Interim report on measurements of landing loads on a ski plane

Uffen, J. P.; Wood, A. D.; National Research Council of Canada. Division of Mechanical Engineering. Structures Laboratory

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40003451
Report (National Research Council of Canada. Division of Mechanical Engineering); no. MM-210, 1948-10-05

COPY NO. 4

NATIONAL RESEARCH COUNCIL OF CANADA

INTERIM REPORT ON MEASUREMENTS OF LANDING LOADS ON A SKI PLANE

REPORT NO. MM - 210

BY

J. P. UFFEN AND A. D. WOOD
DIVISION OF MECHANICAL ENGINEERING

OTTAWA

5 OCTOBER, 1948

NATIONAL RESEARCH LABORATORIES

Ottawa, Canada

REPORT

Division of Mechanical Engineering

Structures Laboratory

Pages - Preface	- 3		Report No. MM-210
- Text	- 11		Date - 5 October, 1948
- App.	- 2		Lab. Order No. - 4964A
Figures	- 16		File No. - M4-A3-49
Tables	- 3		

For: Subcommittee on Aircraft Structures of the Associate Committee on Aeronautical Research.

Reference: Minute 9 - Proceedings of the Second Meeting of the Subcommittee on Aircraft Structures - 12 June, 1948. File No. M4-A3-49.

Subject: INTERIM REPORT ON MEASUREMENTS OF LANDING LOADS ON A SKI PLANE.

Submitted by: W. J. Cox, Laboratory Head

Authors: J. P. Uffen, A. D. Wood

Approved by: J. H. Parkin, Director

SUMMARY

An investigation was made into the loads occurring on the skis of an aeroplane during the landing impact. Bending moments along the skiboards were measured, during one winter while vertical, drag, side, and torque loads were measured the following winter. For the latter, the corresponding normal accelerations, vertical velocities and attitudes of the aeroplane at contact were also obtained. No conclusions are drawn in view of the small number of landings but comparison is made of the measured values and the ICAO design requirements.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

INTERIM REPORT ON MEASUREMENTS OF LANDING LOADS ON A SKI PLANE

1. INTRODUCTION

Although design requirements of licensing bodies exist, the design of aircraft skis is largely conditioned by experience. Manufacturers apply their own arbitrary nose loading conditions. This appears to be the most frequent location of ski breakages, reports of which have included tension failures in the upper surface. The regulations have been subject to question and change, an arbitrary strengthening of the undercarriage equivalent to 1 "g" being at one time required. The Subcommittee on Aircraft Structures of the Associate Committee on Aeronautical Research reviewed the situation and recommended that the laboratories extend their research on aircraft skis to include determinations of the loads during landing and make the data available to the International Civil Aviation Organization as part of Canada's contribution to the group setting strength requirements.

It was considered that the vertical loads needed to be measured on a statistical basis for comparison with wheel landings and to give a quantitative estimate of the value of the sprung pedestals often used to replace the resilience of tires.

The design drag loads were questioned and a need for knowledge of its rate of rise indicated apropos of current interest in dynamic failures in undercarriages.

Data were noted to be lacking on the stresses developed during the process of unsticking frozen-in skis. Investigation of the ski loading was recommended with special reference to the nose. Cognizance was taken of the dependence of all these items upon varying snow and ice conditions and the recommendation made that the tests cover at least one season and if possible several locales.

The decision was made to check the ICAO load requirements, the need for special nose loading conditions and to obtain such other full-scale data as could be had with little extra expenditure of effort. Equipment was provided and flights were made during the late winter of 1947. Data was secured on the ski loading for ice and snow surfaces but the method used to assess the oleo loads failed due to structural redundancies. The following winter, effort was concentrated upon the latter, landings being recorded on an ice runway. The full winter's flying time was not obtained either year so that the results lack statistical significance but it is thought that the particular results obtained to date warrant this interim report.

2. APPARATUS

2.1 Aeroplane

The aeroplane used in the tests was a Noorduyn Norseman Mk. VI., high wing monoplane (see Figure 1).

Span	51 ft. 6 in.
Length	31 ft. 9 in.
Wing Area	296.3 sq. ft.
Chord	87 in.
Wing Section	NACA 2412
V_{so}	68 mph.
Gross Weight At Contact During Ski Tests	6470 to 6730 lb.

2.2 Skis

Three types of skis were used:

(i) USAAF Type Ski
Model 16-6, Noorduyn Aircraft Company
Drawing #16633910
Length 101 inches, width 18 inches,
Contact length 70 inches approximately,
Black iron bottom.

(ii) Bear Paw Type Ski
Model 4-15, Noorduyn Aircraft Company
Drawing #U.5012
Length 116 inches, maximum width 32 inches,
Contact length 87 inches approximately,
Brass bottom.

(iii) North-West Industries M.S. 7500
Length $98\frac{1}{4}$ inches, width 21 inches,
Contact length 68 inches approximately,
Brass bottom.

The first two were used for the test of lengthwise loading. Electrical resistance strain gauges were cemented to five selected stations on the ski. Known moments were applied in the laboratory and the strain read on a Baldwin Strain Indicator. The amplifiers were set to a known strain sensitivity by the use of a calibrating resistor which could be shunted across the active gauge at each station. Records on film were obtained by means of the recording apparatus described in paragraph 2.4.

Cracks developed in the first ski during the tests so that the third pair was obtained for the landing load work the following year. It is a parallel-sided ski similar to the USAAF type used before.

2.3 Measuring Equipment

A summary of the quantities measured and recorded, together with the estimated precision of measurement is given in Table I at the end of this section. Appendix A contains a description of the strain gauge pedestal designed to measure ski loads.

2.3.1 Accelerometers

Normal accelerations were measured at the three points A, B and C (see Figure 6). Accelerometers "A" and "C" were magnetically damped to 0.7 critical with a natural frequency of 50 c.p.s. and differential transformer type pick-ups. Accelerometer "B" was an unbonded resistance strain gauge pick-up with a natural frequency of 220 c.p.s. and fluid damping 0.6 critical.

2.3.2 Attitude Indicators

Two damped pendulums were used to measure angles of pitch and roll. These measurements depend upon the absence of appreciable acceleration and are reliable only up to the instant of contact.

2.3.3 Vertical Velocity Apparatus

The method of vertical velocity measurement using a cine camera mounted vertically in the aircraft to photograph a pattern of parallel lines along the landing strip has been described fully in Reference I. This method was used in an attempt to obtain a greater accuracy of vertical velocity measurement than that possible using photo-theodolite technique. On normal snow conditions, an accuracy of ± 9 per cent was possible. Towards the end of the tests described, the snow condition had deteriorated to such an extent that it was difficult to produce a sharp line pattern on the snow surface. Use was therefore made at this stage of a photo-theodolite to check or obtain some of the vertical velocities.

2.3.4 Horizontal Velocity Apparatus

One Askania photo-theodolite was located as shown in Figure 7. The shutter of the photo-theodolite was operated at intervals of 0.3 seconds by a small synchronous motor. Using this arrangement, the accuracies of horizontal velocity measurement shown in Table I are considered valid.

2.4 Recording Equipment

Figure 5 shows the disposition of the two recorders in the aircraft. Recorder Number 1 was a commercial 5000 c.p.s. carrier system feeding into 2000 c.p.s. galvanometers with 0.6 critical damping. This was used for recording quantities (2) to (6), (Table I). Recorder Number 2 consisted of 4000 c.p.s. carrier type bridge amplifier units feeding into two 375 c.p.s. galvanometers with 0.6 critical damping. The two pendulums were installed in the oscillograph box of this unit, movements of the pendulums being recorded by a direct optical linkage. Time synchronization between recordings on both films was obtained through the use of an 80 c.p.s. tuning fork which reproduced a similar trace on each film. Speed of the 35 mm. camera was determined from a pulse operated by the shutter and appearing on one of the oscillograph films.

2.5 Glide Path Indicator

An attempt was made to specify the vertical velocity for each landing by using a type of glide path indicator. This instrument is illustrated in Figure 8. To the pilot, indication of an approach at any pre-set angle is the appearance of an amber and a red light. In an incorrect approach one or other light is not seen. The angles were chosen each day allowing for wind to bring the aircraft down with vertical velocities of 2, 4, 6, 8 and 10 feet per second while flying at an IAS of 90 miles per hour.

3. TEST PROCEDURE

Figure 7 shows the layout of the landing area during ski tests. Approaches were in nearly every case made along the centre line of the rolled snow strip but from either direction depending on the wind. Guidance to the pilot in making an approach was provided by the glide path indicator and a line of red square markers along the centre of the landing strip. For the majority of the tests the glide path indicator was set to the angle corresponding to a specified rate of descent. The pilot was instructed to maintain a constant air speed and a steady rate of descent using the glide path indicator until contact with the ground occurred. It was found, however, that in spite of the determination of the pilot, some reduction in the rate of descent nearly always occurred. Where this fly-in technique was used, records were taken to include the period during which the aircraft was in contact with the ground. On bouncing clear of the ground after impact, the throttle was opened and the recorder switched off. In addition to these touchdowns, a number of landings classified as normal were made during which the glide path indicator was ignored. In these cases recording was continued during the landing run. All ski landings were carried out by either of two pilots using the same techniques. The flap setting in every case was between 10° and 20°.

4. RESULTS AND DISCUSSION

Since PICAO Document 3031 AIR/181 Item 3.5.1 recommends that the applicable wheel cases (3.4 to 3.4.2. 5.3) may also be applied to the ski cases, they are discussed together below, in the light of the present data. For purposes of comparison, the weight as flown has been used as the gross weight required in the regulations.

4.1 Vertical Velocity

For this aeroplane the required vertical velocity is 9.8 ft/sec. The landing procedure included deliberate attempts to approach with vertical velocities of 8 ft/sec. and 10 ft/sec. Although the landings were not random, the histogram (Figure 10) is presented as a convenient catalogue of the velocities obtained. The highest vertical velocity obtained was 5.1 ft/sec. From the histogram it is seen that the median and the mode are much lower than this and that there is small probability of reaching 10 ft/sec. The flare-out in the approach path prior to contact may be due to involuntary action on the part of the pilot and to ground effect. These remarks do not necessarily apply to landings made using techniques other than that described. During stalled landings, higher vertical velocities may occur. It is probable that a considerably higher value of the mode would be obtained during blind or night landings.

4.2 Centre of Gravity Acceleration

The maximum accelerations at positions A and B are plotted against vertical velocity in Figure 11. Accelerometers A and C were provided to assess pitching accelerations by differencing their readings. The results obtained by this method, however, are not considered acceptable. The readings shown therefore represent accelerations at points slightly removed from the centre of gravity. The normal component of acceleration at positions A and B due to pitching acceleration is estimated to be small. Graphs (i) and (ii) give the values obtained for ski landings while graph (iii) gives the readings for wheel landings made on a tarmac runway at a time when accelerometer B was not present. As Table II indicates, no readings were obtained from accelerometer A on the eighteenth of March. In order to provide a similar number of points for comparison with curve (iii), use was made of some results obtained during preliminary tests. These values are quoted at the end of the table.

A comparison of all three results is made in graph (iv). In the ski case the slopes for both accelerometers are in agreement within the limits of experimental accuracy. It appears from the curves that a higher load factor obtains in the ski case than in the wheel case, which suggests some justification for sprung pedestals or an extra load factor, but the accuracy resulting from the limited extent of the tests precludes a quantitative statement.

4.3 Vertical Load

The histogram of vertical reaction is given in Figure 12. Since this is symmetrical, it is not consistent with the histogram of vertical velocities and the assumption that the acceleration increment of the centre of gravity is linear. The discrepancy is possibly due to asymmetric landings raising the mode to a higher value. Reference to Figure 12 suggests that the slope of the load-acceleration curve in the unsymmetrical case is double that of the symmetrical, which, if substantiated would indicate modification of the Note in requirement 3.4.2.5.3(a)[4], (PICAO Document 3031).

The relative frequency of unsymmetrical landings could not be completely assessed though attitude in roll was measured. Several records were obtained on which significant acceleration occurred before the port leg recorded any load, while the wings were level. These are interpreted as landings on the starboard ski first, due to runway irregularities. Future work employing two-weighing pedestals is planned to clarify this mâtter and to provide a statistical number of landings for the load data.

The maximum recorded load was approximately 60 per cent of the required limit load.

4.4 Drag Load and Co-efficient of Friction

The histogram of the peak drag loads is given in Figure 12. The loads were low relative to the requirements and exhibited marked oscillations of approximately 12 c.p.s. Several cases were observed of "drag reversal" due to the above oscillations, the average of the reverse peaks being 205 pounds. The co-efficient of friction quoted is based on peak values of drag and of vertical force, and thus contains inertia effects. It shows a dependence upon ski loading (Figure 14), as predicted in Reference II, for two of the days but not for the third. On this day the runway was wet due to rain.

30% P. Uffen

The maximum drag measured was about 25 per cent of the required limit load. The values of drag are not to be taken as indicative of the range expected, as Reference II reports co-efficients of friction as high as 0.428 for brass bottom skis.

75% J.Pfeffer

4.5 Side Load

The histogram of peak side loads is given in Figure 12. The maximum measured value is approximately 45 per cent of the limit load required. Table II shows that most of the landings were made with a moderate wind from the starboard side but little swing occurred during the impacts. No loads while turning were recorded.

The side load traces showed vibrations similar to the drag traces (at approximately the same frequency) so that the side loads showed similar reversal.

4.6 Torque Load

50% J.Pfeffer

The peak torque load was about 75 per cent of the required limit load, as flown. The histogram is given in Figure 11. The remarks made above relative to the turning and swinging apply to the torque loads also so that representative operational use may not have been obtained.

4.7 Ski Bending Moments

The recorded bending moments for both ice and deep-snow landings showed oscillations and reversals. Although the records from landings on ice were in general more oscillatory, there were reversals common to the two cases. The first occurred in the region of the nose at the beginning of the impact, and the second occurred over the whole ski at the end of the impact.

The following sequence of events may explain the variations in bending moment shown. Since the ski is trimmed nose-up initial contact is made by its heel causing positive bending moments all along the ski (t_1 Figure 15). The ski then flattens against the landing surface causing negative bending moments in the region of the nose (t_2 Figure 15). Positive bending moments then ensue all along the ski with oscillations in the snow-case or reversals in the ice-case. When the aero-plane leaves the ground for the initial bounce, it allows impact of the oleo-piston against its stops on the return stroke, causing the negative bending moment over the whole ski as mentioned above.

In view of the oscillatory nature of these results and their obvious dependence upon landing surface conditions, it was decided to present the envelopes of the maximum moments encountered at each station. They are thus in a suitable form (Figure 15-(a) and (c)) for comparison with ICAO requirements.) The differences between the two curves may be attributed to varying magnitudes of dynamic effects caused by the differences in plan form and stiffness between the two skis.

On the assumption that the board can take positive and negative moments with equal ease, the negative loops are included with the positive in Figure 16 (b) and (d) where the direct comparison is made. The envelope is seen to be well within the limit requirement of PICAO Document 3031 AIR/181. The original concentrated load requirement of PICAO Document 1548/AIR/62 is also shown. Subject to the assumption above, the requirements cover the loads measured to date. Whether exceptional cases would have been recorded with increased flying time and more varied snow conditions is not known.

5. CONCLUDING REMARKS

The investigations described above provide limited data on the loads encountered by a ski-plane landing gear during the landing impact. The values presented refer to a limited range of vertical velocities and snow conditions. Though the results may be viewed as characteristic of the particular aeroplane, it is hoped that they will provide experimental evidence with which to test the application of contemporary vibration and impact theory. Conclusions applicable to the general design cases for skis await a more extensive programme of tests of greater statistical significance.

6. ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance and cooperation of the R.C.A.F. (NRC) Unit at Arnprior which maintained and flew the aeroplane during these tests.

7. REFERENCES

1. Wood, A.D.........A Method Of Measuring Vertical Velocity Immediately Before Landing. NRC MR 3.

2. Klein, G.J........The Snow Characteristics Of Aircraft Skis. NRC AR 2.

3. ....PICAO Document 1548 AIR/62.

4. ....PICAO Document 3031 AIR/181.

APPENDIX A

LOAD MEASURING PEDESTAL

The pedestal was designed to measure forces and torques in a reference frame attached to the ski. The oleo-leg reaction is transferred by the axle to a weighing platform (Figure 3) which is suspended and restrained in its motion by weigh bars. The axial load in the bars was read by means of calibrated electrical resistance strain gauges. Independence of the readings was sought by arranging the weigh bars in three mutually perpendicular sets. Further reduction of intercoupling was secured by making the rods relatively weak in flexure. The strain gauges on the set of vertical rods are summed electrically in a Wheatstone-bridge circuit. The side rods have two sets of gauges, one summed, the other differenced. The summed set give the side load, and the differenced set give torque about the axis normal to the ski bottom. Drag is read on a single fore-and-aft strut. All gauges are disposed on the rods so as to compensate for temperature and to minimize response to bending.

Each strain gauge bridge was connected to a carrier type amplifier of Recorder No. I. Calibration was effected by mounting the oleo-extension rigidly to a fixed beam and applying loads by hydraulic jacks connected to the ski. Independence of the channels was verified by applying loads in each direction and noting the response of the other channels.

It is to be noted that the reference plane is attached to the ski. Thus the pedestal measures forces parallel to the ski bottom as drag. Components of the vertical force and drag force will thus be registered each in the other's channel as the ski pitches to accommodate the terrain. This is of little moment in the present tests where the landings were on a rolled runway which had become iced. The deviations from level were small. The "out of channel" components being proportional to the sine of a small angle were negligible as were the cosine corrections to the "in channel" loads. However with deep soft snow where the skis are free to trim, it may be necessary to adopt the nomenclature Parallel and Normal instead of the Drag and Vertical now used.

A further error encountered in these channels arises from the trimming device. The error in the drag channel is a sine error on a small angle but nearly the full trimming force is recorded by the vertical load channel. This was minimized by reverting to a rubber bungee trimmer which has the longest available moment arm and hence the least force. The maximum this can be with the ski in the "tail down plus down hill" position is 200 pounds.

The response of a measuring device under transient conditions is affected by its natural frequency. Its period of vibration should be short compared to the transient time. The periods in the various modes are tabulated below together with the recorded transient times for comparison.

Channel	Period	Transient Time
Vertical	0.043	0.002 sec.
Drag	0.014	0.05 sec.
Side	0.014	0.04 sec.
Torque	0.055	0.1 sec.

The accuracies under these conditions are estimated as follows:

Vertical load	± 400 pounds
Drag load	± 50 pounds
Side load	± 100 pounds
Torque load	± 50 foot pounds

TABLE I

	Quantity	Measuring Equipment	Recording Equipment	Accuracy of Measurement
1.	Time	80 c.p.s. tuning fork	Both recorders	± .001 sec.
2.	Vertical load on one ski	Strain Gauge Ski Pedestal (See Appendix A)	No. 1 Recorder and Oscillograph. Carrier System 5000 c.p.s. Galvanometers 2000 c.p.s. 0.6 crit. damping	± 400 lb.
3.	Drag load on one ski			± 50 lb.
4.	Side load on one ski			± 100 lb.
5.	Torque load on one ski			± 50 ft./lb.
6.	Normal Acceleration at Position "B"	220 c.p.s. Accelerometer Fluid damping 0.6 critical	No. 1 Recorder	± 0.25 g.
7.	Normal Acceleration at Position "A"	50 c.p.s. Accelerometer magnetic damping 0.7 critical	No. 2 Recorder and Oscillograph (E_nBox) Carrier System 4000 c.p.s. Galvanometers 375 c.p.s. 0.6 crit. damping	± 0.25 g.
8.	Normal Acceleration at Position "C"			
9.	Aircraft Attitude in pitching plane	Magnetically damped pendulums 0.6 critical	No. 2 Recorder	± 0.1°
10.	Aircraft Attitude in rolling plane			
11.	Aircraft Vertical Velocity at instant of contact	(a) Vertical cine camera and line pattern (b) Askania Photo-theodolite		± 9% ± 1 ft./sec.
12.	Aircraft Horizontal Velocity at instant of contact	Askania Photo-theodolite		± 3 ft./sec.
13.	Wind Velocity and direction	Cup anemometer and Vane at 50 feet above the ground		± 2 mph. ± 10°

TABLE II
SKI LANDING DATA

DATE	TEST NUMBER	LANDING TYPE	WIND VELOCITY FT./SEC.	WIND DIRECTION RELATIVE TO AIRCRAFT HDG.	SURFACE CONDITION	AIR TEMP. °C	VELOCITY VERTICAL FT./SEC.	VELOCITY HORIZONTAL FT./SEC.	AIRCRAFT ATTITUDE AT CONTACT ROLL $\phi°$	AIRCRAFT ATTITUDE AT CONTACT PITCH $\theta°$	CORRECTED WEIGHT LB.	NORMAL ACCELERATION ACCEL. "A" g	NORMAL ACCELERATION ACCEL. "B" g	PORT SKI PEDESTAL LOADS VERT. LB.	PORT SKI PEDESTAL LOADS DRAG LB.	PORT SKI PEDESTAL LOADS SIDE LB.	PORT SKI PEDESTAL LOADS TORQUE FT. LB.	COEFF. OF FRICTION μ
17-3-48 (Flight 1)	1	N	13	30° Stbd.	Rolled snow. Hard and icy.	-9	1.8	115	+2.2	+1.2	6745	1.0	0.6	3300	115	280	430	0.035
	2	N	13	30° Stbd.		-9	2.4	110	-0.5	-0.4	6708	1.5	1.5	4060	805	1035	860	0.20
17-3-48 (Flight 2)	1	N	0	-		-5	1.6	117	-0.1	+0.8	6656	1.4	1.3	3500	517	845	528	0.15
	2	N	0	-		-5	1.5	115	-0.8	+0.2	6625	1.0	1.6	5330	575	1600	671	0.11
	3	B4	0	-		-5	4.0	125	-0.8	+1.9	6594	1.8	1.8	3810	725	1180	1060	0.19
	4	B4	0	-		-5	-	123	-1.0	+0.2	6578	1.6	-	4000	610	1200	1260	0.15
	5	B6	0	-		-5	1.3	120	-2.0	+1.6	6560	1.5	1.6	3850	600	1150	375	0.16
	6	B6	0	-		-5	2.9	118	+0.3	+2.8	6541	1.3	1.6	5500	760	1780	1290	0.14
	7	B6	0	-		-5	-	120	-2.0	+0.9	6532	1.8	-	4200	610	3100	500	0.15
	8	B6	0	-		-5	3.4	120	-1.0	+2.1	6510	1.5	1.5	5700	725	1000	770	0.13
	9	N	0	-		-5	1.5	120	+0.7	+2.8	6497	1.0	1.0	4000	375	1100	770	0.094
	10	N	0	-		-5	1.5	121	-0.9	+2.6	6472	1.0	1.8	4280	590	1000	625	0.14
18-3-48	1	B2	12	60° Stbd.	Rolled snow. Icy becoming soft towards end of tests.	-3	1.3	115	+3.1	+1.7	6723	-	1.5	0	0	0	0	-
	2	B2	12	60° Stbd.		-3	1.2	111	-3.6	+1.2	6709	-	1.2	3800	510	1150	970	0.13
	3	B4	12	60° Stbd.		-3	1.7	115	+0.8	+1.1	6698	-	1.0	4150	710	1200	1700	0.17
	4	B4	12	60° Stbd.		-3	1.6	120	-1.6	+0.2	6685	-	2.2	5200	610	1500	1520	0.12
	5	B6	12	60° Stbd.		-3	2.4	113	-1.4	+1.2	6674	-	1.0	3200	265	1710	780	0.083
	6	B6	12	60° Stbd.		-3	3.4	111	-0.3	+0.6	6663	-	2.1	6450	600	1720	550	0.093
	7	B8	10	60° Stbd.		-3	4.9	117	-2.2	-1.2	6652	-	3.4	5650	730	1900	1270	0.13
	8	B8	10	60° Stbd.		-3	2.4	114	+0.6	-0.2	6639	-	2.1	4200	555	1250	1800	0.13
	9	N	4	60° Stbd.		-3	2.3	120	-0.7	-6.4	6628	-	0.9	3600	660	850	1320	0.18
	10	N	0	-		-3	-	115	0	+0.6	6601	-	1.4	3850	760	650	975	0.20
19-3-48 (Flight 1)	1	N	19	30° Stbd.	Rolled snow. Icy and wet in places.	+1	0.8	101	+2.1	+2.0	6718	-	1.1	3850	190	1400	400	0.049
	2	B2	19	30° Stbd.		+1	1.3	108	+0.5	+0.8	6686	-	0.8	1200	150	400	750	0.13
	3	B2	19	30° Stbd.		+1	1.0	108	+1.5	+0.9	6672	-	0.8	3750	430	800	1060	0.11
	4	B4	19	30° Stbd.		+1	2.4	105	+2.5	0	6662	-	1.1	2550	550	1200	200	0.22
	5	B6	19	30° Stbd.		+1	2.9	108	-1.2	-0.3	6620	1.9	-	-	-	-	-	-
19-3-48 (Flight 2)	1	B8	16	10° Stbd.	Rolled snow Icy, soft and wet. Light rain fell.	+2	2.8	108	+0.2	-0.6	6558	1.6	0.6	2500	180	-	360	0.072
	2	B8	16	10° Stbd.		+2	3.6	112	+0.6	-1.0	6548	2.5	2.0	5100	675	-	2200	0.13
	3	B10	16	10° Stbd.		+2	-	107	-0.9	-0.6	6534	-	2.3	6500	900	-	700	0.14
	4	B10	16	10° Stbd.		+2	5.1	101	+1.9	-1.1	6524	2.3	2.8	7300	700	-	900	0.096
	5	B2	16	10° Stbd.		+2	1.0	108	-0.7	+0.8	6513	0.8	0.6	1900	210	-	150	0.11
	6	B2	16	10° Stbd.		+2	1.7	109	-0.3	+0.2	6505	1.1	1.1	2800	175	-	860	0.063
	7	B4	16	10° Stbd.		+2	2.9	107	+0.3	-1.0	6498	2.1	2.2	5000	300	-	480	0.060
	8	B4	16	10° Stbd.		+2	2.0	105	+0.7	+0.5	6487	1.9	1.5	4300	470	-	420	0.11
	9	B6	16	10° Stbd.		+2	3.9	109			6477	-	2.3	5550	695	-	580	0.13
27-2-48	1	B6	10	20° Stbd.	Rolled snow covered with 1/2 in. new snow.	-1	2.9	These values are also plotted in Figure 11, Diagram (1).				1.9	-	-	-	-	-	-
	2	B8	10	20° Stbd.		-1	3.3					1.6	-	-	-	-	-	-
	3	B8	10	20° Stbd.		-1	3.1					1.7	-	-	-	-	-	-
	4	B6	10	20° Stbd.		-1	2.9					1.7	-	-	-	-	-	-
	5	B6	10	20° Stbd.		-1	3.0					1.3	-	-	-	-	-	-
	6	B8	10	20° Stbd.		-1	2.8					1.5	-	-	-	-	-	-
	7	B8	10	20° Stbd.		-1	3.6					1.9	-	-	-	-	-	-

TABLE II
MM-210

TABLE III

Date	Test No.	Landing Type	Wind		A/C Velocity		A/C Attitude at contact		Landing Weight	Normal Accel. A
			Vel. Ft./sec.	Direction Relative to A/C Heading	Vert. Ft./sec.	Hor. Ft./sec.	Roll ø°	Pitch θ°	Lb.	"g"
22-4-48	1	B2	22	10° Stbd.	1.8	Approx.110 in all cases	-0.4	+1.1	6225	0.7
	2	B2	22	10° Stbd.	2.5		+1.3	+2.1	6212	1.0
	3	B4	22	10° Stbd.	1.9		-0.2	+2.1	6192	1.4
	4	B6	22	10° Stbd.	1.3		+0.5	+2.1	6185	0.8
	5	B6	22	10° Stbd.	3.4		-0.2	+1.0	6175	1.7
	6	B10	22	10° Stbd.	4.0		+0.5	+1.0	6145	1.8
23-4-48	1	B8	15	40° Stbd.	4.7	Approx.120 in all cases	+4.9	-1.0	6210	1.7
	2	B8	15	40° Stbd.	3.4		+2.4	+0.7	6197	1.2
	3	B10	15	40° Stbd.	6.0		+1.3	-2.6	6187	2.1
	4	B10	15	40° Stbd.	5.0		+7.2	-2.9	6177	1.8
	5	B8	15	40° Stbd.	2.2		+2.4	-0.5	6167	0.9
	6	B8	15	40° Stbd.	4.3		+3.5	-0.6	6157	1.6
	7	B6	15	40° Stbd.	1.4		+4.4	-5.0	6147	0.7
	8	B6	15	40° Stbd.	2.7		+4.7	-0.2	6137	0.9
	9	B4	15	40° Stbd.	3.3		+4.3	+0.5	6127	1.2

Footnote to Table III

[x]Zero Pitch Angle corresponds to Rigging Attitude

[xx]Landing Designation

N -- Normal (Flared) Landing

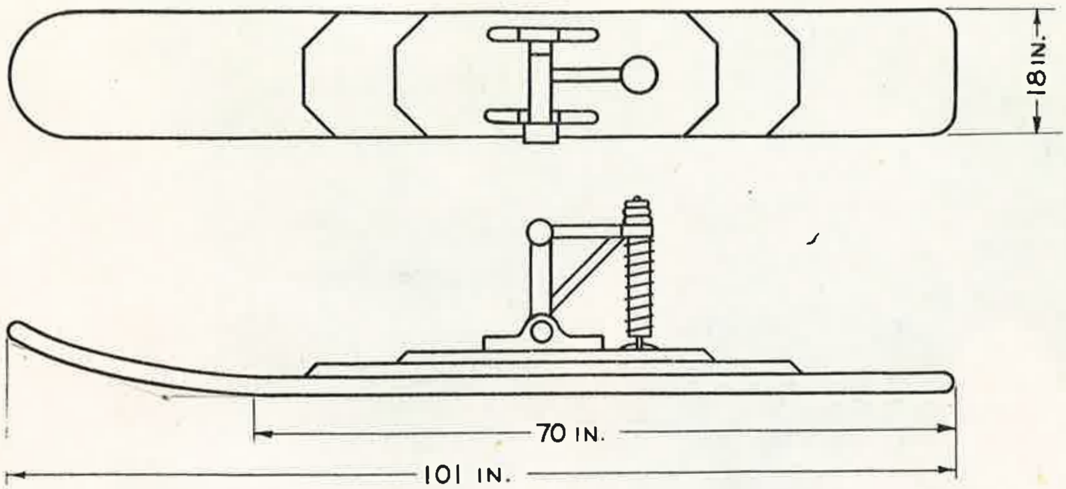
B -- Bounce - Type Landing (using Glide Path Control)

Numeral indicates intended Vertical Velocity in Ft. Per Sec.

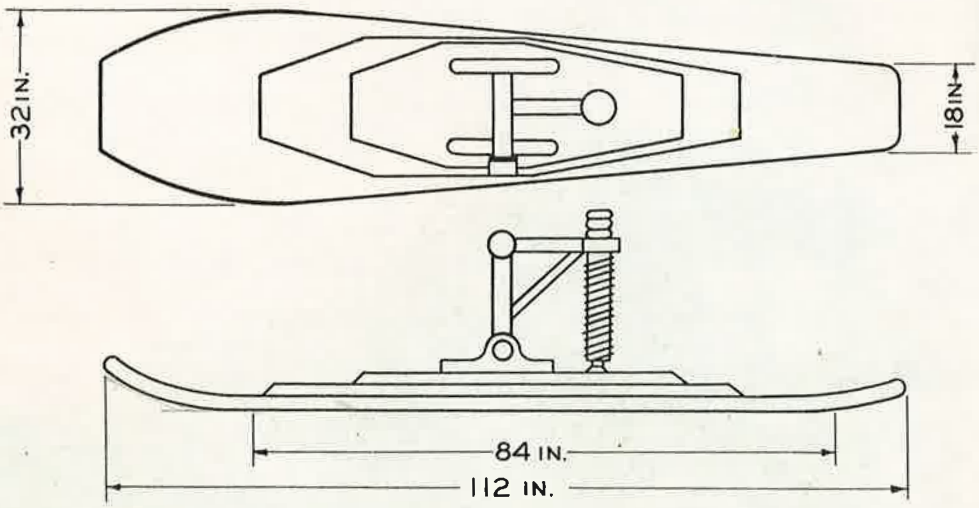
FIG. 1
MM - 210

AIRCRAFT USED IN TESTS

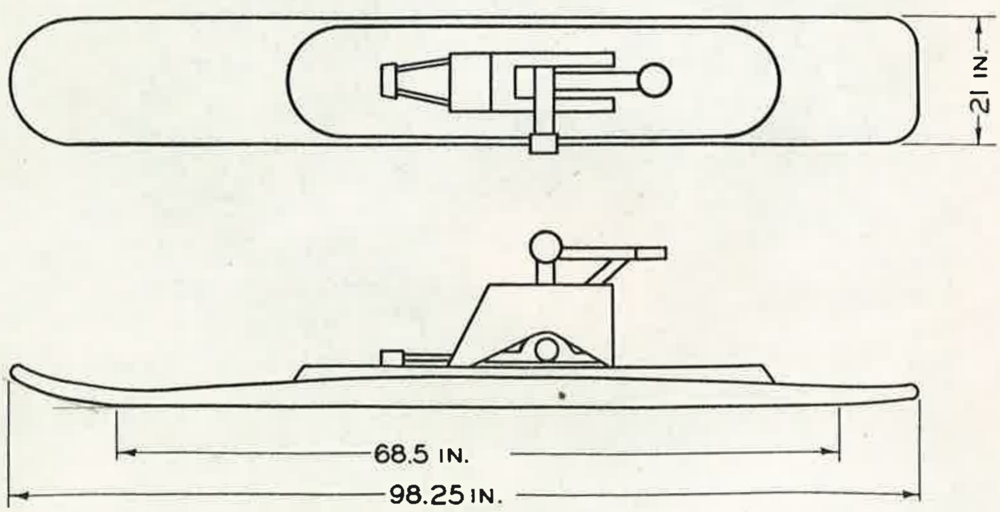
FIG. 2
MM-210



USAAF TYPE SKI

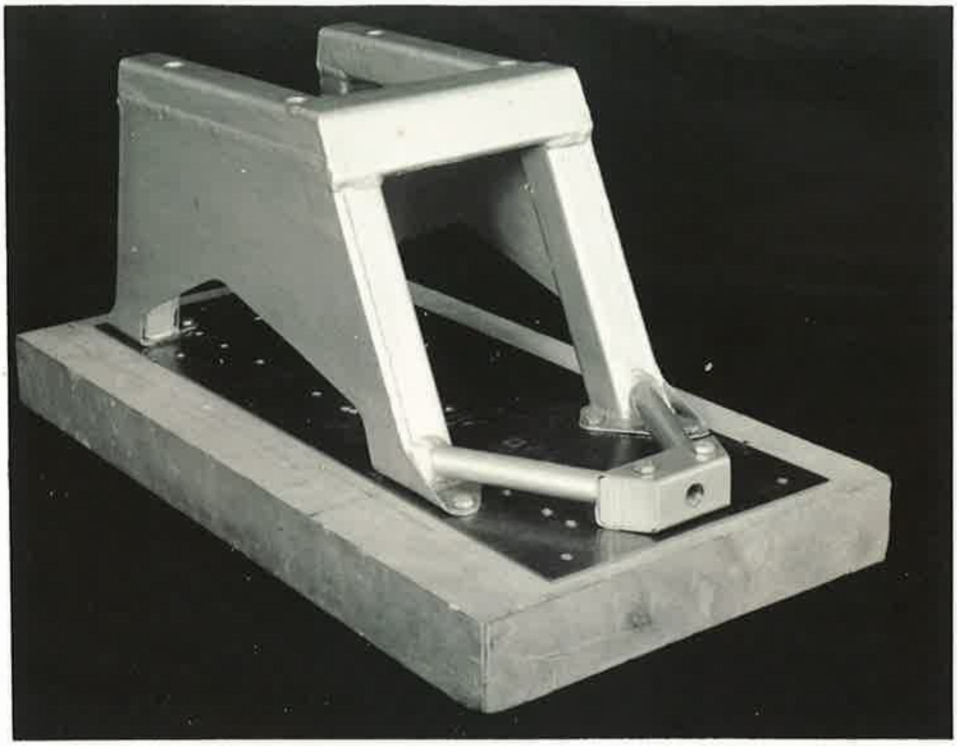


BEARPAW TYPE SKI

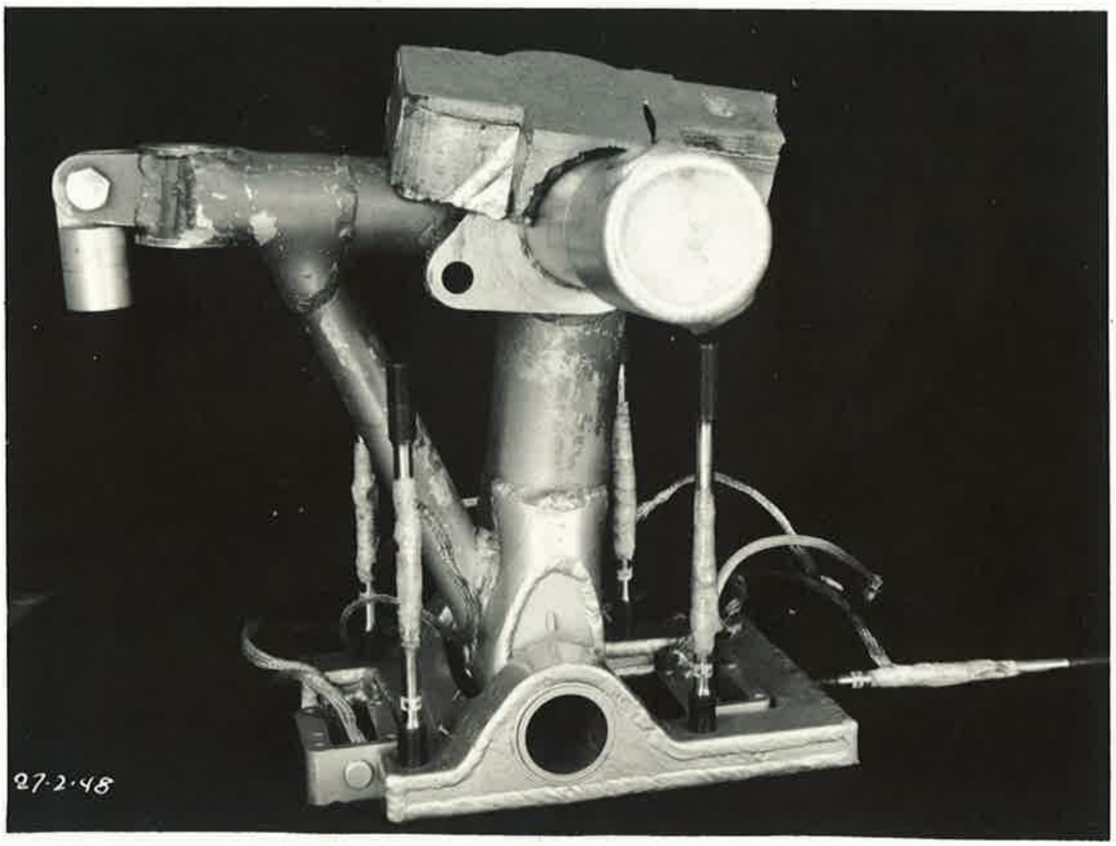


MS-7500 TYPE SKI

FIG. 3 a,b
MM-210

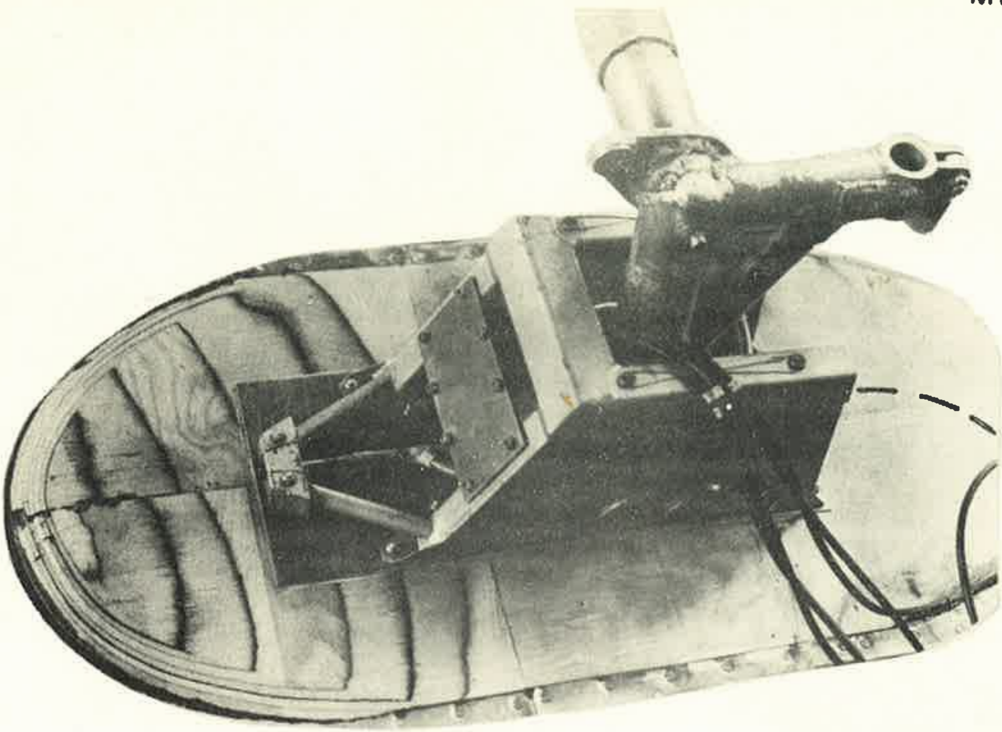


(a) MOUNTING FRAME

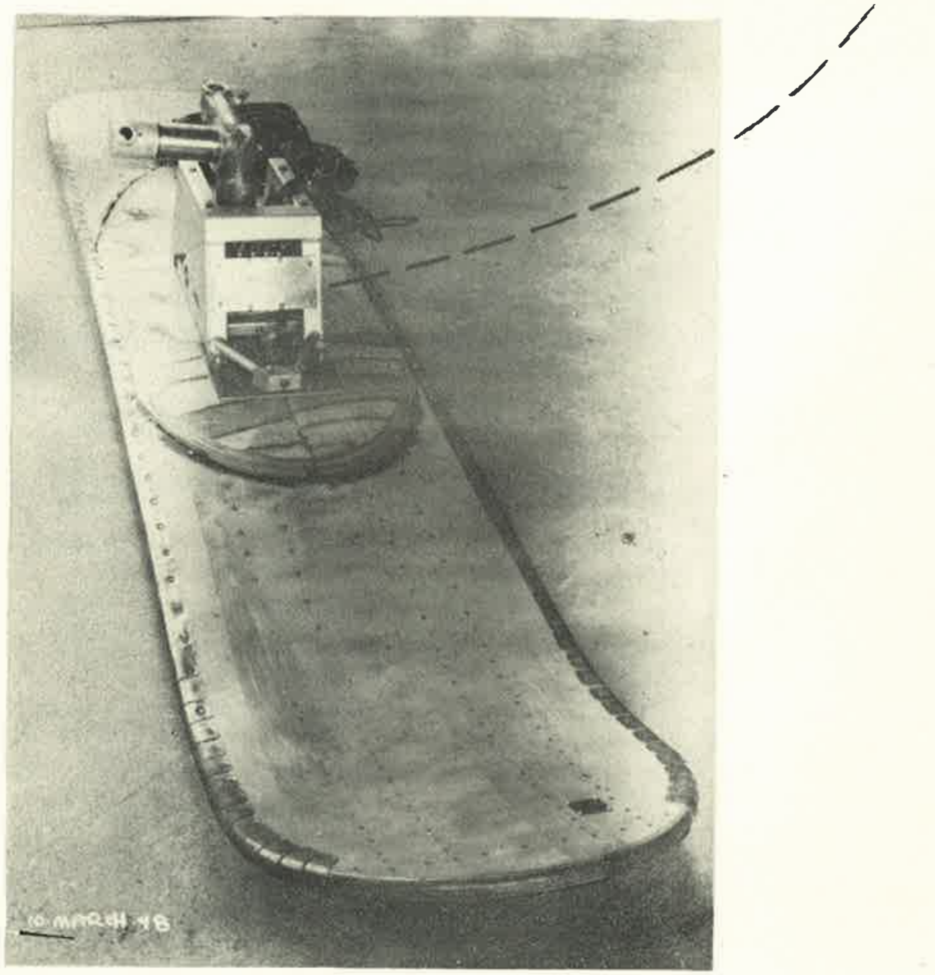


(b) WEIGHING PLATFORM

FIG. 4 a,b
MM-210

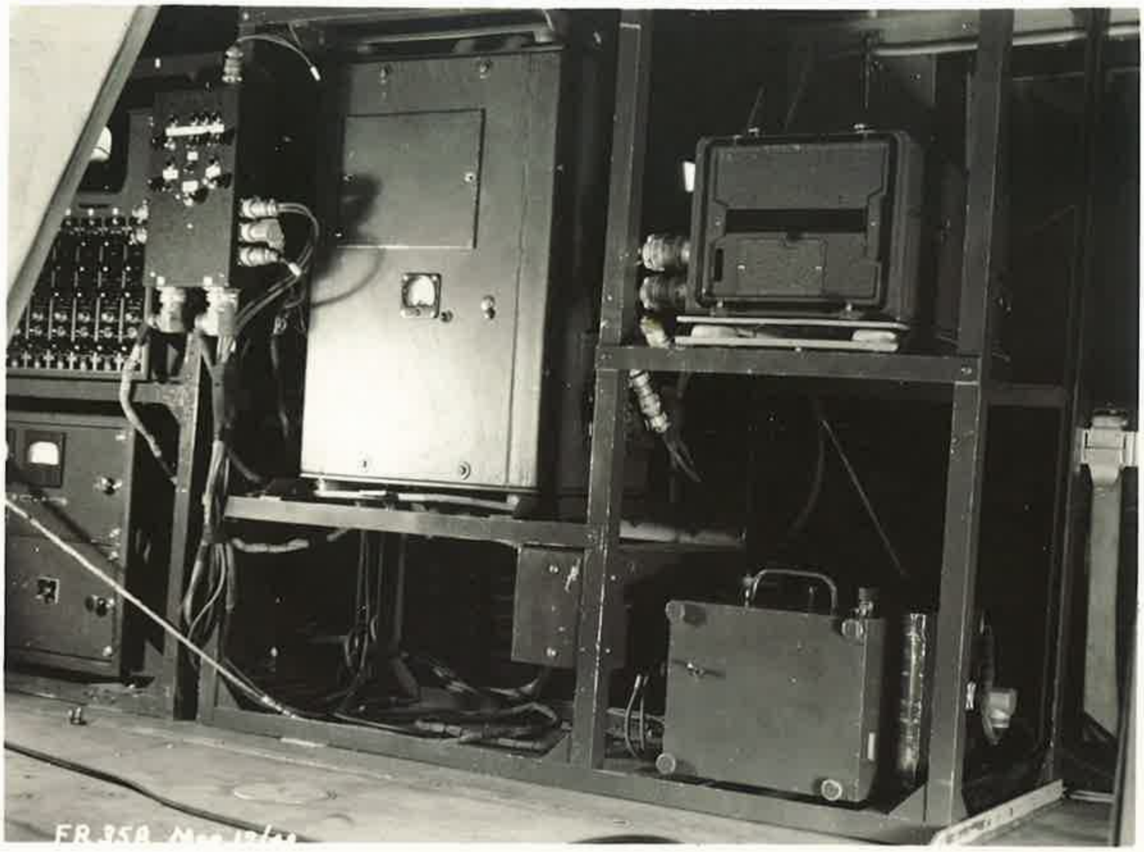


(a)

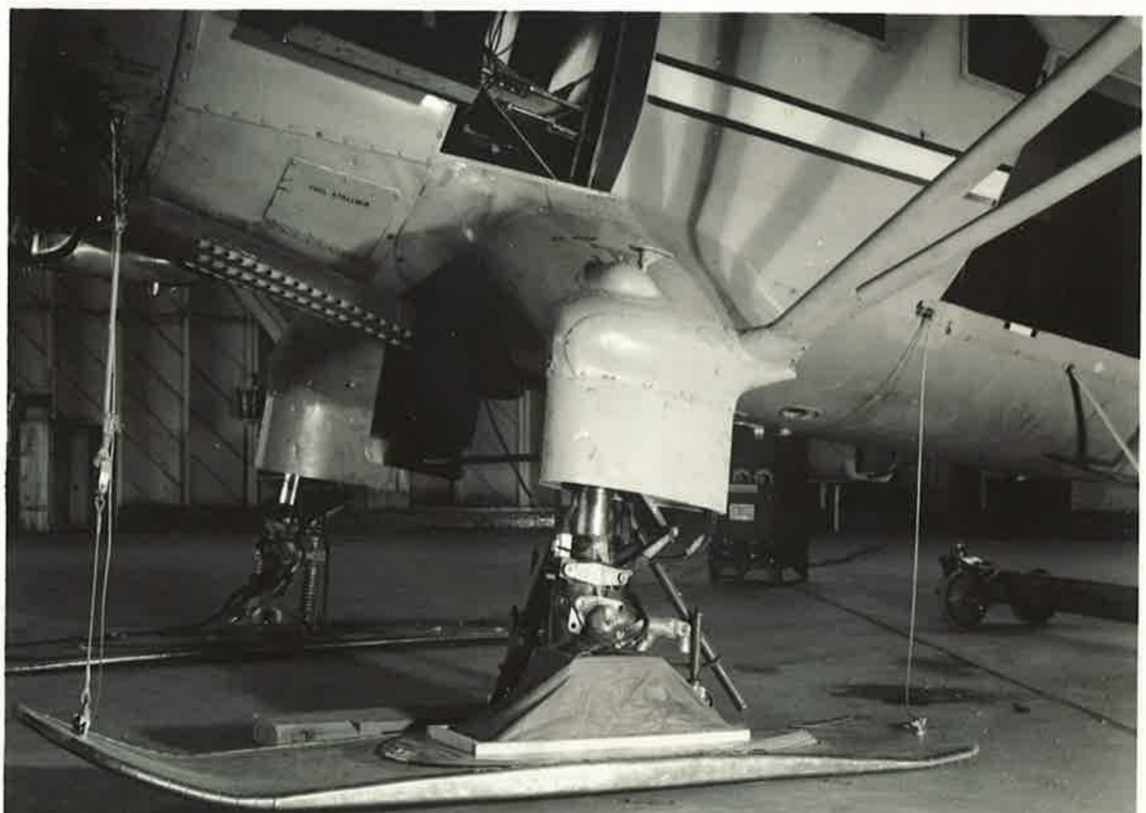


(b)

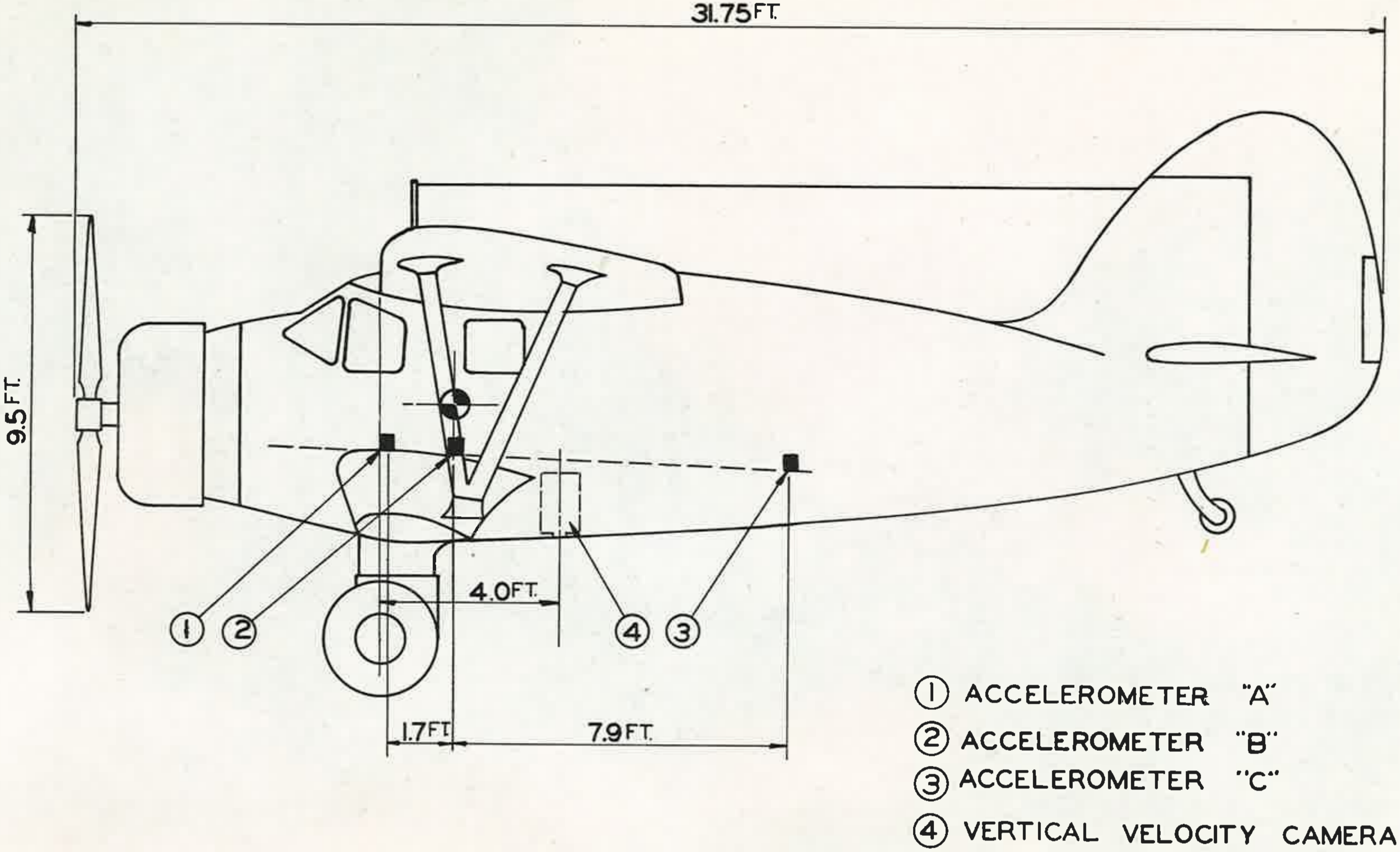
LOAD PEDESTAL ASSEMBLY



(a) RECORDING INSTRUMENTS

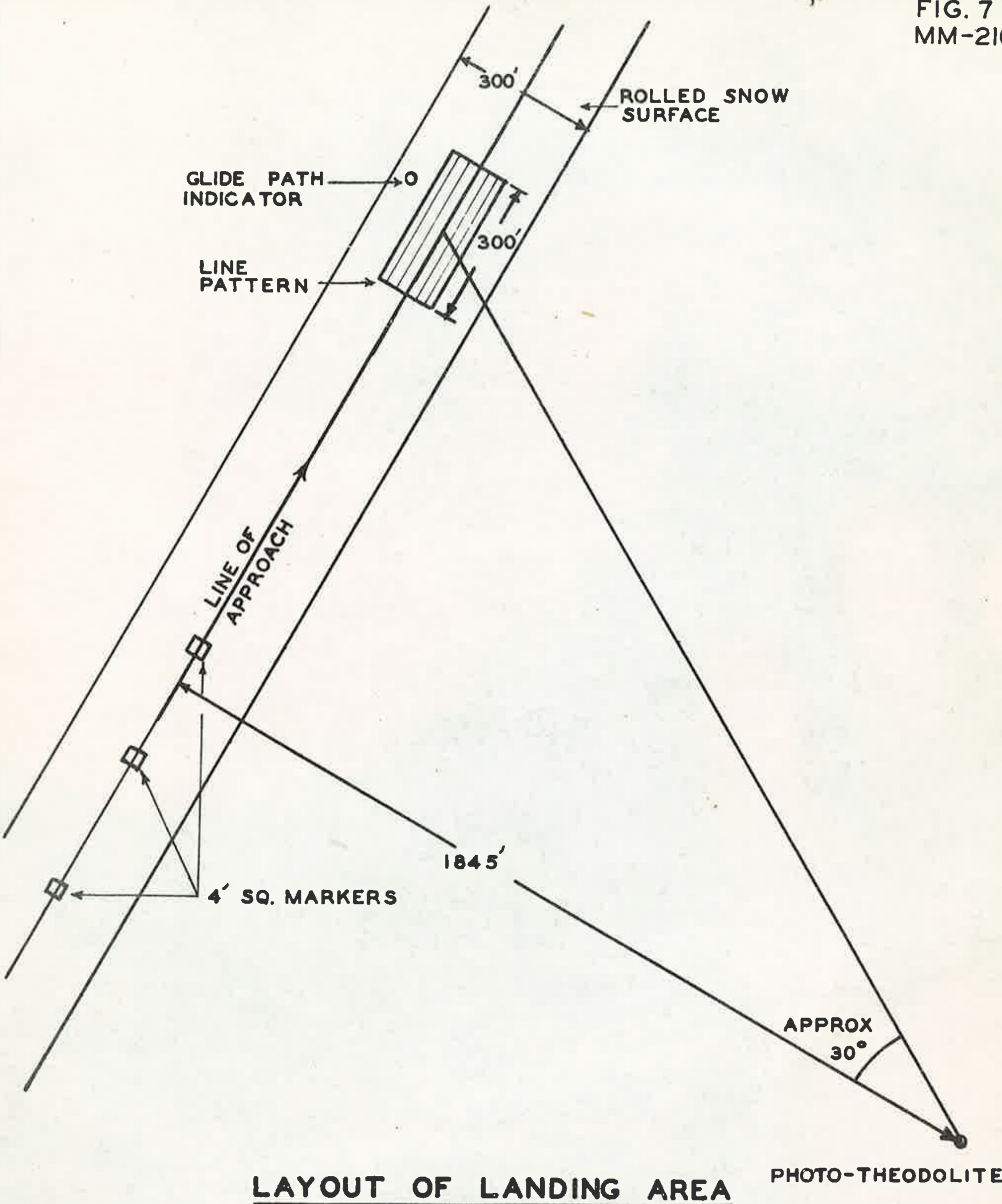


(b) SKI INSTALLATION



LOCATION OF EQUIPMENT IN THE AEROPLANE

FIG. 6
MM-210



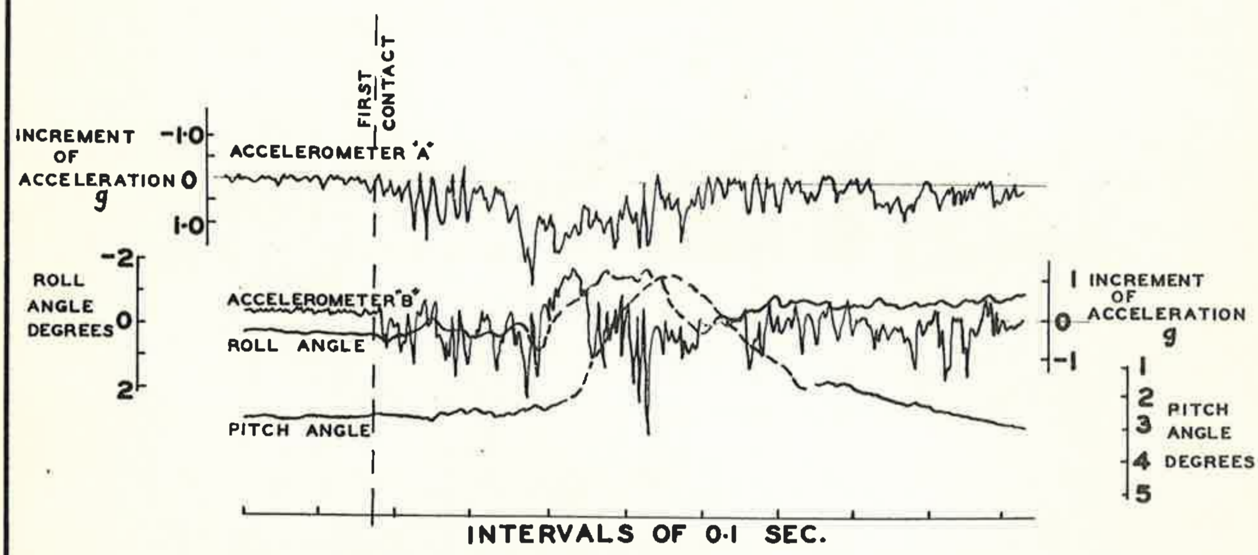
LAYOUT OF LANDING AREA DURING SKI TESTS

FIG. 8
MM-210

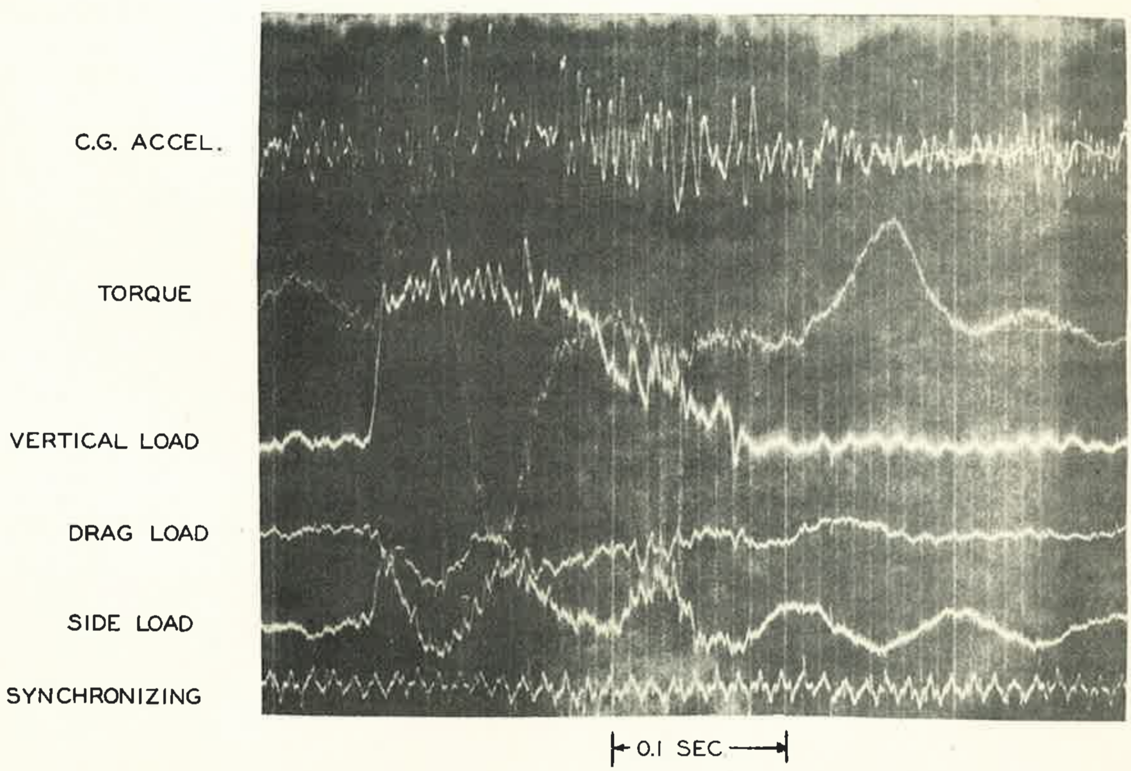
GLIDE PATH INDICATOR

FIG. 9
MM-210

TYPICAL E_N BOX RECORD OF SKI LANDING



TYPICAL LOAD RECORD



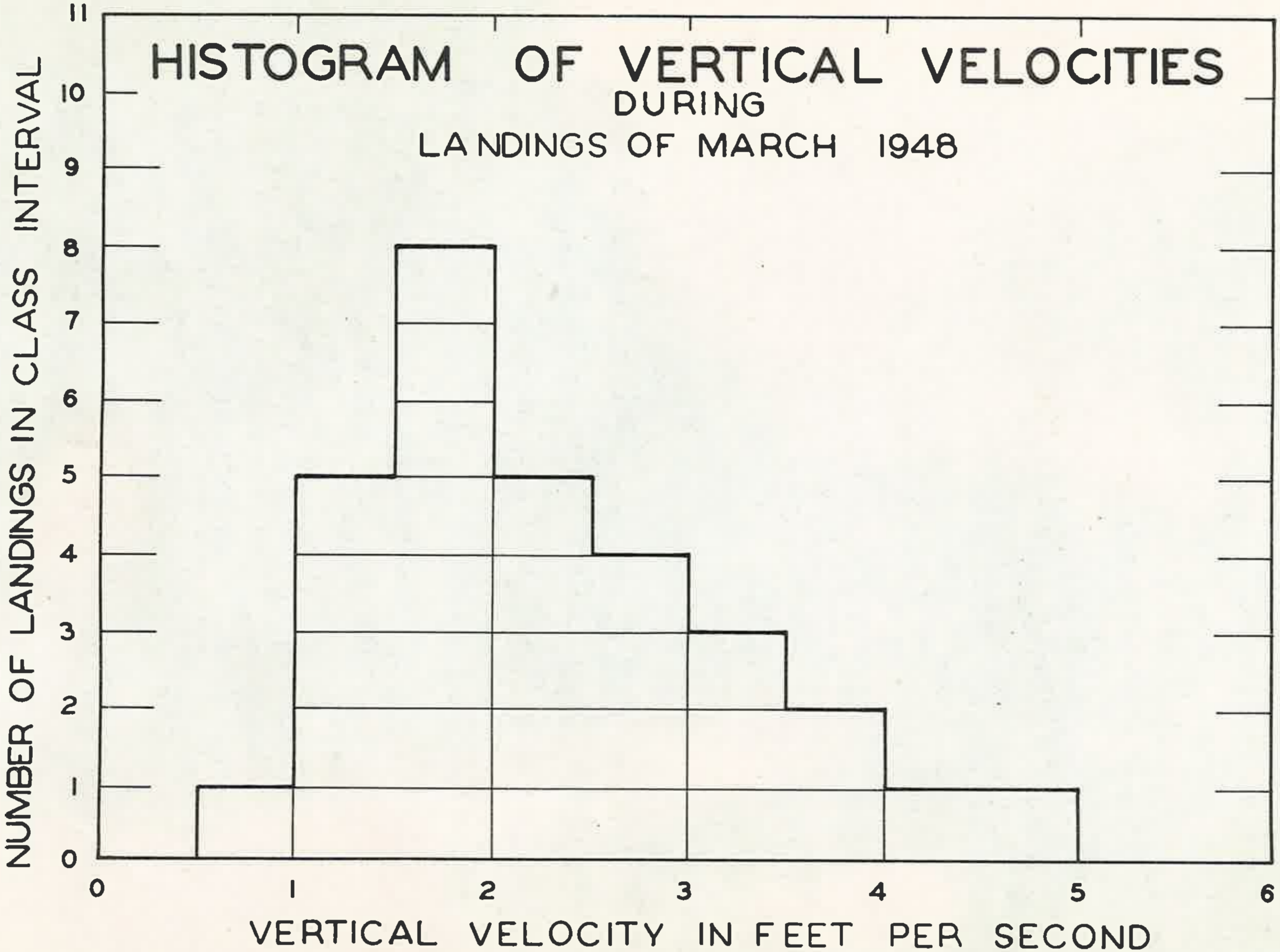

HISTOGRAM OF VERTICAL VELOCITIES
DURING
LANDINGS OF MARCH 1948
NUMBER OF LANDINGS IN CLASS INTERVAL
0
1
2
3
4
5
6
7
8
9
10
11
0
1
2
3
4
5
6
VERTICAL VELOCITY IN FEET PER SECOND

FIG. 10
MM-210

MAXIMUM NORMAL ACCELERATION

DURING LANDING IMPACT

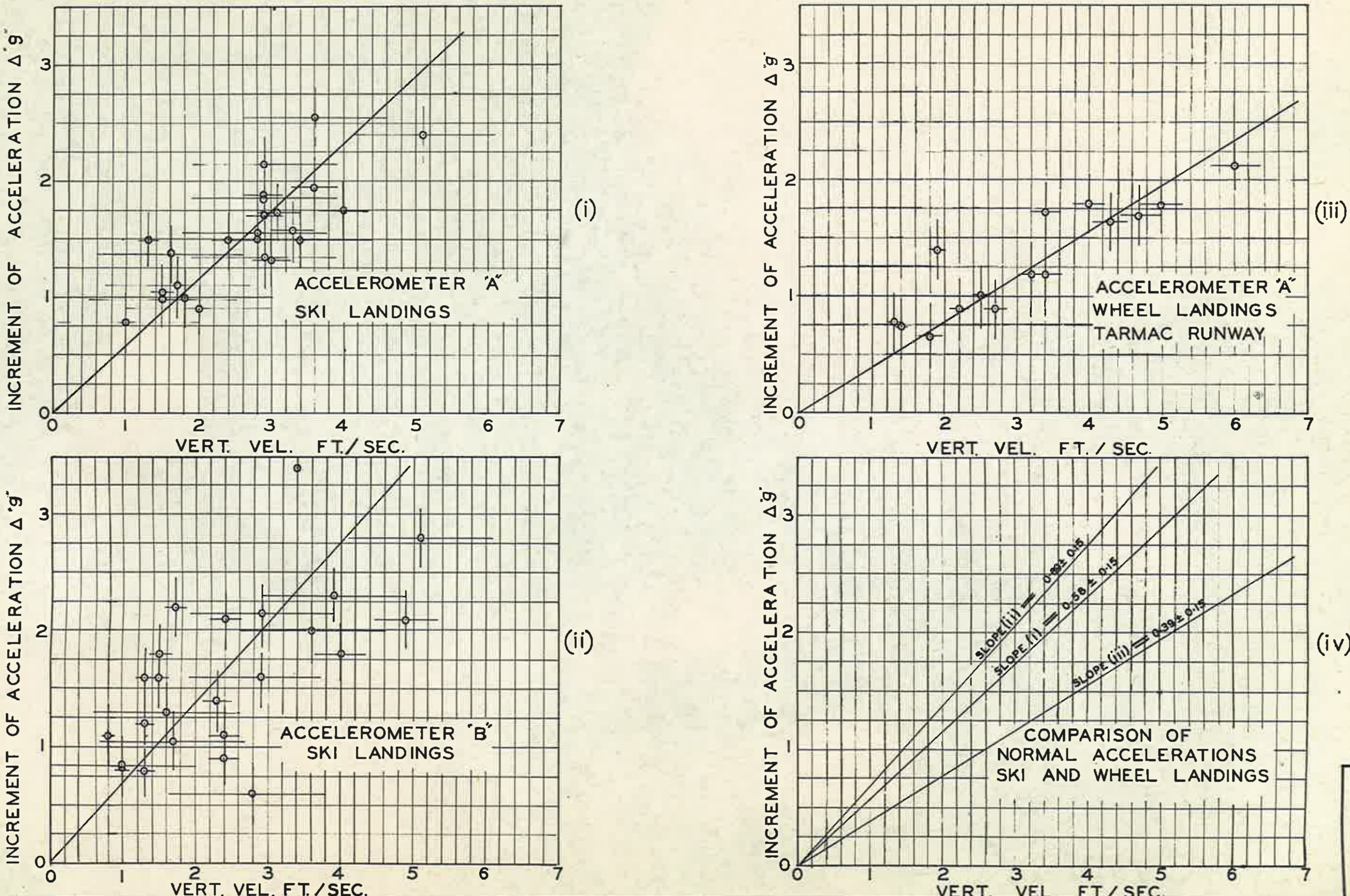


FIG. 11
MM-210

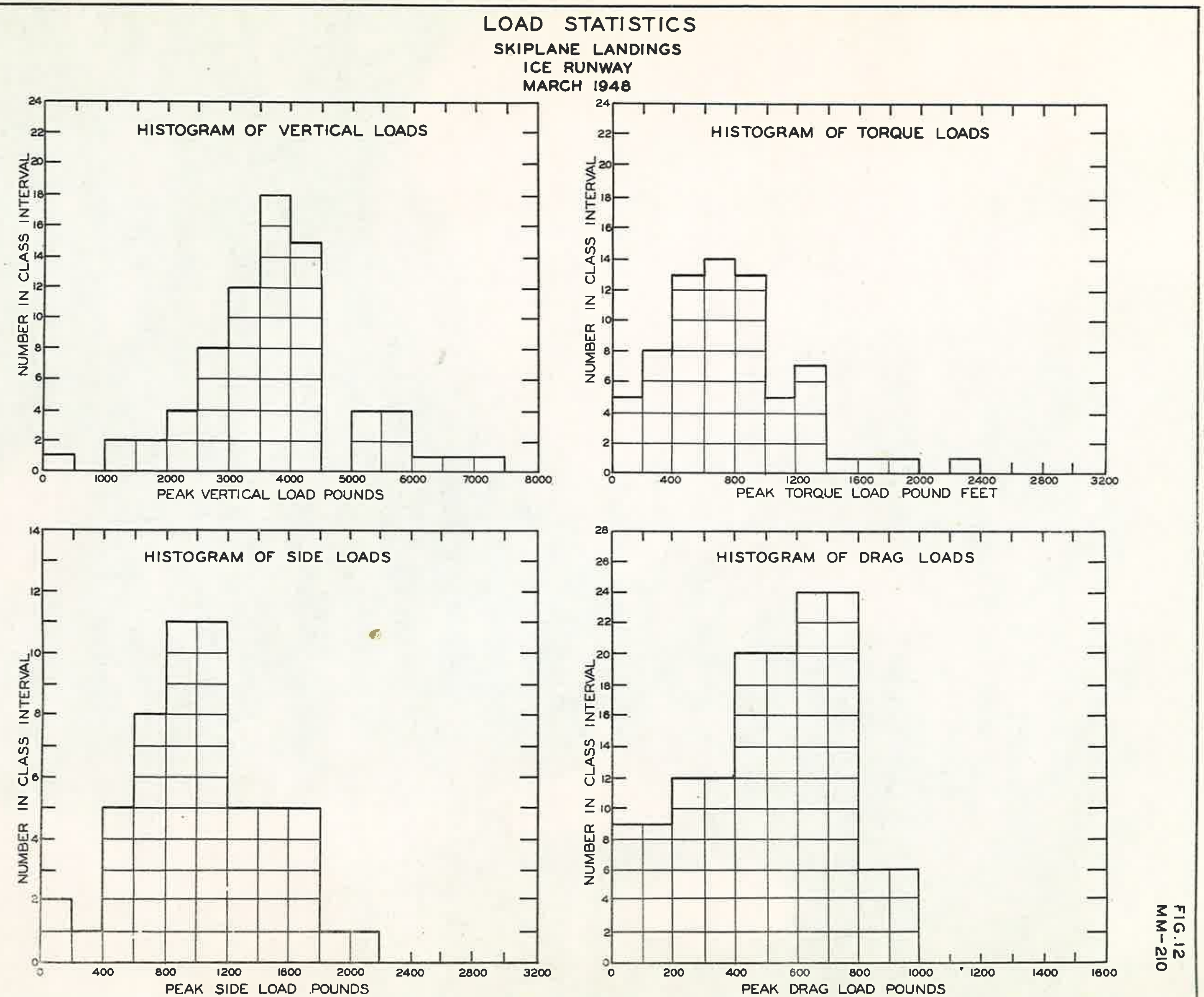
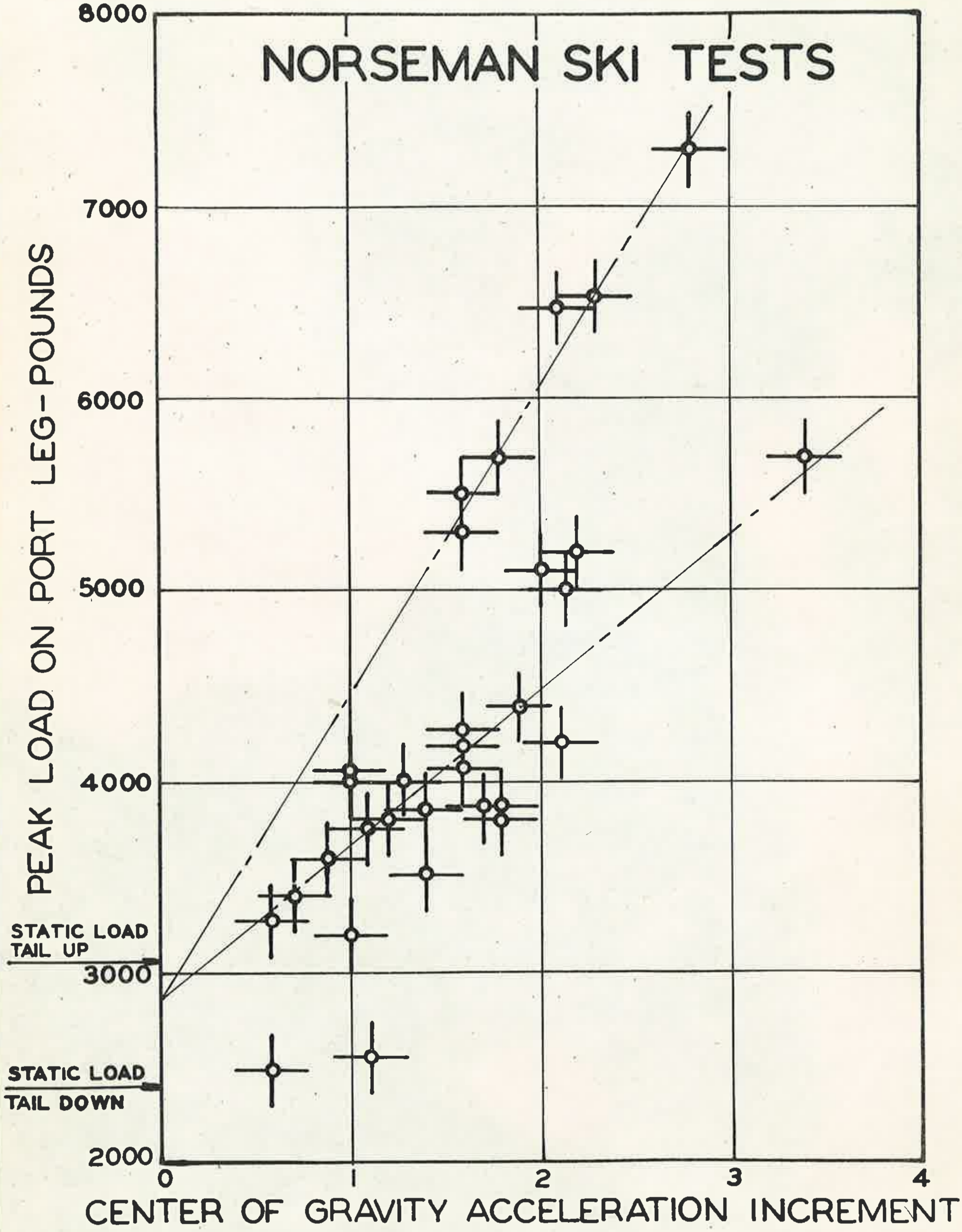

LOAD STATISTICS
SKIPLANE LANDINGS
ICE RUNWAY
MARCH 1948
HISTOGRAM OF VERTICAL LOADS
NUMBER IN CLASS INTERVAL
PEAK VERTICAL LOAD POUNDS
HISTOGRAM OF TORQUE LOADS
PEAK TORQUE LOAD POUND FEET
HISTOGRAM OF SIDE LOADS
PEAK SIDE LOAD POUNDS
HISTOGRAM OF DRAG LOADS
PEAK DRAG LOAD POUNDS

FIG. 12
MM-210

FIG. 13
MM-210



NORSEMAN SKI TESTS
PEAK LOAD ON PORT LEG-POUNDS
8000
7000
6000
5000
4000
3000
2000
STATIC LOAD
TAIL UP
STATIC LOAD
TAIL DOWN
0
1
2
3
4
CENTER OF GRAVITY ACCELERATION INCREMENT

VARIATION OF COEFFICIENT OF FRICTION WITH SKI LOADING

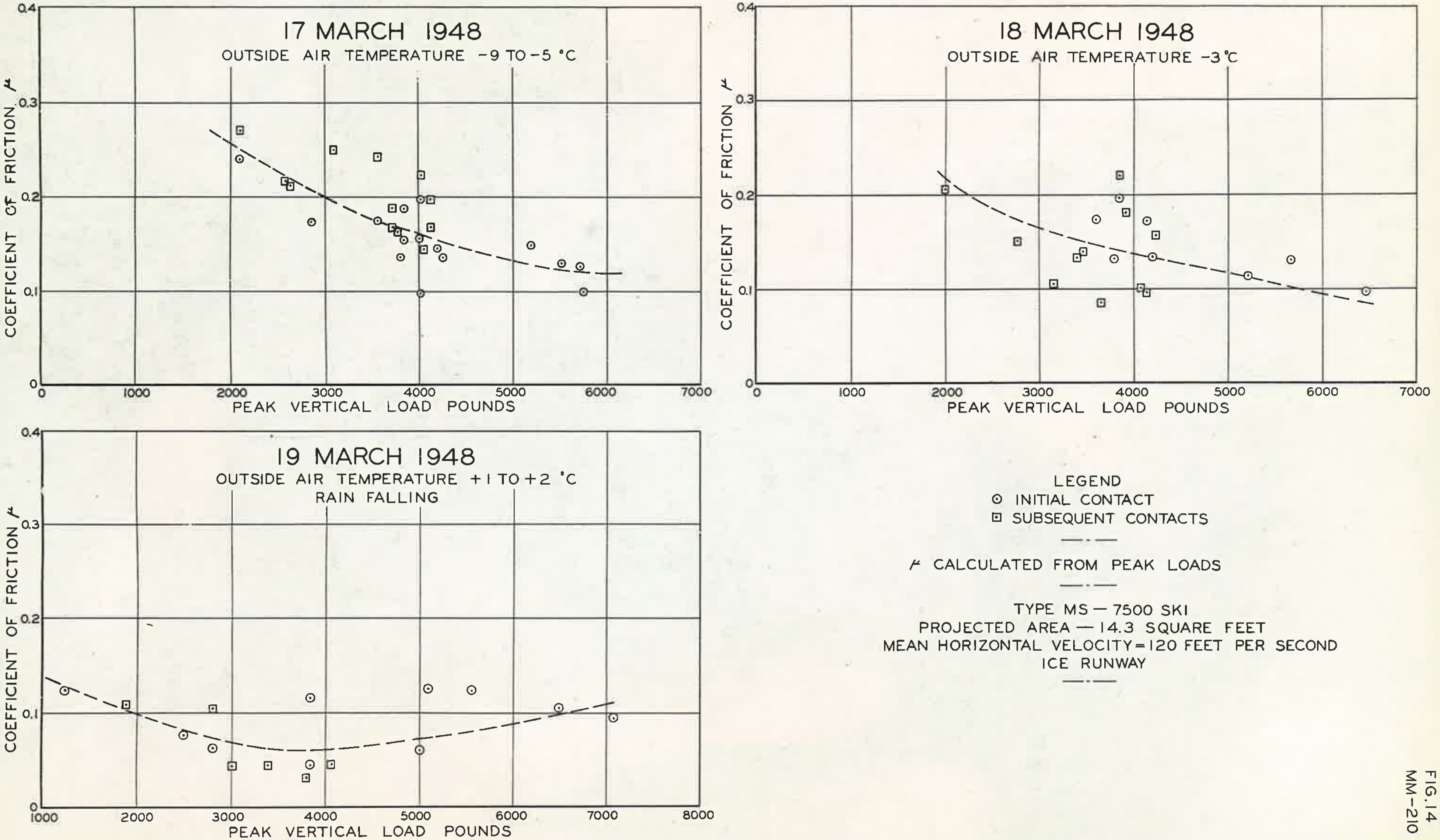
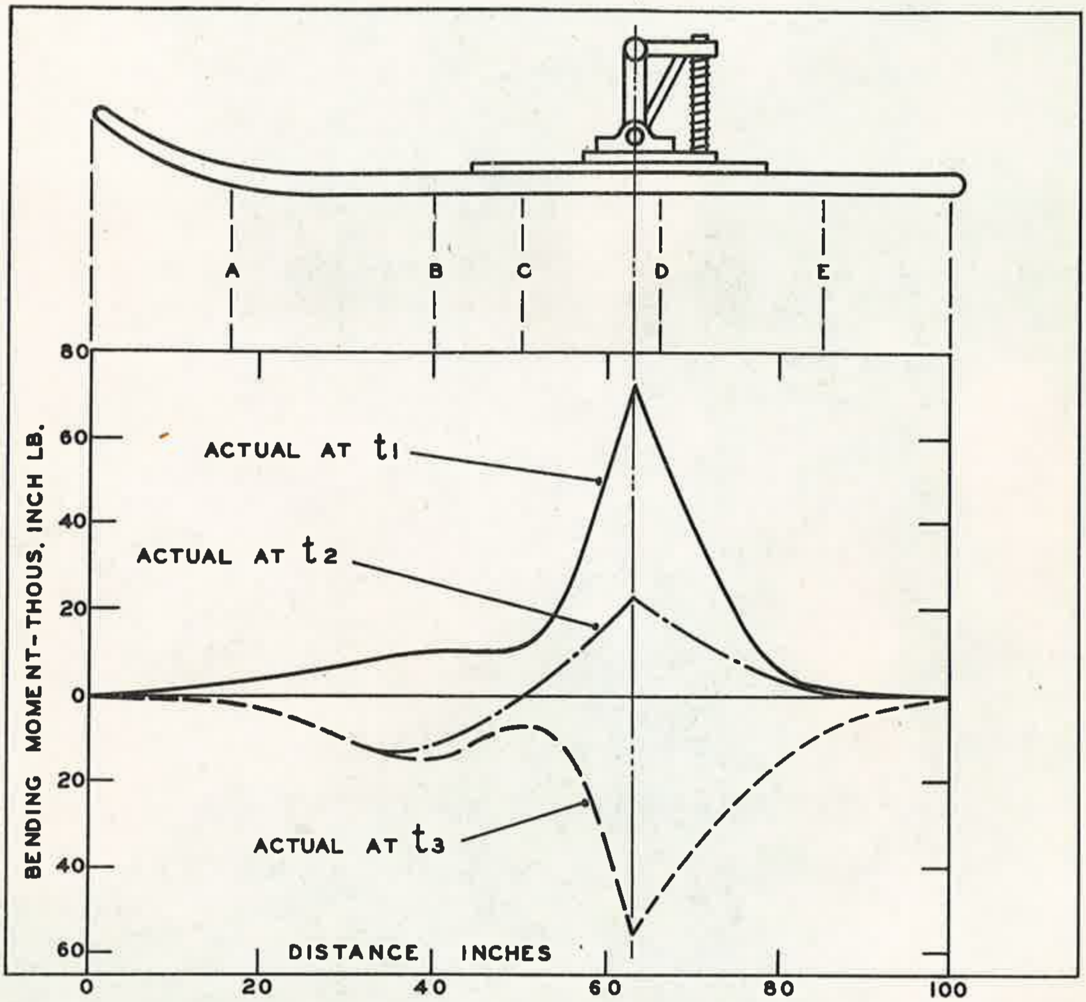


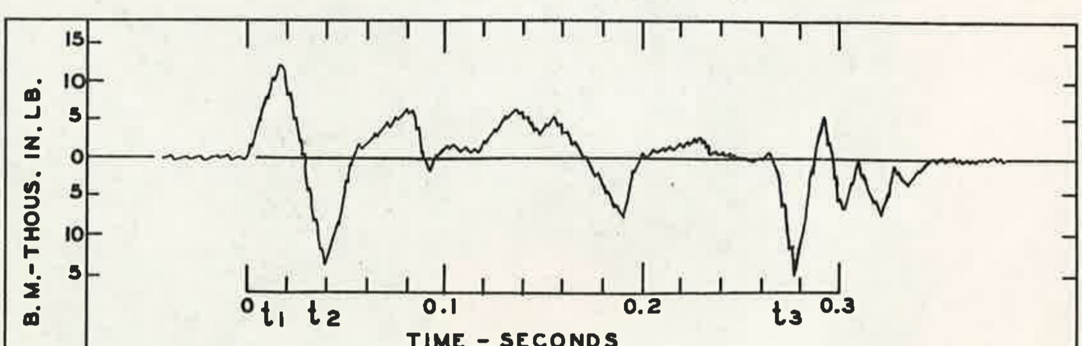
FIG. 14
MM-210

FIG. 15
MM-210

TYPICAL SKI RESPONSE



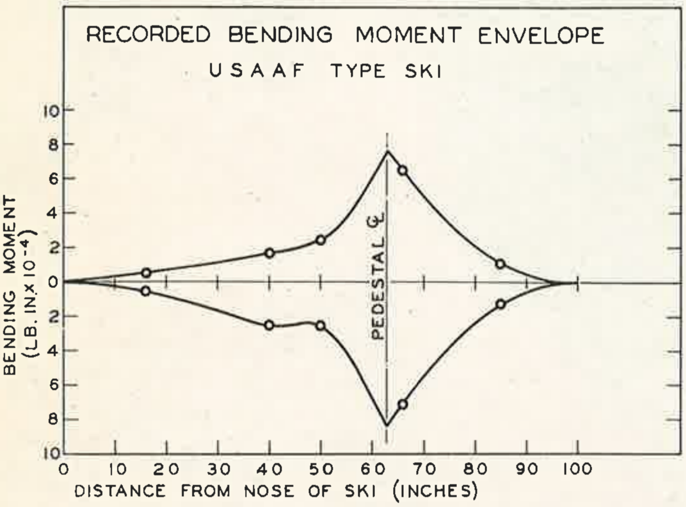
BENDING MOMENT DISTRIBUTION ALONG SKI



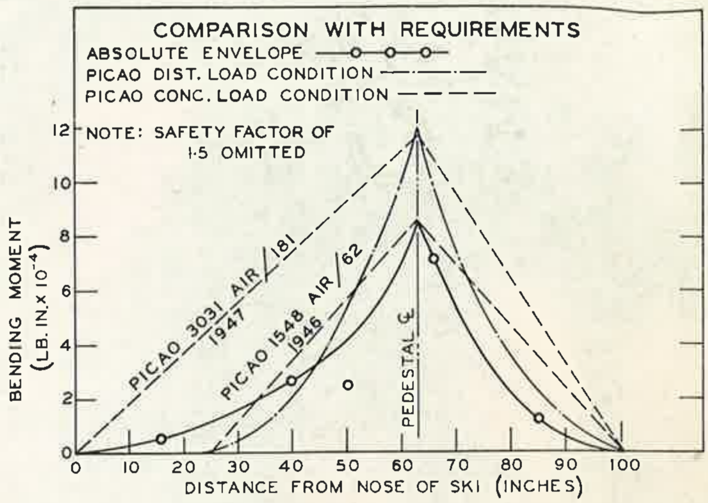
VARIATION IN BENDING MOMENT WITH TIME AT STATION "B"

BENDING MOMENTS

MARCH 1947

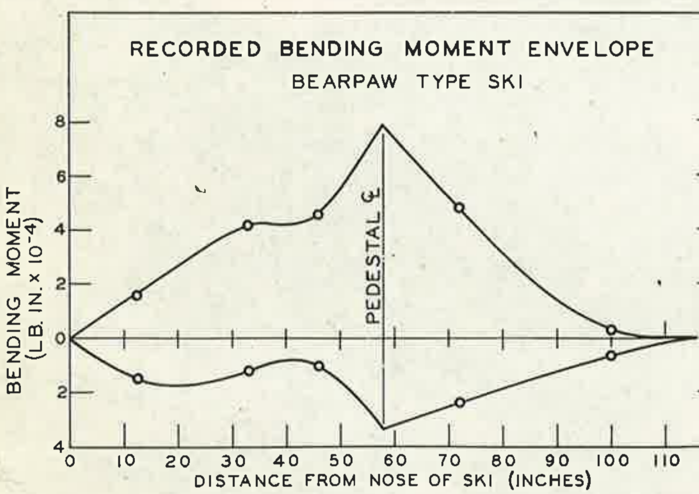


(a)

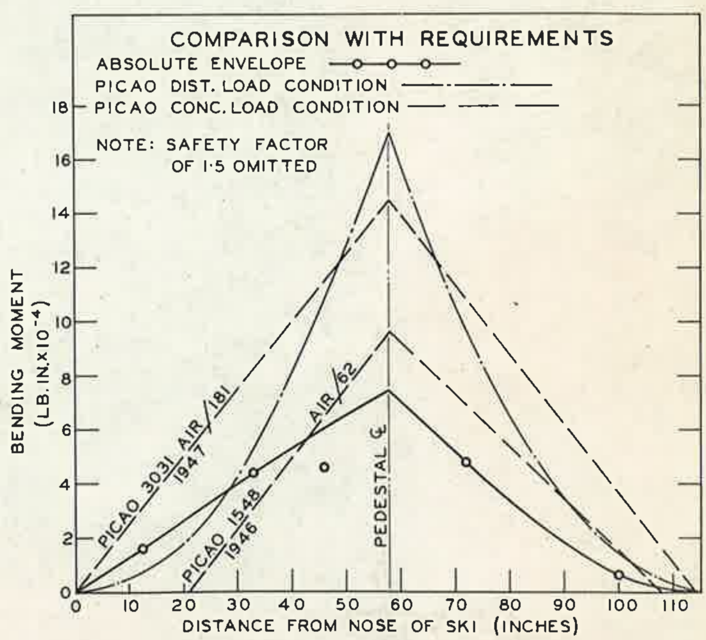


(b)

USAAF TYPE SKI
MODEL 16-6



(c)



(d)

BEARPAW TYPE SKI
MODEL 4-15