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Speeds and Normal Accelerations of Boeing
Clipper Aircraft on North and
South Atlantic Routes

By

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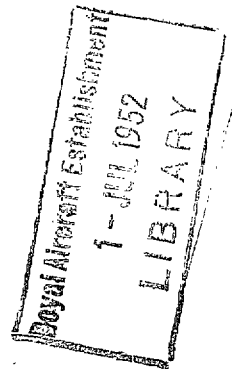
By

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*Reports and Memoranda No. 2633**

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Summary.—This report presents results obtained from *V-g* recorders fitted to Boeing *Clipper* aircraft on the North and South Atlantic routes between September, 1944 and May, 1946. The records cover about 3,300 flying hours and show that the maximum speed recorded is 215 m.p.h. (I.A.S.) and the maximum upward and downward accelerations are $2.3g$ and $-0.3g$ respectively.

The two main groups of records considered differ from one another not only in respect of route but also in seasonal conditions and in proportion of flights made in wartime. Therefore, differences between the results cannot be simply ascribed to differences of route.

It appears from the analysis that the maximum speed likely to be attained in a large flying time is somewhat greater in one group (North Atlantic) than in the other (South Atlantic) and that the maximum accelerations on the other hand are likely to be less for the former than the latter.

1. *Introduction.*—1.1. One of several operational research projects on civil air transports was to determine by *V-g* recorders the maximum speeds and normal accelerations experienced by Boeing *Clipper* aircraft of the British Overseas Airways Corporation on the North and South Atlantic routes. Some preliminary results were reported by Hain Taylor¹ and the project has since been terminated by the withdrawal of these aircraft from service. The purpose of the present report is to provide a complete record of the results of this investigation.

1.2. Both routes terminate at Poole in England and Baltimore in the U.S.A., the North Atlantic route proceeding *via* Foynes and Botwood, and the South Atlantic route including Lisbon, Bathurst, Natal, Belem, Trinidad and Bermuda (*see* Fig. 1). Records for the South Atlantic were received between March, 1945 and May, 1946, and those for the North between September, 1944 and October, 1945.

1.3. Brief particulars of the Boeing *Clipper* are given in Appendix II.

2. *Data and their Presentation.*—2.1. *South Atlantic.*—The total number of *V-g* records for the South Atlantic was 138 covering a flying time of 2,200 hours. The flying times of these records varied widely, the extreme values being 60 hours and 10 hours per record. Variations in the flying time bias the values of speed and acceleration and therefore, for the purpose of the analysis (described in Appendix I), records having a reasonably constant time only were used. The largest number of such records was 77 and the average flying time per record was about 11 hours. The total flying time for these records was 838 hours.

*R.A.E. Report Structures 25—received 20th October, 1948.

2.2. The data obtained from these records comprise the maximum upward and downward accelerations in the 100 to 150 m.p.h. and 150 to 200 m.p.h. bands and the maximum speeds. These, together with the flying time and date of receipt of each record, are given in Table 1. Acceleration readings occurring below 100 m.p.h. are omitted as, in many instances, flight traces below this speed were masked by traces due to alighting and take-off. There were very few records showing speeds above 200 m.p.h.

2.3. *North Atlantic*.—The number of North Atlantic records for which the flying times are known was 59 covering a total flying time of 1,100 hours. For the purpose of analysis the largest number of records of reasonably constant duration was used, this being obtained by selecting those of about 23 hours. Twenty-five records covering a total flying time of 580 hours were obtained in this way and the data are given in Table 2.

2.4. *Diagrammatic Presentation*.—The data are shown diagrammatically in Figs. 2, 3, the acceleration values for upward and downward acceleration being plotted as dots and encircled dots respectively within speed ranges.

3. *Frequency Distributions of Maximum Speeds and Maximum Normal Accelerations*.—3.1. The frequency distributions of maximum speeds are given in Tables 3 and 4 for the two routes separately and are shown in histogram form in Figs. 4, 5. On the South Atlantic route, apart from the exceptionally low single value of 150 m.p.h., the values lie between 165 and 215 m.p.h. On the North Atlantic route the values are between 170 and 215 m.p.h.

3.2. The frequency distributions of maximum accelerations are given in Tables 5 and 6, and Fig. 6. The overall extreme values achieved on the South Atlantic route are 2.3g (in the 150 to 200 m.p.h. band) and 0g (in both bands). On the North Atlantic route the overall extremes are 2.2g (in the 150 to 200 m.p.h. band) and 0g (in the 100 to 150 m.p.h. band).

4. *Values of Speed and Normal Acceleration Attained in a Given Time*.—4.1. One of the main objects of conducting operational research with *V-g* recorders is to assess reasonable design loads, and for this purpose an estimate is required of the speeds and normal accelerations which will be attained very rarely, say once in 10^5 flying hours. Following the analytic method of fitting Pearson Type III curves to the data (described in Appendix I) we derive Fig. 7 which shows that the speeds which are likely to be attained once in 10^5 flying hours are 228 m.p.h. for the South Atlantic and 242 m.p.h. for the North Atlantic.

4.2. By the same analytic method the accelerations expected to be exceeded once in 10^5 flying hours are found to be as follows:

Speed band m.p.h. (I.A.S.)	Accelerations expected to be exceeded once in 10^5 flying hours			
	South Atlantic		North Atlantic	
	Upward	Downward	Upward	Downward
100 to 150	2.74g	-0.48g	2.46g	-0.30g
150 to 200	2.80g	-0.44g	2.68g	-0.19g

5. *Differences Between Results Obtained from North and South Atlantic Routes*.—The curves of Fig. 7 indicate that in flying times of 100 hours or more, higher maximum speeds will occur on the North Atlantic route than on the South Atlantic. Figs. 8, 9 indicate, on the other hand, that higher maximum accelerations are experienced on the South Atlantic route. It should be noted, however, that the two sets of records differ not only in respect of route but also in the season and in the proportion of the total number of flights made in wartime. Differences in the results, therefore, cannot be ascribed simply to differences of route.

6. *Conclusions.*—6.1. On the South Atlantic route the speeds and normal upward and downward accelerations recorded in 838 flying hours have reached and not exceeded 215 m.p.h. (I.A.S.), 2.3g and 0g respectively. A speed of 228 m.p.h. and upward and downward accelerations of 2.8g and $-0.5g$ are expected to be attained once in a flying time of 10^5 hours.

6.2. On the North Atlantic route the speeds and normal upward and downward accelerations recorded in 580 flying hours have reached and not exceeded 215 m.p.h., 2.2g and 0g. A speed of 242 m.p.h. and upward and downward accelerations of 2.7g and $-0.3g$ are expected to be attained once in a flying time of 10^5 hours.

6.3. It seems likely that in any flying time greater than about 1,000 hours in conditions similar to those in which the records were obtained, the maximum accelerations experienced on the South Atlantic route will be greater than on the North Atlantic. The maximum speed is, however, likely to be less on the South Atlantic than the North Atlantic route.

6.4. As the two groups of records considered differ from one another not only in respect of route but also in seasonal conditions and in the number of flights made in wartime, differences in the results cannot be ascribed exclusively to differences of route.

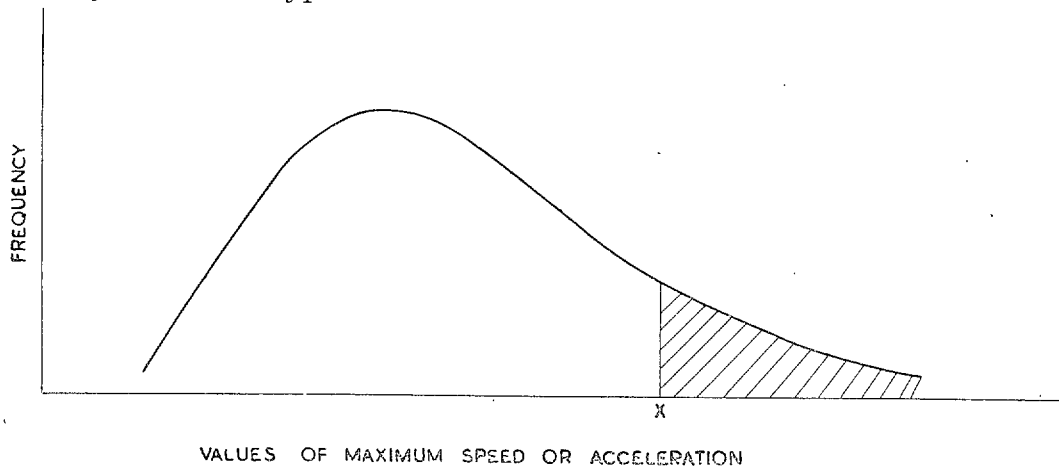
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<i>No.</i>	<i>Author</i>	<i>Title, etc.</i>
1	R. Hain Taylor	Some Preliminary Results from <i>V-g</i> Recorders Installed in Military and Civil Aircraft. R. & M. 2610. December, 1946.
2	D. T. Jones	Interim Report on Results Obtained from <i>V-g</i> Recorders Fitted to Meteor III Aircraft. R.A.E. Report Structures No. 10. October, 1947. A.R.C. 11, 146. (Unpublished.)
3	Salvosa	Annals of Mathematical Statistics. Vol. I. No. 2. February, 1934.
4	.. .. .	<i>Aviation</i> . July, 1938. Page 33.
5	R. V. Rhode and P. Donely	Frequency of Atmospheric Gusts and of Related Loads on Airplane Structures. N.A.C.A. Advance Restricted Report No. L4121. A.R.C. 8551. November, 1944. (Unpublished.)

APPENDIX I

Application of Pearson Type III Curves to the Estimation of Probabilities of Exceeding Given Values of Speed and Acceleration

General.—The method used in this report for estimating the speed and accelerations which will be exceeded in a given time is the same as that described more fully in Appendix I to a previous report² on the results obtained from the use of $V-g$ recorders on Meteor III aircraft. It is assumed on the theoretical basis given in that Appendix that the frequency distribution of maximum speeds and accelerations obtained from a set of records of approximately equal flying times may be represented by a Pearson Type III curve.



Having determined the appropriate curve we have that the probability of a record showing a maximum speed or maximum acceleration greater than a given value x is given by the ratio of that portion of area under the curve cut off by the abscissa above x and the ordinate through x (shown shaded in the accompanying diagram) to the whole area under the curve.

This ratio may be determined by the use of Tables of the Incomplete Gamma Function or by other published tables³ or curves.

Procedure.—The following is a convenient mode of procedure :

For a given distribution find

- (i) the mean = \bar{x} ,
 - (ii) the standard deviation = σ ,
 - (iii) the coefficient of skewness = $\sqrt{\beta_1}$
- $$= \frac{\sum(x - \bar{x})^3}{\sigma^3 n}$$

where n is the number of records.

The probability of exceeding a given value of x can now be found by

- (i) expressing x as a deviation from the mean in terms of the standard deviation, that is, as

$$u = (x - \bar{x})/\sigma,$$

and (ii) entering tables such as those prepared by Salvosa³ (or appropriate curves which have been issued in American Reports) at u and $\sqrt{\beta_1}$.

We may thus find a series of values of the probability, say P , of exceeding given values of speed or acceleration on a record, (that is, during a flight). The number of records which will be expected to include one having a value of speed or acceleration greater than the given value is thus $1/P$. Clearly, if t is the average duration of a record, the time in which the value will be exceeded, say T , is t/P .

In order to construct a curve of T against x a few arbitrary values of x should be chosen, the corresponding values of u found, and hence values of P and t/P determined. The points thus obtained can be conveniently plotted on semi-logarithmic paper, of say five cycles, and it is then possible to read off the time in which a given value will be exceeded once.

Application to Boeing Clipper Data.—The above method was used for the Boeing Clipper data examined in this report. The following table gives the values of \bar{x} , σ and $\sqrt{\beta_1}$ for the distribution of maximum speeds and normal upward and downward accelerations.

Maximum Speed Distributions

	S. Atlantic	N. Atlantic
\bar{x}	177 m.p.h.	183 m.p.h.
σ	9.0 m.p.h.	9.7 m.p.h.
$\sqrt{\beta_1}$	0.9	1.36

Maximum Acceleration Distributions

	South Atlantic				North Atlantic			
	Upward Accelerations		Downward Accelerations		Upward Accelerations		Downward Accelerations	
	100 to 150	150 to 200	100 to 150	150 to 200	100 to 150	150 to 200	100 to 150	150 to 200
\bar{x}	1.51g	1.53g	0.46g	0.51g	1.65g	1.68g	0.34g	0.36g
σ	0.20g	0.23g	0.18g	0.20g	0.15g	0.19g	0.20g	0.22g
$\sqrt{\beta_1}$	1.06	0.84	0.68	0.51	0.97	0.95	-0.15	-0.68

The curves giving the time in relation to maximum speed, upward g and downward g are shown in Figs, 7, 8, 9.

The speeds and accelerations which may be expected to be exceeded in 10^5 flying hours are given in section 4 of the report.

APPENDIX II

Specification Details of Boeing (314) Clipper Aircraft

The following are some of the specification details for the Boeing Clipper aircraft as given in the American journal "Aviation".

Wing span	..	..	..	..	152 ft
Wing area	..	..	..	..	2867 sq ft (not including sponsons)
Wing chord—					
root	..	..	..	..	29 ft 6 in
tip	..	..	..	..	7 ft 4 in
Aspect ratio	..	..	..	..	8.05 to 1
Gross weight	..	..	..	..	82,500 lb
Wing loading	..	..	..	..	28.8 lb/sq ft

The following data are quoted in a NACA Report⁵.

Slope of lift curve	..	..	..	4.69
Relative alleviation factor	..	..	..	1.085

TABLE 1

Maximum Accelerations Recorded in Speed Bands, and Maximum Speeds (S. Atlantic)

Slide No.	Date Received	100 to 150 m.p.h. band		150 to 200 m.p.h. band		Max. speed (m.p.h. I.A.S.)	Flying Time
		Upward	Downward	Upward	Downward		
9	3.45	1.3	0.5	1.2	0.7	175	12
15	3.45	1.3	0.3	1.2	0.7	150	12
17	3.45	1.4	0.5	1.7	0.5	170	10
18	3.45	1.5	0.2	1.5	0.1	175	10
20	5.45	1.5	0.1	1.6	0.3	185	10
23	5.45	1.4	0.4	1.4	0.1	175	12
24	5.45	1.3	0.4	1.3	0.5	175	10
26	5.45	1.7	0.7	1.7	0.7	175	10
30	5.45	1.7	0.2	1.8	0.6	195	10
34	5.45	1.6	0.5	1.8	0.5	175	10
35	5.45	1.4	0.4	1.4	0.5	175	12
36	5.45	1.7	0.3	1.2	0.5	175	12
38	5.45	2.0	0.5	2.0	0.3	180	10
39	5.45	1.4	0.5	1.6	0.4	185	10
49	5.45	1.7	0.3	1.8	0.4	175	11.11
50	5.45	1.8	0.6	1.8	0.5	185	10.30
62	1.46	1.7	0.2	1.6	0.2	190	11.27
63	1.46	1.6	0.3	1.7	0.2	195	11.44
102	3.46	1.3	0.4	1.5	0.3	215	10.26
104	4.46	1.5	0.4	1.7	0.4	180	11.45
105	4.46	1.4	0.7	1.4	0.8	170	10.39
107	4.46	1.4	0.7	1.4	0.8	180	12.06
108	4.46	1.4	0.7	1.3	0.7	195	10.15
109	4.46	1.4	0.6	1.3	0.8	190	10.21
110	4.46	1.3	0.6	1.2	0.8	175	10.21
111	4.46	1.2	0.6	1.3	0.7	185	11.57
112	4.46	1.5	0.6	1.5	0.7	190	11.16
113	4.46	1.3	0.5	1.3	0.7	165	11.47
114	4.46	1.4	0.6	1.5	0.7	175	11.19
115	4.46	1.3	0.7	1.4	0.7	175	11.01
116	5.46	1.5	0.3	1.6	0.6	180	11.20
117	5.46	1.3	0.5	1.2	0.5	175	11.44
118	5.46	1.3	0.6	1.2	0.7	165	11.39
119	5.46	1.4	0.5	1.3	0.6	165	11.24
120	5.46	1.2	0.6	1.3	0.5	180	11.11
121	5.46	1.4	0.7	1.4	0.7	170	10.39
122	5.46	1.4	0.6	1.4	0.6	180	12.06
123	5.46	1.3	0.6	1.3	0.3	180	10.41
124	7.46	1.7	0.5	1.6	0.6	175	10.13
125	7.46	1.3	0.7	1.5	0.7	170	11.09
126	7.46	2.1	0.0	2.1	0.7	185	10.11
127	7.46	1.5	0.7	1.5	0.8	175	10.54
128	7.46	1.6	0.4	1.7	0.4	170	10.55
129	7.46	1.5	0.4	1.6	0.4	180	11.00
130	7.46	1.8	0.1	1.6	0.2	175	10.34
131	7.46	1.4	0.4	1.5	0.3	180	10.21
132	7.46	1.4	0.4	1.5	0.1	185	10.38
133	7.46	1.2	0.4	1.3	0.5	170	10.38
134	7.46	1.5	0.6	1.4	0.6	170	10.14
135	7.46	1.7	0.4	1.7	0.2	175	10.30
136	7.46	1.6	0.2	1.7	0.4	175	10.40
137	7.46	1.4	0.5	1.6	0.5	175	10.48
138	7.46	1.6	0.5	1.7	0.4	175	10.20
146	8.46	1.4	0.0	1.6	0.0	175	10.43
147	8.46	1.6	0.3	1.5	0.3	170	10.32
148	8.46	1.4	0.6	1.4	0.6	170	10.55
149	8.46	2.1	0.4	1.6	0.5	170	11.48

TABLE 1—*continued*

Slide No.	Date Received	100 to 150 m.p.h. band		150 to 200 m.p.h. band		Max. speed (m.p.h. I.A.S.)	Flying Time
		Upward	Downward	Upward	Downward		
150	8-46	1-7	0-5	1-7	0-4	170	h. m. 10-47
151	8-46	1-4	0-1	2-2	0-1	175	10-58
152	8-46	1-4	0-4	1-3	0-5	180	11-03
154	8-46	1-5	0-6	1-6	0-6	185	11-14
155	8-46	1-6	0-6	1-7	0-6	185	10-35
157	8-46	1-7	0-5	1-6	0-6	170	10-31
158	8-46	1-3	0-6	1-2	0-7	170	10-29
159	8-46	1-4	0-0	1-4	0-5	180	10-59
160	8-46	1-6	0-6	1-7	0-1	180	10-48
161	8-46	1-3	0-5	1-4	0-4	185	10-25
162	8-46	1-5	0-5	1-4	0-8	170	10-50
163	8-46	1-3	0-6	1-3	0-4	165	11-24
164	8-46	2-1	0-9	2-3	0-9	175	10-52
165	8-46	1-8	0-5	1-8	0-6	175	10-39
166	8-46	1-5	0-6	1-7	0-7	175	10-41
167	8-46	1-5	0-6	1-5	0-6	175	11-06
168	8-46	1-5	0-6	1-6	0-7	165	10-17
169	5-46	1-7	0-4	1-6	0-4	190	10-16
170	5-46	1-8	0-6	1-8	0-5	175	12-37
171	5-46	1-4	0-3	1-4	0-7	165	10-26

Note: Speeds quoted throughout all tables are I.A.S.

TABLE 2

Maximum and Minimum Accelerations recorded in Speed Bands, and Maximum Speeds (North Atlantic)

Slide No.	Date Received	100 to 150 m.p.h. band		150 to 200 m.p.h. band		Max. speed (m.p.h.)	Flying Time
		Upward	Downward	Upward	Downward		
116	9-45	1-6	0-2	1-6	0-3	175	h. m. 24-41
117	9-45	1-6	0-3	1-7	0-4	175	20-47
118	9-45	1-5	0-3	1-4	0-2	180	24-32
119	9-45	1-7	0-4	1-7	0-4	170	24-53
121	9-45	1-6	0-1	1-6	0-1	190	26-49
123	9-45	1-4	0-6	1-4	0-7	180	21-52
127	9-45	1-7	0-3	1-6	0-4	175	21-53
133	10-45	1-6	0-8	1-5	0-9	170	20-53
137	10-45	1-8	0-0	1-7	0-2	185	20-40
139	10-45	2-1	0-4	2-2	0-3	215	21-48
141	10-45	1-6	0-0	1-5	0-1	180	20-46
143	10-45	1-5	0-4	1-4	0-6	170	20-47
146	10-45	1-7	0-5	1-7	0-6	175	24-10
147	10-45	1-5	0-4	1-7	0-3	180	24-53
148	10-45	1-7	0-0	1-8	0-1	185	20-43
150	10-45	1-5	0-6	1-6	0-7	185	23-51
151	10-45	1-9	0-3	1-8	0-5	180	25-10
153	10-45	1-7	0-3	1-9	0-3	200	24-24
154	10-45	1-9	0-4	2-1	0-2	190	21-54
155	10-45	1-6	0-3	1-8	0-1	190	25-08
156	10-45	1-5	0-4	1-6	0-2	190	22-07
157	10-45	1-7	0-2	1-7	0-1	185	23-41
158	10-45	1-5	0-3	1-6	0-4	185	24-32
159	10-45	1-7	0-4	1-7	0-3	180	25-24
160	10-45	1-7	0-7	1-6	0-7	185	24-05

TABLE 3
*Frequency of Occurrence of Maximum Speeds
 (South Atlantic)*

Speed range (m.p.h. central value)	No. of records
150	1
155	0
160	0
165	6
170	14
175	27
180	12
185	9
190	4
195	3
200	0
205	0
210	0
215	1

TABLE 4
*Frequency of Occurrence of Maximum Speeds
 (North Atlantic)*

Speed range (m.p.h. central value)	No. of records
170	3
175	4
180	6
185	6
190	4
195	0
200	1
205	0
210	0
215	1

TABLE 5
Frequency Distribution of Accelerations (South Atlantic)

	g	Number of records	
		100 to 150-m.p.h. band	150 to 200-m.p.h. band
Upward Accelerations	1.1	0	0
	1.2	3	7
	1.3	14	11
	1.4	21	13
	1.5	13	10
	1.6	8	14
	1.7	10	12
	1.8	4	6
	1.9	0	0
	2.0	1	1
	2.1	3	1
	2.2	0	1
	2.3	0	1
Downward Accelerations	0.9	1	1
	0.8	0	6
	0.7	8	17
	0.6	21	12
	0.5	16	14
	0.4	14	11
	0.3	7	6
	0.2	4	4
	0.1	3	5
	0	3	1

TABLE 6
Frequency Distribution of Accelerations (North Atlantic)

	g	Number of records	
		100 to 150-m.p.h. band	150 to 200-m.p.h. band
Upward Accelerations	1.1	0	0
	1.2	0	0
	1.3	0	0
	1.4	1	3
	1.5	6	2
	1.6	6	7
	1.7	8	7
	1.8	1	3
	1.9	2	1
	2.0	0	0
	2.1	1	1
	2.2	0	0
Downward Accelerations	0.9	0	1
	0.8	1	0
	0.7	1	3
	0.6	2	2
	0.5	1	1
	0.4	7	4
	0.3	7	5
	0.2	2	4
	0.1	1	5
	0	0	0

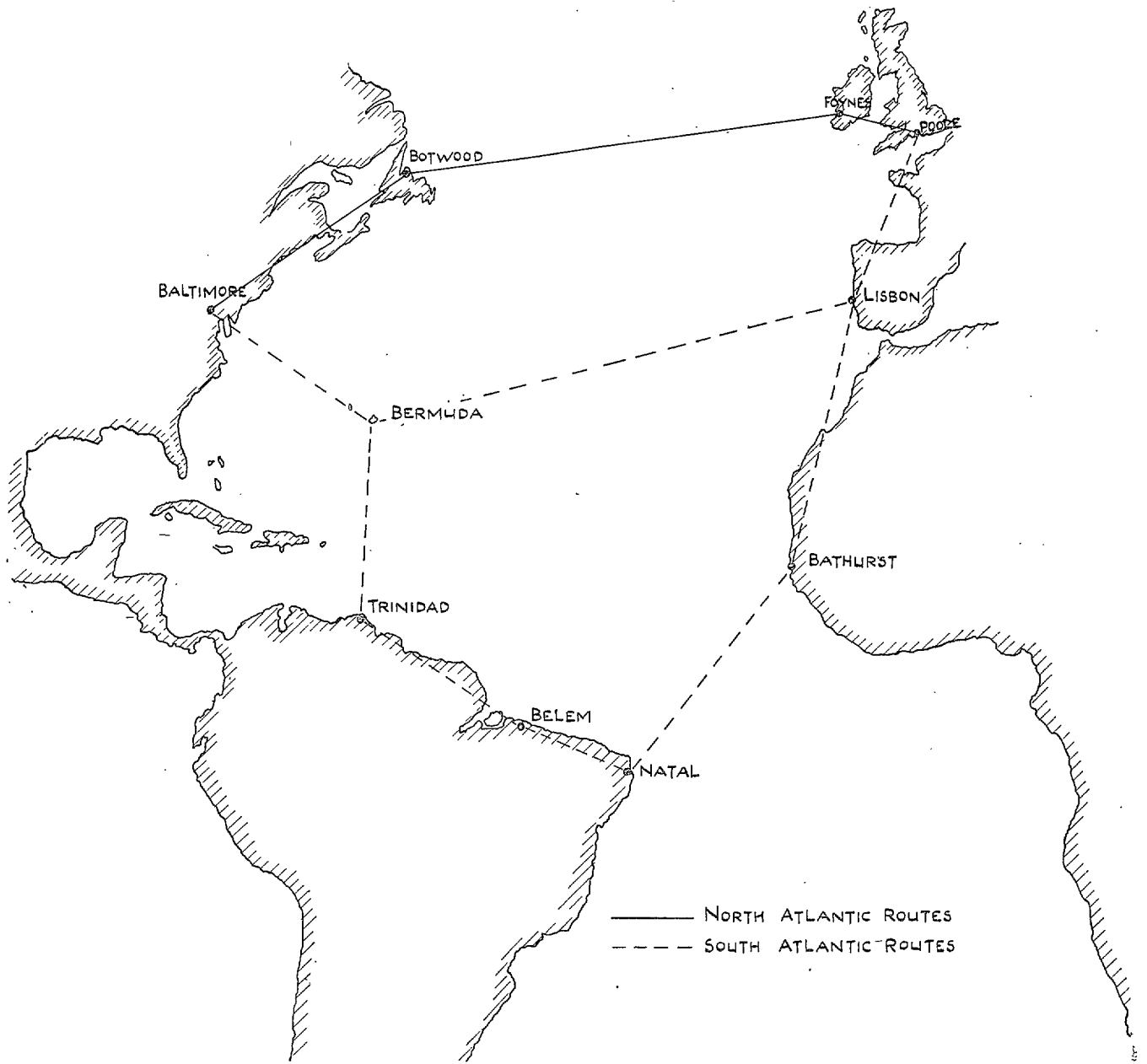
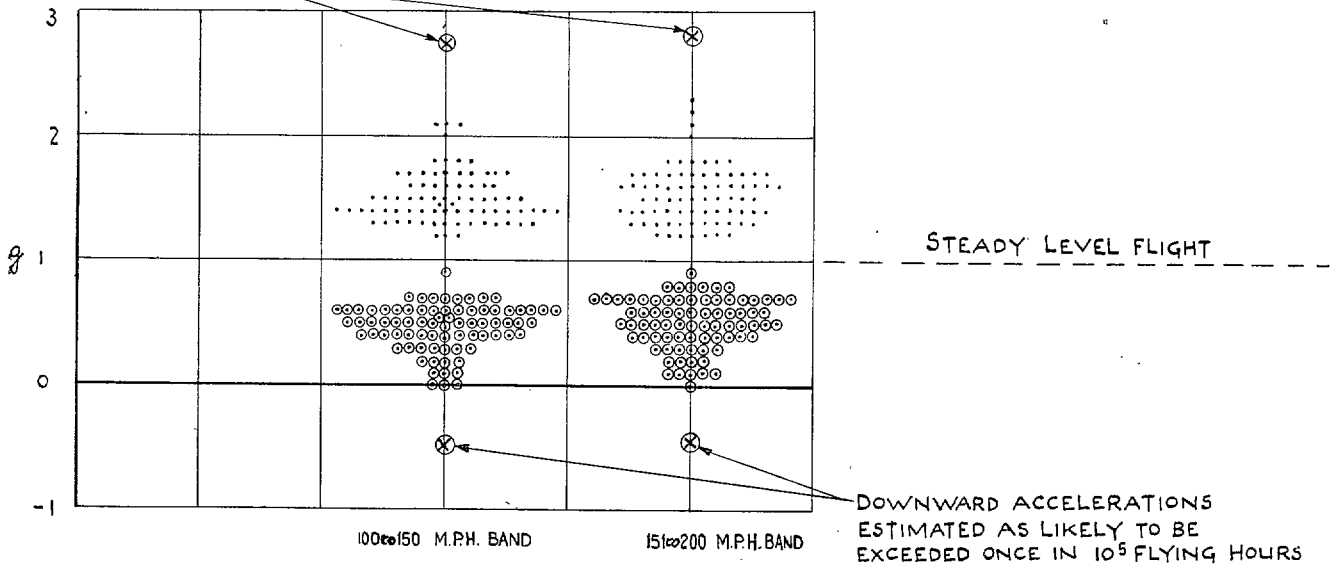


FIG. 1. Sketch map showing routes.

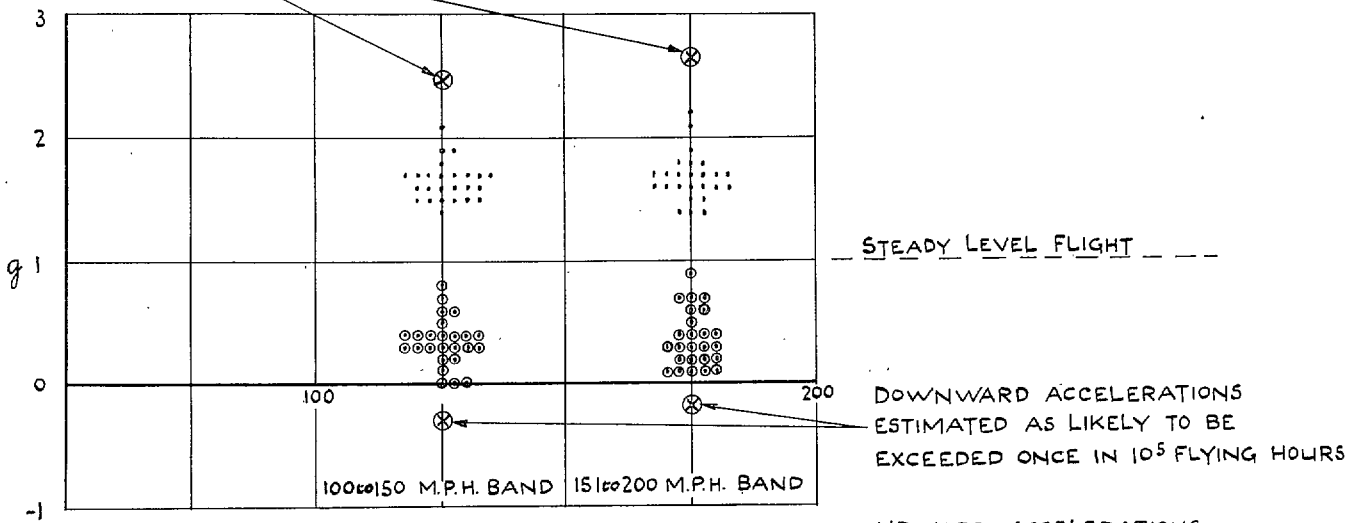
UPWARD ACCELERATIONS ESTIMATED AS LIKELY TO BE EXCEEDED ONCE IN 10^5 FLYING HOURS



• UPWARD ACCELERATIONS
 ⊙ DOWNWARD ACCELERATIONS

FIG. 2. Diagram of recorded accelerations (South Atlantic).

UPWARD ACCELERATIONS ESTIMATED AS LIKELY TO BE EXCEEDED ONCE IN 10^5 FLYING HOURS



• UPWARD ACCELERATIONS
 ⊙ DOWNWARD ACCELERATIONS

FIG. 3. Diagram of recorded accelerations (North Atlantic).

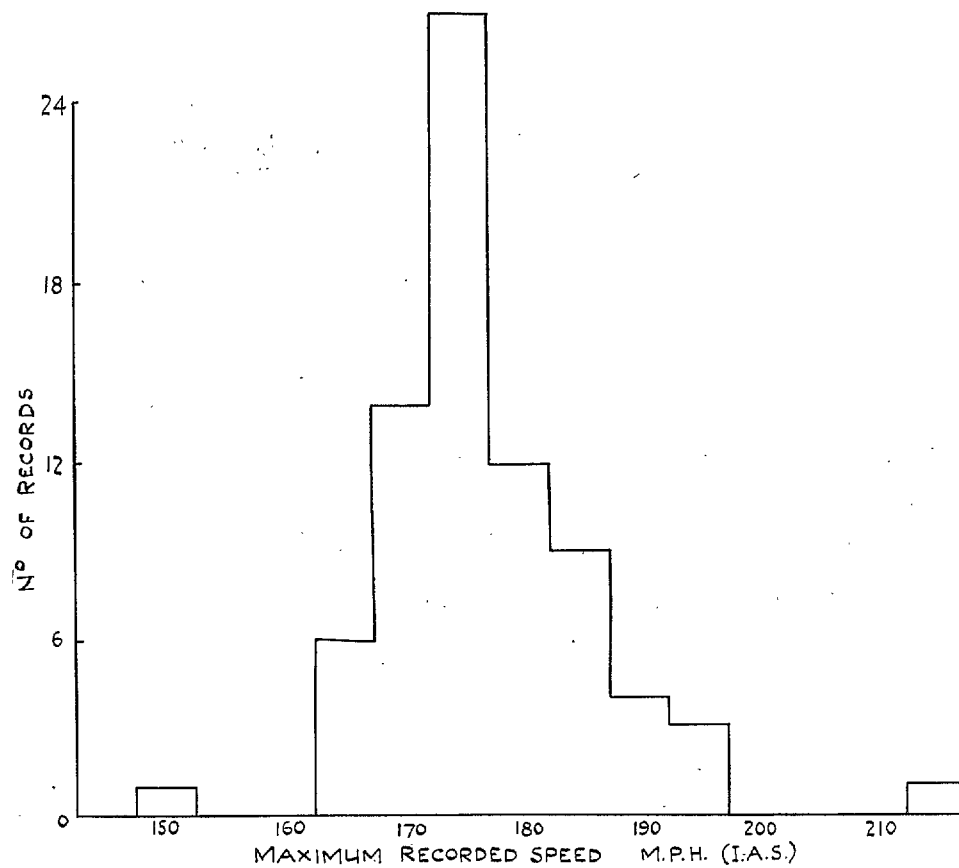


FIG. 4. Frequency distribution of maximum recorded speeds (South Atlantic).

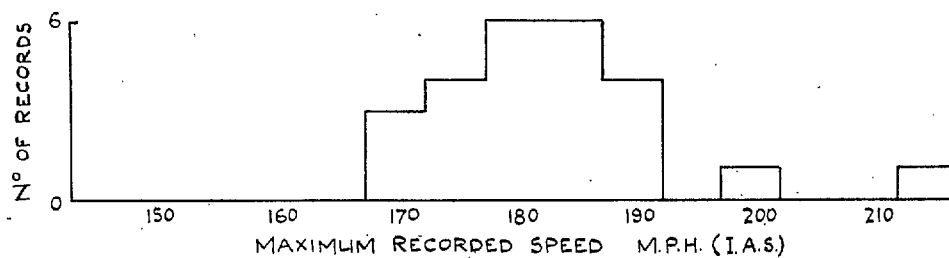
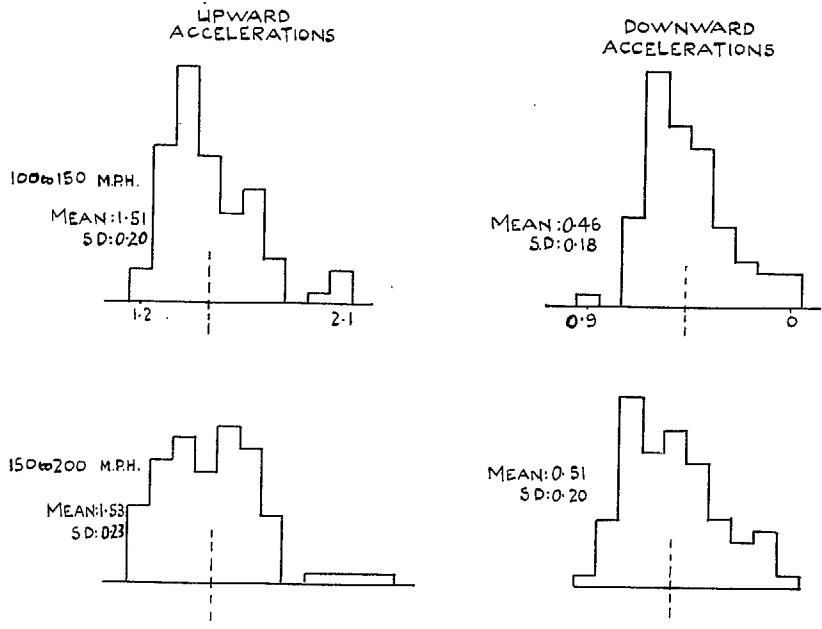


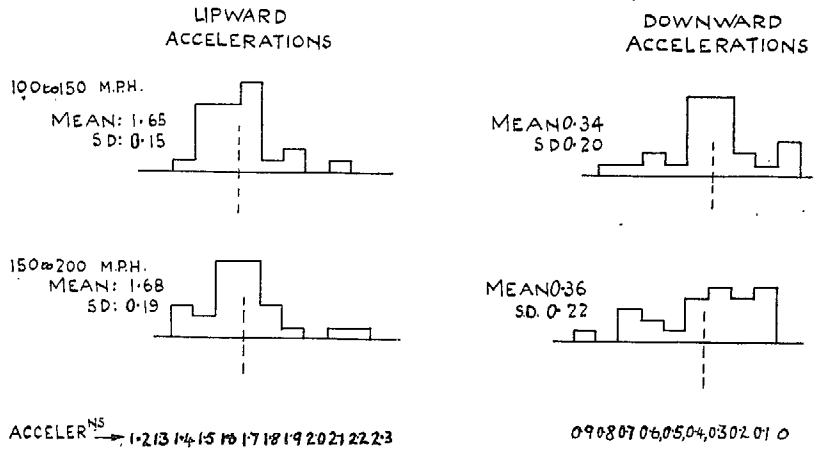
FIG. 5. Frequency distribution of maximum recorded speeds (North Atlantic).

5. ATLANTIC (77 RECORDS)



13

N. ATLANTIC (25 RECORDS)



ACCELER^{NS} → 1.2 13 14 15 16 17 18 19 20 21 22 23

0 9 8 0 7 0 6 0 5 0 4 0 3 0 2 0 1 0

----- POSITION OF MEAN

FIG. 6. Distribution of maximum accelerations (in speed bands).

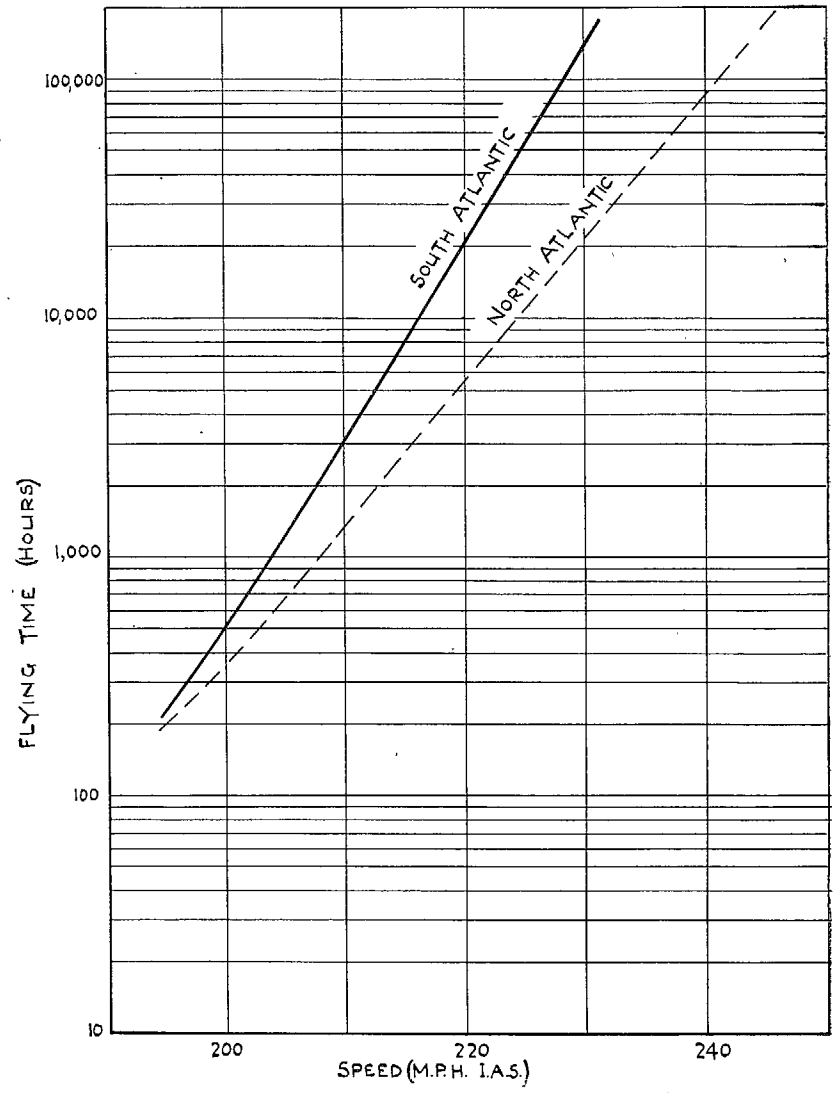


FIG. 7. Estimated time required to exceed a given speed.

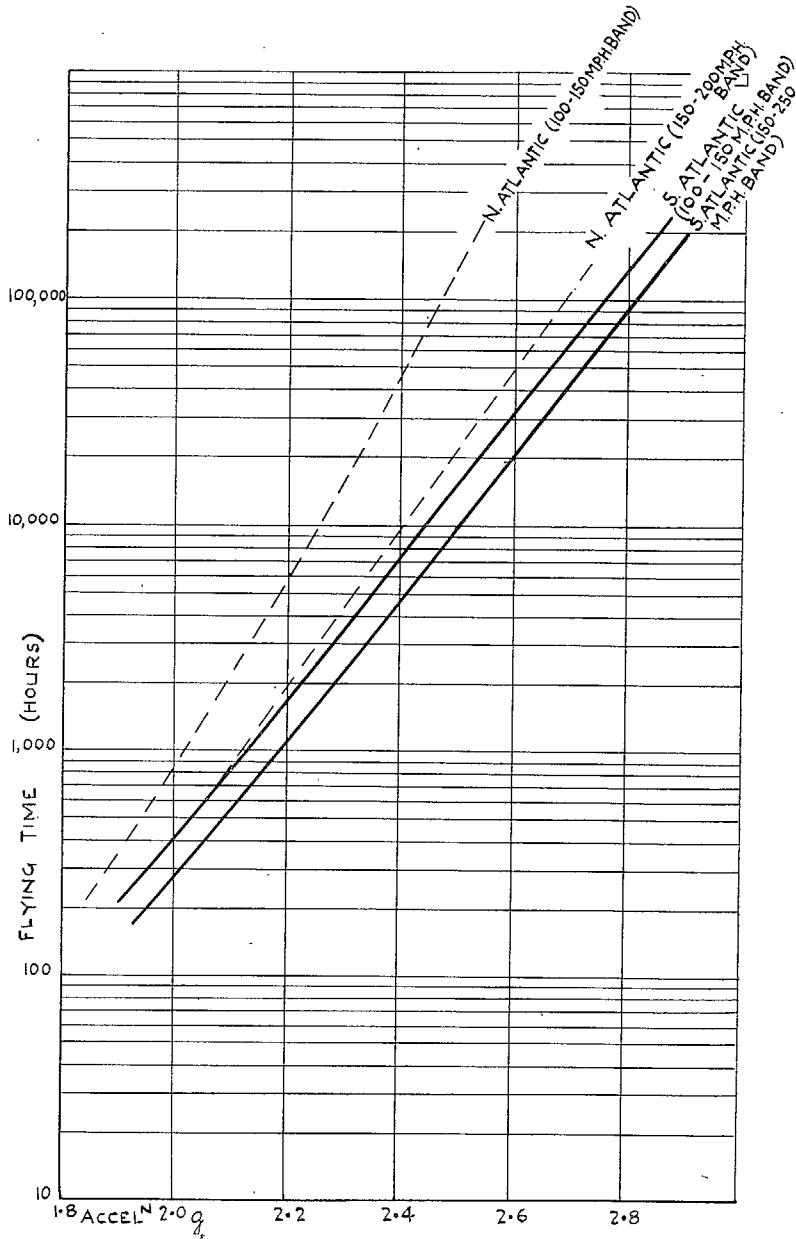


FIG. 8. Estimated time required to exceed a given value of upward acceleration.

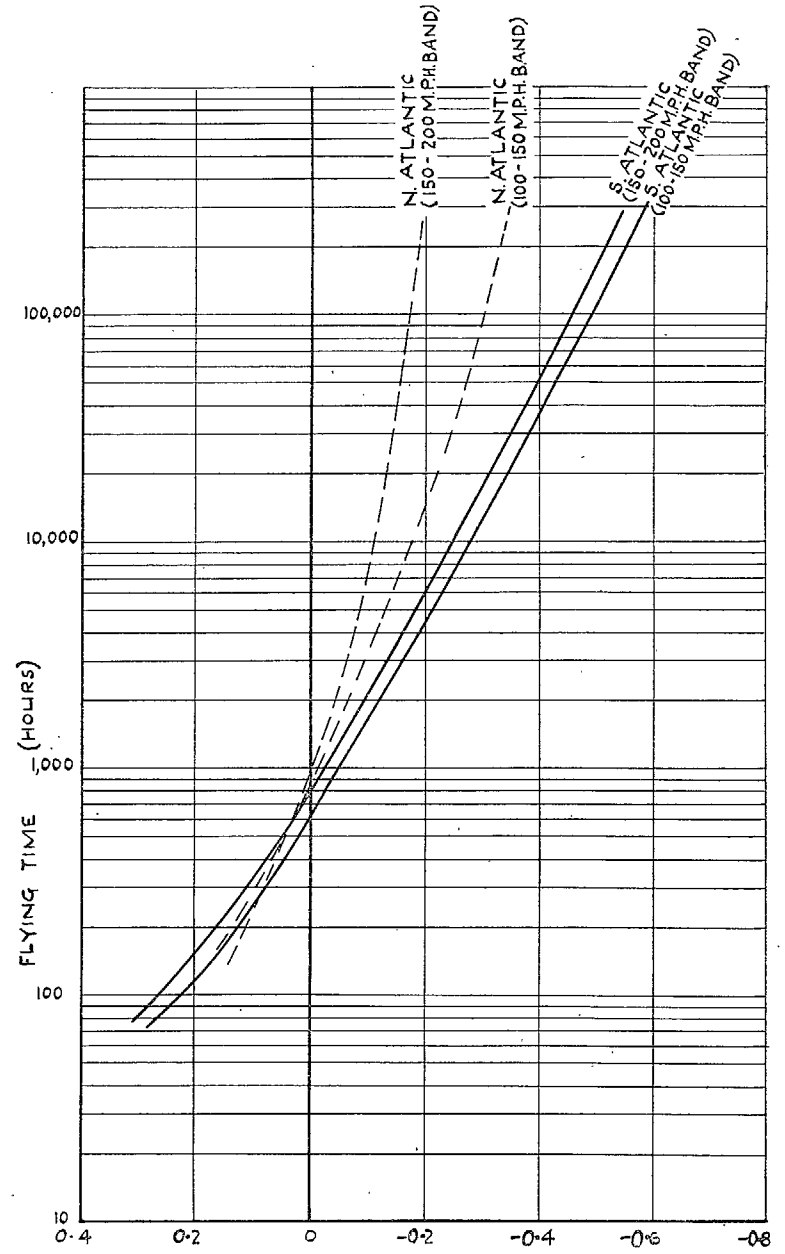


FIG. 9. Estimated time required to exceed a given value of downward acceleration.

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