.1
TRI3	5411	25238.	WAL	313.	0.75	317.	275.	0.66	350.	38.	0.09	-33.	0.969	452.	150.8	28.3
B707	3136	31238.	COA	298.	0.81	318.	248.	0.68	313.	50.	0.13	5.	1.017	481.	144.0	26.5
B747	5122	37238.	WAL	268.	0.83	283.	260.	0.81	274.	8.	0.02	9.	0.965	477.	139.1	24.7
DC_9	2104	26232.	RFS	299.	0.73	306.	250.	0.62	230.	49.	0.11	76.	1.008	451.	135.3	24.9
B727	7454	35238.	OTE	268.	0.79	304.	252.	0.75	287.	16.	0.04	17.	1.025	448.	134.9	22.3
B747	6473	33238.	ABB	282.	0.80	290.	266.	0.76	300.	16.	0.04	-10.	1.044	473.	128.7	23.0
TRI3	121	25238.	STU	307.	0.74	324.	275.	0.66	350.	32.	0.07	-26.	0.986	444.	157.8	28.8
BAC1	7416	15138.	WAL	294.	0.58	266.	245.	0.49	271.	49.	0.10	-5.	0.971	369.	110.2	24.6
B747	2754	28238.	COA	275.	0.70	277.	272.	0.70	230.	3.	0.01	47.	1.022	427.	146.5	29.9
B747	5127	39338.	WAL	260.	0.84	295.	258.	0.83	260.	2.	0.01	35.	0.965	480.	138.8	24.5
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)

TABLE 2

TRANSIT CRUISE/DESCENT SPEEDS AND RELATED CHARACTERISTICS

(Flights inbound to London-Heathrow)

FLIGHT DESCRIPTION			DISTANCE		TRANSIT TIME			TRANSIT CONSUMPTION				
			NTW (NM)	OBS. (NM)	(F) (MN)	(E) (MN)	(B) (MN)	(A) (MN)	(F) (KG)	(E) (KG)	(B) (KG)	(A) (KG)
DC_9	7463	GAB	105.7	119.7	22.5	18.8	24.4	23.3	414	444	482	611
B747	2204	EXM	145.0	152.8	24.7	23.4	25.6	27.6	2031	2112	2164	2972
B737	105	STU	201.4	210.2	37.6	31.0	38.8	35.1	991	1106	1031	1236
TRI3	7464	BTN	155.2	158.7	29.0	26.8	29.3	27.2	1394	1440	1415	1557
BAC1	4457	WAL	162.8	162.0	30.3	29.3	29.9	28.3	677	652	666	735
B747	2067	STU	199.7	196.7	32.4	31.4	32.1	31.3	3094	3126	3034	3422
DC_9	5421	ABB	127.0	146.3	26.4	21.0	29.3	24.4	577	648	676	791
TRI3	4440	POL	165.4	172.6	27.9	27.1	28.7	29.0	1195	1213	1239	1455
B747	4462	ABB	127.0	150.7	26.5	21.1	29.9	28.7	2070	2224	2572	3361
DC_9	4471	GAB	105.9	117.0	22.4	18.8	23.9	22.3	409	434	458	583
TRI3	5034	BTN	153.9	158.0	26.1	25.6	26.5	27.8	1063	1074	1095	1256
B737	2762	COA	153.4	161.3	30.0	25.2	31.0	28.8	751	808	796	929
DC_9	4460	WAL	164.4	180.6	33.1	28.0	35.7	34.6	887	931	978	1079
BAC1	6333	OTE	131.4	143.7	27.3	24.3	29.3	28.7	663	685	722	839
B737	5466	ABB	126.8	153.7	26.6	26.2	27.7	29.4	569	560	605	725
TRI3	5413	ABB	126.3	152.2	24.1	23.0	26.3	28.4	932	874	980	1317
DC_9	4465	GAB	104.8	181.2	22.3	18.9	33.6	33.8	403	423	792	1012
TRI3	5036	BTN	154.2	192.8	26.4	26.4	30.2	35.4	1032	1033	1242	1677
B737	2153	RFS	123.4	166.9	23.6	21.8	30.2	32.3	499	589	710	928
TRI3	5165	BTN	154.9	191.7	27.4	25.9	32.2	35.3	995	974	1257	1615
TRI3	4430	WAL	164.4	159.1	27.7	27.6	31.1	36.7	1146	1146	1332	1699
B727	2504	COA	153.4	186.8	26.7	26.6	31.1	36.1	882	852	1128	1414
TRI3	6453	ABB	126.0	177.5	23.7	23.1	29.5	33.4	987	951	1201	1492
B737	5470	STU	200.6	221.6	36.2	32.2	39.3	38.9	914	959	1014	1196
B707	2515	COA	152.7	206.8	27.1	25.3	34.2	38.8	1077	1348	1531	2136
FK28	2157	RFS	124.0	183.6	27.9	22.1	39.0	37.1	501	571	758	918
DC_9	4434	GAB	105.7	165.9	22.2	22.2	30.5	32.4	371	492	670	836
DC_9	5416	POL	165.1	175.5	31.9	27.7	33.3	33.5	741	764	759	903
B747	5414	OTE	131.2	181.3	23.6	21.6	29.4	32.2	1946	1890	2819	3863
B747	5116	POL	166.1	178.0	29.0	28.4	30.4	31.9	2145	2307	2360	3503
TRI3	4464	WAL	163.7	163.8	27.8	27.6	27.6	26.9	1105	1106	1095	1198
DC_9	5443	OTE	131.4	130.6	27.0	21.5	26.7	25.1	587	662	576	696
TRI3	5001	BTN	154.4	159.3	26.2	25.9	26.7	28.8	1065	1071	1090	1355
TRI3	774	COA	154.0	155.2	26.4	25.7	26.3	25.5	1123	1140	1119	1310
B747	5120	WAL	163.9	166.4	28.7	29.6	28.8	29.1	2095	2633	2112	3006
DC_9	3132	COA	154.0	163.5	29.1	26.4	30.2	32.0	619	625	659	782
TRI3	5411	WAL	164.5	176.8	27.8	26.9	29.4	32.0	1190	1209	1276	1522
B707	3136	COA	153.6	164.8	26.2	25.6	27.6	29.5	1102	1127	1194	1586
B747	5122	WAL	163.9	165.5	28.7	28.0	25.7	28.4	2099	2092	2094	2404
DC_9	2104	RFS	123.9	141.1	25.9	21.0	26.4	25.1	560	608	646	767
B727	7454	OTF	131.6	145.7	24.5	22.8	25.4	24.0	765	713	818	961
B747	6473	ABB	127.0	134.8	24.7	23.2	24.7	24.1	1910	1674	1910	1917
TRI3	121	STU	200.6	209.0	33.2	31.9	34.2	36.1	1486	1508	1542	1753
BAC1	7416	WAL	164.9	177.3	34.9	30.8	37.0	35.8	946	969	1012	1148
B747	2754	COA	154.3	156.2	30.6	25.5	32.1	32.9	2435	2530	2707	3625
B747	5127	WAL	163.9	164.7	29.5	30.1	29.3	28.1	2004	2466	1982	2970
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)

TABLE 3

ACTUAL, PREFERENTIAL AND MINIMUM CONSUMPTION PROCEDURE CHARACTERISTICS

(Flights inbound to London-Heathrow)

CUMULATED CONSUMPTION IN KG.

(A)	(F)	(E)	(D)	(C)	(B)
414.	444.	480.	611.	470.	386.
2445.	2556.	2644.	3583.	2546.	2296.
3436.	3662.	3675.	4819.	3604.	3285.
4830.	5102.	5090.	6376.	5090.	4718.
5507.	5784.	5756.	7111.	5773.	5405.
8591.	8910.	8790.	10533.	8848.	8510.
9168.	9558.	9466.	11324.	9573.	9072.
10363.	10771.	10705.	12779.	10858.	10296.
12433.	12995.	13277.	16140.	13304.	12534.
12842.	13429.	13735.	16723.	13760.	12922.
13905.	14503.	14820.	17979.	14882.	14012.
14656.	15311.	15606.	18908.	15677.	14751.
15543.	16242.	16584.	19987.	16655.	15635.
16206.	16927.	17306.	20826.	17384.	16299.
16774.	17487.	17911.	21551.	18002.	16794.
17706.	18361.	18891.	22868.	19026.	17747.
18109.	18784.	19683.	23880.	19807.	18498.
19141.	19817.	20925.	25557.	21170.	19826.
19640.	20326.	21635.	26485.	21882.	20519.
20635.	21300.	22892.	28100.	23221.	21800.
21781.	22446.	24224.	29789.	24672.	23215.
22663.	23328.	25352.	31203.	25897.	24440.
23550.	24179.	26553.	32695.	27173.	25663.
24464.	25138.	27567.	33891.	28190.	26570.
25541.	26186.	29098.	36027.	29773.	28114.
26042.	26757.	29856.	36945.	30529.	28795.
26413.	27249.	30526.	37781.	31222.	29488.
27154.	28013.	31315.	38684.	32014.	30247.
29100.	29693.	34134.	42547.	34734.	32635.
31245.	32200.	36494.	46050.	37157.	34844.
32350.	33306.	37589.	47248.	38279.	35965.
32937.	33968.	38165.	47944.	38845.	36536.
34002.	35039.	39255.	49299.	39983.	37641.
35125.	36179.	40374.	50609.	41158.	38801.
37220.	38812.	42486.	53615.	43305.	40903.
37838.	39437.	43145.	54397.	43980.	41578.
39028.	40646.	44421.	55919.	45300.	42827.
40130.	41773.	45615.	57505.	46506.	43928.
42229.	43865.	47709.	59909.	48640.	46029.
42789.	44473.	48355.	60676.	49289.	46571.
43554.	45186.	49165.	61637.	50111.	47285.
45464.	46860.	51075.	63554.	51844.	48825.
46950.	48368.	52617.	65307.	53432.	50350.
47896.	49337.	53629.	66455.	54450.	51291.
50381.	51867.	56336.	70080.	57194.	53973.
52385.	54333.	58318.	73050.	59215.	55977.
(1)	(2)	(3)	(4)	(5)	(6)

TABLE 5

CUMULATED FUEL CONSUMPTION

(Flights inbound to London-Heathrow)

TYPE	CODE	ENTRY	DISTANCE		TIME	CONSUMPTION		CAS	
		ALT (FT)	NETW (NM)	OBS. (NM)	(MN)	(C) (KG)	(D) (KG)	(C) (KT)	(D) (KT)
DC_9	7463	30535.	105.7	119.7	23.3	470.	386.	250.	213.
B747	2004	32081.	145.0	152.8	27.6	2076.	1910.	266.	255.
B737	105	25338.	201.4	210.2	35.1	1058.	989.	284.	271.
TRI3	7464	15338.	155.2	158.7	27.2	1486.	1433.	339.	329.
BAC1	4457	29238.	162.8	162.0	28.3	683.	687.	*280.	*280.
B747	2007	33238.	199.7	198.7	31.3	3075.	3105.	298.	299.
DC_9	5421	26238.	127.0	146.3	24.4	725.	562.	304.	256.
TRI3	4440	25338.	165.4	172.6	29.0	1285.	1224.	316.	307.
B747	4462	25338.	127.0	150.7	28.7	2446.	2238.	258.	230.
DC_9	4471	31238.	105.9	117.0	22.3	456.	388.	261.	232.
TRI3	5034	27232.	153.9	158.0	27.6	1122.	1090.	311.	302.
B737	2762	24238.	153.4	161.3	28.8	795.	739.	277.	261.
DC_9	4460	21238.	164.4	180.6	34.6	978.	884.	254.	230.
BAC1	6333	19338.	131.4	143.7	28.7	729.	664.	259.	235.
B737	5466	35238.	126.8	153.7	29.4	618.	495.	245.	199.
TRI3	5413	31238.	126.3	152.2	28.4	1024.	953.	281.	230.
DC_9	4465	31238.	104.8	181.2	33.8	781.	751.	237.	230.
TRI3	5036	29228.	154.2	182.8	35.4	1363.	1328.	252.	230.
B737	2153	31238.	123.4	166.9	32.3	712.	693.	239.	230.
TRI3	5165	33238.	154.9	191.7	35.3	1339.	1281.	261.	230.
TRI3	4430	27238.	164.4	189.1	36.7	1451.	1415.	251.	230.
B727	2504	35238.	153.4	186.8	36.1	1225.	1225.	230.	230.
TRI3	6453	29238.	126.0	177.5	33.4	1276.	1223.	263.	230.
B737	5470	29238.	200.6	221.6	38.9	1017.	907.	255.	231.
B707	2515	33238.	152.7	206.8	38.8	1583.	1544.	241.	230.
FK28	2157	22238.	124.0	183.6	37.1	756.	681.	234.	210.
DC_9	4434	35236.	105.7	165.8	32.4	693.	693.	230.	230.
DC_9	5416	29231.	165.1	175.5	33.5	792.	759.	238.	230.
B747	5414	31238.	131.2	181.3	32.2	2720.	2388.	261.	230.
B747	5116	37240.	166.1	178.0	31.9	2423.	2209.	257.	238.
TRI3	4464	29315.	163.7	163.8	26.9	1122.	1121.	*326.	*327.
DC_9	5443	27238.	131.4	130.6	25.1	566.	571.	252.	254.
TRI3	5001	27338.	154.4	159.3	28.8	1138.	1105.	294.	283.
TRI3	774	24338.	154.0	155.2	25.5	1175.	1160.	341.	338.
B747	5120	37321.	163.9	166.4	29.1	2147.	2102.	273.	270.
DC_9	3132	35338.	154.0	163.5	32.0	675.	675.	230.	230.
TRI3	5411	25238.	164.5	176.8	32.0	1320.	1249.	285.	260.
B707	3136	31238.	153.6	164.8	29.5	1206.	1101.	274.	258.
B747	5122	37238.	163.9	165.5	28.4	2134.	2101.	*274.	274.
DC_9	2104	26232.	123.9	141.1	26.1	649.	542.	265.	230.
B727	7454	35238.	131.6	145.7	24.0	822.	714.	*287.	*284.
B747	6473	33238.	127.0	134.8	24.1	1733.	1540.	287.	269.
TRI3	121	25238.	200.6	209.0	36.1	1588.	1525.	292.	278.
BAC1	7416	15138.	164.9	177.3	35.8	1018.	941.	260.	241.
B747	2754	28238.	154.3	166.2	32.9	2744.	2682.	239.	230.
B747	5127	39338.	163.9	164.7	28.1	2021.	2004.	*260.	*260.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)

TABLE 4

MINIMUM CONSUMPTION AND COST UNDER ATC CONSTRAINTS

(Flights inbound to London-Heathrow)