DEPARTMENT OF INDUSTRY AND COMMERCE
METEOROLOGICAL SERVICE

TECHNICAL NOTE No. 22

AN INVESTIGATION INTO TURBULENCE REPORTED BY AIRCRAFT OVER THE EASTERN NORTH ATLANTIC

BY

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DECIMAL INDEX

551.551

DUBLIN
MARCH 1957

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ABSTRACT:

Approximately 38,000 hourly weather reports from aircraft over a selected area in the Eastern North Atlantic were examined and the occurrence of turbulence analysed. The reports cover the twelve-month period 1 October 1953-30 September, 1954.

Turbulence was reported on approximately one per cent of occasions. The variation of reports of turbulence between aircraft types stands at a highly significant level.

About 38 per cent of the turbulence reports were made in cold air masses and 20 per cent in clear air. One third of the reports of turbulence were associated with aircraft icing.

INTRODUCTION:

Turbulence in the atmosphere is caused by eddy motions or random oscillations of air currents of dimensions ranging from the scale of molecular motion to that of the broadscale features of the general circulation. Turbulence experienced by an aircraft at any time is the resultant of the local effects of the random motions at each point on the surface and causes stresses within the structure of the aircraft and irregular accelerations in the motion of the aircraft. Eddies within a limited range of dimensions (related to parameters of an aircraft) produce aircraft responses which range from below the threshold of perceptibility to bumpiness sufficient to endanger the safety of the aircraft.

Our knowledge of atmospheric turbulence is not adequate to enable meteorologists to forecast accurately on all occasions the location and intensity of turbulence likely to be "felt" by the crew of the aircraft in flight.

This paper gives an analysis of reports of turbulence from aircraft on a large part of the Eastern North Atlantic Ocean over a 12-month period from October, 1953 to September, 1954, in an effort to provide some information on the meteorological conditions favourable for aircraft turbulence in that area and the frequency with which various intensities are reported.

A number of the tables and figures presented in this paper are similar to those in a paper by Rohan and Ó hAonghusa (1956) in which an analysis along similar lines using the same observational material was made of aircraft icing.

Aircraft Weather Reporting Procedure:

During the period of this survey, aircraft flying over the North Atlantic Ocean and operating in accordance with ICAO procedures made and recorded meteorological observations at the same time as the position reports were made. These observations were sent with the position reports via the air/ground communications channels to the appropriate Air Traffic Control centre and were passed immediately to the associated Meteorological office. The time for reporting the position and weather in the case of each flight was at hourly intervals from take off time. With aircraft departing on transatlantic flight from different airports the reporting times for different aircraft were scattered over the hour and with provision in the reporting procedure for indicating the time in the preceding hour at which turbulence, icing, and other significant weather features were observed, the distribution of such phenomena could be well established in space and time.

The form of reporting was changed on 1st September, 1954. The new form restricted the classification of turbulence to light, moderate, and severe within ten minutes of the time of observation and made no provision for routine reporting the time during the previous 50 minutes at which turbulence (inter alia) was observed. This change was a retrograde step as reports in the new form left the meteorologist in doubt as to the extent of the area in which turbulence was experienced, though, of course, with a number of aircraft reporting in a particular area it was frequently possible to determine broadly the limits of the area in which turbulence was encountered. Even this is no longer possible in the North Atlantic Region of ICAO since 1956 under a procedure in which aircraft report at specific meridian lines spaced at approximately hourly intervals of travel. Information on turbulence is now normally confined to strips in the immediate vicinity of the reporting lines or about 30% to 40% of the entire area.

The reports were received in code (POMAR) or in an abbreviated plain language form. They normally included observations of flight conditions, wind, corrected temperature, pressure data, cloud and weather as observed at flight level, as well as details of position and altitude and some operational information of a non-meteorological character (e.g. fuel aboard). Reports of turbulence or icing encountered were added when either phenomenon was observed but "nil" reports were not added when no icing or turbulence was observed. In the period under review some, but not all, aircraft reported airspeed and some reports included remarks on weather phenomena (e.g. frontal passages) which are always very useful to the forecaster.

In the Shannon/Prestwick Flight Information Region (FIR), the boundary of which is shown in Fig.1, the hourly aircraft weather reports were received at Shannon either directly from the aircraft or in collective bulletins from Prestwick. The vast majority of the reports from the Shannon/Prestwick FIR were received either by direct transmission to Shannon or were intercepted by Shannon in transmission to other communications centres. All reports received from the FIR were disseminated in collective bulletins to other meteorological offices.

Classification of Turbulence Reports:

Turbulence observations from aircraft in flight are described in terms of the effect of turbulence on the motion of the aircraft. They may be reported as "light", "moderate", or "severe."

Light turbulence is reported when the bumps are perceptible but are not uncomfortable or alarming.

Moderate turbulence is reported when crew of an aircraft finds difficulty in walking or a marked tendency to be lifted out of ones seat.

Severe turbulence is reported when conditions make it difficult to walk about and/or observe instruments and are such that one may be thrown out of ones seat and loose objects become dislodged.

The criteria for the different intensities of turbulence are intended to relate to the vertical accelerations which would have the effects described.

Light turbulence would be noted when the vertical acceleration due to turbulence was between $\pm$ 0.05 g and $\pm$0.2g.

Moderate turbulence would be noted when the acceleration was between $\pm$ 0.2g and $\pm$0.5g.

Severe turbulence would be noted when the acceleration due to turbulence was $\pm$0.5g and upwards.

The criteria listed above give rough guidance on the reporting of turbulence and are necessarily subjective.

That these criteria fall short of the desirable data on the turbulence encountered is recognised by the WMO and the Meteorological Division of ICAO who at a joint meeting have stated "some indication of the frequency of turbulence experienced by aircraft was desirable, but no decision was reached concerning the precise form in which the existing Classifications should be altered" and recommended that "States continue studies on the classification of turbulence from aircraft reports so that eventually a more refined classification than the existing one may be introduced." (WMO.1954).

Bunker (1955) shows that an aircraft with suitable instrumentation offers a reliable method of determining the turbulent components of the atmosphere within a limited spectral range. Such instrumentation is not fitted to civil aircraft operating over North Atlantic routes. Even if suitable instrumentation was fitted to these aircraft it is possible that during periods of intense turbulence activity full reporting of observations of the instruments by a pilot may not be possible due to pressure of other duties.

The classification of turbulence intensity in terms of the effect of turbulence on the motion of the aircraft as sensed by the crew is subjective, being in terms of the degree in which movement within the aircraft or the carrying out of other duties by the crew members is hindered.

Press (1948) concluded as a result of the study of some of the data from the U.S. Thunderstorm Project that the characteristics of pilot technique appear to affect the influence of turbulence on an aircraft. Other results from the same Project indicate that the thresholds of intensity of turbulence, as reported by crews, become lower on an absolute scale with length of exposure to the turbulence. Bannon (1952) suggests that a pilot may describe turbulence as severe at, say, 30,000 feet because he considers it severe compared with the usual level of turbulence at that altitude rather than severe on an absolute scale independent of height.

There is a suspicion that the perceptible turbulence observed when an aircraft is passing in and out of small patches of cloud is not always reported and the number of reports of light turbulence received from the Shannon/Prestwick FIR in the year under review may substantially understate the number of occasions on which perceptible turbulence was encountered.

Distribution of Aircraft Reports in The Shannon/Prestwick FIR:

In the 12-month period under review, reports were not at hand for 4 full days (27th, 28th October, 7th November and 17th January) but in the remaining 361 days 37,746 aircraft reports were received at Shannon direct from aircraft in flight over the Shannon/Prestwick Oceanic FIR. The distribution of these reports over the area is shown in Figure 1. The figures on the diagram represent the total number of reports for each 1-degree space over the entire 12 months. To facilitate extraction and tabulation of data, reports from the shaded portion on the edge of the FIR south-west of Shannon as shown in Figure 1 were excluded from the survey.

No weather report was received from any aircraft above 25,000 feet which may be regarded as the operating ceiling of the types of commercial aircraft operating over the North Atlantic at that time. Reports were received from aircraft at heights spaced at 1000 feet intervals from 25,000 feet downwards. Westbound and Southbound aircraft operated at even heights (2,000, 4,000, 6,000 feet, etc.) while Northbound and Eastbound operated at odd heights (3,000, 5,000 feet, etc.). Only a small proportion of the flights were Northbound or Southbound, the vast majority were Eastbound or Westbound.

The reports have a marked concentration in the area between latitudes 50°N and 55°N where over 70% of the total number occur. The density of reports falls off to the North of 55°N and is considerably less South of 50°N. In three 1-degree spaces no aircraft weather observation was made in the entire 12 months.

The largest number of reports was received from the degree-space bordered by 53°N, 54°N, 13°W, and 14°W. This maximum total of 1,066 reports representing an average of a little less than 3 reports per day for all heights is due to the fact that aircraft departing Shannon Westbound were very frequently in this space at the end of the first hour of flight.

The frequency of aircraft weather reports on the North Atlantic has a marked diurnal variation with a maximum number of reports per hour being received in the hours between 0200 and 0600 GMT. and a minimum in the early afternoon (1200/1800 GMT.). There is also a marked variation over the year in the number of reports received per day, due to the seasonal pattern of trans-Atlantic flight frequency with heavy schedules in the Summer months and light schedules in the Winter months. The annual variation and the general upward trend of flight activity over the Shannon/Prestwick FIR is shown in Table 1 taken from data presented by ICAO (1956).

Table 1 - Daily Traffic on North Atlantic (Northern) Route

	Average flights per day	
Year	Entire year	Months July, Aug. Sept.
1949	29	41
1950	21	39
1951	30	39
1952	35	45
1953	40	51
1954	46	59
1955	54	70

The North Atlantic (Northern) route in Table 1 is represented by the Shannon/Gander and more northerly routes as distinct from the Southern route via the Azores and Bermuda.

Geographical Distribution of the Turbulence Reports:

A total of 366 reports of turbulence were received from aircraft in flight in the Shannon/Prestwick FIR in the 12-month period. This small number of turbulence reports representing 0.97% of the total aircraft reports suggests that aircraft turbulence is relatively infrequent over the Eastern North Atlantic. However, since a large proportion of the flights operate at heights above 14,000 feet, they can frequently avoid flying through cumulonimbus in which the most frequent and most severe turbulence is encountered. Byers et al. (1949) found over the U.S. that in average airmass thunderstorm conditions, less than 10% of the sky is filled with convective cloud at 20,000 feet. Even assuming coverage of the same order for convective cloud over the Atlantic, it is probable that avoiding action can be and is frequently taken by crews when large cumulus development is sighted.

Figure 2 shows the geographical distribution of reports of turbulence over the Shannon/Prestwick FIR in the period under review. The distribution shown in Figure 2 includes all cases of light turbulence which is not regarded as a hazardous condition for flights operated under ICAO procedure.

Figure 3 shows the geographical distribution of reports of moderate and severe turbulence in the Shannon/Prestwick FIR.

In the case of turbulence described in the reports as "marked" and reports of turbulence which were not classified, it was assumed in the preparation of Figure 3 and in the following analysis of the turbulence reports that the turbulence was moderate.

Analysis of the Reports of Turbulence:

Of the 366 reports of turbulence received, 7 were described as severe, 83 as moderate, 13 as marked, 17 without classification and 246 as light. On the assumption made above, 113 reports were considered to be in the category of moderate turbulence.

Table 2 gives a summary of the reported occurrence of different intensities of turbulence each month.

Table 2 - Summary of Reports of Turbulence of Different Intensities each Month (Oct.53/Sept.54)

Month	No. of air-craft reports	No. of Reports of Turbulence				Percentage Frequency	No. of days on which turbulence was reported
		Severe	Moderate	Light	Total		
Oct. (29 days)	2,820	1	10	12	23	0.81	15
Nov. (29 days)	2,367	1	9	14	24	1.01	16
Dec.	2,684	1	13	13	27	1.00	16
Jan. (30 days)	2,477	2	12	17	31	1.25	11
Feb.	2,078	1	6	6	13	0.62	8
Mar.	2,441	0	12	18	30	1.22	16
Apr.	2,909	0	7	15	22	0.75	12
May	3,588	0	2	9	11	0.30	9
June	4,161	0	0	12	12	0.28	9
July	4,037	0	2	20	22	0.54	13
Aug.	4,042	0	10	32	42	1.03	17
Sept.	4,142	1	30	78	109	2.63	28
Total	37,746	7	113	246	366	0.96	170

The high frequency in September, 1954 is believed to have been abnormal for that time of year. An analogous result in respect of icing in the same area was found by Rohan and Ó hAonghusa (1956). Winston (1954) points out that at 700 mb. the strongest mean winds in the Northern Hemisphere in September, 1954 were located near 50°N, 20°W which is near the centre of the Shannon/Prestwick FIR. These strong winds would be favourable for the occurrence of pronounced vertical wind shear with a resultant increase in the incidence of turbulence.

The reports of severe turbulence were confined to the months September to February.

Only light turbulence was reported in the month of June.

No turbulence was reported on 191 of the 361 days. No turbulence was reported on 13 consecutive days (30th Dec. 1953 to 11th Jan. 1954, inclusive) while on one day (29th Sept. 1954) 14 reports of turbulence were received, 12 of these being between 0000 and 0545 GMT. Figures 4 and 5 give the Surface and Upper Air flow over the area at that time.

A summary of the number of occasions on which different numbers of turbulence reports were received per day over the period is given in Table 3.

Table 3 - Number of days on which various numbers of Turbulence reports were received from the Shannon/Prestwick FIR - period October, 1953/September, 1954

No. of reports of turbulence per day.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
No. of days on which the given number occurred	191	90	36	17	11	7	4	2	0	1	0	0	0	1	1

With an average of 1 report of turbulence per day the above figures indicate coherence as we would expect in the occurrence of reports of turbulence.

Distribution of Turbulence Reports with Height:

The distribution of reports for different altitudes for each type of aircraft operating over the North Atlantic is not uniform, as each aircraft type has optimum operating altitudes in particular circumstances.

The vast majority of flights over the North Atlantic and which reported weather conditions in the period under review were made with aircraft of six general types: Stratocruiser, Superconstellation, Constellation, DC-6, DC-4, and Canadair. It is probable that a number of military flights which reported weather conditions were operated using these types of aircraft but the type of aircraft used by military flights were not known when the investigation was made.

Table 4 gives the distribution of reports for the more common types of aircraft at the various altitudes and the distribution of reports of turbulence from each type of aircraft.

Table 4 - Distribution of reports with height from six types of aircraft operating over the Shannon/Prestwick Oceanic FIR, October, 1953/September, 1954. (Distribution of turbulence reports for the same aircraft shown in brackets)

Height	TYPE OF AIRCRAFT						TOTAL
	St'cr.	Sup.-Con	Con	DC-6	DC-4	CANADAIR	
7000 or below	60 (1)	9	96 (2)	109 (4)	817 (5)	5	1096(12)
8000	148 (1)	27	202 (7)	1036(33)	1714(11)	41	3168(52)
9000	23	12	116 (1)	187 (2)	1983(10)	11	2332(13)
10000	911(10)	210 (2)	615(19)	1377(31)	181 (3)	75	3369(65)
11000	24	17	101 (1)	171	127 (4)	11	451 (5)
12000	583 (4)	528 (4)	307 (6)	1425(22)	4	14	2861(36)
13000	106	79	190 (1)	561 (4)	10	19	965 (5)
14000	613 (6)	605	269 (1)	1863(25)	4	82	3436(32)
15000	320	81	416	1433(23)	0	47	2297(23)
16000	183	119	542 (4)	764 (3)	0	27	1635 (7)
17000	257 (1)	153	2453(13)	1200(21)	0	317	4380(35)
18000	184	294	3235(14)	364 (4)	0	26	4103(18)
19000	850 (1)	583 (3)	1499 (9)	1423(19)	0	32	4387(32)
20000	33 (1)	278	97 (1)	58	0	1	467 (2)
21000	435 (2)	646 (2)	244 (5)	546 (9)	0	1	1872(18)
22000	1	20	0	1	0	0	22
23000	157	115	15	30	0	0	317
24000	0	1	0	0	0	0	1
25000	61	8	0	1	0	0	70
Total	4949(27)	3785(11)	10397(84)	12549(200)	4840(33)	709	

Examination of the data from which Table 4 was compiled indicated that there was a significant variation in the distribution of reports in the different ranges of altitude throughout the year. In view of this, it was not feasible to test the significance of the observed variation of turbulence with altitude.

It can be seen from Table 4 that the majority of reports of turbulence were made from aircraft at even altitudes (westbound). This is an interesting result, as westbound flights, being in the earlier part of their voyage when over the Shannon/Prestwick FIR, would then, in general have slower air speed and greater wing loading and should respond less to turbulence. However, when the westerly winds are stronger than normal, westbound aircraft show a preference for lower altitude and it would appear that, as the majority of the turbulence reports in Table 4 are at heights below 15,000 feet, the high incidence of turbulence with westbound flights is associated with occasions of strong winds when the vertical wind shear might be such as to cause conditions favourable for turbulence.

A chi-squared test of the data in Table 4 indicates that the variation of reports of turbulence between aircraft types stands at a highly significant level.

No turbulence report for a Canadair aircraft was received. These aircraft were operated regularly until mid-May, 1954.

Table 5 gives the distribution with height, of reports of moderate and severe turbulence for the other 5 types of aircraft.

Table 5 - Distribution with height of reports of turbulence termed "moderate" or "severe" by aircraft in the Shannon/Prestwick FIR during year October, 1953/September, 1954.

Height	TYPE OF AIRCRAFT					TOTAL
	St'cr	Sup'con	Con	DC-6	DC-4	
7000 or below	60	9	96 (2)	109 (2)	817 (1)	1091 (5)
8000	148 (1)	27	202 (1)	1036(12)	1714 (3)	3127(17)
9000	23	12	116	187	1983 (4)	2321 (4)
10000	911 (2)	210 (2)	615 (6)	1377(14)	181	3294(24)
11000	24	17	101	171	127	440
12000	583 (1)	528 (1)	307 (3)	1425 (9)	4	2847(14)
13000	106	79	190 (1)	561 (1)	10	946 (2)
14000	613 (2)	605	269	1863 (6)	4	3354 (8)
15000	320	81	416	1433 (8)	0	2250 (8)
16000	183	119	542 (2)	764 (1)	0	1608 (3)
17000	257	153	2453 (3)	1200 (6)	0	4063 (9)
18000	184	294	3235 (4)	364 (2)	0	4077 (6)
19000	850 (1)	583 (2)	1499 (2)	1423 (6)	0	4355(11)
20000	33	278	97	58	0	466
21000	435	646 (1)	244 (1)	546 (3)	0	1871 (5)
22000	1	20	0	1	0	22
23000	157	115	15	30	0	317
24000	0	1	0	0	0	1
25000	61	8	0	1	0	70
Total	4949 (7)	3785 (6)	10397(25)	12549(70)	4840 (8)	

The seven cases of severe turbulence were reported by Constellation (2 cases), DC-6 (3 cases) and DC-4 (2 cases) aircraft and occurred at heights ranging from 4,000 to 19,000 feet.

Association between Icing and Turbulence:

In the data examined, 582 cases of icing were encountered and 121 of these cases were reported simultaneously with turbulence.

Table 6 which is reproduced from an earlier paper (Rohan & Ó hAonghusa, 1956) shows the frequency of icing reports in relation to turbulence.

Table 6 - Frequency of simultaneous occurrence of Icing and Turbulence

		No icing	Icing	Total
No turbulence	......	36,919	461	37,380
Turbulence	......	245	121	366
Total:	......	37,164	582	37,746

Table 6 shows that a third of the reports of turbulence were associated with aircraft icing. A Chi-squared test of the data, coupled with the fact that the first column of Table 6 includes a very considerable number of reports from aircraft flying in conditions where no hydrometeors were present and a number of reports at temperatures which would not admit of icing, confirm that this association was significant. Two of the cases of reported severe turbulence were associated with reports of heavy icing. Icing was not associated with the other cases of severe turbulence. One of these reports was at a temperature which did not admit of icing

Summary of Synoptic Situations in which Turbulence was reported:

An examination was made of the synoptic situations in which turbulence was reported. A summary of the results is shown in Table 7.

Table 7 - Summary of occurrence of turbulence in different synoptic situations in the Shannon/Prestwick FIR, October, 1953/ September, 1954

Synoptic Characteristics	Intensity of Turbulence			Total
	Light	Moderate	Severe	
Warm Front	88	31	1	120
Cold Front	35	21	2	58
Occlusion	21	3	0	24
Warm Air Mass	18	6	0	24
Cold Air Mass	84	52	4	140

The classifications in Table 7 and in Table 9 are necessarily subjective being based on inspection of the Surface and Upper Air charts prepared at Shannon. Six cases of turbulence (5 light, 1 moderate) reported in Secondary Cold Fronts embedded in a cold air stream were classified as Cold Air Mass turbulence. About 38% of the turbulence reports came from aircraft in Cold Air Masses. Four of the seven cases of severe turbulence were reported in Cold Air Masses. The turbulence in Cold Air Masses is generally associated with cumuliform cloud. As avoiding action can frequently be taken by crews when large cumulus or cumulonimbus development is sighted it is probable that the figure for Cold Air Mass turbulence given in Table 6 understates the existence of perceptible turbulence and may be regarded as representing minimum probability for the phenomenon under such conditions.

No case of severe turbulence was reported in an Occlusion or in Warm Air Masses. As a considerable number of frontal systems over the Eastern North Atlantic have reached the occlusion stage by the time they reach 30°W, the small number of cases of turbulence, and particularly of moderate turbulence, in occlusions covered examination of a large proportion of the frontal systems. The cases of moderate turbulence associated with an occlusion occurred in August and September. The cases of moderate turbulence in warm fronts occurred in October, November, August and September.

Reports of turbulence frequently were made in areas in which other aircraft at approximately the same height and time did not experience turbulence. This haphazard occurrence of turbulence which has also been noted by writers investigating turbulence in other geographical regions, suggests that forecasting of turbulence should be in terms of probability or as a statement of risks.

A possible association between the location of pronounced centres of cyclonic vorticity on the 700 mb. and 500 mb. charts and the location of reports of turbulence was explored. The vorticity at the location of the turbulence report was measured on the nearest appropriate chart using a celluloid template after Sander and Kessler (1955). Examination of a few months' data showed a number of cases of turbulence where vorticity was zero and an almost exactly equal number of cases where the vorticity was cyclonic and anticyclonic. In view of the indications so obtained, the remaining cases were not examined in this light.

Turbulence in Clear Air:

An examination of the "flight conditions" reported in association with reports of turbulence gives an indication of the cases of the occurrence of turbulence in clear air. Unfortunately not all reports of turbulence were accompanied by reports of flight conditions and as the reports of turbulence often referred to a time up to one hour previous to the time referred to under flight conditions, it was not possible to establish in all cases if the aircraft was or was not in clear air at the time the turbulence was experienced.

The reports were checked against other available information and it was established that at least 71 cases of turbulence were encountered in clear air. This represents about 20% of all the turbulence reports. Some of the reports were specifically described as "clear air turbulence" in the reports while others merely gave the intensity of the turbulence in conditions in which there was reasonable certainty that the aircraft was neither in cloud nor flying through precipitation associated with cloud at the time the turbulence was experienced.

Table 8 gives a summary of the occurrence of turbulence in clear air and the different positions of the aircraft in relation to cloud cover.

Table 8 - Summary of reports of turbulence in clear air, with different positions of the aircraft in relation to cloud cover, in the Shannon/Prestwick FIR, October, 1953/September, 1954

Cloud conditions at flight level	Intensity of Turbulence			Total
	Light	Moderate	Severe	
No cloud in vicinity of aircraft	8	4	0	12
Aircraft between layers	13	2	0	15
A/c over all cloud	30	14	0	44

Cases where the aircraft was reporting flight conditions "in and out of cloud" were exluded from the category of turbulence in clear air even though in some cases may have been experienced outside the edge of the cloud.

Turbulence reports in clear air were reported in all months except May.

37 of the reports including 11 cases of moderate turbulence occurred in cold air masses.

19 cases (13 light, 6 moderate) occurred in the vicinity of surface warm fronts.

11 cases (9 light, 2 moderate) occurred in the vicinity of surface cold fronts.

3 cases (2 light, 1 moderate) occurred in warm air masses and 2 cases of light turbulence in clear air were reported in the vicinity of a surface occlusion.

Turbulence in clear air was reported at heights ranging from 6,000 to 21,000 feet. In view of the geographical region under discussion the turbulence at the low level could scarcely be associated with orographic effects. 40 of the reports were received for aircraft at even (westbound) altitudes and 31 at odd (eastbound) altitudes.

The general flow pattern on the 700 or 500 mb. chart (0300 or 1500 GMT.) nearest each report of turbulence in the clear air was classified in an effort to give an indication of the frequency with which clear air turbulence is encountered with different flow patterns. The results are shown in Table 9.

Table 9 - Summary of occurrence of turbulence in clear air at different heights in relation to the flow pattern

Height in feet / Position in flow pattern	6,000	7,000	8,000	9,000	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000	18,000	19,000	20,000	21,000
On cold side of Jet			3	1	2	1	3		1	1	1	4	2	4		1
Embedded in Jet			1											1		
Warm side of Jet				1	3					2						
At Jet intake												1				
At Jet outlet														1		
Uniform flow	1		3	1	7			1	2	1	3	4	2	1		2
Slack area			2		1					1		1			1	1
Near centre of Low			1										1			

In classifying the reports in relation to jet stream flow the gradient wind in some cases, particularly on 700 mb. charts, was below the 30 m/s specified for a jet stream in Recommendation 38 (56 - CAe) of the W.M.O. but where the flow had a boundary that was well defined by a change of gradient the flow was classified as a jet stream. On the other hand broad belts of uniform flow which had no well-marked boundary were classified as uniform flow even though on occasions the velocities in the vicinity of the position of the turbulence report were quite high. Slack areas were usually weak highs. The vast majority of cases of turbulence in clear air associated with a jet stream occurred on the low pressure and cold side of the jet. This agrees with results obtained by Bannon (1952) and others investigating severe turbulence. Some cases of moderate clear air turbulence not associated with jet stream were encountered at heights above 15,000 feet which differs from the experience of United Airlines over America as reported by Harrison (1951).

There were not enough cases to indicate any difference, as regards clear air turbulence, between conditions at the entrance or exit of a jet. More cases of clear air turbulence were associated with uniform flow than with any other configuration. The 28 cases of clear air turbulence in uniform flow were associated with gradient wind speeds ranging from 25 to 100 knots, measured from the nearest upper air charts in each case. In addition, as shown in Table 9, seven other cases were reported in slack areas. It was noted that in the case of a number of turbulence reports in uniform flow there was no noticeable vertical wind shear or abnormal vertical temperature gradient between the 700 and 500 mb. levels. A comparison of the gradient wind at the 700 and 500 mb. levels and the overall temperature lapse between the levels is not detailed enough to give a reliable indication of the vertical wind shear and temperature lapse rate at the location of an individual report of turbulence. Wind and temperature profiles (mainly associated with jet streams), produced by Scorer (1956) and others, indicate the existence of shallow layers of very great wind shear and low static stability which in certain circumstances are favourable for the occurrence of turbulence. These shallow layers would not be evident from the data on the charts at the 700 and 500 mb. levels. Consequently, no attempt was made to analyse the turbulence reports in terms of the Richardson number.

The number of clear air turbulence reports near the centres of low pressure was remarkably small but this may be due to the fact that most low centres at the 700 and 500 mb. levels are associated with active surface systems giving extensive cloud development at the centre, and aircraft below 20,000 feet in the area would frequently not be in clear air.

Acknowledgments:

I wish to express my thanks to the various members of the staff of the Meteorological Office, Shannon Airport, for suggestions at all stages of the work.

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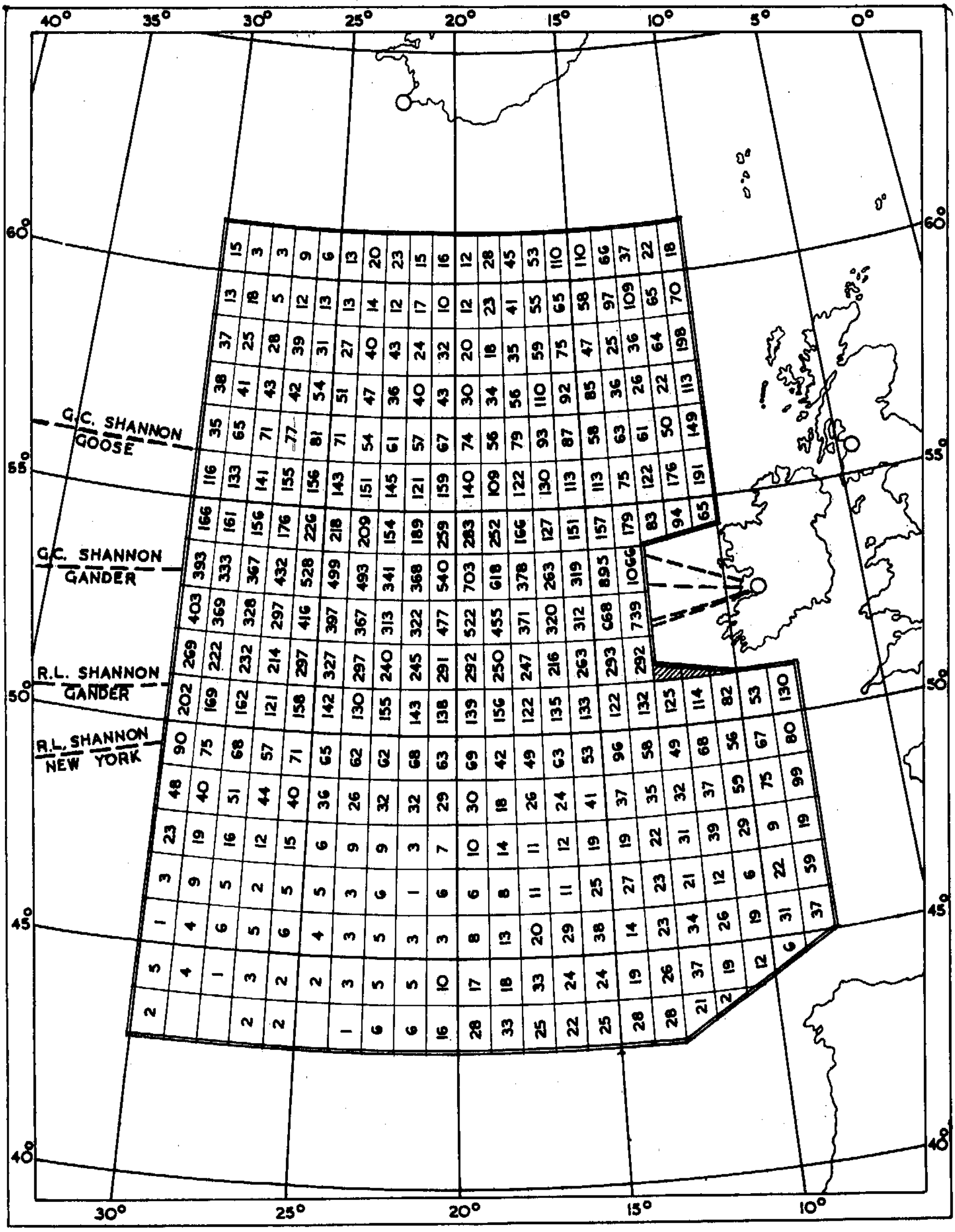


Fig.1 Distribution of Aircraft Weather Reports in the Shannon/Prestwick Flight Information Region for the year October, 1953/September, 1954.

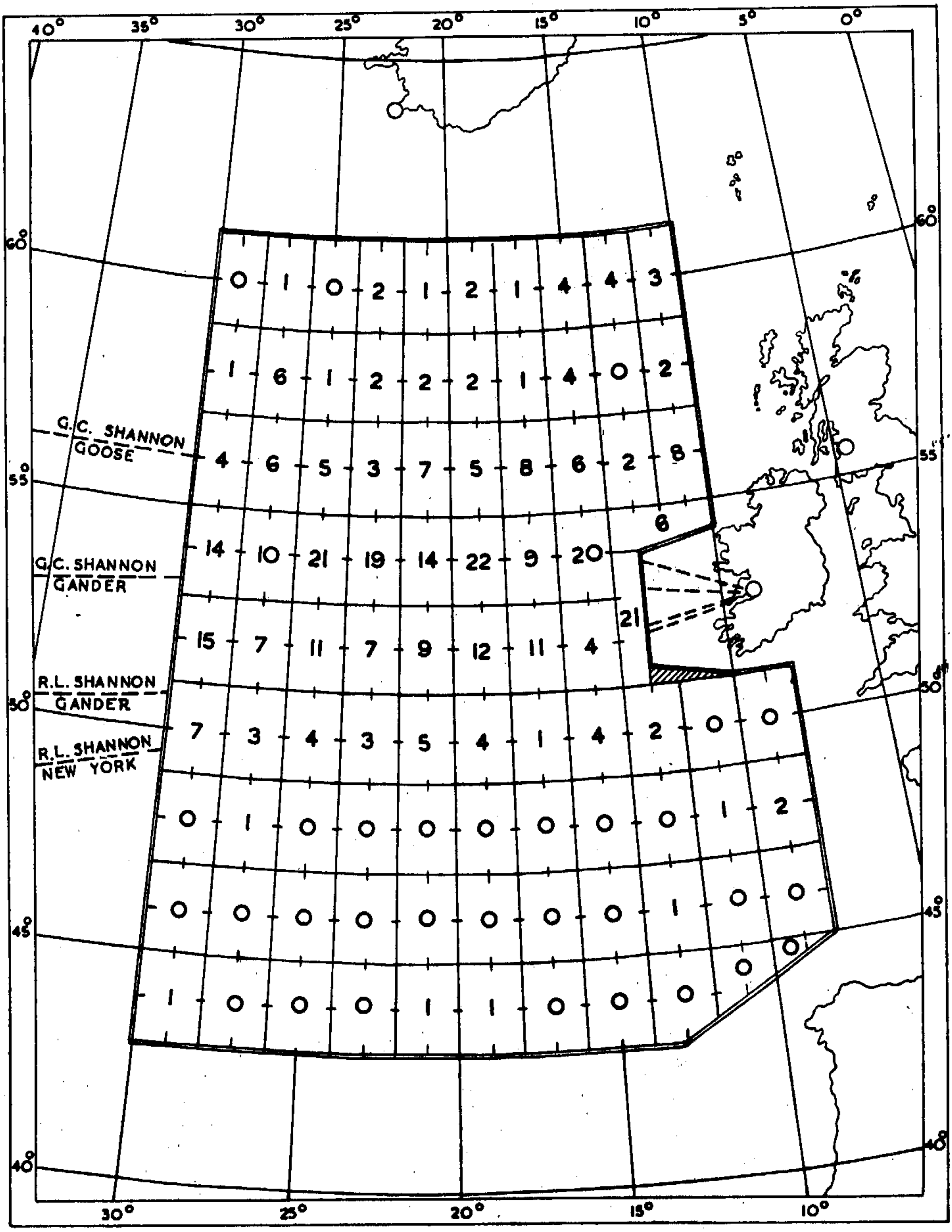


Fig.2 Distribution of reports of Turbulence experienced by aircraft in the Shannon/Prestwick Flight Information Region for the year October, 1953/September, 1954.

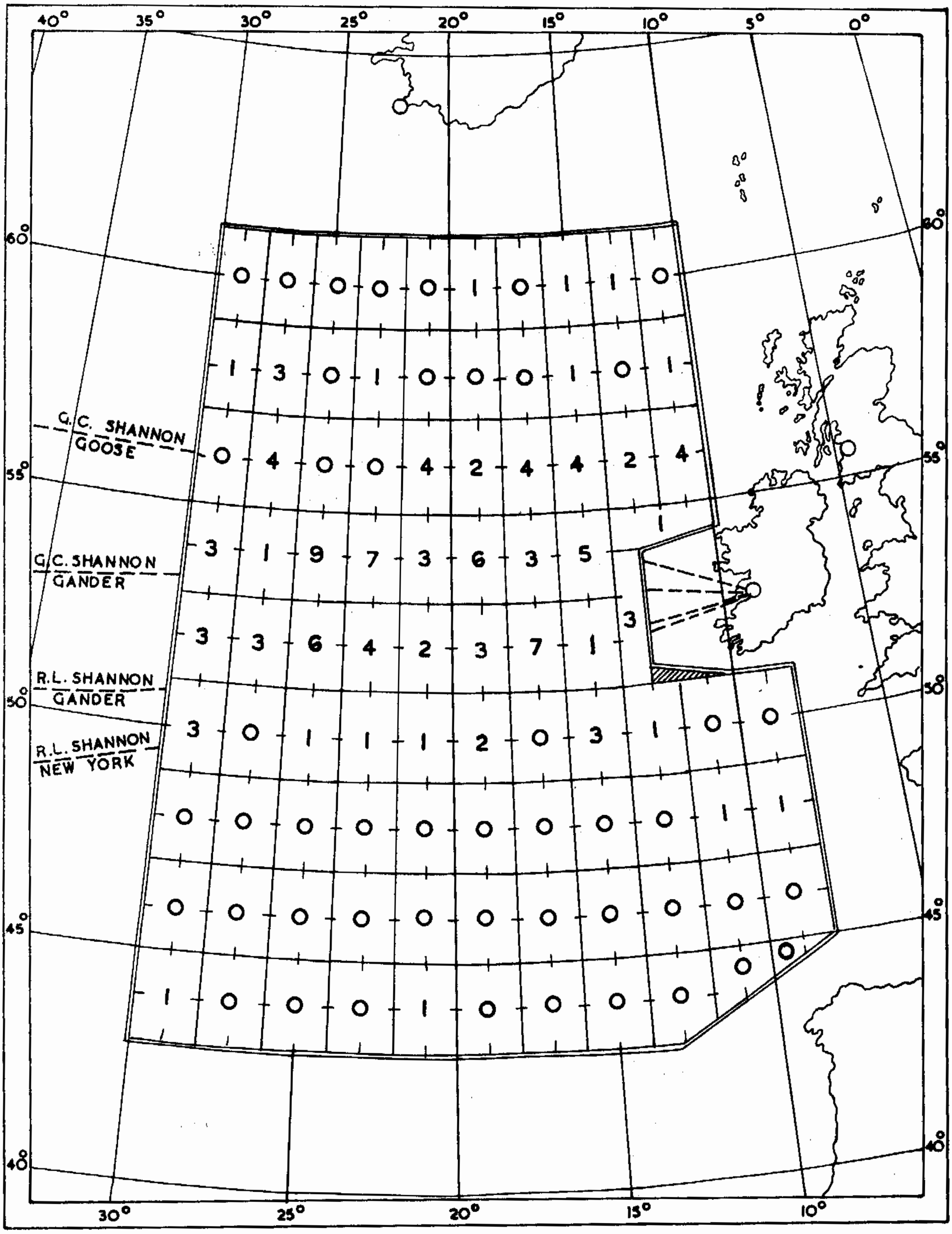


Fig.3 **Distribution of reports of Moderate or Severe Turbulence from aircraft in the Shannon/Prestwick Flight Information Region for the year October, 1953/September, 1954.**

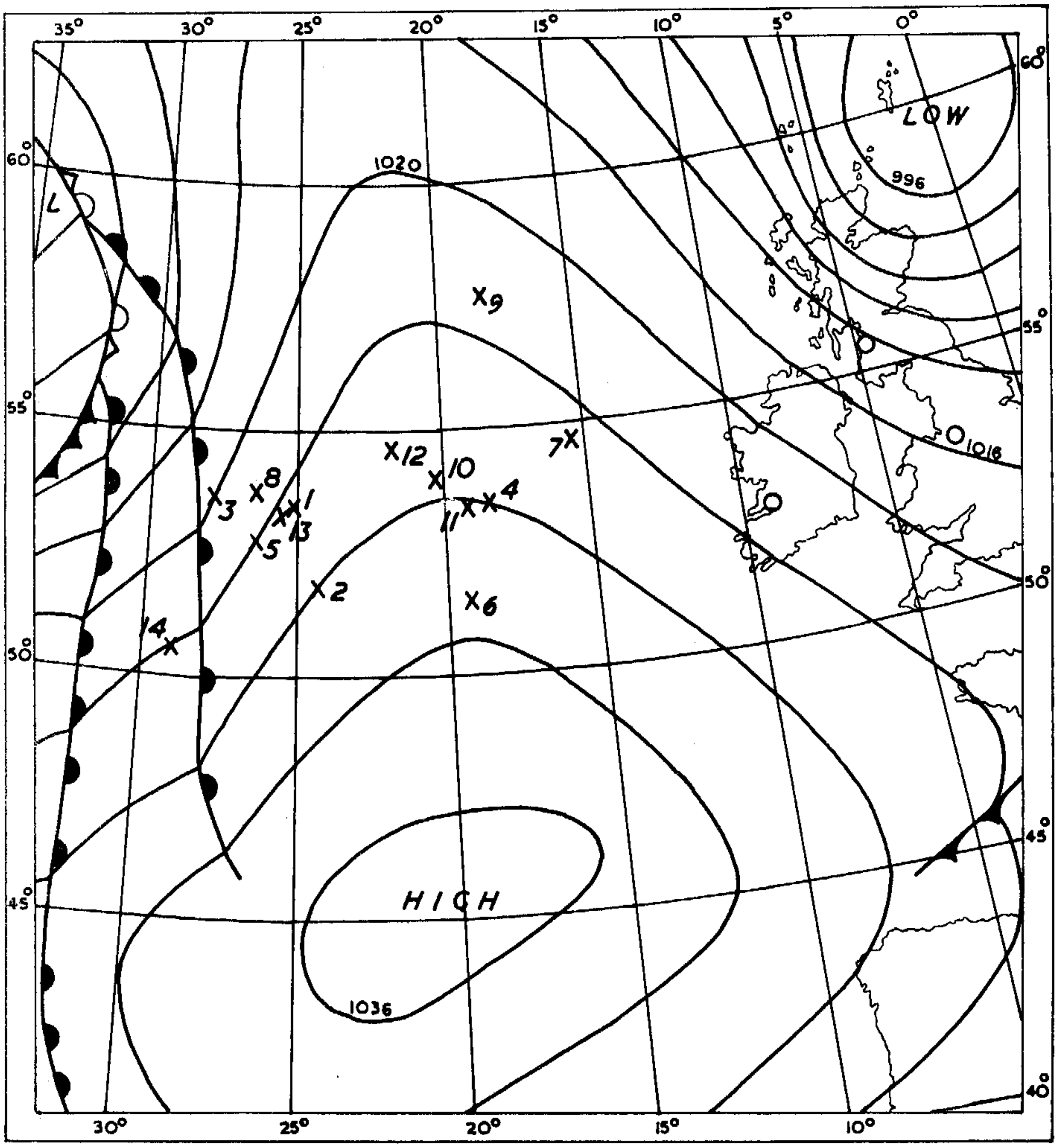
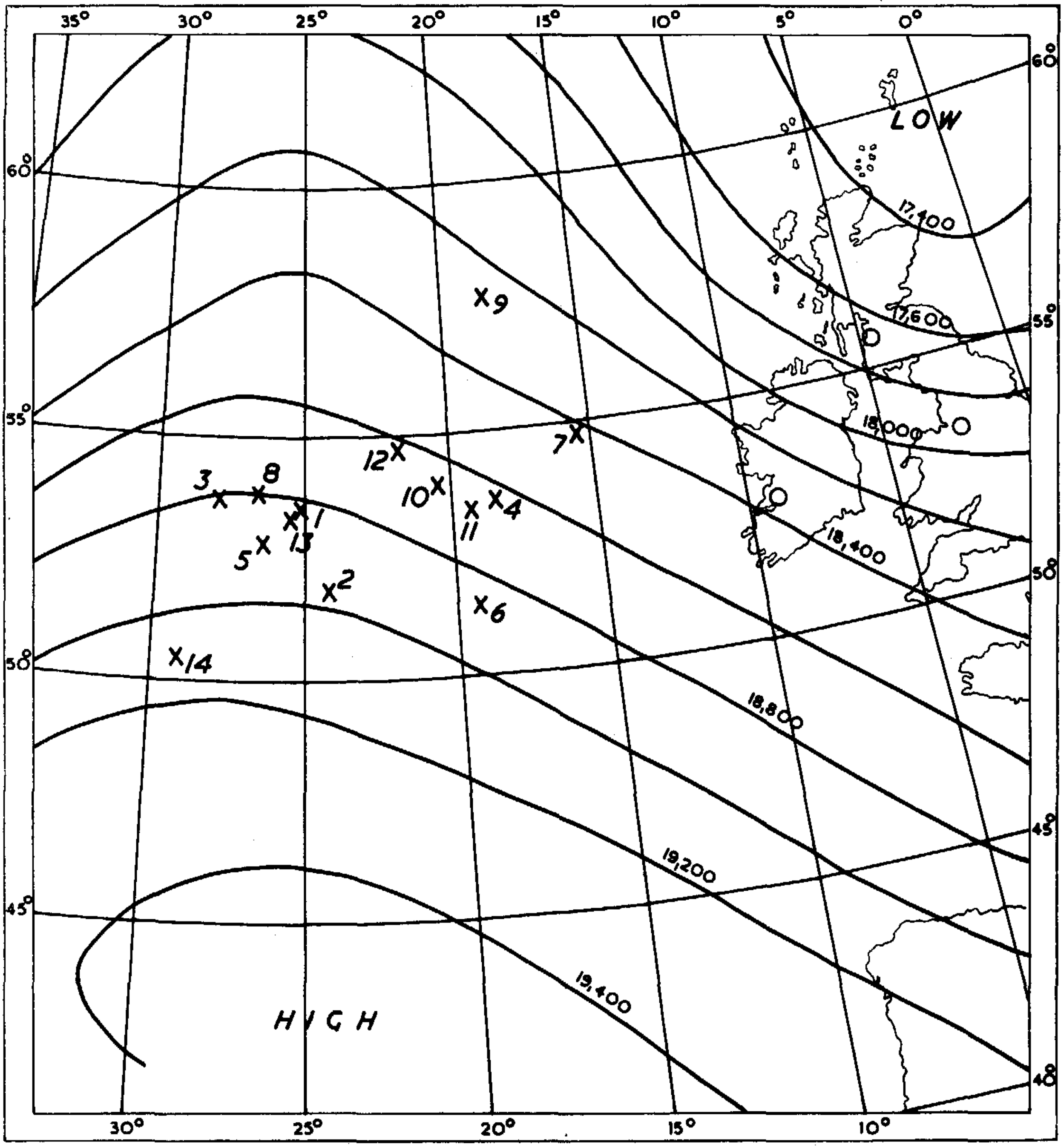


Fig.4 Surface chart 0000 GMT. 29th September, 1954, showing positions at which Turbulence was reported by aircraft.

1.	2230 GMT.	28th Sept.		Light Turbulence at 19000 ft.
2.	2342 GMT.	28th Sept.		Light Turbulence at 17000 ft.
3.	0002 GMT.	29th Sept.		Light Turbulence at 21000 ft.
4.	0242 GMT.	"	"	Light Turbulence at 21000 ft.
5.	0255 GMT.	"	"	Light Turbulence at 15000 ft.
6.	0345 GMT.	"	"	Light Turbulence at 14000 ft.
7.	0345 GMT.	"	"	Light Turbulence at 8000 ft.
8.	0407 GMT.	"	"	Light Turbulence at 8000 ft.
9.	0430 GMT.	"	"	Light Turbulence at 9000 ft.
10.	0445 GMT.	"	"	Light Turbulence at 8000 ft.
11.	0445 GMT.	"	"	Light Turbulence at 17000 ft.
12.	0520 GMT.	"	"	Moderate Turbulence at 10000 ft.
13.	0545 GMT.	"	"	Light Turbulence at 8000 ft.
14.	0545 GMT.	"	"	Moderate Turbulence at 14000 ft.



500 mb. chart 0300 GMT. 29th September, 1954, showing positions at which Turbulence was reported by aircraft.

1.	2230 GMT.	28th Sept.		Light Turbulence at 19000 ft.
2.	2342 GMT.	28th Sept.		Light Turbulence at 17000 ft.
3.	0002 GMT.	29th Sept.		Light Turbulence at 21000 ft.
4.	0242 GMT.	"	"	Light Turbulence at 21000 ft.
5.	0255 GMT.	"	"	Light Turbulence at 15000 ft.
6.	0345 GMT.	"	"	Light Turbulence at 14000 ft.
7.	0345 GMT.	"	"	Light Turbulence at 8000 ft.
8.	0407 GMT.	"	"	Light Turbulence at 8000 ft.
9.	0430 GMT.	"	"	Light Turbulence at 9000 ft.
10.	0445 GMT.	"	"	Light Turbulence at 8000 ft.
11.	0445 GMT.	"	"	Light Turbulence at 17000 ft.
12.	0520 GMT.	"	"	Moderate Turbulence at 10000 ft.
13.	0545 GMT.	"	"	Light Turbulence at 8000 ft.
14.	0545 GMT.	"	"	Moderate Turbulence at 14000 ft.