SUMMARY OF DISCUSSIONS

OF THE

SECOND MEETING OF THE NAT SYSTEMS PLANNING GROUP

(Paris, 21 November - 5 December 1966)

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EXPLANATORY NOTE

(Note: This note does not form part of the Summary of the Second Meeting of the NAT Systems Planning Group. It is added for the convenience of States and Organizations only to recall the events leading to the Second Meeting of the Group.)

1. The Special NAT Meeting 1965 recommended that for turbo-jet aircraft operating in the FIR's Gander, Lisboa Oceanic, New York Oceanic, Reykjavik, Shanwick and Sondrestrom (south of 70°N), the minimum lateral separation should be reduced from 120 to 90 NM. This recommendation was subsequently approved by the Council of ICAO and became applicable on 13 January 1966. NOTAMs announcing the introduction of this new separation standard were published by the provider States concerned in due time.

2. This separation standard had already been a subject of contention by Organizations representing some of the air-crew members and, following its introduction, a number of pilots refused to accept this separation minimum from the ACC's concerned. Since this resulted in a considerable complication of the task of the Oceanic ACC's, the provider States concerned, on 10 June 1966, decided to suspend temporarily the application of 90 NM lateral separation in their FIR's, with the explicit understanding that this in no way reflected on the feasibility of the separation minimum in question. Again NOTAMs to this effect were published by the States concerned. (State letter T 13/8.1 N - 1277 of 25 July 1966 from the Paris Office, addressed to all NAT States, refers).

3. Following discussions in the USA between the FAA and the Organizations representing the members of the air-crews concerned, it was believed advisable that a new survey of navigation accuracy in the NAT Region be made in order to determine whether a reduction in lateral separation was justified in those parts of the NAT Region where this had been recommended. A preparatory meeting between Canada, the UK and the USA on this subject was held in July 1966, at which it was agreed that the NAT Systems Planning Group, together with representatives of other States concerned and from the International Organizations concerned, should hold a meeting in order to develop an agreed method of collection of data on navigation accuracy over the North Atlantic and obtain agreement on the treatment of these data so that it could eventually serve as the basis for the determination of acceptable lateral separation standards. (The ICAO State letter quoted under paragraph 2 above refers.)

4. In this context, it is recalled that the NAT Systems Planning Group was formed in accordance with Recommendation 4/1 of the Special NAT Meeting, 1965, and that this recommendation also specified its terms of reference and working modus. (See ICAO Document 8499, SP/NAT (1965), pages 4-1 to 4-4.)

LIST OF PARTICIPANTS

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

State or Organization	Name
CANADA	A.K. Beak A.L. Elliott W.L. Marr L.D. Nemesvary E.B. Powell C.R. Rowsell *R.H. Smith
FRANCE	Y. Goetzinger J. Maigret *J.F. Sapin J. Villiers
IRELAND	*G.E. Enright P.J. Flanagan
KINGDOM OF THE NETHERLANDS	A.G. Van der Aa D. Bonne A. Pool *J. Ten Velden
UNITED KINGDOM	R.G. Anderson *D.A. Blake K.R. Collins B. Job P.G. Reich
U.S.A.	J.M. Bowman R. Dressler C.E. Dunmire W.R. Fearn *R.F. Huard A.B. Johnson H. Mulvaney A. Nixon S. Ratomsky R.W. Wells
PORTUGAL	A. Barreira
I.A.N.C.	J. Archer L. Bourel R.H. Waldman
I.A.T.A.	W. Hoeveler L. Lee P.G. Powell R. Shaw H. Siegfried T.J. Townsend
I.F.A.L.P.A.	J.H. Bartling T.A. Basnight J. Foy A.J. Gréard H.V. Hart C. Jackson W. Masland V. Nicolaieff H. Van Zandt

AGENDA

* Item 1 : Election of Chairman.

* Item 2 : Approval of the agenda.

Item 3 : Delineation of the area to be considered for data collection purposes.

Item 4 : Method to be adopted in assessing a safe separation standard.

a) The description of risk

b) The acceptable level of risk

c) The calculation of estimates of risk

d) Means of expressing the quality of navigation required to meet a stated level of safety.

Item 5 : Interim measures to improve navigational performance.

Item 6 : Programme of data collection and analysis

a) Sources of data

b) Measuring techniques and sample sizes

c) Organisation of the data collection and the collation, reduction and analysis of data

d) Presentation of the results of the data analysis.

* Item 7 : Review of subjects for future NAT/SPG consideration.

* Item 8 : Future conduct of NAT/SPG business.

Note : Items marked with an asterisk were considered by members of the Group only.

1. INTRODUCTION

1.1 The Second Meeting of the North Atlantic Systems Planning Group was held in the European Office of ICAO in Paris from 21 November to 5 December 1966. On 21 November and on 2 and 5 December the Group met in closed session to discuss Agenda Items 1, 2, 7 and 8, while the remainder of the meeting was held with all participants present in order to discuss Agenda Items 3, 4, 5 and 6.

1.2 Mr. G.E. Enright, the member designated by Ireland, was unanimously elected chairman of the meeting. In the course of the work, the Group established two sub-committees to deal with Item 4 and Items 5 and 6 respectively. Mr. J. Villiers from France was elected chairman of the sub-committee dealing with Agenda Item 4 while Mr. E.B. Powell from Canada was elected chairman of the sub-committee dealing with Agenda Items 5 and 6.

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

PARAGRAPH 2 NOT USED

3. Summary of Agenda Item 3 : Delineation of the Area to be Considered for Data Collection Purposes

3.1 The reduced lateral separation of 90 N.M had originally been intended to be applied only in a selected part of the NAT Region. It was agreed that the area wherein the data collection should be made be defined so that it embraced the major traffic flows across the North Atlantic and is sufficiently representative of the varying navigational and other conditions encountered in North Atlantic operations to allow, with a satisfactory degree of confidence, the application of results obtained to all of the FIR's wherein reduced lateral separation was to be applied.

3.2 It was therefore agreed that the area to be considered for data collection purposes should be defined by the following boundaries :

i) in the North by latitude 70°N;

ii) in the South by the great circle between Nantucket and Madeira;

iii) in the East by the Greenwich meridian between 70°N and 61°N and then along the eastern boundary of the NAT Oceanic FIR's to Madeira;

iv) in the West by the western limit of the NAT Oceanic FIR's between 70°N and its intersection with the great circle between Nantucket and Madeira.

This was considered satisfactory, having regard to the fact that 95% of all traffic flying between Europe and the North American continent operates in the area between 44°N and 63°N.

3.3 FIR Bødø Oceanic was specifically excluded from the data collection area because it was not believed that data obtained from the very limited amount of traffic operating in this FIR could contribute significantly to the review. It was noted that this area is without air traffic control.

3.4 As to the vertical extent of the area, after a brief discussion it was agreed that the data collection should be made with respect to turbo-jet aircraft operating up to and including Flight Level 420 .

Summary on Agenda Item 4 : The Method to be Adopted in Assessing a Safe Separation Standard

A. DESCRIPTION OF RISK

4.1 Before considering the various subdivisions of this agenda item, the Group exchanged general views on how separation standards are assessed. It was agreed that the results of mathematical/statistical studies should be stated in such a way as to ensure that they will not be understood to apply in areas other than the area under consideration within the NAT Region because, for example, the combination of traffic density and navigational environment in this Region is unique. There was a desire to express such results in terms other than collision risk. It was the general view that mathematical/statistical results should be expressed in terms of a range instead of a single figure. This approach seemed necessary in view of the number and nature of the assumptions involved in the process. It was believed that the States and International Organizations of the North Atlantic Region may wish to analyse the data gathered during the survey in the way or ways they consider most valid; and that some will wish in the meantime to continue working on refinements in the application of mathematical/statistical techniques in this matter.

4.2 Discussion indicated that a quantitative expression of risk was useful only to those who fully understand the many assumptions and complexities that go into its determination. Its use should therefore be limited to those directly involved with, or fully briefed on the mathematical/statistical process. The terms used in the expression should involve as little subjective influence as possible, and should clearly apply exclusively to the part of the North Atlantic oceanic area under consideration.

4.3 Accordingly the Group reached the following conclusions :

1) risk is usefully expressed quantitatively only for purposes of mathematical/statistical analysis, for this purpose the most appropriate unit of expression is the number of fatal jet aircraft accidents per 10 million aircraft flying hours en-route in the parts of the NAT oceanic area under consideration, rather than numbers of flights or long periods of time;

2) in presenting the results in a form for general use, the level of risk should be expressed as being based on an improvement of a previous safety record.

B. THE ACCEPTABLE LEVEL OF RISK

4.4 The Group considered it essential to aim at setting a "target level" of safety from collision for the purpose of mathematical/statistical assessment of future separation standards over the North Atlantic. Attention was directed to choosing a target level applicable to the next 5 years of operation in this Region. It was understood that choosing such a target was not equivalent to deliberately building a fixed risk into the system, because in practice the target is being set on a conservative basis and in terms of a range of improvement over the safety level which has applied previously. Proposals were made that this "target level" of safety should be compared not only with those rates of risks recorded by the air transport industry but also other means of transport and/or other human activities (such as population mortality rates in industrialised countries, occupational risks, etc.) and the results of a study by the United Kingdom was offered for consideration. The Group, although considering it desirable that such an approach be pursued, felt it, however, beyond its present responsibilities and agreed that the "target level" of safety should be related, as a point of departure, to the rate of fatal accidents recorded in the recent past by the civil air transport industry.

4.5 Moreover, as the concern of the Group was with the operation of jet aircraft over the NAT Region, it agreed to take into consideration the rate of fatal accidents recorded by civil jet aircraft only. In this respect the Group had before it different views regarding those accidents to be taken into account :

1) the overall number of jet aircraft accidents;

2) jet aircraft accidents during the en-route phase of flight only, collision on North Atlantic routes being treated as one of the en-route risks.

The Group decided to take into consideration the overall rate of fatal accidents recorded by civil jet aircraft, and that a fraction of this rate was due to collision. Examples of other major classes of hazard in any phase of the flight were :

loss of performance

failure of flight control system

loss of control (e.g., due to jet upsets)

structural failure

fire and explosion

loss of information (e.g., instrument failure).

4.6 The Group believed that Systems planning should aim at improving, by a chosen factor, the safety level recorded in the past. Extensive discussion took place on this safety improvement factor and it appeared that any figure would be difficult to justify unless a cost/benefit ratio analysis was made; such a study, which would involve States' policy regarding safety, has been deemed by the Group not to be feasible at this time. The Group could therefore only agree that the improvement factor in safety which could be aimed at would range between 2 and 5, i.e., the safety in aircraft operation would improve by some 100 to 400% in the next 5 years. Views were expressed that general improvements of this magnitude were unlikely whilst others, although agreeing that this could be so for most major classes of hazard, believed that reduction in collision risk could be more easily achieved.

4.7 At this stage the Group felt that any apportioning of the risks due to one of these causes could only be an arbitrary one but thought it necessary in order to arrive at an acceptable assumption of the level of the risk due to collision. This was therefore assumed as being the 1/10 of the overall risk.

4.8 The collision risk was suggested as being made up of :

i) the sum of the risks inherent in the three separation standards (vertical, lateral and longitudinal);

ii) the risks which might arise in emergency situations when an aircraft has to divert from its planned path without awaiting a clearance; and

iii) any risks that may be attributed to the "air traffic control loop".

4.9 The Group agreed that item ii) may be assumed to be negligible. As regards item iii) it was clear that this risk must be understood as deriving from any error occuring in the ATC loop (for instance an error or malfunction that results from garbled communications, misunderstanding of control instructions, errors in issuing ATC clearance).

It was agreed that the collision risk must be the sum of the two risks i) and iii); both can be computed separately and no a priori relationship between them could be established. The computation of the risk due to the ATC loop is considered in para 4.19 below. For the present purpose however, the Group decided to ignore the risk represented by this item recognizing that it was not zero but that it was probably not large and did not accept a proposal that as much as half of the collision risk should be attributed to it.

4.10 Any sharing of the total collision risk between the three separation standards appeared arbitrary to the Group. The Group nevertheless retained an equal sharing of the total risk between the three standards as a starting point for developing a target level of safety for lateral separation, it being recognized that cost/benefit studies or some computed ratios might indicate some other division.

4.11 Factual evidence of the number of accidents which had occurred in the civil jet transports in recent years was examined and it was decided to take the period, January 1959 through 28 September 1966. During this period 34* such accidents in approximately 15½ million flying hours were recorded, giving a rate of jet aircraft fatal accidents of 22 per 10 million aircraft flying hours.

* This figure is to be further checked since evidence forwarded by the United States member of the Group indicated that it might be underestimated.

4.12 Finally, the Group concluded that :

1) the overall target level of safety from collision over the North Atlantic would be to keep the fatal accident rate in the range from 1.1 to 0.44 per 10 million aircraft flying hours or lower;

2) the target level of safety for the lateral NAT separation standard should be to keep the fatal accident rate in the range from 0.366 to 0.146 per 10 million aircraft flying hours or lower.

4.13 The Group agreed to consider a collision between jet aircraft over the North Atlantic as equivalent to two fatal accidents; whilst recognizing that a metallic contact involving two aircraft will not always result in two fatal accidents, it considered, however, this assumption as a conservative approximation of catering for collision risks, with the understanding that States should investigate the factor to be used on a factual basis.

C. THE CALCULATION OF ESTIMATES OF RISK

4.14 The risk associated with separation standards

4.14.1 It was agreed that the discussion on the method of calculating risk could be divided into two subjects :

- a mathematical model developed a number of years ago;
- the application of statistical data to this mathematical model, in order to find quantitative values for the risk.

4.14.2 The mathematical model developed by the U.K. was accepted by the Group as the basis for the calculations. It is described in Appendices A and B. It was, however, pointed out that some of the assumptions used in setting up the model must be verified. In particular, the assumption that the lateral closing speed between two aircraft $\mathring{y}$ and their lateral distance y are statistically independent. This is discussed in para. 4.15.7. Some simplifications made for the convenience of the model will have minor effects on the final result. Should appropriate experimental measurements become available, the validity of these simplifications could if necessary be reconfirmed.

4.14.3 When applying statistical methods to determine the values of the parameters in the equations of the mathematical model, there is some difficulty in finding exact figures which would be valid for the period when reduced separation standards would become applicable. This is mainly due to three causes :

1) the number of statistical data on some of the parameters available now or in the near future may not be entirely sufficient;

2) some of the data are not fully representative of the situation at the moment at which they were measured;

3) future changes in the traffic density, the types of aircraft, the navigation equipment, the flight-deck procedures, ATC systems, etc., may cause some parameters to vary somewhat in the future.

4.14.4 The Group examined the effects of this non-representative sampling on the estimated risk of collision and felt it desirable to investigate the correlation between the results obtained during the present survey and the true characteristics of traffic, with regard to any of the above-mentioned parameters.

4.14.5 It was also agreed that account should be taken of any foreseeable improvements in flight level keeping accuracy in the near future, as these would tend to increase the collision risk due to failure of lateral separation. In this connection, it was observed that the rectangular array of flight paths (i.e. that in which aircraft in adjacent tracks are flying at the same flight levels) is not necessarily the best way of reducing collision risks. If composite separations were applied so that the flight levels assigned for adjacent tracks were staggered, the risk would be appreciably lower for the same traffic density. The applicability of such a procedure should be seriously studied.

4.15 Determination and processing of estimates for random variables

4.15.1 The uncertainty in the parameters can be expressed by accepting the possibility that they may lie in a range of values (grey area) around the value calculated from the statistical data. It was agreed that the bounds of these "grey areas" should be based on judgment if sufficient data were not available and should be decided by the Group. In the mathematical expressions of the model this can be expressed by replacing each parameter which is not exactly known by a random variable w. One of the parameters is expressed by using more than one random variable. The equation to be used is given in Appendix C.

4.15.2 Random variables were introduced for the following effects:

w (tail area)	:	tail area
w (tail shape)	:	tail shape
w (α)	:	visual collision avoidance
w [Ty(same)]	:	same direction lateral proximity
w (ΔV)	:	longitudinal closing speed for pairs of same-direction aircraft
w (Λ_x)	:	effective collision length
w [Nz(o)]	:	frequency with which vertical separation shrinks to less than aircraft thickness for pairs nominally at the same flight level
w ($\dot{y}$)	:	lateral closing speed of a pair of aircraft which has lost lateral separation
w [Ty(opp)]	:	opposite direction lateral proximity.

4.15.3 A calculation of the collision risk by the method indicated above will produce therefore a "grey area and the Group had to agree which value from this "grey area" will have to be used in deciding whether a certain separation standard is safe or not. Discussion showed that if for all random variables the most "optimistic" value were chosen (i.e. the value which would lead to the lowest value of the risk), the value calculated for the risk would be unsafe to be used. On the other hand, using all "cautious" values of these variables, a much too high value of the risk would be obtained because of the improbability that all adverse assumptions should apply at the same time. Methods for calculating intermediate values were proposed and a Digital Simulation method based on a well-known statistical process called the "Monte Carlo" was accepted (this is referred to hereafter as the DS method).

4.15.4 In order to apply the DS method, it is essential to represent the various random variables by a probability distribution function. For some of these parameters this probability function is known a priori. An example of such a function is w (tail area) which is derived from a binominal distribution (as approximated by the Poisson distribution and described in Appendix A). For a number of other parameters, such as w (ΔV), w $[N_z(o)]$ and w ($\dot{y}$), enough data will be available to establish the distribution function. On the other hand, the limits of the distribution of some of the random variables w (tail shape), w (α), w $[T_y(opp)]$ are only specified by their assumed bounds. It is very probable that the real distributions will have a peak near the centre of the distribution. It was decided by the Group that for these distributions the cautious assumption that there will be an equal probability for each value between the bounds will be used. Only for w (tail shape) a special procedure was accepted which will be described in para 4.15.5 below. For the determination of w (Λ_x) a special procedure is described in para. 4.15.13.2 below.

The Group discussed the values and "grey areas" of each of the parameters referred to above separately.

4.15.5 <u>The probability of "lateral overlap" k.w (tail area) w(tail shape)</u>

4.15.5.1 The probability P_y(std), that the lateral overlap (i.e. wing overlap) occurs with a pair of aircraft flying nominally on adjacent flight tracks, will be determined from the data on across-track errors of single aircraft observed during the forthcoming data collection exercise. The distribution of the lateral distance between pairs of aircraft can be studied by 2 different ways:

1) by convoluting with itself an inferred distribution of across-track errors of individual aircraft

2) by inferring a distribution of separation errors from direct observations of the lateral separations of proximate pairs of aircraft.

4.15.5.2 The first method has the advantage that it supplies in practice much more information for a given size of sample. If a correlation exists between the across-track errors, this should be determined from the data. In that case the distribution obtained by the "convolution" process might give the more cautious estimates of risk. Methods for determining P_y(std) for both cases are discussed in Appendix B.

4.15.5.3 The uncertainty which exists on this parameter stems from two sources:

1) the number of observations in the tail is relatively small and other samples of similar size might have produced a different number of observations in that area. The uncertainty about this tail area is expressed by the random variable w (tail area). The method for calculating this parameter is discussed in para. 4.15.5.4 below.

2) It could be more difficult with this relatively small sample to assess the tail shape and assumptions must be used for this shape. This is expressed by the random variable w (tail shape). The method by which this will be done is discussed in para. 4.15.5.5 below.

4.15.5.4 <u>w (tail area) - The proportion of across- track errors exceeding the semi-standard</u>

The Meeting agreed that equation (9) of Appendix B can be regarded as the cumulative distribution function (c.d.f.) of the tail area. For a given total sample of across-track errors, the number exceeding the semi-standard uniquely specifies the notional c.d.f. of tail area. This is a case which does not call for judgment to be exercised in representing the distribution of a w (....).

4.15.5.5 <u>w (tail shape)</u>

4.15.5.5.1 In the process of assessing a separation standard, it is to be expected that the number of available observations of across-track errors in the tails (i.e. in excess of the semi-standard) will be insufficient to determine precisely the shape of the error distribution tails.

Observations taken in the past suggest that the frequency curve of the across-track errors observed in the proposed data collection is likely to lie between the curves corresponding to the "level tails" and "exponential tails" models described in Appendix B. These models lead to estimates of P_y(std) which are roughly in the ratio of 10:1 for tail areas in the range 10^{-4} to 10^{-2}. The Group agreed that if the observed data were clearly shown to lie closer to the "exponential rather than the "level" shape, a reasonable cautious DS method treatment for w [P_y(std)] would be to replicate the quantity

$$W\,[P_y\,(\text{std})] = k.w\,(\text{tail area}).\,w\,(\text{tail shape})$$

in which w (tail shape) is uniformly distributed between the limits set by the "level" and "exponential" models and k is a scaling factor.

4.15.5.5.2 After sufficient data are collected, one of three distinct possibilities may occur:

1) The area of the tail is so small, regardless of its shape, that the separation standard under consideration can be judged "safe". The next step will then be to analyse a smaller separation standard.

2) The data falling outside the half-separation point are so complete that an accurate judgment on shape will be possible and no assumed wide range for w (tail shape) will be necessary.

3) The intermediate case where the data are not sufficient for a precise determination of risk without assumption on shape, and where precise determination of shape is also not possible. The basic procedure here will then be to use a flat distribution between "flat" and "exponential" shape assumptions.

4.15.5.5.3 If this case should occur, it has been suggested that more precise information may possibly be obtainable by the following additional test:

Define a general p.d.f. such as:

$$p(y, \beta) = (1 - \beta) \cdot \text{flat} + \beta \cdot \text{exponential}$$

where β is a weighting parameter ranging between zero and one. For each of a set of values β_i within this range, a standard χ^2 (Chi-Square) hypothesis test can be applied to the extremal data for $p(y, \beta_i)$, and by inversion of the usual process, the confidence level C_i for which transition between "yes" and "no" occurs may be determined. Then a graph of $C_i(\beta_i)$ may possibly show a strong maximum somewhere within the (0,1) range. If this should occur, then a more accurate p.d.f. for w (tail shape) might be constructed. The figures 3, 4, 6, 7 in RAE TR 66295 seem to indicate that the true shape may depart slightly from exponential, so this χ^2 study may therefore be appropriate, since the upper bound (flat) is that specific flat shape after maximization of the risk, and hence may indeed be too pessimistic for sufficiently high accuracy in this case.

4.15.6 <u>The longitudinal closing speeds w (ΔV) and 2 V</u> - The distribution function of the relative longitudinal speed between aircraft flying in the same direction will be determined from the data collection exercise. It was remarked that it will be necessary to check these data with regard to a possible correlation with the longitudinal distance between two aircraft. It was decided that for the longitudinal closing speed 2 V of aircraft flying in opposite directions a single figure will be used: 960 kt.

4.15.7 <u>The lateral closing speed w ($\dot{y}$)</u> - The value of this parameter is to be determined from the data collected by the ship-borne radar measurements in the forthcoming data collection exercise. It was suggested that there are reasons to suppose that some correlation may exist between the lateral speed and the across-track deviations of the aircraft and the Group decided that the data should be tested with regard to this correlation. From the results of this test it will be possible to extrapolate to the probability distribution of the closing speed when the lateral distance between two aircraft has become zero.

4.15.8 <u>$w(\alpha)$ - Visual collision avoidance parameter</u> - It was suggested that this parameter should take into account those occasions where one of the pilots in two aircraft on a collision course will sight the other aircraft and take evasive action. A factor of 1.0 would mean that evasive action will not be successful; a factor of zero meaning that in every case collision will be avoided by evasive action. Discussion revealed different opinions of the problem. However, the Group agreed that a factor of 1.0 should be used in the calculation of the risk estimate, it being understood that, as a result of this assumption, the risk so evaluated should be described as "the blind flying collision risk" and thereby probably overestimate the collision risk rate.

4.15.9 <u>$w(T_y$ same) and $w(T_y$ opp) - Proximity values.</u>

4.15.9.1 There is a need to sample certain characteristics of controlled traffic flows which reflect the extent to which each of the three dimensions of space is to be used in separating aircraft, within the period to be considered. These characteristics, which are termed "proximities" are described in Appendices "A" and "B". They are sampled from observations of actual traffic patterns together with forecasts of future traffic. For same-direction traffic, the proximities are likely to increase somewhat more slowly than the square of the total amount of traffic because there is a tendency for ATC to increase the available number of flight-paths as traffic increases. Day-to-day variations in sampled traffic patterns (ten 24-hour periods have recently been analysed by the United Kingdom) seem to lead to only small differences in the daily amount of same-direction proximity, provided allowance is made for the amount of traffic in the respective sample, and it appears that predictions can be made almost as reliable as the forecasts of future traffic flow rates. If the latter are correct to within ± 20%, then it seems likely that the spread in forecast same-direction proximities can be kept within ± 40%.

4.15.9.2 Forecasting opposite-direction proximity is more difficult for two reasons. There is considerable sampling variation (i.e. one 24-hour period may give a very different proximity to another) due to weather patterns. Moreover, there is considerable difficulty in forecasting the amount of the against-the-tide traffic which determines the opposite-direction proximity - for example, there is considerable uncertainty in predicting the upward trend of westbound night freighting. Thus, upper and lower extremes of the forecast future opposite-direction proximity may be in a ratio as large as 10:1. However, it is to be expected that at least 80% of the total collision risk in the period to be considered will be associated with the same-direction proximities, and so the uncertainties in forecasting opposite-direction proximity are not so important as they seem at first sight.

4.15.9.3 If, as may be expected, there is only a limited number of samples of actual proximity (e.g., of the order of 10 periods of 24 hours), then it would seem reasonable to take a rectangular distribution between the extremes of forecast proximities inferred by extrapolating to future traffic intensities. Of course, it is to be understood that same- and opposite-direction proximities would be treated separately in this respect.

4.15.10 <u>The probability of "vertical overlap" - $P_z(o)$.</u> The quantity $P_z(o)$ represents the probability that a pair of aircraft assigned to the same flight level are separated in the vertical dimension by less than an aircraft's thickness. There is considerable evidence from which to estimate $P_z(o)$ in current operations. It seems unlikely that $P_z(o)$ will change substantially in the period considered; which is roughly equivalent to saying that the standard deviation of the height separation between two aircraft is unlikely to change substantially. The meeting agreed that the most reliable data from which to estimate $P_z(o)$ is that given in IATA Doc Gen 1951, based on observations taken in 1963. It is shown in R.A.E. Technical Report N° 64043 that this leads to the estimate : $P_z(o) = 1/4$.

4.15.11 <u>$w[N_z(o)]$ - Distribution of the frequency of vertical overlap.</u> The distribution of $w[N_z(o)]$, that is of the frequency with which vertical separation of a pair of aircraft assigned to the same flight level shrinks to less than aircraft thickness might be based on data already available. Traces of the flight profiles of NAT jets in level flight have been obtained using a missile-tracking radar at R.A.E., Aberporth to monitor a section of U.K. Airway G.1. These confirm the presence of oscillations of the order of 1 minute period, as expected from calculations of the "stick-fixed" phugoid frequency, and show amplitudes ranging from 10 to 100 feet. If it is assumed that the oscillationa of close neighbours are independent, then pairing the traces gives a means of sampling the frequency. It appears likely that $N_z(o)$ is located in the range 20 to 60 per hour and, since this term makes only a small contribution to the total risk, it may well be considered that the available data are sufficient. The Group noted that observations during a period of a few minutes on approximately 20 flights will give a sufficiently accurate representation of the distribution of $w[N_z(o)]$.

4.15.12 <u>S_x - The along-track criterion of proximity.</u> The Meeting agreed that this quantity does not affect the final result in the computation of collision risk. Its value is chosen so as to facilitate the data collection needed to sample the proximities T_y(same) and T_y(opp). Since the T_y's are simply proportional to S_x, it is obvious that the terms $T_y(\text{same})/S_x$ and $T_y(\text{opp})/S_x$ in the risk equation [equation (1) of Appendix C] are independent of S. It follows from the form of this risk equation that the computed risk must also be independent of S_x. (cf. also Section 4 of Appendix B).

4.15.3 <u>The effective collision size and shape of an aircraft</u>

It was pointed out that with respect to these parameters, there are two problems :

1) the dimensions of the collision shape to be used if only metallic collisions are to be considered;

2) a possible extension of this collision shape to allow for the vertices shed by an aircraft, should it be found that these present a fatal danger to a following aircraft.

4.15.13.1 <u>Dimensions of the slab.</u> In previous calculations with the mathematical model the aircraft has been represented by a rectangular slab with dimensions $\lambda x = 150$ ft., $\lambda y = 150$ ft. and $\lambda z = 40$ ft. It was pointed out that the length, span and thickness under cruising conditions of some of the stretched versions of current aircraft now in operation will slightly exceed these values. On the other hand, it was mentioned that because an aircraft does not completely fill its rectangular slab in about 40% of the cases when these slabs intersect each other, no metallic collision occurs. It was decided that in future calculations the collision shape for metallic collisions will be rectangular with the dimensions :

$\lambda x = 150$ feet $\lambda y = 150$ feet and $\lambda z = 40$ feet.

4.15.13.2 <u>Influence of vortices on the dimensions of the slab - Determination of $w(\Lambda x)$.</u> Conflicting information was brought to the Group on the subject. On one hand it was indicated that unpublished theoretical calculations suggested that the vortices shed by transport aircraft might be strong enough to jeopardize the safety of another jet transport penetrating them. In particular, in the cores of those vortices circumferential velocities of 75 to 200 feet/second can occur at large distances behind the aircraft inducing gust loading and rolling moments to the following aircraft which might lead to fatal accidents. Such effects could increase the accident rate due to structural failure by some 8 times more than accidents due to metallic collision and the accident rate due to fatal loss of control by as much as 100 times, even after allowing for the fact that only one of a pair of aircraft is at hazard. It was proposed that, although the theory of vortices on which these calculations are based is very uncertain and many of the dynamic problems are imperfectly understood, this effect should be seriously considered in any calculation of risk.

4.15.13.2.2 On the other hand, information based on both theoretical evidence and on practical experience seemed to indicate that no fatal accidents were likely to occur due to vortices. Theoretical calculations based on data contained in FAA Reports N° RD-64-4 (January 1964) and RD-64-55 (May 1964) prepared by Boeing Co. indicate that for the Boeing 707-320 cruising at a Mach number of 0.85 at flight level 350, the maximum core velocity would be 57 ft/sec at the point of vortex roll-up about 750 feet behind the aircraft (the core radius being some 11 feet). This would cause incremental load factors on aircraft between + 1.5 g and - 0.5 g, which are well within the jet transport aircraft design limits. Rolling velocities of the order of 20 degrees per second could be induced whilst Boeing 707-320 has a lateral roll-control capability of 30 d°/sec. This appeared to be well within the roll control performance of the aircraft. In addition to this information which is dependent in part on theory and in part on experiment, it was conveyed verbally to the Group that refuelling operations and formation flying did not record any accidents which could be attributed to vortices.

4.15.13.2.3 The Group noted that the latter information on vortices are based to some degree on theoretical computations and concluded that these computations cannot be accepted as final evidence. As regards the information based on experiences with refuelling and formation flying, it was questioned whether the manoeuvres are not executed in such a way as to minimize or even preclude any entrance into the vortices of the leading aircraft. The Group therefore concluded that there seemed to be evidence that the risk due to vortices was less than suggested in para. 4.15.13.2.1 but that there was as yet insufficient evidence available that it could be completely neglected and that States should be requested to provide for additional evidence on vortices to be gathered and disseminated to all concerned as soon as possible.

4.15.13.2.4 As mentioned in Appendix C there is no need to radically change the form of the collision risk equations in order to make them compatible with any change in effective collision size of an aircraft due to vortices. To a first approximation they may be rewritten as though each aircraft were a rectangular slab $\Lambda_x \cdot \lambda_y \cdot \lambda_z$. That is, only the longitudinal dimension need be changed. The length, Λ_x, must of course be adjusted to allow for the special shape of vortices and for the fact that only one of a pair of aircraft is at hazard during a vortex penetration.

4.16 <u>Presentation of the results of the DS method (computed risk rates)</u>

4.16.1 The Group agreed that the collision risk estimates for the lateral separation under consideration resulting from the DS process should be presented in the following manner:

4.16.1.1 The computer will explicitly evaluate the risk formula for a large number n of trials. For each trial, generation of independent random numbers in the (0,1) interval will pick values of each input parameter, consistent with the given probability-density function (p.d.f.) for each parameter. The n numbers, each corresponding to a calculation of the risk rate R can then be used to define a cumulative probability distribution and a p.d.f. for the R variable. The final result is then the precise presentation of these distribution curves, which range from 0 to the highest value computed in the n trials. The p.d.f. curve, which will have a sharp peak (mode) at a "central" or "most probable" value of R can then be calibrated for various values of its area, e.g. values of area 0.80, 0.90,......, 0.99. The values of $R = R_{80}, R_{90}, \ldots\ldots, R_{99}$ correspond to the one-sided confidence levels of 80%, 90%, ..., 99% respectively.

4.16.1.2 These "confidence levels" for the actual collision risk are somewhat different from confidence levels usually used by statisticians. Since the choice of the input distribution of paras. 4.15.5.1 through 4.15.13 plus other cautious approximations have all been chosen with the intention to over-estimate the risk as given by the output p.d.f., these confidence levels are conservative estimates of the true confidence levels.

4.16.1.3 For any value of R which will be chosen, the associated Poisson density distribution defining the random occurrence of collisions is thereby known and can be used to calculate directly the actual probability that there will be zero collisions in the next five years. A tabulation of such collision-free probabilities can then be presented as part of the final results. Such numerical results are meaningful and useful without the necessity of separately defining and accepting any target level of safety.

4.16.1.4 The shape of the p.d.f. for R and the values of each confidence level for R are clearly dependent upon the p.d.f.'s known or assumed for each input parameter, although the final effect of each upon the output is less than it would be if no DS procedure were used. Nevertheless, it is desirable as a supplement to the presentation of the output risk R as described, to show how sensitive the calculated confidence levels are to variations in the p.d.f.'s and the assigned limits. There does not seem to be any difficulty in developing techniques for this purpose.

4.17 Required number of independent observations

4.17.1 The target level of safety to be associated with each of the three separation standards as has been discussed by the Group is likely to lie in the range 0.14 to 0.36 aircraft accidents per 10 million flying hours. As a guide to forecasting the required quantity of data on across-track errors, it seems useful to take the hypothesis that the risk is estimated as follows :

1) Using the equations and numerical values given in Appendix "A" to find the range of P_y (90 NM) which is consistent with the target range. (This would imply the assumption that there is "blind flying" and that only accidents due to metallic collisions are to be taken into account.)

2) To find how many independent observations are needed to confirm, to a 97½% level of confidence, that P_y (90NM) is as small as a given target level, assuming :

   a) a "level-tails" distribution;

   b) independence of across-track errors of proximate aircraft; and, of course

   c) that the quality of navigation is indeed such as to make the actual value of P_y (90 NM) acceptably small.

4.17.2 From the theory given in Appendix "B" the requirement is then to show, to a 97½% confidence level, that the proportion of across-track errors exceeding 45 NM is consistent with the target level of safety. For the lower end of the target range, the requirement is to show that this proportion is less than 10^{-3}; for the upper end the corresponding figure is 4×10^{-4}. Very roughly, these proportions can be demonstrated to 97½% confidence using, respectively, 3 600 and 9 000 independent observations.

4.17.3 There are probably two "pessimistic" tendencies in the estimation of the required number of observations, viz. the "blind flying" and "level tails" assumptions. Moreover, exploiting the "tendency to centrality" is likely to lead to reduced estimates of risk. It may also emerge from a data collection that correlations in the across-track errors of proximate aircraft are such as to make the above estimations somewhat pessimistic. On the other hand, to the extent that wing-tip vortices may possibly be proved to have a substantial effect, these estimations are "optimistic". On balance, and bearing in mind that observations may be costly, it would seem adequate to aim for 5000 independent observations.

D. MEANS OF EXPRESSING THE QUALITY OF NAVIGATION REQUIRED TO MEET A TARGET LEVEL OF SAFETY

4.18 When considering this subject, the Group noted that the United Kingdom has used as a simple criterion a proportion of flight time spent with an error in excess of half the standard separation but considered it premature at this stage of the surveys to make any decision regarding the quality of navigation required to meet the proposed target level of safety.

E. COMPUTATION OF THE RISK DUE TO THE "ATC LOOP" ERRORS

4.19 As already referred to in paragraph 4.9 above, it did not appear acceptable to the Group to attribute as much as half of the collision risk to the "ATC loop" errors but considered it desirable that estimate of the risk attributed to these errors should be computed. A method for such computation is given hereunder :

"Let X_1 be the number of ATC loop errors per year which result in an aircraft having the same nominal track and flight-level as aircraft going in the <u>same direction</u>, but no planned longitudinal separation from them.

Let X_2 be the corresponding number for the <u>opposite direction</u> case.

Let P_1 and P_2 be the average proportions of the total oceanic flight time (approx. 3 1/4 hours) for which the same- and opposite-direction types of system error are allowed to persist.

The equations and numerical values in Appendix A give the order of magnitude of the blind-flying risk due to metallic collisions as $10^{-3}(P_1 X_1 + P_2 X_2)$ fatal aircraft accidents per year, assuming "blind flying" (i.e. no successful visual collision avoidance) and that wing-tip vortices have no influence on the effective collision length of an aircraft.

Assuming that there are roughly 60,000 jet flights per year over the North Atlantic, the above risk is equivalent to 0.05 $(P_1 X_1 + P_2 X_2)$ fatal aircraft accidents per 10 million aircraft hours.

The target level for the <u>total</u> allowable risk due to collision lies in the range 0.4 to 1.1 fatal aircraft accidents per 10 million aircraft hours.

If it is assumed that :

a) the standard deviations of across-track errors and height-keeping errors will not decrease substantially in the period considered; and,

b) the correlations of these errors will not increase substantially during this period;

then one has to be satisfied that $(P_1 X_1 + P_2 X_2)$ is of the order of 1 per year or lower in order to neglect the risk due to the ATC loop errors."

$P_1 X_1 + P_2 X_2 \leq 1$

ESTIMATED RISK ASSOCIATED WITH SEPARATION STANDARDS - BASIC PRINCIPLES

1 THE APPROACH TO ESTIMATING COLLISION RISK

The process of estimation is to piece together the transient risks to individual aircraft so as to give the expected number of collisions arising from all traffic during the period considered. In practice, this will almost always be a fractional number very much less than unity. For illustration, one can simplify by supposing all aircraft to be flying on parallel flight-paths; both same-direction and opposite-direction traffic will be considered. From this, the general extension to a multi-directional traffic area should become evident (although its exposition would be rather tedious).

(a) Representing the planned exposure to risk

Air traffic control separation standards denoted by S_x(std), S_y(std) and S_z(std) for, respectively, the along-track, across-track and vertical directions are shown by the inner box of Fig. I. The intended position of an aircraft, as determined by the accepted flight plan, is shown at A. The controller's task is to ensure that the intended position B of any other aircraft is never inside the inner box. A significant collision risk will arise only when B is intended to be on one of the faces of the inner box, or just outside it, because the risk can be expected to fall off very rapidly with distance outside this box. Fig. I shows an enveloping shape, the 'proximity shell', outside which the collision risk between aircraft A and B can be assumed to be negligible, and within which an aircraft, B, is said to be in proximity with A and the pair are exposed to the risk of collision. The problem is to estimate the total collision risk, for all pairs of aircraft which become 'proximate', in this sense, in the traffic region over a given period of time. One must therefore take account of the expected number of times each aircraft flying in the region during this period has another aircraft in its proximity shell. For reasons to be discussed shortly, one must also take account of the expected length of time this other aircraft will remain in the shell, and the path it describes through the shell.

(b) Representing the collision process

Because of the errors in keeping to speed, track and height (which are here termed "flying errors") the true positions, shown at A' and B' in Fig. 2, differ from the intended ones. The collision risk for the pair of aircraft is the chance that the vector (A'B') shrinks sufficiently for the aircraft to touch. This chance depends, of course, both on the intended separation (AB) (i.e. the location of B within the proximity shell) and on the flying errors. For a period of time during which the expected number of collisions is small, this (fractional) number is itself a convenient and very close approximation to the chance of collision. Thus, assuming a safe traffic system, it is convenient to refer to an expected number of collisions as the risk. So far, the word 'risk' has been used rather loosely. In what follows the term <u>collision risk</u> will be used for the expected number of collisions over a specified period of time. For example, one may talk of the collision risk for the duration of flight by a pair of aircraft which become proximate at some stage, or for all aircraft flying in a traffic region during a period of several years. The term <u>collision rate</u> will denote the expected number of collisions per unit time between a pair of aircraft at some given (and possibly transient) intended separation (AB).

In general, the intended separation (AB) varies as the flight progresses; and, in the planned passage of B past A, B may describe a trajectory which takes it into the proximity shell of A. If the two aircraft are travelling in the same direction at about the same speed, the variation is slow, and B may remain in the proximity shell for several hours. For an opposite-direction pair, on the other hand, B may pass through the shell so quickly that the flying errors remain sensibly constant during the period of exposure risk; in this case, the exposure to risk could be treated as a discrete event, viz the 'passing' of the two aircraft. The exposure for the same-direction pair cannot be treated as a discrete event in this way. The only general approach to collision risk in a traffic region is to treat the shrinkage of (AB) as a time-dependent process. Accordingly, the collision risk for the flight of a proximate pair of aircraft is to be computed by taking elements of time small enough for the intended separation, (AB), to remain sensibly constant, then summing the expected numbers of collisions occurring in each such element of time.

To estimate the collision risk, i.e. the expected number of times, in a given time interval, the actual separation (A'B') shrinks to collision size, (A'B') must be considered as a time-varying quantity. In addition to our knowledge of (AB) it is necessary to know two properties of the flying errors:

(i) the probability distributions of the error magnitudes

(ii) the probability distributions of the rates of change of these magnitudes.

The need to consider both properties can be seen in the example of two aircraft on nominally parallel paths flying at the same intended speed in the same direction. In this case variation of (A'B') is due solely to the flying errors.

(expected frequency with which (A'B) shrinks to collision size)
= (proportion of time during which (A'B') is less than collision size)
/(average duration of the intervals during which (A'B') is less than collision size). .... (I)

On the right-hand side of equation (I) the first term may be inferred from property (i); the second term has to be inferred from property (ii). To put it in familiar terms, one needs to consider the wavelengths, as well as the amplitudes, with which aircraft oscillate about their intended positions.

Having shown that a general approach must represent the time-dependent behaviour of (A'B'), it is simplest to think in terms of components of motion (assumed to be independed of one another) along cartesian coordinates, x, y and z, corresponding to the along-track, across-track and vertical dimensions. Taking the motion of one aircraft relative to the other, the collision process may be looked on as a particle bombarding a slab. In Fig. 3, A and B again show the intended positions, and the change in separation which is due to the combined flying errors of the two aircraft is shown by (BB"). Both aircraft have been given a notionally rectangular collision shape, with λ_x, λ_y and λ_z representing, respectively, the length, span and thickness. The collision rate is given by the expected number of times the particle, shown at B", enters the slab through the sides, the ends, and the top and bottom. It is only by summing these three contributions that the total rate can be found. For simplicity, the examples given here take the metallic length of aircraft to set the effective collision length. However, if hazardous wake effects are significant and can be quantified they can be taken into account. (See Appendix C.)

The following quantities may be defined:

N_x is the expected frequency with which the along-track separation shrinks to less than λ_x.

N_y and N_z are similarly defined for, respectively, the across-track and vertical directions.

P_x is the probability that the along-track separation is less than λ_x, i.e. the proportion of time the aircraft spend in this condition.

P_y and P_z are similarly defined for, respectively, the across-track and vertical directions.

Suffix (A B) denotes values which the above quantities take throughout periods when the planned separation may be taken as sensibly constant at the vector (AB).

The frequency with which the particle B" enters the slab through either end is given by the probability that its y and z coordinates lie within the dimensions λ_y, λ_z of the end faces, multiplied by the frequency with which its x co-ordinate becomes less than λ_x. For the constant intended separation (AB), this may be written

$$(N_x P_y P_z)_{(AB)}$$

Similarly the frequency of entering through the top or bottom is given by

$$(N_z P_x P_y)_{(AB)}$$

and through either side by

$$(N_y P_z P_x)_{(AB)}$$

Thus the collision rate for the intended separation (AB) may be written

$$(N_x P_y P_z)_{(AB)} + (N_z P_x P_y)_{(AB)} + (N_y P_z P_x)_{(AB)} \qquad \ldots\ldots\ldots\ldots (2)$$

Using equation (I) one may deduce an equivalent expression for the collision rate

$$(P_x P_y P_z)_{(AB)} \left(\frac{1}{t_x} + \frac{1}{t_y} + \frac{1}{t_z} \right)_{(AB)} \qquad \ldots\ldots\ldots\ldots (3)$$

where

t_x is the average of the time intervals during which along-track separations are less than λ_x.

t_y and t_z are similarly defined for the across-track and vertical directions.

One can now see clearly what is implied in treating the intended 'passing' of two aircraft as a discrete event, instead of integrating the collision rate with respect to time as their flights progress, i.e. as A and B change. Take, for example, a pair of aircraft intended to pass once only in opposite directions on parallel tracks. Because the across-track and vertical velocity components (due solely to the flying errors) are small compared with the relative along-track component, t_y and t_z are much larger than t_x; also, P_y and P_z remain constant, because the flight-paths are parallel. The collision rate for the pair (at an intended separation (AB)) is therefore, from equations (2) and (3), approximately

$$(N_x P_y P_z)_{(AB)}$$

the second and third terms of equation (2) being negligible. The collision risk during the 'passing' is obtained by summing this quantity over the flight path of either aircraft, or in practice, over that part of the path of one aircraft which lies within the proximity shell of the other. That is over all values of (AB) within the shell. This gives

$$\sum_{\text{all}(AB)} (N_x P_y P_z)_{(AB)}$$

or, because P_y and P_z are constant

$$P_y P_z \sum_{\text{all }(AB)} (N_x)_{(AB)}$$

which, because there is one passing, becomes simply

$$P_y P_z$$

Thus the risk of collision per flight, when the flight plans are such that only a high-speed pass is involved, is determined solely by the y and z error probability distributions. On the other hand, for slow passings, such as are implied in same-direction traffic on airways, relative velocities are comparable in the three directions, and therefore all three terms in equation (2) are important. The collision risk then depends upon the probability distributions of the rates of change of the errors, which influence the N's, as well as on the probability distributions of the error magnitudes which determine the P's.

(c) Treatment of the flying errors

By their nature, separation standards are always associated with extremely small collision risks. It is to be expected that any procedural standard (S, say) will be of such a size that very few of the flying errors, in the dimensions considered, will exceed $\frac{1}{2}$S. Collision can occur only when at least one aircraft in a pair makes an error greater than $\frac{1}{2}$S and it is the large rare errors (rather than those of moderate size which form the bulk of observations) that mainly determine the risk of collision. Thus the key to making useful estimates of the safety of separation standards lies in the treatment given to the 'tails of probability distributions. These 'tails' are illustrated in Fig. 4, where the intended paths of the aircraft have been set one separation standard S apart; the axis can be taken to represent any one of the coordinates x, y and z. Both the size and the shape of the 'tails' are important in risk estimation.

Now, in practice, the shape of the 'tails' is usually uncertain, because its determination would require more data than it is feasible to collect. Such data as have been collected show decisively that the popular assumption that flying errors obey the gaussian distribution law gives a low count of the number of errors in the 'tails', and leads to dangerous underestimate (Ref. 17) of risk. Indeed no simple theoretical distribution adequately describes all the observed data, and there seems little prospect of developing one which could be safely used to decide separation standards from a small sample of data; for example, from a sample which is no larger than is needed to estimate standard deviation precisely. Accordingly, it is necessary to seek estimating methods which allow a set of upper "confidence levels" of risk to be inferred from the observed data, which make particular use of the observations of large errors, and which avoid, as far as possible, arbitrary assumptions on the detailed shape of the tails.

The reliability of such estimates, and indeed of estimates produced by any other means, depends on the quantity of flying error data used. This must therefore be one of the quantities taken into account when giving estimates in the form of 'confidence levels'.

Two further factors complicate the treatment of flying errors. As has been seen, the knowledge of rates of change of these errors is important to collision risk estimation. The N's of equation (2) depend on probability distributions of both the magnitude of the error and of its rate of change. One has therefore to investigate the tendency for large errors and large rates of change to occur together before estimating the N's. There may also be a tendency for a pair of proximate aircraft to make the same error at the same time. Discussion of these factors is given in Appendix B

(d) Proximities

The time for which a pair of proximate aircraft is exposed at a given intended separation is termed a PROXIMITY. The expected number of collisions between the pair during the period for which this separation is intended to persist is, of course, simply the product: collision rate x proximity. The detailed notion of proximities is not altogether easy to grasp, and the notes which follow are intended to fix ideas.

It is not sufficient to measure simply the total time for which each aircraft flies with some other aircraft in its proximity shell (Fig. I), since each sort of intended separation (for example, same direction aircraft assigned to adjacent tracks at the same flight-level) has a characteristic collision rate. In other words, the P's and N's of equation (2) vary according to the path taken by B within the shell. The time spent by B within the shell must be specified as a particular sort of proximity. For traffic on parallel tracks, for example on airways and sometimes on North Atlantic routes, this is a straightforward process, since there are only a few possible sorts.

To study the safety of proposed separation standards in a given traffic region, the aggregate of each sort of proximity, for all flights, is estimated for the period considered, which may be several years. Thus it is necessary to take account of forecast traffic intensities, route configurations, and the A.T.C. procedures which will determine the apportioning of proximities between the three separation dimensions. The total risk is estimated by summing over the range of all sorts of proximity terms of the form: (proximity of a given sort occurring during the period considered) x (collision rate attributable to this sort of proximity).

2 BASIC REQUIREMENTS WHEN ESTIMATING COLLISION RISK

It is extremely easy to overlook essential principles when considering the safety of separation standards, or the necessary accuracy of navigation, or the data on which to judge these issues. Although the principles set out below appear very simple, they can all too easily become submerged in arguments of safe separation analysis, and so elude 'theoretical' and 'practical' people alike. Unless these principles are followed, much effort may be spent in collecting data and forming arguments which are not relevant to collision risk; indeed, such arguments might convince an authority that a standard is safer than it actually is. It is essential to recognise the considerable limitations inherent in calculating collision risk, and the need for administrative authorities to be able to exercise their own judgments of the validity of risk estimates. Below, seven requirements are suggested which any estimates of collision risk must satisfy before it can be used as a basis for deciding on a safe separation standard. These place on the estimator the onus of showing the sensitivity of his results to any critical assumptions, and to the quantity and quality of the data he has used.

(i) All possible directions from which one aircraft can come into collision with another should be accounted for.

This is the requirement discussed in section 1 (b)

The process of formulating the collision risk from all directions, which in practice leads to expressing the effects of flying errors in each of the three dimensions of space, has the added advantage of showing clearly the separate contributions of each to the total risk. One can see immediately, for example, the effect of increased precision of track-keeping on the safety afforded by vertical separation for aircraft assigned to the same track. Again, one can readily compare the extent to which the rates of change of the three component flying errors (as distinct from their magnitudes) contribute to the total risk.

(ii) Where, because of a shortage of data or otherwise, the value of a parameter cannot be known exactly, it should be given a "safe representation in the risk equation.

(iii) If an arbitrary assumption is made about the probability distribution of the flying errors there should be strong reasons for believing it to err (if anything) on the safe side and the sensitivity of the estimates to changes in the assumption should be indicated.

As pointed out, estimates of risk are highly sensitive to assumptions on the form of the tails or error distributions. Perhaps the most obvious pitfall is to assume that the proportion of the large, rare errors can be found from the standard deviation (i.e. r.m.s. values) of a small sample; for example by assuming a gaussian (normal) error distribution.

(iv) The method of estimating should take account of the extent to which each of the three dimensions of space is used in separating aircraft.

As discussed in section 1(d), due allowance should be made for the 'proximities' (i.e. exposures to risk) which are determined by the prevailing traffic intensities, route configuration and A.T.C. procedures in the traffic region, and over the period of time, to be considered.

(v) When estimates of risk depend on limited samples of data, account should be taken of the uncertainty due to sampling fluctuations.

The significance of this requirement is largely due to the fact that the incidence of the large, rare flying errors (which mainly determine the collision risk) has, in practice, to be estimated from a very small number of observations. The use of "confidence levels" when presenting the risk estimates can be made to show whether the sample is large enough to form a useful basis for decision.

(vi) When different sets of data on flying errors lead to contradictory conclusions a safe interpretation of the overall situation should be used.

Data on flying errors are likely to vary with operating conditions, techniques of observation, and geographic location within the traffic region considered. It is essential that the sub-samples are so weighted, or rejected, that the final assembly of data is safely representative of the whole traffic region and period of time considered; i.e. that the selection of data does not lead to an under-estimate of the risk. Where there is doubt on which samples to select, the effects of alternative choices on the risk estimates should be made clear.

And, finally, a requirement which is almost self-evident:

(vii) Estimates should be presented in a form suitable for executive use.

Almost any estimation of aircraft collision risk is of interest to a much wider circle than the specialists in the subject. Moreover, the specialists themselves benefit if results are presented in a way which brings out the nature of the key assumptions, and the effects of changing them. The risks should be expressed in units which can be readily understood.

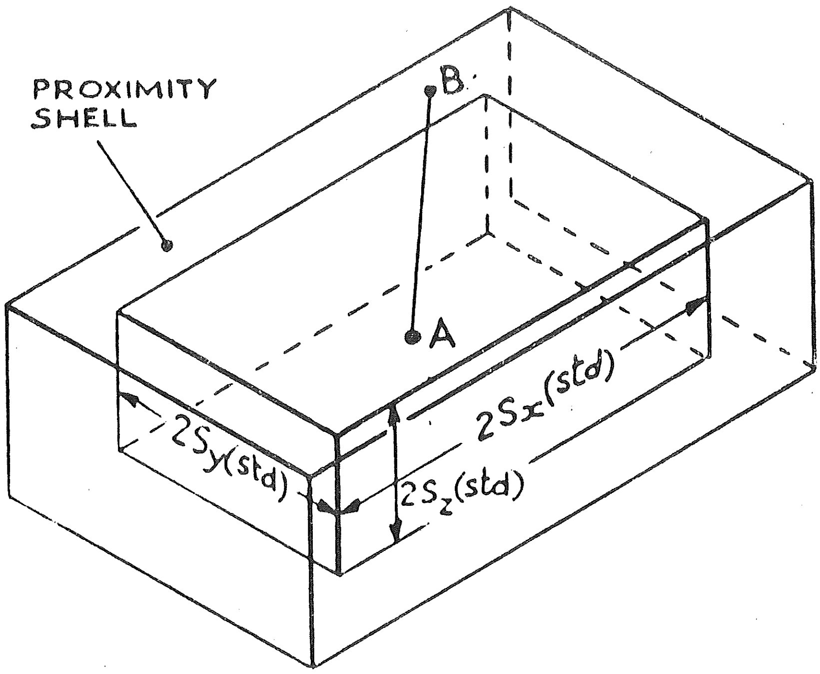


FIG. 1. EXPOSURE TO RISK

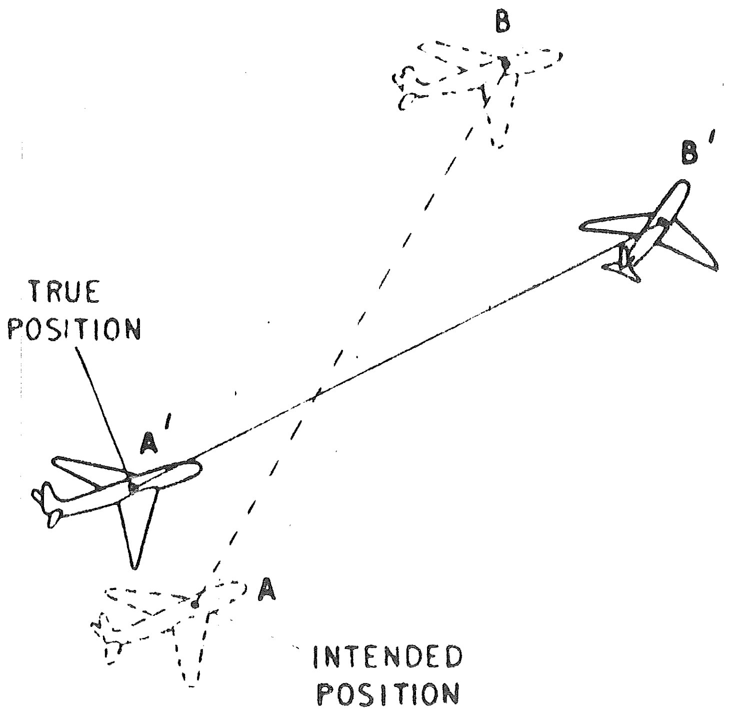


FIG 2. SEPARATION VECTORS

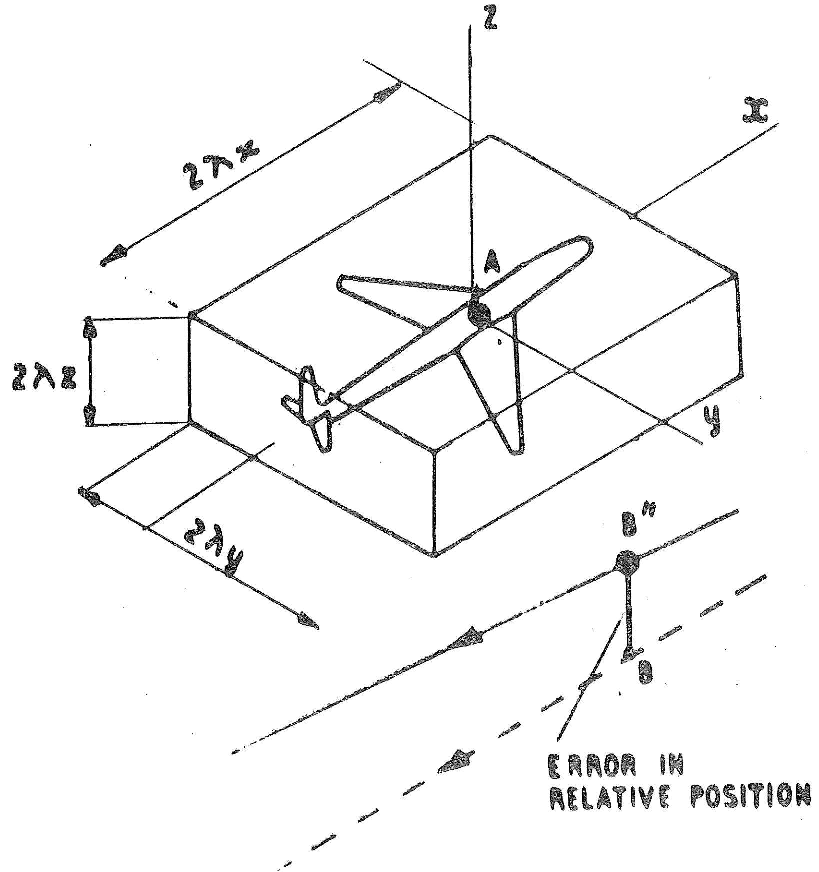


FIG 3. COLLISION SLAB

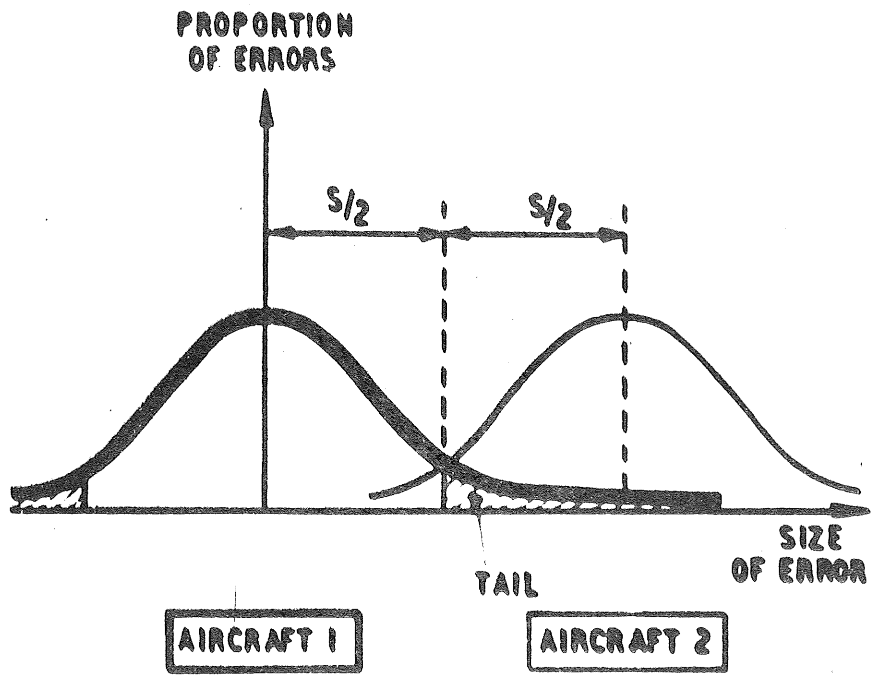


FIG. 4. DISTRIBUTION TAILS

ESTIMATED RISK ASSOCIATED WITH SEPARATION STANDARDS - THEORY

1. The techniques described in this Appendix deal with separations which are not monitored on the ground, and are confined mainly to studying the collision risk to aircraft nominally separated, by a lateral or vertical standard, on parallel flight paths. Although a more general approach has been made (Refs. 20, 21, 22) its presentation here would be rather cumbersome, and would tend to mask the essentials.

2. EXPRESSIONS FOR THE COLLISION RATE OF A PAIR OF AIRCRAFT

As described in Appendix A aircraft are given a notionally rectangular collision shape, in which λ_x, λ_y and λ_z represent, respectively, the length, span and thickness. For a pair of aircraft on parallel paths, the collision rate (C.R.) is expressed as follows:

$$C.R._{[AB]} = (N_x P_y P_z)_{[AB]} + (N_z P_x P_y)_{[AB]} + (N_y P_z P_x)_{[AB]} \qquad (1)$$

where

N_x is the expected frequency with which the along-track separation shrinks to less than λ_x.

N_y and N_z are similarly defined for the across-track and vertical directions.

P_x is the probability that the along-track separation is less than λ_x (i.e., the proportion of time aircraft spend in this condition).

P_y and P_z are similarly defined for the across-track and vertical dimensions.

Suffix [AB] denotes values which the above quantities take throughout periods when the planned separation may be taken as sensibly constant at the vector [AB].

In this Appendix, the "blind-flying" assumption is made. That is, visual collision avoidance is assumed to have no effect on the P's and the N's.

The P's have to be estimated from observation of the magnitudes of flying errors but, as discussed in Appendix A, the N's depend not only on these magnitudes, but also on their rates of change. At the end of this Appendix, Derivation I shows that the relation for the N's is

$$(N_r)_{[AB]} = 2 \int_0^\infty \dot{r} \, G_{[AB]}(\lambda_r, \dot{r}) \, d\dot{r} \qquad (2)$$

where r represents the separation of the aircraft pair in any one of the directions x, y and z, and $\dot{r}$ its rate of change with time.

$G_{[AB]}(r, \dot{r})$ is the joint probability density function of r and $\dot{r}$ (i.e. $G_{[AB]}(r, \dot{r})\, dr\, d\dot{r}$ is the proportion of time that separation in the r dimension lies between r and r + dr and is changing at a rate between $\dot{r}$ and $\dot{r} + d\dot{r}$). Equations (1) and (2) express the basic theory for satisfying (c.f. Appendix A)

Requirement (i): all possible directions from which one aircraft can come into collision with another should be accounted for.

It should be remembered that equation (1) rests on the assumption that flying errors in the three axes are independent of one another. Since the function $G_{[AB]}(r, \dot{r})$ is likely to change only slightly over an interval of twice the collision size, λ_r, equation (2) can be approximated by

$$(N_r)_{[AB]} \doteqdot 2 \int_0^{\infty} \dot{r}\, G_{[AB]}(o, \dot{r})\, d\dot{r} \quad . \tag{3}$$

In practice, it may sometimes be much more difficult to collect sufficient data to estimate the joint density function $G_{[AB]}(r, \dot{r})$ than to estimate the density function ($\phi_{[AB]}(r)$, say) of r alone. It is seen that in the case of r and $\dot{r}$ being statistically independent of one another, equation (3) simplifies to

$$(N_r)_{[AB]} \doteqdot \overline{|\dot{r}|}\phi(0)_{[AB]} \tag{4}$$

where $\overline{|\dot{r}|}$ is the average value of $|\dot{r}|$.

Approximating further by taking $\phi_{[AB]}(r)$ to be constant over an interval of $2\lambda_r$ gives

$$(N_r)_{[AB]} \doteqdot \overline{|\dot{r}|}P_{r[AB]}/2\lambda_r \tag{5}$$

Although there may not be sufficient evidence to say that r and $\dot{r}$ are independent, it will usually be possible to set a plausible upper limit to $\overline{|\dot{r}|}$ or to infer from samples a range of $\dot{r}$ associated with substantial loss of separation and hence to make safe use of equation (5). For example, an upper limit for $\overline{|\dot{x}|}$ for a pair of proximate jet aircraft in cruise could probably be set by mach number limitations or (perhaps better) by evidence from quite a small number of observations of relative elapsed times of flight. (c.f. Requirement (ii) of Appendix A).

Shortly, in Section 4, attention will be directed to collision risk on parallel flight paths separated by either the lateral or the vertical separation standard, and, in particular, to the collision rates $(C.R._y)_{[AB]}$ and $(C.R._z)_{[AB]}$ associated with the breakdown of, respectively, the standard lateral and vertical separations. It is convenient to rewrite equation (1) for pairs of aircraft assigned either to adjacent flight levels on the same track or to adjacent tracks at the same flight level, viz:

$$(C.R._y)_{[AB]} = (N_x)_{[AB]}P_y(std)P_z(0) + (P_x)_{[AB]}\{N_z(0)P_y(std) + N_y(std)P_z(0)\} \quad (6)$$

$$(C.R._z)_{[AB]} = (N_x)_{[AB]}P_y(0)P_z(std) + (P_x)_{[AB]}\{N_z(std)P_y(0) + N_y(0)P_z(std)\} \quad (7)$$

where

$P_y(std)$ is the probability that the across-track separation of a pair of aircraft, nominally spaced at the lateral standard, is less than λ_y.

$P_y(0)$ is the probability that the across-track separation of a pair of aircraft, assigned to the same track, is less than λ_y.

$N_y(std)$ is the expected frequency with which the across-track separation of a pair of aircraft, nominally spaced at the lateral standard, shrinks to less than λ_y.

$N_y(0)$ is the expected frequency with which the across-track separation of a pair of aircraft, assigned to the same track, shrinks to less than λ_y.

$P_z(std)$, $P_z(0)$, $N_z(std)$, $N_z(0)$ are similarly defined for the vertical dimension.

On the right-hand sides of equations (6) and (7), the suffix [AB] need only be used with the N_x and P_x terms, since the other terms are now treated as constants, determined by the separation standards and by the probability distributions of the errors of track-keeping and height-keeping.

3. PROBABILITY DISTRIBUTION OF THE FLYING ERRORS

(a) Basic requirements. From the discussion given in Appendix A it was concluded that the incidence of the large rare flying errors (i.e. those errors which are important to collision risk) cannot safely be deduced by simple theories which extrapolate from the evidence of small samples (e.g. from estimates of standard deviations). However, it will hardly be feasible to increase the number of observations sufficiently to ensure that frequencies of the large errors are estimated with negligible uncertainty, and so special statistical techniques have to be used to estimate the P's of equations (1), (6) and (7). Referring again to Appendix A, the techniques have to be consistent with:

Requirement (iii): if an arbitrary assumption is made about the probability distribution of the flying errors there should be strong reasons for believing it to err (if anything) on the 'safe' side and the sensitivity of risk estimates to changes in the assumption should be indicated.

Requirement (v): When estimates of risk depend on limited samples of data, account should be taken of the uncertainty due to sampling fluctuations.

(Requirement (iv) is dealt with in Section 4.)

(b) Sampling fluctuations. Consider the simple approach which one might make to estimating any of the P's. In Fig. 1, the observed histogram of errors (i.e. of the random departures from nominal flight-path for an aircraft, measured in one of the three dimensions) is shown centred at A. The same histogram, translated to A', represents the errors for a second aircraft navigated in the same way, and the segment AA' represents the nominal separation of the aircraft pair. If the errors for the two aircraft are uncorrelated then one can approximate to the probability (given by the so-called 'convolution integral') that the actual separation lies within a given range simply by taking sums of the products of pairs of observed proportions. But having derived an estimate in this way the questions remain: What degree of confidence can be placed in it? How is it affected by sampling fluctuations?

There does not seem to be any ready-made technique for placing confidence limits to such an estimate in a way which enables efficient use to be made of the observations. An initial exploration (Ref.23) of the problem, using a digital computer, showed that efficient techniques would be forbiddingly complex. However, experience has shown that changes in the separation standards come up for consideration even in cases where there is a complete absence of observed error data along a large part of the separation axis. In such cases the gap between efficiently and not-so-efficiently estimated confidence limits will not be so large as it would in cases where detailed data on the larger errors are available. On this account, and also because of the difficulties in developing efficient confidence limit techniques, there is some justification for the simple technique described below. Essentially, the compromise used here is to make use of a distribution function which depends only on the total size of the available sample of flying errors and on the proportion of them which exceed one-half of the separation standard. This enables the collision risk to be expressed as a distributed variable, given certain assumptions on the rate of decay of the probability distribution of the large errors.

(c) 'Body' and 'tails' of a probability distribution. Consider the separation of a pair of aircraft in the dimension r (where r represents one of the dimensions x, y and z), assigned to paths placed S_r apart (where S_r is at least as large as the separation standard) and let f(r) be the probability distribution of the errors in path-keeping, as shown in Fig. 2. The term 'body' is chosen for the portion of f(r) lying within $\pm S_r/2$ of the mean, and the term 'tails' for the portions falling outside these limits. In practice, the separation standard is sufficiently large to make P_r very small. Now separation in the r dimension can shrink to aircraft size only if errors of ($S_r/2$ - half the aircraft size), or greater, occur; and, unless there are some very queer kinks in f(r) in the range $\pm S_r/2$, a small value of P_r implies small tail areas. In any event it is essential, in estimating P_r, to take enough observations to tell us something about the area of the tails and in doing so one gets sufficient observations to define the shape, as well as the area, of the body quite clearly. Estimates of P_r are not likely to be very much affected by the shape of the body, within the range of variations in body shape which are met in practice, but are likely to be sensitive to the shape assumed for the tails. For simplicity, in the treatment that follows, f(r) is taken to be symmetrical, so that the two tail areas are equal.

(d) Use of the tail area to express the uncertainty due to sampling fluctuations. This is a straightforward application of confidence limit theory to the tail area. Consider first the binomial distribution:

$$B(M,p)$$

where M = total number of independent observations

p = probability that an observation falls in the tails and, of course,

1 - p = probability that an observation does not fall in the tails.

Since $p << 1 << M$, one can use the Poisson approximation to the binomial series so that:

Probability that n or fewer observations fall in the tails

$$= e^{-pM}\left\{1 + pM + \frac{(pM)^2}{2!} + \ldots + \frac{(pM)^n}{n!}\right\} \qquad (8)$$

Now, suppose a fraction α of the M observations has been observed to fall in the tails and it is required to base a confidence limit on this result. That is, to find the fraction, β, such that, if $p = \beta$, the chances would be c : 1 against getting αM or fewer in the tails (c being the chosen level of confidence). The required condition is:

$$e^{-\beta M}\left\{1 + \beta M + \frac{(\beta M)^2}{2!} + \dots + \frac{(\beta M)^{\alpha M}}{(\alpha M)!}\right\} = \frac{1}{c+1} \qquad (9)$$

Equation (9) can be used to construct a cumulative distribution curve for β, given α and M, and hence to represent the uncertainties in tail area which are due to sampling fluctuations.

(e) Alternative assumptions on tail shape. It is mainly in the choosing of a tail shape (i.e. of modelling the rate of decay of the probability distribution in the region of large errors) that the process of estimating the safe standard must depend to some extent on judgment. The purpose here is to describe three alternative clearly defined assumptions and to show their implications in a way which can be readily understood. The assumptions are given here in order, as it were, of increasing optimism as to the shape of the tails.

(i) It is assumed for the 'pessimistic spike' model that all errors in one tail actually occur on the intended flight path of the neighbouring aircraft at distance S_r, as shown in Fig. 3(a). This is indeed to take a gloomy view of things, but may conceivably be justified, if nothing at all is known of the tail shape, on the grounds that one cannot neglect the possibility that the frequency distribution f(r) has subsidiary maxima, one of which may coincide with the neighbouring flight-path. It is conceivable that certain radio aids giving rise to a periodic pattern of errors could lead to this property in f(r) if it were not properly looked after in their design or use.

(ii) The distribution f(r) is taken to be non-increasing outside $\pm S_r/2$ for the level tails model. Within this assumption, the most 'unfavourable' frequency distribution for the tails is that errors are uniformly distributed, as shown in Fig. 3(b). The limit of the distribution, point r_3, is chosen to maximize the risk of overlap as shown in Derivation II at the end of this Appendix.

This seems a prudent choice of model when, although little is known (from observations or otherwise) of the tail shape, there is reason to assume that the path-keeping process will not give subsidiary maxima in the tails of f(r). For most navigation procedures used in practice, it seems likely that periodic causes of error will be accompanied by many other non-periodic causes, and that the level-tail assumption is quite pessimistic enough to cover their combined effects.

(iii) In certain of the observational data on path-keeping errors that have been examined (the radar observations from Ref. 17, for example), the rate of decay of the frequencies of the larger errors is more closely approximated by an exponential function; that is, so that the proportion of errors of size r is proportional to $\exp(-K|r|)$, where K is some constant. In some other collections of data (for example, those on height-keeping errors given in Ref. 24) a rate considerably slower than exponential has been observed for the decay of the frequencies of large errors, and there seem to be no cases recorded of a decay rate in the tails faster than 'exponential', such as would be given, for instance, by a Gaussian distribution. The assumption of exponential decay for the tails, illustrated in Fig. 3(c), therefore represents the most optimistic view on tail shape which can reasonably be taken in the absence of very detailed observational data. The assumption would not be a prudent one, however, if there were neither observational nor mechanistic evidence to support it.

(f) Computation of the P's from the assumed tail shapes. The next problem is to relate P_r to tail area for each of the three tail shapes. As in para. 3(c) the symbol r will be used to represent any one of the x, y, z dimensions, and the separation, S_r, is taken to be of the order of the separation standard, or larger. To proceed, it is necessary to make a working assumption on the shape of the 'body' of the distribution of flying errors made by an aircraft in the r dimension. The results will not be sensitive to changes in the detailed shape of the body, and experience with observational data suggests that it is adequately described by the 1st Laplacian distribution:

$$f(r) = \frac{1}{\sqrt{2}\sigma_r} \exp[-\sqrt{2}\,|r-\mu_r|/\sigma_r] \qquad (10)$$

where σ_r = standard deviation of the flying errors in the r dimension

μ_r = mean of the flying errors in the r dimension.

It is further assumed that systematic flying errors have been removed, so that the (long-term) mean deviation, μ_r, from intended position is negligible. Also, it is assumed in this sub-section that the flying errors of aircraft nominally separated by S_r are uncorrelated.

The computations of P_r are detailed in Derivation II, at the end of this Appendix, and the results are summarized in Fig. 4, using a log versus log scale for convenience. The quantity $P_r\sigma_r/\lambda_r$ has been plotted against tail area (for several levels of S_r/σ_r in the cases of 'level tails' and 'exponential decay') in order to have a generalized presentation which is independent of the absolute values of λ_r, S_r and σ_r.

It is seen from Fig. 4 that in the regions to which one would expect to make most frequent reference (viz. tail area in the range $10^{-3} - 10^{-2}$ and $S_r/\sigma_r = 10$) the three assumptions lead to values of P_r which are, very roughly, in the ratio 100 : 20 : 1.

(g) Treatment when flying errors are given in relative form. In certain cases, instead of the error data applying to measurements made on single aircraft, the data comes in a form which gives the relative error for each pair of proximate aircraft. Indeed, for some measurements it is only by means of pairing in this way that the data acquires its value. An example of such pairing is given by the I.A.T.A. study of aircraft height-keeping errors, (Ref.25) in which measurements of the true heights of proximate jet aircraft, having known nominal height separation, were compared; a comparison between true height and assigned pressure level for single aircraft would have had little value, because of the difficulty in estimating the true heights corresponding to given pressure levels at jet cruising altitudes. The treatment of relative error data is discussed in Derivation III at the end of this Appendix.

4. GETTING PRACTICAL MEASURES OF RISK FROM THE COLLISION RATE EQUATIONS.

So far, the techniques described provide a means of estimating the expected number of collisions per unit time for a pair of aircraft separated by some fixed value of the vector [AB]. The final step is to estimate collision risk, by which is meant the expected total number of collisions in a traffic region during some future period, typically of a year or more. The dependence of this step upon factors peculiar to the region (e.g. traffic intensities and A.T.C. procedures) led, in Appendix A, stating:

> Requirement (iv): The method of estimating should take account of the extent to which each of the three dimensions of space is to be used in separating aircraft.

It is not feasible to predict the detailed behaviour of the vector [AB] for each pair of aircraft which will become 'proximate' (in the sense discussed in Appendix A) during the period considered. However, it is both feasible and sufficient to study the aggregate behaviour of the traffic statistically. The ease with which this can be done depends very much on the configuration of flight paths which will prevail. It is straightforward when fixed numbers of parallel paths are to be used, but tedious otherwise (as is evident from Ref.21). It suffices here to gives the theory for a system in which aircraft are assigned to a set of parallel tracks and flight levels, each separated by either the lateral or the vertical separation standard. In this case there are three components of risk to take into account, associated with the usage of lateral vertical and (for aircraft on the same track and flight level) longitudinal separation standards. For simplicity, only the first two of these will be dealt with here. It is assumed that the along-track positions of aircraft on adjacent flight-paths are independent of one another: also, that the risk to aircraft nominally separated by two or more standard increments of separation is negligible. The four sorts of proximate pair to be considered are shown in Fig. 5. (Note that in each case the aircraft are counted as proximate only when their nominal along-track separation is less than the longitudinal standard, $S_x(\text{std})$.) Associated with these, there are four sorts of proximity (i.e. times of exposure) defined as follows:

$T_y(\text{same})$ = aggregate of times spent by all pairs in the configuration of Fig. 5(a)

$T_y(\text{opp})$ = aggregate of times spent by all pairs in the configuration of Fig. 5(b)

$T_z(\text{same})$ = aggregate of times spent by all pairs in the configuration of Fig. 5(c)

$T_z(\text{opp})$ = aggregate of times spent by all pairs in the configuration of Fig. 5(d).

Suppose, for the moment, that these four proximities have already been determined. Then, if one knew the averages of their respective collision rates, $\overline{(\text{C.R.})}_y$ and $\overline{(\text{C.R.})}_z$, say, the collision risks would also be determined. To find these averages, the assumption of independence between the nominal along-track positions of aircraft on adjacent paths implies

$$\text{average of } (P_x(\text{std}))_{[AB]} \doteqdot \frac{\lambda_x}{S_x(\text{std})},$$

and, from equation (5),

$$\text{average of } (N_x(\text{std}))_{[AB]} \doteqdot \frac{\overline{|\dot{x}|}}{2S_x(\text{std})}.$$

Hence, from equations (6) and (7),

$$\overline{(\text{C.R.})}_y = \frac{1}{S_x(\text{std})}\left[\frac{\overline{|\dot{x}|}}{2} P_y(\text{std})P_z(0) + \lambda_x P_y(\text{std})N_z(0) + \lambda_x N_y(\text{std})P_z(0)\right] \quad (11)$$

$$\overline{(\text{C.R.})}_z = \frac{1}{S_x(\text{std})}\left[\frac{\overline{|\dot{x}|}}{2} P_y(0)P_z(\text{std}) + \lambda_x N_y(0)P_z(\text{std}) + \lambda_x P_y(0)N_z(\text{std})\right] \quad (12)$$

On the face of it, there are only two $\overline{(\text{C.R.})}$'s corresponding to the four T's. This is not really so, since $\overline{|\dot{x}|}$ takes two values:

For opposite-direction traffic

$$\overline{|\dot{x}|} = 2\,\bar{V}$$

where $\bar{V}$ is the average cruising speed,

and for same-direction traffic

$$\overline{|\dot{x}|} = \Delta \bar{V}$$

where $\Delta \bar{V}$ represents the average difference of cruising speed in pairs of aircraft. Thus one unit of opposite-direction proximity is equivalent to $2 \bar{V}/\Delta \bar{V}$ units of same-direction proximity, and it is clearly essential to distinguish between the two. The collision risks due to failure of the lateral and vertical standards can now be written as follows:

Lateral risk (same)

$$= \frac{T_y(\text{same})}{S_x(\text{std})}\left[\frac{\Delta \bar{V}}{2} P_y(\text{std})P_z(0) + \lambda_x P_y(\text{std})N_z(0) + \lambda_x N_y(\text{std})P_z(0)\right] \quad (13)$$

Lateral risk (opp)

$$= \frac{T_y(\text{opp})}{S_x(\text{std})} [\bar{V}P_y(\text{std})P_z(0) + \lambda_x P_y(\text{std})N_z(0) + \lambda_x N_y(\text{std})P_z(0)] \quad (14)$$

Vertical risk (same)

$$= \frac{T_z(\text{same})}{S_x(\text{std})}\left[\frac{\Delta \bar{V}}{2} P_y(0)P_z(\text{std}) + \lambda_x N_y(0)P_z(\text{std}) + \lambda_x P_y(0)N_z(\text{std})\right] \quad (15)$$

Vertical risk (opp)

$$= \frac{T_z(\text{opp})}{S_x(\text{std})} [\bar{V}P_y(0)P_z(\text{std}) + \lambda_x N_y(0)P_z(\text{std}) + \lambda_x P_y(0)N_z(\text{std})] \quad (16)$$

To return to the problem of computing the T's, consider the system shown in Fig. 6, in which each track has length L. It is assumed that the traffic flow into and along the paths is statistically steady during the period of examination. Let the respective flow rates on the paths shown in Fig. 6 be

$$m_{11}, m_{12}, \ldots m_{ij}, \ldots m_{tf} .$$

For the moment, no distinction will be made between same- and opposite-direction traffic. Taking an aircraft on path (i, j), the expected number of aircraft within an along-track separation $\pm S_x(\text{std})$ of it on path (i - 1, j) is

$$\frac{2S_x(\text{std})}{\bar{V}} m_{i-1, j} .$$

The average proximity generated by this aircraft, vis-à-vis aircraft on path (i - 1, j), during the time it takes to fly along the segment of length L is given approximately by

$$\frac{L}{\bar{V}} \cdot \frac{2S_x(\text{std})}{\bar{V}} m_{i-1,j};\ S_x << L \ .$$

So that the rate at which paths (i - 1, j) and (i, j) generate lateral proximity is given approximately by

$$\frac{2LS_x(\text{std})}{\bar{V}2} m_{i-1,j}\, m_{i,j}$$

(Note that this 'rate' is dimensionless: it is a time of exposure per unit time of operation.) And the track system as a whole generates lateral proximity at the rate $\mathring{T}_y$, where:

$$\mathring{T}_y \div \frac{2LS_x(\text{std})}{\bar{V}2} \sum_{i=2}^{i=t} \sum_{j=1}^{j=f} m_{i-1,j}\, m_{i,j} \qquad (17)$$

Similarly, vertical proximity is generated at a rate $\mathring{T}_z$, where

$$\mathring{T}_z \div \frac{2LS_x(\text{std})}{\bar{V}2} \sum_{j=2}^{j=f} \sum_{i=1}^{i=t} m_{i,j-1}\, m_{i,j} \qquad (18)$$

$\mathring{T}_y$ and $\mathring{T}_z$ are now resolved into their same-direction and opposite-direction constituents. Usually, it will be necessary to aggregate the proximities over a lengthy period (e.g. one year) during which the traffic intensity fluctuates. For this, the period is divided into sections for which the intensity is sensibly constant, and the quantities $\mathring{T}_y$(opp), $\mathring{T}$(same), &c., are integrated numerically. Two features are clear from equations (17) and (18). For a fixed number of paths, proximities (and hence collision risk) are proportional to the square of the traffic intensity. Secondly, that S_x(std) finally cancels out in the collision risk equations (13) - (16). That is, in the case studied here (Fig. 6), the along-track criterion of proximity does not directly affect the result, and can be selected for convenience in computing, provided it is small compared with the distance an aircraft flies during a statistically steady period.

A numerical example may help to fix ideas on computing the T's. Fig. 7 shows the hourly traffic rates on a simple airway system. Taking S_x(std) as the along-track criterion of proximity, how much lateral and vertical proximity would be generated on the 500 n.m. segment in 10 hours of steady state operation? (Given: $\bar{V}$ = 300 kt, S_x(std) = 30 n.m.)

We have

$$\frac{2LS_x(\text{std})}{\bar{V}^2} = \frac{1}{3}\ \text{hour}^2$$

and

$\hat{T}_y(\text{same}) = 0$

$\hat{T}_y(\text{opp}) = \frac{1}{3}[10 + 24 + 10 + 9] = 17.7$ hours of proximity/hour

$\hat{T}_z(\text{same}) = \frac{1}{3}[12 + 30 + 15 + 20 + 8 + 6] = 30.3$ hours of proximity/hour

$\hat{T}_z(\text{opp}) = 0$

so that the proximities generated in the 10-hour period are

$$T_y(\text{opp}) = 177 \text{ hours}$$

$$T_z(\text{same}) = 303 \text{ hours}$$

5. KEY ASSUMPTIONS

In addition to the 'blind flying' assumption which is discussed in the main text there are two important assumptions which call for some discussion.

(a) Assumption that path-keeping errors of an aircraft in the three dimensions are independent

This assumption, used in deriving the fundamental collision rate equations in Appendix A, is probably unimportant when there is nominal separation at least as large as the separation standard in one dimension, whilst nominal separation in the other dimensions may be small or zero. This is the usual way of applying separation standards at present. It is very unlikely that a large error which causes loss of separation in the first dimension is specially associated with the particular combination of small errors which produces loss of separation in the other two dimensions. But, when composite separation standards are considered, i.e. those which rely on the separation standards being applied simultaneously in two or three dimensions, the assumption of independence may have an important effect. If the large errors in two dimensions were in fact correlated, one could not rely on the techniques described to give cautious estimates of the collision risk. Quite plausible arguments can be advanced to suggest that large errors in different dimensions may occasionally occur together. For example, failure of crew vigilance is a factor common to errors in all three dimensions, the altimeter static pressure system is shared by the A.S.I. and machmeter, and so on. It is therefore essential to check by observation the degree of correlation between large errors in the three dimensions before estimating collision risk for composite separation standards.

(b) Assumption that the path-keeping errors of neighbouring aircraft in the same dimension are independent

When considering the probability of a loss of separation of the order of a separation standard, this assumption of independence is likely, if anything, to err on the safe side, i.e. to overestimate the risk of losing separation. This is because any correlation that occurs whilst the actual separation, in one dimension, is shrinking will tend to equalize the errors and so work against the occurrence of a complete loss. But, when considering the risk of losing separation in a dimension in which the nominal separation is zero, or nearly so, the same correlation has the opposite effect: it augments the risk. To put it another way, a good deal of protection against collision comes, in practice, from the random deviations about intended paths when the paths are not deliberately separated. If these deviations are correlated, for pairs of proximate aircraft, then some of this protection is lost. Clearly, the assumption of independent errors for neighbouring aircraft may 'cut both ways' in the estimates. Since one expects each error made when flying close to intended track to arise from many sources one would not, perhaps, expect a very strong correlation between the small errors for different aircraft, but the only safe course is to check by observation.

DERIVATION I : THE FREQUENCY OF LOSING SEPARATION IN ONE DIMENSION

Using the notation of section 2, the time taken for separation, in the r direction, to change from r to r + dr is

$$\frac{dr}{|\dot{r}|}$$

and the average frequency with which the separation passes through the element r, $r + dr$, when the velocity is in the range $\dot{r} \rightarrow \dot{r} + d\dot{r}$, is

$$\frac{G_{[AB]}(r, \dot{r})\, dr\, d\dot{r}}{\text{time taken to cross the element}}$$

$$= |\dot{r}|\, G_{[AB]}(r, \dot{r})\, d\dot{r}$$

Summing over all $\dot{r}$ gives the total frequency with which separation passes through r, namely

$$\text{total frequency} = \int_{-\infty}^{\infty} |\mathring{r}| \; G_{[AB]}(r, \mathring{r}) \; d\mathring{r}$$

$$= 2 \int_{0}^{\infty} \mathring{r} \; G_{[AB]}(r, \mathring{r}) \; d\mathring{r} \qquad (19)$$

assuming that $\mathring{r}$ is symmetrically distributed about zero mean.

The required frequency $(N_r)_{[AB]}$ with which separation shrinks to aircraft size is the frequency with which separation enters the region lying between $-\lambda_r$ and $+\lambda_r$. On the assumption of symmetry it is seen from (19) that

$$(N_r)_{[AB]} = 2 \int_{0}^{\infty} \mathring{r} \; G_{[AB]}(\lambda_r, \mathring{r}) \; d\mathring{r} \qquad (20)$$

Since, although separation passes through $-\lambda_r$ as often as through $+\lambda_r$, only one half of these passes (those entering the region) are counted.

DERIVATION II : COMPUTATION OF THE P'S FROM THE ASSUMED TAIL SHAPES

Notation: As in the main test, the suffix r is used to denote one of the three dimensions x, y, z. Also

λ_r = the aircraft collision size in the r dimension

S_r = intended separation of a pair of aircraft in the r dimension

P_r = probability that separation in the r dimension is less than λ_r

$f(r)$ = function chosen to describe the 'body' of the probability distribution of flying errors of an aircraft in the r dimension

σ_r = standard deviation of these flying errors

Throughout these computations the 'body-shape' assumed in section 3 will be used. This is the 1st Laplacian, given by

$$f(r) = \frac{1}{\sqrt{2}\sigma_r} \exp[-\sqrt{2}\,|r|/\sigma_r] \qquad (21)$$

Computation of P_r for the 'pessimistic spike' assumption

For this model the whole of the area, $\beta/2$, of one tail is put in a spike of infinitesimal width at distance S_r from intended path, i.e. on the intended path of the neighbouring aircraft as shown in Fig. 3(a). There are, by symmetry, two such spikes to lead to loss of separation of the two aircraft, and the chance that aircraft centres lie within a distance dr is given by

$$2(\beta/2)f(0)dr = \frac{\beta dr}{\sqrt{2}\sigma_r} \tag{22}$$

so that

$$P_r = \int_{-\lambda_r}^{\lambda_r} \frac{\beta}{\sqrt{2}\sigma_r} dr$$

i.e.

$$P_r \doteqdot \sqrt{2}\beta\lambda_r/\sigma_r \; ; \; \lambda_r << \sigma_r \tag{23}$$

Computation of P_r for the 'level tails' assumption

In this model the tails are uniformly distributed, and the problem is to fix the range of the uniform distribution - that is, to suitably place the point r_3 in Fig. 3(b) so that P_r is maximized. Consider first the right-hand tail of the distribution curve for aircraft 1, Fig. 3(b). Since a uniform distribution is assumed for the tails, each of area $\beta/2$, the probability that aircraft 1 is centred between r and (r + dr) is given by

$$\frac{\beta/2}{r_3 - r_1} \cdot dr \; ; \; r_1 \leq r \leq r_3 \tag{24}$$

The probability that aircraft 2 lies within λ_r of point r is, by the assumption of the 1st Laplacian distribution

$$\frac{1}{\sqrt{2}\sigma_r} \int_{r-\lambda_r}^{r+\lambda_r} \exp(-\sqrt{2}\,|S_r - r|/\sigma_r)\, dr \doteqdot \frac{\sqrt{2}\lambda_r}{\sigma_r} \exp(-\sqrt{2}\,|S_r - r|/\sigma_r) \; ; \; \lambda_r << \sigma_r \tag{25}$$

So the probability that separation becomes less than λ_r in the right-hand tail of aircraft 1 is given approximately by

$$\frac{\lambda_r \beta}{\sqrt{2}(r_3 - r_1)\sigma_1} \int_{r_1}^{r_3} \exp(-\sqrt{2}\,|S_r - r|/\sigma_r)\, dr \tag{26}$$

It is obvious that if (26) is to be maximized, r_3 cannot lie to the left of r_2, since in this region the integral increases faster with r_3 than does the linear term $(r_3 - r_1)$ in the denominator. Thus one can write (26) as

$$\frac{\lambda_r \beta}{\sqrt{2}(r_3 - r_1)\sigma_1}$$

$$\left\{ \int_{r_1}^{S_r} \exp(-\sqrt{2}\,|S_r - r|/\sigma_r)\, dr + \int_{S_r}^{r_3} \exp(-\sqrt{2}\,|S_r - r|/\sigma_r)\, dr \right\} \qquad (27)$$

Noting that $r_1 = S_r/2$ and that in cases of practical interest

$$S_r << \sigma_r$$

one can further approximate by substituting $\sigma_r/\sqrt{2}$ for the first integral in (27) and rewrite as

$$\frac{\lambda_r \beta}{\sqrt{2}(r_3 - S_r/2)\sigma_r} \left\{ \sigma_r/\sqrt{2} + \frac{\sigma_r}{\sqrt{2}} [1 - \exp(-\sqrt{2}\,|S_r - r_3|/\sigma_r] \right\}$$

$$= \frac{\lambda_r \beta}{r_3 - S_r/2} \{1 - \tfrac{1}{2} \exp(\sqrt{2}(S_r - r_3)/\sigma_r)\}, \; r_3 \geq S \qquad (28)$$

Applying a factor of 2 to (28), to take account of the symmetrical risk, i.e. that due to the left-hand tail of Aircraft 2 in Fig. 3(b), it is now only required to substitute the value of r_3 (r_3^*, say) which maximizes the expression, to derive the required value of P_r. Thus

$$P_r \div \frac{\lambda_r \beta}{r_3^* - S_r/2} \{2 - \exp[\sqrt{2}(S_r - r_3^*)/\sigma_r]\}, \; r_3 \geq S_r \qquad (29)$$

A suitable plotting function is shown in Fig. 8 for several values of S_r/σ_r. The maxima of the curves give the quantity $P_r \sigma_r/\lambda_r \beta$ for the respective values of S_r/σ_r.

<u>Computation of P_r for the exponential decay assumption</u>

The tails for this model (Fig. 3(c)) are part of the curve

$$Ae^{-k|r|}$$

where the parameters are found from the conditions:

$$\int_{S_r/2}^{\infty} Ae^{-k|r|}\,dr = \beta/2 \tag{30}$$

$$\int_{0}^{\infty} Ae^{-k|r|}\,dr = 1/2 \tag{31}$$

Equation (30) satisfies the requirement for tail area, whilst equation (31) fixes the remaining parameter by making the tail part of an exponential distribution function starting from the centre of the body distribution as shown in Fig. 3(c). Thus the tail can be regarded as part of a 1st Laplacian distribution. The latter will usually have a larger variance than the body distribution because of the inflation of the observed tail area which takes place when setting confidence limits.

Equations (30) and (31) gives the parameters of the exponential tail in Fig. 3(c) as follows

$$kS_r = 2\log_e(1/\beta) \tag{32}$$

Also

$$A = k/2 \tag{33}$$

Attention is directed first to the contribution to P_r which arises from errors in the right-hand tail of Aircraft 1:

(i) In the range $S_r/2 \leqslant r \leqslant S_r$, it is clear that:-

Chance that Aircraft 1 is centred between r and r + dr $= \dfrac{ke^{-kr}}{2}\,dr$ (34)

Chance that Aircraft 2 is centred between r and r + dr $= \dfrac{dr}{\sqrt{2}\sigma_r}\,e^{\sqrt{2}(r-S_r)/\sigma_r}$ (35)

So that the chance that the aircraft centres are both within an element dr is given by I_1, where

$$I_1 = \frac{k\,dr}{2\sqrt{2}\sigma_r}\int_{S_r/2}^{S_r} \exp[-kr + \sqrt{2}(r - S_r)/\sigma_r]\,dr \tag{36}$$

From which

$$I_1 = \frac{k\,dr}{2\sqrt{2}\sigma_r(\sqrt{2}/\sigma_r - k)}\,[\exp(-kS_r) - \exp - (S_r/\sqrt{2}\sigma_r) + kS_r/2)]\,,\ k \neq \sqrt{2}/\sigma_r \tag{37}$$

and

$$I_1 = \frac{kS_r\,dr}{4\sqrt{2}\sigma_r}\exp(-\sqrt{2}S_r/\sigma_r) = \frac{S_r\,dr}{4\sigma_r^2}\exp(-\sqrt{2}S_r/\sigma_r)\,,\ k = \sqrt{2}/\sigma_r \tag{38}$$

(ii) In the range $S_r \leqslant r < \infty$, the procedure is the same except that one must write $-(r - S_r)$ for $(r - S_r)$ in equation (35).

In this case, the chance that the aircraft centres are both within the element dr, (with $S_r \leqslant r < \infty$) is given by I_2, where

$$I_2 = \frac{k\,dr}{2\sqrt{2}\sigma_r}\int_{S_r}^{\infty}\exp[-\,kr + \sqrt{2}(S_r - r)/\sigma_r]\,dr\,. \tag{39}$$

From which

$$I_2 = \frac{k\,dr}{2\sqrt{2}\sigma_r(\sqrt{2}/\sigma_r + k)}\exp(-S_rk)\,,\ k \neq 2/\sigma_r \tag{40}$$

and,

$$I_2 = \frac{k\,dr}{8}\exp(-\sqrt{2}S_r/\sigma_r) = \frac{dr}{4\sqrt{2}\sigma_r}\exp(-\sqrt{2}S_r/\sigma_r)\,,\ k = \sqrt{2}/\sigma_r \tag{41}$$

Taking account also of the left-hand tail of Aircraft 2, the total chance that both aircraft lie in the element dr is

$$2(I_1 + I_2)$$

and P_r is given approximately by

$$2(I_1 + I_2)\,\frac{2\lambda_r}{dr}\,,\ \lambda_r \ll \sigma_r$$

Hence, from (37) and (40),

$$P_r \doteq \frac{\sqrt{2}\lambda_r k\exp(-S_rk)}{\sigma_r}$$

$$\left\{\frac{1 - \exp[S_rk/2 - S_r/(\sqrt{2}\sigma_r)]}{\sqrt{2}/\sigma_r - k} + \frac{1}{\sqrt{2}/\sigma_r + k}\right\}\,,\ k \neq \sqrt{2}/\sigma_r \tag{42}$$

Whilst, from (38) and (41),

$$P_r \doteq \frac{\lambda_r \exp(-\sqrt{2}S_r/\sigma_r)}{\sigma_r}\left\{\frac{1}{\sqrt{2}} + \frac{S_r}{\sigma_r}\right\}, \quad k = \sqrt{2}/\sigma_r \qquad (43)$$

Equation (43) gives the special case where the tails are continuous with the body and both aircraft have the same 1st Laplacian error distribution.

DERIVATION III : TREATMENT OF RELATIVE ERRORS

(cf. section 3(g))

(i) Self-sufficient data

If the histogram of the observed relative errors, i.e. of the variations in the actual aircraft separation for a given nominal separation, extends as far as the separation standard being considered, then conventional statistical techniques suffice. The data can be divided into cells of convenient size, and combinatorial methods, of which the χ^2 test is a familiar example, may be used to set confidence limits to estimates of overlap risk.

(ii) Modelling the tails for distributions of relative error

It will, perhaps, be more usual for the extreme values in the histogram to fall well short of the separation standard being considered, in which case there is a need for special techniques of the sort described in Se tion 3. There is no useful general means of relating the assumptions on tail area and tail shape, which are outlined in Section 3, to the corresponding assumptions for relative errors. The models illustrated in Fig. 9, however, have the same intuitive appeal as those proposed in Section 3 and are taken as the basis for treating relative errors. In these models a limit α has been assigned to one side of the histogram (which, for simplicity, is taken to be a sample from a symmetrical distribution), so that to the right of α there are either no observations or just one or two stragglers. The number of observations to the right of α may be used in conjunction with equation (9) of Section 3(d) to set a confidence limit, $\beta/2$, to the proportion in the right-hand tail. The value of P_r associated with the chosen confidence limit is then given for each of the three tail shapes by the black areas in, respectively, Figs. 9(a), 9(b) and 9(c). Thus one derives the analogues of equations (23), (29) and (42):

(a) 'Pessimistic spike'

$$P_r = \beta/2 \qquad (44)$$

(b) 'Level tails'

$$P_r = \frac{\lambda_r \beta}{S_r + \lambda_r - a} \qquad (45)$$

(c) <u>'Exponential decay'</u>

The requirements for the exponential curve Ae^{-kr} are

$$\int_0^\infty Ae^{-kr}\,dr = \tfrac{1}{2} \qquad (46)$$

$$\int_a^\infty Ae^{-kr}\,dr = \beta/2 \qquad (47)$$

from which it is easily shown that

$$P_r \doteqdot \lambda_r k \exp(-kS_r) \qquad (48)$$

where

$$k = \frac{\log e(1/\beta)}{a} \qquad (48)$$

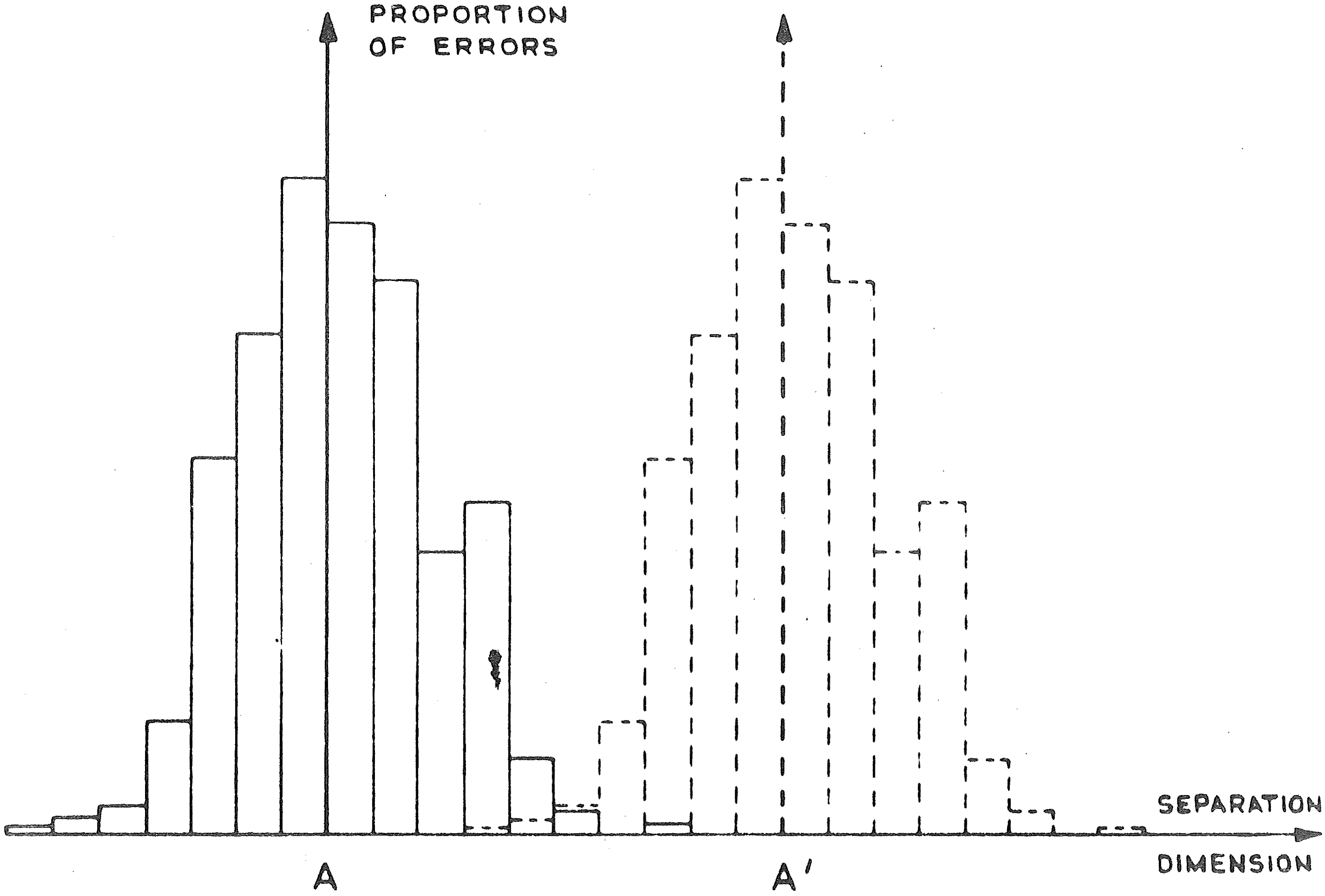


FIG. 1 ERROR HISTOGRAMS.

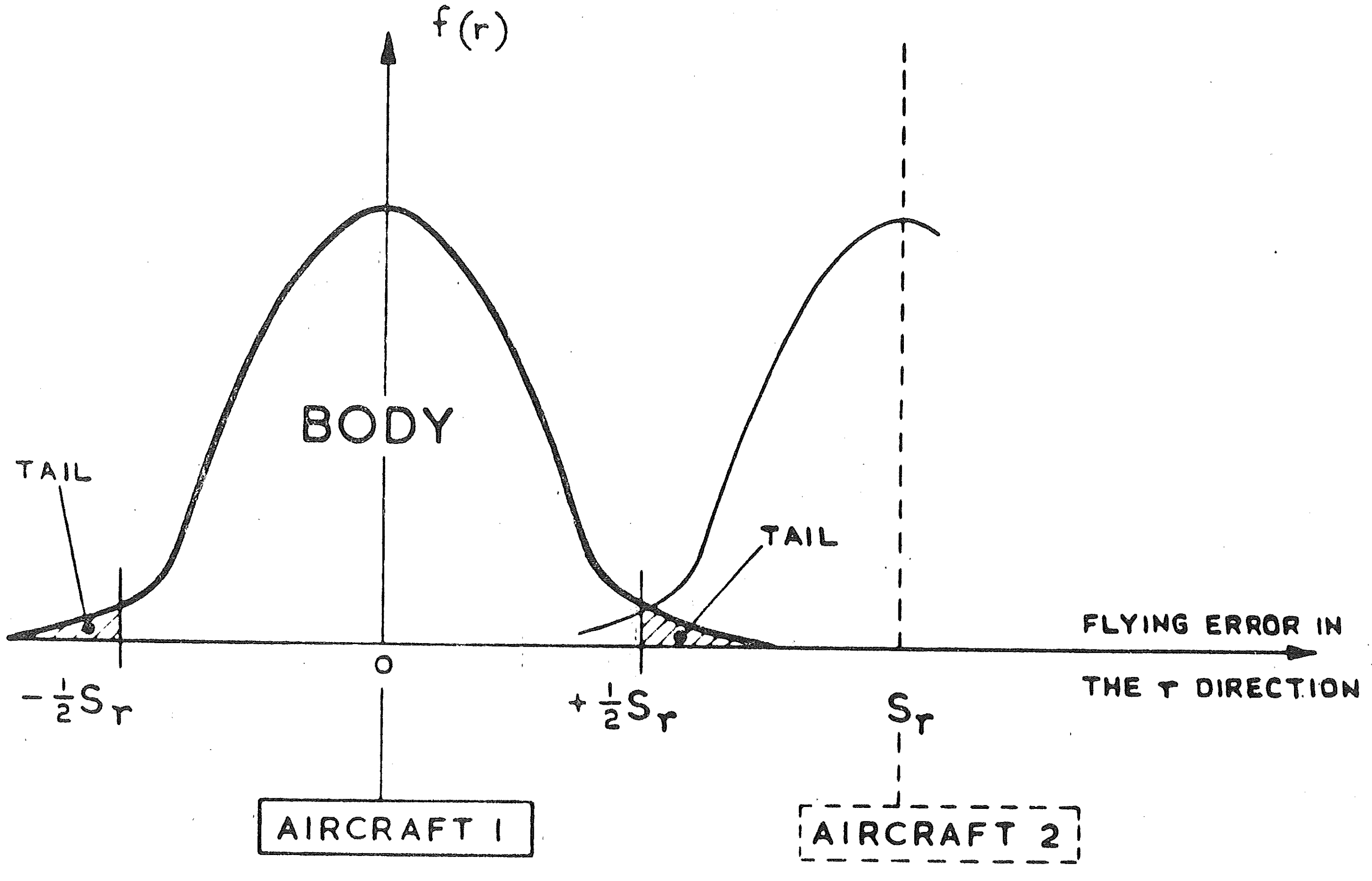
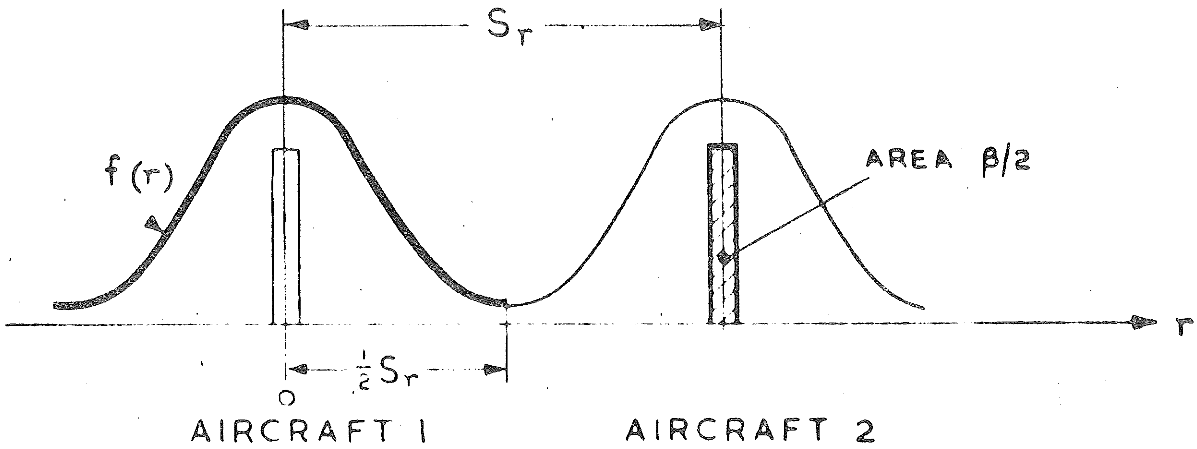
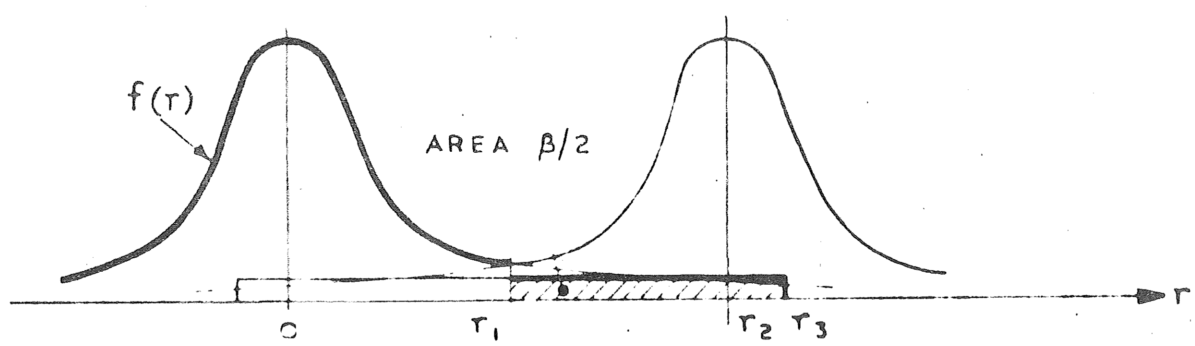


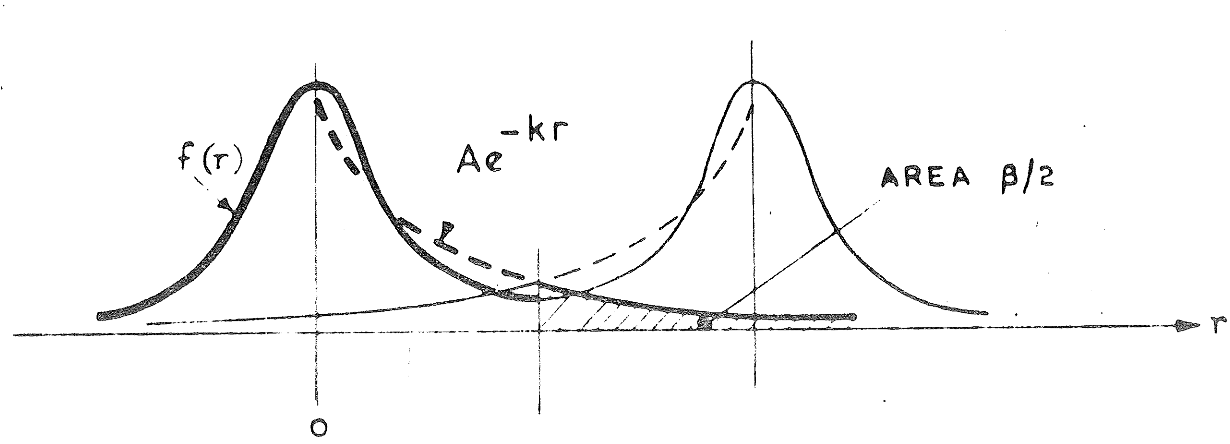
FIG. 2 BODY & TAILS OF AN ERROR DISTRIBUTION



(a) THE "PESSIMISTIC SPIKE" ASSUMPTION



(b) "LEVEL TAILS" ASSUMPTION



(c) "EXPONENTIAL DECAY ASSUMPTION

FIG. 3. ALTERNATIVE ASSUMPTIONS OF TAIL SHAPE

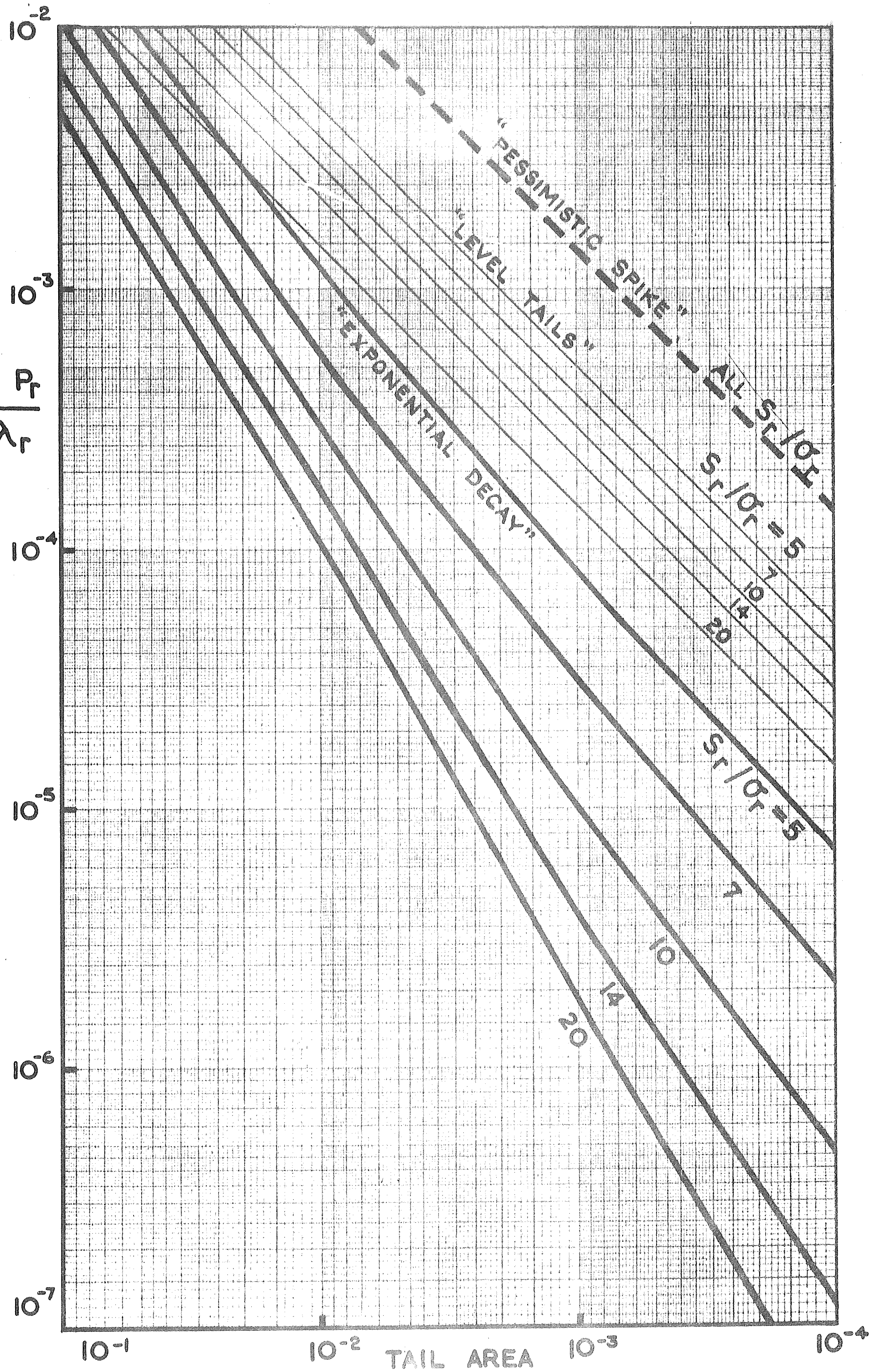


FIG. 4. RELATING TAIL AREA TO P_r

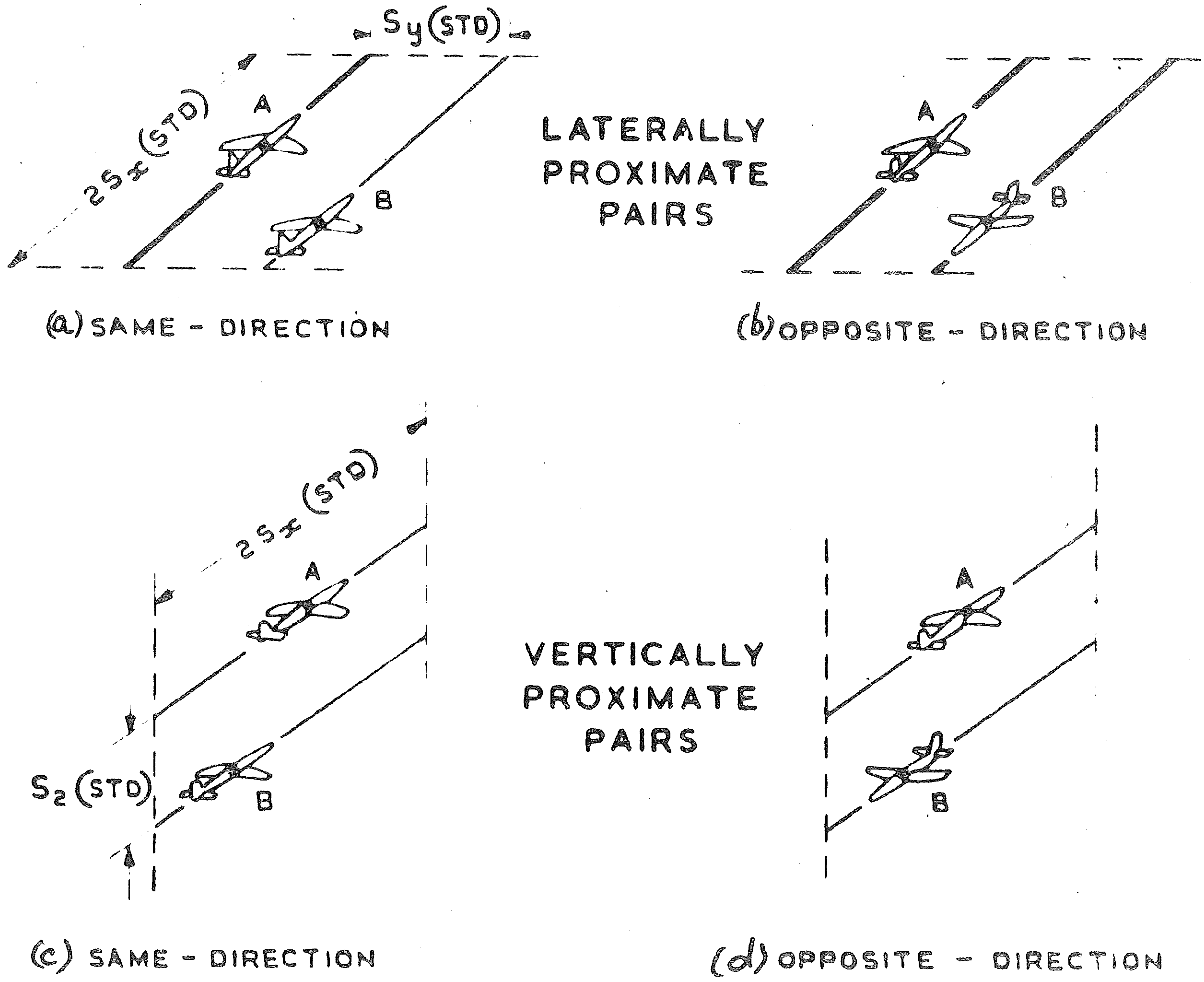


FIG. 5. PROXIMATE PAIRS.

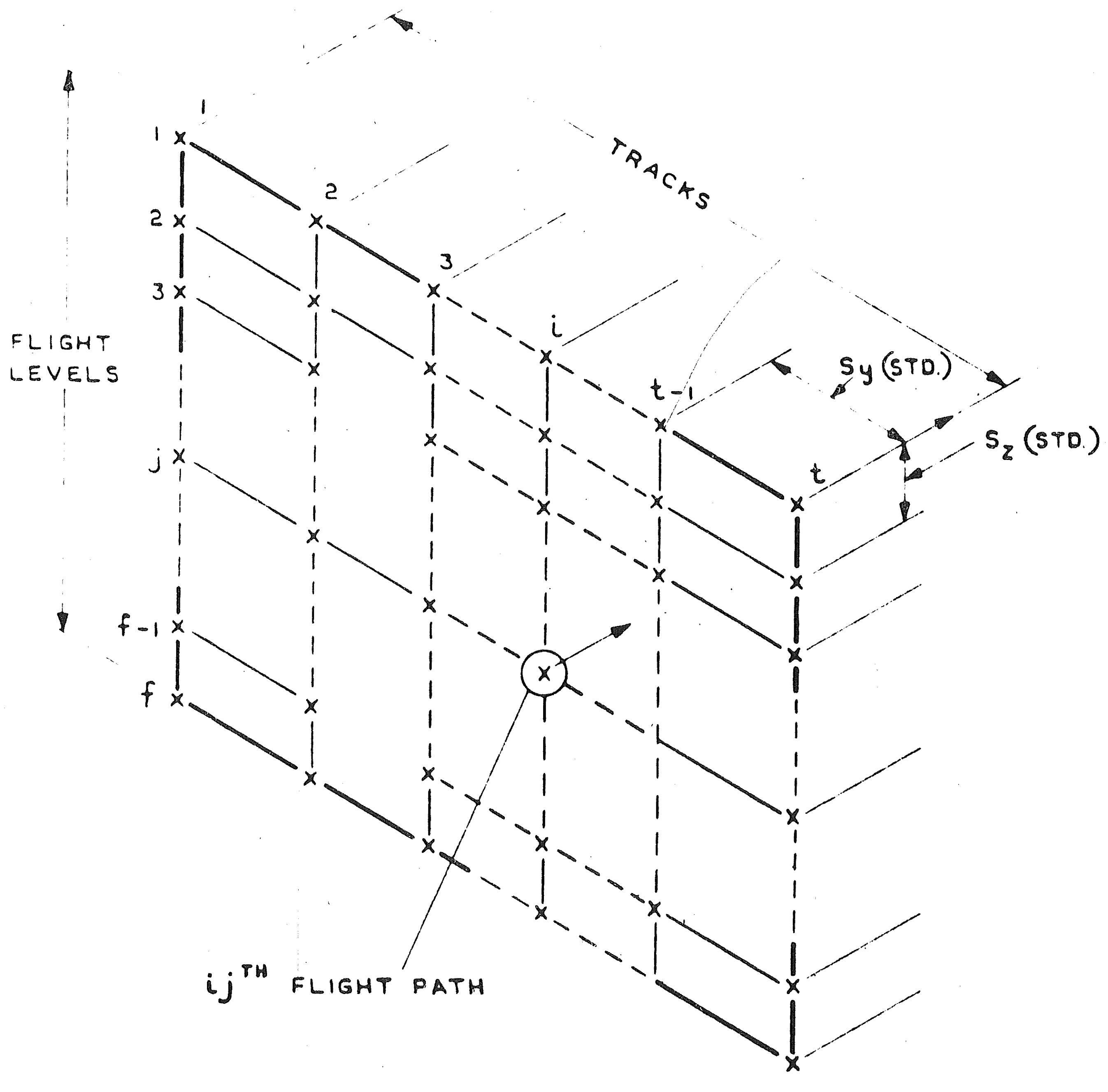


FIG. 6. PARALLEL TRACK SYSTEM

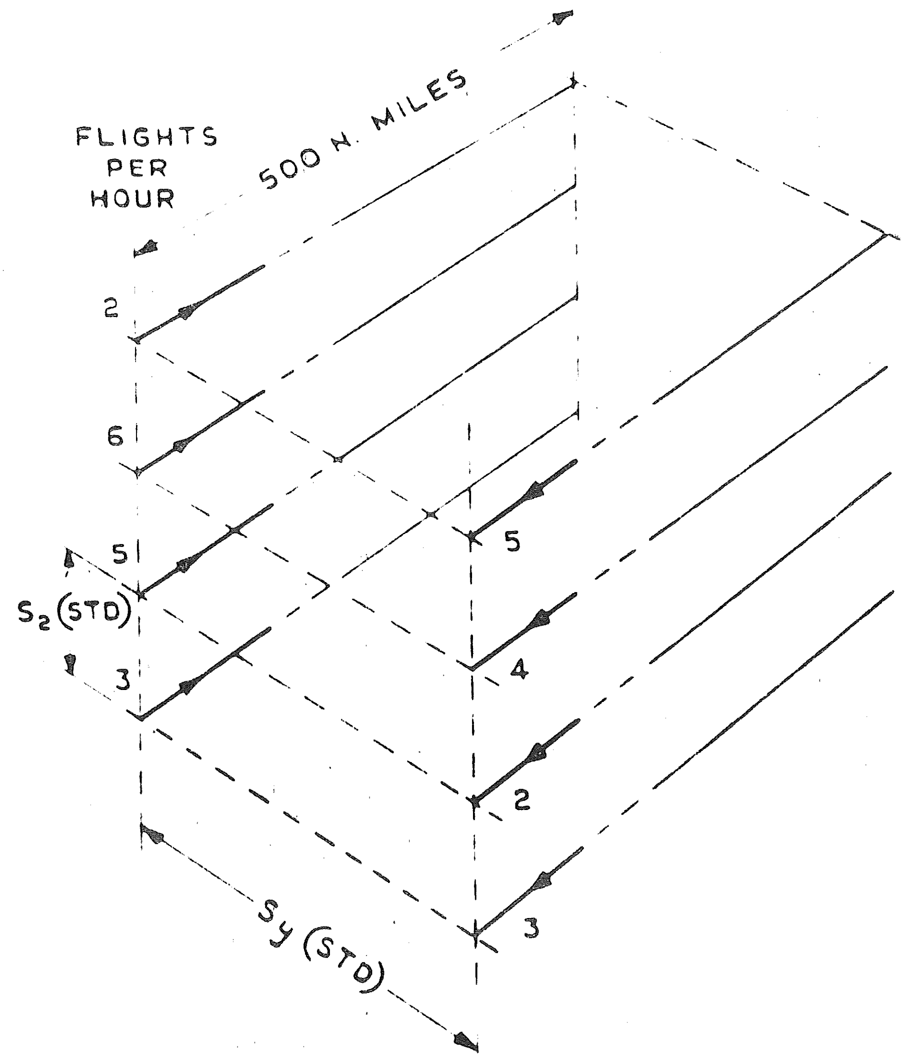


FIG. 7. TWO TRACK AIRWAY.

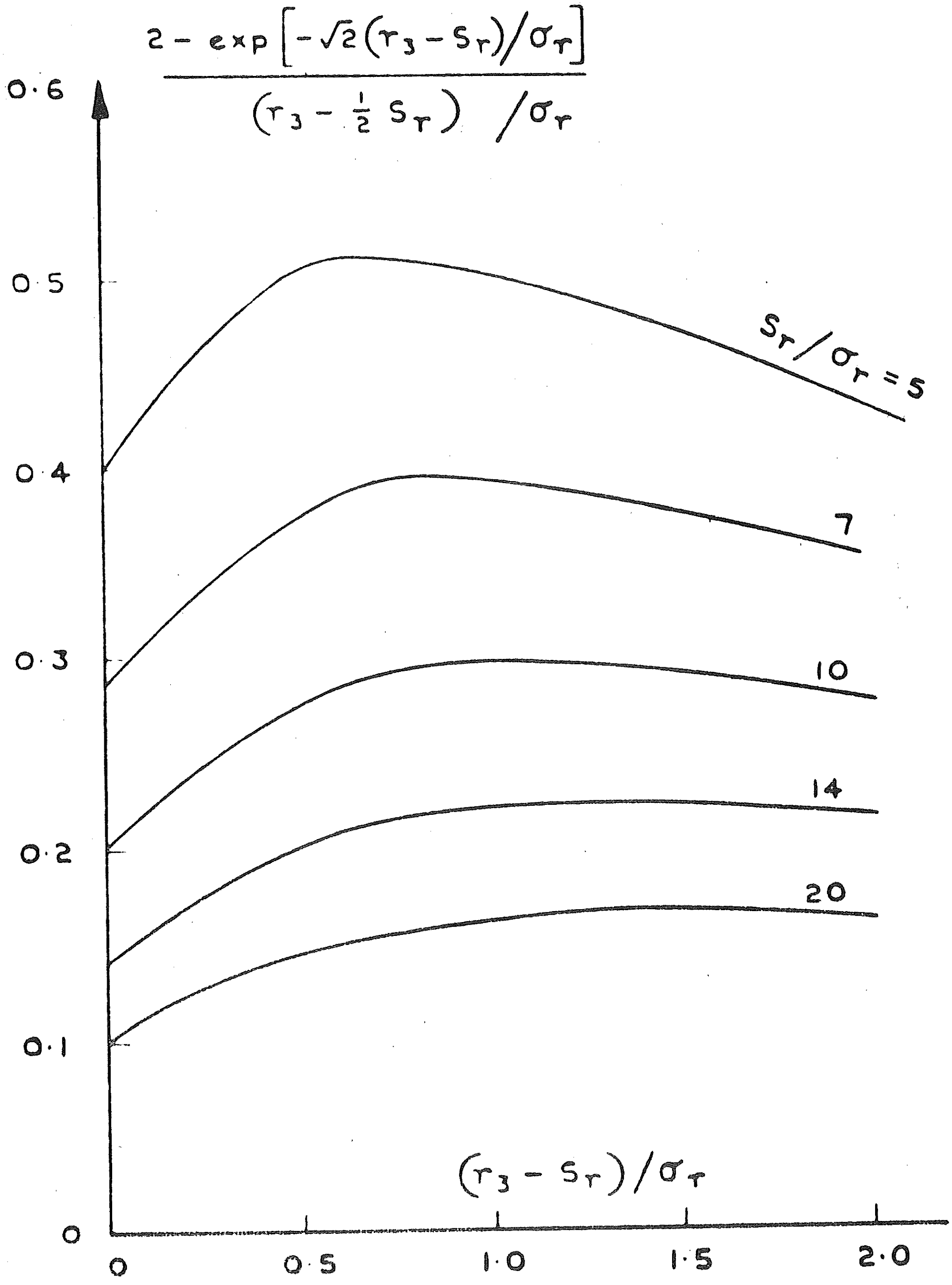


FIG. 8. MAXIMIZING AN EXPRESSION FOR P_r

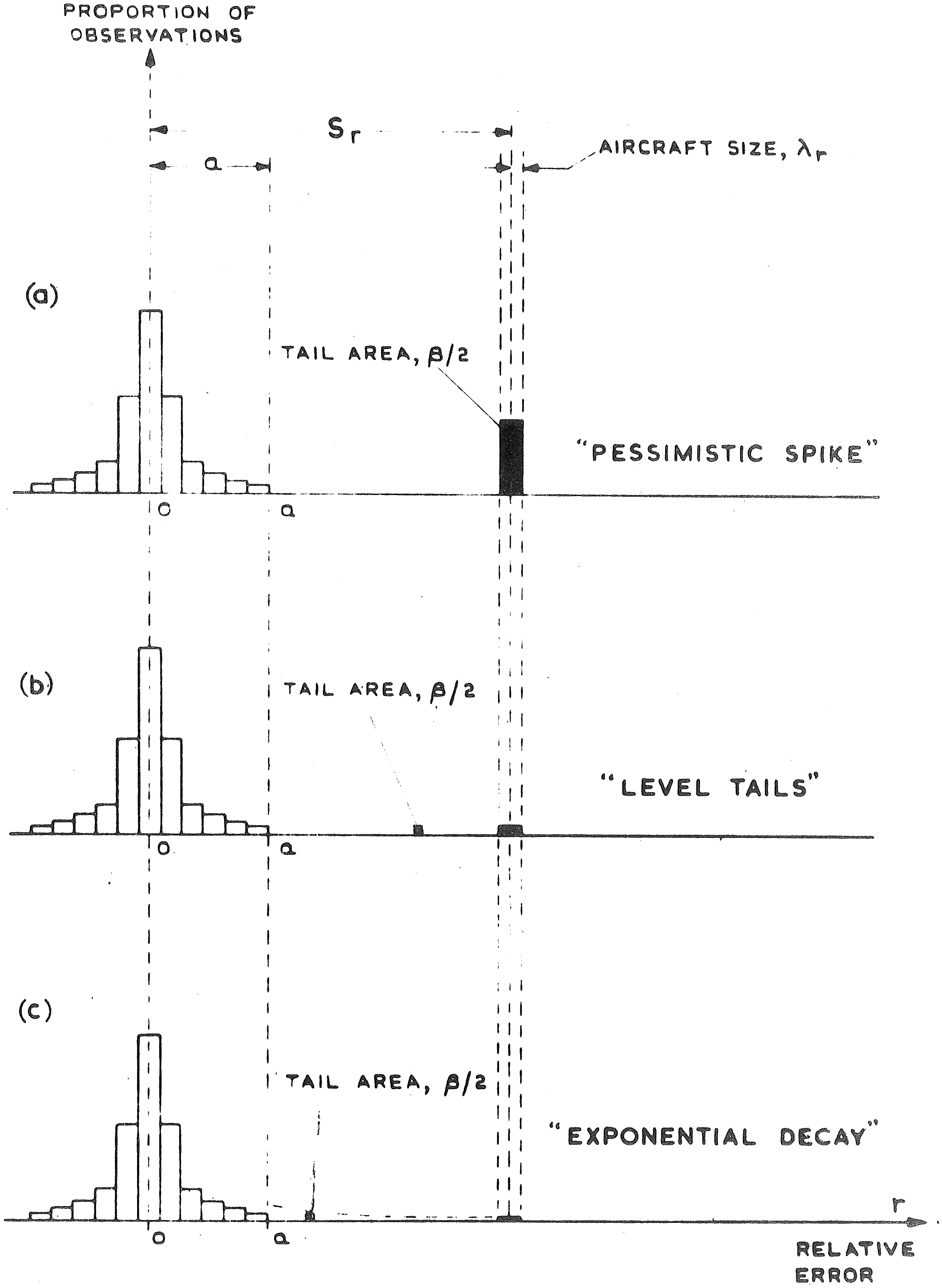


FIG. 9. TAIL SHAPES FOR RELATIVE ERRORS.

NOTATION USED IN THE MONTE CARLO PROCESS

The theory given in Appendix B, with the slight changes listed below, leads to the following expression for the expected number N_a, of aircraft accidents occurring in a given period, due to failure of lateral separation :-

$$N_a = 2\,P_y\,(\text{std}) \left\{ \frac{T_y\,(\text{same})}{S_x} \left[\frac{\Delta\bar{V}}{2}\,P_z(0) + \gamma\Lambda_x\,N_z(0) + \frac{\Lambda_x\,|\bar{\dot{y}}|\,P_z(0)}{2\lambda_y} \right] + \frac{T_y(\text{opp})}{S_x} \left[\bar{V}\,P_z(0) + \gamma\Lambda_x\,N_z(0) + \frac{\Lambda_x\,|\bar{\dot{y}}|\,P_z\,(0)}{2\,\lambda_y} \right] \right\} \quad \ldots\ldots (1)$$

In this equation, a metallic collision is counted as two aircraft accidents, but a fatal vortex penetration is counted as only one. Λ_x is the "effective" collision length of an aircraft after taking account of wing-tip vortices, and replaces λ_x, the metallic collision length of an aircraft defined in Appendices A and B. The coefficient γ applied to the N_z terms allows alternative models of the effective collision shape to be simply represented in the equation as rectangular slabs of constant cross-section $\lambda_y\,\lambda_z$, set by the metallic thickness and span of an aircraft. γ is unlikely to be substantially greater than unity, the N_z terms are unlikely to make a major contribution to the total risk, and therefore little accuracy will be lost in treating γ as a constant. $|\bar{\dot{y}}|$ is redefined as the mean relative velocity of a pair of aircraft which has lost vertical separation. χ is a reduction factor applied to the "blind-flying" collision risk to take account of visual avoidance.

The quantities $P_z(0)$, S_x, λ_y, V and γ can be treated as known constants. The remaining 8 quantities in eqn (1) have either to be estimated more or less imprecisely from limited numbers of observations, or depend to some extent on judgement. In the Monte Carlo approach each of these 8 quantities, with the exception of P_y(std) is to be represented as one distributed variable, which is sampled either from observed distributions or from distributions decided by "judgement". P_y(std) has to be represented by a product of two distributed variables, as may be inferred from the discussion of "tail area" and "tail shape" given in Section 3 of Appendix B.

Thus one has the following correspondence, in which it is to be understood that each w(...) represents a random variable :-

$$w(N_a) = 2k\, w(\text{tail area})\, w(\text{tail shape})\, w(\alpha) \left\{ \frac{w(T_y \text{ same})}{S_x} \left[\frac{w(\Delta V) P_z(o)}{2} + \gamma w(\Lambda_x) w\left[N_z(o)\right] + \frac{P_z(o) w(\Lambda_x) w(|\bar{\dot{y}}|)}{2\lambda_y} \right] + \frac{w(T_y \text{ opp})}{S_x} \left[\bar{V} P_z(o) + \gamma w(\Lambda_x) w\left[N_z(o)\right] + \frac{P_z(o) w(\Lambda_x) w(|\bar{\dot{y}}|)}{2\lambda_y} \right] \right\} \quad \ldots\ldots\ (2)$$

in which k is a constant scaling factor to enable the distributed variable w(tail shape) to be expressed in simple terms, for example as a shape varying continuously between the extremes corresponding to "level" and "exponential" (cf. section 3 of Appendix B).

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5. Summary of Agenda Item 5 : Interim measures to improve navigational performance

EXTENSION OF LORAN A COVER

5.1 It was noted that Recommendation 6 iii/5 of the Special NAT Meeting 1965 referred to the operation of LORAN A chains "C" and "D". In fact preparations required for their continuous operation had already been initiated by the various States and Agencies concerned. It is hoped that early in 1967 States would complete all necessary details, even though this might impose a number of difficulties on other than air navigation interests. It was therefore believed appropriate to express the appreciation of all concerned to those who have been of assistance thus far in overcoming the numerous problems which this matter posed.

5.2 It was also noted that the next issue of chart 3071 produced by the U.S.A, which is expected to be published in December 1966, will show the cover of LORAN A chains "C" and "D" with an appropriate note, indicating that the chains are still on test operation.

NOTIFICATION OF GROSS NAVIGATIONAL ERRORS TO OPERATORS

5.3 The Canadian representative explained that, as early as 1963, they had instituted a procedure whereby the operators concerned were notified on a monthly basis of any of their flights which by radar observation had been found to be more than 20 NM off track or which were in error longitudinally by more than 3 minutes. While this had generally been a useful tool providing operators with supplementary data for investigation, analysis and, where necessary, corrective action, it had however been found that in certain cases such reports had not had the anticipated beneficial effect. It was therefore suggested that a copy of such reports be also provided to the administration of the State of registry of the operator concerned.

5.4 The U.K. representative stated that, at irregular intervals, they also provided summaries of navigational accuracy observed on Killard radar to the operators. In addition, in cases where a deviation from track by more than half of the lateral separation standard (at present 60 NM) was observed, this was reported immediately to the operator concerned for investigation. This latter exceptional procedure had in fact proved to be very effective in those cases where it had to be applied.

5.5 After some discussion which centred primarily on the suggestion by Canada for notification to administrations, in addition to operators, on a routine basis, of observed deviations and on the value used by the U.K. in order to initiate its special notification procedure, it was agreed that :

i) Canada would continue to notify operators as in the past, of deviations of more than 20 NM from track and longitudinal errors greater than 3 minutes and that they would, at their discretion, notify the administrations concerned;

ii) that the UK would continue its method of notification with the exception that the special procedure would be applied when deviations from track of 45NM or more were observed;

iii) that both Canada and the U.K. would provide IANC, IATA and IFALPA with copies of their summaries.

IMPROVED NAVIGATIONAL TECHNIQUES

5.6 It was considered that for the purpose of conducting a meaningful data collection exercise in 1967 it is not only essential that the best possible method of data collection should be engineered but also that the navigational environment be improved as much as is possible in the short time available by activation of Loran A chains "C" and "D". It was noted that action was being taken with the aim of making these chains available. Similarly as much as possible should be done to ensure that a high standard of navigation be achieved at the present time which will also be representative of navigational performance in the next few years.

5.7 Standardization of aids has in the past been a primary means of achieving a similar and adequate navigation performance (e.g., standard short range aid) and when backed up by radar has permitted ATC separation standards to be applied which have had a beneficial effect on the capacity of the system. In respect of long range aids no such standard was deemed necessary, although in the NAT Region Consol and Loran are "Recommended Practices". Over the North Atlantic, without radar, the size of ATC separation standards, and hence the capacity of the system, must depend on existing and planned aids and on the navigational capability represented by the variety of installations of self-contained aids, Doppler/Inertial, now to be found in aircraft. It is thus important to ensure by all practicable means the maximum exploitation of these facilities. It is suggested that guide lines in this respect should be :

i) that the navigational target performance is to maintain cleared track;

ii) that the international organizations represented at this meeting and the operators should be encouraged to develop their navigational procedures so as to achieve the target performance. In following this requirement it should be borne in mind that track keeping accuracy may depend largely upon the frequency with which track is checked with reference to outside fixing aids, provided that the quality of the observations is high and that workload is not increased to the point where human error becomes a factor.

5.8 In this respect it was noted that IANC and IFALPA held the view that there were instances when a more frequent rate of fixing position and/or track checking would improve navigational accuracy. They therefore hoped that all users would draw the necessary conclusions resulting from this view. This position was supported by some administrations.

5.9 Finally, it should be noted that the organization of the flow of air traffic in the form, for example, of the application of organized track systems by ATC, specifications of navigation equipment and performance, and an overall navigational capability which will meet, to the maximum extent possible, the target performance, is essential as the alternative to a reduced rate of flow of traffic or an increased risk of collision, or both.

THE CONDUCT OF GENERAL AVIATION AND OTHER ITINERANT TRAFFIC IN THE NAT REGION

5.10 It was noted that at present approximately 30 flights a month were conducted across the North Atlantic by general aviation turbo-jet aircraft and it was expected that this number would increase over the next few years. It was felt that the evolution in this field should be carefully observed since it was believed that this could present a problem, especially if equipment or other limitations of such aircraft prevented their full integration into the flow of scheduled commercial air traffic.

5.11 It was further noted that the number of turbo-jet flights conducted by non-scheduled operators in the NAT Region was much greater and currently amounted to about 400 flights a month. About one third of these were cargo flights and the remainder were charter operations carrying passengers.

5.12 Because of widely different national regulations there existed no uniform requirements regarding aircraft equipment or crew qualifications for flights in the NAT Region. For a variety of reasons it could also not be expected that concerted national efforts towards this aim would be successful in the foreseeable future and any hope for legal action to impose compatibility of equipment and qualifications between scheduled, non-scheduled and other operators in the NAT Region, should this be found to be necessary, was therefore remote.

5.13 In the absence of detailed information on equipment, qualification and operating procedures used by general aviation turbo-jet aircraft engaged in NAT operations, it was agreed that the only valid course of action available at this time was :

i) to obtain more information on actual and planned operations by general aviation in the NAT Region through contacts on the national level with the appropriate representatives of this part of the flying public; and

ii) to start, again on the national level, an education programme with the intent of thoroughly familiarizing general aviation aircrews with the environment of the NAT Region.

5.14 In this respect, it was noted that the U.S.A. had already established contact with their Aircraft Owners and Pilots Association (AOPA) and that the FAA was in the process of preparing a publication containing pertinent information necessary to pilots intending to operate flights across the North Atlantic. It was expected that this publication would be available early in 1967.

5.15 A suggestion to segregate general aviation from other operations in the NAT Region was discarded after a brief discussion because it was believed that, apart from the difficulties created both for the pilot concerned and ATC, this was not a valid solution of the problem on a long term basis.

5.16 With regard to non-scheduled turbo-jet operators it was noted that this type of traffic differed from general aviation since it consisted mainly of direct East-West flights with aircraft types similar to those used by scheduled operators. While it was thought likely that the navigation equipment carried was similar to that used by scheduled flights there was no information available at present on crew competency. Accordingly it was agreed that the NAT Oceanic ACC's would continue to collect information on non-scheduled operations so that this question may be later reviewed.

5.17 With regard to military operations in the region it was noted that, apart from the inevitable fact that their requirements occasionally conflicted with civil needs, the coordination procedures were such that any civil-military problems could be handled safely.

6. Summary of Agenda Item 6 : Programme of Data Collection and Analysis

GENERAL

6.1 In recent years several reviews have been conducted regarding aircraft navigational capability in the NAT Region. Due to differences in objectives or for various other reasons such as limited measurement capability, data omissions, possible data bias, inadequate sample size, etc., neither the individual nor the collective results of these reviews have been accepted by all parties interested in the NAT Region as conclusive evidence of navigational capability within this Region. In addition, providers as well as users involved in decisions concerning procedural or technical changes to the air navigation system were repeatedly faced with the problem of obsolescence of previously collected data caused by the improvement or the introduction of new navigation techniques and of new aircraft types.

6.2 In view of current and forecast air traffic densities and because of the recognized obligation to maintain not only a safe but also an efficient air space utilization it was agreed that the providers and users of the air navigation system in the NAT Region carry out a data collection and analysis in order to provide, to the satisfaction of all, reliable evidence on the current navigational capabilities in the NAT Region.

6.3 The objective of the data collection programme is to obtain data which is as accurate and unbiased as possible and which will indicate the degree of track keeping accuracy existing in the area. In addition it should also serve to obtain information which may lead to an improvement in track keeping accuracy by determining the relationship between gross errors and any other factor which might become apparent. The programme should particularly provide information on the following:

i) across track navigational errors;

ii) the rate of change of individual aircraft across track deviation;

iii) correlation of across track errors between adjacent aircraft;

iv) correlation of along track relationship between successive aircraft;

v) variations of navigation errors with relation to specific areas of the NAT Region;

vi) seasonal variations of navigation errors;

vii) variations of navigation errors between day and night;

viii) variations of navigation errors between various types of airborne equipment and navigation techniques.

Note: The listing of the subjects under i) to viii) above does not necessarily imply any order of priority.

6.4 In order to achieve the objective it is believed essential that all available sources of data on navigational capability information should be used. This will require the full cooperation of users and providers and it is therefore hoped that everybody concerned will give full support to the data collection programme presented below.

6.5 Since the coordination of all the activities required for the programme and the preparation and testing of data collection procedures and equipment involves rather complex processes, it was agreed that the target date for starting the collection of data should be 1 July 1967. In addition, in order to keep costs and any burden imposed on participants in the programme to a minimum it was agreed that a major part of the necessary data collection should be carried out during the period from July to end of September 1967 since this constitutes the peak traffic period of the year. In the interest of confirming data obtained during this period or in order to obtain more data on the seasonal influence on navigational capability, certain follow-up activities of a smaller scope should be arranged.

SOURCES OF DATA

6.6 It was agreed that the sources of data from which information on navigation capability could be obtained were, in the order of importance:

i) radar data;

ii) flight log data.

In addition ATC data would be essential to supplement this data.

6.7 With regard to radar data it is obvious that, from a purely technical point of view, the only information obtained from the surveillance system is:

i) the rho-theta position of an aircraft in relation to a radar antenna;

ii) the SSR code in Mode A/3 used by the aircraft concerned.

It is therefore essential to process this data further, together with other data (in the case of shipborne radar the ship's position), in order to obtain information on the absolute position of an aircraft at a given time. A method to obtain this data is described below.

6.8 With respect to flight log data this requires the post-flight examination of records kept in flight in order to determine the aircraft's actual position with respect to points on the surface of the earth and it is evident that thoroughness on the part of the analyst, together with considerable experience in this type of work are essential. This implies the availability of a high level of current operational advice.

6.9 As far as air traffic control is concerned it is evident that any additional demands placed on the oceanic ACC's must be kept to an absolute minimum because the primary task of the ATC personnel must be directed to efficient control of air traffic. The requirement for ATC data and the desired machinery for effectively correlating this with radar and flight log data is specified in Appendix "A". In addition, an SSR Code Assignment Plan is also given in this Appendix.

6.10 From the mathematical/statistical point of view it would also appear necessary to keep a proper balance between radar derived data and flight log data since, otherwise, the statistical values obtained from each one of these two sources of data may not be of appropriate significance. This consideration applies, however, only in those cases where radar cover is provided while in all other areas flight log data, by necessity, is the only means of obtaining data.

MEASURING TECHNIQUES AND SAMPLE SIZES

6.11 The efforts made by Canada, Ireland, the UK and the USA to realize the data collection programme were noted with great satisfaction. It was further noted that Canada, the UK and the USA would, as soon as possible after the meeting, confirm the availability of data collection equipment and certain other support necessary for the success of this programme. Details regarding radar data acquisition and recording techniques as well as a radar station deployment plan are contained in Appendices "B" and "C" to this summary. It should be noted that no voice communication with the aircraft observed by radar is necessary in acquiring data on its position.

6.12 The description of the flight records required for the analysis is contained in Appendix "D".

6.13 As regards sample sizes which can be obtained during the data collection programme, details concerning the radar data sampling and the estimated results of it are contained in Appendix "E" to this paper.

With respect to the shore-based radars it was felt prudent to allow for their operation throughout the whole period of the programme; it would probably not be possible to run the data collection programme again if the sample achieved was not adequate. For this reason it was agreed that the operation of the facilities in Ireland and Canada should be planned to operate on a daily basis as far as practicable.

6.14 The collection period for the flight log data should be arranged in such a way that flight log data on approximately 4 000 flights become available. It is not considered necessary to fully integrate the flight log collection period with that for the collection of radar data. However, at least part of the two collection periods should coincide in order to allow the comparison of flight log data with that obtained from radar observations. In addition, in order to preclude possible bias, it was agreed that any one period of flight log data collection should not be less than 3 consecutive days. Any such collection periods should be distributed evenly throughout the entire period of data collection in order to take into account seasonal variations, reduce the influence of persistent meteorological conditions and ensure that all types of operations are included in the sample.

ORGANIZATION OF THE DATA COLLECTION AND THE COLLATION REDUCTION AND ANALYSIS OF DATA

6.15 As far as the organization of the data collection is concerned it was agreed that in order to ensure widest possible participation of all users of the airspace the provider States concerned would issue an Information Circular at least 28 days in advance of the beginning of the data collection in order to alert all concerned to this programme. A draft text for this Information Circular is attached in Appendix "F". In addition, all States concerned are requested to notify all concerned in an appropriate manner, drawing their attention to this programme.

6.16 The data obtained by radar collection will include the following items:

i) the recording date (month and day);

ii) the SSR code used by each aircraft observed;

iii) the range and azimuth of each aircraft position observed;

iv) the time (in hours, minutes and seconds) of each data under iii) above;

v) a special annotation identifying any unreliable data entry;

vi) in the case of data derived from shipborne radar, information on the ship's position. (This data will, with reference to data under iv) above, show the identification of the Loran C chain, the identity of the slave station, the time difference between master and slave station and, as appropriate, a sky-wave or a lost signal symbol.)

This data will be stored on magnetic tape and extensive use of automatic techniques are envisaged:

a) for the conversion of stored data into a presentation which is readily comparable with other data, and

b) for the collation and analysis of this data.

6.17 In order to provide for as uniform as possible a presentation of the flight log data the Meeting agreed that standard forms should be used by all operators when providing this information. A sample form, developed for this purpose, is attached in Appendix "G".

6.18 With respect to flight log data, in order to preclude selection it is essential that data on all flights during the evaluation periods be examined and reported on by the operators concerned. In addition, independent analysis teams should be established on a national basis composed of representatives of the administrations, civil and military operators, the national pilots' associations and air navigators' associations. It is hoped that all parties concerned will cooperate in the provision of an adequate number of suitably qualified personnel for participation in this programme. These teams should examine a sufficient number of flight logs to ensure the validity of the evaluations made by the operators concerned. They should also investigate, with the operators concerned, flights which indicate gross deviations from track or which are otherwise of particular interest with a view to establishing the possible cause for these errors. A method of analysis is shown in Appendix "H".

6.19 As far as flight log data on military aircraft was concerned, Canada, the UK and the USA stated that flight log data from these aircraft would be reviewed and the results of such review made available for the programme. However, details on data of individual flights could only be made available if no military security problem was involved.

6.20 It was further agreed that the USA would attempt to obtain the ATC data required to correlate radar observations in the Gander, Lisboa Oceanic and New York Oceanic FIR's and that the UK will assemble essential data from Reykjavik, Shanwick and Shannon FIR's. After collation the USA will forward its data to the Royal Aircraft Establishment for further reduction and analysis. The Meeting unanimously requested the UK to make available its facilities at the Royal Aircraft Establishment for the analysis of both the radar and the flight log data. A diagram of the intended data flow is attached in Appendix "I".

6.21 It was also agreed that all data pertaining to this data collection programme, such as flight plan data, flight progress strips, meteorological maps used for the plotting of MTP's and establishing a datum line, coordinates of organized routes and information on their periods of use as well as all other relevant data, be retained by the administrations or operators concerned until the programme is completed.

PRESENTATION OF THE RESULTS OF THE DATA ANALYSIS

6.22 After a brief discussion it was agreed that the results of the data analysis should be presented in two phases. Immediately following the processing of the data a report should be prepared containing factual results only. This report should provide the following detailed information:

i) relation of specific data to identifiable geographic areas of the NAT Region;

ii) flight levels used;

iii) distribution of data by reference to its source (shore-based radar, shipborne radar, flight log, ATC data);

iv) breakdown of data into user categories;

v) navigation equipment and techniques used;

vi) variables introduced into the navigation by:

a) seasonal changes

b) changes of the time of the day

c) radio propagation phenomena;

vii) exceptional flight conditions (turbulence, static, etc.)

6.23 It was further agreed that, upon request from interested States and organizations, more detailed information such as on user categories would be provided in an agreed manner by the appropriate agency.

6.24 In due time this report should be followed by an interpretative study in which the factual results were measured against agreed mathematical models and which would contain an analysis of the results thus obtained. It was agreed that the UK would provide such a study and that each interested party was free to take similar action if it so wished.

6.25 Since the results of the data collection programme could not be anticipated in any way at this time, it was believed best not to take any decision regarding possible further action resulting from these studies.

CONCLUSIONS

6.26 As a result of the discussions on this agenda item the following conclusions were drawn:

i) that all parties concerned (provider as well as user States, operators engaged in commercial and non-commercial flights, military operators and particularly flight crews) be invited to give their full support and cooperation to the data collection programme;

ii) that the USA be invited to make their resources available in order to carry out the shipborne radar data collection, that Ireland and the UK be invited to establish a shore-based radar system to provide data collection from the coast of Ireland and that Canada should be requested to make available their existing radar system;

iii) that the UK and the USA make available their data processing facilities in order to rapidly process the data once it had been collected;

iv) that the UK use its services and facilities in order to prepare an initial factual report and a later interpretative study of the results obtained and make these available to all interested parties;

v) that once the report and the study (plus any others that might be prepared by others) are available, a further meeting be convened in order to agree, in a spirit of cooperation, on the measures to be taken as a result of the data collection and analysis exercise.

ATC FACILITY DATA AND SSR CODE ASSIGNMENT PLAN

1. AIR TRAFFIC CONTROL FACILITY DATA

1.1 In carrying out the data collection programme every effort should be made to minimize the amount of support activities imposed on Oceanic ACC personnel. This is especially important since much of the data collection effort will be conducted during busy summer months.

1.2 In view of the automatic radar data acquisition capability, which will probably be operated by maintenance rather than controller personnel, the principal support required from Oceanic centers will relate to SSR code assignment and cleared track/flight level details. The requirements can be summarized as follows :

i) A daily record (the day being based on GMT) of all oceanic code assignments plus notation of any turbo-jet aircraft operating without a functioning SSR transponder. Thus this would be a complete record of jet aircraft flights.

ii) A daily record, based on GMT, of cleared track, cleared flight level(s), reported times at reporting meridians, and corresponding aircraft identification details appropriate to the radar collection areas active at the time.

iii) Radar system and auto acquisition equipment serviceability records where these are kept at the ACC.

iv) Retention of all jet aircraft flight data (including teletype messages and flight progress strips), weather maps used in plotting flight plan tracks, MTP's and datum lines, co-ordinates of organized tracks and other pertinent operational data for the period of the data collection and afterwards for such time until authorization is given for routine destruction.

Note: As much of these data will be required on an "on call" basis the greatest care should be taken to ensure their retention in an orderly and accessible manner.

With regard to the above, standard forms and procedures will be developed as necessary.

1.3 Detailed requirements are as indicated below :

1.3.1 All main radar collection periods (Configuration C in Appendix C)

Oceanic ACC	Data Requirements (Westbound Flights)	Data Requirements (Eastbound Flights)
Shanwick	1. Daily list of jet flights with SSR codes.	In respect of each flight: 1. Date (related to GMT entry time Oceanic CTA) 2. SSR Code 3. Identification 4. Operator 5. Aircraft Type 6. Cleared latitudes at 20°W and 10°W (or Bdy) 7. Reported times at 20°W etc. 8. Cleared flight levels at 20°W etc. 9. Cleared Mach No's. (see note a) below)
Gander	In respect of each flight: 1. Date (related to GMT entry time Oceanic CTA) 2. SSR Code 3. Identification 4. Operator 5. Aircraft Type 6. Cleared latitudes at 30°W, 40°W and 50°W 7. Reported times at 30°W etc. 8. Cleared flight levels at 30°W etc. 9. Cleared Mach No's. (see note b) below)	1. Daily list of jet flights with SSR codes 2. As for Westbound flights, items 1-9; 30°W and 40°W data only in respect of items 6, 7 and 8 (see note b) below)
Lisboa Reyjavik	1. Daily list of jet flights with SSR codes (see note c) below)	1. Daily list of jet flights with SSR codes (see note c) below)
New York		1. Daily list of jet flights with SSR codes (see note c) below)

Notes:

a) Best estimated time for 10°W (or boundary) permissible for item 7.

b) If a ship or ships are positioned East of 35°W longitude cleared latitude and flight level for 20°W may also be required. Effective coordination with Shanwick will be necessary for this purpose.

c) Detailed coordination arrangements will be needed between centers and/or agencies collating data.

d) Appropriate cleared track, flight levels and reported times are required if a flight is predominantly N-S through the data collection area. Normally these would be given in 5° latitude increments for the vicinity of radar coverage.

1.3.2 Land-based radar collection periods (Configuration E in Appendix C)

As 1. except 20°W, 30°W and 40°W data not required from Gander.

1.3.3 Additional data requirement for supplementary ship radar collection periods (Configurations B and D in Appendix C)

Oceanic ACC	Data Requirement (Eastbound and Westbound Flights)	Remarks
New York Lisboa Gander	1. Date related to GMT entry time Oceanic Area. 2. SSR Code 3. Identification 4. Operator 5. Aircraft type 6. Cleared latitude at longitude X and Y. 7. Reported times at longitude " " " 8. Cleared flight level(s) at longitude X and Y. 9. Cleared Mach No's.	These items are only required when requested by appropriate data collation center after the processing of the radar records

II SSR CODE ASSIGNMENT PLAN

2.1 Because only about 50% of jet air traffic are expected to be equipped to 4096-code standards in mode 3/A, it is proposed to allocate codes within the 64-code system capability. It is believed that the following codes should be excluded from the code assignment plan :

00 - this is a General Purpose code;

03, 14, 24 - already assigned to Killard (Northern Ireland); (Note: If satisfactory procedures can be developed these 3 codes may become available to the data collection programme.)

76 - radio failure code;

77 - emergency code.

2.2 In addition ten codes are thought to be permanently available to State aircraft over the North Atlantic. Once these are identified they should be removed from the assignment plan, except that, by arrangement with the appropriate authorities, it may be possible to use one or more of these codes for State aircraft participating in the data collection exercise.

2.3 Assuming that ten codes are withdrawn 48 codes would remain for allottment and these are provisionally apportioned in the manner shown in the table below. The computer analysis programme for the reduction of radar data will permit the assignment of the same band of codes for opposite direction traffic. In view of the anticipated hourly flow rates of jet aircraft in the main flow traffic areas it is expected that no single code will be used more than about once every hour. The normal method of allocation will be by consecutive extraction from a list of codes available to a given ATC center, issued in approximate order of arrival at a specified meridian of longitude. The aim throughout should be that aircraft using the same code should not pass through a particular radar service area with less than about one hour's longitudinal spacing. As radar observations will be time referenced there should subsequently be no problem in deriving correct identification of aircraft, flying specified tracks, in the data analysis programme.

2.4 Codes will be allotted to all jet aircraft cleared at levels up to and including Flight Level 420. In order to ensure the success of the data collection exercise it would be essential for unambiguous instructions to be issued to Controllers at all concerned Air Traffic Control centers. Attention would have to be given to procedures authorizing aircraft to change code to/from codes in use in Continental domestic airspace so that data was not lost.

2.5 It will be necessary for five control centers to maintain daily records of code assignment and these should be made available to the designated data collation authority throughout the period of the data collection programme. An agreed form will be supplied for this purpose. Notation of any turbo-jet aircraft operating without a functioning SSR transponder should be made in these records.

TABLE

SIMPLIFIED SSR (MODE A) CODE ASSIGNMENT PLAN

- ALL DATA COLLECTION CONFIGURATIONS

(See Appendix C)

Oceanic ACC responsible for issue of clearance (and SSR code)	Provisional No. of codes allocated	Direction of Flight	Categories of jet traffic to which codes will be allocated.
GANDER	38 (a)	Eastbound	All flights.
	-	Westbound	Not applicable.
NEW YORK	38 (a)	Eastbound	All flights expected to enter the radar data collection area.
	-	Westbound	Not applicable.
SHANWICK	-	Eastbound	Not applicable.
	38	Westbound	All flights.
LISBOA	5 (b)	Eastbound	All flights not having a code previously allocated by another center and entering the radar data collection area.
		Westbound	All flights expected to enter the radar data collection area.
REYJAVIK	5 (b)	Eastbound	1. Aircraft within Reyjavik Oceanic CTA and subsequently entering Shanwick and crossing 10°W longitude South of 56°N. 2. Aircraft within Reyjavik Oceanic CTA and subsequently entering Lisboa Oceanic CTA
		Westbound	Aircraft not having a code previously allocated by another center and entering the radar data collection area

Notes:

a) Codes will be shared between Gander and New York centers after daily appraisal of the traffic situation.

b) If the traffic situation warrants, additional code allocation will be temporarily requested from either Shanwick or Gander/New York centers as appropriate and the transaction recorded on the daily code allocation list at both the co-operating centers.

c) For "round robin" type flights (flights proceeding into Oceanic airspace and then returning without intermediate landing) code assignment will be determined after inter-center coordination.

RADAR DATA ACQUISITION AND RECORDING TECHNIQUE

1. The system described herein is designed to provide automatic acquisition and recording of SSR code (4096 and 64 codes Mode A/3) and aircraft position as it relates to the ground or shipboard radar station. Included in the electronic processing equipment is a precision clock whereby positional information may be referenced in seconds of time. All of the above data elements will be digitized and recorded on magnetic tape. In the case of shipborne radar stations, the ship's position, obtained by Loran C, will also be recorded identifying the chain in use and the time difference in microseconds. Conversion of the recorded time difference to latitude and longitude will be accomplished by computer technique during the data reduction and analysis programme. All of the data recorded on magnetic tape will be in a format suitable for computer processing.

2. Equipment - The equipment items required for the data collection system are shown on the system block diagram in Figure 1 and consist of the following :

1. SSR Digital Processor sub-assembly:
   - a. Decoder for 4096 Codes
   - b. Target Detector
   - c. Azimuth Computation Unit
   - d. Range Computation Unit
2. Azimuth Pulse Generator
3. Loran Digitizer
4. Loran Interface Unit
5. Digital Clock
6. Sequence Control Unit
7. System Monitor Unit
8. Tape Recorder

3. In the case of shore-based systems, items 3 and 4 will, of course, not be required.

4. Technical Description of Digital System - The SSR processor is, in effect, a small, scaled-down version of larger digital processors. It is, essentially, a single-channel device without extensive memory elements. It has been further simplified by reducing the degree of sophistication which is normally needed in the larger digital processors because of the relatively low density environment in which it will be used. For example, the tight decoding tolerances normally required for degarbling and multiple target detection are not considered necessary.

5. A block diagram of the SSR processor is shown in Figure 2. The range computation unit, which consists essentially of a range counter and a range storage register, performs two functions. First, it provides a digital range to the nearest 1/16 of a mile for each of the SSR replies that are detected in the reply detection unit. Second, it provides 25 range sectors of 8 miles each. The processor will sequence through the range sectors on each successive antenna scan so that every target, regardless of range and azimuth, will be detected. The target detection unit makes use of the well-known "sliding window" technique and will determine where the leading and trailing edges of each target are, thus permitting azimuth to be computed and stored in the azimuth computation unit. The azimuth pulse generator, although not a part of the SSR processor, is used exclusively by the azimuth computation unit. It generates the required 4096 azimuth change pulses and one north marker for every scan of the antenna. The processor will include sufficient test functions and test indicators to permit maintenance personnel to manually step through each processing cycle and check each output register to make sure that the equipment is functioning properly. The PPI shown in Figure 1 relates to this data acquisition technique only as a device for checking to assure proper system operation. The Loran C time difference digitizer is shown in modified form in Figure 3. The digital clock will be a commercially available unit and will provide a digital output which can be sampled with a data sequence control unit.

6. The sequence control unit is shown in block form in Figure 4 and consists of a data bit control section, a shift counter control section, a sequence control section, and a serial output control section. The sequence control section will provide the proper timing for the sampling of each of the various output registers that are to be recorded. The data bit control section and the shift counter control section keep track of the number of bits as they are received from each of the output registers. The serial output control section accepts bits from each of the registers and converts them into the proper digital form for recording by the magnetic tape unit. As denoted in the block diagram for the sequence control unit, SSR code information would be sampled immediately after a start pulse is generated, then range, azimuth, and so on until a complete target record has been recorded. A proposed format for the serial read-out data is shown in Figure 5.

7. The equipment will be built from digital logic modules and will be packaged in a 3-1/2 foot rack. The logic card assembly, while more expensive than fixed assemblies, provides easy access to the equipment for maintenance and repair.

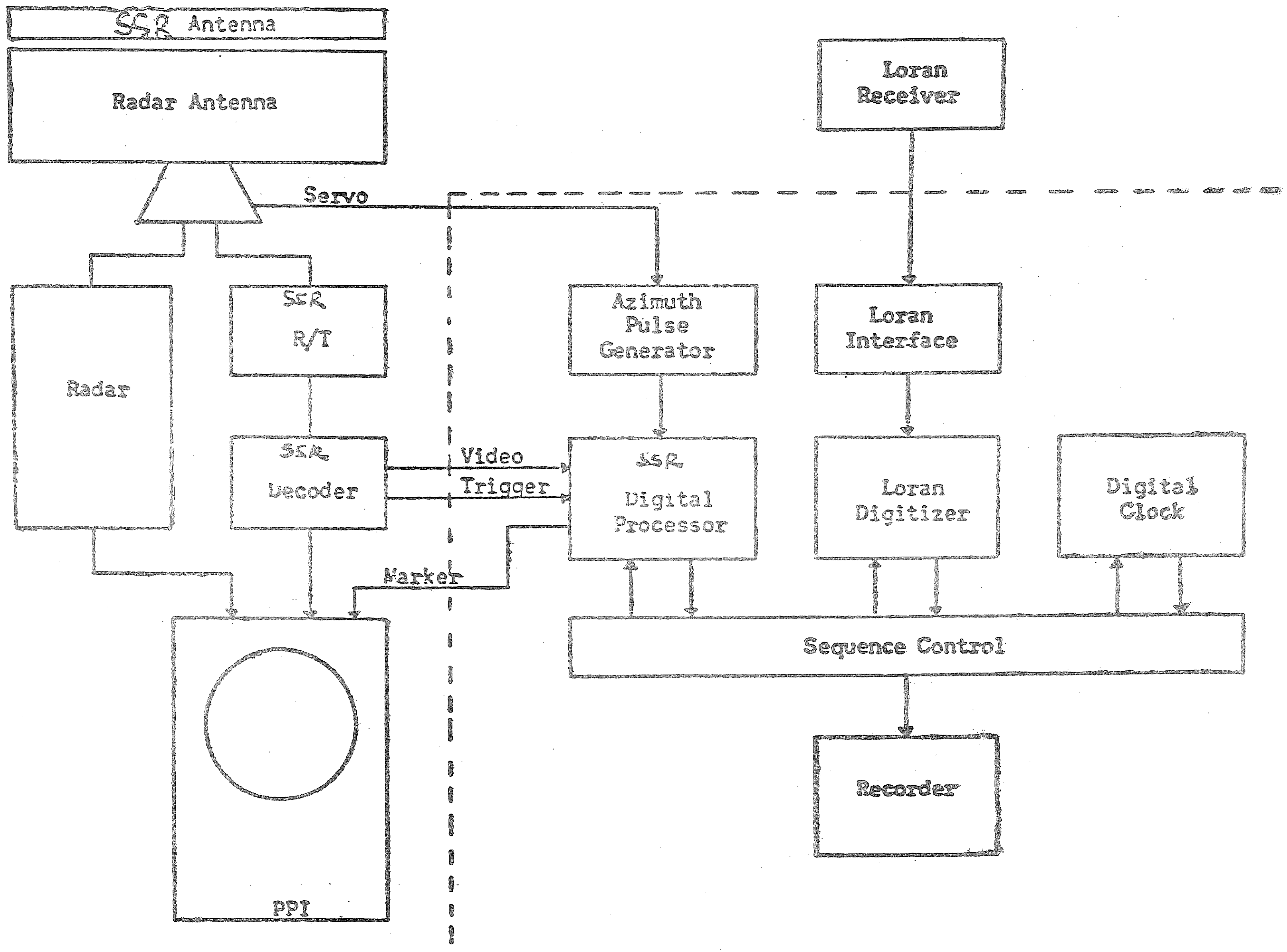

Fig. 1 System Block Diagram

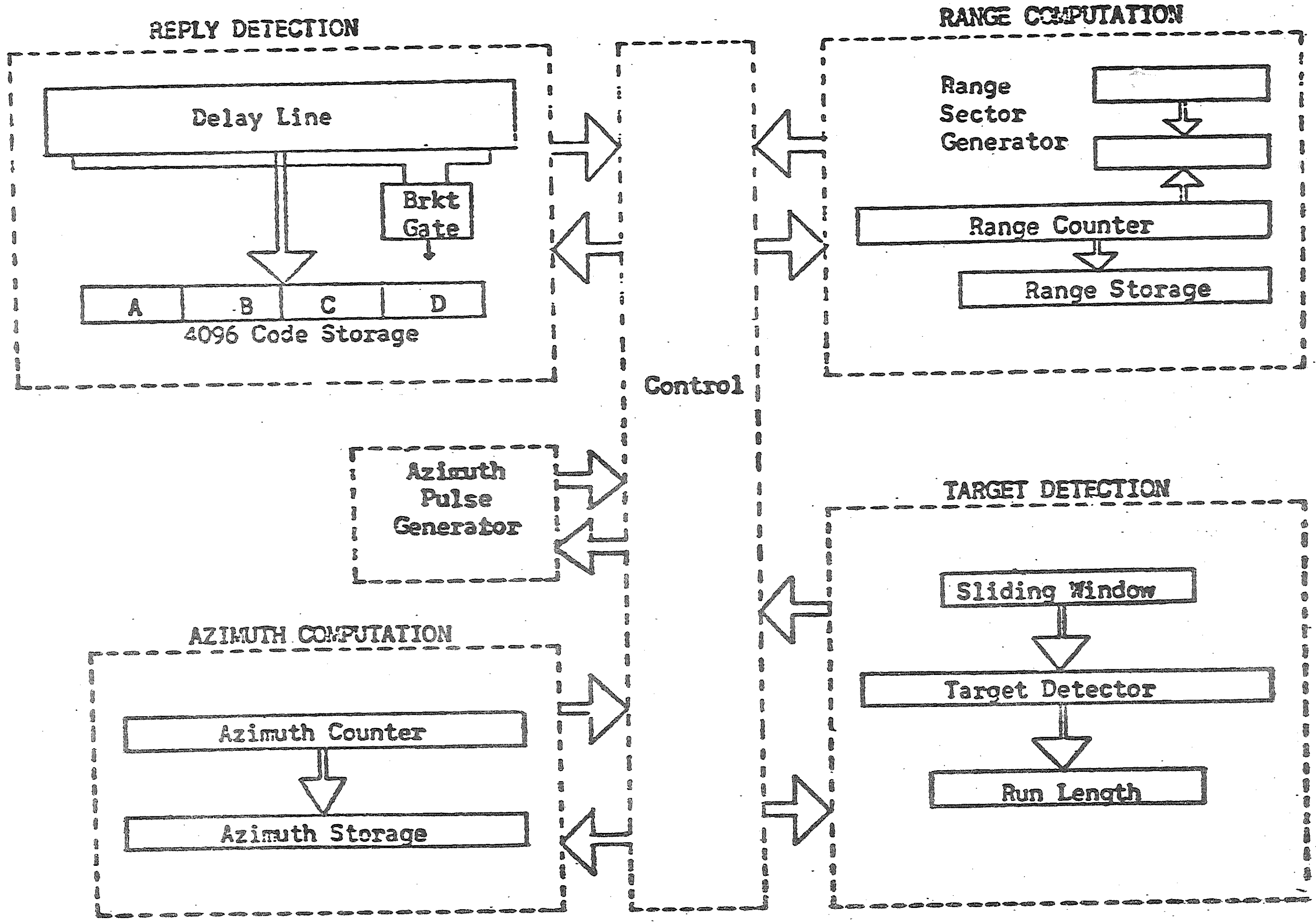

Fig. 2 SSR Digital Processor

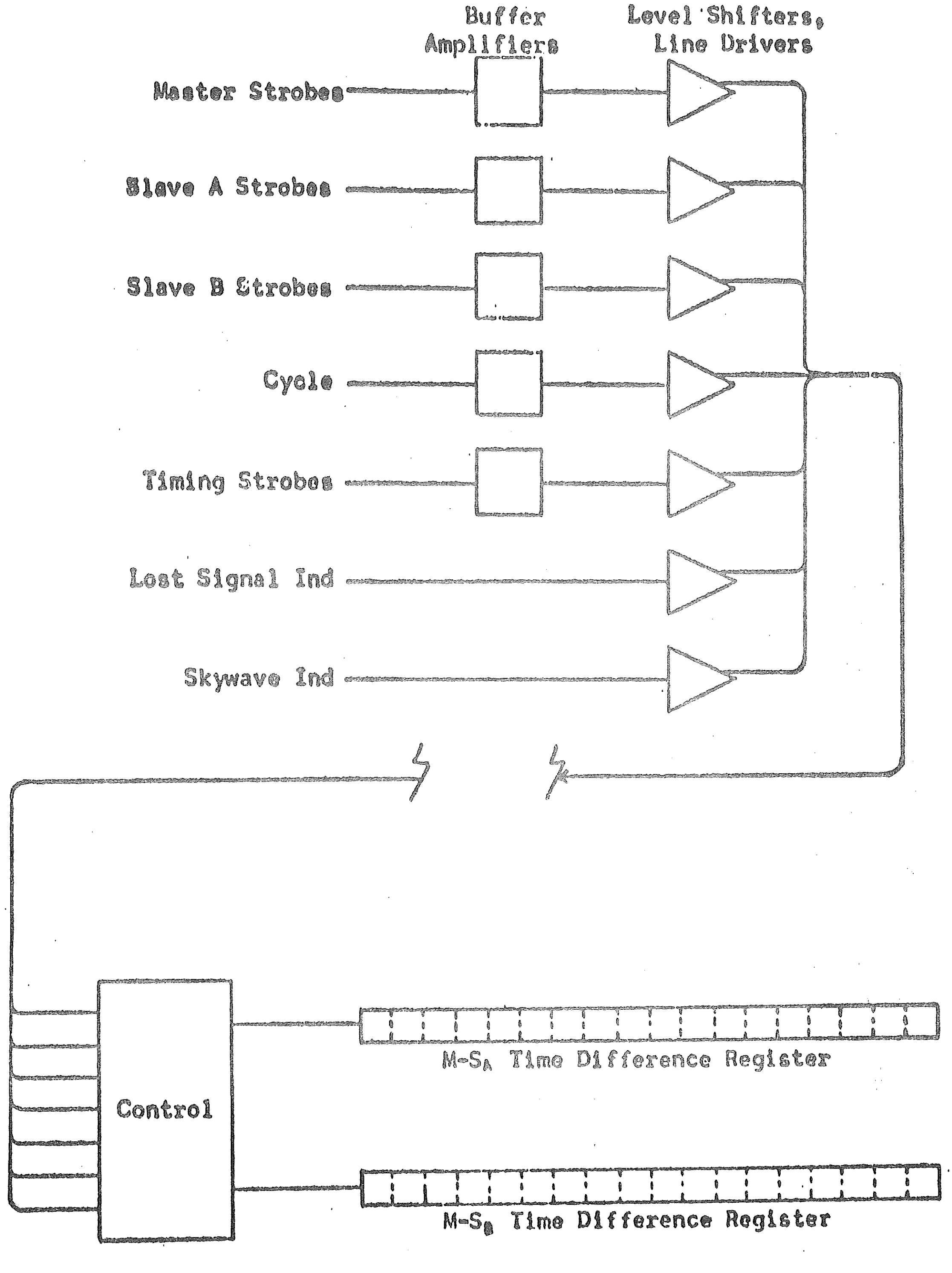

Fig. 3 Loran Receiver Interface

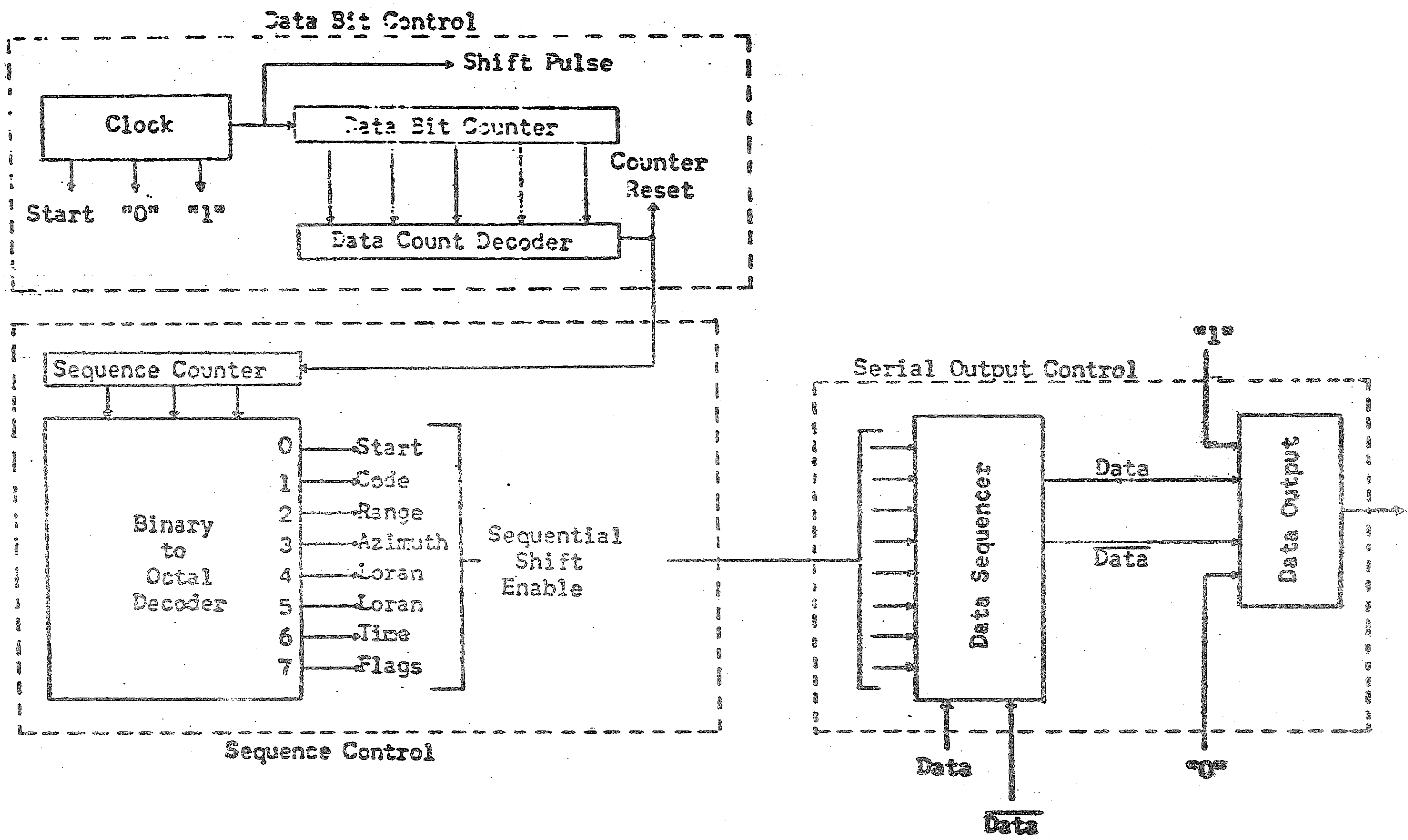

Fig. 4 Sequence Control

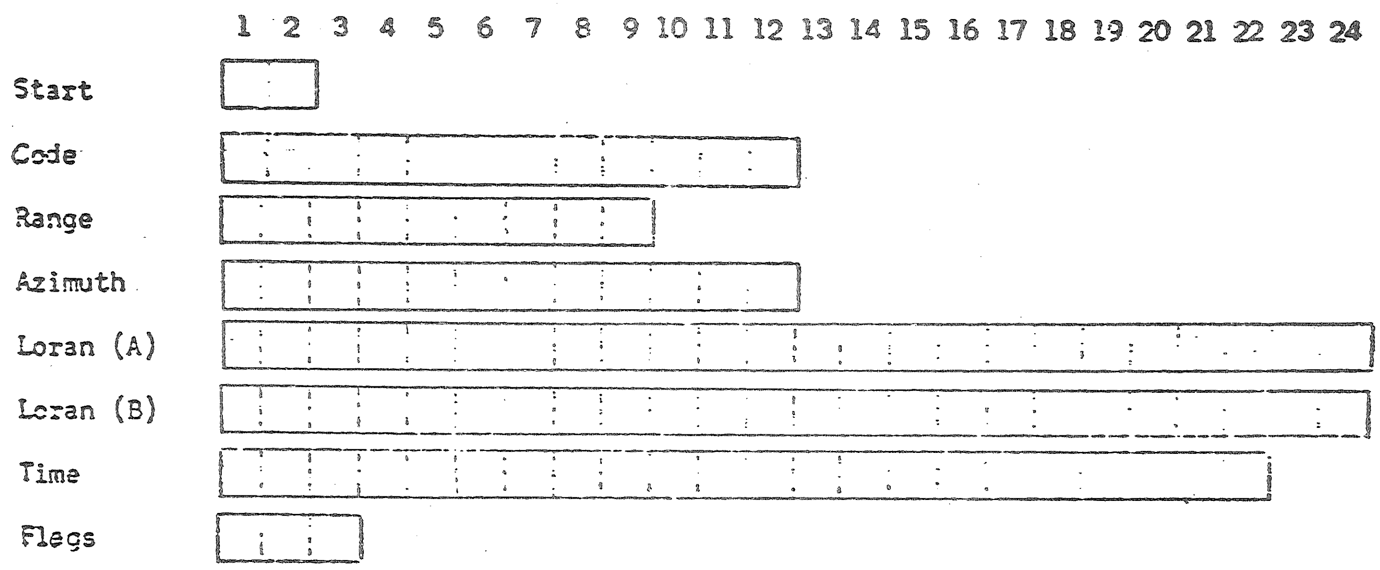

Fig. 5 Serial Readout Format

RADAR STATIONS DEPLOYMENT PLAN

1. Based on previous studies* it appears that the eastbound and westbound routes employed by a large majority of North America - European turbo-jet flights pass longitude 35° 30'W (on which OSV "Charlie" is stationed) between latitudes 45° and 61°N. The radar cover depicted by areas 3, 4, and 5 in Figure 6-C-2 extends throughout essentially all of this latitude range. Shipborne radar stations will be deployed at the centres of areas 3, 4, and 5 whereby the centre of area 3 is identical with the position of OSV "Charlie". The coordinates of these centres are :

Station 3	- 52°45'N
(OSV "Charlie")	- 35°30'W
Station 4	- 57°45'N
	- 35°30'W
Station 5	- 47°45'N
	- 35°30'W

2. One of the shore-based radars will be the one already in operation at Gander. The other shore-based station will be a radar temporarily deployed at Kilkee in Ireland (52°38'N 09°45'W).

3. The shipborne radar stations will remain within approximately 5 N.M. of the reference points. Accordingly, with 200 N.M. SSR range even if adjacent stations were at the maximum point of opposite direction movement some overlap in cover should remain. Recorded station positions will be determined by Loran C.

4. Various configurations of SSR cover are presented in the following diagrammes. Each of these configurations represent individual activities within the overall radar data collection programme. The letters assigned to the configurations indicate, by alphabetical sequence, the order in which the various data collection activities are planned. However, more than one sampling period will be effected at certain configurations.

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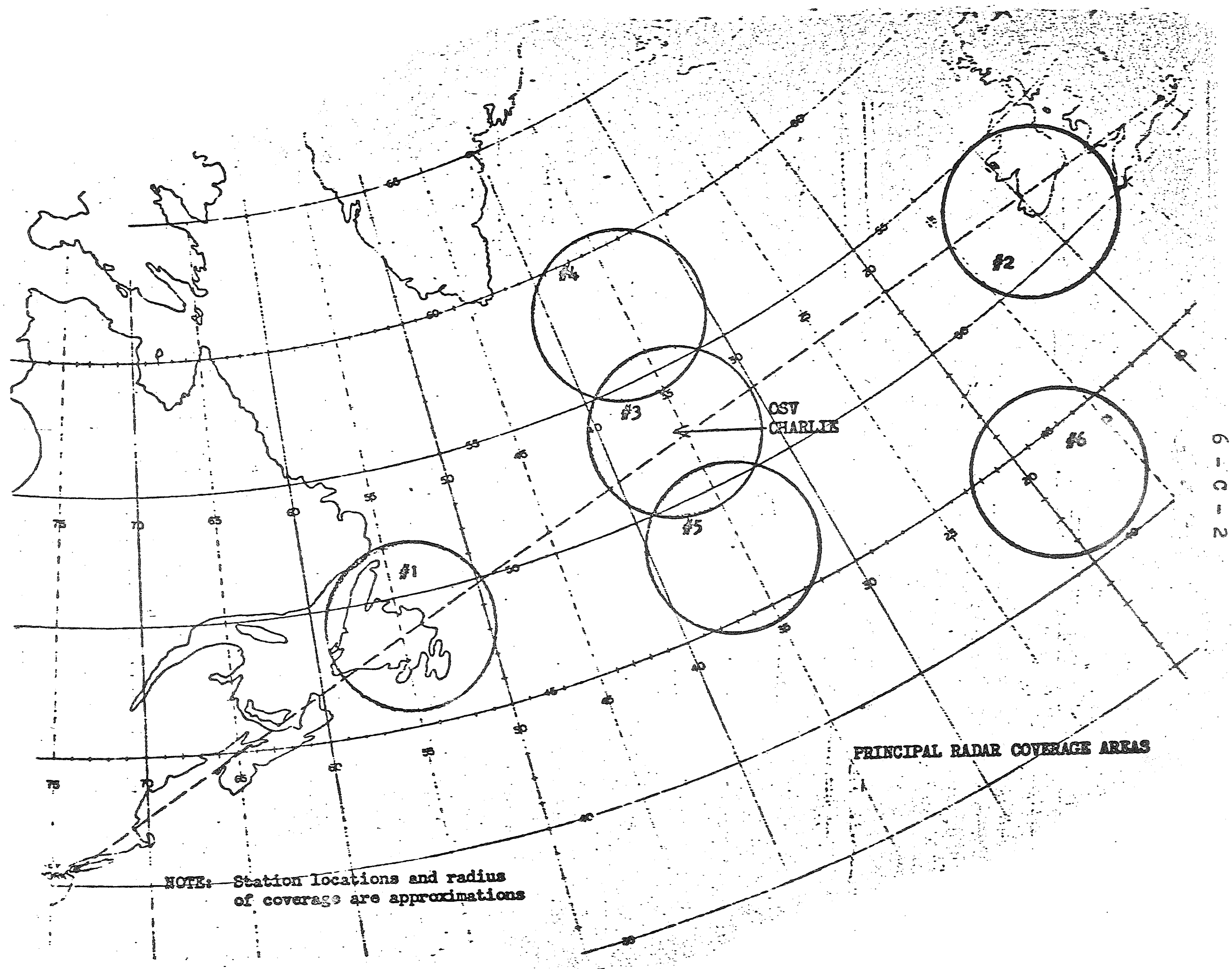
*RAE Technical Report N° 64062, "An Analysis of Planned Aircraft Proximity and its Relation to Collision Risk, with Special Reference to the North Atlantic Region, 1965-71," P.G. Reich, November 1964.

RAE Technical Note, MATH 97, "An Analysis of Jet Traffic Crossing the North Atlantic on the 7th and 8th of September, 1962," P. Reich and R. Towns, April 1963.

Summary of Analysis of Wind and Weather Factors on the New York - London Air Route for Selected Peak Traffic Days, Stanford Research Institute, June 1963.



PRINCIPAL RADAR COVERAGE AREAS

NOTE: Station locations and radius of coverage are approximations

5. Configuration A on Table 6-C-4 which includes the two shore-based radars plus one shipborne radar at the position of OSV "Charlie", is the initial configuration from which sample data will be taken. This period of data collection will extend throughout 21 days (the routine period of OSV "Charlie" on-station duty is 23 days) but will not necessarily include every day of this period. This initial period will serve as a final check-out of the data collection techniques at shore-based as well as shipborne radar stations. If procedural or other adjustments are found to be necessary, those which cannot be refined "on-the-spot" will be incorporated in following data collection periods. Depending on the extent of modifications found to be necessary in the initial plan for radar data collection and recording, part of the data obtained in this first trial period may not be useable in the analysis. In any event, a second period of data collection is planned using radar stations 1, 2 and 3 as illustrated by Configuration A.

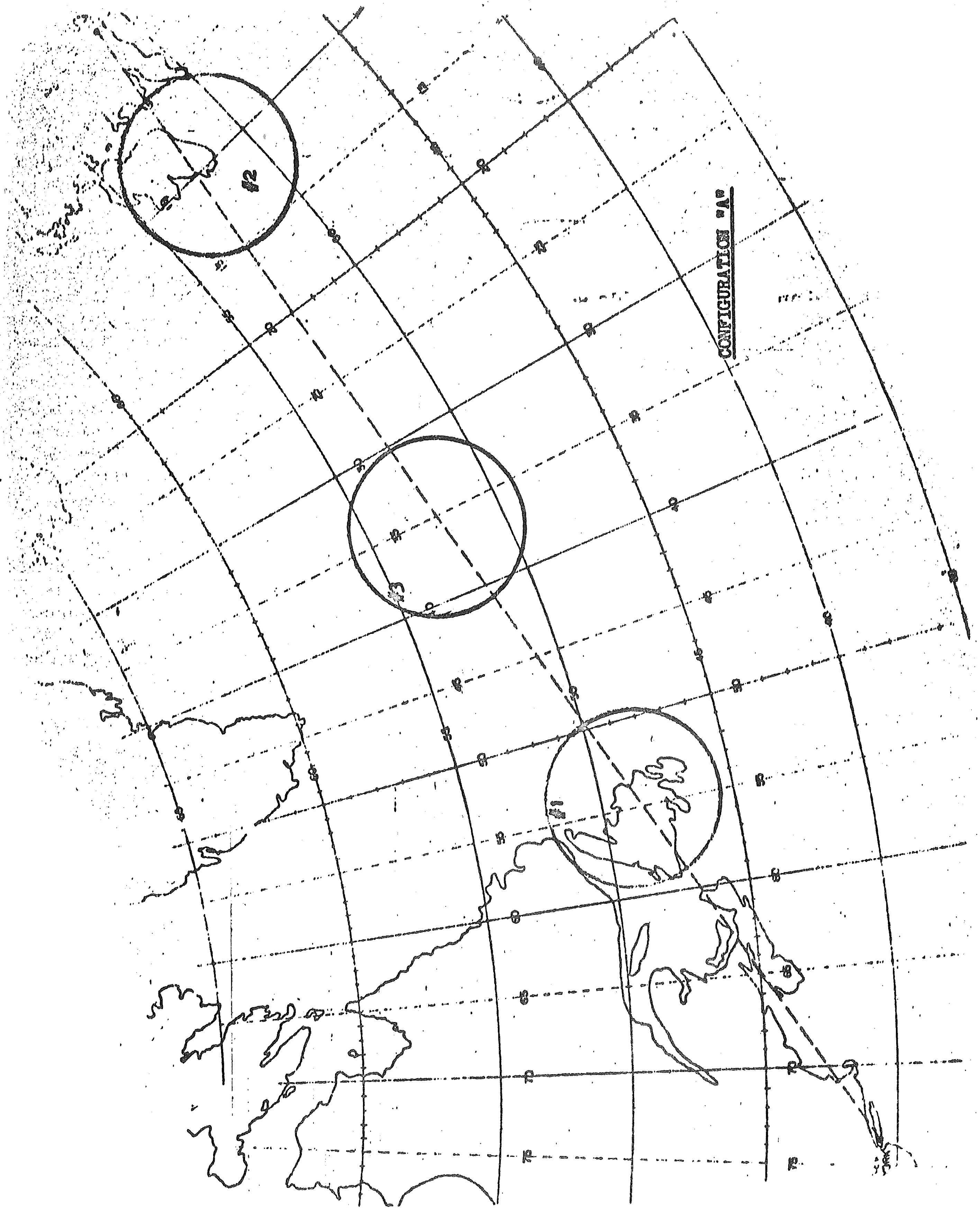
6. Configuration B illustrates an example of a planned data collection during a portion of the cruise between port and the station locations shown in the following Configurations. It will be conducted in both directions, however only in those areas where adequate Loran C cover is available to determine the ship's position with sufficient accuracy.

7. Throughout this segment of cruise, radar observations of aircraft will be recorded by the station in the same manner as planned for on-station operations. The same en route data collection is also planned for ships serving stations 3 and 5. Ships serving stations 3, 4 and 5 will be dispatched so as to arrive on their respective stations within a 24-hour period.

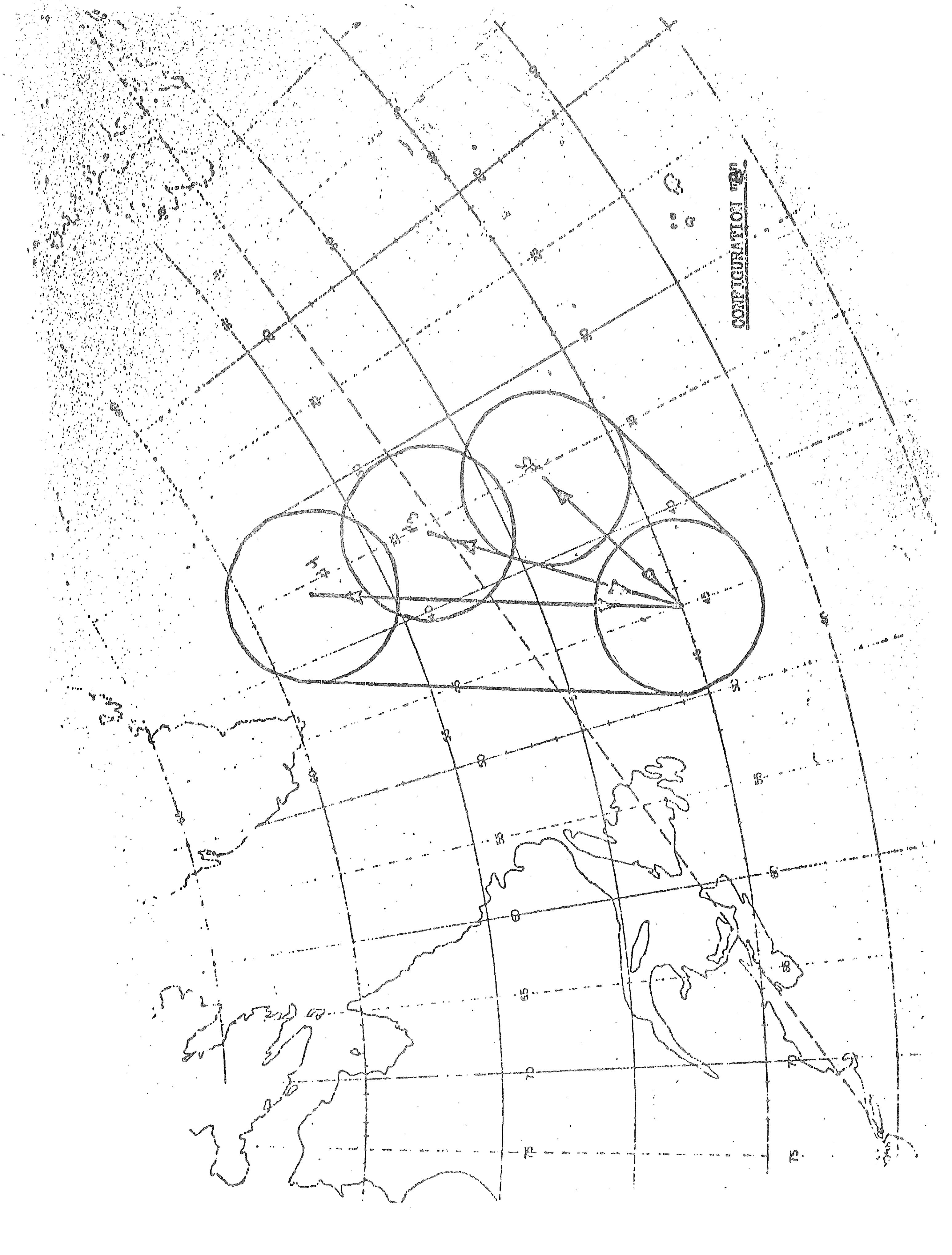
8. Configuration C illustrates the 5 station complex planned for the major radar collection. The two shore-based radars, along with the 3 shipborne radar stations aligned as indicated, will take observations throughout a 21-day summer period. Station 3 (OSV "Charlie"), in addition to the data collection, will conduct its routine functions while on station.

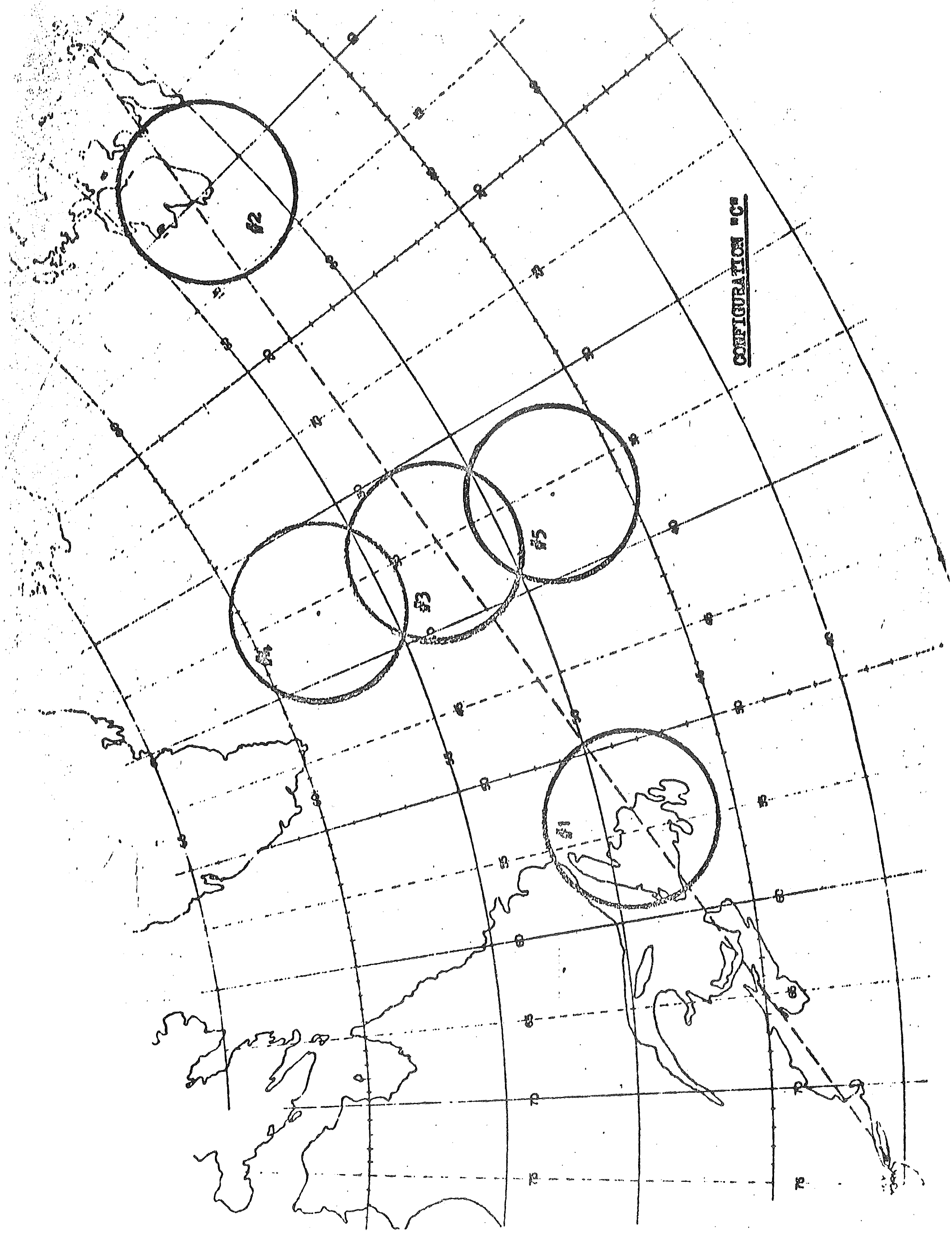
9. Configuration D illustrates the deployment of a shipborne radar station to gather data in the Eastern portion of the North Atlantic by using Loran A cover from chains "C" and "D". The planned location for this station is 43°, 45'N, 18°, 35'W. This station will be served by one of the vessels used earlier in Configuration C. Data will be collected en-route subject to the conditions specified for Configuration B above.

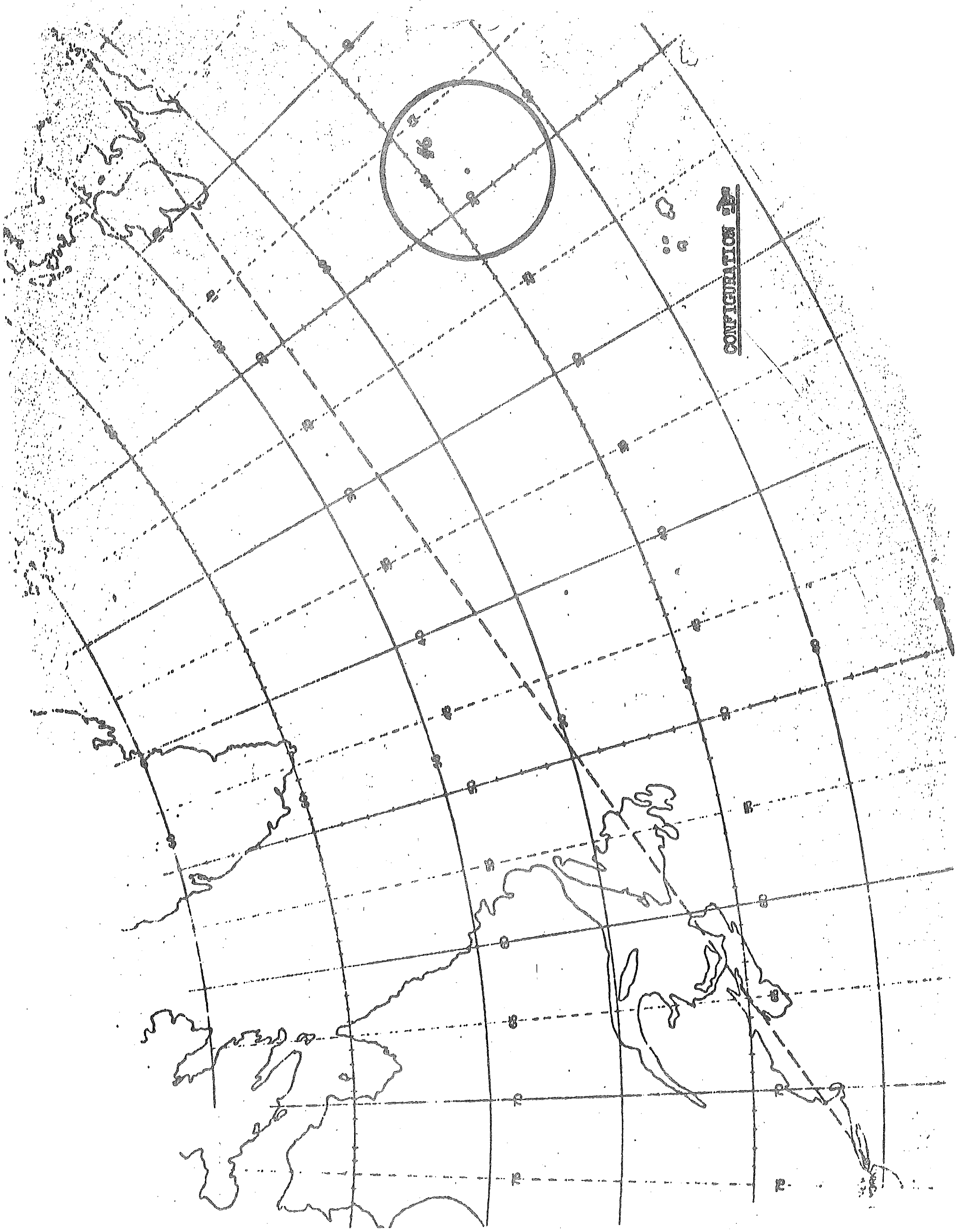
10. Configuration E shows the possibilities for data collection on the part of shore-based radars 1 and 2 only at periods additional to their participation in other configurations.

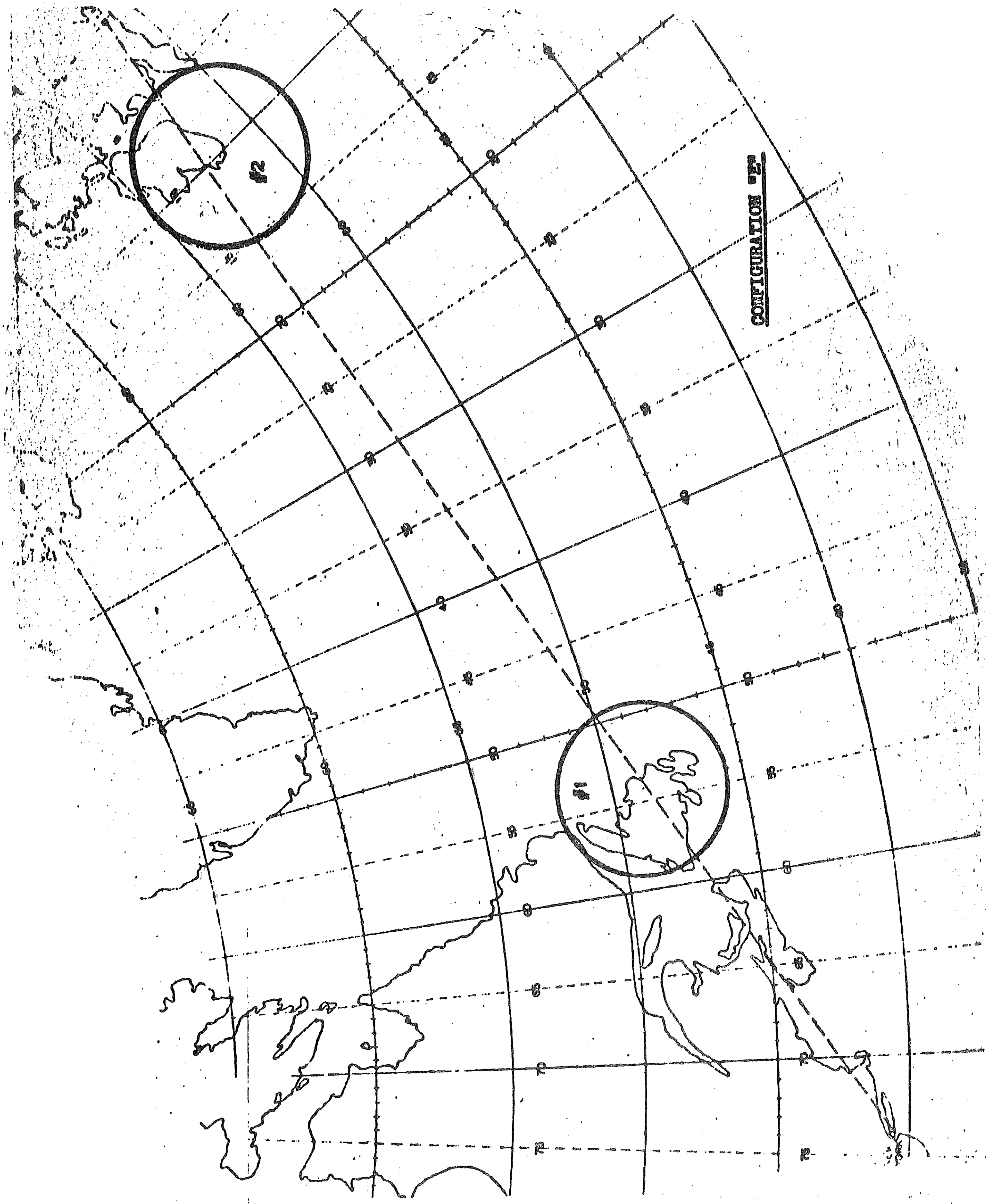


CONFIGURATION "A"
#2
#3
#1


CONFIGURATION "B"


CONFIGURATION "C"
#2
#3
#5


CONFIGURATION


CONFIGURATION "E"
#2
#1

FLIGHT RECORDS TO BE KEPT FOR THE FLIGHT DATA COLLECTION

1. It is essential that each flight keep the normal record of the flight (flight log and chart, including such working papers as would assist a detailed post-flight analysis) and that these are held for a period of 6 months to be made available if required to the administration of the state of registration of the aircraft.

2. Important parameters which should be noted in the record made in the aircraft, in so far as it applies to the individual operators are, for example :

a) the component parts of each position fix together with GMT, navigation computer along and across track readings, or inertial read-outs as necessary to enable each fix to be re-plotted, Loran, Consol and sextant readings, VOR radials, ADF bearings, radar observations, etc.;

b) all doppler or inertial computer settings with GMT;

c) GMT at which each compass system is unslaved and re-slaved and the north reference (grid, true, or other) to which the freed compass is set;

d) which compass system is being used for guidance;

e) the directional reference used for bearing measurements by ADF, airborne radar, etc. (i.e., true, grid, magnetic, compass, or relative - and in the latter two cases, the compass used);

f) method of track guidance; e.g., following VOR radial, steering headings passed by navigator, following computer cross-track indication or doppler or inertial auto-pilot tie-in, giving GMT at which changes of method occur;

g) at least one of the following with relevant GMT or position:
   - headings steered and true airspeeds or mach numbers flown, or
   - tracks set on computer and cross track indications and up-dates, doppler/computer system in use, or
   - read-outs of inertial system in use;

h) when available, spot winds, compass checks, and other such information which could prove useful in reconstruction.

RADAR DATA SAMPLING AND ESTIMATED RESULTS

1. In view of the turbo-jet traffic loads observed during the summer of 1966 in the principal area, and taking into account the forecast increase of traffic for 1967, it appears that during the summer months of 1967 an average of at least 200 jet flights a day will operate through the area covered by radar stations 3, 4 and 5 shown in Appendix C. This figure of 200 is taken to be the potential daily flight sample for the combined cover areas of radar stations 3, 4, and 5. While this is the potential, the actual daily yield of flights measurable in the desired manner is expected to be less. On some days a few of the mainstream North America - Europe turbo-jet flights may operate on routes outside of this combined cover area. Additionally, some of the desired data points will no doubt be lost on some aircraft due to such problems as:

1. course changes by ships required to remain on-station which affect the antenna tilt;
2. failure or absence of an operating transponder on the aircraft;
3. aircraft passage through the extremities of the cover area on a chord of insufficient length to permit acquisition of a sufficient number of successive data points.

2. As a result of the above considerations, it is estimated that about 80% of the daily turbo-jet traffic in the principal area will be measurable by one or another of stations 3, 4 or 5, provided these stations operate on a full 24 hour/day measurement programme. Since it is proposed that 24 hour sampling be conducted during the 21 day sample period, shown in Configuration C of Appendix C, it is estimated that this configuration will yield data on at least 3300 flights (160/day x 21 days).

3. It should be recalled that on each measurable flight passing through the SSR cover of any one of the stations many (e.g., 1 every 3 minutes) separate position points will be recorded. Thus, while they cannot be treated as independent observations, several thousand aircraft position points would result from the above measurement activity. These are important to the study of deviation rate of change.

4. One of the main purposes of having stations 1 and 2 in operation during the same sampling period as stations 3, 4, and 5 is to obtain data from which the correlation of along course errors between successive aircraft can be derived. If stations 1 and 2 measured 25 pairs of outbound aircraft per day per each facility, then approximately 1 000 pairs of aircraft could be observed by both a shore based and a shipborne radar during a 21-day sample period. It would be expected that many of these pairs could be observed by both of the shore based facilities plus one of the shipborne stations thus providing three reference points for assessing aircraft pair relationships: coast-out, mid-ocean, and coast-in. In summary, the 21-day sampling period shown in Configuration C of Appendix C which will include flight log as well as radar data, could be employed to obtain a major portion (well over 50%) of the data essential to horizontal error and error correlation analysis.

5. In respect to the station deployment shown in Configuration A, it is difficult to predict the useable sample yield since this is a procedural and hardware check-out phase. Accordingly, it is not planned, at least for shore-based radars, to conduct data collection on a 24-hour/day basis during this preliminary run. Nevertheless, it is hoped that the equivalent of at least 10 days of busy period (eastbound and westbound) sampling can be attained. Since the area of cover in this configuration is substantially smaller than that shown in Configuration C perhaps useable data on 40 flights per day for 10 days is a reasonable estimate for this first sampling period. Accordingly, useable data on some 400 flights might be obtained during this period.

6. In respect to sampling obtained during the enroute phase illustrated in Configuration B it will be noted that the enroute segments involved are approximately 500 N.M. in length. Based on an average cruise speed of 15 Kts of the ships, the time period of sampling would extend for about 33 hours. While it is difficult to predict the number of flights which would pass through this cover area on a given day, it may be that the combined sample output resulting from the use of this procedure by the three vessels enroute to an from stations 3, 4, and 5 could approach 400 flights.

7. In regard to the sampling time associated with Configuration D, the volume of traffic passing within radar cover will be substantially less than in areas 3, 4 and 5. It is believed that it would be optimistic to expect more than an average of ten measurable jet flights per day within this area. In view of the importance of measuring navigational capability in this area where Loran A cover has only recently been established, a substantial number of days may be required to obtain an appropriate sample. At present there is of course no data available regarding the specific error sample distribution to be expected from cover area 6. Thus the actual number of observations necessary from station 6 will depend largely on the stability of the error distribution obtained in the early stages of measurement. It is possible that data on not more than 200 to 400 flights, along with appropriate statistical tests, would suffice. If this arbitrary estimate of area 6 sample size is employed for preliminary planning, it may be seen that a minimum of 20 days of observations may be required in this area. Due to the undesirability of prolonged tours on the part of ship's crews, one 21 day sampling period is planned for area 6.

8. Since the ship employed in Configuration A is carrying out the regular tour of OSV "Charlie", the second period of Configuration A sampling will extend to three weeks. Thus, if the average number of in-range flights per day were 50, then about 1 000 additional flights could be observed during this period. Additional 3-week observation periods may be provided by the regularly scheduled OSV "Charlie" patrols.

9. In respect of Configuration E, in addition to the participation of these radars in Configurations A and C several additional sampling periods should be arranged.

10. Because of the workload involved it is considered appropriate to specify only the general overall data requirements under this configuration and let the respective facilities select the specific date and sampling hours. This should however be coordinated between the radar stations concerned. It may be appropriate to schedule these periods (two or three days each) so as to fall on different days of the week in order to observe operators who do not operate daily trans-atlantic flights.

If an average of only 50 aircraft per day were sampled under Configuration E for only the 24 days shown in the attached table about 1 200 observations could be gained.

11. The attached table presents a tentative schedule of radar data collection activities and related events. This schedule takes account of the availability of ships and crews by the U.S. Coast Guard, the provision of electronic data recording equipment on board the ships concerned and other pertinent technical and operational factors. In addition, it also constitutes the optimum balance between the costs involved in this operation and obtainable results.

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TENTATIVE RADAR DATA COLLECTION SCHEDULE

MONTH / Data collection and related ACTIVITY	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	Estimated Flight Results
D/C - CONF. A_1	21 x								400
VESSEL X ENROUTE TO PORT		5 x							
VESSEL X IN PORT (D/C Equip. modification -?)		21 x							
D/C - CONF. B_1 VESSEL Y ENROUTE TO AREA 4			6 y						120
D/C - CONF. B_2 VESSEL X ENROUTE TO AREA 3			5 x						80
D/C - CONF. B_3 VESSEL Z ENROUTE TO AREA 5			4 z						40
D/C -CONF. C			21 x,y,z						3300
D/C - CONF. B_4 VESSEL Z ENROUTE TO PORT				4 z					40
D/C - CONF. B_5 VESSEL Y ENROUTE TO PORT				6 y					120
D/C - CONF. B_6 VESSEL X ENROUTE TO PORT				5 x					80
VESSELS Y & Z IN PORT				21 z	y				
VESSEL Z ENROUTE TO AREA 6					8 z				
D/C - CONF. D_1					21 z				200
D/C - CONF. A_2							21	y_3	1000
D/C - CONF. E_1 ... i	------	---- 3	3 ----	3 - 3	3 -- 3	------	3 ----	--- 3 -	1200 +
							SAMPLE TOTAL		6580 +

LEGEND

D/C - Data collection

CONF. - Radar Coverage configuration

- Number of days

X - Participating ocean vessel (x,y,z)

A_1 - Numerical subscript denotes 1st, 2nd, 3rd period of D/C for indicated conf.

DRAFT INFORMATION CIRCULAR

Programme of Data Collection in the NAT Region

1. In order to obtain more information on the navigation capability of turbo-jet aircraft transitting the North Atlantic oceanic areas, it is proposed to conduct a data collection programme from .... to ....

2. All operators using turbo-jet aircraft, up to and including flight level 420, in that part of the North Atlantic Control Areas described below, are required to submit to the .... a detailed report on all such flights on the attached form.

Description of area:

Northern limit:	70° North
Eastern limit :	between 70°N and 61°N the Greenwich meridian, then along the Eastern boundary of Shanwick and Lisboa Oceanic FIR's to Madeira.
Southern limit:	the great circle between Nantucket and Madeira.
Western limit :	the Western limit of Sondrestrom Gander Oceanic and New York Oceanic FIR's from 70°N to its intersection with the Southern limit.

3. It is requested that great care should be taken by all operators to ensure an accurate and complete record to be kept of the in-flight details for the purposes of subsequent post-flight analysis. Aircraft log forms and charts for these flights should be retained by the operator for a period of six months from the date of the flight concerned.

To assist in this purpose a team has been formed under the general direction of ...., and also including national representatives from pilots' associations and air navigators' associations to review with the operators navigational data which has been extracted from flight logs and charts, including those working papers which would be of help in a detailed post-flight analysis, during this evaluation period.

STANDARD FORM TO BE USED FOR THE POST-FLIGHT RECORDING

OF DATA ON INDIVIDUAL FLIGHTS

1. It was agreed that the attached form should be used by operators as the standard form for post-flight recording of data extracted from flight logs and charts for individual flights.

2. An example of a completed form has been added to illustrate the manner in which forms should be filled out.

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NORTH ATLANTIC NAVIGATION REPORT

FORM TO BE COMPLETED BY AIRLINE/OPERATOR** FROM REVIEW OF FLIGHT LOG AND CHART

AIRLINE/OPERATOR ------------ AIRCRAFT TYPE ------------ DIRECTION OF FLIGHT (MARK BOX E OR W) ---> [ ]

FLIGHT NO. ------------ REGISTRATION NO. ------------ SSR MODE/CODE USED ------------

MARK BOX IF NO DEVIATION OF 30 N.M OR MORE ---> [ ]

TIME IN OCEANIC AREA (TOTAL) --- HR --- MIN

TIME SPENT LESS THAN 30 NM OFF TRACK --- HR --- MIN

ATC CLEARED TRACK →

LONG	OAC BOUNDARY	50°W	40°W	30°W	20°W	OAC BOUNDARY
LAT						
FL						

DATE/TIME GMT W. BOUNDARY → / :

DATE/TIME GMT E BOUNDARY / :

OFF TRACK DETAILS 30 NM OR MORE -

30-44 NM OFF TRACK				
TIME OFF		BETWEEN*		MAX
hrs	min	W	W	NM
hrs	min	W	W	NM
hrs	min	W	W	NM

45-59 NM OFF TRACK				
TIME OFF		BETWEEN*		MAX
hrs	min	W	W	NM
hrs	min	W	W	NM
hrs	min	W	W	NM

60 NM OR MORE				
TIME OFF		BETWEEN*		MAX
hrs	min	W	W	NM
hrs	min	W	W	KM
hrs	min	W	W	NM

NAVIGATION EQUIPMENT →

	ON BOARD	USED
ADF		
VOR / DME		
LORAN "A"		
DOPPLER AND COMPUTER		
DOPPLER - SENSOR ONLY		
INERTIAL		
RADIO ALTIMETER		
CELESTIAL		
CONSOL		
Other (Specify)		

REMARKS:-

* EXPRESS THIS IN TERMS OF LONGITUDE eg 40°W 30°W. ** FOR GENERAL AVIATION INCLUDE UNDER REMARKS CREW COMPOSITION AND CAPTAIN'S NAME AND ADDRESS.

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6-G-5 (EXAMPLE)

NORTH ATLANTIC NAVIGATION REPORT

FORM TO BE COMPLETED BY AIRLINE/OPERATOR** FROM REVIEW OF FLIGHT LOG AND CHART

AIRLINE/OPERATOR RURITANIA AIRL. AIRCRAFT TYPE B 707

FLIGHT NO. 100/27 REGISTRATION NO. K-AWXY

DIRECTION OF FLIGHT (MARK BOX E OR W) → E

SSR MODE/CODE USED A/21

MARK BOX IF NO DEVIATION OF 30 N.M OR MORE → ☐

TIME IN OCEANIC AREA (TOTAL) 5 HR 00 MIN

TIME SPENT LESS THAN 30 NM OFF TRACK 4 HR 05 MIN

ATC CLEARED TRACK →

LONG	OAC BOUNDARY	50°W	40°W	30°W	20°W	OAC BOUNDARY
LAT	52	53	53	52	51	49
FL	330	330	330	350	350	370
DATE/TIME GMT W. BOUNDARY →	27 NOV / 2100				DATE/TIME GMT E BOUNDARY →	28 NOV / 0200

OFF TRACK DETAILS 30 NM OR MORE -

30-44 NM OFF TRACK		
TIME OFF	BETWEEN*	MAX
0 hrs 10 min	48 W 46 W	44 NM
0 hrs 10 min	43 W 41 W	44 NM
0 hrs 20 min	16 W 12 W	43 NM

45-59 NM OFF TRACK		
TIME OFF	BETWEEN*	MAX
0 hrs 15 min	46 W 43 W	47 NM
hrs min	W W	NM
hrs min	W W	NM

60 NM OR MORE		
TIME OFF	BETWEEN*	MAX
hrs min	W W	NM
hrs min	W W	KM
hrs min	W W	NM

NAVIGATION EQUIPMENT →

	ON BOARD	USED
ADF		
YOR/DME	✓	✓
LORAN "A"		
DOPPLER AND COMPUTER		
DOPPLER-SENSOR ONLY	✓	
INERTIAL		
RADIO ALTIMETER		
CELESTIAL	✓	✓
CONSOL	✓	✓
Other (Specify)		

REMARKS:-

1.) NAVIGATOR UNDER TRAINING
2.) DOPPLER-SENSOR U/S
3.) DIFFICULTIES IN RECEPTION OF CONSOL
4.) TURBULENCE BETWEEN 16 AND 12 W
5.) ENGINE #3 OVERHEATING.

* EXPRESS THIS IN TERMS OF LONGITUDE eg 40°W 30°W. ** FOR GENERAL AVIATION INCLUDE UNDER REMARKS CREW COMPOSITION AND CAPTAIN'S NAME AND ADDRESS.

METHODS OF POST-FLIGHT RECONSTRUCTION

1. Although details will vary, depending on modes of operation, the following steps would appear to be essential :

i) all position information should be checked, re-plotting where necessary;

ii) the path of the aircraft should be reconstructed with reference to:

a) headings steered, compass checks, measured winds and probable change of wind, and/or

b) doppler/computer tracks set and compass checks, or

c) inertial settings;

iii) judgement would need to be used, in weighing the fix reliability against the consistency of the residual system tracking error found between successive fixes;

iv) where inadequate records or uncertainty of interpretation precludes reconstruction of any portion of the flight path, this should be stated.

DIAGRAM OF INTENDED DATA FLOW

1. The attached diagram shows the intended flow of data resulting from the data collection programme. In addition, it also indicates the intended handling of the data and the presentation of the results obtained from its analysis.

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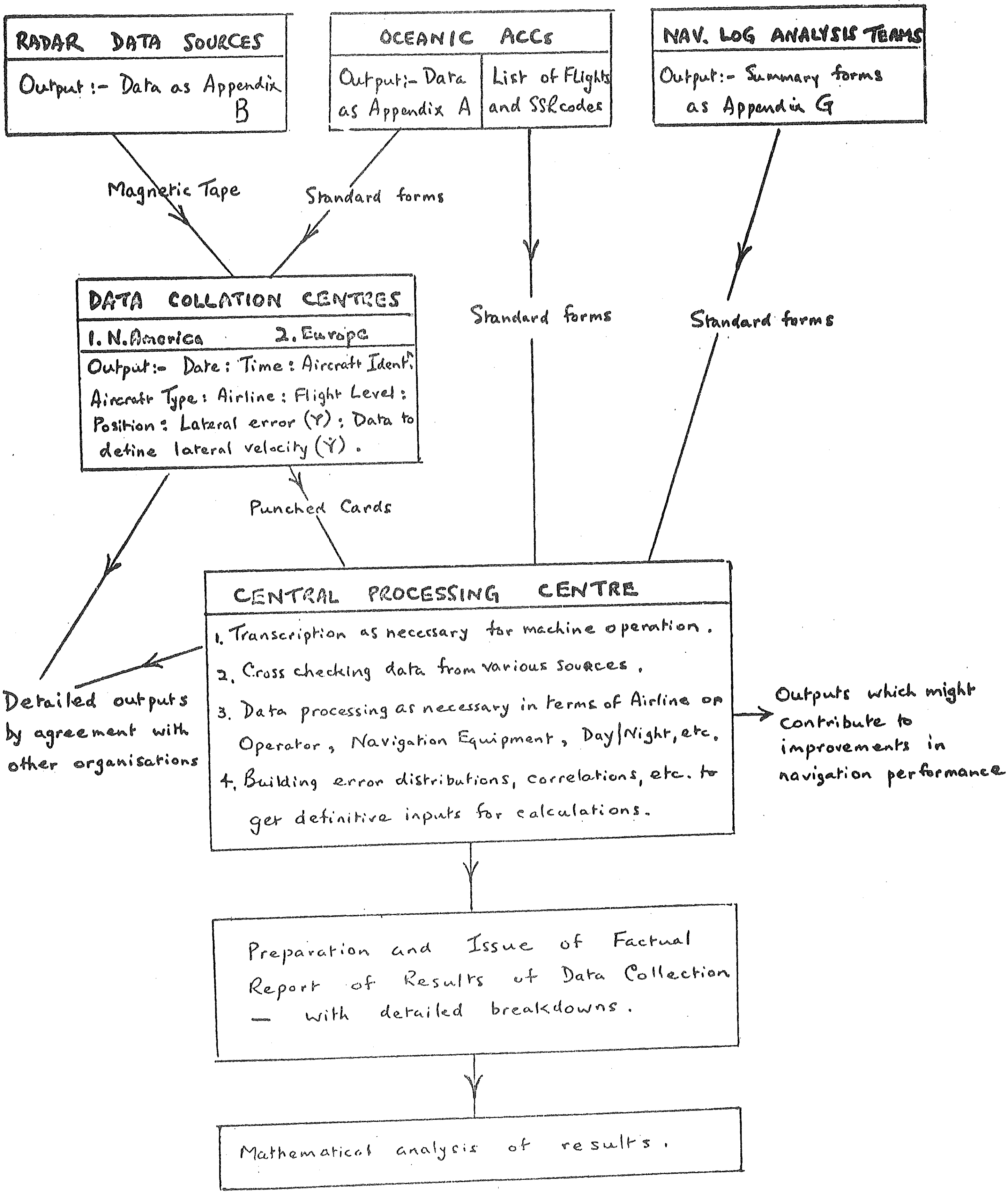
DIAGRAM OF INTENDED DATA FLOW



Summary of Agenda Item 7 : Review of Subjects for Future NAT/SPG Consideration

INTRODUCTION

7.1 As already indicated in the Agenda, this Agenda Item was considered in a closed session by members of the Group only and a complete review was made of all documents (including the Summary of the First Meeting of the Group held in October 1965) and any other information available to the Group indicating that a problem existed in the NAT Region which could be subject to handling by the Group.

7.2 This review revealed that, at this time, the following subjects should be retained on the work programme of the Group :

- i) Long Term Planning Programme;
- ii) Impact of SST Operations on the NAT Air Navigation System;
- iii) Developments in Satellite Communications;
- iv) Improvement of Logical Methods for the Determination of Separation Minima;
- v) Future Planning for NAT Aeronautical Fixed and Mobile Services;
- vi) Provision of Ocean Stable Platforms;
- vii) Future Planning for NAT Meteorological Services;
- viii) Criteria for the Assessment of System Performance;*
- ix) Review of NAT Air Reporting Procedures;
- x) Vertical Separation Above Flight Level 290 in Specified Parts of the NAT Region;
- xi) Longitudinal Separation in Specified Parts of the NAT Region;
- xii) Review of NAT ATC Procedures;
- xiii) Consideration of Up-dated Traffic Forecasts.

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*Note: In the Summary of the First Meeting this item was called "Further Development of Systems Criteria".

7.3 It was recognized that, on the one hand, it would be unrealistic to expect the Group to undertake simultaneous work on all of these subjects since this exceeded by far the capacity of its members. On the other hand, the Group was fully aware of the interest shown by States and Organizations in its work and it believed it therefore essential to give a brief summary of the situation with respect to each of the items listed above and to indicate, as far as possible, which of the subjects, in the Group's opinion, deserved priority treatment as items for consideration at its next meeting.

REVIEW OF INDIVIDUAL SUBJECTS

7.4 "Long Term Planning Programme"

7.4.1 It was felt that this was a subject which did not yet lend itself to specific treatment because many of the factors having a bearing on this subject were still in too fluid a state of development. It was therefore agreed that this subject should be retained for review.

7.5 "Impact of SST Operations on the NAT Air Navigation System"

7.5.1 With respect to this item it was decided to retain it for review.

7.6 "Developments in Satellite Communications"

7.6.1 The Group noted that this subject had been considered by the recent COM/OPS Division and that feasibility studies on this COM system were now under way. It was therefore believed that, until more detailed information becomes available, it would not be very useful to pursue this subject within the Group.

7.7 "Improvement of Logical Methods for the Determination of Separation Minima"

7.7.1 It was believed that this meeting had made considerable progress in this field, at least as far as the lateral aspect of it was concerned. As it was expected that the vertical aspect of this item would inevitably have to be considered once the question of vertical separation was taken up, it was agreed that this item, as a separate subject, did not require priority treatment at this time.

7.8 "Future Planning for NAT Aeronautical Fixed and Mobile Services"

7.8.1 It was envisaged that there was a close relationship between this item and Satellite Communications as well as the question of air reporting and the ATC procedures. It was expected that the most urgent aspects of this question would therefore automatically come up when these subjects were discussed. Consequently, a general review of this field was not believed of immediate urgency.

7.9 "Provision of Ocean Stable Platforms"

7.9.1 The UK member indicated that this subject embraced numerous non-technical aspects which had not yet been resolved and on which further studies were required. It was therefore agreed that the item should be retained for future review whenever a purely technical discussion of the matter would be useful.

7.10 "Future Planning for NAT Meteorological Services"

7.10.1 It was found that with respect to this item the situation was similar to that described in paragraph 7.8 with regard to the NAT COM services and that its review should therefore be subject to identical conditions.

7.11 "Criteria for the Assessment of System Performance"

7.11.1 When considering this subject the Group noted that Canada had now prepared a preliminary study and that both the UK and the USA had already done work on it. It was however indicated that, before any definite conclusions could be drawn, it would be essential to obtain the user's point of view. It was therefore agreed that at least a preliminary exchange of views on this subject should be held as early as possible and that representatives from appropriate International Organizations should be invited to participate in this.

7.12 "Review of NAT Air Reporting Procedures"

7.12.1 It was noted that this item had been the subject of correspondence between ICAO and the States and Organizations concerned and that it had become apparent that this matter deserved early attention in order to correct a number of difficulties which now appear to exist in respect of all aspects (ATC, COM and MET) of this matter.

7.12.2 It was therefore agreed that the Group should review this subject at an early date and, since it was known that a Working Group of IATA NAT operators was working on this problem, that IATA should be requested to present, as early as possible, its proposals for improvement to the Group to serve as a basis for discussion representing a common user's view. In addition, it was agreed that the appropriate International Organizations should be invited to participate in the discussion.

7.13 "Vertical Separation Above FL 290 in Specified Parts of the NAT Region"

7.13.1 In early 1966 this question had been referred to the NAT/SPG by the ANC for consideration to assist the ANC in the appreciation of the desirability of convening the EUM NAT (RAC) Meeting called for by Recommendation 6i/6 of the Special NAT Meeting 1965. In view of the pressing circumstances regarding the question of lateral separation and the resultant workload, the NAT/SPG had however not found it possible to comply with this request at this meeting, even though it had accepted the task.

7.13.2 It was therefore agreed that this item should be placed on the Agenda of the Group's next meeting. With regard to the handling of this matter by the Group it was noted :

i) that IFALPA intended to carry out a data collection on height keeping accuracy in January-February 1967 and had discussed it informally in the UK with the RAE. No arrangements had been made with the UK for processing the data and no assurance could be given that the UK would be able to undertake this work immediately due to the commitments resulting from the UK's participation in the data collection agreed at this Meeting (Item 6). The member from the Kingdom of the Netherlands agreed to investigate the possibility of assistance by his Administration, if so requested by IFALPA. This would be cleared in direct contacts between the Netherlands and IFALPA;

ii) that it would be essential for the Group's work on this matter to include in its consideration the results of the work on static pressure systems now conducted by the Airworthiness Committee;

iii) that some States required still more time in order to complete national studies which were now in course;

iv) that, based on the above, the Group felt at this time that a LIM NAT Meeting dealing with the subject of vertical separation would not serve a meaningful purpose before early 1968.

7.14 "Longitudinal Separation in Specified Parts of the NAT Region"

7.14.1 The Group felt that the general consideration of this question at this time could only confuse the already complicated situation regarding separation in the NAT Region and, since experience has shown that this had not given rise to serious problems, it agreed to keep this subject pending until a more opportune time. It nevertheless noted that the application of 15 minutes longitudinal separation to turbo-jet aircraft following the same track and applying the Mach number technique continues to be satisfactory.

7.15 "Review of NAT ATC Procedures"

7.15.1 It was agreed that those aspects of this item (automation, inter-area communications, etc.) not already covered by the consideration of separation questions and air reporting were not sufficiently mature to be considered in the near future.

7.16 "Consideration of Up-dated Traffic Forecasts"

7.16.1 The Group confirmed its previous position, i.e., that the up-dated traffic forecasts were essential for its work, and it expressed therefore the hope that the forecasts prepared by Canada, the UK and the USA would continue to be made available to the Group and to all other NAT States through ICAO.

ARRANGEMENTS FOR THE NEXT MEETING

7.17 The Group felt that, since it would be essential to hold another meeting prior to the beginning of the data collection programme agreed under Item 6, this should be extended to cover also those items which the Group had selected for early action. It was therefore agreed that :

i) the next meeting of the Group should be planned for a duration of two weeks in the latter part of April 1967, at the Paris Office of ICAO;

ii) the first point on the agenda should be a progress report by all concerned on the data collection programme agreed under Item 6 and that this should be arranged so that it did not require more than a maximum of two days of discussion;

iii) the remainder of the agenda should tentatively include the following subjects :

a) Vertical Separation

b) NAT Air Reporting

c) Exchange of Views on Criteria for the Assessment of System Performance;

iv) the organization of the next meeting should again tentatively envisage two main working groups; one dealing with a), the other with b) above, while the item under c) would be dealt with by the Group as a whole, together with invited States and Organizations;

v) IATA and IFALPA should be invited to make supporting documentation available with respect to items a) to c) above (see paragraph 7.12);

vi) the question of States to be invited for the next meeting should be pursued further in correspondence between the chairman and other members of the Group;

vii) appropriate International Organizations should again be invited to participate in the next meeting of the Group;

viii) ICAO be requested to make available its services and facilities in the same manner as has been done for this meeting.

7.18 The Group noted that the member of the USA, for internal reasons, was not able at this time to commit himself definitely as to the date and agenda of the next meeting but would advise the chairman of the Group in due course.

Summary of Agenda Item 8 : Future Conduct of NAT SPG Business

8.1 Experience since the creation of the NAT/SPG had shown that the initial manner of conducting the Group's business, i.e., that each member wrote to each other member on matters of concern to the Group, had a number of drawbacks, particularly that of crossing of correspondence which tended to affect efficiency in the conduct of business by the Group, especially during the preparatory stages of a meeting.

8.2 It was therefore unanimously decided that the question of chairmanship and that of correspondence procedures required some modification and the Group therefore agreed on the following :

8.2.1 At the end of a meeting the Group would elect its Chairman for the next meeting with the understanding that this mandate would include the responsibility for :

i) initiating any action deemed necessary for the efficient conduct of the work of the Group during correspondence phases;

ii) developing the agenda, date and place of the next meeting in consultation with all members;

iii) issuing invitations to all States and Organizations which the Group has decided to invite to its next meeting;

iv) chairing the next meeting;

v) transferring to the next chairman any pending matters which have not yet been cleared.

8.2.2 In application of the above, the Group confirmed Mr. G.E. Enright of Ireland as chairman for its next meeting.

8.2.3 As to the question of correspondence procedures, the Group felt that this could best be handled by addressing all correspondence to the chairman of the Group who would thus serve as coordinator and would also ensure that correspondence addressed to him was promptly sent to all other members of the Group and, if so required, to other States and Organizations concerned.

8.2.4 It was agreed that, when writing to the chairman, all members should send a copy of such correspondence to the ICAO Paris Office.

8.2.5 In order to keep the workload thus imposed on the chairman within acceptable proportions, the Group unanimously requested that the Paris Office provide the chairman with those services and facilities required for the efficient and expeditious discharge of his responsibilities. These were expected to be :

i) to serve as forwarding agency for all correspondence addressed to the chairman by members of the Group and other States and Organizations;

ii) to reproduce and distribute correspondence from the chairman to members of the Group and, if necessary, other States and Organizations;

iii) to assist the chairman in the preparation of the agenda, the organization of meetings and the reproduction and distribution of supporting documentation received from members of the Group or, as the case may be, other invited States and Organizations;

iv) correspondence in French from the French member to the chairman would be translated by the Paris Office before onward transmission to the chairman and other members of the Group;

v) as regards supporting documentation provided by the French member in French, arrangements for its translation would be made on an ad-hoc basis between him and the Paris Office of ICAO having regard to the latter's capacity at that time.

8.3 The Group fully realized that the above arrangements would impose an additional workload on the Paris Office, but, in view of past experience, seriously hoped that ICAO would find it possible to accede to its request for assistance.

9. SUMMARY OF OTHER BUSINESS

9.1 Following its discussions regarding the data collection programme (see Summary on Item 6 and paragraph 7.17) the Group noted that as of the time of the end of the Meeting there would exist a continuous requirement for coordination, primarily between Canada, Ireland, the UK and the USA, in order to resolve problems of detail which might develop during the preparation period. It was therefore agreed that this should normally be done in direct bi-lateral or multi-lateral contacts and that the Group (and other interested parties) should be informed of this coordination only if this was essential for the orderly progress of the preparations.

9.2 In order to ensure efficiency in these contacts it was, however, agreed that the following members should assume coordination functions for the following parts of the programme :

i) Canada will coordinate all matters concerning the collection of flight log data on the North American continent;

ii) the UK will coordinate all matters regarding flight log data in Europe and those concerning ATC and radar data from the UK, Iceland and Ireland;

iii) the USA will coordinate all matters regarding the overall collection of radar data and those concerning ATC data from Canada, Portugal and Spain.

9.3 The Group noted with appreciation the offer by the member for Canada that Canada was prepared to print and distribute to the NAT provider States, ICAO and IATA the forms required for the flight log data collection (see Appendix G to the Summary on Item 6). The forms required by other NAT States would be distributed via ICAO.

9.4 It was further noted that once the programme was started the UK would request all States and Organizations concerned to send completed flight log forms collectively once every month to the address which will be shown in its copy of the Information Circular (see Appendix F to Summary on Item 6).

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