FINAL VERSION

SUMMARY OF DISCUSSIONS

OF THE

SIXTH MEETING OF THE NAT SYSTEMS PLANNING GROUP

(Paris, 4 - 16 September 1969)

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INTRODUCTION

1. The Sixth Meeting of the NAT Systems Planning Group was held in the European Office of ICAO in Paris from 4 to 16 September 1969 under the Chairmanship of Mr. J.F. Sapin, member from France.

2. On 4 September in the morning, and on 16 September in the afternoon, the Group met in closed session in order to discuss matters of internal interest to the Group only and Agenda Items 7 and 9. The consideration of the other Agenda Items was entrusted to two sub-groups, with the exception of Agenda Item 1 which was dealt with in plenary session. One of the sub-groups handling Item 2 and certain aspects of Items 3 and 6, was chaired by Mr. A. White from the United Kingdom, while the other sub-group, chaired by Mr. E.B. Powell and, part-time, by Mr. A.L. Elliott, both from Canada, dealt with Items 3, 4, 5, 6 and 8.

3. Mr. P.G. Berger and Mr. A. Azzaoui, both from the European Office of ICAO, served as secretaries of the Meeting.

4. Mr. F.E. Sperring, actiony ICAO Representative, welcomed the Group at its opening session and recalled the interest which the work of the Group had for NAT States, especially in view of the forthcoming NAT V RAN Meeting in April 1970.

AGENDA

Item 1 : Joint meeting with the NAT Traffic Forecasting Group to discuss matters of common interest.

Item 2 : Establishment of methods for the assessment of system performance

Item 3 : Review of progress of studies towards the application of composite separation.

Item 4 : Review of work so far accomplished by the Group and possible resultant action.

Item 5 : Preparation of appropriate documentation for the Fifth NAT RAN Meeting.

Item 6 : Exchange of views on the questions posed by the Secretary of the ASTRA Panel.

*Item 7 : Review of the work programme of the Group, including arrangements for the next meeting.

Item 8 : Any other business.

*Item 9 : Election of the next Chairman.

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* Reserved for consideration by members of the Group only.

LIST OF PARTICIPANTS

Note : Names marked with an asterisk are those of Members of the Group

State or Organization		State or Organization	
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KINGDOM OF THE NETHERLANDS	A. Pool * J. Ten Velden		
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+ For consideration of Agenda Item 1 only

GENERAL MATTERS

1. Request from EUROCONTROL for participation in the Meeting

1.1 As on two previous occasions, Mr. Sapin, the Chairman of the Group had received prior to the Meeting a letter from EUROCONTROL requesting to be invited to participate in this meeting of the NAT/SPG. Consultations amongst the members of the Group revealed once more that it was not possible to reach the required agreement of at least 5 of the 6 members of the Group to such an invitation and it was therefore not possible for the Group to acceed to EUROCONTROL's request. The Chairman of the Group informed EUROCONTROL accordingly by letter.

1.2 In this context, the Group once more noted that ATS problems relating to the transition area between the EUM and NAT Regions had been designated within ICAO as falling within the province of EUM regional consideration and would therefore be dealt with by EUM regional meetings to which EUROCONTROL had been, and will be, regularly invited.

2. Presentation to ICAO of supporting documentation prepared by the Group for the NAT V RAN Meeting.

2.1 After a brief discussion of this subject between members of the Group it was agreed that any supporting documentation, prepared by the Group of this Meeting for the NAT V RAN Meeting, should be presented to ICAO by France on behalf of the Chairman of the Group.

2.2 It was understood that France, when submitting such documentation to ICAO would make it clear that this measure should in no way commit either France or any of the other States having nominated members to the NAT/SPG with respect to the contents of such documentation and that, as a consequence, their national positions, taken at the NAT V RAN Meeting would not be commited in any way by the documentation in question.

3. Statement by the Representative of the International Air Navigators' Council (IANC).

3.1 At the opening of this Meeting, the Representative from IANC made a general statement in which he expressed the regret of his organization over the fact that, even though some of the operators served by members of his organization had, since years, made considerable financial and technical efforts regarding the installation of improved and new navigation equipment aboard their aircraft operating across the North Atlantic which had resulted in very noticeable improvements to the accuracy of navigation of the aircraft concerned, these operators were still deprived of the expected operational benefits from such efforts, mainly in the form of reduced separation, because others had not yet seen fit to do so. He therefore believed that the time had come to take a closer look at this aspect of the problem and, if necessary, take regulatory measures regarding airborne navigation equipment in aircraft engaged in North Atlantic operations and navigation performance by such flights in order to finally allow progressive and imaginative operators to enjoy the desired operational benefits of their efforts.

Summary of Agenda Item 1: Joint meeting with the NAT Traffic Forecasting Group (NFG) to discuss matters of common interest.

1.1 Introduction

1.1.1 Because of the very satisfactory results, both for the NAT/SPG and the NAT Traffic Forecasting Group (NFG), obtained at the joint session held during the 5. Meeting of the NAT/SPG in December 1968 in Montreal, it had been agreed between the two Groups that this should be repeated at this meeting of the NAT/SPG.

1.1.2 Consequently a joint session of the NAT/SPG and the NFG was held in the afternoon of 4 September 1969 during which the NFG made a brief presentation of their proposals on busy period forecasts, followed by a general discussion regarding the problems they were encountering and the preparation and utilisation of the forecasts produced.

1.2 Presentation by the NFG

1.2.1 General remarks regarding proposed measures of busy period forecasting methods and indices

1.2.1.1 In their presentation to the 5. Meeting of the NAT/SPG, the NFG pointed out that their methods of forecasting busy period traffic levels and indices were virtually unchanged from those first introduced some years before. It was suggested therefore, and agreed by the NAT/SPG, that the NFG should study the desirability of introducing improved methods and indices for future busy period forecasts. As a consequence an additional Appendix was included in the latest annual forecast covering the period 1969-78, setting out a number of possible alternatives and comments were invited from members of the NAT/SPG on those alternatives.

1.2.1.2 These comments have been studied and further work carried out by the NFG, as a result of which it is now possible to propose revised procedures for busy period forecasting of North Atlantic air traffic and these are summarized below.

1.2.2 Annual traffic forecasts

1.2.2.1 The methods used in the up-dating of the forecasts of annual totals of air traffic over the North Atlantic have been revised and improved a number of times in the past few years and no further revision is proposed at present. It will be assumed below that such annual totals are already available as a starting point for the busy period forecasts.

1.2.3 Definition of busy period

1.2.3.1 This period has always been taken to be the two busiest months of a year, i.e. July and August. There is no indication at present that any other month is about to approach these months closely in terms of traffic levels and so no change in this definition is proposed for the present.

1.2.3.2 However, there is evidence that these two months have been accounting for an increasing proportion of the total traffic each year, unlike the position in most other busy traffic areas where the busiest month's traffic is either declining or is roughly stationary in relation to the traffic over the rest of the year (although the actual traffic levels may well still be increasing).

1.2.3.3 It is proposed to take account of this trend in the forecasts of traffic for the next few years, by assuming that the busy period proportion will continue to increase but at a reducing rate, until it eventually begins to decline gradually as has already happened in other areas.

1.2.4 Busy day forecasts

1.2.4.1 The average busy day index at present used is the number obtained by dividing the forecast total for the busy period, derived as described in the previous paragraph, by 62, the number of days in the two months. It is therefore a forecast for the "average day" in the busy period. This has proved to be a useful and meaningful index, and it will therefore be retained.

1.2.4.2 However, it is not in the true sense a "busy day" index, since something like half the days in the busy period may be expected to have larger totals of traffic than the average so calculated. As explained in the Appendix to the latest forecast report, indices representative of the traffic levels in the busier periods near the peaks would be more useful, although it is generally accepted that absolute peak levels cannot be forecast with any precision. The pattern of the frequency distribution of daily totals in the busy period over a number of years has been studied, and from this it has been possible to estimate with reasonable confidence the population distributions from which these samples may be assumed to have arisen. The stability of various percentages, such as the 90% and the 95% values, has been inspected, from which it has been concluded that the 90% value is an adequately stable index for the near-peak busy day. It is therefore proposed to include this value in the next up-dated report, alongside the average busy day figures previously quoted. This 90% value is such that it is likely to be exceeded only about six times on average during the busy period (i.e. during the year). It is therefore, in other words, a forecast of the seventh busiest day's traffic.

1.2.5 Busy hour forecasts

1.2.5.1 The so-called average busy hour index previously used has been criticized on many grounds. It is not an overall average (as is the average busy day above described) and its use gives rise to a number of anomalies. It will be quoted in the next forecast report purely for comparisons with previous forecasts, in case this should be required. Thereafter it is proposed to omit this index altogether.

1.2.5.2 A study of the pattern of the frequency distributions of the busiest hours in the busy period in recent years reveals that the population distributions from which these samples may be assumed to have arisen can be estimated with even greater confidence than in the case of the busy day totals outlined above. A similar argument therefore leads to the proposal for the adoption of the 90% value in the distribution as a stable and useful measure of the near-peak busy hour. It will in fact be a forecast of the seventh busiest hour's traffic in the busy period (i.e. during the year). Any trend detected in the relationship between busy hours and busy days will be taken into account in the forecast in what appears to be the most suitable form. The ratio of busy hour to busy day traffic has been decreasing in recent years, indicating that some "peak-spreading" is already taking place during the day despite the opposite trend at present over the year as a whole.

1.2.6 Distribution "shape" forecasts

1.2.6.1 It will also be possible to provide outline forecasts of the trends in certain "shape" distributions, certainly seasonally (over the months of the year) and diurnally (over the hours of the day). It is proposed to include these with the traffic forecasts, not for every year in the forecast but possibly related to significant change periods, such as the introduction of the SST, or a forecast change in a "peak-spreading" trend.

1.3 Discussion of matters of common interest

1.3.1 Need to include non-jet traffic in future forecasts

1.3.1.1 In the discussion following the presentation of the NFG, it was pointed out that commercial non-jet traffic across the North Atlantic was continually declining in number and would soon reach a level that no longer constituted a noticeable factor in the forecasts. It was therefore suggested that this traffic be completely omitted from future forecasts and this was agreed.

1.3.2 Definitions of the areas for which forecasts are made and of the traffic to be forecast within these areas

1.3.2.1 As a first observation it was pointed out that the figures now shown against "Polar Routes" in the Traffic Forecast Report were in fact not referring to polar flights as used in the operational meaning of this expression. It was therefore suggested that the area in question should be redesignated as "North of the Principal Area".

1.3.2.2 With regard to the traffic forecasts shown against the "Principal Area" it was stated by some members of the NAT/SPG that actual traffic figures were significantly above the corresponding figures shown in the previous forecasts for the year in question. The NFG pointed out that this was due to three conditions :

i) the forecasts were essentially "long-term" and were not intended to be accurate short-term forecasts for the early years in the ten-year period covered;

ii) the busy period forecasts will always be lower than actual peak traffic figures since, even for the busy hour, they have represented average values and <u>not</u> the maximum values attained;

iii) in the Principal Area the forecast and the actual traffic figures will, in addition, significantly vary as long as the NFG is required to show for the Principal Area only those flights which operate between Europe and America and stay within the Principal Area <u>throughout</u> the portion of their flight in the NAT Region.

It was recognized that this was basically a question of definitions and users of the forecast would have to be made aware of this.

1.3.2.3 In the ensuing discussion on the problem raised by the condition mentioned in iii) above it was pointed out by the NAT/SPG that in order to be most meaningful from an operational point of view, it would be desirable to have the figures for the Principal Area show the total of all traffic which was at any time in the flight operating in the Principal Area. After having considered the various elements within the above traffic, it was agreed that to attempt to forecast each element separately would exceed, by a considerable degree, the present capacity of the NFG and could not be realised without a significant increase to its working methods. It was therefore agreed that forecasts for the Principal Area should in future cover all traffic placing a demand on the air traffic control services in the Principal Area, whether for the whole or for only part of the flight.

(Note: Forecasts on the previous basis (see para. 1.3.2.2 iii) above) will also be included in the next up-dated report for comparison purposes.)

1.3.2.4 As regards the actual traffic counts now made by Gander and Shanwick OACs at 50° W and 10° W respectively, which constituted a valuable aid to the work of the NFG, it was noted that they not only varied considerably from corresponding figures in previous forecasts (due to the conditions stated in para. 1.3.2.2 above) but also differed from each other, for valid reasons. It was suggested that traffic counts by both OACs should be made at 30° W and should include all traffic operating between, say, 44° N and 64° N. It was pointed out that this did not resolve any of the problems mentioned in para. 1.3.2.2 above nor would it directly improve the forecasts, but it would at least help to explain better the differences in the traffic counts of Gander and Shanwick OACs. It was agreed that this suggestion should be given further consideration.

1.3.3 Appreciation of sociological and other trends in the forecasts

1.3.3.1 The question was posed whether the NFG took into account sociological, political and economic trends, such as change to the cycle of the scholastic years in major traffic generating States, the expansion of charter operations, changes to the fare structures, etc. The NFG stated that this was done to the limited extent possible.

1.3.4 Forecasts for SST operations in the NAT Region

1.3.4.1 IATA pointed out that, in their opinion, the forecast figures shown for SST operations in the latest report of the NFG covering the period from 1969 to 1978 were highly optimistic and there was at present no indication that these figures could be reached. It was agreed that this matter be kept under careful review by the NFG.

1.3.5 Preparation for the NAT V RAN Meeting

1.3.5.1 In view of the discussions, especially with regard to the revision of the forecasts proposed by the NFG, the Meeting felt that it might be useful if the NAT/SPG were to advise the NAT V RAN Meeting of the situation, explaining the revised forecast indices and those significant changes made to the forecasting methods since the Special NAT Meeting 1965 and their effects on the forecasts. (See also Appendix 4-A, para. 3.3.)

Summary of Agenda Item 2: Establishment of methods for the assessment of system performance.

2.1 General aspects

2.1.1 Cost-benefit relations in system performance

2.1.1.1 In a general discussion on this subject, the Group reviewed its aim with respect to the studies of system performance criteria. As already expressed in para 1.4.5.3, page 1-27 of the Summary of Discussions of the 4. Meeting, the Group agreed that a principal aim should be to carry out cost/benefit studies in order to evaluate system performance.

2.1.1.2 Three basic types of costs are involved in this connection :

i) the costs (to the operators and to the general public) of the deviations from the most desired flight paths and related delays;

ii) the costs (to operators and to provider States) of navigational aids, ATC equipment and personnel;

iii) the costs (to operators, to the general public and to States) of collisions.

2.1.1.3 The Group noted that great progress has now been made in developing the costing of operator penalty due to ATC deviations. It agreed in general to the principles of the methodology described in para. 2.2 below and the Appendices.

2.1.1.4 The Group deemed it desirable to develop methodologies for analysing costs ii) and iii). It is recognized that strictly commensurate values cannot be obtained for the costs of some of these factors (especially the cost of human lives); nevertheless, it is believed that the relative values developed by quantitative cost studies will be of great value in assessing proposed system changes.

2.1.2 Specification of navigation capability in relation to system performance

2.1.2.1 An exchange of views took place on another aspect of system performance, based on a study carried out by the United Kingdom of navigational capability, in terms of accuracy (standard deviations) and reliability (MTBF's) which might be specified for airborne equipment in order to ensure that the requirements of particular ATC environments are met.

2.1.2.2 A view was expressed that the methods developed by the Group to determine the separation standards appropriate to the navigation capability measured in the data collection exercise, could be applied for future system planning. Thus if it were possible to express what would be a reasonable cost of deviation from the optimum flight path, the costing model would permit the approximate determination of the separation needed; in turn further development of the concept might permit the specification of navigation capability required to support such a separation standard in terms meaningful to system engineers, namely accuracy and reliability.

2.1.2.3 The basic idea of the UK study was to divide the permissible collision risk for a particular type of separation (for example, diagonal collision risk in a subsonic composite system) into two portions : one for what is here called "normal" operation, and the other for those cases in which the primary navigation system has broken down and reliance must be placed on a less reliable back-up system. The breakdown situation is, of course, much more dangerous, but since it happens infrequently, its total contribution to the collision risk may be about the same.

2.1.2.4 It is therefore a convenient assumption that one should divide the permissible collision risk equally between reliability and accuracy - and it turns out that this assumption has comparatively little effect on the final conclusions (which is one of the interesting conclusions of the study).

2.1.2.5 The calculations for the "normal" situation are routine, the only difference being the lower permissible level of risk. The calculations for the breakdown situation involve some unverified assumptions ; for example, the independence of probabilities of breakdown of redundant systems (such as duplicated inertials). The result of such calculations are permissible MTBF's (mean time between failures) to achieve a given level of risk.

2.1.2.6 Some interesting results of such analysis are the following: if both of a pair of duplicated systems must work, then very large MTBF's (i.e. very reliable systems) are required; if either of a pair of duplicated systems is adequate, and if they fail independently, then very small MTBF's (i.e. very unreliable systems) are acceptable. Some of these conclusions are summarized in Table 1 below, which represents the results of the UK study on the subject.

Table 1

Typical System Reliability Requirements

Available for use at take-off	Required for "normal" navigation	Inertial failure detect-ability	Loran MTBF assumed	Individual inertial MTBF required
2 Inertials	1 Inertial	50 %	NA	200
3 "	1 "	50 %	NA	41
2 "	2 "	NA	NA	780
3 "	2 "	NA	NA	66
2 Inertials + Loran	2 Inertials or 1 Inertial + Loran	NA	300	19

Notes: NA = Not applicable;
MTBF = Mean time between failures;
All MTBF's in hours;
A low value "MTBF required" means comparatively unreliable inertial is acceptable;
All numbers are tentative, but relative magnitudes are believed to be trustworthy.

2.1.2.7 It must be stressed that the numbers of this table have not been accepted by the Group, but the Group does believe that the relative values of these numbers are approximately correct.

2.1.2.8 The Group recognized the value of the study made by the United Kingdom for systems planning and agreed that the results be brought to the attention of the NAT V RAN Meeting.

2.2 Costing of the NAT subsonic and supersonic systems

2.2.1 The Group discussed studies submitted by the United Kingdom. The first study presented a method of estimating airline operating cost penalty due to ATC deviations as a criterion for assessing NAT systems performance; the other two studies were applications of this method to the present planned NAT ATC systems for subsonic and supersonic operations respectively. The main contents of the method and its application with some additions and alterations proposed by the Group, are given in Appendices 2-A, 2-B and 2-C.

2.2.2 The Group agreed in general on the principles of the method, which estimates the penalty incurred by operators because they cannot fly on the optimum flight plan path. The method provides a tool for comparing the costs to the airlines of different track systems; it also provides the means for estimating the benefits to the airlines which accrue from a change in the ATC system, for comparison with the cost of such a change.

2.2.3 However, while it was agreed that the work conducted by the United Kingdom on this subject was very useful both with respect to the development of methodology and in illustrating its application on the part of subsonic and supersonic flights, certain aspects of this methodology, as well as the numerical results shown in the Appendices, are accepted only on a tentative basis subject to further examination of the various assumptions and input quantities employed. In this regard, the Group identified a number of areas which may require further refinement. The list of items below represents preliminary thinking on this matter. Others may come to light after more detailed study.

i) Costs of unpunctuality: The cost to operator of missed connections, a loss of good-will of passengers, etc., should be considered together with the cost of methods of avoiding unpunctuality (e.g. use of uneconomical cruise procedures).

ii) Estimation of fuel reserves: The method used in determining the fuel reserve increment attributable to ATC deviations leads to the result that these will vary to some extent with the average duration of holding delays at the destination. This assumption requires further examination.

iii) Lost revenue estimates: The calculations on lost revenue in Appendix 2-B are based on data from a few aircraft types and from a limited number of routes. As the final results are critically dependent on the distribution of payload carried and on the stage lengths for the different aircraft types, it was felt that more data would be required.

iv) Costs for crossing aircraft: Aircraft operating between terminals other than those for which the track structure has been designed suffer additional penalties. These penalties result from having to fly :

a) at uneconomical flight levels in order to overfly or underfly the system;

b) around the system;

c) by planning a route via one of the organized tracks.

Comparison between the costs associated with planned flight paths and actual flight paths will be an underestimation of the total cost to such traffic.

v) Distribution of aircraft types: Due to differences in their operating costs and performance characteristics more consideration should be given to the types of aircraft to be expected in the environment and their ratios of participation.

vi) Traffic forecast: The traffic assumptions used as input in these costing exercises should receive further examination and revision should be made if appropriate.

vii) Eastbound flow: A more thorough examination is required of penalty costs to eastbound traffic. The assumption as to their ratio to westbound costs may need revision.

viii) Flight path loading: Reasons suggested in paras 6.2.2 to 6.2.4 of Appendix 2-B should be re-examined together with the assumption that they will become less prominent.

2.2.4 The Group noted the following preliminary results of the application of the methodology by the United Kingdom :

i) The provisional results given in Appendices 2-B and 2-C based on the prediction of the NAT Traffic Forecasting Group show the annual cost penalty of subsonic aircraft on the North Atlantic to attain a peak by 1977 at just over twice the current value; even then the penalty represents less than ½ % addition on total operating cost if current separation standards remain unchanged.

ii) The level of penalty to supersonic traffic should build up rapidly after start of service and should reach the annual subsonic penalty by 1976 - the study of the supersonic system has been based entirely on the Concorde, since insufficient data on other SST's was available.

iii) The estimate of supersonic penalty by 1978 represents about 2% of the total operating cost at the level of separation standard envisaged by the Group (60 NM lateral and 10 mins longitudinal separation).

iv) A reduction in separation standard has a much greater effect on the supersonic system than the subsonic. Thus halving any separation standard reduces by 90% the cost penalty to supersonic aircraft and by 50% the cost penalty to subsonic aircraft.

v) The introduction of a composite system for subsonic aircraft with 60 NM and 1 000 ft separations will also reduce by 50% the penalty resulting from the current value of separation.

APPENDIX 2-A

A METHOD OF ESTIMATING AIRLINE OPERATING COST PENALTY AS CRITERION FOR ASSESSING AIR TRAFFIC SYSTEMS

1. Introduction

1.1 This note describes the methods that have been developed at RAE over some years for estimating the operating cost penalty suffered by airlines which arises out of the need to maintain safe separation in an air traffic system. This figure can be expressed either as an average cost per flight or as a total cost for all aircraft in a given period. Whichever of these two alternatives is employed, it expresses the effectiveness of the system under consideration in a meaningful way as a single figure.

1.2 While these methods have been developed with particular reference to North Atlantic operations, they should be applicable with some modifications to any parallel track system.

1.3 The effect on operating cost of the delays and diversions which may occur on a single flight is first considered. Building up these costings into a statistical model of the system as a whole, which can give the average penalty per flight occurring in the system under given conditions of traffic loading, is then discussed.

2. Operating cost

Attention has been concentrated on the direct operating cost (DOC) i.e. that part of an airline's expenditure which can be directly associated with the operation of aircraft (it amounts to about half the total airline expenditure). Direct operating cost comprises the following items :-

Landing Fee
Engineering (maintenance and overhaul)
Standing Charges
Aircrew Costs
Fuel Costs

The effect of deviations causing relatively small increases in flight time and fuel are discussed hereunder. The resulting increase in cost can be expressed as an average cost increment per flight, or as a percentage increment on the direct operating cost for the flight, or as a percentage increment on the total operating cost.

2.1 Effects of deviations on Direct Operating Costs

2.1.1 The landing fee per flight will be unaffected unless the deviation is so great as to require an intermediate stop for refuelling.

2.1.2 Engineering costs are usually assumed to be proportional to flight time. However, most wear and tear on both airframe and engine occurs during take-off, low altitude flying, and landing. To increase the engineering costs associated with a given flight by 5%, following a 5% increase in flight time due to increased distance flown at altitude would be unduly severe. The engineering costs are therefore divided into two parts; one part conventionally known as the overhaul cost, is proportional to flight time, whilst the other, called the maintenance cost, is independent of it for such relatively small variations as are produced by air traffic control in the great majority of flights. The overhaul and maintenance costs are of about equal importance. A representative figure of engineering cost per flying hour has been taken and half this ratio will give the increase in engineering cost per unit time of en-route ATC delay.

2.1.3 Standing charges comprise depreciation and insurance fees; both of which are properly expressed as a fixed cost per annum. To obtain the cost to be apportioned to an individual flight the latter figure is divided by the number of flights per annum*. This will not be affected by deviations due to air traffic control except in so far as the resulting time increments are such as to reduce the number of revenue flights an individual aircraft can achieve in one year. If the annual number of flights is reduced, the amount of standing charge apportioned to each flight is increased and the increment represents an additional cost effect of the deviation. The increment represents the penalty to the operator due to loss of "utilisation", i.e. a reduction in the useful work output obtained from the capital tied-up in the aircraft. It has in general been assumed, in the studies on the North Atlantic, that ATC deviations have no effect on standing charges.

2.1.4 Aircrew costs. The effect of small increases in flight time on crew pay depends on the practice of the operator. Some operators pay a fixed annual salary while others pay according to time spent in the air. In the former case small increases in flight time will only affect staff costs if time increases affect "staff availability", i.e. require extra crew members to be engaged. Taking the second assumption would about double the cost penalty of extra flight time.

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*In this argument it is assumed that each individual aircraft operates on one route only. In practice aircraft usually operate a variety of routes of different stage lengths. The argument is then similar but more complex; for each flight the standing charges are apportioned on a basis of the length of that particular route.

2.1.5 Direct fuel costs will increase in proportion to the quantity of fuel used. This may increase because the aircraft is diverted to a track which involves flying more air miles than the optimum track, or because it is forced to hold before entry to the system, or because it is allocated a flight level other than that for most economic operation. Under this particular item only the extra fuel burnt because particular deviations are encountered on a given flight is taken into consideration. The extra fuel burnt because of increased take-off weight consequent on the uplift of extra fuel in anticipation of deviation forms a separate item (see 3.2 below).

2.1.6 Thus, of the different items of operating cost discussed above, engineering and fuel costs are selected as suffering significant alteration with the types of deviation and delay imposed by ATC on North Atlantic routes (aircrew charges may also be significant). These penalties form what we called "low" cost of deviation; they relate specifically to the deviations encountered to each individual flight. In addition there are other penalties which are related to the average expectation of deviation, and which therefore depend on the overall pattern of deviations over a period of time; they apply equally to every flight, irrespective of the paths allocated on particular occasions. Such are the penalties dependent on fuel reserves.

2.2 Other operating costs

2.2.1 Other penalties created by late arrivals. Poor punctuality is disliked by airlines because it may result in both publicity (lost connections, etc.) or create inconvenience at terminal airports. However, for the purpose of this study, it has been assumed that these penalties are intangible and have been ignored in this model. This makes the result conservative in terms of penalty assessment.

3. Fuel reserves

3.1 Effect of deviations on fuel reserves

3.1.1 Consideration is given to the effect of en-route ATC deviations on the fuel reserves uplifted at take-off. For most operations over the North Atlantic the level of fuel reserve is determined by considerations of regularity of service, i.e. to keep the incidence of diversions from the airport of destination for reasons of lack of fuel down to a commercially acceptable level. Fuel reserve is fuel carried above the flight plan fuel to cater for a variety of contingencies such as worse-than-forecast winds, holding at destination and en-route ATC deviations.

3.1.2 If the incidence of en-route ATC deviations increases, the operator has two alternatives :

a) To maintain the level of fuel reserves. This implies that the en-route ATC deviations will more often eat into the fuel carried to meet other contingenices; hence the aircraft will more often have to divert from the designated destination.

b) To increase the fuel uplift so as to maintain the level of regularity.

3.1.3 Both choices will carry a penalty. We expect for small increases in en-route deviations, operators will not change their fuel reserve policies, which usually include allowance for en-route deviations in some such way as increasing the flight plan fuel by a fixed percentage. The extra ATC penalty then appears as a loss of regularity. As the level of incidence of en-route deviations increases, a critical level will be reached at which the fuel reserve policy will be changed to maintain regularity.
For a given airline the fuel reserves will vary with the ATC deviations as a step function. The penalty appears either as a loss of regularity or extra fuel load.

3.1.4 For convenience in estimating the ATC fuel reserve penalty averaged over a number of airlines, it is assumed that all changes in the incidence of ATC deviations are reflected in change of fuel reserve policy so that regularity remains constant. The penalty is then expressed entirely in terms of fuel load.

3.1.5 The relationship between fuel reserve and regularity of service for North Atlantic operations of both subsonic and supersonic aircraft was studied by an RAE working party. The results were published as Reference 1.

3.1.6 The statistical method of estimating the regularity reserve starts by considering all the major ways in which the flight to destination can vary from the idealized flight plan drawn up before take-off. Each variation will lead to fuel consumption different from that planned. For example, a headwind greater than forecast will lead to more fuel being used on the flight, and a lower-than-forecast headwind will lead to less being used. Each variation, or contingency, can be defined in terms of the probability of meeting any particular magnitude of, say, headwind. The characteristics of the aircraft then enable the effect to be turned into fuel used in excess of the flight plan.

3.1.7 The method of assessing the effect of the en-route ATC system on fuel reserves is as follows. From statistical models of the system described in para. 5 below, the frequency histogram of extra-to-flight-plan fuel requirements arising from ATC deviations is obtained. Corresponding histograms for all other sources of variation are obtained by methods described in Reference 1. By process of convolution all the histograms <u>except</u> that for en-route ATC are combined to give a frequency distribution of fuel requirements for all other sources of variation. The maximum fuel requirement not exceeded on "x%" of occasions, "x" being commercially acceptable regularity is extracted from this distribution. The ATC fuel histogram is then combined with the overall histogram, and a new histogram is obtained from which a new figure of fuel requirement at "x%" is extracted. The difference between these two fuel requirements is the effect of the ATC deviations on the fuel reserve.

3.1.8 The detailed process of convolution is described in Annex I which is largely extracted from Reference 1. It should be noted that there is no need to re-assess the fuel requirements for sources of variation other than ATC for each separate ATC study. The combined histogram for contingencies other than ATC can in fact be one of the standard inputs to a programme for assessing the economic effects of ATC. Examples of such histograms for subsonic and supersonic aircraft are given in Annex II.

3.1.9 One property of this convolution method of assessing the ATC fuel reserve increment is that the result will be affected by variations in the incidence of other sources of fuel variability. For instance, a decrease in the incidence of terminal holding delays would result in an increase in the fuel increment attributable to en-route ATC, by as much as 25% in the extreme case of a reduction of the holding delay to zero.

3.1.10 This method of assessing the increased fuel uplift corresponding to a given pattern of deviations is complex, but can be easily handled on a digital computer. It is found in practice that the use of simpler methods cannot give an acceptable approximation of the effect of ATC on fuel reserves and consequent cost. Particularly is this true for supersonic operations.

3.2 <u>The Effect of Fuel Reserves on Cost</u>

The increment in fuel reserve due to ATC deviations will affect the operating cost in two ways :

a) by increasing the aircraft weight and hence fuel consumption;

b) by occasionally reducing payload capacity.

3.2.1 The "Carry" Cost Estimate

3.2.1.1 On the majority of flights, an increment in fuel reserve of the order of size required by an en-route ATC system will be taken up by an increase in aircraft take-off weight. This in itself results in increased fuel consumption during the flight; the extra fuel burnt represents an additional cost arising from the ATC deviations. For transatlantic operation of subsonic aircraft, an increase in fuel uplifted at take-off of quantity "f" produces an increase in fuel burnt of approximately 0.3f. For transatlantic operation of Concorde the figure becomes 0.4f. The cost of this fuel is called the "carry" cost.

3.2.2 The "Lost Revenue" Estimate

3.2.2.1 On a fraction of flights, the situation will be such that the take-off weight is at or close to the maximum permitted by performance or structural considerations. On these flights, an increment in fuel reserve requirement will result in a loss of payload capacity. This will not necessarily reduce the payload actually carried except on those flights where the payload offering exceeds the reduced payload capacity. This will not happen on every flight; indeed on the North Atlantic the average load factor (ratio of payload carried to capacity available) lies between 50% and 60%. When payload does exceed capacity, the operator has two alternatives :

a) to leave payload behind, preferably freight;

b) to operate with an effectively reduced fuel reserve and hence an increased chance of having to divert

3.2.2.2 Both alternatives carry a cost penalty. The first alternative has been chosen for costing purposes as it is easier to assess; however it is believed that if the cost penalty of the second alternative could be assessed it would be similar.

3.2.2.3 An estimate of the cost corresponding to the payload occasionally displaced can be estimated; this is called the "LOST REVENUE" cost. A model for estimating this "lost revenue" is described in Annex III for both subsonic and supersonic aircraft and the results are shown in Figures 3, 4 and 5. Annex III also shows that with the above assumptions the mean load factor increases with the introduction of the ATC reserve. This implies a reduced standard of service, inasmuch as a passenger will less often be able to take the flight of his choice.

4. Summary of Cost Items included in penalty

4.1 As described in preceding sections we have selected the following cost items as contributing to the cost penalty of Air Traffic Control deviations in a system such as that for the North Atlantic :

a) Engineering Cost

b) Fuel Burnt because of Deviation

c) Fuel Burnt to carry Fuel Reserve Increment

d) Lost Revenue because of Fuel Reserve Increment

e) Aircrew Costs

Items a) and e) are proportional to the mean increment in flight time and b) to the mean increment in fuel used. Items c) and d) are related to the total spread of fuel penalties and depend largely on the rather more extreme diversions.

4.2 Definition of Terms

4.2.1 The "LOW" Cost comprises only those items of cost that can be related to the particular deviation encountered on a particular flight, i.e. the sum of items a), b) and e) above.

4.2.2 The "MID" Cost includes, in addition to the "low" cost, the allowance for the cost of fuel to carry the extra fuel reserve, i.e. items a), b), c) and e) above. The concept of the "mid" cost implies the assumption that the extra fuel reserve can always be taken up within the maximum weight of the aircraft, without reducing payload.

4.2.3 The "HIGH" Cost includes also the effect of lost revenue due to payload reduction, i.e. all items a) to e). This is the most realistic estimate of cost and it is the cost quoted in subsequent parts of this note.

5. Systems Analysis

Consideration is now given to the way of assessing the spread of penalties in terms of fuel, time, and hence cost for a given ATC system. For existing systems the distribution of deviations and delays among aircraft using the system may be obtained by sampling. Further study may still be necessary to assess the fuel and time penalties resulting from a given deviation, (see para. 2). For hypothetical systems a mathematical model has to be constructed. This may be more or less complex according to the number of details of the system which it is required to simulate, and the degree of accuracy required in the final estimate of cost penalty. However, all models must contain three elements :

a) a description of the geometry of the system;

b) a description of the traffic offering, both in terms of intensity and arrival pattern;

c) a description of the logic of the method of controlling this traffic.

5.1 System Geometry

5.1.1 Most studies of the North Atlantic traffic system have assumed some kind of arrangement of parallel tracks either in three or two dimensions. The first step is to associate a cost penalty with each flight path* of the system. This is the extra cost incurred by an aircraft in isolation using that flight path. This cost penalty may be related to either the best flight path in the system or to the ideal best flight path for a given pair of terminals. It is the former of these alternatives that has been used in deriving the figures quoted subsequently; there is an additional penalty because of the difference between the best path in the system and the ideal best path. Since the tracks are mainly oriented to cater for the main stream of Atlantic traffic, for flights in this stream this extra penalty will be small. For flights operating other routes, however, particularly those crossing the main stream at an appreciable angle, the extra penalty may be large. The percentage of traffic operating such routes increases year by year. For this reason the cost figures based solely on aircraft in the main stream will underestimate the total system cost, and the discrepancy will vary with the route flown.

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* A flight path is defined as a combination of an assigned track and flight level.

5.1.2 The cost penalty attached to one particular flight path in isolation must be assessed in the "low" sense, i.e. without considering fuel reserves. It is clear that to determine this cost (and fuel and time) penalty account should be taken of not only the geometry of the system but also of aircraft performance characteristics and (at least for subsonic aircraft) meteorological considerations. In the subsonic system, indeed, the position of a given track may fluctuate laterally from day to day and the consequent penalty may also vary. In this case knowledge of the average cost penalty of this track and possibly also the degree of variation is required. A practical study of this aspect, based on forecast wind data on the North Atlantic, is given in Appendix 2-B.

5.1.3 Under this heading, therefore, not only the geometry of the system but also other characteristics such as aircraft performance and meteorological conditions are included. These are all "static" in the sense that they do not depend on traffic conditions.

5.1.4 In a multi-terminal system sharing the same set of track, it is clear that a given flight path will carry different penalties according to the origin and destination of the flight using it.

5.2 Traffic Conditions

5.2.1 Under this heading are included the average intensity of traffic offering and the way it varies with time; also, where relevant, the way this traffic is distributed among different origins and destinations. For subsonic trans-atlantic aircraft there is a well-marked tidal surge of both westbound and eastbound traffic throughout the 24-hour period. A corresponding diurnal pattern is expected to obtain for the SST, different from the subsonic aircraft in that there is a double tidal surge of aircraft throughout the 24 hours[2]. In addition to this large-scale variation in flow rate, it is necessary to know the fine-scale fluctuation of the flow. In most studies conducted to date it is assumed that the individual entry times of aircraft to be completely random, i.e. Poisson. Thus the times of aircraft offering themselves for oceanic entry form a Poisson sequence with the hourly flow rate varying, either according to the diurnal pattern, or, in simpler simulations, held constant. The assumption of constant flow rate implies that the average flow remains steady long enough for the system to settle down. As will be seen, this assumption, if justifiable, can simplify the system assessment.

5.2.2 An alternative to the random or Poisson arrival assumption is to consider the aircraft to arrive according to some definite schedule, with or without perturbations. For current subsonic traffic, where aircraft take-off from many terminals with no correlation between them, the Poisson entry process is probably realistic. For supersonic aircraft, it may be possible to impose a greater degree of regularity on the flow. The effect of this is being investigated.

5.2.3 In the system model, opposite direction flows must be considered separately, even though they occur at the same time. For each assessment, the effect of the counter-flow is to make a certain number of flight paths unusable.

5.3 Control Procedure

5.3.1 Under this heading we include the rules whereby controllers allocate aircraft to various flight paths. The first item under this heading is the minimum longitudinal spacing between aircraft entering the same track. This has a specified value determined by safety considerations. In practice, however, controllers may employ somewhat larger minima than the specified minimum i.e. they may divert an aircraft to another track when its separation is somewhat greater than the legal minimum. This controller's caution may arise from several causes, among them experience of inability of aircraft to meet their estimated time of oceanic entry. Where this is the case, some model of controller behaviour should be included in the system model. (See para. 7.1 below.) In some systems also the specified minimum longitudinal spacing may vary with the speeds of the relevant aircraft. In addition other constraints may in some cases be applied e.g. in a staggered system there may be longitudinal separation between aircraft in adjacent tracks. For supersonic aircraft there may be a further requirement for aircraft to be separated at crossing points in the transition zone before reaching the oceanic system.

5.3.2 These considerations will define whether a path is blocked or unblocked at the time when an aircraft intends to enter the system. If a desired path is blocked the controller has the option of delaying the aircraft until the path becomes permissible or of diverting the aircraft to a less favourable path. Delay, when necessary, may be brought about by causing the aircraft to fly extra-distance at cruising speed before joining the oceanic track (circling or dog-leg tracks) or, in the case of supersonic aircraft, by changing the along-track point at which the transonic acceleration commences. The penalty per minute of delay in terms of time, fuel and cost is estimated according to the delay method used. When entry delay is employed, we assume that each aircraft is allocated that path for which the combination of intrinsic cost penalty and penalty of associated delay (in the "low" sense) is a minimum.

5.3.3 Rules of this sort will determine the distribution of aircraft among paths. In all this work it has been assumed that arriving aircraft are considered one by one in order of their estimated times of oceanic entry. It is possible that a different order of priority might in some cases give an overall economic benefit. However, for the present purpose it is unnecessary to consider the system to this degree of complexity.

6. Methods of Analysis

Having defined the system to be studied, methods of deriving the distribution of penalties among aircraft are now considered. These fall into two categories :

a) Analytical methods based on the theory of queues.

b) Simulation.

Analytical methods have the advantage of being free from sampling error and may require less computing time than simulation. They are, however, only applicable in simple cases.

6.1 Analytical Methods

6.1.1 Of the various systems studied analytical methods have been found applicable in two cases. Both of these assume a Poisson input with constant hourly flow rate. The first case refers to a system with an unlimited number of paths. These are arranged in order of preference which is the same for all aircraft. No delay at entry is allowed and each aircraft in succession is allocated to the best vacant track at time of entry. The proportion of aircraft p(r) allocated to the rth track is given by the formula

$$p(r) = \frac{\dfrac{\lambda^{r-1}}{(r-1)!}}{1 + \lambda + \dfrac{\lambda^2}{2!} + \cdots + \dfrac{\lambda^{r-1}}{(r-1)!}} - \frac{\dfrac{\lambda^r}{r!}}{1 + \lambda + \dfrac{\lambda^2}{2!} + \cdots + \dfrac{\lambda^r}{r!}}$$

where λ is a non-dimensional constant equal to a.T, and a is the mean flow rate and T the (constant) minimum allowed longitudinal separation between two aircraft on the same path.

The above formula determines the distribution of aircraft among tracks. It is proved in textbooks on queuing theory[6] to apply to the case where the minimum separation on tracks is not constant but follows an exponential law. Some simulation results strongly suggested that the same formula applied to the case where the minimum separation is constant. A proof of this case has subsequently been developed using a method derived from Ref. 4. This proof is given as Annex IV.

Since no delay at entry is allowed, the formula also determines the distribution of penalties among aircraft.

6.1.2 The other case where an analytical result is possible refers to a limited number of paths. No distinction is made between these paths in terms of intrinsic penalty. Entry delay is permitted and each aircraft on entry is allocated to the path carrying least delay. An analytical solution defining the distribution of delays among aircraft is available[5]; it is however cumbersome to use and the complexity increases markedly with the number of paths.

6.1.3 This latter case is not applicable to conditions on the North Atlantic although it appears very suitable to some terminal area problems. The former case, however, represents quite closely current practice on North Atlantic subsonic jet traffic and has been much used in the studies.

6.2 Simulation

6.2.1 In cases where the system is too complex for the solution to be determined by queuing theory, fast-time simulation on a digital computer must be employed. The computer generates a series of so-called "random numbers" (distributed evenly between 0 and 1). These are converted into a series of oceanic entry times for hypothetical aircraft according to the method of distribution to be employed, which may be a Poisson input with fixed or varying hourly flow rate or some kind of disturbed schedule. In addition where a multiple-terminal situation is simulated, another series of random numbers is used to determine the origin of each aircraft, within some defined pattern of distribution of aircraft between terminals. The program input will include sets of numbers representing the intrinsic penalties (time, fuel and cost) attached to each path in the system (these may differ for aircraft from different origin). Another set of numbers represents for each path the earliest time at which a new aircraft can enter that path; this latter set must be updated for each path when a new aircraft has been assigned to that path*. As the program generates a new aircraft entry time it compares this with the "earliest unblocked times" for all paths, assesses the necessary entry delay (where allowed) and its cost and computes the sum of intrinsic and delay penalties for all paths. The aircraft is then assigned to the best path, subject to any constraints that may be included in the program, such as maximum length of delay. The computer repeats the cycle for a suitable number of aircraft (10 000 are generally used). It accumulates histograms of fuel penalties and delay periods and stores the distribution of aircraft among paths. It notes also the cumulative "low" cost penalty per aircraft. When the simulation is complete, further chapters of the program can assess the ATC fuel reserve increment (para. 3) and its corresponding penalty in terms of carry cost and lost revenue.

6.2.2 Simulation suffers from sampling error and can be relatively expensive in computer time. It can, however, be applied to complex situations for which analytical results are unavailable. A typical computer program in the form of a flow diagram is given in Fig. 2-A-7.

7. Suggested Methods for NAT Cost Analysis

In this section particular methods of cost estimation applicable to North Atlantic conditions are specified. Different methods will be required for the two cases of subsonic and supersonic traffic.

7.1 Subsonic Traffic

For the case of North Atlantic subsonic jet traffic it is proposed to use the analytical formula given in para. 6.1. This is based on the assumption of no entry delay which agrees closely with present NAT practice. It is also shown that little benefit is gained for subsonic aircraft by changing the method of allocation to one which does allow entry delay; there is thus little reason to alter current practice in future systems. There are, however, three main differences between the theoretical and the actual system :

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* For supersonic traffic we expect that the minimum longitudinal separation will be kept down to the legal minimum. This will be both desirable because of the sensitive economics of this aircraft and possible because of improved navigation and computer assistance to controllers.

a) the mean hourly flow rate is assumed steady, while in practice it has a diurnal fluctuation;

b) the minimum allowable longitudinal separation is assumed constant, whereas in practice it can vary (para. 5.3);

c) the order of preference of paths is assumed to be the same for all aircraft. In practice it will vary with the origin and destination of the aircraft and may vary with the airline.

7.1.2 With regard to the first point it has been found that for subsonic aircraft the cost penalty varies with the flow rate in a linear fashion. It follows that the fluctuating flow can be fairly represented in the cost analysis by a steady flow provided that a suitable mean rate is chosen. This mean rate must be averaged over all aircraft, not over the relevant period of time. For instance, if N_1, N_2, N_3 ... N_{24} represent the expected number of aircraft movements in successive hours of a day, the mean flow rate in this sense is given by :

$$r = \frac{1}{N} (N_1^2 + N_2^2 + \cdots + N_{24}^2)$$

where N is the total number of movements in 24 hours.

More generally, if the period of time under consideration is divided into a series of intervals t_1, t_2 etc., and n_1, n_2 are the corresponding numbers of aircraft movements in these intervals, the mean flow rate is given by :

$$r = \frac{\sum \frac{n^2}{t}}{\sum n}$$

7.1.3 The second point concerns the variability of the minimum longitudinal separation. It is assumed that this can be adequately represented by its mean value in the analysis. In support of this view, it may be noted that the same formula for distribution of aircraft among tracks is proved to hold when the minimum spacing, instead of being constant, follows a negative exponential law of distribution[6]. The problem therefore is to select a suitable mean value for the average minimum longitudinal separation. This is discussed in Appendix 2-B.

7.1.4 The third point refers to differences in order of preference that may occur between different aircraft. Simulations of systems combining aircraft from two or more different origins for which the optimum track is displaced laterally by one separation standard have been conducted. It is found that, while the pattern of distribution of aircraft among tracks differs somewhat from the one-terminal case, the overall cost penalty differs little from that which would obtain if all aircraft come from the same terminal, provided that suitable average values for the penalties attached to given deviations are used in the assessment.

7.1.5 It is concluded therefore that the simple analytical model gives a sufficiently accurate cost estimate for the subsonic system considered as a whole, provided that suitable average values are chosen for the various constants defining the system. Where the system is to be studied in more detail, e.g. for the cost analysis of one particular section of the traffic, it may be necessary to resort to simulation.

7.2 Supersonic Traffic

7.2.1 For the case of supersonic traffic, the method described above it inapplicable and simulation must be used. The main reason for this is that for this aircraft a system involving entry delay shows great advantage[2] and it is likely that such a system will be employed. Other points to note are that the variation of cost with flow rate is non-linear; hence it is not sufficient merely to assume constant flow at the mean rate - the diurnal pattern should also be simulated. Again the assumption of a multi-terminal system introduces extra problems of separation in the transition area, which affect the distribution of traffic and increase the cost. Allowance must be made for all these points in the simulation. A flow diagram for a supersonic simulation exercise is given in Fig. 2-A-7.

8. Summary of Proposed Methods for System Cost Analysis

The various steps in the NAT system cost analysis for subsonic and supersonic aircraft are summarized hereunder. Phases in the study that are similar for both types are considered together; phases where the treatment differs for subsonic and supersonic aircraft are divided into two subsections.

Step 1: The system is considered as a set of paths arranged in three dimensions (subsonic) or two dimensions (supersonic). The number of paths considered should be amply sufficient to contain the expected flow. Some paths may have to be inhibited to contain the opposite-direction flow.

Step 2: Each path is considered separately and the time and fuel penalty for an aircraft taking this path (without entry delay) estimated. For subsonic aircraft allowance should be made for the effects of wind changes in lateral diversions. For supersonic aircraft a separate set of penalties should be estimated for each of a number of aircraft departure points. The penalties are combined to give the "low" cost penalty for each particular path. All penalties are assessed relative to the best path of the system. For subsonic aircraft the paths are then arranged in order of increasing cost (see for example Fig. 2-A-6).

Step 3 - Subsonic aircraft: For subsonic aircraft the next step is to describe the flow input in terms of a mean rate as explained in para. 7.1. In addition the effective minimum longitudinal separation is defined along the lines of para. 5.3. These two quantities together define the parameter "λ" used in the equation of para. 6.1. Using this equation the proportion of aircraft entering paths of cost ranking order 1, 2, etc., is derived. Theoretically the formula distributes aircraft among an infinite set of paths but in practice the system can be cut off at the path for which the proportion allocated falls to a suitably low value (say 0.001). An example of the distribution obtained by this method is given in Table I, page 2-A-39.

Step 3 - Supersonic aircraft: The peak flow rate, and also the diurnal pattern of flow, are defined. The distribution of aircraft among origins is also required. These quantities define the input to a fast-time simulation exercise; within each hour the distribution of arrival times follows a Poisson pattern with the expected hourly rate. The program considers each aircraft in succession and allocates it to the track which carries the lowest overall cost (intrinsic + delay penalty). The simulation continues for 10 000 aircraft and accumulates the following distributions :

a) aircraft among tracks;

b) cost penalties (track + delay) among aircraft;

c) fuel penalties (track + delay) among aircraft.

In addition the program computes the average value of "low" cost penalty.

Step 4: For subsonic aircraft the distribution of aircraft among paths is readily converted into a distribution of penalties (cost and fuel) among aircraft since each path carries its own penalty and no entry delay is allowed. The next step for both types is to estimate the fuel reserve increment. For this purpose the distribution of fuel and penalties must be expressed in terms of fuel uplifted at take-off; that is, each separate diversion and delay must be assessed as though it were anticipated before take-off and the take-off weight increased accordingly. In practice this means that the fuel penalties used in assessing the "low" cost (assuming no change in take-off weight) must be multiplied by a factor which is constant for the type of aircraft (about 1.4 for subsonic and 1.7 for supersonic). This factor should be built into the program. The fuel distribution is then expressed as a histogram showing the proportion of aircraft suffering penalties in the ranges 0 - 500 lb, 500 - 1 000 lb, 1 000 - 1 500 lb etc.

Step 5: The histogram is combined with the standard histogram of Annex III to give the histogram of fuel penalties from all causes of fuel variation. From this combined distribution the fuel reserve to give the required regularity of service is obtained. From this the standard figure for the fuel reserve for the same regularity without the ATC element is subtracted. The difference is the ATC fuel reserve increment.

Step 6: The carry cost of fuel to carry this fuel reserve increment is obtained by multiplying the fuel reserve by a factor which depends on the type of aircraft.

Step 7: The lost revenue corresponding to the fuel reserve increment is estimated from a relationship such as that given in Fig. 2-A-5. This relation can be expressed as a quadratic or cubic equation (Annex III).

Step 8: The sum of the average "low" cost per flight, the carry cost and the lost revenue cost gives the criterion for assessing the system.

Steps 3 to 8 can be suitably combined in a computer program (see Fig. 2-A-7 for the flow diagram for supersonic traffic).

ANNEX I TO APPENDIX 2-A

THE STATISTICAL METHOD OF ASSESSING THE FREQUENCY DISTRIBUTION OF FUEL REQUIREMENTS AND HENCE THE "REGULARITY" FUEL RESERVES

1. A set of histograms with different frequency is first obtained, each one defining the probability of the aircraft using different-from-flight-plan fuel for the particular contingency acting in isolation. Any flight is made up from a random selection of probabilities from the whole set of contingencies. Thus the chance occurrence of, say, a greater than forecast headwind can be offset by the lucky absence of holding at destination. The statistical combination (or convolution) of the set of individual contingency histograms correctly takes this into account in arriving at a single combined histogram for the flight to destination.

2. For the practical cases considered here the contingency histograms can be considered to cover a finite range of fuel weight, and they have all been expressed as relative frequency at equal increments of fuel weight (ΔW = 500 lb in this study).

3. The pair of histograms can be set out in tabular form as below, where W represents the fuel weight, F_a the relative frequency distribution of contingency A, and F_b that of contingency B.

4. The way the combined contingency histogram F_{ab} is built up can be seen from considering, for example, the probability of using zero units of fuel, when contingencies A and B are acting.

5. Zero units can be used by using -2 units due to A, and +2 units due to B, the probability of this occurring being $a_{-2}b_2$. Zero units can also be used by using -1 unit due to A, and +1 unit due to B, the probability of this being $a_{-1}b_1$. As these ways of using zero units (and all the other possible ways) are mutually exclusive on a particular flight, the total probability of using zero units of fuel, ab_o, is built up as the sum of the products. The table below is derived in this way.

6. Negative values of fuel requirement occur because the datum is taken to be the flight plan fuel to cover normal flight in the forecast MET conditions. Better than forecast MET conditions will lead to negative fuel requirements. ATC deviations, on the other hand, will give positive fuel requirements except in such rare cases as deviation to higher altitude than requested.

$\underline{W}$ units of fuel wt	Contingency A F_a (Rel.freq.)	Contingency B F_b (Rel.freq.)	Combined contingency AB F_{ab} (Rel.freq. of combination)
-2	a_{-2}		$ab_{-2} = a_{-2}b_o$
-1	a_{-1}		$ab_{-1} = a_{-2}b_1+a_{-1}b_o$
0	a_o	b_o	$ab_o = a_{-2}b_2+a_{-1}b_1+a_ob_o$
1	a_1	b_1	$ab_1 = a_{-1}b_2+a_ob_1+a_1b_o$
2	a_2	b_2	$ab_2 = a_ob_2+a_1b_1+a_2b_o$
3			$ab_3 = a_1b_2+a_2b_1$
4			$ab_4 = a_2b_2$
	$\Sigma a_n = 1$	$\Sigma b_n = 1$	$\Sigma ab_n = 1$

7. Certain general properties of such a combination are of interest. Clearly the sum of the relative frequencies of the combined histogram, like the two components, is unity, and in addition it can be shown that :

a) The mean fuel weight of the combined histogram is the sum of the means of the individual contingency histograms.

b) The variance (σ^2) of fuel weight of the combined histogram is the sum of the variances of the individual contingency histograms.

These relations are useful for checking the arithmetic, and for quick estimates of the effects of small changes to the individual contingency histograms, (though there are obvious dangers in doing this).

8. For the present purpose the histograms for contingencies other than en-route ATC are first combined. Following Ref. 1 these may include :

- take-off in unfavourable direction;
- delayed climb;
- minor navigation errors;
- holding at destination;
- wind forecast errors;
- temperature forecast errors;
- uncertainty in aircraft weight at take-off;
- variation in drag;
- variation in engine performance;
- variability of fuel measurement;
- variation in cruise speed.

9. The combined histogram for all these contingencies need only be estimated once for a given aircraft type, origin and destination, and can then be applied to a variety of en-route ATC systems. Examples of such histograms are given in Annex II. For each system it is then necessary to estimate the single histogram of en-route fuel requirements due to deviations in that system and combine it with the standard histogram by the above process. From the combined histogram the fuel requirement corresponding to a standard cumulative frequency "x" (see Annex II) is estimated.

10. From this fuel requirement we subtract the corresponding fuel requirement of the standard "everything except en-route ATC" histogram. The difference represents the effect of en-route ATC on the fuel reserve.

11. This process is well suited to simulation on a digital computer. Now, for the more complex ATC systems, the statistical characteristics can only be assessed by simulation on a computer. The convolution program can therefore be conveniently built into such a simulation program as a standard sub-routine. This has been done by the United Kingdom.

ANNEX II TO APPENDIX 2-A

HISTOGRAMS OF FUEL REQUIREMENTS FOR CONTINGENCIES OTHER THAN EN-ROUTE ATC

1. In this Annex tables of the distribution of extra-to-flight plan fuel requirements for the BO 707 and Concorde on the London-New York route for the contingencies listed in Annex I are given. In the case of the Boeing, the information was derived from the work described in Ref. 1. In the case of the Concorde, the assumptions made were those of Ref. 1 except that the estimate of fuel requirements has been updated in the light of later aircraft performance and meteorological information. The tables give the proportion of occasions when the fuel requirement in excess of a given datum lies between given limits. The exact value of the datum fuel is unimportant for the present purpose; this is because the fuel requirements are assessed, first neglecting and then allowing for en-route ATC, both with respect to the same datums and then taking the difference between them.

2. The tables are given in a form suitable for input to a computer program. Of the two columbs labelled "n" and "p", "p" represents the proportion of occasions when the excess fuel requirement lies within the limits (500n)lb and (500n - 500)lb.

Histogram of Excess Fuel Requirements for Boeing 707

n	p x 10^4	n	p x 10^4	n	p x 10^4
1	1	26	261	51	116
2	1	27	287	52	99
3	1	28	311	53	85
4	2	29	333	54	71
5	3	30	354	55	60
6	4	31	371	56	50
7	5	32	385	57	41
8	7	33	395	58	33
9	9	34	402	59	27
10	12	35	405	60	22
11	17	36	403	61	18
12	22	37	397	62	14
13	28	38	387	63	11
14	35	39	373	64	9
15	45	40	357	65	7
16	57	41	337	66	5
17	68	42	317	67	4
18	83	43	293	68	3
19	100	44	270	69	2
20	118	45	246	70	2
21	139	46	222	71	1
22	161	47	198	72	1
23	185	48	176	73	1
24	210	49	154		
25	236	50	134		

3. The corresponding histogram for the Concorde is less regular in shape. This arises from the fact that the most important constituent of its fuel requirements is fuel for terminal holding rather than fuel to allow for meteorological variations[1].

Histogram of Excess Fuel Requirements for the Concorde

n	p x 10^4	n	p x 10^4	n	p x 10^4	n	p x 10^4
1	8	26	520	51	2	76	2
2	10	27	392	52	8	77	0
3	4	28	324	53	0	78	0
4	4	29	236	54	2	79	0
5	4	30	216	55	8	80	2
6	18	31	142	56	4	81	0
7	16	32	116	57	4	82	2
8	24	33	98	58	6		
9	38	34	84	59	2		
10	64	35	50	60	0		
11	80	36	34	61	0		
12	118	37	38	62	6		
13	170	38	22	63	0		
14	244	39	28	64	0		
15	310	40	22	65	0		
16	408	41	16	66	0		
17	572	42	18	67	0		
18	580	43	26	68	2		
19	644	44	12	69	0		
20	688	45	12	70	0		
21	806	46	14	71	0		
22	728	47	4	72	0		
23	668	48	6	73	0		
24	712	49	8	74	2		
25	586	50	2	75	0		

4. The remaining item required for the convolution program is the commercially acceptable regularity at which fuel requirements are assessed. Following Ref. 1 this is taken to be 0.988 for aircraft carrying blind landing equipment. Applying this figure to the above tables we obtain as the fuel requirement above the datum neglecting en-route ATC 29 130 lb* and for the Concorde 21 310 lb. These figures can also be part of the standard program input.

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* It should be re-emphasized that these figures represent increments over arbitrarily chosen fuel datums, which are in this case chosen for convenience of avoiding negative values of "n" in the histograms. They do not therefore represent actual fuel reserves for Boeing 707 and Concorde and the fact that the Concorde figure is lower has no significance.

ANNEX III to APPENDIX 2-A

MODEL FOR ESTIMATING LOST REVENUE FROM PAYLOAD DISPLACED BY EXTRA FUEL RESERVE

(Note: This model is a development of that due to P. Reich[3].)

1. To estimate the mean payload loss per flight, following a reduction in payload capacity, consider first the variation in payload demand. For any flight there is a probability distribution of payload offered which is expressed by the density function f(p) such that f(p)dp represents the probability that the payload offered for that flight will lie between p and p + dp. f(p) is a continuous function over all positive values of p. But on those occasions when the payload offered, p, exceeds the capacity of the aircraft, which is denoted by P, some payload must be refused; only when p is not greater than P can all the payload offered be carried. The probability of the former occurrence is denoted by F(P), given by :

$$F(P) = \int_{P}^{\infty} f(p)\,dp \qquad (1)$$

2. The distribution function of payload carried per flight will therefore be identical with that of payload offered for value of p less than P but will be zero for values of p greater than P and will form a "spike" of area F(P) for p equal to P. The shape of the distribution is shown diagrammatically in Fig. 2-A-1a).

3. Now, consider the effect on this payload distribution of a reduction in payload capacity ΔP, such as might follow from an increase in fuel reserve. For the estimate of lost revenue cost (para. 3.3) it is assumed that there is no change in the payload demand or in the number of flights operated. Then on those flights on which full payload P would have been carried before capacity reduction only $P-\Delta P$ can be carried, i.e. there is a loss of payload ΔP due to the capacity reduction. The frequency of occurrence of this is $F(P)$. In addition some payload must be refused on those flights when the payload offered lies between P and $P-\Delta P$. For a payload offered denoted by p, this lost payload is $p-P+\Delta P$.

4. Denote by Δp the mean payload lost (averaged over all flights) because of the capacity reduction ΔP. Δp is given by the equation :

$$\Delta p = \Delta P \times F(P) + \int_{P-\Delta P}^{P} (p - P + \Delta P) f(p) dp \qquad (2)$$

To use this equation requires to know $F(P)$ and the form of $f(p)$.

From statistics of the distribution of payloads carried in service histograms such as that shown as Figure 2-A-1b) can be drawn; this can be regarded as a sample drawn from the continuous distribution shown in Figure 2-A-1a). There are several samples of the distribution of payloads carried by subsonic jets on North Atlantic services and, while the corresponding histograms are similar in that they all suggest a "spike" corresponding to the position of maximum capacity payload, there is much variation in the general shape of the distribution. Fortunately, only the upper part of the distribution curves, say between 70% and 100% of payload capacity, are of interest since any system which restricted payload to less than 70% of capacity would entail penalties so severe as to be unacceptable in practice. Between 70% and 100% of maximum capacity, the probability density curve of payload carried as a straight line may be represented with sufficient accuracy. The equation of this line is taken as the best fit in the least squares sense to the frequencies for all the intervals of the histogram corresponding to payloads greater than 70% capacity, <u>except</u> the interval containing 100% capacity. The frequency of the latter interval will be larger than expected from the linear relationship because of the presence of the "spike" F(P). In fact F(P) is derived as the difference between the actual frequency of the uppermost histogram interval and the expected value given by the linear relation.

5. The process of deducing F(P) and f(p) from a histogram of payload distribution can be described as follows. Let n be the number of intervals of the histogram between 70% and 100% payload capacity; then the interval size is $\frac{0.3P}{n}$. Let h_1, h_2, etc. be the ordinates representing the frequency of occurrence of payloads falling in each interval starting with the smallest, i.e. that including 70% capacity payload; then h_n represents the frequency of payloads in the interval including 100% capacity. Assuming a linear relation for the probability density function, viz

$$f(p) = ap + b, \tag{3}$$

where a and b are to be determined from the histogram. To do this, note that the expected value of h for a payload interval is given by :

$$h = (ap + b)\frac{0.3P}{n} \tag{4}$$

where p here represents the payload corresponding to the mid-point of the interval. Using (4), determine the values of "a" and "b" which give the best fit to the given values of h_1, h_2 ...... $h_{(n-1)}$ (but not h_n) on the least squares criterion. Finally, F(P) is the difference between the actual value of h_n and that given by the formula, i.e.

$$F(P) = h_n - \left[aP(1-\frac{0.3}{2n}) + b \right] \frac{0.3P}{n} \qquad (5)$$

6. From the data, approximate values of F(P) and the variation of f(p) with p have been derived. Substituting these in (2), an equation for the variation of mean lost payload Δp with capacity reduction ΔP is obtained. This equation may be conveniently expressed in the form :

$$\frac{\Delta p}{\Delta P} = K_o + K_1 \frac{\Delta P}{P} + K_2 (\frac{\Delta P}{P})^2 \qquad (6)$$

where K_o, K_1 and K_2 are dimensionless functions of a, b and P. The ratio of Δp to ΔP is essentially less than unity, since the reduction in payload carried can never exceed the reduction in capacity on any flight and on some flights will be less than the capacity reduction or even zero. Denote by L the load factor for a given flight, i.e. the ratio of payload carried to payload capacity available. With the introduction of the restriction on capacity to $P-\Delta P$, there are three possibilities for change in L :

a) If payload offered is P or greater, L is unity both with and without restriction.

b) If payload offered lies between P and $P-\Delta P$, L is less than unity without the restriction but is unity with it.

c) If payload offered is less than $P-\Delta P$, L is less than unity both with and without restriction. The payload carried is the same in both cases but the payload capacity is less with the restriction, hence L is greater in this case.

7. Thus with the introduction of capacity restriction the load factor L remains constant on some flights and increases on others. Averaged over all flights, therefore, <u>the effect of capacity restriction is to increase the load factor</u>. This is a fundamental consequence of the assumptions for deriving the revenue loss. An example of the increase in load factor with capacity reduction is given in Fig. 2-A-4.

8. Several sets of statistics of payload distribution have been analysed, including that given by Reich[3] and more recent information from the Statistics Branch of the UK Ministry of Technology. Although the shapes of the payload distribution curves differ between the sets of data, the resulting formulae for the mean lost payload are reasonably consistent, when allowance is made for the different levels of mean payload of the samples. With increasing average load factor, a full payload is more often offered, and hence also the average loss in payload following a reduction in capacity is greater. From the various traffic samples an empirical curve is derived showing how the mean lost payload, due to capacity reduction, varies with the load factor in the absence of capacity reduction. This is given as Fig. 2-A-3; while Fig. 2-A-4 shows the payload loss derived from the data for a mean load factor of 60%.

9. Having shown how to derive the relation between average payload loss and payload capacity reduction, it remains to relate the capacity reduction to the increase in fuel load. As shown in Fig. 2-A-1, this relation depends on the stage length operated. The usual commercial practice is to operate aircraft over a variety of stage lengths, some of which will be shorter than that corresponding to the critical point B in Fig. 2-A-2 while some will be longer. These cases are discussed in turn.

10. For operations over stage lengths shorter than critical, an increase in fuel load must exceed some quantity X' before reducing payload capacity. For an increase in fuel load X, greater than X', the capacity reduction ΔP is equal to X-X'. The mean payload loss is obtained as before from equation (6). The fuel quantity X' is given by the formula :

$$X' = \frac{\Delta S}{r_o} \qquad (7)$$

where ΔS is the difference between the critical and actual stage lengths and r_o is the specific fuel consumption corresponding to take-off weight.

11. Operating over stage lengths longer than the critical stage the maximum payload is already limited, in the absence of fuel reserve, to some value P' less than the maximum over the critical stage. The reduced capacity is given by :

$$P' = P + \frac{\Delta S}{r_o} \qquad (8)$$

where the symbols have the same meaning as in (7) and ΔS is now negative. The capacity reduction due to extra fuel load is equal to the extra load X. To determine payload loss, equation (6) is used with P' in place of P.

12. For a given increase in fuel load, the mean payload loss for operations over any stage length may be thus obtained. The mean payload loss over an entire route network is next estimated, assuming the increase in fuel load to apply over all routes. To do this, the relative frequency of operation of the various routes is used.

13. Finally, to commute the "lost revenue" cost from the lost payload, the following conversion factors used by Reich[3] are introduced :

Passenger revenue	£0.40 per pound of payload
Freight revenue	£0.15 per pound of payload.

14. Fig. 2-A-5 shows the results of estimated lost revenue for a typical subsonic jet and for a Mach 2 transport similar to the Concorde, both operating a North Atlantic route network. In both cases the mean load factor before payload reduction is taken as 60%, a fairly representative figure for North Atlantic operation. The distribution of stage lengths is that given by Reich[3] except that for the supersonic transport, the longest stages are omitted as they would be impracticable in the earlier stage of development of this aircraft. In the case of the subsonic transport, the displaced payload is assumed to consist almost entirely of freight. This is likely to be the case in practice as a large proportion of payload does consist of freight. The lower revenue obtained from freight suggests, that, when payload has to be restricted, freight would be displaced preferentially. The first supersonic transports, however, are expected to be purely passenger carrying aircraft; so that in this case it is assumed that displaced payload for the supersonic transport must be costed at the higher rate appropriate to passengers. It is further assumed that the critical stage length for the early supersonic aircraft will be shorter than that of the subsonic, so that the former type will more frequently be operating a stage length equal to or greater than its critical stage. This, and the higher revenue loss per pound of lost payload, are the reasons why the revenue loss for the supersonic aircraft is 3-4 times greater than that of the subsonic aircraft for the same increase in fuel load. Any figures quoted for the supersonic aircraft must of course at this stage be regarded as tentative.

ANNEX IV TO APPENDIX 2-A

A DERIVATION OF THE FORMULA FOR DISTRIBUTION OF AIRCRAFT AMONG FLIGHT PATHS

1. The following assumptions are made :

a) that the number of possible flight paths is large;

b) that these flight paths can be arranged in order of preference 1, 2, 3 etc., and that this order is the same for all aircraft;

c) that aircraft present themselves in Poisson arrival sequence with a constant mean flow rate;

d) that the minimum separation between aircraft assigned to a given path is constant;

e) that on arrival each aircraft is assigned to the best track (i.e. that of lowest ranking order) which is then vacant (i.e. has no aircraft which entered at less than the minimum separation before);

f) no delay before entry is allowed.

Denote the minimum time separation on a track by T. The constant flow rate is then defined by denoting the expected number of aircraft in time T by λ.

Analysis

2. Divide the system into two parts, one part comprising the best n flight paths and the other the remainder. Any aircraft on arrival will enter the first sub-system if any of the n flight paths is not blocked by a previous aircraft.

3. Denote by P $[s, t]$ the probability that a number s and only s of the first n flight paths are blocked at arbitrarily chosen time t.

4. If a flight path is blocked it means that a previous aircraft entered that flight path at some time interval less than T before time t. Divide the minimum separation time interval T into K equal time intervals ΔT in length, where K is large and ΔT correspondingly small.

5. When a flight path is blocked it means that a previous aircraft is on that flight path in some jth interval of length ΔT ahead of the entry, where

$$0 < j \leqslant K$$

6. At a time $t + \Delta T$ this aircraft will have moved to the (j + 1)th interval. When j = K at time t, the flight path will be unblocked at time $t + \Delta T$.

7. Let $P[s, (j_1, j_2 \ldots, j_s), t]$ denote the probability that, at time t, s flight paths are blocked and that the blocking aircraft in them lie in time intervals (in the above sense) which are numbered $j_1, j_2 \ldots j_s$ from the entry. Arrange the numbers j_1, j_2, etc., in increasing order of magnitude, not in order of the ranking of the corresponding flight paths (this is irrelevant at this stage).

8. Since ΔT is small, the chance of one aircraft arriving in a time interval of this size is $\lambda . \frac{\Delta T}{T}$. Because the n tracks considered are the most desirable tracks of the system, an arriving aircraft automatically enters a vacant track of this sub-system rather than one of the remaining tracks. Hence the probability of an aircraft arriving in time ΔT and entering a vacant track of the sub-system, is also $\lambda . \frac{\Delta T}{T}$. The chance of more than one arriving in the same time interval is regarded as negligible.

9. Consider the case at time $(t + \Delta T)$ when only one flight path is blocked and the blocking aircraft has just entered it. In the notation, the probability of this is $P\left[1, (1), t + \Delta T\right]$. For this to be the case at time $(t + \Delta T)$, one aircraft must have arrived in the time interval between t and $(t + \Delta T)$ and either the n flight paths were unblocked at time t or one flight path was blocked and about to become vacant (not necessarily the same flight path which is occupied by the arriving aircraft). This gives the equation :

$$P\left[1, (1), t + \Delta T\right] = \frac{\lambda \Delta T}{T} \left\{ P\left[0, t\right] + P\left[1, (k), t\right] \right\} \quad (1)$$

10. Similarly, the chance of s flight paths being occupied at time $(t + \Delta T)$ and that an aircraft has just entered one of them (i.e., $j_1 = 1$) is given by :

$$P\left[s, (1, j_2, j_3, \ldots j_s), t + \Delta T\right]$$

$$= \frac{\lambda \Delta T}{T} \left\{ P\left[s-1, (j'_1, j'_2, \ldots, j'_{s-1}), t\right] + P\left[s, (j''_1, j''_2 \ldots, K), t\right] \right\} \quad (2)$$

where j' (s-1) in the expression for the probability of (s-1) flight paths being occupied at time t must be less than K.

11. Now when the process attains a stationary state, the probabilities will be independant of the time t. Also the Poisson arrival process implies that an aircraft is equally likely to arrive in any time interval ΔT. This further implies that, given that a flight path is blocked at a certain instant, the blocking aircraft is equally likely to be any of the K time intervals from the entry. Thus the expression $P\left[s, (j_1, j_2, \ldots, j_s), t\right]$ is independent of the value of t and of the values $j_1, j_2 \ldots j_s$.

12. Hence, for example

$$P\left[1,(1),t+\Delta T\right] = P\left[1,(K),t\right] = P\left[1,(j),t\right] \qquad (3)$$

Substituting in equation (1) and re-arranging :

$$P\left[1,(j),t\right] = \frac{\frac{\lambda\Delta T}{T}}{1-\frac{\lambda\Delta T}{T}} \times P\left[0,\ t\right] \qquad (4)$$

Similarly

$$P\left[s,(1,j_2,\ldots,\ j_s),\ t+\Delta T\right] = P\left[s,(j_1',j_2',\ldots,j_s'),t\right] \qquad (5)$$

Therefore, from equation (2),

$$P\left[s,(j_1,\ldots,\ j_s),\ t\right] = \frac{\frac{\lambda\Delta T}{T}}{1-\frac{\lambda\Delta T}{T}} \times P\left[s-1,(j_1,\ldots,\ j_{s-1}),t\right] \qquad (6)$$

13. By successively applying equation (6) for s = 2, 3, 4, etc., to equation (4) we obtain

$$P\left[s,(j_1,\ \ldots,j_s),t\right] = \left[\frac{\frac{\lambda\Delta T}{T}}{1-\frac{\lambda\Delta T}{T}}\right]^s \times \left[P\ 0,t\right] \qquad (7)$$

$P\left[s,(j_1\ \ldots\ j_s),t\right]$ represents the probability that s flight paths are blocked at time t and that the blocking aircraft are in arbitrarily chosen time intervals $j_1,j_2,j_3,\ldots,\ j_s$ from the entry. It is required to know the overall probability P (s, t) that s flight paths are blocked, without reference to the position of the blocking aircraft. To obtain this sum all the (equal) probabilities of the various blocking aircraft being in particular sets of time intervals from entry. Each particular case is defined by a set of numbers j_1 ---- j_s all lying between 1 and K inclusive, arranged in arbitrary order of magnitude and with no two numbers in the same set equal*. The number

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* This would have implied that two aircraft arrived in the same time interval ΔT, which is excluded.

of cases is thus the number of sets of s things that can be chosen from K.

Hence

$$P\left[s,t\right] = \frac{K(K-1)(K-2) -- (K-s+1)}{s!} \times P\left[s,(j_1,\ldots,j_s),\ t\right] \quad (8)$$

14. Now substitute equation (7) in equation (8) and let ΔT become vanishingly small. Since $K = \frac{T}{\Delta T}$ we obtain

$$P\left[s,t\right] = \frac{\lambda^s}{s!} \times P\left[0,t\right] \quad (9)$$

Summing all possibilities for the first n flight paths we obtain

$$P\left[0,t\right] + P\left[1,t\right] + \ldots + P\left[n,t\right] = P\left[0,t\right]\left\{1 + \frac{\lambda}{1!} + \frac{\lambda^2}{2!} + \ldots + \frac{\lambda^n}{n!}\right\} \quad (10)$$

This must equal unity.

Hence,

$$P\left[0,t\right] = \frac{1}{\sum_{i=0}^{n} \frac{\lambda^i}{i!}} \quad (11)$$

and $$P\left[s,t\right] = \frac{\frac{\lambda^s}{S!}}{\sum_{i=0}^{n} \frac{\lambda^i}{i!}} \quad (12)$$

In particular

$$P\left[n,t\right] = \frac{\frac{\lambda^n}{n!}}{\sum_{i=0}^{n} \frac{\lambda^i}{i!}} \quad (13)$$

15. Equation (13) gives the probability that the whole n flight paths of the sub-system, i.e. the best n flight paths of the entire system will be blocked at arbitrary time t.

16. Under the rules of allocation an aircraft will enter the rth flight path if on arrival the first (r-1) flight paths are blocked and the rth flight path is unblocked. Let p (r) be the probability of both of these occurrences. Consider the probability that the first (r-1) flight paths are blocked. This is the sum of two mutually exclusive probabilities :

a) that the first r flight paths are blocked;

b) that the first (r-1) flight paths are blocked and that the rth path is unblocked.

Hence

$$P\left[r-1,\ t\right] = p(r) + P\left[r,\ t\right] \tag{14}$$

$$\text{whence } p\,(r) = \frac{\dfrac{\lambda^{r-1}}{(r-1)!}}{\sum_{i=0}^{r-1} \dfrac{\lambda^{i}}{i!}} - \frac{\dfrac{\lambda^{r}}{r!}}{\sum_{i=0}^{r} \dfrac{\lambda^{i}}{i!}} \tag{15}$$

17. Equation (15) gives the probability of an arbitrary aircraft entering the rth flight path or the proportion of all aircraft expected to be allocated to that path.

TABLE I

PROPORTION OF AIRCRAFT ALLOCATED TO FLIGHT PATHS

on the Formula of Section 6.1

(Steady Poisson input; no entry delay)

Assumptions: Flow Rate 30 aircraft/hour

Mean minimum longitudinal separation 20 minutes

i.e. "λ" = 10

Order of Preference of Path	Proportion of Aircraft Allocated to Path*	Mean Flow Rate along Path (aircraft/hour)
1	0.091	2.73
2	0.089	2.68
3	0.088	2.63
4	0.085	2.56
5	0.083	2.48
6	0.079	2.38
7	0.075	2.26
8	0.071	2.12
9	0.065	1.95
10	0.059	1.76
11	0.051	1.54
12	0.044	1.30
13	0.035	1.06
14	0.028	0.83
15	0.020	0.61
16	0.014	0.43
17	0.009	0.28
18	0.006	0.17
19	0.003	0.10
20	0.002	0.06
21	0.001	0.03

* Note These figures add up to 0.998, leaving a proportion 0.002 of the flow for paths of rank 22 and above.

Fig. 2-A-1

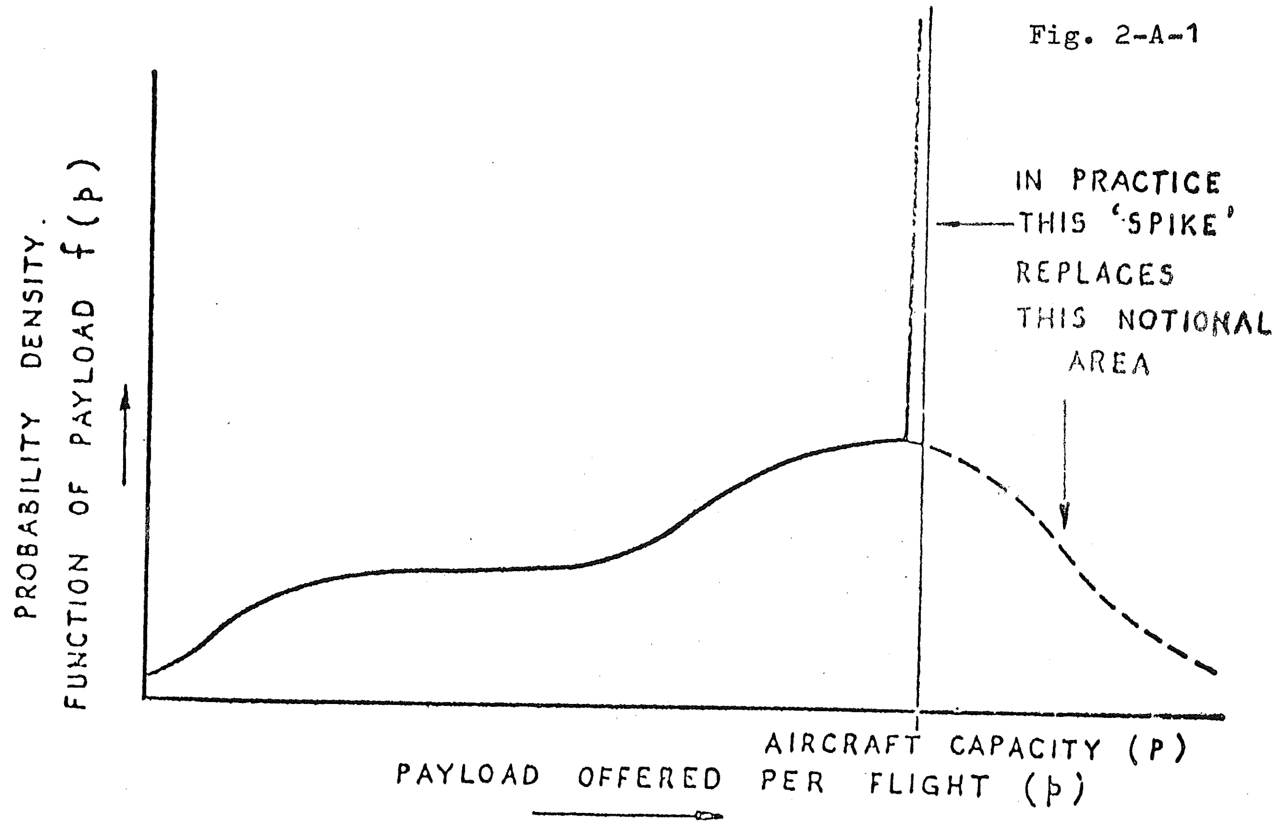


FIG.(1a) DISTRIBUTION OF PAYLOAD OFFERED

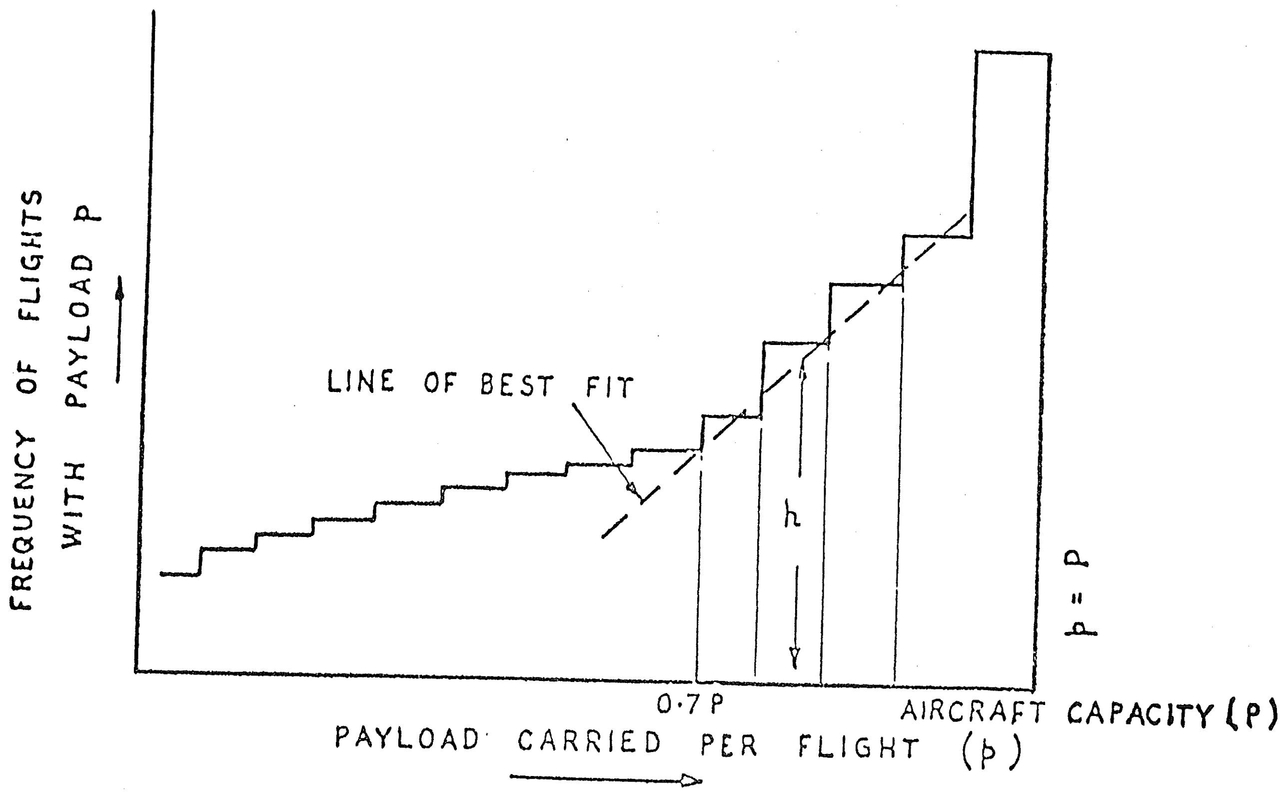


FIG.(1b) HISTOGRAM SHOWING SAMPLE OF PAYLOAD CARRIED

Fig. 2-A-1 VARIATION OF PAYLOAD PER FLIGHT

Fig. 2-A-2 & 2-A-3

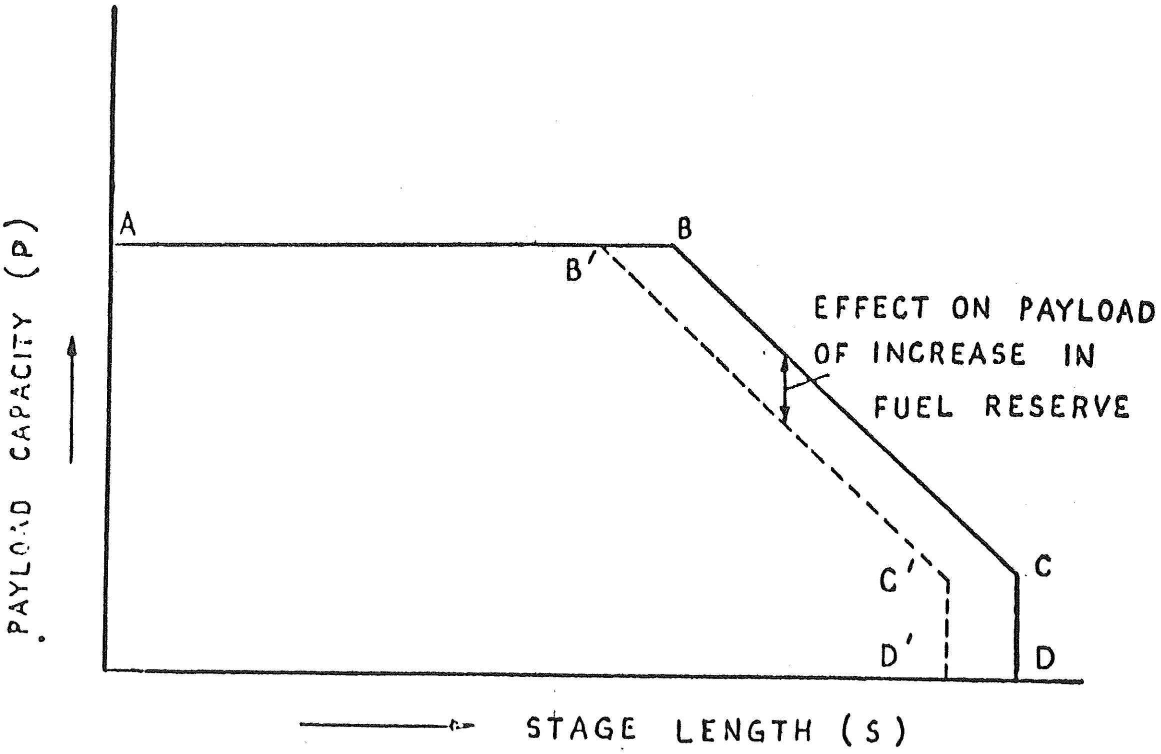


Fig. 2-A-2 VARIATION OF PAYLOAD CAPACITY WITH STAGE LENGTH

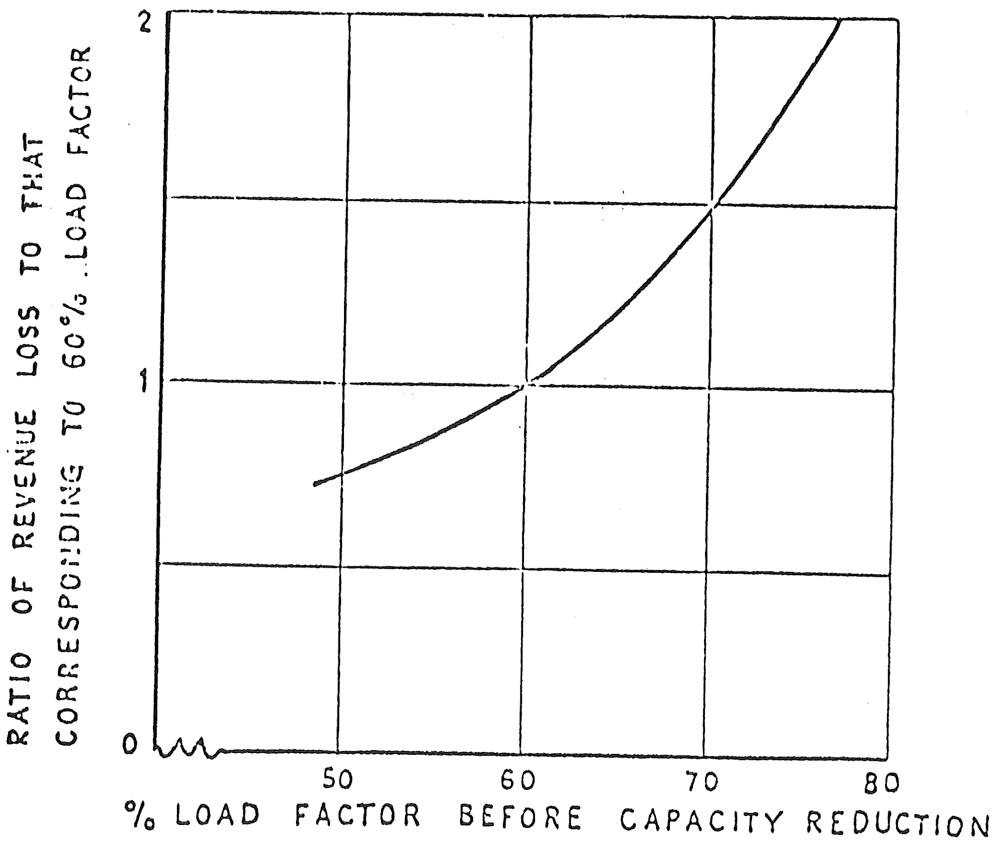


Fig. 2-A-3 VARIATION OF REVENUE LOSS WITH LOAD FACTOR FOR A GIVEN REDUCTION IN CAPACITY

Fig. 2-A-4

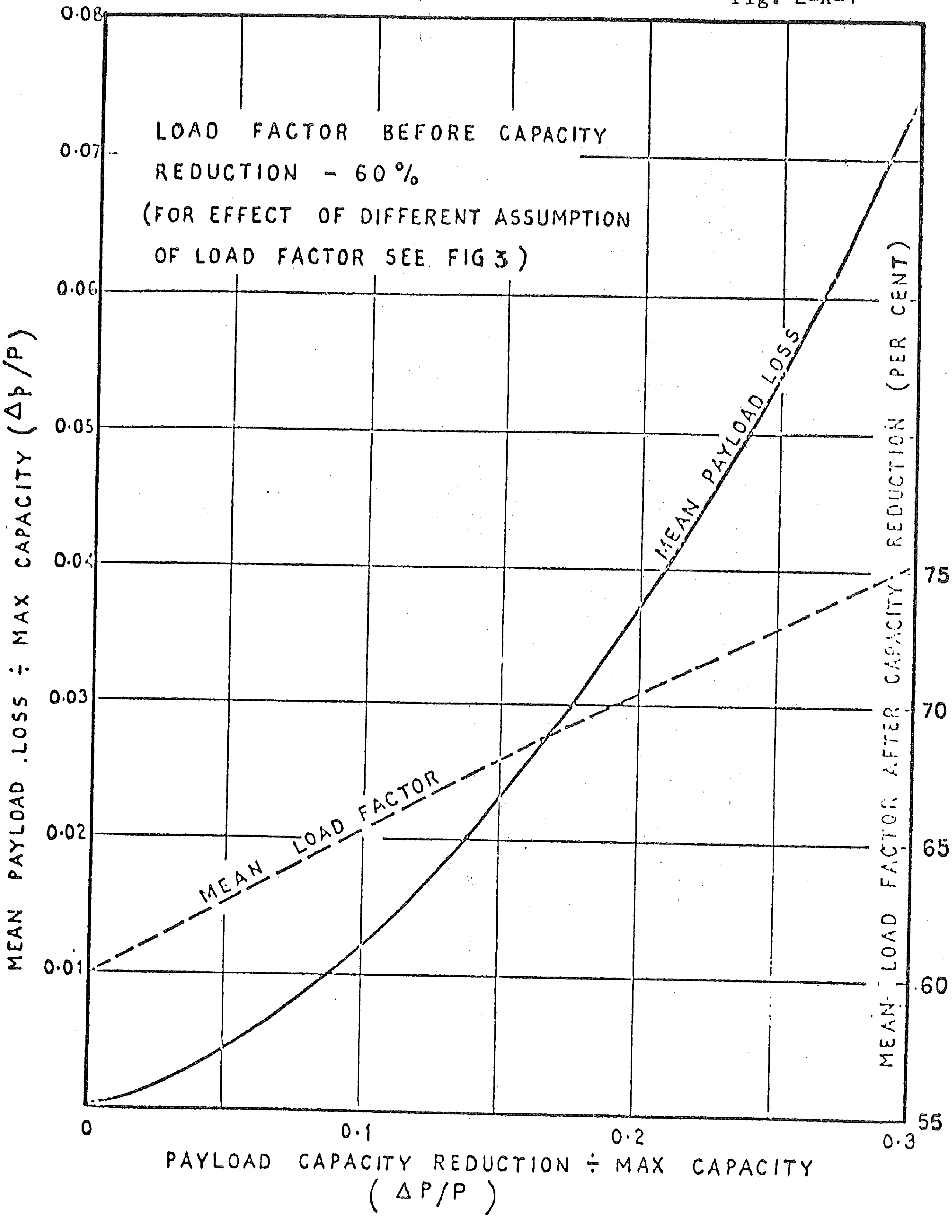


Fig. 2-A-4 MEAN PAYLOAD LOSS FOLLOWING CAPACITY REDUCTION

Fig. 2-A-5

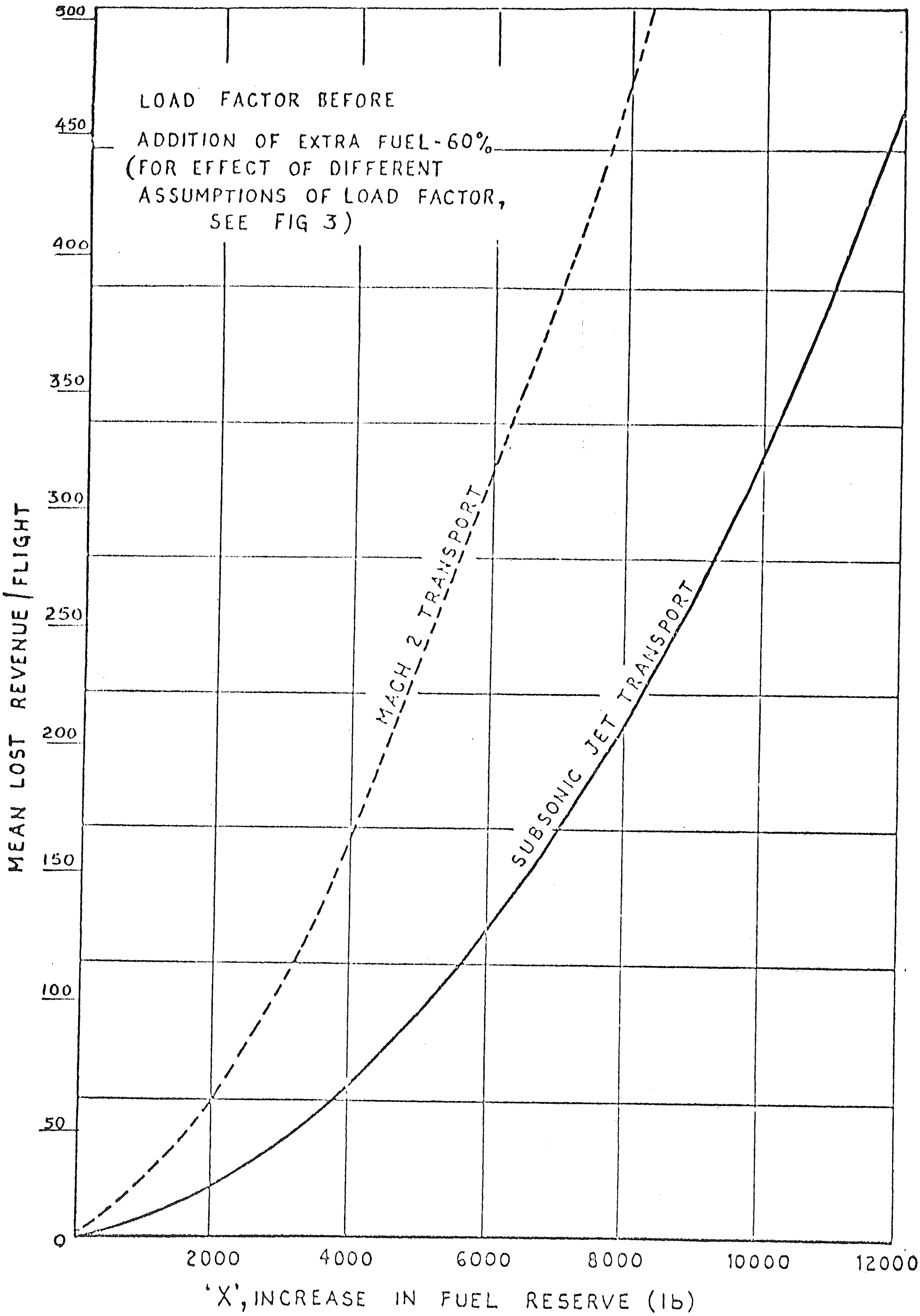


Fig. 2-A-5 REVENUE LOSS DUE TO INCREASED FUEL RESERVE FOR AIRCRAFT OPERATING N. ATLANTIC ROUTE NETWORK

Fig. 2-A-6

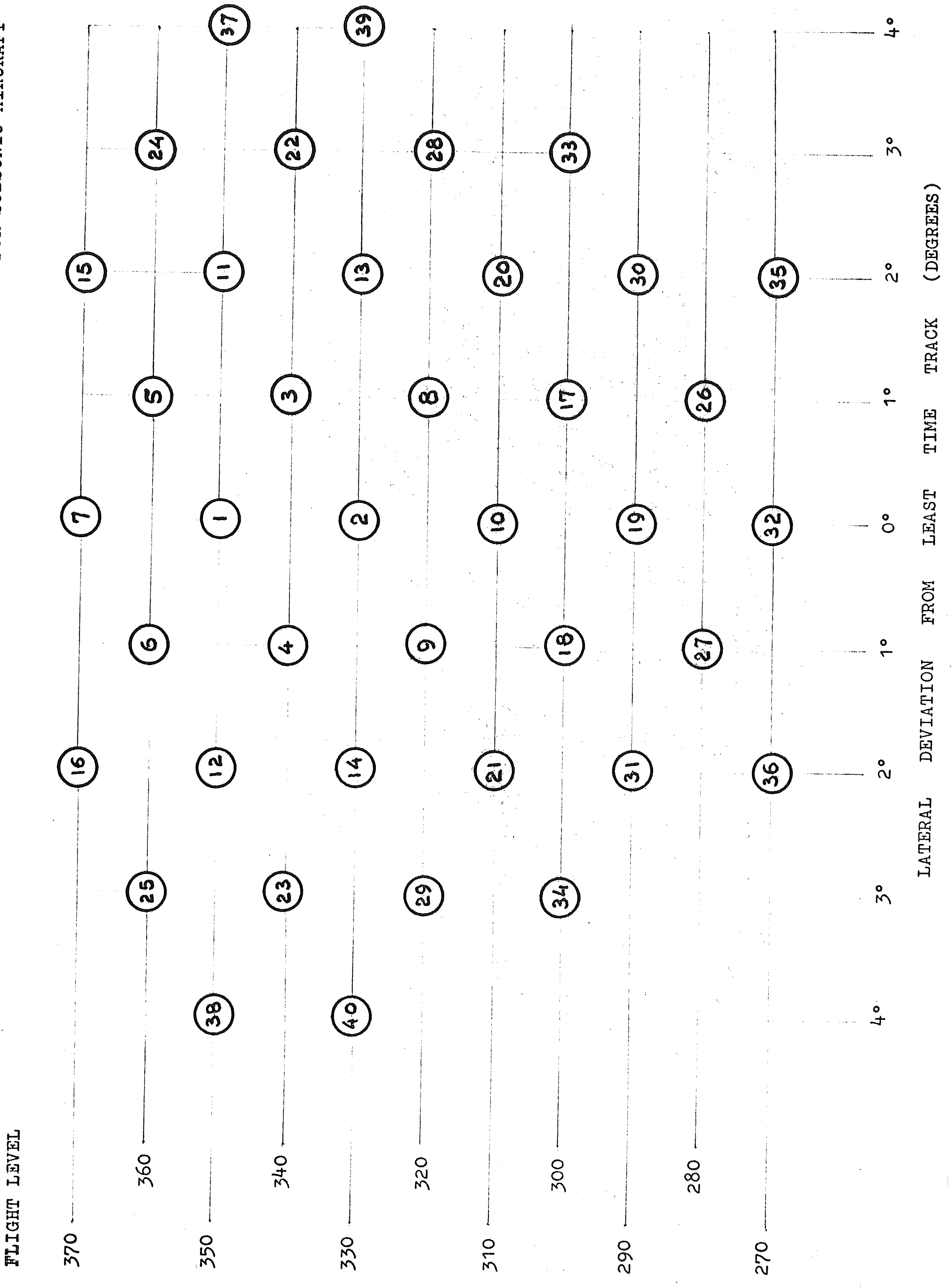
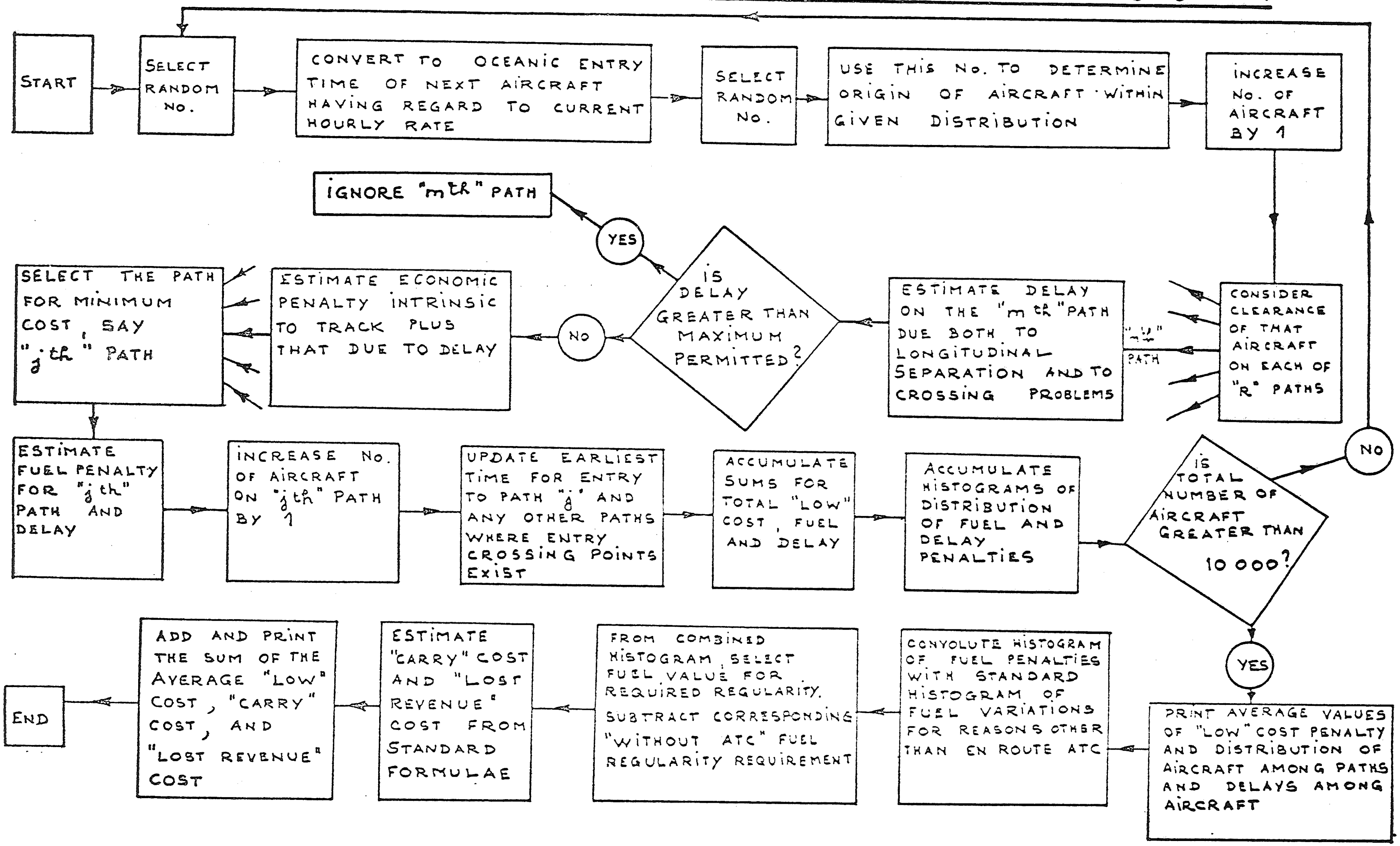


Fig. 2-A-6 ORDER OF PREFERENCE OF PATHS OF COMPOSITE SYSTEM FOR SUBSONIC AIRCRAFT

Fig. 2-A-7 FLOW DIAGRAM FOR COST ANALYSIS OF SUPERSONIC SYSTEM



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APPENDIX 2-B

RESULTS OF COSTING THE NAT SUBSONIC SYSTEM

1. Introduction

1.1 This note gives the results of the application of the methods developed by the United Kingdom for costing air traffic systems (Appendix 2-A) to the North Atlantic subsonic jet traffic system. The system considered is that currently in use, with the present separation standards, but traffic flow rates up to those forecast for 1977 (the peak year for subsonics) are considered. The effect of a change to the composite system of tracks is also included. In assessing the system penalties, allowance is made for day to day variations in the wind pattern over the Atlantic. The model for deriving the track loading is based on data obtained from the recent data collection on longitudinal separation.

2. Operating cost

2.1 Appendix 2-A shows that for North Atlantic operations, deviations due to en-route air traffic control may affect engineering costs and staff costs in addition to fuel costs. The effect of an increase in flight time due to en-route diversion on engineering charges at half the overall engineering cost per flying hour* has been assessed. The effect on crew charges depends on the remuneration policy of the particular airline. As an average, the effect on crew costs of ATC deviations is taken as half the overall crew cost per flying hour*. Estimate for a Boeing 707 (B-707) aircraft indicates $3.6 per minute of extra cruise flight as the increase of cost due to maintenance and crew remuneration. These figures are supported by data on actual operating costs given in Ref. 1.

2.2 In previous studies of North Atlantic subsonic jet traffic, (Ref. 2 and 3) the B-707 has been taken as typical of aircraft types comprising this traffic. During the period under review, however, much larger jet aircraft will be mixing with the existing types in increasing numbers. It has not yet been possible to analyse the cost penalties of the B-747 in the same detail as that of the B-707, but it appears that the combined engineering and crew cost will be increased by a factor of 1.95 while fuel costs will be increased by a factor of 1.75. The passenger accommodation is increased by a factor of 2.5. The relative effect of height and track deviations on cost and fuel penalties is taken to be similar for the B-747 as for the B-707; this is reasonable because it depends chiefly

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*These assumptions do not critically affect the final values of cost penalty, which depend mainly on costs associated with fuel consumption.

on aerodynamic factors which are similar for both types. Since fuel costs have a rather greater influence on the ATC penalty than the other costs, the overall ATC penalty for the B-747 is taken to be 1.823 times the corresponding penalty for the B-707. The ATC penalty per passenger on the B-747 is thus estimated as 72% of that of the B-707. These figures are used in the study of annual ATC penalty (para. 6.3).

2.3 One known difference between the B-747 and the B-707 is that the former aircraft is designed to have a shorter range with maximum payload. This difference arises because of the higher rates of capacity payload to all-up weight of the B-747, due to its very large freight volume. It follows from Annex III to Appendix 2-A that a given level of ATC deviations will more often result in revenue loss in the case of the B-747, provided that this aircraft is operated over the same route network as the B-707 and provided that the larger aircraft can be operated at the same load factor. The ATC revenue loss for the B-747 would then be relatively greater than that given by simple scaling up from the B-707. In view of the uncertainty of the operation of this aircraft the effect has not been included in the figures quoted in Table 6 below; it could increase the annual cost in 1978 by as much as 25%.

3. Track system and associated penalty

3.1 As described in Appendix 2-A, the system analysis begins by associating a specific penalty (time, cost and fuel) with each flight path (combination of track and flight level) in the system. In previous studies (Ref. 2) the penalty for getting a non-optimum track has been assessed on a basis of extra ground mileage with some allowance for meteorological variations. In the present study it has been possible to draw on regular daily analyses of tracks made by BOAC. Their computer output has given, for twice-daily forecast wind conditions, the air mileage corresponding to the optimum least-time track from London to New York and also the air distance between the same two points using various ATC designated tracks over the ocean. These tracks, of course, are separated by 120 NM. From this, the difference in air mileage between the ideal track (A) and the best ATC-designated track (A') are obtained as well as the differences between the best ATC track and the other tracks (B', C', etc.). The means and standard deviations of these quantities over the first six months of 1969 are given in the table below :

TABLE 1

Air Mileage Differences between NAT Subsonic Tracks

Track Difference	A'-A	B'-A'	C'-A'	D'-A'	E'-A'
Mean (NM)	14	19	51	92	129
Standard Deviation (NM)	15	13	28	54	59

3.2 Table 1 shows that the spread of these penalties is appreciable in comparison with their average values. Now in assessing the "low" costs (engineering, crew and extra fuel burnt) only the average values of track penalty need be taken into account, but in assessing the fuel reserve and associated penalty, the spread of track penalties is also relevant. The program for handling the data takes this into account.

3.3 In assessing the penalty for vertical deviation, the performance characteristics of the aircraft are significant rather than the variation of meteorological conditions (Ref. 2). The penalties for vertical deviation in terms of time and fuel burnt are given in the table below relative to cruise at 35 000 ft.

TABLE 2

Time and Fuel Penalties relative to 35 000 ft.

Height	Time Penalty (mins)	Fuel Penalty (lb)
37 000	1.4	300
35 000	0	0
33 000	-2.4	680
31 000	-3.9	1 830
29 000	-4.4	3 770

For comparison with the lateral deviations, the penalties for extra flight distance of 10 NM are 1.3 mins and 230 ob of fuel burnt*

* This fuel penalty and those given in Table 2 are assessed on the basis of constant take-off weight. When estimating the required increase of fuel reserve for a given set of deviations, they must be increased by a factor of about 1.4 (see Appendix 2-A, para. 8).

3.4 For the first study, therefore, the present system of trans-Atlantic parallel tracks in three dimensions separated by 120 NM laterally and 2 000 ft vertically is considered; the track system is moved from day to day to approximate to the average of least time tracks between origins and destinations on both sides of the Atlantic (this of course is implicit in the derivation of the data of Table 1). The proposed "composite" system is similarly dealt with in para. 7. The next step in the analysis is to derive a suitable model of the distribution of aircraft among flight paths.

4. Path loading

This part gives the derivation of a model for allocation of aircraft to flight paths which gives path loadings in good agreement with those actually observed during the recent NAT data collection exercise.

4.1 Para. 6.1 of Appendix 2-A gives a formula for aircraft distribution among flight paths. This formula is based on the assumptions of random arrival time, no delay at entry to the system and a constant value of the minimum longitudinal spacing used between aircraft on the same path. In fact the effective longitudinal spacing (i.e. the spacing below which controllers will clear the following aircraft onto another flight path) varies somewhat in practice, instead of being always equal to the minimum longitudinal separation. Appendix 2-A advances the hypothesis that the formula for aircraft distribution is unaltered by the variability of the minimum spacing, provided that the average value of this spacing is used in the formula. This hypothesis has received further support from some of the work on which the present note is based. Simulations have been run of systems in which the minimum longitudinal spacing, so far from being constant, varies quite widely. In all cases tested the resulting aircraft distribution agrees well with that given by the formula of Appendix 2-A. It is therefore concluded that the distribution of aircraft among tracks depends on the average value of minimum longitudinal spacing (and, of course, on the traffic flow rate).

4.2 An effective value of the average minimum spacing has now to be determined. From the North Atlantic data collected statistics of the distribution of longitudinal spacings between pairs of aircraft on the same flight path have been extracted. This data has been confined to westbound aircraft during periods of relatively high traffic intensity; even so it has been possible to include over one thousand pairs in the study. This distribution of course is of the actual spacings between pairs of aircraft; it cannot be related directly to the distribution of minimum spacing because in many cases the actual spacing will be greater than the minimum. The method of comparing the two has been to run simulations of the system employing various distributions of the minimum longitudinal spacing and to compare the resulting distribution of aircraft spacing with that derived from the NAT data collection. The distribution of longitudinal spacing from the data collection is given in Table 3.

TABLE 3

Distribution of Longitudinal Spacings

Range	10-12 mins	12-14 mins	14-16 mins	16-18 mins	18-20 mins	20-25 mins	25-30 mins
% of flights	0.09	0.45	1.00	2.18	2.73	6.82	6.73

4.3 It is necessary to construct a mathematical model of the process of allocating aircraft to tracks which will result in approximately this pattern of longitudinal spacing at the relevant flow rate (about 20 aircraft/hour). A series of simulations showed that a simple model with a random flow input and a constant value of the minimum longitudinal spacing did not give this pattern for any value of the longitudinal spacing. The model was therefore developed by assuming a variable value of the minimum longitudinal spacing. A further series of simulations showed that a log-normal distribution of the minimum spacing gave the best fit to the existing data, and that to account for the relatively small number of aircraft with spacings less than 30 minutes, the mean value of this minimum spacing should be relatively high, about 35 mins. Table 4 shows the theoretical distribution of longitudinal spacings given by a simulation at the mean traffic flow rate corresponding to Table 1 and with a minimum spacing whose mean value is 35 mins and standard deviation 24 mins*.

TABLE 4

Distribution of Longitudinal Spacings from Simulation

Range	10-12 mins	12-14 mins	14-16 mins	16-18 mins	18-20 mins	20-25 mins	25-30 mins
% of flights	0.39	0.75	1.36	1.67	2.22	7.43	9.40

* A slight complication arises because the data from the NAT collection was taken at 20°W instead of 10°W, as it should be for a study of oceanic entry spacings. This means that the model of oceanic allocation, in effect includes the extra deviation in the distribution of longitudinal spacings due to the differential speed effect between 10°W and 20°W. This introduces an extra term in the distribution of the minimum spacing corresponding to a standard deviation of 1-2 mins, but should not affect the mean value.

4.4 This very high value of the mean minimum longitudinal spacing is surprising in view of the fact that the separation standard is 15 mins. Part of the difference undoubtedly arises from the uncertainty of the aircraft's ETA at oceanic entry at the time when it makes its request for oceanic clearance. Because of this uncertainty controllers may adopt a larger longitudinal spacing in allocating aircraft to paths than would otherwise be the case. To fully explain the difference, however, it must also be assumed that in many cases aircraft for various reasons deliberately opt to take a track which is not the best theoretically open to them. This is further discussed in para. 6.2.

4.5 In constructing the model of the trans-Atlantic system it must therefore be allowed for the fact that there appears to be some "slack" in track loading at present. This slack should decrease with increased traffic loading.

5. Cost estimate

5.1 The method of estimating the average penalty in the system is described in para. 7.1 of Appendix 2-A. For a given traffic flow the distribution of aircraft among tracks is obtained from the formula; the average value of the "low" cost and the distribution of fuel requirements follows from this. Then the fuel distribution is used to estimate the ATC fuel reserve increment by convolution with other items of fuel variation, the "mid" cost penalty, including the cost of fuel burnt to carry the fuel reserve increment, and finally the "high" cost, including lost revenue from payload occasionally displaced by the extra fuel reserve.

5.2 It appears from para. 4 that this estimate should be made not only for a range of traffic rates but also for a range of values of the average minimum spacing. Fortunately for the amount of work involved, the two quantities are interchangeable in the sense that a high traffic rate with a small spacing gives the same pattern of flow and hence cost penalty as a lower traffic rate with a larger spacing. Thus in Fig. 2-B-1 it has been possible to express the cost penalties for a range of flow rates and for three separate values of longitudinal spacing, by altering the scale of the flow rate. Fig. 2-B-1 shows that the variation of cost with flow rate is nearly linear, in contrast to the supersonic system; also that the costs dependent in fuel reserve comprise 40% - 50% of the total, the proportion increasing slightly as the traffic rate increases. This proportion is much larger in the supersonic system, for which the fuel reserve costs are dominant.

5.3 It is of interest to compare the results given here with an estimate of deviation penalties made for the 5. NAT/SPG Meeting. This study was based on actual deviations measured in practice by comparing actual flight paths of westbound aircraft with operators' requests. The results are given below in comparison with the present estimates for the relevant traffic flow rate of 20 aircraft/hour and a minimum spacing of 35 mins :

TABLE 5

Comparison of Cost Estimates per Flight

	NAT/SPG-5	Current Estimate
"Low" cost	$ 37	$ 34
"Mid" cost	$ 57	$ 46
"High" cost	$ 74	$ 65

5.4 The results are in fair agreement considering the very different methods used in deducing them. (A discrepancy of 10% can be accounted for by assuming some degree of eastbound flow in opposition.) This agreement suggests that the high value of 35 mins for the effective minimum longitudinal spacing does give a valid picture of the incidence of deviations.

6. Annual cost penalty.

In converting the figures of Fig. 2-B-1 to annual cost penalties allowance must be made for the following factors :

i) The forecast peak traffic flow rate and its relation to the total annual flow.

ii) The effective minimum longitudinal spacing and its variation with increasing traffic rate.

iii) The mix of aircraft types.

iv) Correction factors to allow for the presence of counter-flow and a multiplicity of terminals.

These factors are discussed hereunder.

6.1 Annual flow variation

6.1.1 Forecasts of North Atlantic traffic for the years up to 1978 are given in Ref. 4. This gives both the expected number of flights per year and the busy hour rate. Relating hourly costs to annual costs requires to know the variation of hourly flow rate throughout the year. For subsonic aircraft the problem is simplified because the relation of cost penalty with hourly flow rate is nearly linear; this means that it is necessary to only determine the flow rate averaged over all aircraft throughout the year to determine the average cost penalty. Reich (Ref. 5) gives a model for annual distribution of flow rate. Applying this model to the data of Ref. 4 one finds that it implies that the "busy hour" rate will be attained or exceeded on 2% of occasions in 1969, increasing to 9% of occasions in 1978. This appears to be in reasonable agreement with the definition of busy-hour rate given in Ref. 4; the increase in frequency of "busy hours" with time reflects the expected spreading of peaks as traffic builds up. Reich's model is therefore used to determine annual flow rate; it implies that the average flow rate is 38% of the busy hour rate in 1969, increasing to 46% by 1978.

6.2 The effective longitudinal minimum spacing

Para. 4 has shown that the present track loading can be represented by a model in which the effective longitudinal spacing is 35 mins in place of the standard separation of 15 mins. This means that track loading is much lighter than would be indicated by a simple theoretical model. The various possible reasons for this are discussed below.

6.2.1 Inaccuracy of Oceanic ETA

6.2.1.1 Some slack in the system will arise because of inaccuracy in forecast oceanic arrival times at the time when aircraft request clearance (on average about 50 mins before oceanic entry time). Such inaccuracy may make controllers cautious of admitting two aircraft on the same path when their estimated entry times differ by only 15 mins. Alternatively if they are so cleared, and as the aircraft approach the oceanic entry point it becomes apparent that the true difference between entry times will be less than 15 mins, one aircraft will be re-cleared or delayed; while if the true difference turns out to exceed 15 mins, re-clearance is less likely. Either way, the effect will be to increase the average value of the minimum entry interval above 15 mins. Some data from the Prestwick Oceanic Centre shows the average value of inaccuracy of ETA to be 2½ mins, while errors of 15 mins or more occur on about 1% of occasions. This should have the effect of increasing the average minimum entry spacing from 15 mins to 20 mins or more, depending on how often aircraft are re-cleared.

6.2.2 Differences in flight paths preferred

6.2.2.1 One of the assumptions behind the model of aircraft allocation described in Appendix 2-A is that the order of preference of flight paths is the same for all aircraft. In practice this preference will differ between aircraft. This difference may be real, as when two aircraft have different origins and destinations or when two airlines use different costing policies, or only apparent as when two airlines use different forecasts to describe the same weather situation. Differences in origin and destination and forecast differences will result in differences in track preference (for the vast majority of traffic this should be only a change of 1 track, i.e. 120 NM). Differences in costing policy may result in differences in the relative importance of fuel and time penalties and hence in the preferred flight level, possibly by as much as 4 000 ft. For the system as a whole such differences will tend to reduce the loading on the central flight paths and hence to increase the longitudinal spacing. Some studies of particular situations suggest that the effect on path loading is not very critical. It could be represented by an increase in effective minimum spacing of about 5 mins.

6.2.3 Selection of paths for reasons other than direct operating cost

6.2.3.1 From discussions with ATC personnel, it appears that aircraft may select paths for reasons other than the optimisation of direct operating cost as defined in para. 3. For instance a relatively uncongested path may be chosen to reduce cockpit work-load or to allow the aircraft to cruise at greater speed than the main stream of traffic; this high speed may be desirable for prestige reasons or to allow a particular aircraft to complete a flight within the overhaul period. The incidence of these cases is uncertain, but they will tend to reduce the loading on the most-used paths. One would expect path selection on a basis other than direct operating cost to occur less often as traffic increases and larger, more expensive aircraft are introduced into service.

6.2.4 Non-availability of paths

6.2.4.1 In the model of aircraft utilization, it is assumed that any aircraft can take any path. In practice this may not be so. For instance, the higher flight levels may be unattainable by some aircraft; this applies at the moment particularly to heavily-laden aircraft flying to the West Coast of the USA (about 1% of total traffic), but may also apply to the B-747. In other cases, tracks may be unavailable to some aircraft because of traffic conflicts in the domestic-oceanic transition area. This problem particularly affects the SST, but may also influence the subsonic case. Again it is difficult to quantify this effect, but it may be expected to reduce with improvements in domestic and oceanic ATC.

6.2.4.2 Paras. 6.2.1 to 6.2.4 have discussed various causes of the present relatively low loading of flight paths. In many cases these causes will become less prominent as time goes on. Better navigational equipment will result in improved estimates of oceanic arrival time. The increasing use of computers in flight planning will tend to standardize flight plans between different airlines. As traffic intensity increases, so will the incentive to choose the path giving lowest direct operating cost irrespective of other considerations. On the other hand some causes of the distortion of aircraft distribution among paths will not diminish. Among these are the multiplicity of terminals and limitations on flight level placed by aircraft performance. For these reasons it is expected that the effective mean value of the minimum longitudinal spacing will diminish by 1978 from its present value of about 35 mins but not to the standard separation of 15 mins. For the purpose of constructing an economic model for 1978, it is tentatively put at 25 mins, thus halving the discrepancy for a doubling of traffic. A linear variation in the intervening years* is assumed.

6.3 The mix of aircraft types

6.3.1 Ref. 4 gives forecasts of the proportion of large aircraft among the subsonic traffic. The influx of large jet aircraft is allowed for in the estimate of annual cost by applying the factor of para. 2 to the appropriate proportion of flights.

6.4 The multiplicity of terminals

6.4.1 The fact that different aircraft have different orders of preference for flight paths will affect the cost analysis in two ways :

i) the distribution of aircraft among paths is distorted;

ii) because the optimum paths of aircraft are not the same, each aircraft has a somewhat greater chance of getting its particular optimum path, or one close to it.

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* Studies of supersonic traffic have assumed that the effective minimum longitudinal separation is maintained at the nominal minimum value. Here, however, a high degree of navigational capability and automation is expected, both in the cockpit and on the ground, together with a strong economic incentive for achieving maximum traffic density on the best paths. In addition, by varying the point of trans-sonic acceleration, the controller has a convenient and powerful means of varying the longitudinal spacing.

6.6 Total penalty of westbound flow

6.6.1 Applying the factors described in paras. 6.1 to 6.5 gives the following estimates for the annual "high" cost penalty to westbound aircraft.

TABLE 6

Annual Cost Penalty (Westbound Only)

Year	Penalty (Millions of Dollars)
1969	2.63
1970	3.10
1971	3.58
1972	4.26
1973	4.29
1974	4.97
1975	5.19
1976	5.51
1977	5.74
1978	5.17

The penalty for eastbound aircraft will be similar but rather less because the fuel reserves are less critical in this direction.

7. The composite system

7.1 In the proposed system using composite separation standards, tracks would be separated by only 60 NM, but the permissible flight levels, expressed in thousands of feet, would be alternately odd and even numbers. Thus aircraft on adjacent tracks would be separated by 60 NM and at least 1 000 ft of altitude. The cost penalties attached to the flight paths in this system have been estimated by interpolation from the figures already given. The cost estimates of the system, on the same basis as described in para. 5, is given in Fig. 2-B-1. Comparison of the two curves shows that the effect of the introduction of the composite system is approximately to halve the cost penalty. This is because the composite method of separation nearly doubles the number of flight paths that can be contained within a given volume of airspace.

6.4.2 These two effects will influence the overall operating cost in opposite directions. It is believed that for the vast majority of aircraft, the preferred tracks will not differ by more than 120 NM, nor the optimum flight level by more than 4 000 ft. Studies have been made of a hypothetical system in which half the aircraft have optimum tracks separated by 120 NM from the other half. The extreme assumption is made that all this traffic is distributed in accordance with the preferences of one half of it. The result shows an increase in average cost of 10%. Similarly, study has been made of a system in which half the aircraft have optimum flight levels 4 000 ft from the other half; this system gives a cost increase of 4%. Since in both cases the unrealistic and pessimistic assumption is made that the preferences of one half the traffic are ignored, it may safely be assumed that the true cost increases will be less than these figures. They may even be negative; some estimates of aircraft on "fringe routes" taken from the NAT data collection showed cost penalties less than those of the main stream. For the present study, therefore, no factor is included in the cost estimate to allow for the multiplicity of terminals.

6.5 Opposite-direction flow

6.5.1 For subsonic traffic the major eastbound and westbound flows occur at different times of day and there is no conflict between them. However, a proportion of eastbound traffic crosses at the time of the main westbound flow and it appears that this counterflow is likely to increase in future years. On some occasions the eastbound and westbound tracks will be separated in space by wind effects. When conflict between the two systems does occur the effect will be that some flight paths which would otherwise be available to westbound aircraft will not be so. This will not affect the pattern of longitudinal spacing but will increase the size of deviations encountered by westbound aircraft and hence their cost penalty. Some simulations have been run of a situation where the eastbound counterflow is 20% of the westbound flow. The flight paths are distributed between the flows so as to equalize the penalty between flights in opposite directions. Under these circumstances the cost penalty of the westbound aircraft is found to be 36% greater than it would be in the absence of eastbound aircraft.

6.5.2 However, this coincidence of traffic flows in space only occurs on about one-quarter of occasions. Averaged over the whole westbound flow, the effect of the counter-flow is to increase cost by 10%.

7.2 The annual costs of the composite system are given in Table 7. The assumptions used are the same as those described in para. 6. In particular the same pattern of longitudinal separation has been used. In practice, there may be some additional difficulty in sequencing aircraft on to the composite track system which would result in somewhat lower track loadings. In this case the costs would be slightly greater.

TABLE 7

Annual Cost Penalty in Composite System (Westbound Only)

Year	Penalty (Millions of Dollars)
1969	1.17
1970	1.37
1971	1.59
1972	1.89
1973	1.91
1974	2.21
1975	2.31
1976	2.46
1977	2.56
1978	2.29

8. Discussion

8.1 Estimates show that with the forecast traffic increase and the current separation standards the NAT subsonic system cost penalty will reach a peak of six million dollars for westbound aircraft per annum by 1977. This figure appears large but represents $1 per passenger or less than ½% of passenger fare. The introduction of composite separation standards will approximately halve this penalty. Further improvements might result if, for example, the introduction of a satellite surveillance system enables lateral standards to be reduced. The possible gain in this direction is less than with the supersonic system because for subsonics the cost penalty is proportional to the lateral standard and not to its square as for supersonics. Thus for the subsonic aircraft, both eastbound and westbound, halving the lateral standard in a composite system in 1977 would result in a saving of about $2 M (corresponding figure for the supersonic system for 1978 is $24 M). It appears that, assuming that a composite system can be successfully introduced, there is little scope for further dramatic reductions in cost penalty, although satellite surveillance and an improvement in methods of sequencing aircraft on to tracks should give useful gains.

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No.	Author	Title
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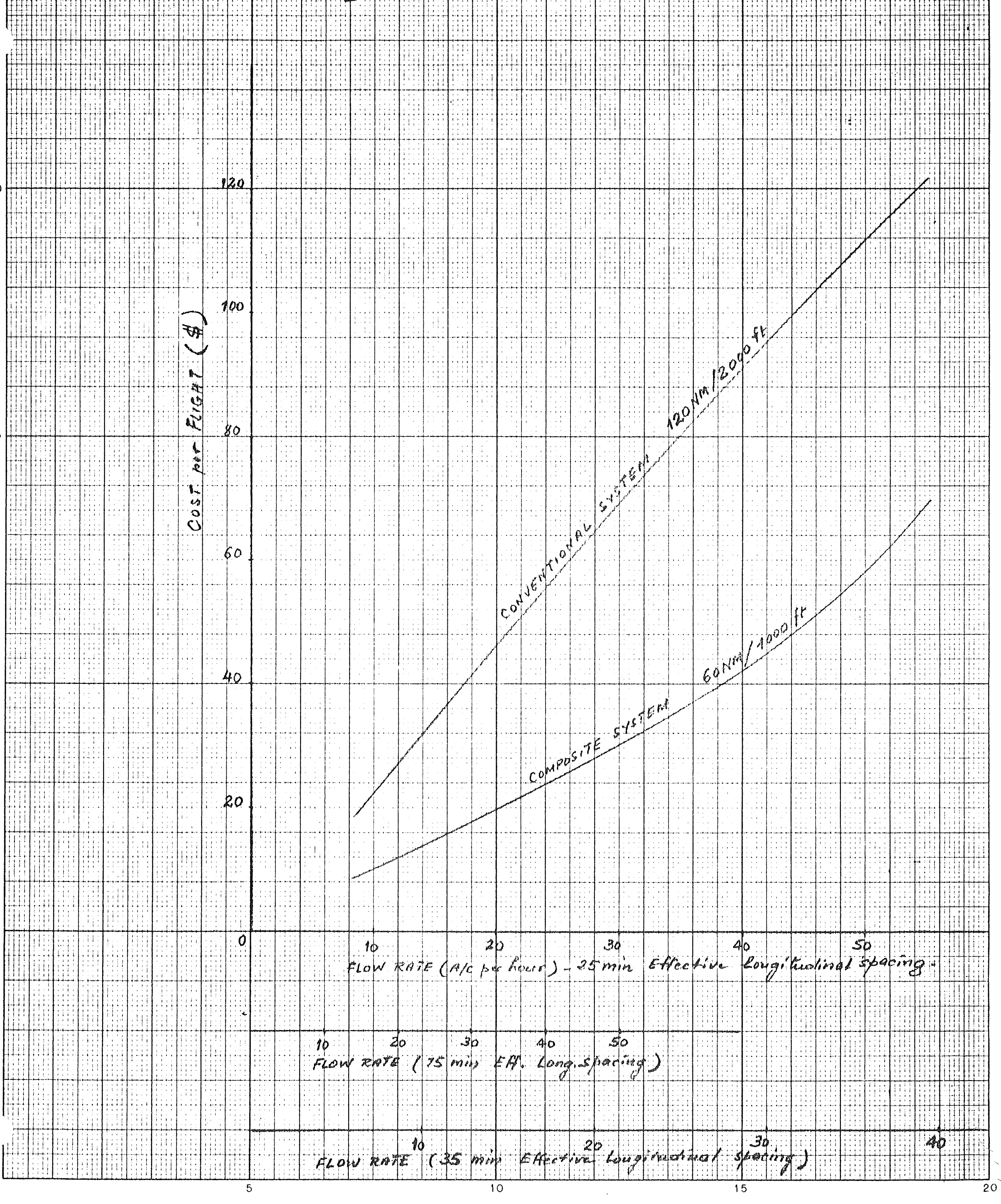
Fig 2-B-1 COST PENALTY



APPENDIX 2-C

RESULTS OF COSTING THE NAT SUPERSONIC SYSTEM

1. Introduction

This note gives some results of the application of the methods of system cost analysis described in Appendix 2-A as applied to the expected supersonic transport system over the North Atlantic, at the flow rates forecast for the years up to 1978. The track system is that illustrated in Figures 2-C-1 and 2-C-2, i.e., assuming that no overland supersonic flight is allowed. Results quoted include the distribution of aircraft among tracks and the distribution of penalties in terms of operating cost for westbound SSTs operating from five European terminals. The effects of modifications to the system, including variation in track position, reduction in separation standard, and introduction of flow control, are given.

2. The track system

2.1 Lateral separation between tracks is 60 NM and minimum longitudinal separation on tracks is 10 minutes. In addition, 3 minutes minimum separation must exist between aircraft on crossing tracks in the transition region (NAT/SPG-5, Appendix 1-J). Since westbound and eastbound flows are expected at the same time of day, only alternate tracks are available for westbound traffic. Starting from the most northerly these are designated Tracks 1, 3, 5, etc....

2.2 In addition to the system as illustrated in Figures 2-C-1 and 2-C-2, the effect of some variation in geometry of the system on the eastern side have also been assessed, maintaining the assumption of no overland supersonic flight. In Figure 2-C-2 the northern-most Track 1 is drawn starting at 52°N 15°W. The overall length of Track 1 would in fact be shorter if it commenced at 51°N, but the more southerly tracks, being forced further south, would be lengthened. In the original study, therefore, 52°N was chosen as a more suitable starting point as giving better overall economics for all aircraft on all tracks. The choice of 52°N was made on a qualitative basis in the first instance; the matter has now been investigated more deeply by analysing systems with Track 1 starting at various points between 51°N and 55°N. (In fact 52°N is shown to have been a good choice, but might be changed to 53°N as the flow rate builds up.) Figure 2-C-5 shows systems starting at 52°N and 53°N.

2.3 The effects of reductions in lateral separation to 30NM and in longitudinal separation to 5 minutes are also considered. These might follow from changes such as the introduction of satellite surveillance.

3. Aircraft flow pattern

3.1 As is well known, the flow of trans-Atlantic subsonic traffic throughout the day follows a tidal pattern with eastbound flow mainly overnight and westbound flow during daylight hours. This pattern is illustrated in Fig. 2-C-3, which is based on traffic samples. No actual traffic flows are given in Fig. 2-C-3 (and Fig. 2-C-4, the corresponding supersonic figure), because we expect the general pattern of flow to persist over a wide range of overall traffic level. It is dictated by the desire of passengers to depart and arrive at convenient hours and by regulations at airports to avoid take-offs and landings during "quiet hours", combined with the differences in local times on opposite sides of the Atlantic. Operating within these limits, a subsonic jet transport can made one crossing of the Atlantic each way in 24 hours. For the supersonic transport the pattern will differ because of the much shorter time of flight. The supersonic transport should be able to achieve two crossings each way in 24 hours, but even the Mach 3 cannot do more than this without unduly short turn-round times or airport movements during "quiet hours". To achieve a high utilization most aircraft will have to be scheduled for two round trips; this will involve an eastbound crossing during daylight hours in addition to an eastbound crossing overnight, which is derived from the study given as Ref. 1. The expected pattern of flow is shown in Fig. 2-C-4; this shows an eastbound overnight peak flow similar to the subsonic case, but also a further peak during the day involving traffic moving in both directions with a combined flow rate similar to the overnight peak.

3.2 The scale of the flow pattern, such as Fig. 2-C-4 is defined by fixing the size of the peak flow rate. The following estimates of the peak westbound supersonic flow at various dates are obtained from the latest report of the NAT Traffic Forecasting Group.

TABLE 1

Flow Rates

Year	Westbound flow during busy hour (aircraft/hour)
1973	2
1974	3
1975	5
1976	7
1977	9
1978	13

3.3 This study considered traffic levels corresponding to westbound peak flow rates of from 2.5 aircraft/hour to 12.5 aircraft/hour; the daily pattern remaining that of Fig. 2-C-4.

3.4 The traffic flow is normally taken to be random in character within the hourly pattern. However, some studies have also been made of the effect of a degree of flow control. These are described in para. 8 below.

4. The simulation model

4.1 As explained in Appendix 2-A the characteristics of such a system can only be determined by simulation. The flow diagram of the simulation program is given as Fig. 2-A-8 in Appendix 2-A. In the simulation, traffic is generated by London, Paris, Brussels, Amsterdam and Frankfurt in proportions deduced from the recent NAT data collection study. Each aircraft is considered in succession in order of its expected time of arrival at the oceanic boundary. As shown in Fig. 2-C-2, there are three normal start-of-acceleration points; the most northerly is used by London traffic, the southern by Paris traffic and the central point by traffic from the remaining airports. The method of allocation of aircraft to tracks is as follows. Each track is considered for every aircraft. For some tracks a delay will be necessary before the aircraft can enter it either in order to maintain longitudinal separation on the track itself or to maintain separation from other outbound SSTs at a crossing point before entering the track. Any necessary delay is carried out by altering the time at which the aircraft begins trans-sonic acceleration*. For each aircraft the cost penalty of being allocated to each track, allowing for necessary delay, is computed; the aircraft is allocated to the track carrying the least penalty and its time for start of acceleration is adjusted to give the necessary delay.

4.2 This method of allocation of aircraft to tracks is, in essence, that planned by the UK authorities for SST operation. It is complex and will require the services of an on-line computer, but has been shown to give a better use of airspace and lower operating costs than simpler methods of allocation.

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*A limit of about 10 minutes is placed on the delay possible by this method by the requirement that accelerations take place in radar range. Where the delay required before entry to a track is greater than this, that track is excluded from consideration for that aircraft. (See also para. 5.4.)

5. Results of simulation

5.1 Cost estimates

5.1.1 The program estimates the average cost penalty to aircraft in the system on the "high cost" basis, i.e. the cost including the effect of the associated fuel reserve requirements on fuel burnt and payload. These are given in the table below for the system with 60 NM lateral and 10 mins longitudinal separation and for a range of flow rates and positions of the eastern end of the track system.

TABLE 2

Average Cost Penalty per Flight* (Dollars)

Peak Flow (aircraft/hour)	Latitude of Entry to Track 1				
	51°N	52°N	53°N	54°N	55°N
2.5	$ 25	$ 29	$ 74	$130	$217
5.0	91	62	88	144	230
7.5	259	170	133	170	252
10.0	417	335	263	220	291
12.5	780	599	520	465	407

5.1.2 Table 2 shows the large (non-linear) increase of cost penalty with increase in flow rate. It also shows how the optimum position of the northerly track moves further north as the flow rate increases; the increasing penalty of Track 1 being outweighed by the lesser penalty on Tracks 3 and 5 as the system is moved north (Fig. 2-C-5). For comparison purposes a penalty per flight of $166 represents a 1% increase in passenger fare.

5.1.3 In addition to the cost penalty the simulation gives valuable information on other aspects of the system. These are described in subsequent paragraphs.

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*In order to give a valid comparison, all costs in this table are quoted relative to the best track on the system starting at 51°N, not as is usually done, relative to the best track in the particular system considered. For example, in the simulation of the system starting at 54°N, all aircraft carry a positive penalty since no track in that system is as short as Track 1 from 51°N.

5.2 Number of tracks required

5.2.1 One of the outputs of the simulation program gives the proportion of aircraft allocated to each track. It is standard practice to include in the input to the program the data on a greater number of tracks than is likely to be required to carry the flow. Then the simulation itself selects the track requirements for its particular flow rate. The resulting aircraft distribution shows greatest loading of the optimum track and a progressive decrease in loading for the less desirable tracks, as expected.

TABLE 3

Distribution of Aircraft among Tracks

(Track system starting at 52°N, 15°W)

Peak Flow Rate (aircraft/hour)	2.5	5	7.5	10	12.5
% of aircraft using	%	%	%	%	%
Track 1	84.9	73.8	63.8	57.0	50.6
Track 3	14.5	23.4	29.5	31.8	32.3
Track 5	0.5	2.5	5.4	8.2	11.4
Track 7	0.1	0.3	1.0	2.3	3.9
Track 9		0.1	0.2	0.6	1.0

5.2.2 In deciding the number of tracks actually required in the real system, the very lightly loaded tracks may be ignored, assuming that aircraft which would be allocated to these could be treated as special cases to be met by special procedures or even rejected by the system. It may be taken as criterion that only tracks carrying more than 1% of the traffic need to be set up*. On this basis the numbers of tracks required (for both direction traffic) are as follow :

*At the highest traffic peak considered 1% of traffic represents little more than 1 aircraft per day. At this loading eastbound and westbound aircraft could share tracks.

TABLE 4

Number of Tracks Required

Peak Flow (Westbound)	Year Forecast	No. of Tracks
aircraft/hour		
2.5	1973	4
5	1975	6
7.5	1976-7	6
10	1977	8
12.5	1978	8

5.2.3 Other configurations of the system, i.e. with different positions for the eastern ends of the track, yield similar results in terms of track numbers required, although the distribution of aircraft among tracks differs somewhat.

5.3 Aircraft on crossing tracks

5.3.1 One result of moving the track system further north is that the northerly Track 1 becomes less desirable for aircraft from the more southerly airports and Tracks 3 and 5 more desirable. This would be expected to produce some natural segregation between aircraft from the various airports and to reduce the incidence of encounters between aircraft on crossing tracks in the transition region. To test this, one of the outputs of our program gives the proportion of aircraft which have to be delayed specifically to maintain 3 minutes longitudinal separation between them and other aircraft on crossing tracks. This proportion is shown below for a peak flow rate of 7.5 aircraft/hour :

TABLE 5

Proportion Delayed for Crossing Separation

Latitude of Track 1	51°N	52°N	53°N	54°N	55°N
Proportion (per cent)	10.2	8.3	5.3	5.0	6.4

5.3.2 The proportion decreases steadily as the system moves up to 54°N. For 55°N it increases again because the northernmost track is now becoming undesirable even for aircraft from London.

5.3.3 At higher flow rates the proportion of aircraft affected increases approximately in proportion to the flow rate. Thus the actual number of interventions required increases as the square of the flow rate. At 12.5 aircraft/hour peak flow over 10% of aircraft are affected even with the best track configuration (Track 1 at 54°N).

5.4 Aircraft rejected

5.4.1 Under conditions of temporarily high flow rate a delay of 7 minutes or more may be built up among aircraft wishing to enter a desirable track. If an aircraft from a southerly airport is allocated to that track, a subsequent aircraft from a more northerly airport might find itself in a situation where it is unable to take the desirable track without exceeding the maximum allowable delay of 10 minutes; or to take a more southerly track without either infringing the crossing separation with the previous aircraft or exceeding the maximum delay. Such an aircraft would not be able to commence acceleration within radar range, and would have the alternatives of returning to base or completing the flight at subsonic speeds. A previous simulation (briefly reported to the 5. NAT/SPG) showed that with the flow rates currently considered, the proportion of aircraft so rejected could be unacceptably high (above 5%). Further simulation showed that the rejection rate could be greatly reduced by adopting the following rule: while 10 minutes delay at entry is the maximum permitted by radar range, an aircraft is only to be allowed to use this delay to resolve a crossing situation. When the problem is merely to give sufficient longitudinal separation with an aircraft ahead on a desired track, the delay allowed is not to exceed 7 minutes - otherwise a less desirable track must be used.

5.4.2 This rule is incorporated in the logic of the current simulation. With the rule in use the rejection rates for various flow rates become as given in the table below :

TABLE 6

Rejection Rates

Peak Westbound Flow (aircraft/hour)	2.5	5	7.5	10	12.5
Rejection rate (per cent)	0	0	0.02	0.1	0.2

6. Annual costs

6.1 Before discussing the effects on cost penalty of other variations in the system, we first consider how the costs per flight quoted in Table 2 may be converted into annual costs. To estimate the cost over the whole year from cost penalties based on hourly flow rates, we have to consider both how the flow rate is likely to vary throughout the day and how the daily flow varies throughout the year. The diurnal variation is already included in the program, which generates the average penalty throughout 24 hours for a given peak hourly flow. We have to consider how the daily flow rate varies throughout the year. From NAT/SPG traffic forecast figures we find that the total annual flow is 80% of that which would result if the busy daily flow were maintained over the whole year. This implies less variation in flow throughout the year than is the case with supersonic aircraft. We anticipate that operators will try to keep their supersonic aircraft operating at the highest possible frequency all the year round because of the high capital cost of these aircraft. It may also be argued that business, rather than tourist, passengers will predominate in the first few years of service of the SST. For both these reasons the seasonal variation in traffic flow of supersonic aircraft is expected to be less than that of subsonic aircraft.

6.2 However, some variation will still exist, due partly to the practice of withdrawing aircraft from service for annual overhaul in winter. We have derived a convenient model of the annual variation of flow rate which agrees with the figures of the NAT/SPG Traffic Forecasting Group. From this and from the variation of average flight penalty with daily flow we find that the annual cost penalty of a given year is 77% of that which would result if the flow rate corresponding to the "busy day" were maintained throughout the year.

6.3 This gives the following values for annual cost penalties for the system starting at 52°N :

TABLE 7

Annual Cost Penalties

Year	Annual Flow (Westbound) (No. of Flights)	Annual Cost (Westbound Traffic) (Thousands of Dollars)
1973	5,500	79
1974	6,100	196
1975	13,500	644
1976	19,300	2,200
1977	27,000	5,640
1978	39,600	14,800

6.4 This table covers westbound traffic only. The penalties of eastbound traffic are not specifically considered in this note. While the number of aircraft flying east should be the same, the cost penalty per flight should be somewhat lower because the problems of allocating aircraft to tracks should be less severe on the American side. The overall cost penalty, therefore, will be rather less than twice the figure given in Table 7.

7. Effect of reduction in separation standards

7.1 The system with reduced separation standards has only been simulated at the higher flow rates, since it is under these conditions that the reduction will show most benefit. The higher flow rates also occur in the later years of operation when the required navigational improvements are most likely to be available. The following table shows the effect on the average cost of a reduction in lateral separation from 60 NM to 30 NM. (System starting at 52°N.)

TABLE 8

Effect of Reduction in Lateral Separation

Peak Flow (aircraft/hour)	Average Cost Penalty per Flight (Dollars)	
	Lateral Separation 60 NM	Lateral Separation 30 NM
7.5	170	32
10	335	41
12.5	599	61

7.2 The table shows a marked reduction in penalties; halving the separation standard reduces penalties by nearly 90%. It follows that the gain in operating cost from such a reduction is very large; by 1978 it could be $13M annually for westbound aircraft alone. It also follows that the incentive to further reduce separation standards below 30 NM is not great.

7.3 A further simulation shows that the affect on cost of a reduction in longitudinal separation from 10 minutes to 5 minutes is almost the same as halving the lateral standard. Such a reduction would probably require some measure of speed control and would be more difficult to effect than the lateral reduction, even with satellite surveillance.

8. Effect of scheduling

This section discusses the effects of modifying the assumption of completely random arrival times at oceanic entry. It is assumed that iarlines attempt to schedule their departure times from their various airports so as to reach the oceanic boundary at regular intervals. Now unless the SST is to be given absolute priority at airports and in the domestic region and, indeed, unless minor delays for other reasons than ATC never occur, it is clear that these times of departure will in practice be subject to some degree of scatter. Any realistic simulation of the system must therefore include the effect of some degree of scatter of oceanic entry times. The question has been studied in two ways; both by fast-time simulation similar to that used to study random traffic and by a slow-time simulation to determine in detail the pattern of aircraft allocation.

8.1 Fast-time simulation

8.1.1 In this simulation the pattern of diurnal flow is the same as that of the random study. Within each hour, however, aircraft are programed to arrive at oceanic entry at equal intervals of time. This orderly sequence of arrivals is perturbed by a random disturbance whose standard deviation in successive simulations ranged from 5 mins. to 15 mins. The geometry of the system simulated is that with Track 1 starting at 52°N.

8.1.2 The results show clearly that the effectiveness of this type of scheduling decreases as the traffic intensity increases. Presumably this is because as intensity builds up, the time interval between aircraft decreases, and when it becomes comparable with the standard deviation of the schedule disturbance the flow pattern is in effect random. In fact, with the S.D. of the disturbance equal to 15 mins., scheduling shows no advantage, even at the lowest flow rate.

8.1.3 The cost results for lower values of standard deviation are given in the table below for the flow rates at which the cost is lower than for random flow.

TABLE 9

Costs of Scheduled System

Peak Flow (aircraft/hour)	Cost Penalty per Flight (Dollars)		
	Unscheduled System	Scheduled System with Disturbance of Standard Deviation: 5 minutes	Scheduled System with Disturbance of Standard Deviation: 10 minutes
2.5	29	14	17
5.0	62	24	not better than random arrival
7.5	170	82	not better than random arrival

8.2 Slow-time simulation

8.2.1 For the slow-time simulation the case of a relatively small number of aircraft arriving at the oceanic boundary at equal intervals of time was examined; the size of this interval was determined by the flow rate. It was found that with the intervals remaining strictly equal, a pattern of allocation of aircraft to tracks is built up. Firstly a number of aircraft are allocated to Track 1 in succession; their entry delay increases steadily from aircraft to aircraft until it reaches the limit of 10 mins; the next aircraft then has to go into Track 3, after which the succession of aircraft into Track 1 begins again. At higher flow rates aircraft are allocated alternately to Tracks 1 and 3 with delays steadily building up until Track 5 has to be used. In all cases a repetitive cycle of events occurs and the desirable tracks are filled to capacity. Only Track 1 is used for flow rates up to 6 aircraft per hour and only Tracks 1 and 3 for flow rates up to 12.5 aircraft per hour.

8.2.2 The next step was to investigate the effect on the system of small departures from schedule. It was found that in all cases there was a finite interval of time or slot during which the aircraft could take-off without altering its track allocation or the system capacity; any resulting disturbance to the steady flow is compensated for by adjusting the delay before entry. When tracks are filled to capacity the size of this time interval is equal to the maximum allowable delay period i.e. 10 mins.

8.2.3 The result of this work therefore indicates that a system with the highest possible use of the better tracks and therefore lower possible cost penalty would result if aircraft could be operated in such a way that they never departed from a time slot of 10 mins. width. A rectangular distribution of departures from schedule with an extreme limit of 10 mins. corresponds to a standard deviation of 2.9 mins. This is consistent with the result of the fast-time simulation which showed a steady decrease of cost with improvement of schedule keeping down to a standard deviation of 5 mins.

8.2.4 If, in fact, schedule keeping can be improved to the point where departures from schedule of more than 10 mins. become rare, the oceanic clearance system could be changed. Aircraft could then be allocated both an oceanic track and an oceanic entry time before take-off, and small variations in departure time could be absorbed by altering the point of trans-sonic acceleration. It is unlikely, however, that this degree of precision could be attained at least in the early years of SST operation.

9. Discussion

9.1 It has been shown that a study of a traffic system to determine primarily the cost penalty can yield information on many other aspects of the system, particularly when it is intended that the system shall be cost-optimised. Consider first the desirable positioning of the tracks. Studies show that the currently accepted position of Track 1 starting at 52°N, 15°W is correct for flow rates up to 7.5 aircraft/hour westbound peak (forecast for 1976) but that there is then a case for moving the eastern end of the track system further north, by one or even two degrees of latitude. (A move of two degrees north, to 54°N, may lead to difficulty in that the aircraft has to fly a large turn around the South of Ireland at trans-sonic speeds.) The simulation has also shown clearly the advantage of a method of allocation of aircraft to tracks using entry delay where necessary by adjusting the point of start of trans-sonic acceleration. (The results of simulations using simpler methods of allocation are not reported here in detail but result in cost penalties increased by factors of up to four.)

9.2 The advantage of flow control, by scheduling departures from airports so that aircraft arrive at the oceanic boundary at regular intervals, have been examined. It appears that, except in the earliest years of operation (when cost penalties are small anyway), there is no advantage in such scheduling unless schedule disturbances can be kept down to a level of standard deviation of 5 mins. or less. Such schedule disturbances will arise from pre-take-off delays, take-off delays, and modifications to initial climb profile arising from ATC and meteorological conditions. Unless some measure of priority on take-off can be given to the SST, such precision of operation appears unlikely in the timescale considered.

9.3 With regard to the cost penalties themselves, they are estimated to increase to a level of about 3% of fare by 1978, unless separation standards can be decreased from the levels of 60 NM lateral and 10 mins. longitudinal by then. By 1978 the annual cost penalty (eastbound and westbound aircraft) is about $24M. Halving either separation standard would reduce this figure by nearly 90%. This gives a measure of the desirable expenditure on measures to reduce separation standard, whether by satellite or other means.

Fig. 2-C-1

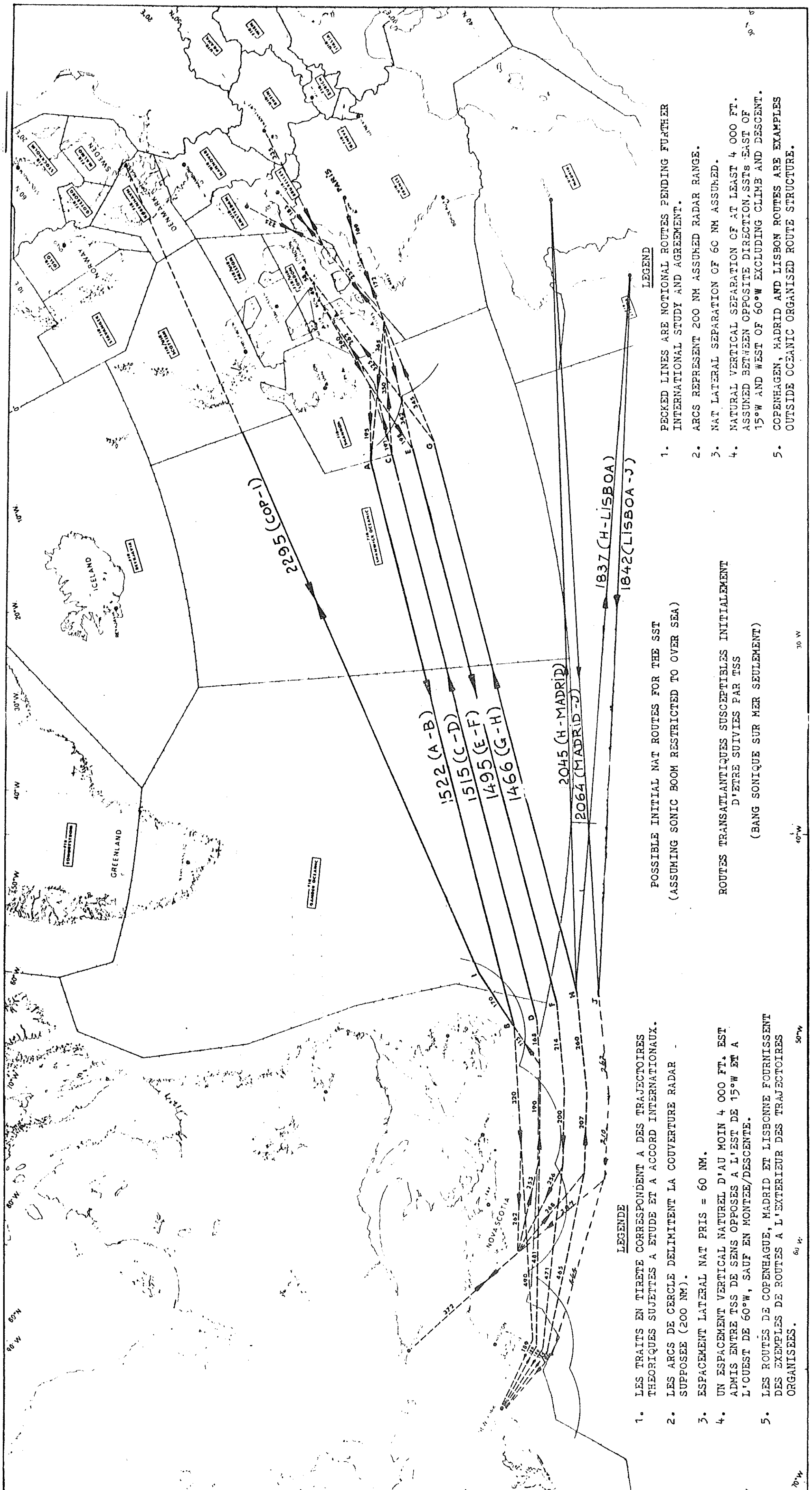

POSSIBLE INITIAL NAT ROUTES FOR THE SST
(ASSUMING SONIC BOOM RESTRICTED TO OVER SEA)
ROUTES TRANSATLANTIQUES SUSCEPTIBLES INITIALEMENT D'ETRE SUIVIES PAR TSS
(BANG SONIQUE SUR MER SEULEMENT)
LEGEND
1. PECKED LINES ARE NOTIONAL ROUTES PENDING FURTHER INTERNATIONAL STUDY AND AGREEMENT.
2. ARCS REPRESENT 200 NM ASSUMED RADAR RANGE.
3. NAT LATERAL SEPARATION OF 60 NM ASSUMED.
4. NATURAL VERTICAL SEPARATION OF AT LEAST 4 000 FT. ASSUMED BETWEEN OPPOSITE DIRECTION SSTs EAST OF 15°W AND WEST OF 60°W EXCLUDING CLIMB AND DESCENT.
5. COPENHAGEN, MADRID AND LISBON ROUTES ARE EXAMPLES OUTSIDE OCEANIC ORGANISED ROUTE STRUCTURE.
LEGENDE
1. LES TRAITS EN TIRETE CORRESPONDENT A DES TRAJECTOIRES THEORIQUES SUJETTES A ETUDE ET A ACCORD INTERNATIONAUX.
2. LES ARCS DE CERCLE DELIMITENT LA COUVERTURE RADAR SUPPOSEE (200 NM).
3. ESPACEMENT LATERAL NAT PRIS = 60 NM.
4. UN ESPACEMENT VERTICAL NATUREL D'AU MOIN 4 000 FT. EST ADMIS ENTRE TSS DE SENS OPPOSES A L'EST DE 15°W ET A L'OUEST DE 60°W, SAUF EN MONTEE/DESCENTE.
5. LES ROUTES DE COPENHAGUE, MADRID ET LISBONNE FOURNISSENT DES EXEMPLES DE ROUTES A L'EXTERIEUR DES TRAJECTOIRES ORGANISEES.
2295 (COP-1)
1522 (A-B)
1515 (C-D)
1495 (E-F)
1466 (G-H)
2045 (H-MADRID)
2064 (MADRID-J)
1837 (H-LISBOA)
1842 (LISBOA-J)
ICELAND
GREENLAND
NOVA SCOTIA
NORWAY
SWEDEN
DENMARK
PARIS

Fig. 2-C-2

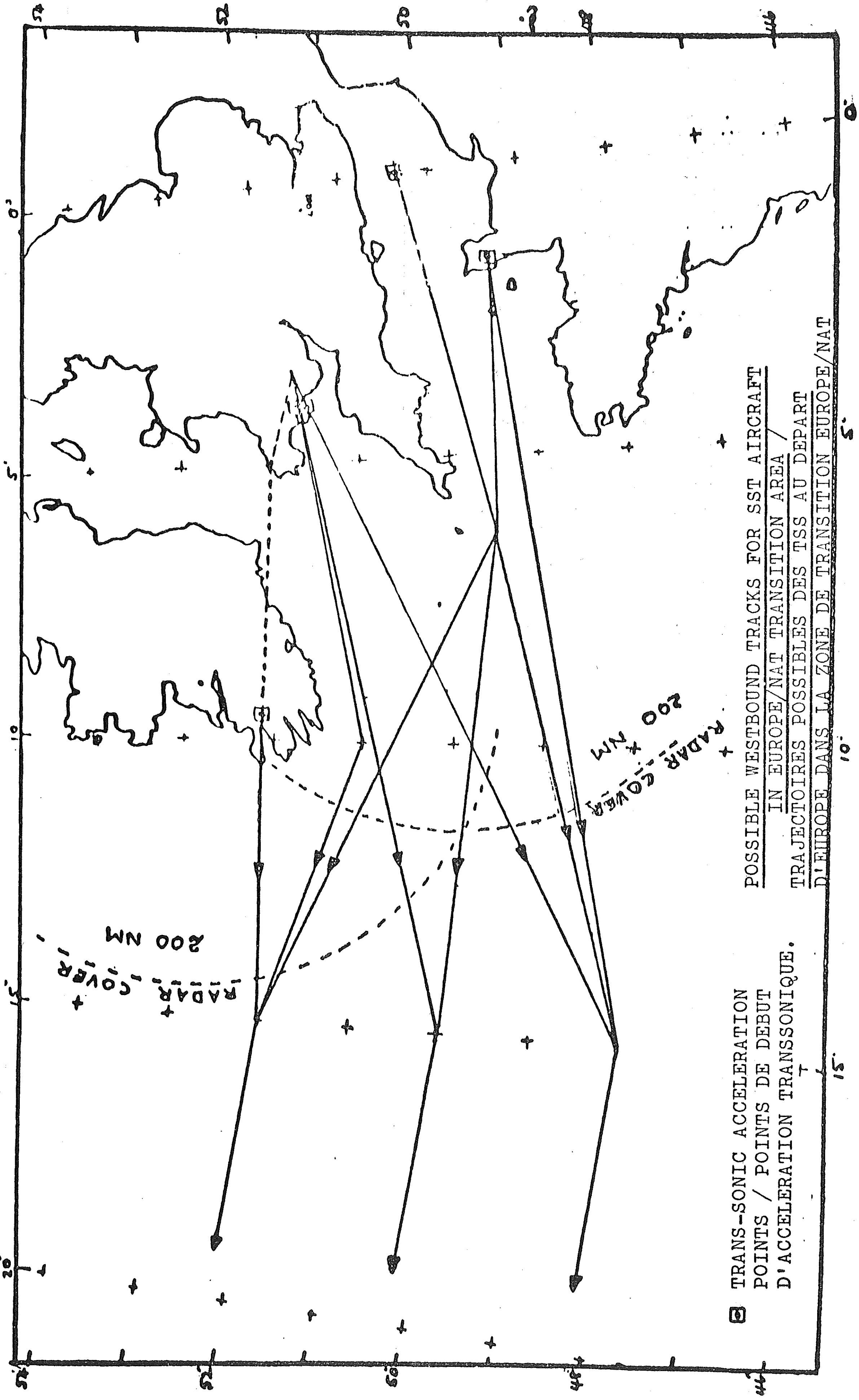

POSSIBLE WESTBOUND TRACKS FOR SST AIRCRAFT
IN EUROPE/NAT TRANSITION AREA /
TRAJECTOIRES POSSIBLES DES TSS AU DEPART
D'EUROPE DANS LA ZONE DE TRANSITION EUROPE/NAT
TRANS-SONIC ACCELERATION
POINTS / POINTS DE DEBUT
D'ACCELERATION TRANSSONIQUE.
RADAR COVER
200 NM
RADAR COVER
200 NM

Fig. 2-C-3
and
Fig. 2-C-4

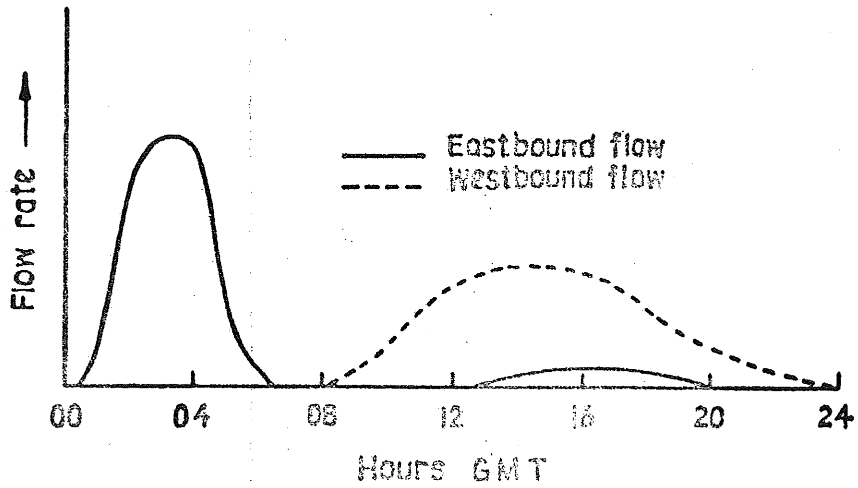


Fig. 2-C-3 Diurnal cycle of flow of subsonic traffic into North Atlantic region

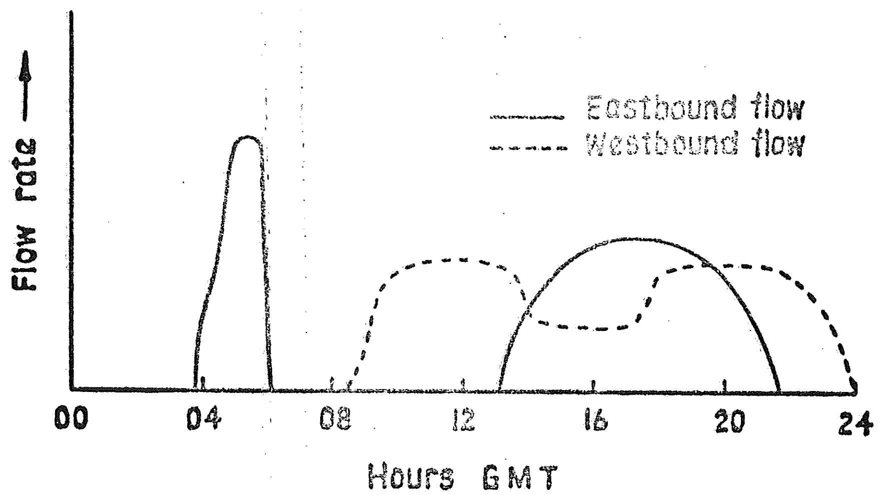
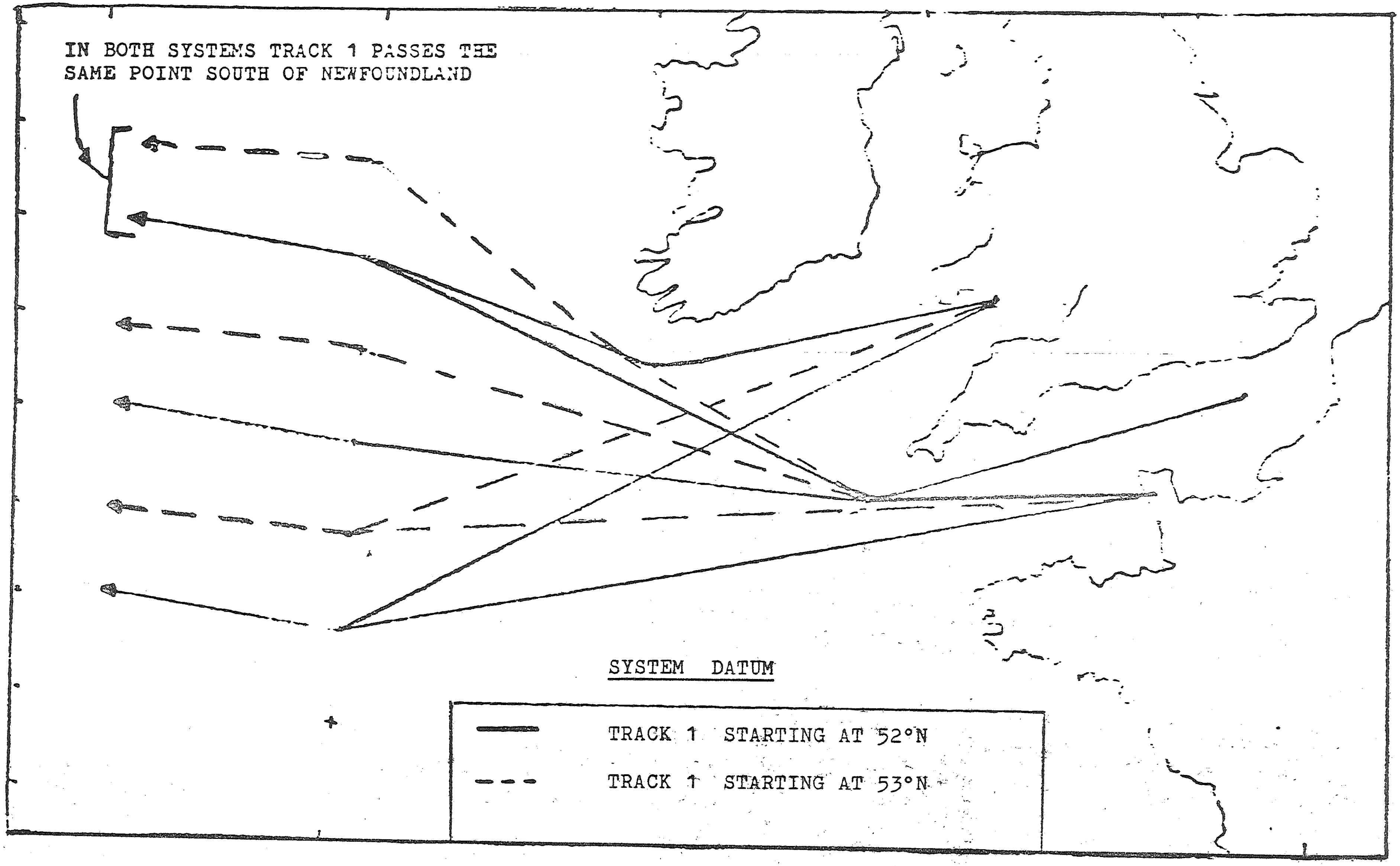


Fig. 2-C-4 Diurnal cycle of flow of supersonic traffic into North Atlantic region

Fig. 2-C-5

ALTERNATIVE TRACK SYSTEMS

(NOTE: SOME OF THE TRANSITION TRACKS ARE OMITTED FOR CLARITY)



REFERENCES

No.	Author	Title
1	V.W. Attwooll	Studies of the Design of a Trans-Atlantic Route Structure for Supersonic Transports, RAE Technical Report No. 68183, July 1968.

Summary of Agenda Item 3 : Review of progress of studies towards the application of composite separation.

3.1 General

3.1.1 When considering this item, the Group agreed that this should be done once more under the two following aspects :

i) the operational considerations;

ii) the considerations of collision risk.

3.1.2 As a consequence, the summary on this item is presented under these two main headings, followed by the conclusions which the Group drew at the end of its discussions.

3.2 Operational considerations

3.2.1 Under this item the Group reviewed the following aspects of composite separation, after having taken account of the collision risk considerations contained in para 3.3 below :

i) the type of composite separation to be applied and the area of application;

ii) preparatory measures and operating procedures required for its application;

iii) the possible manner of application;

iv) the possible time-scale for application.

3.2.2 After considerable discussion which, inter alia, included the consideration of a proposal for the application of 90 NM lateral separation combined with 1 000 ft. vertical separation, the Group came to the conclusion that, with respect to i) above :

i) the values used for composite separation in the NAT Region should be 60 NM lateral separation combined with 1 000 ft. vertical separation;

ii) the area of application of this type of separation should be limited to the organized track structure established within the principal area of the NAT Region;

iii) its application should be permissible between aircraft operating in the same or opposite directions.

3.2.3 These conclusions were reached for the following reasons :

i) no other combination of two forms of separation in order to obtain composite separation appeared to be feasible at this time;

ii) only the values now chosen were likely to increase the capacity of the ATS system to a degree which compensated for the increased complexity in the operation of the ATC system (see also para. 3.3.7 on the question of "safety" of these values);

iii) the exclusive application of composite separation to aircraft operating in the same direction creates so many difficulties, especially in and near the transition area between the continental and the oceanic area, that its application was not practicable.

3.2.4 With respect to the preparatory measures and operating procedures required for the application of composite separation the Group found that the following conditions would have to be met :

i) radar cover in the entry/exit area where composite separation was applied;

<u>Note</u>: It was also noted that procedural provisions would have to be made to cover the potential case of radar failure.

ii) the navigational environment in the entry/exit areas should be such that aircraft could navigate accurately along the routes assigned to them. This may be achieved either by the provision of adequate radio navigation aids or by the provision of suitable navigation equipment on board the aircraft or a suitable combination thereof;

iii) the entry/exit procedures in the transition area to and from the oceanic airspace should be such that a smooth transition between the fixed ATS route network and the organized track structure, based on the use of composite separation, is possible.

3.2.5 In addition the Group agreed that it would be necessary to develop operating procedures which should cover the following conditions :

i) procedures to effect changes of cruising levels of aircraft operating in the organized track structure based on the application of composite separation;

ii) procedures to be applied to aircraft changing track within or crossing the organized track structure when composite separation is applied;

iii) procedures to apply to aircraft joining or leaving the organized track structure when composite separation is applied;

iv) urgency procedures (particularly in case of forced return) to be used by pilots when operating in the organized track structure where composite separation is applied.

3.2.6 As regards the possible manner of application of this type of separation (see para. 3.2.1 iii)) the Group felt that, even though this type of separation meets the agreed safety requirements, it constituted such a change from existing procedures, both to pilots and controllers, that it would be advisable to apply this new type of separation on a progressive basis. Initial limited application is expected to permit earlier implementation since facilities and services required for the full implementation will, in some cases, not be available before a number of years. At the same time the limited application will permit controllers and pilots to familiarize themselves progressively with the required procedures, thus avoiding an abrupt overall change to existing procedures.

3.2.7 In the light of these considerations the Group felt that it would be best to leave the arrangements for the start of application, as well as its initial mode of application and possible expansion, to the provider States concerned on the understanding that :

i) full coordination would be effected between them prior to any step taken in this field, and

ii) necessary aeronautical information publications informing operators of the intended measures would be published well ahead of any date of application.

3.2.8 With regard to the time scale for application of composite separation in the NAT Region, the Group fully realised that firstly, the amendment made to Annex 11 by the 6. Air Navigation Conference would have at least to be processed to the point where its adoption would no longer be doubtful and that, secondly, the NAT V RAN Meeting would have to come to the regional agreement specified for the application of this type of separation. It was, however, hoped that with appropriate action on the part of the NAT V RAN Meeting formal action on this matter could be accelerated to the point where this type of separation could, in its initial form, be applied during 1970. This obviously presupposes that provider States concerned have, by that time, reached agreement on the degree of application and have completed both their preparatory and operational measures.

3.2.9 Finally, the Group noted that since the level of safety of this type of separation was directly related to the degree with which it was applied to aircraft operating in opposite directions, it would be necessary for the provider States concerned to keep the developments regarding over-laps in time between the flows of traffic operating in opposite directions and their general navigation capability under close review.

3.3 Considerations of collision risk

3.3.1 Introduction

3.3.1.1 The main part of the discussion on this subject was on the composite track system with 60 NM and 1 000 feet separation. A vertical section, perpendicular to the flight direction of such a system is given diagrammatically in figure 3.1 on page 3 - 9. In such a system, four types of separations should be considered :

i) the lateral separation with aircraft flying at the same flight level on tracks 120 NM apart.

ii) the vertical separation with aircraft on the same track but at flight levels 2 000 feet apart.

iii) the diagonal separation with aircraft flying on tracks 60 NM apart and at levels 1 000 feet apart.

iv) longitudinal separation (15 minutes minimum) with aircraft flying on the same flight path (i.e. same track and level).

3.3.1.2 The Group discussed a number of aspects of such a system and reached agreement on some of the points left over during the previous Meeting.

3.3.1.3 Some of the points on which agreement was reached here are equally applicable to the "Conventional" (non-composite) systems discussed at earlier meetings. These points include the independence of occupancy and probability of longitudinal overlaps (para. 3.3.2) and the conclusion on the tail shape of vertical errors (para. 3.3.3).

3.3.2 Independence of occupancy and probability of longitudinal overlaps

3.3.2.1 At previous meetings the Group pointed out that, in all calculations, it had been assumed that aircraft were fed at random into proximate tracks or flight levels. It had been stressed (see for instance Appendix 2-B of Summary/5) that the collision risk could be many times higher than had been calculated, if there were a high probability that aircraft should be flying side-by-side or one above the other for longer periods than were commensurate with random introduction into the system. The Group had stated that no conclusions could be reached without a detailed study of this problem (para 2.5 of Summary/5 refers).

3.3.2.2 The UK presented to the Group a paper in which it was asserted that actual data on longitudinal overlaps of aircraft would be so rare, and that the precision of the measurement should be so high (within 15 feet) that it was impossible to obtain data directly. Any dependence of the longitudinal separations between vertically or laterally proximate aircraft should, however, show up in the distribution of time intervals between aircraft crossing meridians in the oceanic area. The UK therefore analysed the time differences between reported times of crossing 20° W and 40° W of pairs of aircraft on adjacent tracks and on adjacent flight levels, which were proximate (i.e. within 15 minutes) longitudinally. This was done on the data obtained on 25 days, chosen at random between July 18th 1967 and January First, 1968. The total number of pairs of aircraft which had reported time differences of 0, 1, 2, etc..., to 15 minutes during this period for vertically proximate pairs and for laterally proximate pairs are given in the following Table 3.1 :

Table 3.1

Incidence of longitudinal separations for proximate pairs of same-direction aircraft

Reported time separation in minutes	Number of proximate pairs of a/c															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Vertically proximate																
at 20° W	57	117	114	102	118	119	129	114	123	103	113	99	137	112	127	104
at 40° W	56	104	104	111	112	123	132	129	118	122	103	122	110	109	108	131
Laterally proximate																
at 20° W	43	91	100	93	82	89	101	105	100	101	96	110	104	111	104	103
at 40° W	46	106	112	102	107	81	74	84	82	96	89	100	105	107	94	80

3.3.2.3 A uniform distribution of relative position would give rise to a gap-distribution in which all values from -15 to +15 are equally probable when measured in some arbitrary way (e.g. ATA of higher aircraft minus ATA of lower). The way in which Table 3.1 was compiled combines the data so that for example gaps of +1 and -1 are added together and therefore their expected sum is twice that of zero-gaps. The situation is almost analogous to throwing two dice : the probability of their being the same is 6 chances out of 36; the probability of their differing by 1 is 10 chances out of 36, slightly less than double in this case because the dice have a finite number of faces.

3.3.2.4 Thus a proportion one-thirty first (1/31) of the proximate pairs should have a longitudinal separation of zero and indeed this is found to be the case, within the limits of random sampling error.

3.3.2.5 The distributions of longitudinal separation shown in Table 3.1 were tested using chi-squared tests to see if they were significantly different from a uniform distribution. The values of chi-squared obtained (14.0, 12.3, 8.7, 21.8) were not significant.

3.3.2.6 The Group agreed on the conclusion that this investigation had failed to show any evidence of non-uniformity in the distribution of longitudinal occupancy of aircraft occupying vertically or laterally adjacent tracks. It was concluded that this justifies the assumption of independence used in the calculations of collision risk for vertical and lateral separation, and for diagonal separation in a composite system.

3.3.3 Tail shape of vertical errors

Effect of dammage near static ports

3.3.3.1 In the composite system, vertical errors contribute to the risk of collision with up to two vertical neighbours (separated by 2 000 feet) and up to 4 diagonal neighbours (separated by 1000 feet and 60 NM). In previous meetings, conservative estimates on the possibility of gross vertical errors led to tentative acceptance of a "1200 foot level tail" - i.e. to the assumption that if a gross vertical error were made, it was equally likely to be of any magnitude up to 1200 feet. The present Meeting has concluded that this estimate is too pessimistic, and that a conservative estimate should be based on an 800 foot level tail.

3.3.3.2 The reasoning behind the original 1200 foot level tail was based on the possibility of damage to the area of the fuselage in the vicinity of the static ports, and the modification is based in part on a new UK study which in turn is based on data collected by IATA. Specifically, IATA reports on returns received from 18 airlines covering approximately 15 000 000 flying hours. There were reported 169 observations of damage to the fuselage, of which 102 were sufficiently significant to require repairs. Damage on the static plate was not considered since it is believed that this would be immediately detected and, if significant, repaired. The details available on the damage and on the routine for inspection and repair varied from airline to airline.

3.3.3.3 The data on magnitude of deflection of the fuselage were then subjected to theoretical aerodynamic analysis to determine the altitude error which each would produce. The methodology used was linearized small perturbation theory, ignoring boundary-layer effects. The UK study asserts that the error produced by the largest dent discovered by IATA would produce an altitude error not larger than 200 feet at Mach 0.9 and flight level 360.

3.3.4 Effect of navigational precision

3.3.4.1 The Group noted a certain "paradox" of collision probabilities which has already been highlighted by the studies considered at previous meetings of the Group : namely that increased navigational precision actually increases collision risk. For example, loss of lateral separation is more likely to lead to collision if vertical station keeping is precise than if it is sloppy. Similar arguments apply to other dimensions.

3.3.4.2 A clear distinction is necessary here between precision and accuracy. In the data collected during the 1967-68 exercise, the standard lateral error was of the order of 13 NM. More precise navigation equipment, as is anticipated from inertial systems, should lead to a reduction of such errors, and therefore to more accurate navigation. It is conceivable, however, that the number of gross errors or blunders may not decrease. Any increase in precision without reduction in gross errors must inevitably increase collision risk in a conventional system. In a composite system, it will increase the probability of collision with vertical or lateral neighbours (of whom there are fewer) but will not increase the probability of collision with diagonal neighbours. In an environment characterized by increasing navigational precision, the Group noted therefore that a composite system becomes more and more attractive.

3.3.5 Edge effects

3.3.5.1 The conventional track system and the composite track system with 60 NM and 1 000 feet separation are illustrated in Figures 3.1 and 3.2. Each Figure indicates 16 flight paths, arranged in 4 flight tracks.

Fig. 3.1

Conventional track system with the same number of flight paths as figure 3.2

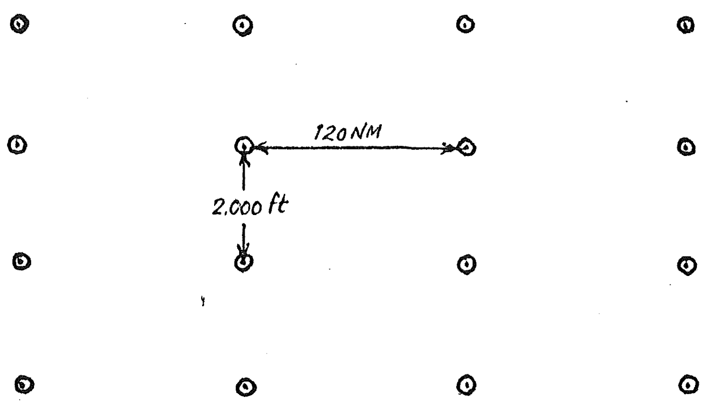
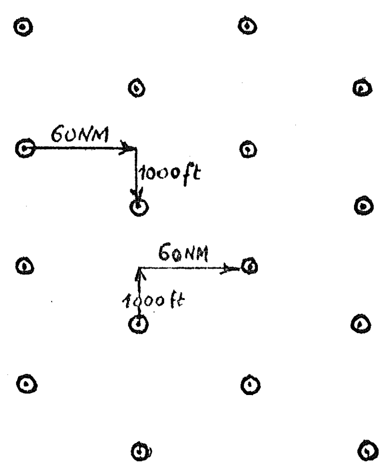


Fig. 3.2

Composite track system with 60 NM and 1 000 feet separation



3.3.5.2 In the conventional system each flight path has up to 2 vertical neighbours and 2 lateral neighbours. In practice, the average number of neighbouring flight paths is smaller because of "edge" effects : the highest flight path, for instance, has only one vertical neighbour. Counting pairs in figure 3.1 shows that each flight path has, on the average, 1½ vertical and 1½ lateral neighbours for this particular configuration. In the composite system of figure 3.2 each flight path has up to 2 lateral, 2 vertical and 4 diagonal neighbours. However, for this number of flight paths, edge effects reduce this to an average of 1½ vertical, 1 lateral and 2 5/8 diagonal.

3.3.5.3 Should all flight paths have the same average longitudinal separation between aircraft, the occupancies and therefore the collision risks of the system would be reduced in the same ratio as the average numbers of neighbours. If the flight paths are loaded to a different degree, or if there should be more flight paths in the system, these ratios would change. Nevertheless the lateral occupancy in a composite system will be less than in a conventional system with the same number of flight paths.

3.3.5.4 Since lateral collision risk seems to be greater than diagonal risk, the composite system may actually be as safe as, or even safer than, a conventional system with the same number of flight paths, in spite of the near doubling of the density. However, the edge effects become less significant as traffic increases, and with many tracks the composite system must be less safe than a conventional one, although the difference may not be great.

3.3.6 Flight path changes

During its 5. Meeting the Group found that there was some confusion about the interpretation of the conclusions on the added risk due to changes of flight level and changes of track in a composite system. This problem was, therefore, again discussed during this Meeting.

3.3.6.1 Changes of flight level

3.3.6.1.1 The extra collision risk for a composite track system with 60 NM and 1000 feet separation has been calculated for the case where there was an average of one climb (or descent) over 2000 feet per ocean crossing (para. 2.2 of Appendix 3-A of the Summary of Discussions of the 5. Meeting refers). According to table 3.1 of Summary/5, the calculated collision risk of diagonal separation would be increased in this case from 0.037 to 0.055 accidents per 10 million flying hours (assuming non-segregated opposite-direction traffic and altimetry-error tails to 800 feet).

3.3.6.1.2 The Group agreed that the average number of changes of flight level of 2000 feet in the present system was far below one per flight. It was deemed unlikely that the number of flight level changes would increase beyond an average of one per flight in the future, unless some drastic changes were made in the methods of air traffic control in the Oceanic Area. Should this occur, then it would have to be considered. It was therefore concluded that for the present there seemed to be no reason why changes of flight levels should be restricted in a possible composite track system with 60NM and 1000 feet separation.

3.3.6.2 Changes of track

3.3.6.2.1 In para. 2.3 of Appendix 3-A of the Summary of Discussions of the 5. Meeting the extra collision risk for a composite track system with 60 NM and 1000 feet separation has been calculated for the case that there was an average of one change of track of 120 NM per ocean crossing. It was found that this would increase the calculated collision risk of diagonal separation by a factor of 13.

3.3.6.2.2 It was concluded that this increased the risk appreciably, even though the average number of such track changes would be well below one. The Group therefore agreed that changes of track over 120 NM would only be acceptable, if the two adjacent flight levels of the track at 60 NM were unoccupied. It noted that this will make the composite system somewhat more inflexible for allowing aircraft to cross the track system.

3.3.6.3 Diagonal changes of flight path

3.3.6.3.1 The added collision risk due to a change over 60 NM and 1000 feet depends on the manner in which the change is made. If this change is made "diagonally" - that is, such that it would appear on Fig. 3.1 as a straight line between the two paths, the resulting increase in collision risk is small; however, it is not believed that such changes are operationally feasible.

3.3.6.3.2 On the other hand, if the aircraft first changes its track 60 NM laterally and then its flight level 1000 feet vertically or vice-versa, the resulting increase in collision risk is of the same order as that of para 3.3.6.2.

3.3.6.3.3 It may be that some other method of effecting this change of the flight path such as 30 NM followed by 1000 feet and then additional 30 NM, might be safer and operationally feasible; but no study of such changes has been made.

3.3.6.3.4 The Group therefore agreed that diagonal changes of flight path would not be acceptable if the adjacent tracks are occupied until further studies of their implication are completed.

3.3.7 Estimate of total collision risk

3.3.7.1 During its second meeting the Group decided to divide the target level of risk due to collisions equally between vertical, lateral and longitudinal separation. That was done mainly because the initial work was done on lateral separation only and no estimates were available for the vertical and longitudinal separations. The discussions on composite separation complicated the picture because a fourth separation (diagonal separation) had to be considered in combination with the other three.

3.3.7.2 The Group felt that its work is now advanced sufficiently to enable it to assign estimates for the risk due to each of the separations. It therefore agreed that when evaluating composite separation standards there was no reason for retaining the division of risk into three equal parts.

3.3.7.3 A list was drawn up of the "best estimate" and "cautious estimate" values of the number of accidents per 10 million flying hours which would contribute to the risk in a composite track system with 60 NM and 1000 feet separation ;

Table 3.2

	"Best Estimate"	"Cautious Estimate"
Lateral separation (120 NM)	0.11	0.18
Vertical separation (2000 ft)	0.02	0.05
Diagonal separation (60 NM + 1000 ft)	0.03	0.04
Longitudinal separation (15 min.)	0.05	0.15
Flight level changes	0.01	0.02
	0.22	0.44

3.3.7.4 Both the above figures of collision risk should be compared with the target level of safety agreed during the third meeting of the Group i.e.: the target level should be within the range of 0.45 to 1.2 accidents per 10 million flying hours. It should be stressed here that the figures in Table 3.2 must be used with care. In the first place those for the vertical separation of 2000 feet and for longitudinal separation of 15 minutes are estimates which are not based on any detailed analysis, but must be regarded as cautious opinions of the Group on the basis of their overall experience with this matter. The estimates for the risks due to lateral separation of 120 NM, to diagonal separation of 60 NM + 1000 ft, and to the changes of flight level are based on the mathematical analysis made by the Group.

3.3.7.5 More confidence can be placed in the relative values of Table 3.2 than in absolute values.

3.3.8 Conclusions on composite systems

3.3.8.1 The Group agreed that a composite system of separation using 60 NM and 1000 feet appears to meet the requirements of the target levels of safety (i.e. 0.45 to 1.20 fatal accidents per 10 million flying hours) even without segregation of opposite-direction traffic.

3.3.8.2 However, it was recognized that the above composite separation might not yield the same level of safety throughout future years; two reasons which might cause an increase in risk estimates given in Table 3.2 are :

i) the opposite-direction occupancy might increase due to the larger proportion of opposite-direction traffic which is expected in the future (see also section 3 of NAT SPG Summary/5);

ii) the same-direction occupancy might increase if the effective longitudinal separation which is at present about 35 minutes (see para. 4 of Appendix 2-B) should become nearer to the minimum standard value of 15 minutes.

3.3.8.3 It was therefore pointed out that a safer system could be obtained by segregating opposite-direction traffic from the main flow by leaving a separation of a minimum of 120 NM lateral separation plus 1000 feet vertical separation between tracks having opposite-direction traffic. It has been noted in earlier meetings that the danger of colliding with an occupant of a neighbouring flight path is much greater if that path was used also by opposite-direction traffic than if it was only used by same-direction traffic. In general, this has not been a major contributor to collision risk because the bulk of opposite-direction traffic has been segregated by the diurnal flow patterns, and by meteorological conditions. Nonetheless, the small amount of opposite-direction traffic which was mixed into the system (about 2 % during the 1967-68 data collection) contributed about 25 % of the lateral and vertical collision risk and would contribute a similar amount to the diagonal collision risk in a composite system. The possible increase in opposite-direction occupancy mentioned above would increase this effect (a sevenfold increase in opposite-direction proximity would approximately double the total collision risk estimate). States should monitor changes in the system such as those mentioned in para 3.3.8.2 above with regard to the possible need for remedial action.

3.3.8.4 Another method of obtaining a safer system would be to use a composite track system with 90 NM and 1000 feet separation, without segregation of opposite-direction traffic. Although the traffic density and therefore the capacity of such a system would be lower than that of the composite system with 60 NM and 1000 feet separation, it has the advantage that several of the risk compoments of Table 3.2, including that of lateral separation, would be markedly reduced.

3.4 Final Conclusion

3.4.1 After considering all relevant factors the Group agreed to propose to the NAT V RAN Meeting that it makes appropriate provisions to permit the application of a type of composite separation in the NAT Region consisting of 60 NM lateral separation combined with 1000 ft. vertical separation, and this under specified conditions. An appropriate proposal to this effect is attached in Appendix 3-A.

APPENDIX 3-A

SUPPORTING DOCUMENTATION FOR THE ICAO NAT V RAN MEETING RELATED TO THE APPLICATION OF COMPOSITE SEPARATION IN THE NAT REGION

(Agenda Item 10)

1. Introduction

1.1 After having convinced itself that the type of composite separation proposed meets the target levels of safety which the Group had developed, it was agreed that its application should be proposed to the NAT V RAN Meeting in accordance with the specifications listed below.

1.2 In addition, in order to facilitate discussion of this subject at the NAT V RAN Meeting, the Group agreed to make specific proposals for those procedures and preparatory measures required for its application, including amendments to the NAT RAC SUPPs, which appeared to be necessary.

1.3 Finally, the Group proposes a possible manner of application and an associated time-scale if the Meeting agrees to the use of this separation.

2. Type of composite separation to be applied and area of application

2.1 With respect to the type of composite separation, it was accepted that the form in which this separation was applied should be to combine the half value of the presently applied lateral separation (60 NM) with the half value of the vertical separation applied to aircraft operating above FL 290 (1 000 ft.).

2.2 As regards the area of application, it was found that it should be limited to the organized track structure established in the principal area of the NAT Region. In addition, in this organized track structure, it should be limited to turbo-jet aircraft operating in the airspace at and above FL 290 in the area in question and that it should be applicable between aircraft operating in the same or opposite directions.

3. Procedures required

3.1 In order to ensure uniform application of this type of separation, the Group agreed that it would be necessary to establish the following operating procedures which should be included in the NAT RAC SUPPs :

i) procedures to effect changes of cruising levels of aircraft operating in the organized track structure when composite separation is applied;

ii) procedures to be applied to aircraft changing track within, or crossing, the organized track structure when composite separation is applied;

iii) procedures to apply to aircraft joining or leaving the organized track structure when composite separation is applied;

iv) urgency procedures (particularly in case of forced return) to be used by pilots operating in the organized track structure when composite separation is applied.

4. Preparatory measures required

4.1 As regards the preparatory measures required by the provider States concerned by the application of composite separation in the NAT Region, the Group agreed that these should at least cover the following :

i) the provision of radar cover in the entry/exit area where composite separation is applied;

Note: It should also be noted that procedural provisions will have to be made to cover the potential case of radar failure.

ii) the navigational environment in the entry/exit areas shall be such that aircraft can navigate accurately along the routes assigned to them. This may be achieved either by the provision of adequate radio navigation aids or by the provision of suitable navigation equipment on board the aircraft or a suitable combination thereof;

iii) the entry/exit procedures in the transition area to and from the oceanic airspace shall be such that a smooth transition between the fixed ATS route network and the organized track structure, based on the use of composite separation, is possible.

5. Possible manner of application and time-scale

5.1 As regards the possible manner of application of this type of separation the Group felt that, it constituted such a change from existing procedures, both to pilots and controllers, that it would be advisable to apply this new type of separation on a progressive basis. Initial limited application will permit better utilization of the airspace since it is expected to permit earlier implementation, because facilities and services required for the full implementation will, in some cases, not be available before a number of years. At the same time the limited application will permit controllers and pilots to familiarize themselves progressively with the required procedures, thus avoiding an abrupt overall change to existing procedures.

5.2 In the light of these considerations the Group felt that it would be best to leave the arrangements for the start of application, as well as its initial mode of application and possible expansion, to the provider States concerned on the understanding that :

i) full coordination would be effected between them prior to any step taken in this field, and

ii) necessary aeronautical information publications informing operators of the intended measures would be published well ahead of any date of application.

5.3 With regard to the time-scale for application of composite separation in the NAT Region, the Group fully realized that, firstly, the amendment made to Annex 11 by the 6. Air Navigation Conference would have at least to be processed to the point where its adoption would no longer be doubtful and that, secondly, the NAT V RAN Meeting would have to come to the regional agreement specified for the application of this type of separation. It was, however, believed that with appropriate action on the part of the NAT V RAN Meeting formal action on this matter could be accelerated to the point where this type of separation could, in its initial form, be applied during 1970. This obviously presupposes that provider States concerned have, by that time, reached agreement on the degree of application and have completed both their preparatory and operational measures.

6. Other considerations

6.1 The Group noted that the level of safety of this type of separation was directly related to the degree with which it was applied to aircraft operating in opposite directions. It was therefore necessary for the provider States concerned to keep the developments regarding over-laps in time between the flows of traffic operating in opposite directions and their general navigation capability under close review.

6.2 The Group noted that the question of crossing traffic required continued attention as it was not likely that the use of composite separation in itself will facilitate a solution of this problem.

7. Proposals for amendment of the Regional Supplementary Procedures applicable in the NAT Region

7.1 As a consequence of the above, the Group proposes to the NAT V RAN Meeting that the following amendments be made to Part II, "Rules of the Air, Air Traffic Services and Search and Rescue" of the Regional Supplementary Procedures applicable in the NAT Region :

i) under the heading "Separation" insert a new paragraph as follows :

"X. Composite separation

X.1 For turbo-jet aircraft operating at or above FL 290 and within the organized track system when established within the Gander Oceanic, New York Oceanic, Reykjavik, Shanwick and Søndrestrøm (south of 70°N) control areas, composite separation, consisting of the combination of 60 NM lateral with 1 000 feet vertical separation, may be applied.

Note: When such separation is used, aircraft on tracks separated by at least 60 NM but less than 120 NM will be assigned cruising levels which are different by at least 1 000 feet.

X.2 This type of separation may be applied between aircraft operating in the same or opposite directions."

ii) under the heading "Establishment and use of organized tracks" insert the following new paragraphs :

"Y.1 When composite separation is used in the organized track system, the following procedures shall apply :

Y.1.1 Aircraft may be cleared to join the outer track of the organized track system at points other than the normal entry points in the OCA provided required minimum longitudinal or vertical separation will exist between such aircraft and others operating along this track. The clearance shall, however, provide that joining shall be effected via a track extending between the point of joining and a point which, at 10 degrees of longitude from the joining point is laterally not less than 60 NM or more than 120 NM distant from the track in question.

Y.1.2 Aircraft flying along the outer track of the organized track system may be cleared to leave the system provided that the separation from all other aircraft in the system continuously increases until another form of separation is established.

Y.1.3 Aircraft changing tracks within the organized track system or which are crossing the organized track system shall be cleared to do so only if they are provided with minimum longitudinal, lateral or vertical separation with respect to all other aircraft of concern to them.

Y.1.4 Aircraft operating in the organized track system may be cleared to change levels on the same track provided minimum longitudinal separation will exist at the new level between the aircraft concerned and other aircraft on the same track and level.

Y.1.5 If an aircraft is unable to continue flight to its destination, it should :

i) initiate a turn, if possible to the right, and descend until it regains its assigned track in the opposite direction at a level which is 1 000 feet lower than the one which was assigned to it in its ATC clearance, or

ii) initiate a turn, if possible to the right, so as to regain the next adjacent track in the opposite direction maintaining its assigned level.

Whenever possible, these manoeuvres should be conducted in VMC. In addition, the pilot should broadcast his intentions on frequency 121.5 Mc/s. (NAT COM SUPPs refer.)

Y.1.6 If an aircraft is required to make a rapid descent it should, whenever possible, alter its course, if possible to the right, and descend within a distance not exceeding 30 NM but parallel to its assigned track. If level flight can be resumed by the aircraft concerned it should return to its previously assigned track and maintain a level which is not normally assigned on this track. In addition, the pilot should broadcast his intentions on frequency 121.5 Mc/s. (NAT COM SUPPs refer.)

Y.1.7 As it is not possible to provide for all possible circumstances, the procedures in paras. Y.1.5 and Y.1.6 cannot provide more than guidance. However, ATC shall be advised of the action taken at the earliest possible time and a revised ATC clearance restoring minimum separation shall be obtained by the pilot concerned as soon as this is practicable."

Summary of Agenda Item 4: Review of work so far accomplished by the Group and possible resultant action.

4.1 General

4.1.1 At its 5. Meeting, the Group agreed that a review of the work so far accomplished by it should be undertaken in order to serve as a basis for a submission, on behalf of the Group, to the forthcoming NAT V RAN Meeting.

4.1.2 In the meantime, ICAO Headquarters requested the Paris Office to prepare a similar paper for the information of all NAT States prior to the NAT V RAN Meeting, which should, however, not only cover the work done by the Group but should also provide information on its working methods and present a review of that part of the documentation produced by the Group which is still valid. This latter aspect is believed to be of particular interest to those who do not regularly participate in the work of the Group and may therefore have difficulty in following its progress.

4.1.3 In order to avoid duplication of effort it was therefore agreed that the two tasks should be combined so that States interested in NAT matters will receive only one consolidated document covering both aspects. This has now been prepared and is presented in Appendix 4-A.

APPENDIX 4-A

SUPPORTING DOCUMENTATION FOR THE ICAO NAT V RAN MEETING RELATED TO THE ACTIVITIES OF THE NAT/SPG

(Agenda Item 3)

1. Activities of the Group since 1965

1.1 It will be recalled that the Special North Atlantic Meeting 1965, which was held in February - March 1965 in Montreal, established the North Atlantic Systems Planning Group and developed its terms of reference (DOC 8499, SP/NAT (1965), Agenda Item 4 and especially Recommendation 4/1 refer).

1.2 Since then the Group has held six meetings, the first of which was essentially devoted to the establishment of a work programme, the working methods of the Group and necessary "housekeeping" matters while the remaining five meetings were each devoted to two or more specific subjects. These meetings were the following :

i) 1. Meeting, held from 19 to 21 October 1965 in Paris with the participation of members only.

ii) 2. Meeting, held from 21 November to 5 December 1966 in Paris with the participation of members and, on invitation, Portugal, IANC, IATA and IFALPA. The major subjects treated by this meeting were :

a) Development of a method for assessing a safe separation standard;

b) Interim measures to improve navigational performance;

c) Development of a programme of data collection and analysis.

iii) 3. Meeting, held from 17 to 28 April 1967 in Paris with the participation of members and, on invitation, IANC, IATA and IFALPA. The major points considered by this meeting were :

a) A progress report of the data collection and analysis programme;

b) Vertical separation between aircraft operating above FL 290 in the NAT Region;

c) Review of the NAT Air Reporting Procedures;

d) Exchange of views on criteria for the assessment of system performance.

iv) 4. Meeting, held from 16 to 28 June 1968 in Paris with the participation of members and, on invitation, Iceland, IANC, IATA and IFALPA. The major points of the agenda were :

a) Review of the results of the data collection programme;

b) Development of a method for the determining of longitudinal separation standards in the NAT Region;

c) Exchange of views on a possible work programme regarding SST operations in the NAT Region.

v) 5. Meeting, held from 4 to 18 December 1968 in Montreal with the participation of members and, on invitation, IANC, IATA and IFALPA. The major items of this meeting were :

a) Determination of preparatory ATS measures required for the start of SST operations in the NAT Region;

b) Review of developments regarding the application of reduced vertical separation above FL 290;

c) Review of the possibility of applying composite separation in the NAT Region;

d) Review of progress made in the assessment of longitudinal separation in certain parts of the NAT Region, including the possible use of DME for this purpose;

e) Review of the criteria for the assessment of system performance.

vi) 6. Meeting, held from 4 to 16 September 1969 in Paris with the participation of members and, on invitation, IANC, IATA and IFALPA. The major items of this meeting were :

   a) Discussion with the NAT Traffic Forecasting Group of matters of common interest;

   b) Establishment of methods for the assessment of system performance;

   c) Review of progress of studies regarding the application of composite separation.

2. Working methods of the Group

2.1 Because of the special status of the Group, accorded to it by the Special NAT Meeting 1965, it arranges its own work programme and decides on its meetings and their agenda by consultation between all members.

2.2 In addition, the Group, between meetings, maintains contact through correspondence which, as a rule, is circulated to all members. The Chairman of the Group is elected at the end of each meeting for a mandate which covers the period until the end of the following meeting. At present, the member from France, Mr. J.F. Sapin, is serving in this capacity.

2.3 For each meeting individual members prepare supporting documentation which is normally only available to the meeting in question. This serves as a basis for the preparation of the summary containing the results of each meeting. Thus the summaries constitute the consolidated view of the Group on the various subjects covered at the meetings. However, in some cases bibliographies have been added to the summaries of specific agenda items within these summaries since they were believed to be of interest to those wishing to obtain more detailed information on the subject in question. It is understood that the documentation mentioned can, if desired, be directly obtained from the national administration or organization of the author quoted, provided they are still applicable and available.

2.4 The summaries are subsequently distributed to all NAT States for information and comment. Comments received from States on these summaries are forwarded, through the Paris Regional Office, to the Group and, where necessary, replies to them are prepared at the following meeting of the Group and passed to the Paris Office for onward transmission to the State concerned.

3. Work accomplished by the Group

3.1 The following represents a brief summary of the major subjects dealt with by the Group during its existence from 1965 to the end of 1969. As, for obvious reasons, it is not possible to give a detailed description of the various subjects it is believed useful if, in respect of each item, reference is made to those parts in the six summaries where these matters have been dealt with in detail. In addition, wherever possible, a description of the action which is still required on the subject is given.

3.2 Criteria for assessment of system performance

(References: Item 4 in Summary /3 - Part I,
paragraph 7.2.3 in Summary /4,
Item 5 in Summary /5,
Item 2 in Summary /6.)

3.2.1 Based on the work done on this subject during the Special NAT Meeting 1965 (DOC 8499, SP/NAT (1965), Agenda Item 3, pages 3b-1 to 3b-6 refer) the Group considered this subject during three of its meetings. At its 3. Meeting, where an exchange of views on this subject was held, it became apparent that, in order to arrive at a meaningful assessment of the system as a whole, the assessment could not be limited to the NAT Oceanic Area only. In fact it was believed that assessment of the system as a whole must inevitably include consideration of problems encountered in the transition areas between oceanic and continental and, in some cases, those encountered between major terminal areas and the transition areas. (See paragraph 4.1.3 of Summary /3 - Part I.)

3.2.2 At its 5. Meeting the Group reviewed a paper presented by the UK member, which described the method used and the results obtained from an analysis of data obtained during the NAT Data Collection Programme of 1967-68 regarding deviation penalties imposed on individual flights in the NAT Region by air traffic control during the period of the Programme. The Group believed that the method used by the United Kingdom in arriving at an assessment of system performance had considerable merit since it provided a practical tool in providing meaningful values in terms of cost in order to demonstrate the degree of efficiency of a system. It felt, nevertheless, that further study was required, especially in view of the fact that the UK member advised that they were continuing their studies.

3.2.3 At its 6. Meeting the Group examined further detailed material presented by the UK which proposed methods of examining the costs of operation of the total air traffic in the NAT environment to establish a concept of cost/benefit related to specific values of separation, taking into account system occupancy. These methods offered both the possibility of determining the overall efficiency of a particular system and providing a method of appreciating the effects of changes which might be adopted.

3.2.4 The Group accepted the value of the suggested method and was able to confirm its usefulness in the context of the discussions of the 5. Meeting. It further recommended an extension of the studies to include reference to the costs of risks inherent in the various values of separation which would enhance the validity of the calculations. (See Appendix 2-A.)

3.2.5 At its 6. Meeting the Group also reviewed a UK proposal which discussed the need for specifications of navigation accuracy and reliability as aspects of system performance. Further development of this concept as related to separation standards was deemed valuable and meaningful to future system studies.

3.2.6 From the above it is apparent that cost penalties implicit in the value of separation used can be determined, thus assisting the cost/benefit assessment of any changes in the system that may be proposed in the future.

3.3 <u>Cooperation with the NAT Traffic Forecasting Group</u>

(References: DOC 8499, SP/NAT (1965), Agenda Item 2a), paragraph 5 on page 3 in Summary /5, Item 1 in Summary /6.)

3.3.1 At the Special NAT Meeting 1965, Canada, the United Kingdom and the United States of America were requested to continue the task of NAT traffic forecasting, in cooperation with the ICAO Secretariat, since it was believed that this constituted a valuable element for systems planning in the NAT Region.

3.3.2 Following this Meeting it was, however, noted that, due to a number of circumstances, the up-dated 10-year traffic forecasts prepared at yearly intervals by the NAT Traffic Forecasting Group were not given the desired distribution with the result that the work of the Group could not be sufficiently taken into account when planning. Because of this situation and also because it had become apparent that some of the parameters upon which the traffic forecasts were based needed review, the NAT/SPG and the NAT Traffic Forecasting Group agreed to hold a joint session during the 5. Meeting of the NAT/SPG. At this meeting the NAT Traffic Forecasting Group outlined a number of possible modifications with forecasts and sought the views of the NAT/SPG on these. In addition, the NAT/SPG requested its Chairman at this time to contact ICAO in order to reach agreement on a better method for the distribution of the traffic forecasts to all concerned. As a result of this intervention the traffic forecasts covering the period 1969-78 have now been distributed, through the Paris Office, to all interested parties and this method of distribution will be applied in future.

3.3.3 In view of the satisfactory results obtained for both Groups during the joint session at the 5. Meeting of the NAT/SPG, a joint session was also arranged during the 6. Meeting which led to the following main results :

i) it was agreed that the "busy day" and the "busy hour" figures should be redefined so as to represent a forecast to the seventh busiest day and the seventh busiest hour in the year as this was believed to be a more meaningful index for planning purposes (paras. 1.2.4 and 1.2.5 of Summary /6 refer);

ii) it was agreed that certain distribution "shape" should be included in future reports of the NAT Forecasting Group (para. 1.2.6 of Summary /6 refers);

iii) it was agreed to eliminate forecasts for non-jet air traffic because of their future insignificance (para. 1.3.1 of Summary /6 refers);

iv) it was agreed that future forecasts for the Principal Area should cover all traffic placing a demand on the air traffic control services in the Area, whether for the whole or only part of the flight (para. 1.3.2 of Summary /6 refers).

3.4 Basic principles for assessing risks associated with any form of separation in the NAT Region

(Reference: Item 4 in Summary /2.)

3.4.1 In the course of its early discussions the Group agreed that there was a need to establish values for a number of parameters which would be relevant to an examination of collision risk in the particular NAT Separation environment. Since these values would be specific to the traffic density, types of aircraft operated and navigational capability in this environment they would be unique to the Principal Area of the North Atlantic and would not have direct application elsewhere.

3.4.2 In view of the nature and number of the parameters involved in the process of formulating the basic principles used in the assessment of risk it became evident that the determination of specific values would not be possible and that the conclusions of the Group would therefore have to be made in terms of range. Agreement was reached on this approach and on the treatment of the data which could be used to this end.

3.4.3 The Group recognized that conditions in the environment were fluid and that it should endeavour in its calculations to take into account the longer term effect of changes in both traffic density and navigational capability which might predictably alter the current situation. In this context it will be noted that at the 6. Air Navigation Conference the member States of ICAO recorded an urgent need for re-examination of the whole concept of separation. The work of the NAT/SPG should be of considerable value in such wider application.

3.4.4 A mathematical model of collision risk was presented to the 2. Meeting by the UK Member, and with subsequent modifications has been accepted by the Group. Data for this model have been obtained principally from the 1967-68 data collection exercise, modified by the changes in traffic forecast by the NAT Traffic Forecasting Group. Most of the conclusions presented below have been derived in this way. The Group believes that this model has been a very useful tool, first because it has permitted increased qualitative understanding of collision risk, and second because it has allowed prediction of certain numbers. Of these latter, the Group believes that considerable confidence may be placed in some (such as the relative safety of composite and conventional separation in itself and when applied to opposite-direction and same-direction traffic flows, and of 90 NM and 120 NM lateral separation). Rather less confidence may be placed in other numbers (such as the absolute value of lateral collision risk); and still less in others (such as the absolute value of vertical and longitudinal collision risk).

3.5 Lateral separation

(References: Item 3 in Summary /2, Item 1 in Summary /3 - Part I, Item 1 in Summary /4.)

3.5.1 Because of the dispute which arose subsequent to the Special NAT Meeting 1965 regarding the application of 90 NM lateral separation within the NAT Region, the Group organized a data collection exercise on the navigational capabilities of aircraft in the NAT Region which was conducted from July 1967 until March 1968 and which yielded valuable data, not only on the navigational capabilities but also on a number of related aspects of flight operations in the NAT Region. This data was processed in the United Kingdom and an analysis of the results obtained against the previously agreed formulation of principles suggested that while the currently applied separation of 120 NM was well above the target level of safety agreed by the Group, a separation of 90 NM would have been below it.

3.5.2 It proved possible for the Group to isolate a number of the factors which had led to these conclusions and to suggest measures which should be taken as pre-requisites toward the achievement of standards of navigation performance which might permit a reduction in lateral separation at a later date.

3.5.3 The Group will continue to maintain a close watch on navigational performance in the NAT environment with particular emphasis on the implementation of measures leading to conditions under which a reduction in lateral separation may be introduced.

3.6 Longitudinal separation

(References: Item 4 in Summary /4, Item 4 in Summary /5.)

3.6.1 Based on a proposal made by the French Member at the 3. Meeting of the Group, the data obtained during the data collection exercise mentioned in paragraph 3.5.1 above was also reviewed with a view to obtaining information on the longitudinal separation in the NAT Region. In addition, the French Member proposed a method of mathematical treatment of this data for this purpose.

3.6.2 At its 4. Meeting the Group made a general review of longitudinal separation and noted that without making any fundamental changes at this time there still remained a number of areas where improvements were possible, either by the extension of the area of application of certain procedures or by obtaining agreement to the application of separation standards agreed at the Special NAT Meeting 1965. It therefore suggested a number of specific actions to be taken by provider States in this field and States are now in the process of responding to this invitation. (See also para. 8.2.)

3.6.3 With regard to the more basic problems involved in longitudinal separation, the Group, at its 5. Meeting, developed a method for estimating collision risks associated with the application of procedural longitudinal separation. It then reviewed the present longitudinal separation used in the NAT Region and found that it was adequate. However, the scope of any study required to establish the limit of possible reductions of this type of separation was such, especially as regards the collection and processing of actual flight data, that it was agreed not to undertake any new data collection exercise for this purpose.

3.6.4 The Group also reviewed the possibility of reducing longitudinal separation based on the provision, on board of the aircraft concerned, of monitoring devices permitting pilots to keep informed about the actual longitudinal separation existing between their aircraft and those which were of concern to them. It was noted that tests in this field had recently been made in the USA on which definite results were, however, not yet available. The Group agreed to keep this question under review.

3.7 Vertical separation above FL 290 in the NAT Region

(References: DOC 8499, SP/NAT (1965), pages 6-I-2 to 6-I-9, paragraph 6i)-1.2,
Item 2 in Summary /3 - Part II,
Item 2 in Summary /5.)

3.7.1 Following the Special NAT Meeting 1965 where the question of the use of reduced vertical separation above FL 290 in the NAT Region was discussed extensively, the NAT/SPG, at its 3. Meeting, developed a mathematical/statistical method for the assessment of the collision risk due to loss of vertical separation. As insufficient data on the static pressure error was available to provide a basis for a statistical analysis, the Group discussed two methods for periodic monitoring of the static pressure error :

i) the trailing cone method;

ii) the performance check method developed by the Netherlands.

3.7.2 At its 5. Meeting the Group again reviewed the question of vertical separation in detail, and in particular the results obtained with the application of the methods mentioned above. The Group came to the conclusion that there was, at the present time, insufficient evidence to show that the application of 1 000 ft. vertical separation above FL 290 would be safe on the track system over the North Atlantic. However, it stated a number of actions which would be necessary if further progress towards the use of this separation was to be made (para. 2.7.2 on page 2-9 of Summary /5 applies).

3.7.3 From the work so far done on this question and because of the many difficulties which have been found in the course of it, it would appear that the application of the reduced vertical separation of 1 000 ft. above FL 290 in the NAT track structure cannot be expected in the near future.

3.8 Composite separation

(References: Item 3 in Summary /5,
Item 3 in Summary /6.)

3.8.1 As a consequence of the work done with respect to lateral and vertical separation the Group, at its 5. Meeting, reviewed a proposal for mathematical treatment of composite separation presented by the Netherlands and its possibility of application in the NAT Region. It was found that from the ATC viewpoint the type of composite separation composed of the application of a half value of lateral separation combined with a half value of vertical separation was practical in the NAT Region provided radar cover existed in the transition area and appropriate track structures to absorb NAT flights were established in the continental airspace. (Para. 3.10 on page 3-8 of Summary /5 refers.)

3.8.2 At its 6. Meeting the Group decided that since the type of composite separation, referred to in para. 3.8.1, was both safe and practicable it was possible to discuss the practical measures required for its application.

3.8.3 It was further agreed that this type of separation should initially be applied on a limited basis, preferably in the course of 1970 and that its application should be expanded as facilities and services required to this end became available and experience gained in its practical use increased. (Item 3 of Summary /6 refers.)

3.9 Improvement of navigation techniques and notification of gross errors to operators

(References: Paragraphs 5.3 to 5.9 in Summary /2,
Paragraph 7.2.3 in Summary /5.)

3.9.1 In the course of its work on the data collection exercise in the NAT Region (see para. 3.5.1 above) the question of improvement of navigation techniques by operators (and, to the extent possible, their standardization) as well as the notification of gross errors to operators was raised. It was believed that appropriate action on these two aspects could significantly assist in the improvement of safety in operations in the NAT Region as navigation has a marked effect on the separation standards which have to be applied.

3.9.2 It was noted that Canada as well as the United Kingdom have already instituted procedures whereby observed gross errors are brought to the attention of operators and, at the 5. Meeting, the Group proposed that a summarised review of the navigation system based on observed navigational errors should be made at regular intervals and brought to the attention of all NAT States and operators by the Paris Regional Office. This has now been instituted.

3.9.3 It was also noted that IATA has a programme in being, aimed at advising airlines on those methods of navigation shown to be successful during the data collection exercise. IATA information on this subject has been disseminated to virtually all NAT operators and not limited to their own members. In addition it was noted that an increasing number of aircraft have been equipped with dual doppler navigation equipment since the data collection exercise took place in 1967/68.

3.9.4 Despite the progress noted in this field, the Group nevertheless felt that more energetic efforts were required in order to accelerate the general speed of progress. It therefore agreed that this matter should be brought to the attention of the NAT V RAN Meeting for appropriate action. (Appendix 5-D refers.)

3.10 Operation of Loran A chains "C" and "D"

(References: Paragraph 5.1 in Summary /2,
Item 2 in Summary /4,
Item 3 in Summary /5.)

3.10.1 At the Special NAT Meeting 1965 it was recommended that the continuous operation of Loran A chains "C" and "D" could significantly contribute to the improvement of navigation in their area of cover. It was, however, also recognized that because of certain technical difficulties this continuous operation was difficult to realize. The Group therefore devoted considerable time to the development of measures which would permit overcoming the difficulties in question and it was largely due to its efforts that satisfactory solutions could finally be found which have now resulted in the inclusion of these two chains in the list of radio navigation aids required in the NAT Region.

3.10.2 At its 6. Meeting the Group noted that, owing to continued difficulty with the problem of interference with maritime interests, it had not proved possible to achieve 24-hour operation of chain "C" which was currently closed down between 0800 and 1200 GMT daily. The Group agreed that, in view of the importance of this chain to the maintenance of accuracy of navigation in its area of cover, a determined effort should be made by the provider States concerned to overcome these difficulties (para. 8.1 refers).

3.11 Revised NAT Air Reporting Procedures

(References: Item 3 in Summary /3 - Part I,
Item 3 in Summary /4,
paragraph 2 in Summary /5.)

3.11.1 During its 3. Meeting the Group made a complete review of the NAT Air Reporting Procedures as they were then published in DOC 7030 and proposed a number of amendments to them which were intended to facilitate application of the Procedures, eliminate unnecessary operational complications and reduce the traffic load on the air-ground communication channels.

3.11.2 These proposals were later submitted formally by the United Kingdom to ICAO as a proposal for amendment of the appropriate NAT Regional Supplementary Procedures and are now incorporated in DOC 7030.

3.12 SST operations in the NAT Region

(References: Item 5 in Summary /4,
Item 1 in Summary /5.)

3.12.1 Based on a proposal by the UK member, made during its 4. Meeting, the Group devoted considerable time to a review of all foreseeable operational and technical problems which may be expected with the advent of SST operations in the NAT Region. In addition it proposed a number of possible solutions for the operational problems which are expected to be created by this type of operation.

3.12.2 It is expected that the findings of the Group will be extensively used at the forthcoming NAT V RAN Meeting in the preparation of necessary measures by all concerned in order to allow the successful operation of this new type of aircraft in the NAT Region. (Appendix 5-C refers.)

3.13 Geostationary satellite for aeronautical purposes in the NAT Region

(References: Paragraph 5.2.4 in Summary /3 - Part I,
Item 6 in Summary /6.)

3.13.1 At its 3. Meeting the Group was informed by the US member that the USA, early in 1968, intended to place an experimental geostationary satellite into position over the NAT Region which would be used primarily for experimental air-ground communications in this Region. The Group supported this experiment and requested all States to give full support to this programme in view of its importance for future developments.

3.13.2 In addition, at its 5. Meeting, the Group having noted the creation of the ASTRA Panel by ICAO felt that, since this body was primarily oriented towards the technical aspects surrounding the use of stationary satellites for air navigation purposes, it might be useful to establish contact with this Panel in order to provide them, as far as the NAT Region was concerned, with information on the operation and cost/benefit aspects of this new technique.

3.13.3 As a result of this decision and based on informal contacts established between the secretaries of the two Groups in question, the ASTRA Panel posed a number of questions to the Group which were of particular interest to the Panel. At its 6. Meeting the Group reviewed these questions and provided the ASTRA Panel with its preliminary views on them.

Summary of Agenda Item 5: Preparation of appropriate documentation for the Fifth NAT RAN Meeting, mainly in respect of its Item 3.

5.1 Introduction

5.1.1 When considering this item, the Group noted that there were 3 distinct aspects under which it would have to be considered :

i) general views on Items 2 and 3 of the Agenda of the NAT V RAN Meeting;

ii) report on progress made by the NAT/SPG with respect to items referred to it specifically by the Special NAT Meeting 1965 (para. 5.1.4 on pages 5-20 to 5-23 of ICAO DOC 8499, SP/NAT (1965) refers);

iii) specific proposals for action by the NAT V RAN Meeting resulting from work done by the NAT/SPG and related to a number of agenda items of the NAT V RAN Meeting.

5.2 General views on Agenda Items 2 and 3 of the NAT V RAN Meeting

5.2.1 On the Agenda of the NAT V RAN Meeting, Item 2 is "Operational Requirements and Planning Criteria" and Item 3 is "Long-Term Systems Plan". The Group felt that it was important for the statements agreed under these items to be realistic. In particular, the statement of operational requirements for the life-time of the Regional Plan should not be over-burdened with requirements which might be desirable, but which were either not essential or alternatively, could not be realized within the life-time of the Plan.

5.2.2 In this respect the Group noted that the 16. Assembly of ICAO, in its Resolution A16-19 (Resolving clause (3) of Appendix E refers) had apparently been guided by the same considerations when it had stated that :

"(3) action be taken to obtain, analyse and disseminate the necessary information and to give guidance on the basic criteria on which far-sighted and realistic Regional Plans can be formulated."

5.2.3 Because of the limited time available, the Group, much as it desired to do so, was not in a position to develop complete detailed proposals regarding the basic operational requirements and the long-term systems plan to be established by the NAT V RAN Meeting, but it nevertheless felt that it might be useful to draw States' attention to this question so that appropriate action may be taken at the Meeting itself. In addition, in those cases where the Group had been able to do some work it prepared specific proposals for action.

5.2.4 In this respect the Group also noted that the recent decision taken within ICAO to present the Air Navigation Plan for the NAT Region in two separate Regional Plan Publications (the eastern half of the Region in the EUM RPP and the western half in the NAT, NAM, PAC RPP) and, as far as charts were concerned, on maps having different scales, did not facilitate the task of the Group nor, as it appeared, that of administrations or operators. Even though the Group was not aware of all the reasons underlying ICAO's decision in this respect, it nevertheless felt that it might be useful if this matter were to be considered by the NAT V RAN Meeting in order to explore possible remedial action. (See Appendix 5-A.)

5.3 Progress report on items referred to the NAT/SPG by the Special NAT Meeting 1965

5.3.1 The Group noted that the Special NAT Meeting, under its Agenda Item 5 had referred a number of subjects specifically to the NAT/SPG for consideration (para. 5.1.4 on pages 5-20 to 5-23 of ICAO DOC 8499, SP/NAT (1965) refers). Even though the Group had, throughout its work since 1965, been guided by these subjects, it had nevertheless been found that, due to the need to establish priorities for the subjects which it could possibly handle, and due to developments having taken place since the time of the establishment of this list, not all of the subjects received equal consideration. As it is, however, likely that the NAT V RAN Meeting may wish, under its Agenda Item 3, to develop a similar but up-dated list of subjects for future planning, the Group believed it useful to give a brief summary of the situation with respect to each of the items listed, as seen by the Group, so that the NAT V RAN Meeting may take this into account when preparing its new long-term plan for the Region. (See Appendix 5-B.)

5.4 Specific proposals for action by the NAT V RAN Meeting

5.4.1 ATS measures for SST aircraft in the NAT Region

5.4.1.1 At its Fifth Meeting the NAT/SPG made a very detailed study of the preparatory ATS measures which might be required for the start of SST operations in the NAT Region. The results of this study are reflected in Summary /5 under Agenda Item 1.

5.4.1.2 From this resulted a number of proposals for specific action and these have now been extracted from Summary /5 and presented in a consolidated form for submission to the NAT V RAN Meeting. (See Appendix 5-C.)

5.4.2 Composite separation in the NAT Region

5.4.2.1 The question of application of composite separation in the NAT Region is dealt with under Item 3 of this Summary as well as the action proposed to the NAT V RAN Meeting on this subject. (See Appendix 3-A.)

5.4.3 Monitoring of the navigation capability

5.4.3.1 It was found that navigation capability has the most significant influence on the separation applied in the NAT Region, and thus the capacity of the air navigation system as a whole. Any improvement in this field will therefore result in direct improvements to the overall situation. However, due to the need to consider the performance of all aircraft in any assessment of the navigation capability it is possible that the lack of provision of modern navigation equipment or the non-application of advanced navigation techniques by one or more users of the airspace in question may appreciably retard the introduction of improved ATC procedures and/or reduced separation. As a consequence more progressive operators may therefore, for prolonged periods, be deprived from obtaining the benefits which their improved navigation deserves.

5.4.3.2 It was therefore believed necessary to draw States' attention to this rather unsatisfactory situation in order to ensure that coordinated efforts be made by all concerned to reach a uniformly high level of navigational performance. (See Appendix D.)

5.4.4 "Target levels" of safety from collision

5.4.4.1 At its 2. Meeting the Group developed "target levels" of safety from collision which, despite their imperfections, had been found to be of considerable value. As it was now apparent that the question of separation was to be reviewed on a broader scope within ICAO, the Group believed that it could be of interest to draw the attention of the NAT V RAN Meeting to this part of its work. (See Appendix 5-E.)

APPENDIX 5-A

SUPPORTING DOCUMENTATION FOR THE ICAO NAT V RAN MEETING RELATED TO THE DEVELOPMENT OF OPERATIONAL REQUIREMENTS, PLANNING CRITERIA AND A LONG-TERM SYSTEMS PLAN FOR THE NAT REGION

(Agenda Items 2 and 3)

1. General

1.1 After several years of experience, the NAT/SPG came to the conclusion that the basic operational requirements upon which regional planning in the NAT Region has been based so far have been unrealistic. The technical and economical means for their realization, as well as the time required for their implementation have frequently been underestimated.

1.2 It would therefore appear desirable that the basic operational requirements, as well as the planning criteria should be as realistic as possible in order to establish the proper balance between progressive forward planning and the abilities of States and operators concerned to meet the requirements stated within the life-time of the plan.

1.3 The Group also wishes to point out that ICAO's decision to eliminate one of the more important planning tools used by the Group extensively in its work, i.e. the Regional Plan Publication for the NAT Region, and to incorporate NAT facilities and services into two different Regional Plan Publications with differing and incompatible presentations, especially as far as maps were concerned, had proved to be a handicap to the Group.

2. Action proposed

2.1 The NAT/SPG proposes that the NAT V RAN Meeting takes a close and detailed look at the basic operational requirements and the planning criteria on which the Regional Air Navigation Plan for the NAT Region is to be based in order to ensure that the requirements and criteria, both for the short-range and long-term plans be as realistic as possible while still giving sufficient impetus to States so as to further progressive developments.

2.2 Even though the NAT/SPG is not aware of all the reasons underlying ICAO's decision to discontinue the issuing of a Regional Plan Publication presenting all the facilities and services of the NAT Region, it is nevertheless proposed that the NAT V RAN Meeting may wish to look into this matter with a possible view to improving the present unsatisfactory situation.

APPENDIX 5-B

SUPPORTING DOCUMENTATION FOR THE ICAO NAT V RAN MEETING CONCERNING A REVIEW OF WORK DONE BY THE NAT/SPG WITH RESPECT TO SUBJECTS REFERRED TO IT BY THE SPECIAL NAT MEETING 1965

(Agenda Item 3)

1. Introduction

1.1 The NAT/SPG feels that, apart from its detailed report on the work accomplished, as contained in NAT V - WP/-, it might be useful to the NAT V RAN Meeting to provide it with a brief review of work done on the subjects referred to it by the NAT Special Meeting in 1965 as shown in para. 5-1.4 on pages 5-20 to 5-23 of ICAO DOC 8499, SP/NAT (1965). This is done mainly to provide the Meeting with an appreciation, based on five years' experience in planning, of the possibilities which exist with regard to planning and the time scale required for the completion of specific subjects.

1.2 In addition this review may also serve as an example of the way in which subjects tend to be subject to changes as developments continue and, as a consequence thereof, their importance changes. It is in this respect that the review may be of value to the Meeting when it develops its new long-term plan for the NAT Region.

2. Review of subjects

2.1 Organization of airspace (para. 5-1.4.2)

2.1.1 As will be seen from NAT V - WP/- the Group found that the amalgamation of FIRs, especially to cater for SST traffic, was not believed to result in the improvements expected from such a measure in 1965. In fact it was found that, at least during the initial stages, this might, in the particular NAT environment, create more difficulties than it could be expected to resolve. It was found that it would be more rewarding to concentrate on improved coordination not only between OACs but also between them and the adjacent continental ACCs in order to resolve the problems presented by high-speed aircraft, including the SST.

2.2 Continental Transition Airspace (para. 5-1.4.3)

2.2.1 The problems of the transition area are becoming more and more acute, especially with the introduction of SST aircraft into operation and the use of composite separation within the NAT Region. The Group has given some consideration to this aspect of operations. However it was found that many of the proposed solutions to the ATS problem in the NAT area are directly and inseparably linked to the developments in the transition areas on both sides of the North Atlantic.

2.3 Application of ATC Computers to Oceanic Control (para. 5-1.4.4)

2.3.1 Even though the Group did not go into any detailed consideration it thought that this subject, and more especially the automatic data exchange between oceanic centres and adjacent continental ACCs, may require closer review in the immediate future.

2.3.2 Also, the advent of SST aircraft in the NAT Region will increase the need for computer assistance because of the more demanding operational requirements, especially as regards the determination of the start of acceleration for such aircraft and the preparation of suitable oceanic clearances.

2.4 Automated Flight Planning (para. 5-1.4.5)

2.4.1 This subject has so far also not been considered in great detail by the Group. However, as traffic density in the NAT Region increases and approaches saturation during specific periods it may be found necessary to consider this subject more closely in relation to the organization of the traffic flow by the oceanic area control centres in order to maintain a proper balance between the automated flight planning done on a purely individual basis for each flight and the systematic planning of the flow of air traffic carried out by the OACs, if it is to be avoided that the automated flight planning for individual flights becomes purely theoretical.

2.5 ATS Procedures (Oceanic Centres) (para. 5-1.4.6)

2.5.1 This subject has been under continuous review by the Group since any proposed changes to the air navigation system obviously resulted in consequences to the ATS procedures employed by the oceanic area control centres concerned. Specific cases are the procedures for the handling of SST aircraft (NAT V - WP/- refers) and the envisaged application of composite separation in the NAT Region (NAT V - WP/- refers).

2.5.2 It is expected that this subject will have to remain under continued review both as regards short-range and long-term planning.

2.6 Navigation Systems (para. 5-1.4.7)

2.6.1 This item, together with the question of separation, to which it is inseparably linked, has received major attention by the Group during the last five years. While it has been possible to resolve, to a more or less satisfactory degree, the problem of the operation of Loran-A chains "C" and "D" there still remain questions with respect to both the provision of radio navigation aids on both sides of the North Atlantic and the installation and operational use of self-contained navigation systems.

2.6.2 It is therefore expected that this subject will also require careful review in the coming years.

2.7 Separation Minima (para. 5-1.4.8)

2.7.1 As mentioned above this subject has absorbed the major part of the work conducted by the Group since its inception and, even though it has been possible to do considerable spade-work in this field of more than regional significance, much remains to be done, especially as developments in the field of navigation and altimetry continue.

2.7.2 It is therefore believed that despite the efforts now undertaken on a world-wide basis within ICAO, this subject still remains one of continuing concern.

2.8 Communications (para. 5-1.4.9)

2.8.1 Apart from a review of the air-reporting procedures for ATS purposes in the NAT Region, and which resulted in an amendment to the Regional Supplementary Procedures, the subject of communications has so far not been reviewed in any great detail. This was mainly due to the fact that it became apparent that without a new approach to this question there was very little scope for improvement without engaging the provider States concerned in economical expenses which were hardly acceptable.

2.8.2 With the advent of space communication techniques in recent years it can, however, be expected that this subject will require closer follow-up and the recent contact established between the ASTRA Panel and the NAT/SPG may be taken as an indication of future developments.

2.9 Meteorological Services (para. 5-1.4.10)

2.9.1 So far the Group has completely abstained from entering into this field as it is believed that with the present developments fostered both by WMO and ICAO on a world-wide basis, there is very little scope for useful activities by the Group at this time.

2.9.2 It should, however, be noted that in the course of the revision of the Communication Procedures mentioned in para. 2.8 above it has been possible to reduce the amount of MET reporting required from pilots operating in the NAT Region significantly while, at the same time, rendering the reports retained more meaningful.

2.10 Aeronautical Information Services (para. 5-1.4.11)

2.10.1 This subject has only been touched upon whenever this became necessary in order to ensure that national aeronautical publications issued by provider States with respect to specific operational questions were presented in a uniform manner. Cases in question are the conduct of the North Atlantic Data Collection Exercise and the application of the new air reporting procedures in the NAT Region.

2.10.2 Indications are that in this field the situation is not likely to change significantly until it should be found that, with the introduction of SST aircraft, new requirements develop.

APPENDIX 5-C

SUPPORTING DOCUMENTATION FOR THE ICAO NAT V RAN MEETING RELATED TO THE OPERATION OF SST AIRCRAFT IN THE NAT REGION

(Agenda Items 10 and 16)

1. Introduction

1.1 During its Fifth Meeting, the NAT Systems Planning Group (NAT/SPG) made a detailed review of preparatory ATS measures required for the start of SST operations in the NAT Region. A full record of the discussions held by the Group on this subject may be found in the Summary of the Fifth Meeting of the Group under its Agenda Item 1.

1.2 In the course of these discussions, the Group reached a number of conclusions which are believed to be of interest to the NAT V RAN Meeting and could serve as a basis for the formulation of appropriate recommendations by that Meeting. They are therefore herewith presented to the Meeting, while the detailed supporting discussion on each of the conclusions reached may be found in Summary/5 of the NAT/SPG.

Note : In order to facilitate cross reference between the conclusions presented in this paper and the discussion contained in Summary/5 of the NAT/SPG, the reference of the conclusion in Summary/5 of NAT/SPG is added to each one of them.

2. Separation of SST aircraft

2.1 Horizontal separation

2.1.1 Longitudinal separation

2.1.1.1 The "exposure time" of SST aircraft while operating in the NAT oceanic area is much shorter than that for sub-sonic traffic and will not normally exceed 2-1/2 - 3 hours, depending on the track flown and on the destination. It is therefore believed that initially the provision of 10 minutes longitudinal separation between successive SST aircraft at the oceanic entry point will be satisfactory. It is possible that this may be revised to a shorter interval as operating experience confirms the anticipated capability of SST aircraft to adhere accurately to their predicated flight profile. (Summary/5, page 1-2, para. 1.3.1.2.2)

2.1.2 Lateral separation

2.1.2.1 For SST aircraft the lateral separation depends to some extent on the time required between the detection of a lateral deviation from track and a successful corrective intervention by the pilot. This in turn is again related to cockpit operating procedures which are thus of particular importance. Subject to the satisfactory completion of trials with pre-production aircraft it was agreed that ATC planning should be based on the provision of 60 NM lateral separation between adjacent tracks for either opposite or same direction traffic. (Summary/5, page 1-4, paras 1.3.1.3.3 and 1.3.1.3.4)

2.1.3 Radar separation

2.1.3.1 During subsonic flights the normal radar separation minima prescribed by the competent authority should be applied to SST aircraft. However, whenever an SST aircraft in trans-sonic flight or in flight at supersonic speed is involved, a minimum of 10 NM radar separation should be applied between the aircraft concerned. This value has been used in simulation studies and seems to cater not only for the types of radar normally employed for the surveillance of SST aircraft during trans-sonic flight, but covers also the needs created by the application of the extreme range of the radars when used for SST operation. (Summary/5, page 1-4, para 1.3.1.4)

2.2 Vertical separation

2.2.1 While operating at sub-sonic speeds SST aircraft will be separated vertically from other aircraft in accordance with normal procedures.

2.2.2 During acceleration to supersonic flight, the provision of vertical separation between SST aircraft may not always be feasible. However the flight profiles of SST aircraft in acceleration and those in deceleration are such that an automatic vertical separation is likely to exist between them in the transition area between domestic and NAT airspace. In addition the use of Mode C of Secondary Surveillance Radar offers a potential means of ensuring vertical separation between SST aircraft.

2.2.3 Above FL 500 and up to the maximum normal operating level of FL 600 SST aircraft will cruise climb up to the end of cruise ("top of descent"). Normally during this phase only lateral or longitudinal separation can be applied to them.

2.2.4 When operating in an organized track structure with a common cruise climb regime, the provision of vertical separation between SST aircraft is unnecessary since they will not achieve proximate vertical relationship in the cruise phase of flight, separation being maintained in a common horizontal plane laterally or longitudinally. Because of the very slow rate of climb achieved in cruise-climb operation the passage of crossing and/or opposite direction traffic through the level of approaching traffic can only be permitted in two small areas about 900 NM from the mid-point of the route system where sufficient separation can be applied.

2.2.5 For planning purposes "sufficient vertical separation" for the SST aircraft is assumed to be 4 000 ft. This assumption is based on a prediction that the standard deviation of the altimetry system of SST aircraft will probably not exceed approximately 1 000 ft. Should experience with pre-production aircraft show that the predicted standard deviation is smaller this should be reflected in the separation applied.
(Summary/5, pages 1-4 and 1-5, para 1.3.2)

3. Airspace organization

3.1 Extent of FIR's

3.1.1 The start of SST operations will not, in itself, create a requirement to change the present FIR boundaries. However, co-ordination and transfer of control procedures between adjacent ACC's will require detailed attention not only between adjacent OAC's but also between them and the North American and European domestic airspace. This latter applied particularly to the area south-west of the United Kingdom and south of Ireland where the existing problems will be considerably aggravated if early preparatory action is not taken.
(Summary/5, pages 1-7 and 1-8, para 1.5.1.)

3.2 Track structure

3.2.1 From studies it would appear that at least at the initial state of planning, it would be advantageous to assume that an organized track structure based approximatively on a great circle should be used in order to cater for the main traffic flow across the North Atlantic. This track structure is however also dependent on decisions taken with regard to sonic boom. It should in addition be understood that the use of such a track structure would not imply that tracks by SST flights outside such a track structure would not be accepted by ATC whenever conditions permitted.
(Summary/5, page 1-7, paras 1.4.7 and 1.4.8)

3.2.2 There might be merit in studying the possibility of assigning by the OAC concerned to each SST aircraft a special code sign together with the oceanic clearance which should be used during the flight in the NAT Region and which, by its combined use with the usual call sign would provide to ATC and to other SST aircraft in a readily understood form information on the track on which the aircraft concerned was operating and its sequence number in the flow of SST traffic on this track. (Summary/5, page 1-14, para 1.9.14)

4. Oceanic clearances for SST aircraft

4.1 It will be necessary to develop a special oceanic clearance technique for SST aircraft taking into account the following:

i) there should be established positions at which acceleration to supersonic speed should normally be started.

ii) Adjustment of longitudinal spacing of succesive SST aircraft on NAT tracks, and sequencing of crossing traffic, should be accomplished by delaying the commencement of acceleration to supersonic speed.

iii) The principle of first-come-first-served could be applied for the west-bound flow through the use of a datum line (meridian) which would need to be as far east as possible but not east of any major traffic generating centre. To avoid a requirement for ETA's at this point, and to facilitate the mechanics of issuing an oceanic clearance, it might be preferable to establish a standard time relationship between this datum line and the various established positions at which acceleration to supersonic speed should normally begin.

iv) As the interval between the moment of take-off of an aircraft and the time when the oceanic clearance is needed will be short, it seems likely that filed flight plans received in the OAC will have to be up-dated by the transmission of a departure message via the domestic ATS inter-area communication channels to the OAC concerned. The oceánic clearance may then have to be relayed to the pilot using the same channels should it be found that the present technique of using a special frequency for delivery of the oceanic clearance to the pilot is not suitable. (Summary/5, pages 1-11 and 1-12, para 1.8.7)

5. Air-ground communications

5.1 For the safe and efficient operation of SSTs it is essential that the best facilities be provided and that progress should continue towards the introduction of a suppressed carrier SSB system. The Group considers that, as part of the essential preparatory measures for the start of SST operations, the evaluation of HF/SSB techniques should now be actively pursued by the States concerned. (Summary/5, page 1-13, para 1.9.9)

6. Turn-back procedure

6.1 The Group agreed that studies regarding a turn-back procedure should be made to cater for those cases where an SST aircraft may be unable to continue its flight to destination and is forced to return. Such a procedure should envisage that the SST aircraft in question would descend approximately 2 000 to 4 000 ft. from the level occupied at the time of the decision to return before starting to reverse course. An ATC clearance should be obtained prior to descent or, if this is not practicable, as soon as possible thereafter. (Summary/5, page 1-15, para 1.10.2)

7. Rapid descent procedure in case of urgency

7.1 The following procedure is proposed for further study :

i) In case of need to descend because of solar radiation the pilot shall broadcast on VHF (121.5 Mc/s) his decision to descend by giving his call sign and the code number assigned to his flight by the OAC of entry and the level to which he will descend.

ii) The pilot shall contact ATC as soon as possible after having started his descent in order to obtain a new ATC clearance for the level selected or, in case this is unsatisfactory, for any other level and other particulars concerning the continuation of the flight.

iii) Descents below FL 450 shall in no case be made without having obtained an appropriate ATC clearance. (Summary/5, pages 1-15 and 1-16, para 1.10.5)

8. Distress descent procedure

8.1 The degree of hazard caused by the descent of an SST aircraft into the band of levels used by the subsonic aircraft will depend on the subsonic track structure in use at the time. An added complication will be the requirement of the SST, when in subsonic flight, to continue on the best track depending on the wind field. It will be essential for the SST pilot to have detailed knowledge before take-off of the subsonic track structure in use. It would appear that in order to present the least danger of collision, an SST making a distress descent should :

i) notify the OAC concerned as soon as possible of the nature of distress, stating its position, flight level, intentions, etc., and if appropriate, request clearance to a more suitable level;

ii) as soon as possible, broadcast information regarding the nature of distress, including position, flight level, intentions, etc., on VHF (121.5 Mc/s) in order to warn subsonic jets in the vicinity. (The NAT COM SUPPs require aircraft on long over-water flights in the NAT Region to guard 121.5 Mc/s continuously, with due regard to equipment limitations and cockpit duties.)

8.2 The OAC controller will then issue the most suitable clearance depending on the traffic situation at the time. (Summary/5, page 1-16, para 1.10.8)

APPENDIX 5-D

SUPPORTING DOCUMENTATION FOR THE ICAO NAT V RAN MEETING RELATED TO MONITORING OF THE NAVIGATION CAPABILITY OF AIRCRAFT OPERATING IN THE NAT REGION

(Agenda Item 4)

1. Introduction

1.1 When reviewing the question of separation in the NAT Region, the NAT/SPG found that the navigation capability of aircraft is the most significant factor and has, as a consequence, an all important influence on the separation minima which are possible for application. As, in turn, separation has a direct influence on the capacity of any air navigation system it is evident that the lack of provision of adequate navigation capability will reflect not only on the operational but also on the economic situation in any given area.

1.2 In the case of the NAT Region, work on the subject of separation has revealed that some users of the airspace in question have gone to considerable lengths in the provision of navigation equipment on board their aircraft, with resultant improvement to their navigational capability while others seem to have been slower and more conservative in this respect. As a result, it was found that, since in any assessment of the navigational capability in the Region, all aircraft and their performances have to be considered, the more progressive users are deprived from obtaining the deserved operational and economic benefits which they could reasonably expect as a result of their efforts.

2. Action proposed

2.1 The Group believes it necessary that the NAT V RAN Meeting draw the attention of States to the present, rather unsatisfactory situation regarding the uniform provision of accurate and reliable navigation equipment and the application of sound methods of navigation on all aircraft operating in the NAT Region. It is therefore proposed that the NAT V RAN Meeting take necessary measures to ensure that coordinated efforts be made by all concerned to reach a uniformly high level of navigational performance.

APPENDIX 5-E

SUPPORTING DOCUMENTATION FOR THE ICAO NAT V RAN MEETING RELATED TO THE WORK ON "TARGET LEVELS OF SAFETY FROM COLLISION"
(Agenda Items 2 and 3)

1. General

1.1 At its 2. Meeting, the Group established values for the "target levels" of safety from collision, in order that it would be possible to assess the adequacy of separation criteria. These levels were derived on the basis of certain assumptions (Summary /2, Item 4 refers), and it was agreed to express the target level in terms of an average number of accidents due to collision per ten million flying hours, one collision being counted as two accidents. Clearly it could be suggested that some of the assumptions were arbitrary. Furthermore the target levels could have been expressed in other ways; but despite imperfections this method of expressing them has seemed to be adequate for their immediate purpose.

1.2 It is now likely that other bodies, such as, for instance, the one which was recommended during the 6. Air Navigation Conference, will be studying methods of establishing safe separation criteria, and in the opinion of the Group it would seem possible that such bodies might wish to be made aware of the work which has been done by the Group in this connection and in its own somewhat limited field.

2. Action proposed

2.1 The Group therefore proposes that the NAT V RAN Meeting may wish to review the Group's work on the question of target levels of safety and, if deemed desirable, bring it to the attention of the appropriate bodies within ICAO.

Summary of Agenda Item 6: Exchange of views on the questions posed by the Secretary of the ASTRA Panel.

6.1 History

6.1.1 At the 5. Meeting of the NAT/SPG, held in December 1968 in Montreal, it had been pointed out, especially during discussions on Item 1 of that meeting "Determination of preparatory ATS measures required for the start of SST operations in the NAT Region", that it might be useful to advise the ICAO Panel on "Application of space techniques relating to Aviation (ASTRA)" of the Group's feeling with respect to some operational and cost/benefit aspects of the scope of operational and economical options available in this field.

6.1.2 As the ASTRA Panel, during its first meeting in November 1968, had expressed similar thoughts on the matter, the Secretary of the NAT/SPG was requested to contact the Secretary of the ASTRA Panel, informing him of the willingness of the NAT/SPG to provide the panel with information on these aspects with respect to the NAT Region if so requested. Consequently, after groups coordination with the members of the ASTRA Panel, its Secretary, in February 1969, addressed four questions to NAT/SPG through his Secretary regarding cost/benefit, implementation and accuracy aspects of air traffic surveillance systems based on the use of space techniques. Members of the Group commented on these questions during the correspondence stage between the 5th and the 6th Meeting but it became apparent that it would not be possible to obtain consolidated views on this matter without a meeting of the Group.

6.1.3 It was consequently agreed by the NAT/SPG that this matter should be placed on the Agenda of its 6. Meeting.

6.2 Action taken

6.2.1 At the 6th Meeting, the Group agreed that the exchange of views on the questions posed by the Secretary of the ASTRA Panel should be held in the presence of all participants in this meeting and that subsequently the Group would prepare a reply to the Panel, based on these discussions, for onward transmission to its Secretary by the Secretary of the Group.

6.2.2 It was however also agreed that it should be stressed in the reply that :

i) the Group could only express itself with regard to requirements concerning the NAT Region, and

ii) that its reply, even though it constituted the optimum views at this time, should not be taken as final.

6.2.3 A reply has accordingly been prepared at the Meeting and has been forwarded by the Secretary of the Group to the Secretary of the ASTRA Panel.

*Summary of Agenda Item 7: Review of work programme of the Group, including arrangements for the next meeting.

7.1 General

7.1.1 Assuming that, in the light of results achieved, the NAT V RAN Meeting will confirm the continuation of the NAT/SPG, it believed that its future work programme should be based primarily on the action taken at that Meeting.

7.1.2 It was therefore agreed that the new work programme of the Group should be established at its first meeting after NAT V RAN.

7.1.3 It was further believed that, under the assumption of continued operation of the Group, its next meeting could only be held once the action taken at the NAT V RAN Meeting had passed an initial review by the responsible bodies of ICAO and contracting States concerned.

7.2 Proposed action

7.2.1 In view of the above, and should the NAT V RAN Meeting confirm the continued existence of the NAT/SPG, it was therefore agreed that :

i) the next meeting of the Group, if not otherwise required subsequent to action taken at NAT V RAN, should be held some time early in 1971 at the Paris Regional Office of ICAO, taking into account other possible meeting commitments;

ii) the exact date, duration and agenda of this meeting should be established in correspondence between the Chairman of the Group and its members as of September 1970;

iii) the future work programme of the Group should form one point of the agenda of its next meeting, taking into account the mandates given to the Group by the NAT V RAN Meeting and any points raised at previous meetings under this subject which are still applicable;

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* This item was considered by members of the Group only.

iv) a review of progress made with the application of composite separation in the Region and of the question of assessment of system performance should be retained as subjects for consideration by the Group at its next meeting;

v) the policy of the Group to invite IANC, IATA and IFALPA to participate in its meetings under the established arrangements should be continued;

vi) ICAO should be requested to continue present arrangements for the meetings of the Group which had been found highly satisfactory.

Summary of Agenda Item 8: Any other business.

8.1 Operating times of Loran A chains "C" and "D"

8.1.1 The Group noted with satisfaction that Loran A chains "C" and "D" were now included in the NAT Regional Plan. It was, however, noted that chain "C" was not operating on a 24-hour basis, but was daily shut down between 0800 and 1200 GMT. It was further noted that this was a critical area and that therefore the operation of this facility on an uninterrupted 24-hour basis was deemed essential by the Group.

8.1.2 The French Member explained that this shut-down was due to the fact that certain problems of interference between this chain and maritime mobile communication services had not yet been overcome, and it had therefore been decided to resort to this solution. The Group felt that in view of the relative importance of the services rendered by Loran A chain "C" to aviation, as compared with the services rendered to maritime interests, this solution was not acceptable. It therefore strongly recommended that the States concerned should make every effort possible to overcome the difficulties so as to put Loran A chain "C" on a 24-hour operation at the earliest possible time.

8.2 Situation with regard to longitudinal separation in the NAT Region

8.2.1 Further to the review of the situation with regard to longitudinal separation made at its 4. Meeting (Summary/4, para 4.2 refers), the Group again reviewed the present situation in this field. It was noted that, as far as the application of 15 minutes longitudinal separation to turbo-jet aircraft operating on the same or diverging tracks is concerned, the USA had now made a proposal for amendment of the NAT RAC SUPPs aimed at the application of this procedure in the New York Oceanic Control Area.

8.2.2 With respect to the application of 20 minutes longitudinal separation between all other turbot-jet aircraft, south of 70° N, it was noted that all provider States concerned, with the exception of the USA, had already twice given their approval to its application. The USA Member stated that they were not yet in a position to agree to the application of this type of separation due to internal coordination difficulties. IATA pointed out that this posed an ever increasing problem to the rapidly growing traffic operating across the North Atlantic from Portugal and Spain and points further east. In the light of these representations, the Member from the USA stated that the USA were prepared to continue their efforts in order to obtain earliest possible national agreement to the application of 20 minutes longitudinal application and he hoped that this might be possible by Spring 1970.

8.2.3 In this context the UK Member raised a problem which might be expected to develop once the B-747 aircraft are introduced into service in the NAT Region, because of the difference in cruising speed which may exist between them and current type turbo-jet aircraft. In fact, while the present type turbo-jet aircraft generally cruised at a Mach number of 0.82, the B-747 is expected to cruise at Mach 0.85 - 0.87. As the current application of longitudinal separation, based on the use of the Mach number technique, requires that for each increase of Mach 0.01 between a preceding and a following aircraft three minutes additional time separation be provided over the entry point into the NAT Area, this would require that B-747 aircraft cruising at Mach 0.87 and following a present type jet aircraft be provided with 30 minutes longitudinal separation from the preceding aircraft at the entry point into the NAT Area. This will obviously result in a reduction of the overall traffic capacity because of the reduced utilization which can be made of the track and level concerned.

8.2.4 The same applies inversely if an aircraft cruising at Mach 0.82 follows a B-747 along the same track and level, and the present requirement for the provision of 15 minutes longitudinal separation at the point of entry in the NAT Region between the two aircraft concerned is retained.

8.2.5 In fact it can be expected that under these conditions the capacity per track and level will drop to two aircraft or less per hour since the minimum separation of 15 minutes is seldom achieved because of the random arrival of aircraft over the entry points. It is expected that, without a change of the present procedures, the worst effects of this situation may be expected during Spring and Summer 1970 when comparatively small numbers of B-747 will be operating simultaneously with large numbers of other type jet aircraft in the NAT Region.

8.2.6 The Group therefore believed that it would be essential that provider States concerned give careful consideration to this problem with a view to making appropriate suggestions for amendment of the longitudinal separation standards to be applied in the area affected by this problem.

8.3 <u>Filing of flight plans in the NAT Region</u>

8.3.1 The NAT RAC SUPPs specify that in flight plans for flights in the NAT Region the planned track shall be defined by significant points. However, many pilots operating within the Principal Area are now planning their flights along one of the organized tracks, and it would therefore be advantageous both for pilots and ATC if the track designator could be used in Item 15 of the flight plan to describe the planned track.

8.3.2 This simplification of flight planning is expected to result in a considerable saving of time and effort on the part of all concerned having to deal with flight plan messages. It would only have to be ensured that the designation of organized track was made in an unambiguous manner so as to avoid any possible source of errors recognizing that the existing procedure of read-back by the pilot of the full details of the track assigned in the oceanic clearance is a continuing requirement.

8.3.3 The Group felt that this proposal merited serious consideration by States and operators concerned and hoped that at the NAT V RAN Meeting appropriate proposals to amend the NAT RAC SUPPs would be made, including a standard manner for the designation of tracks in the organized track structure.

8.4 Environment changes due to the introduction into operational use of Inertial Navigation Systems (INS)

8.4.1 The Group noted certain current developments regarding inertial navigation systems. It was agreed that the precision of INS was such that its introduction would be likely to reduce the standard deviation of track-keeping inaccuracy and in this respect was greatly to be welcomed. However before full reliance was placed on INS, it was necessary for an adequate level of reliability to be demonstrated.

8.4.2 The Group therefore recommends that individual States of Registry satisfy themselves thoroughly on this point before approving operations using INS without there being available to the aircraft crew an adequately accurate alternative method of navigation such as Loran.

8.5 Implementation of HF/SSB

8.5.1 Further to discussions at the 5. Meeting of the Group (Summary/5, para 1.9.9 refers), the Group noted that the 3 stations concerned (Gander, New York and Shannon) had started the operational evaluation of the HF aeromobile SSB system.

8.6 ATS inter-area communications between Lisboa and Shanwick OAC's

8.6.1 Further to discussions held on this subject during its 5. Meeting (Summary/5, para 1.9.13 refers), the Group noted from a report by its UK Member that part of the difficulties experienced in providing a reliable ATS inter-area communications link between Lisboa and Shanwick OAC's was due to the uncertainty regarding the final location of the OAC serving the Lisboa Oceanic FIR. There were now indications that the OAC may be retained at Santa Maria and this matter may be finally resolved at the NAT V RAN Meeting. In the meantime, arrangements had been made between Portugal and the UK to provide an HF/SSB link from Birdlip to Lisboa and from there to Santa Maria, and it was expected that after some minor problems these links, as well as a link from Birdlip to Prestwick, should come into full operational use so that by October 1969 direct controller-to-controller communications between Shanwick and Santa Maria OAC's should be possible.

8.6.2 The Irish Member pointed out that the RTT circuit Shannon-Santa Maria was in operation and had sufficient capacity available to be used whenever this was required.

8.6.3 In this context IATA pointed out that due to the growing traffic operating from or across the Iberian Peninsula into the NAT Region, there was a growing need for the provision of an ATS inter-area communication link between Madrid ACC and Shanwick OAC. The UK Member pointed out that this had been recognized and that negotiations regarding the provision of such a link were in progress between the two Administrations concerned.

*Summary of Agenda Item 9: Election of the next Chairman.

9.1 On a proposal by Mr. R. Huard, member of the United States of America, and seconded by Mr. A.L. Elliott, member of Canada, the Group re-elected unanimously Mr. J.F. Sapin, the member of France, as the Chairman of the Group until the end of the next meeting.

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*This item was considered by members of the Group only.

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