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A Correlation between Rain Erosion of Perspex Specimens in Flight and on a Ground Rig

by

T. J. Methven and B. Fairhead

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ROYAL AIRCRAFT ESTABLISHMENT

A CORRELATION BETWEEN RAIN EROSION OF PERSPEX SPECIMENS IN FLIGHT AND ON A GROUND RIG

by

T. J. Methven

and

B. Fairhead

SUMMARY

The amount of surface erosion on Perspex has been measured for specimens flown on an aircraft in rain and tested on a whirling arm ground rig in artificial rain. Specimens were compared at 400 knots and similar rain concentrations.

Results show that 1 in/hr rain in flight gives similar erosion to 1.5 in/hr on the ground rig, this may be due to the greater range of droplet sizes found in flight.

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1 INTRODUCTION

1.1 It was required to establish how closely the rain erosion obtained on an R.A.E. ground test rig, compared with that obtained in flight.

2 GROUND TEST APPARATUS

2.1 The apparatus developed (Ref.1) to measure rain erosion properties of aircraft materials consists of a 9 ft 6 in. diameter arm with the erosion samples mounted at the tips. This arm was mounted vertically and could be rotated to give tip speeds of up to 480 knots. The erosion samples made in the form of hollow cylinders, 1.45 in. or 2.9 in. long and 1.85 in. diameter (Fig.1) were bolted to each side of the tip with their longitudinal axis at right angles to the plane of rotation. 1 in./hr artificial rain was produced by feeding 8.5 gal/hr of water on to a 2 ft 4 in. diameter disc rotating at 160 r.p.m. in a plane parallel to that of the arm's rotation. Drop sizes varying from 0.6 to 3.0 mm were obtained with a predominance of 2 mm diameter drops (50% of total volume between 1.85 mm and 2.20 mm). The drop sizes were assessed by catching the drops on filter paper dusted with Rhodamine dye, and the rate of rainfall was also measured. All the droplet measurements were made close to the samples with the rig operating.

3 FLIGHT TEST APPARATUS

3.1 The erosion test specimens were supplied by R.A.E. and were the same type as used on the whirling arm rig. The specimens were mounted on a bar projecting through the nose of a Meteor 8, as shown in Fig.2. The mounting was designed for three long or six short specimens to be carried each side of the nose, with the inboard specimens nine inches from the fuselage.

3.2 An aluminium foil apparatus (Ref.2) was designed and installed in the nose of the aircraft to measure the rainfall, the drops hitting the foil through a $\frac{3}{4}$ in. by $\frac{3}{8}$ in. aperture, see Fig.3. This instrument consisted of three spools; a free running feed spool with a friction pad to prevent over-running, a free running drum faced with 400 mesh phosphor bronze gauze, and a take up spool belt driven by a 3 r.p.m. actuator motor. The aluminium foil, 1 in. wide 0.001 in. thick passed over the 400 mesh gauze spool just behind the aperture in the aircraft nose, so that each raindrop striking the foil imprinted a mark of the mesh in it. From previous calibration, (Ref.2), the size of the raindrop could be calculated from the size of the imprint. From the speed of the foil 2.2 in. per second, and the speed of the aircraft, 400 knots, the concentration of the rain could also be calculated.

3.3 During the initial flights several breakages of the foil occurred, usually by tearing due to the air entering the nose aperture. Modifications, to overcome this trouble included the fitting of a solenoid operated shutter. A warning system was fitted, operated by a micro switch actuated by four hollows on the feed spool, and also by a microswitch operated by the shutter solenoid, so that satisfactory operation resulted in a light flicking on and off in the cockpit.

3.4 As an alternative method of recording rain concentration, a 1 in. diameter pitot collector tube was mounted on the starboard side of the erosion specimen bar (Fig.2). The rain entered the horizontal pitot section of the tube and was then stored in a vertical section of tube; a valve at its base enabled the water collected to be measured after each flight.

4 DESCRIPTION OF FLIGHT TESTS

4.1 Three pairs of samples of different materials were tested in the initial flights, onazote, glass cloth laminate and Perspex. The onazote samples eroded rapidly during the first flight, one sample disappearing completely. These two samples were therefore replaced with four Perspex samples each half the length of the previous samples, these were labeled 2 and 3 port, and 2 and 3 starboard. The glass laminate samples also eroded rapidly and unevenly due to lifting of the glass cloth layers. Four to five layers, equivalent to a depth of 0.04 to 0.05 in. were eroded before these samples were removed and replaced by a further four Perspex specimens. The new Perspex specimens were numbered 4 and 5 port, and 4 and 5 starboard. All the Perspex samples were now weighed and mounted on the aircraft in numerical order with the number one samples outboard. Flights were then made, and the samples were weighed at frequent intervals to determine the weight loss due to erosion. These weights have been listed in Table 1 as percentages of the original specimen weight.

4.2 All the flights were made at 400 knots at an altitude of approximately 1000 ft, and where possible consisted of a series of runs in rain beneath a single cloud. The foil indicator was operated continuously while the aircraft was in rain, the time of exposure being noted by the pilot. The pitot tube rain collector was fitted for the later flights, and the total water collected in each flight was measured after landing. The sequence of flights, together with actual and calculated flight times are listed in Table 1. The method of calculating the latter times is described in the following paragraphs.

5 ANALYSIS OF RESULTS

5.1 The analysis of the foil records by measuring the diameter and number of drops (Ref.2) gave the rain conditions to which the specimens had been exposed. These conditions were examined in detail for the first flight for which a foil record was obtained. This flight, Number 6, consisted of seven runs under the same cloud, and the drop size distribution for each run has been plotted in Fig.4. The variation of rain concentration through each run has been plotted in Fig.5. For subsequent flights the individual runs were ignored since the rain concentration varied in a very random manner, hence the rain drop sizes and concentration were only considered for the flight as a whole. The drop size, volume distribution for these flights are shown in Fig.6; the volume median diameter of the rain varied from 1.7 mm to 3.3 mm but in all rain, drops of 4 mm diameter were encountered. Natural rain distributions of Ref.3 and the artificial rain distribution on the ground rig, Ref.4, are shown in Fig.7. It can be seen that the natural rain distributions of 1 in. and 2 in./hr rainfall have a volume median diameter of 2.2 and 2.5 mm respectively with some 10% of the volume in drops of 4 mm and larger, whereas the artificial rain has a volume median of 2 mm but contains no drops larger than 3.2 mm diameter.

5.2 The pitot tube rain collector introduced in the later flight tests was also used to estimate the rain concentration. The volumes of rain collected are included in Table 1, and plotted against the corresponding volumes collected on the foil recorder in Fig.8.

5.3 In order to compare the flight results with those obtained on the ground rig the flight times in rain had to be corrected to the equivalent flight times in 1 in./hr rain. The method of determining this correction is given in Appendix 1, and the values obtained are given in Table 1. For flights 13 and 14 where only the quantity of water caught in the pitot tube was recorded, the catch was reduced to the equivalent catch on the foil recorder, from Fig.8. The drop size was then assumed to be 2 mm diameter, and the equivalent time in 1 in./hr calculated. The drop size was also assumed to be 2 mm diameter for flight Number 8 where no analysis of the drop size spectrum was made. To obtain an estimate of time in 1 in./hr rain for the remaining flights where no measurements of rain concentration were obtained, the total time in 1 in./hr rain for flight 6, and 8 to 18 was divided by the total flight time for these flights. This gave one minutes actual flight time equal to 0.133 minutes in 1 in./hr rain.

5.4 A correction also had to be applied to the ground test erosion curves for Perspex, given in Ref.4, to reduce them from 435 knots (500 m.p.h.) to 400 knots, the flight test speed. The method used to obtain this correction is given in Appendix 2. Corrected curves for 1 in./hr, 1½ in./hr and 2 in./hr, together with the flight erosion curve for the number one samples are given in Fig.9. Flight erosion curves are also given in Figs. 10 and 11, but only the corrected 1½ in./hr ground test curves has been included in these figures.

6 DISCUSSION OF RESULTS

6.1 The curves of rain drop size distribution obtained from the flight tests (Figs. 4 and 6) show a general similarity to curves obtained for natural rain from Ref.3 (Fig.7). All these drop distributions differ from the artificial rain produced on the ground rig (Fig.7) in that natural rain has a far greater range in drop size. The presence of a number of drops larger than 2 mm diameter in natural rain may well account for the large discrepancy in erosion rates between flight and ground tests shown in Figs. 9, 10 and 11. It can be seen from these figures that the erosion in flight in 1 in./hr rain is equivalent to erosion on the ground rig in 1½ in./hr rain.

6.2 It can be seen from Fig.11 that an increase in weight occurred on samples 4 and 5 after flying in rain. This was probably due to water absorption of the Perspex and was not evident on the other specimens as they were all flown in rain before being weighed. After flying in equivalent 1 in./hr rain for 15 minutes the Number 4 and 5 port and starboard specimens were reversed and flown for a further 4.9 minutes in 1 in./hr rain. An increase in weight again occurred, indicating that previous exposure to a damp atmosphere does not affect the water absorption properties of Perspex. It is not considered that this weight gain materially affects the analysis of the results, as both flight and ground test specimens were subject to water absorbtion, and in any case the proportion of weight gain to total erosion loss was generally small.

6.3 A comparison of the areas of erosion on the flight and ground test specimens shows very good agreement. The mean flight test angles of erosion were 76° for the maximum, and 96° for the overall erosion. The corresponding angles for the ground rig tests were 73° and 93°. This difference in flight and ground test angles is negligible and could be accounted for by errors in measurement and in obtaining a true mean value. Photographs of the flight specimens are shown in Fig.12.

7 CONCLUSIONS

7.1 Comparitive tests of Perspex samples on the ground and in flight has indicated heavier erosion in flight. The erosion from exposure to 1 in./hr rain in flight has been found to equal erosion from 1½ in./hr rain on the ground test rig. The most probable cause of this difference is the existence of a greater proportion of large rain drops in the natural rain.

7.2 Water absorption of Perspex specimens has given an increase in specimen weight after exposure to rain. An attempt to cure this effect by exposing the specimens to rain erosion conditions before commencing on actual test was unsuccessful.

7.3 The areas of erosion were found to be similar for flight and ground tests.

7.4 Suitable isolated rain showers do not occur very frequently in the U.K.; only 18 flights were made in the year: the flights involved a considerable amount of risk and discomfort for the pilots who had to fly straight and level at 400 knots at 1000 ft with no forward vision.

7.5 The highest rain concentration measured by the foil was 6.25 gm/m^3; the rain showers were very variable in intensity.

LIST OF REFERENCES

Ref No.	Author(s)	Title, etc.
1	Fyall, A. A., Strain, R. N. C.	The "Whirling Arm" test rig for the assessment of the rain erosion of materials. ARC.19,412 December, 1956.
2	Bigg, F. J., Methven, J., McNaughton, I. I.	The measurement of rain from an aircraft in flight. Unpublished ARC Report September, 1956.
3	Laws, J. C., Parsons, D. A.	Relation of raindrop size to intensity. Trans. Amer. Geophys. Union 1943 Part II page 457.
4	Fyall, A. A., King, R. B., Strain, R. N. C.	Rain erosion Part III. A gravimetric assessment of the erosion resistance of various materials. ARC.20,075 September, 1957.

APPENDIX 1

CONVERSION OF FLIGHT RAIN RECORDS TO EQUIVALENT 1 IN./HR RAINFALL

Considering an area of 1 sq ft exposed to 1 in/hr rainfall, then 1/12 cu ft of rain will collect on this area in one hour. Assuming the rain consists of drops of a uniform size falling with a velocity V_T ft/sec, then the 1/12 cu ft of rain would have been distributed in a column of air 1 x 1 x $3600V_T$ cu ft giving a concentration of

$$\frac{1}{12} \times \frac{1}{3600V_T} \text{ cu ft of water/cu ft of air}$$

$$= \frac{23.2}{V_T} \text{ grm of water/cu metre of air.}$$

Considering now the rain recorder, the volume of air swept out by the 0.75 in. by 0.375 in. aperature at 400 knots will be 2.25 cu metre/min.

Therefore the recorder collection rate in 1 in/hr rain will be

$$\frac{23.2}{V_T} \times 2.25 \text{ grm/min}$$

or $\frac{V_T}{23.2 \times 2.25}$ minutes will be required to collect 1 grm of water in 1 in/hr rain.

As shown in Table 2 there was a considerable range in rain drop size for the flight tests, therefore in assessing the equivalent time in 1 in/hr rain, each size range was taken separately. e.g. for flight No.6, (Table 2) the equivalent time in 1 in./hr rain contributed by the $\frac{1}{2}$ to 1 mm drops was

$$\frac{0.8}{100} \times \frac{2955}{1000} \times \frac{V_T}{23.2 \times 2.25} \text{ min.}$$

Assuming a mean drop size of 0.75 mm dia, then $V_T = 12$ ft/sec see Table 3. Considering the other ranges of drop size the total equivalent time in 1 in/hr rain for flight No. 6 is given by

$$T = \frac{2955}{23.2 \times 2.25} \times 10^{-5} \begin{Bmatrix} 0.8 \times 12 + 6.1 \times 15 + 17.2 \times 18 + 25.8 \times 21 \\ + 22 \times 23 + 15.4 \times 24 + 10.4 \times 25 + 2.3 \times 25 \end{Bmatrix}$$

$$= \underline{\underline{1.725}} \text{ min.}$$

For the flights where the total quantity of rain, but not the size distribution was measured the rain was assumed to be of a constant drop size of 2 mm dia, this gave 1 grm of water catch equal to 0.37 mins flight in 1 in/hr rain. This compares closely with an average value of 1 grm of water catch equal to 0.43 mins flight, for the flight analysed on the drop size basis.

APPENDIX 2

THE CORRECTION OF GROUND RESULTS GIVEN IN REFERENCE 4 TO EQUIVALENT FLIGHT CONDITIONS

In Reference 4 the erosion tests were made at 300,400 and 500 m.p.h., from which a velocity-erosion relationship of

$$R = 3.86 \times 10^{-6}(V - 208)^{3.37}$$

was obtained for erosion in 1 in/hr rain. Where R was the erosion rate in mm^3/cm^2 h, and V the velocity in m.p.h. Using this equation for the 400 knots (460 m.p.h.) flight case, a value of 485 mm^3/cm^2 h was obtained for R, this is 0.618 of R for 500 m.p.h.

Reference 4 also stated that the rate of erosion on Perspex was directly proportional to the rate of rainfall, the speed correction should therefore apply to the rates of rainfall considered in the ground tests viz, 1, 2 and 3 in/hr.

To obtain erosion curves for intermediate rates of rainfall the values of R at 500 m.p.h. for 1, 2 and 3 in/hr rain were multiplied by the speed factor 0.618 and plotted against rate of rainfall. This gave the slope of the linear portion of the weight loss, erosion time curve for any rate of rainfall up to 3 in/hr. The position of the curves was determined by the intercept of the linear curve on the time axis. These were first obtained from the ground tests by plotting the values for 300, 400 and 500 m.p.h. and interpolating to obtain the intercept for 400 knots (460 m.p.h.) at 1 in/hr rainfall. The intercepts for 2 in/hr and 3 in/hr at 400 knots were taken in the same proportion as for 500 m.p.h., the only ground speed over which the rate of rainfall were varied. Thus a linear curve of weight loss against erosion time could be plotted. The initiation times for the various rates of rainfall were obtained by first plotting the ground times for the three speeds of 300, 400 and 500 m.p.h., to obtain an interpolated value for 400 knots at 1 in/hr rainfall. The initiation periods for the other rates of rain fall were taken to be proportional to those at 500 m.p.h. The Reference 4 curves for erosion at different rates of rainfall all appeared to depart from the linear relationship below approximately 1.25% weight loss for the 500 m.p.h. ground case, and this was assumed to apply also to the 400 knot cases.

The speed corrected erosion curves for 1 in/hr, $1\frac{1}{2}$ in/hr and 2 in/hr are plotted in Fig.9.

TABLE 1

A RECORD OF RAIN EROSION FLIGHTS MADE WITH METEOR VT 150

Flight No.	Date	Flight time in rain min	Rain catch on foil ccs	Rain catch in pitot tube ccs	Running total of sample exposure time to the equivalent of 1 in/hr rain - minutes					Percentage weight loss — Sample number									
					Onazote	Glass Laminate	Perspex No.1	Perspex 2 & 3	Perspex 4 & 5	1 Port	1 Stbd	2 Port	2 Stbd	3 Port	3 Stbd	4 Port	4 Stbd	5 Port	5 Stbd
1		4	Not measured	Not fitted	0.53	0.53	0.53	Not fitted	Not fitted										
2		5	" "	" "	Not fitted	1.19	1.19	0.66	" "										
3		5	" "	" "	" "	1.85	1.85	1.32	" "										
4	30/ 7/56	1	" "	" "	" "	1.98	1.98	1.45	" "										
5	10/ 8/56	5	" "	" "	" "	2.64	2.64	2.11	" "										
6	24/ 8/56	6	2.955	" "	" "	4.37	4.37	3.84	" "										
7	3/10/56	8	Not measured	" "	" "	Not fitted	5.43	4.90	1.06										
8	Two flights 4/10/56	22	8.347	" "	" "	" "	8.51	7.98	4.14	0.164	0.204	(Gain) 0.009	0.023	0.014	(Gain) 0.021	(Gain) 0.250	(Gain) 0.267	(Gain) 0.255	(Gain) 0.242
9	5/10/56	7.5	8.456	" "	" "	" "	13.58	13.05	9.21										
10	24/10/56	15.5			" "	" "				0.745	0.759	0.392	0.405	0.439	0.302	(Gain) 0.062	(Gain) 0.063	(Gain) 0.057	(Gain) 0.036
11	30/10/56	8	2.109	" "	" "	" "	14.30	13.77	9.93	1.133	1.180	0.717	0.683	0.823	0.560	0.087	0.084	0.108	0.153
12	12/11/56	5.5	2.366	" "	" "	" "	15.28	14.75	10.91										
13	25/ 1/57	18	Records	5.0	" "	" "	15.93	15.40	11.56										
14	25/ 1/57	15	unreadable	2.0	" "	" "	16.18	15.65	11.81										
15	20/ 3/57	15	2.869	7.0	" "	" "	17.28	16.75	11.91	1.720	1.71	1.26	1.06	1.33	0.960	0.525	0.345	0.490	0.465
16	10/ 7/57	5	2.839	11.5	" "	" "	18.49	17.96	13.12	2.48	2.37	1.99	1.72	2.09	1.52	1.03	0.76	0.96	0.91
17	12/ 7/57	20	8.625	19.0	" "	" "	21.81	21.28	3.32	3.95	3.90	3.64	2.91	3.62	2.65	(Gain) 0.54	(Gain) 0.028	0.49	(Gain) 0.013
18	13/ 8/57	10	4.040	13.0	" "	" "	23.36	22.83	4.67	4.97	4.77	3.98	3.20	3.93	2.97	(Gain) 0.008	(Gain) 0.008	0.016	0.009

TABLE 2

Rain drop diameter spectras obtained from various flights in rain

Drop Diameter mm	$\frac{1}{2}$–1	1–$1\frac{1}{2}$	$1\frac{1}{2}$–2	2–$2\frac{1}{2}$	$2\frac{1}{2}$–3	3–$3\frac{1}{2}$	$3\frac{1}{2}$–4	Above 4	Total Number	Total Volume
Percentage Number of Drops / Percentage Volume of Drops										
Flight No. 6	16.2 / 0.8	25.3 / 6.1	25.9 / 17.2	18.4 / 25.8	8.5 / 22.0	3.6 / 15.4	1.6 / 10.4	0.3 / 2.3	691	2955
9 and 10	3.2 / 0.7	13.7 / 1.3	17.3 / 4.8	21.8 / 12.7	18.9 / 18.5	10.9 / 19.3	6.8 / 18.5	7.4 / 24.2	623	8456
11	51.2 / 9.6	30.6 / 26.6	13.1 / 31.3	4.2 / 21.2	0.6 / 5.5	0.2 / 3.1	0.07 / 1.7	0.03 / 1.0	2675	2109
12	7.2 / 0.4	32.8 / 8.3	35.4 / 23.9	16.2 / 23.4	3.7 / 9.9	1.2 / 5.3	1.0 / 6.8	2.7 / 22.0	597	2366
15	25.8 / 2.3	36.5 / 15.0	22.7 / 25.8	9.7 / 23.3	2.4 / 10.4	2.5 / 18.0	0.3 / 3.7	0.1 / 1.5	893	2869
16	8.9 / 0.4	38.8 / 8.2	25.8 / 15.3	12.1 / 15.1	5.5 / 12.6	3.7 / 14.1	2.0 / 11.7	3.2 / 22.6	495	2839
17	56.4 / 7.1	21.7 / 12.5	13.8 / 22.0	1.7 / 5.9	4.6 / 27.0	0.9 / 9.6	0.5 / 8.6	0.4 / 7.3	4371	8625
18	22.1 / 1.8	32.8 / 12.1	32.7 / 33.0	6.5 / 13.8	2.5 / 9.7	1.9 / 12.3	1.0 / 10.4	0.5 / 6.9	1053	4040

TABLE 3

Mean terminal velocities

Size range. mm	$\frac{1}{2}$-1	1-1$\frac{1}{2}$	1$\frac{1}{2}$-2	2-2$\frac{1}{2}$	2$\frac{1}{2}$-3	3-3$\frac{1}{2}$	3$\frac{1}{2}$-4	Above 4
Mean size mm	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4
T.V of mean size ft/sec	12	15	18	21	23	24	25	251

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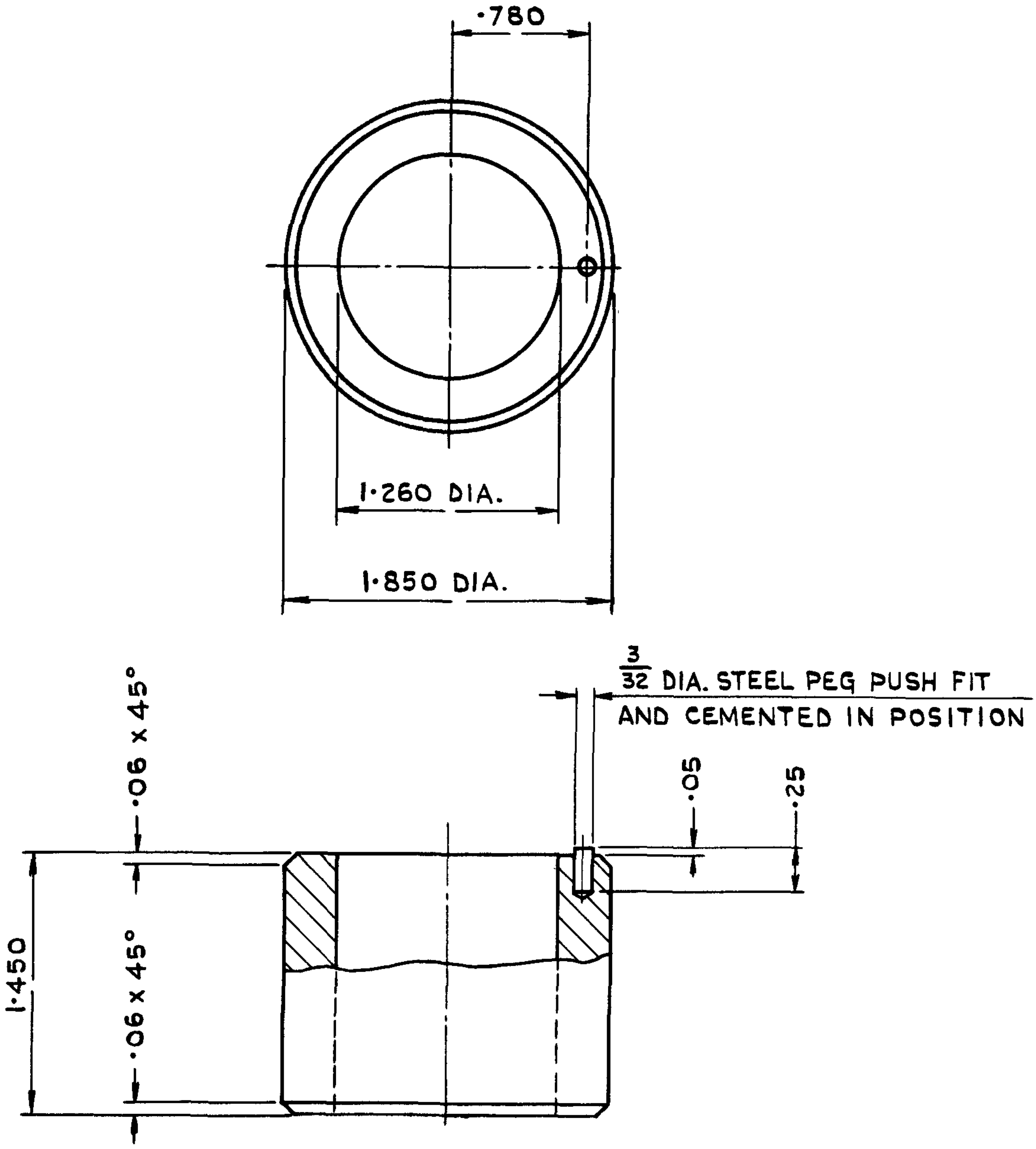
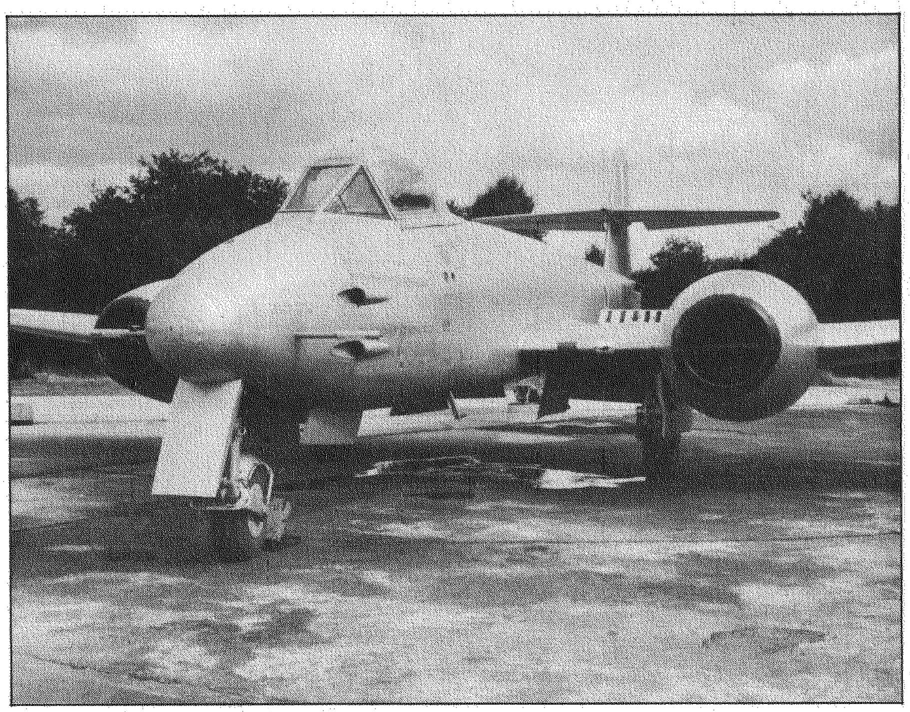
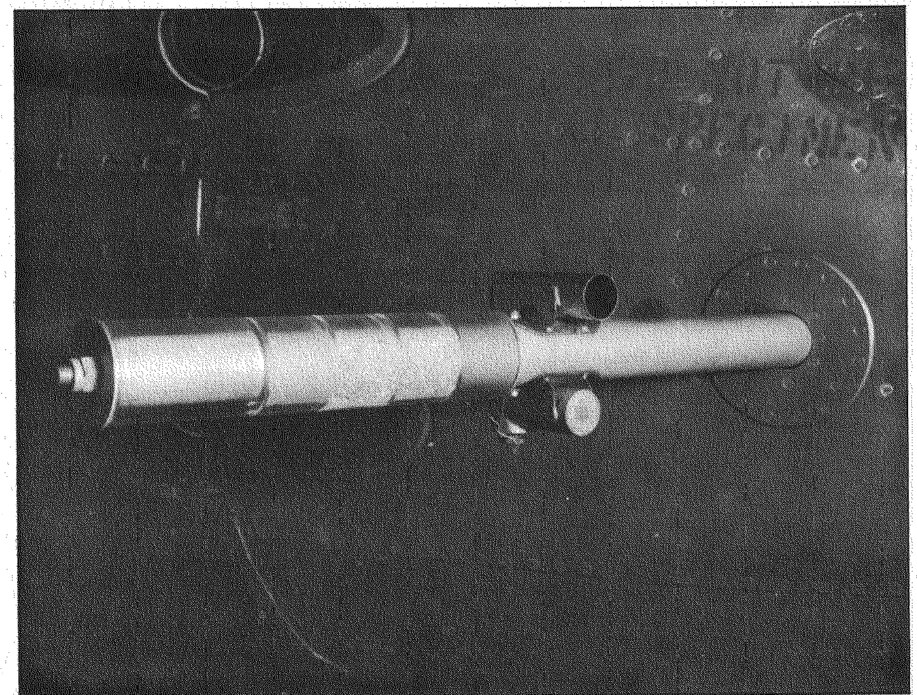


WEIGHT (MAX.) -- ·127 LB.

FIG.1. TEST SPECIMEN (SHORT).

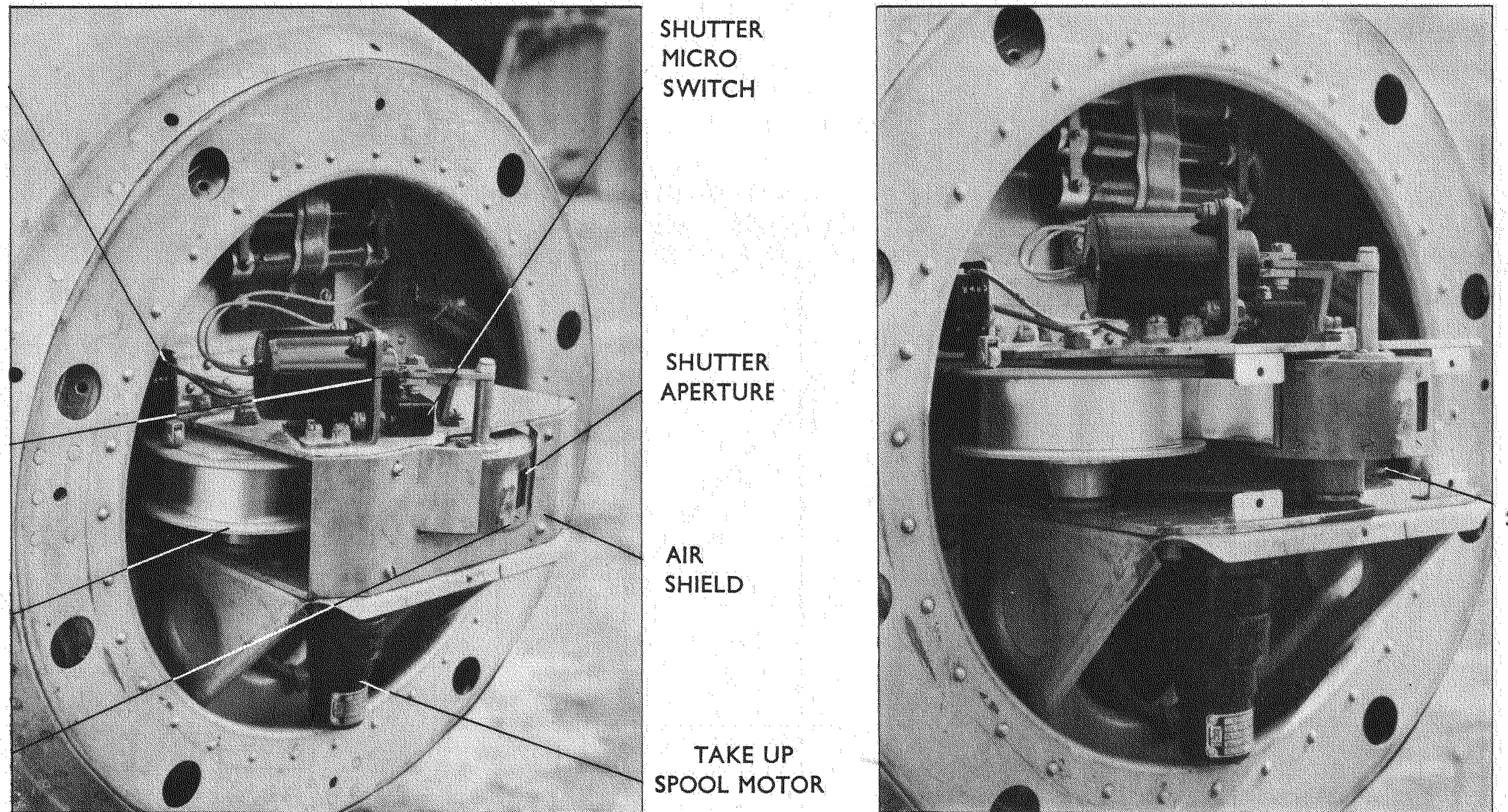


PERSPEX SAMPLES MOUNTED ON BAR THROUGH METEOR NOSE



CLOSE-UP OF SAMPLE MOUNTING ON STARBOARD SIDE
SHOWING THE PITOT TUBE RAIN COLLECTOR

FIG.2. RAIN EROSION SAMPLE MOUNTING ON METEOR VT. 150



RECORDER WITH AIR SHIELD IN POSITION

RECORDER WITH AIR SHIELD REMOVED

FIG.3. ALUMINIUM FOIL RAIN RECORDER MOUNTED IN THE NOSE OF METEOR VT. 150

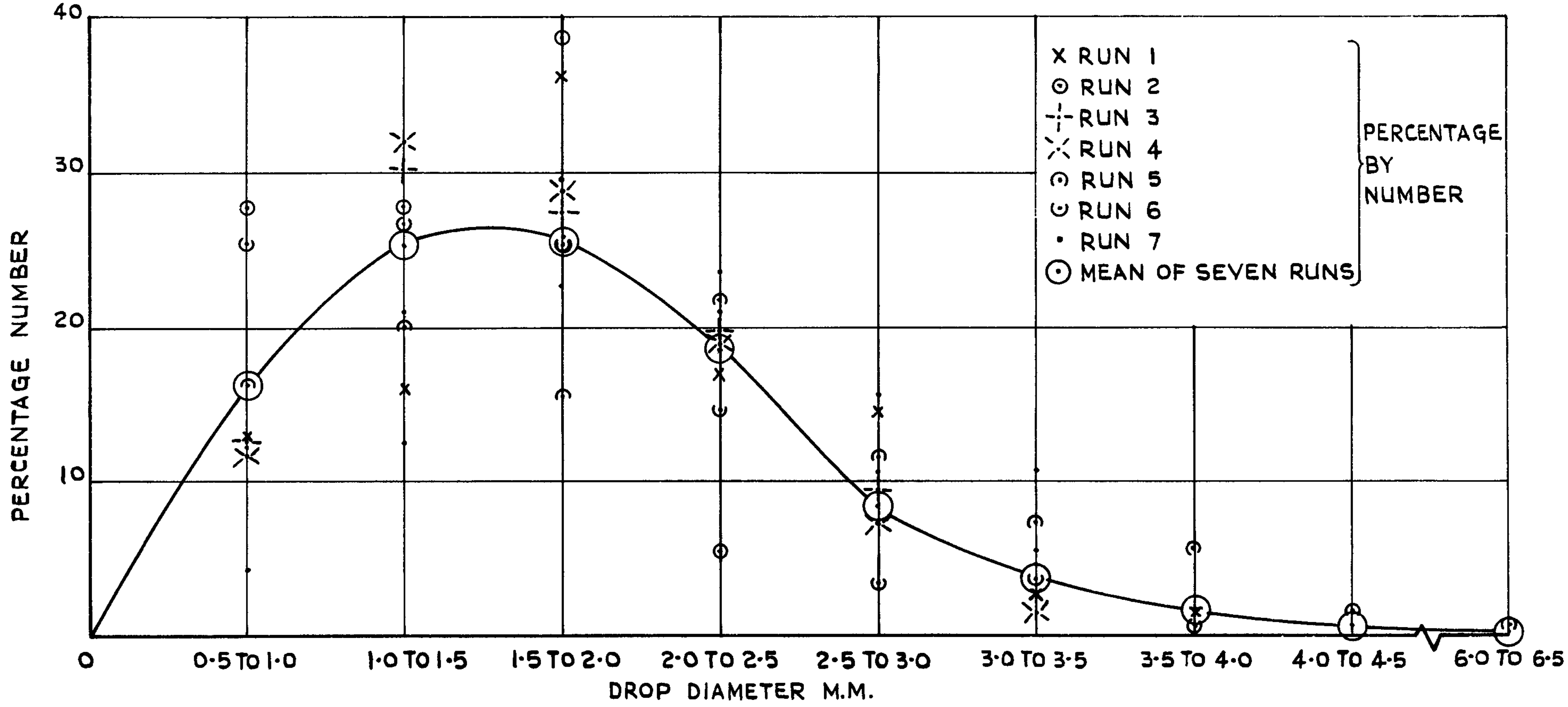


FIG.4. RANGE OF RAIN DROP SIZES OBTAINED ON FLIGHT 6.

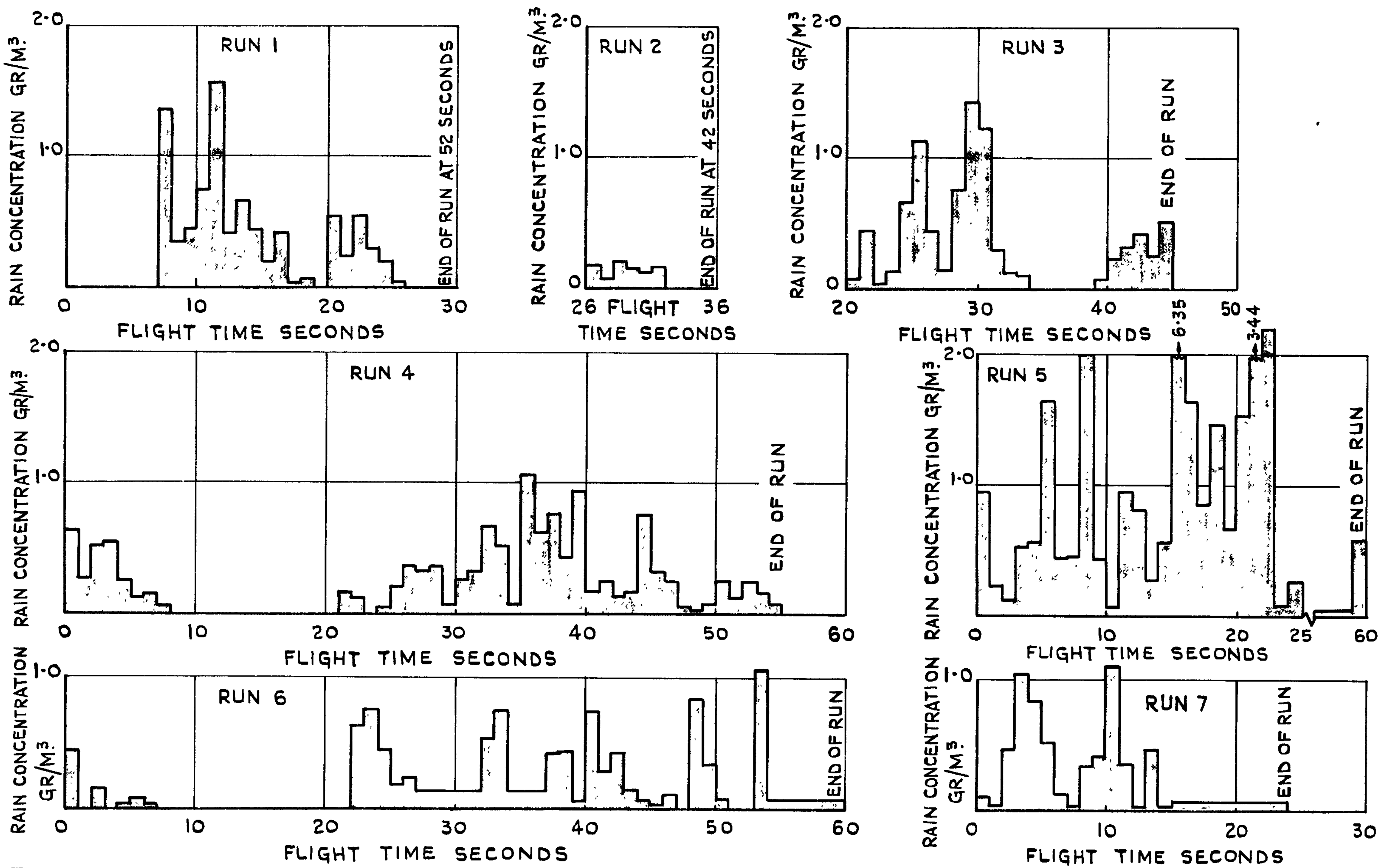


FIG.5. VARIATION OF WATER CONCENTRATION OBTAINED ON DIFFERENT RUNS THROUGH THE SAME RAIN FLIGHT Nº 5.

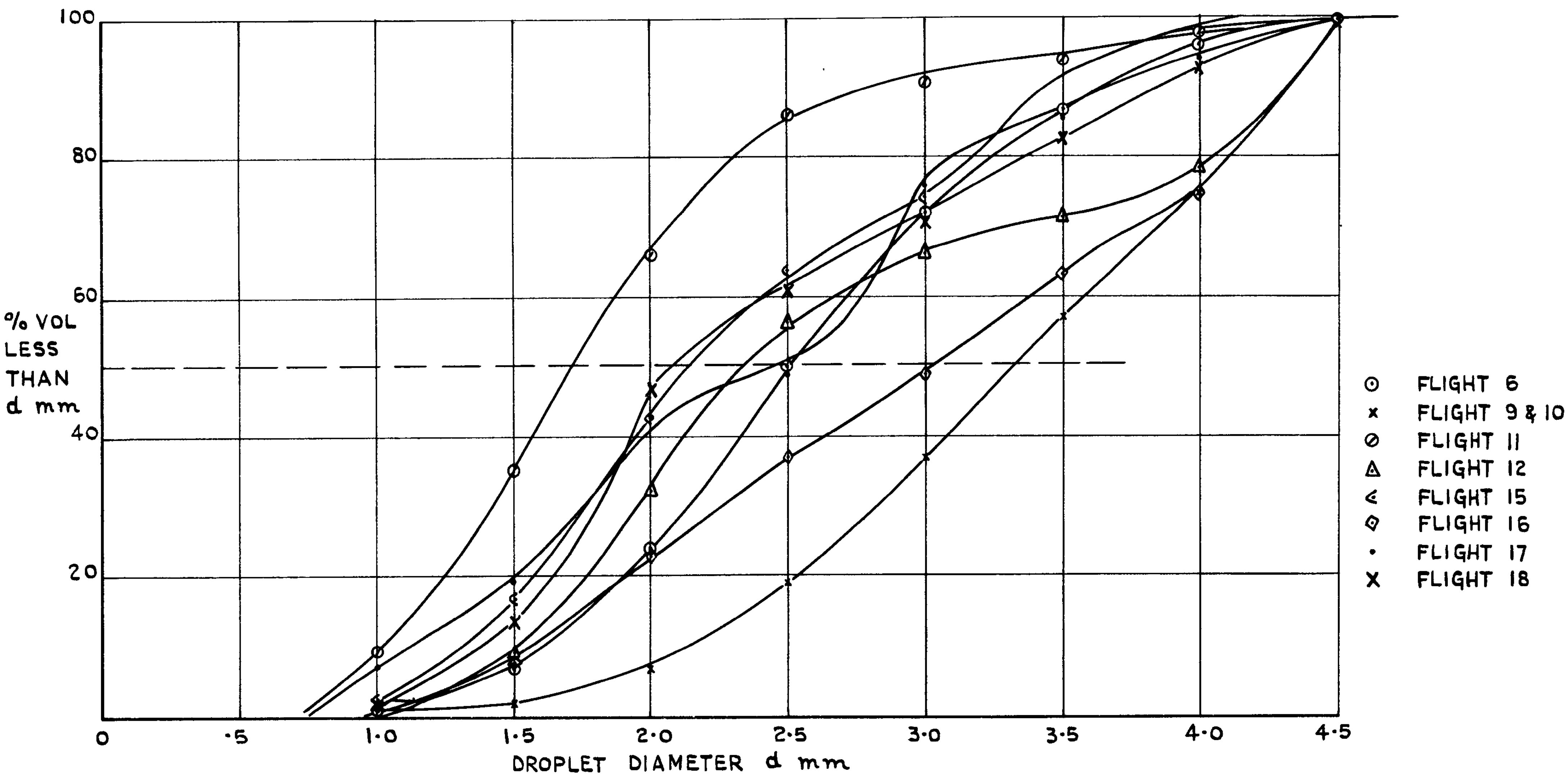


FIG.6. RANGE OF RAIN DROP SIZES OBTAINED IN FLIGHT.

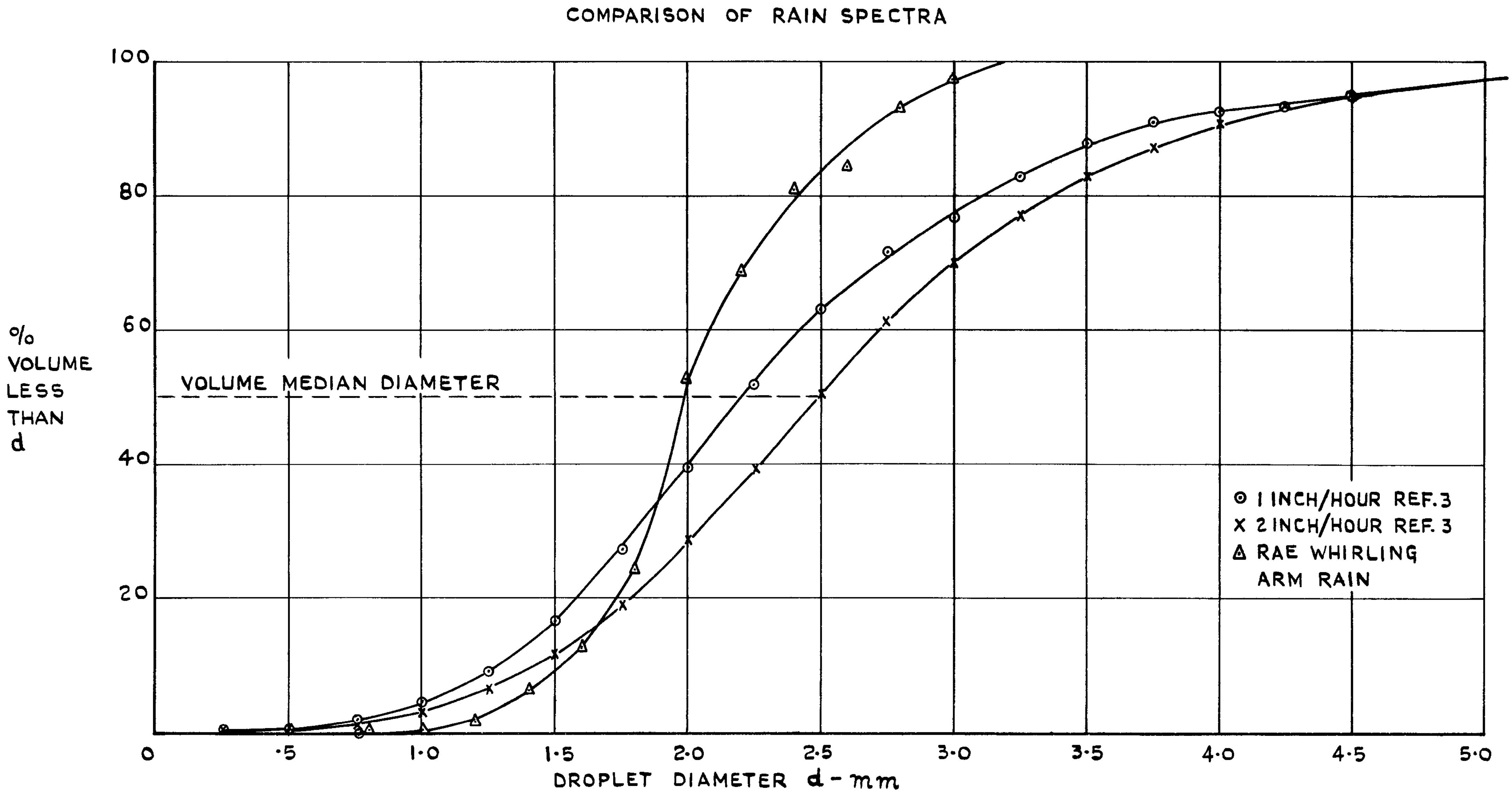


FIG.7. RAIN DROP SIZE DISTRIBUTION FOR NATURAL & ARTIFICIAL RAIN.

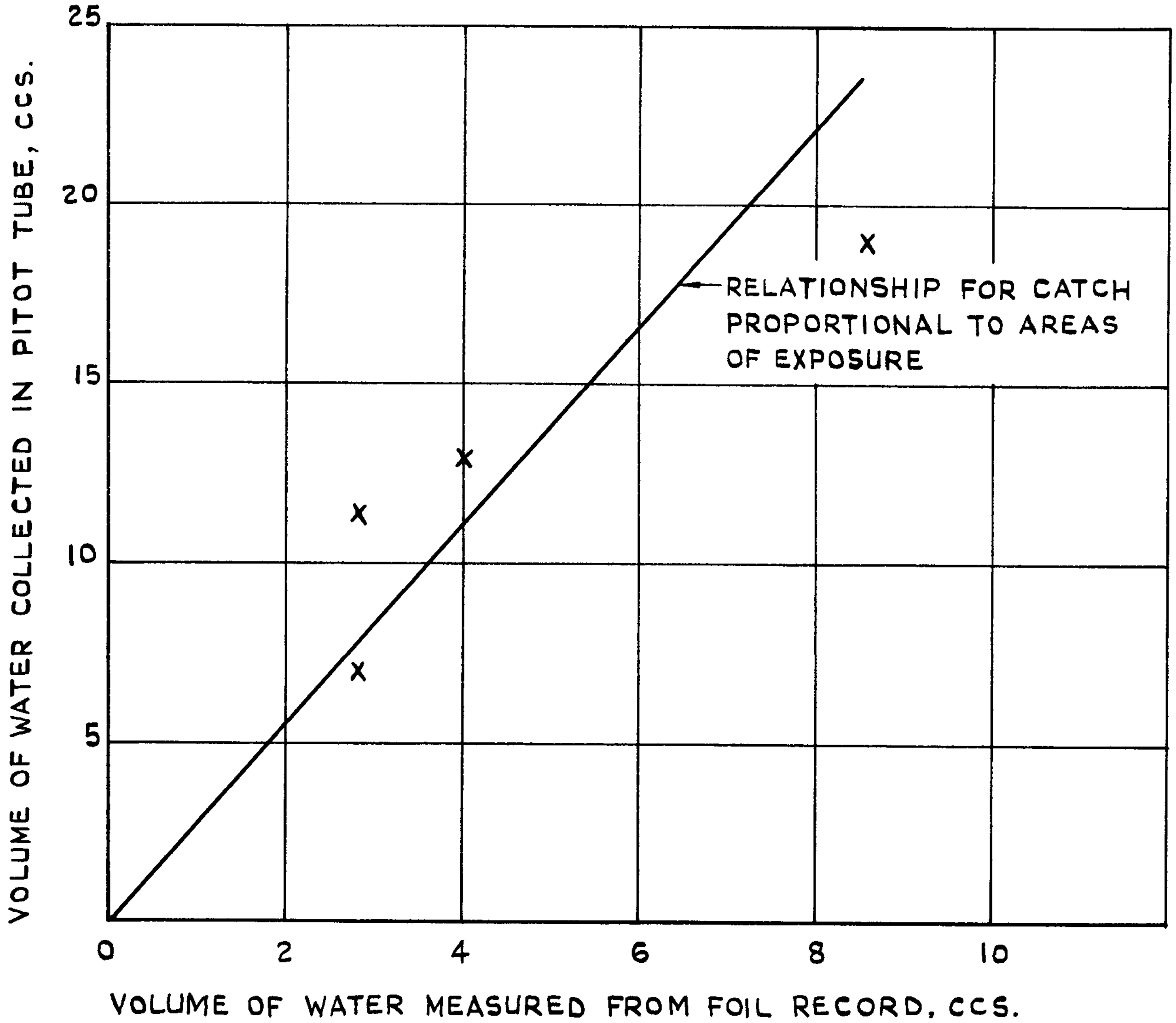


FIG. 8. VARIATION OF PITOT CATCH WITH FOIL CATCH.

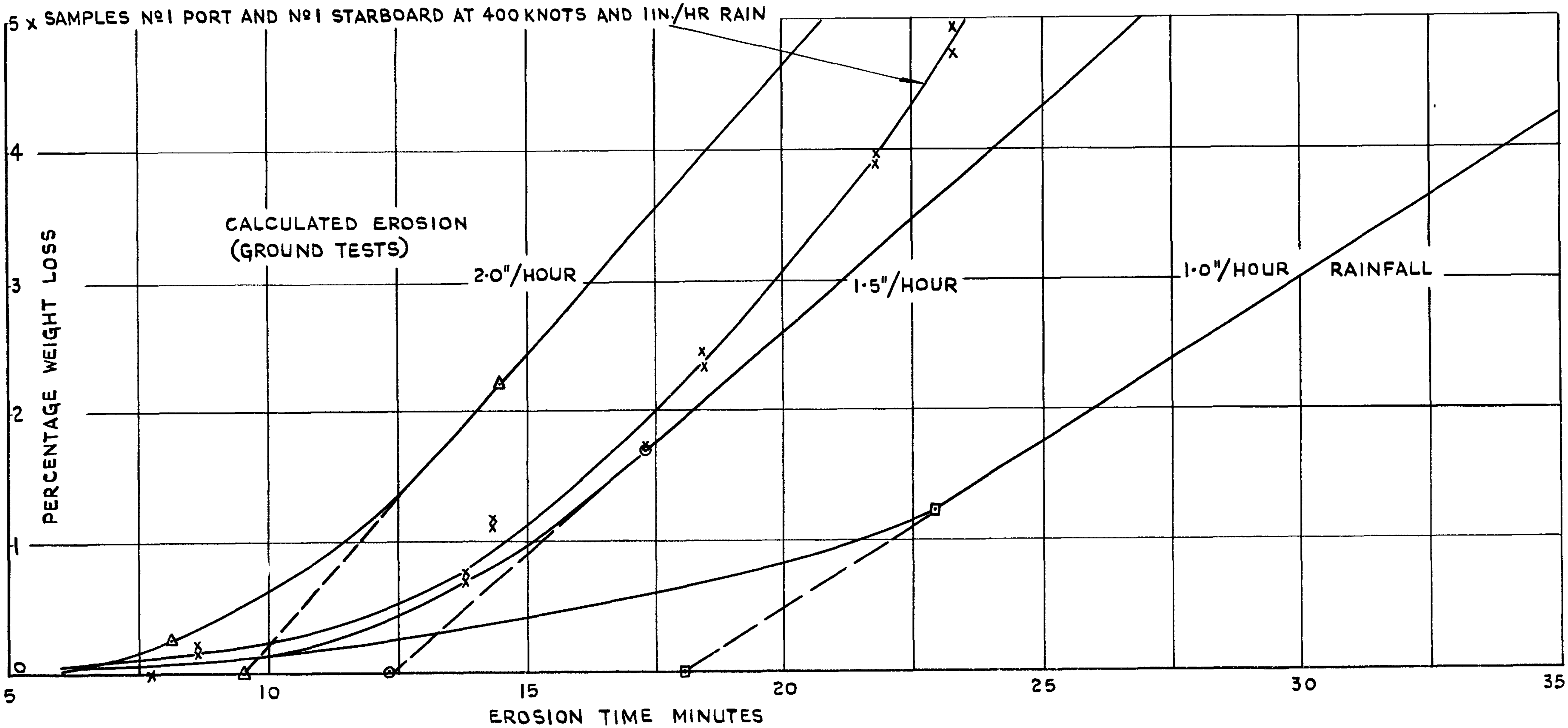


FIG.9. A COMPARISON OF WEIGHT LOSS BY PERSPEX SPECIMENS ON THE WHIRLING ARM RIG AND IN FLIGHT.

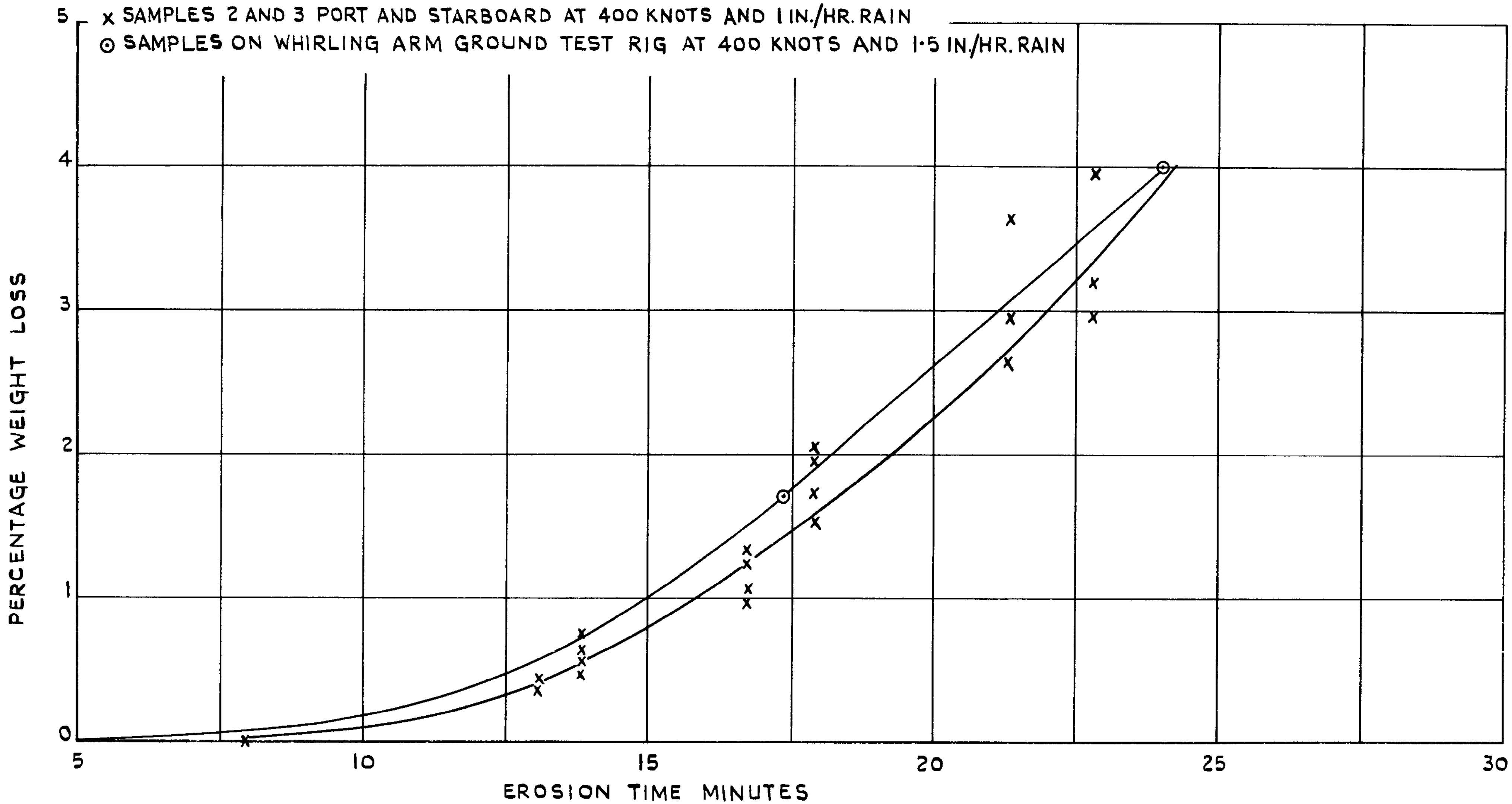


FIG.10. A COMPARISON OF WEIGHT LOSS BY PERSPEX SPECIMENS ON THE WHIRLING ARM RIG AND IN FLIGHT.

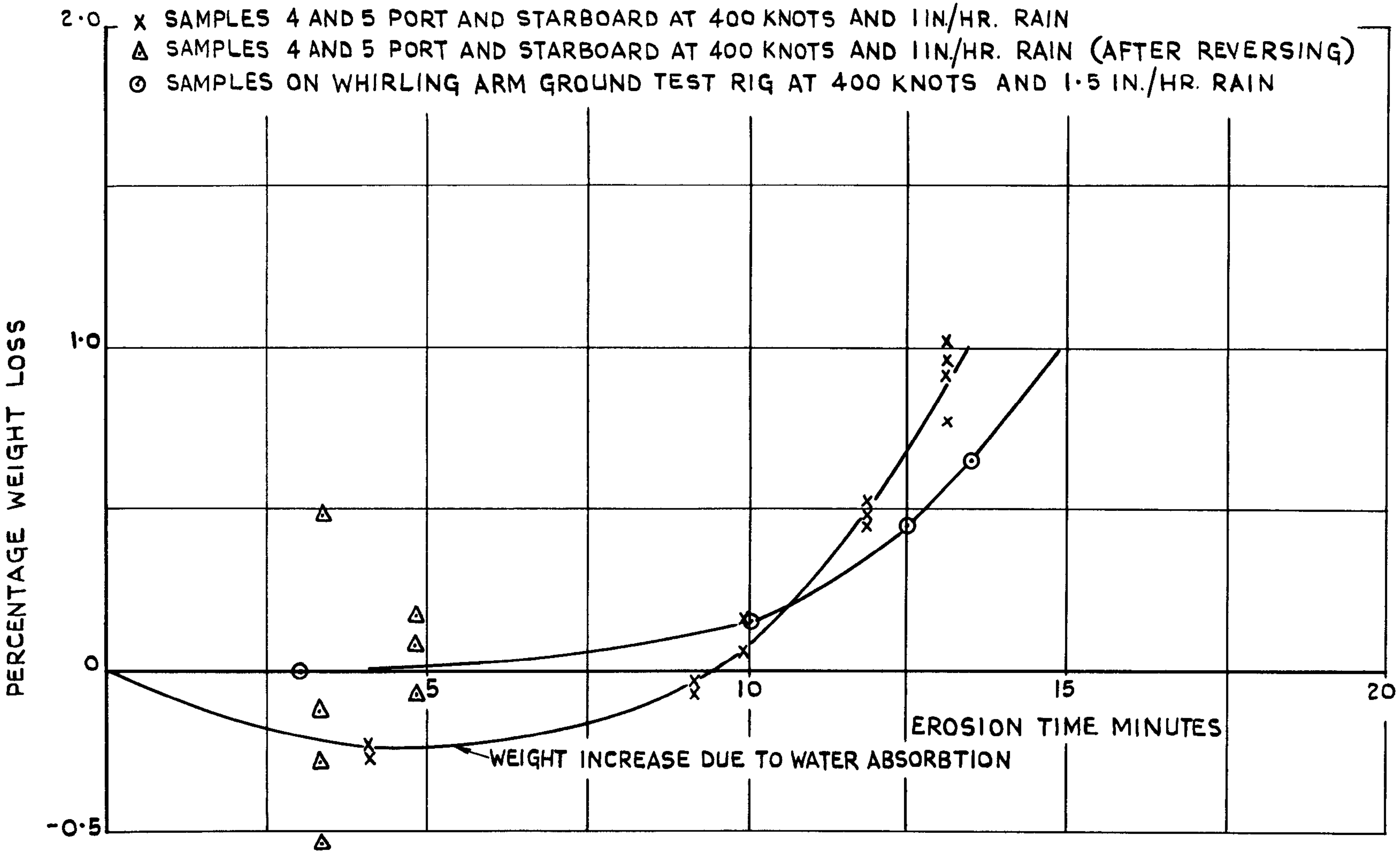
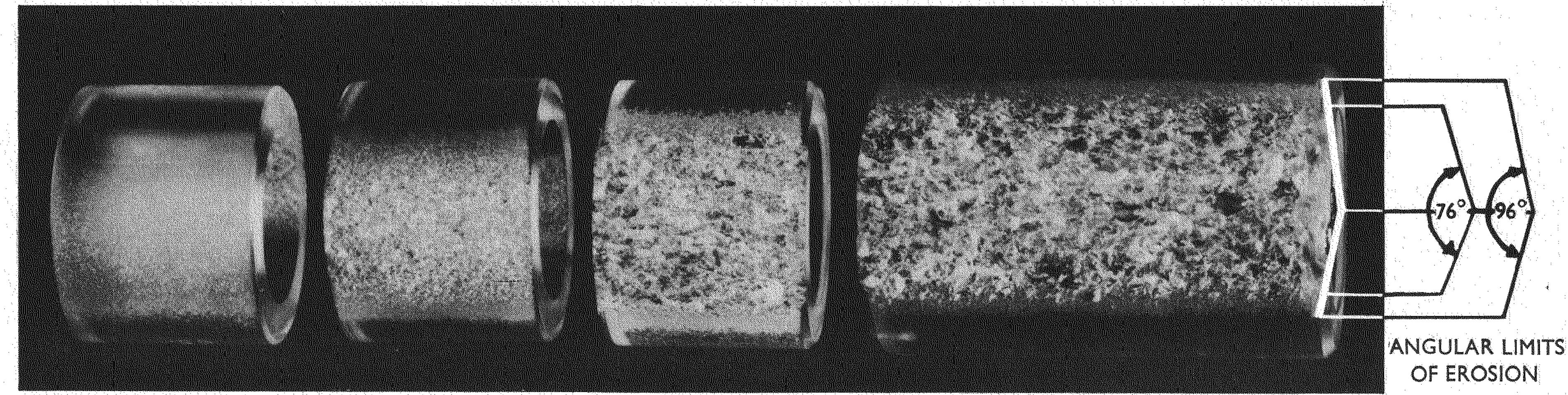
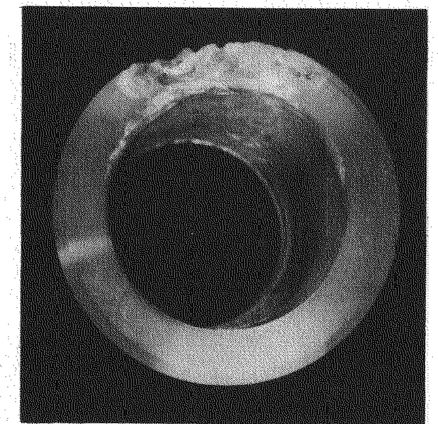


FIG.11. A COMPARISON OF WEIGHT LOSS BY PERSPEX SPECIMENS ON THE WHIRLING ARM RIG AND IN FLIGHT.



5.1 min. 13.2 min. 21.4 min. 21.9 min.

EQUIVALENT TIME EXPOSED TO 1 in./hour RAIN AT 400 knots AIRSPEED



21.9 min.

FIG.12. RAIN EROSION OF PERSPEX SPECIMENS EXPOSED TO RAIN IN FLIGHT AT 400 knots

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