## Flight tests on undercarriage loads for a single-engined aircraft equipped with skis

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# FLIGHT TESTS ON UNDERCARRIAGE LOADS FOR A SINGLE-ENGINED AIRCRAFT EQUIPPED WITH SKIS

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BY

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SUMMARY

Results are presented of a series of tests to determine the loads experienced by a ski undercarriage while landing and during other ground manoeuvres. Tests cover a wide range of snow conditions.

Comparison is made between skis of different plan form and area. Occasional very severe vertical loads are found to result from landings made on undulating snow surfaces encountered north of the tree-line. The highest torque load on a ski may be produced by external manipulation of the aircraft unless the nature of such ground handling is restricted.

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# FLIGHT TESTS ON UNDERCARRIAGE LOADS FOR A SINGLE-ENGINED AIRCRAFT EQUIPPED WITH SKIS

## 1. INTRODUCTION

It is the purpose of this report to present accumulated data on the maximum pedestal loads experienced in operation by a single-engined aircraft equipped with skis.

The tests reported constitute an extension of a programme initiated in 1947 from which limited data was made available and published in Reference 1. Further instrumentation of the aircraft to include load measurements on two skis and a greatly increased number of records obtained in different localities have provided information of greater statistical significance. It is not intended that this report should include an analysis of the pecularities in load development associated with ski landings. It is thought rather that a compilation of peak ski-load data and a statement of the circumstances under which such loads occurred will be of convenience in further treatment of the results and of some general interest to those concerned with the design of ski-equipped aircraft.

## 2. SCOPE OF TEST PROGRAMME

The principal objectives of the work undertaken have been stated in Reference 1. It was realized that the variable nature of the surface provided by snow-cover necessitated a rather large number of individual records covering as wide a range of snow characteristics as could be found, in addition to the other variables normally associated with aircraft ground loading cases. It was decided that the greater part of this programme could be conducted at Arnprior, Ontario, where over a period of two months, snow conditions would be roughly representative of conditions elsewhere south of the tree-line.

Tests for which load records were obtained are classified in Table I.

To include snow surface conditions known to be peculiar to barren, wind-swept areas, the aircraft was flown to Churchill, Manitoba, where further landing, take-off and taxi tests were made between 17th and 21st March 1949.

All flying was carried out by five pilots of the R.C.A.F. Their cooperation, together with that of other R.C.A.F. personnel, is gratefully acknowledged.

## 3. AIRCRAFT AND INSTRUMENTATION

Some of the equipment used has already been described in Reference 1. Since certain changes have been made, a summary is included here for completeness.

### 3.1 Aircraft

The Noorduyn Norseman Mk. VI aircraft shown in Figure 1 was used throughout the test programme.

Details of the configuration are given in Table II.

### 3.2 Skis

Two pairs of skis were used during tests at Arnprior. Principal characteristics are listed in Table III.

Only the MS 7500 type skis were flown at Churchill. The installation of these skis is shown in Figure 2.

### 3.3 Measuring and Recording Equipment

A summary of the quantities measured and recorded and the estimated precision of measurement is given in Table IV. Each ski was provided with a four-component load-measuring pedestal as described in Reference 1. The four components were measured with reference to the ski bottom in the vertical, drag, side and torque directions.

Three accelerometers, all with differential transformer type pickups, were mounted to a rigid frame at the centre of gravity of the aircraft. The accelerometers responded respectively to normal acceleration, angular acceleration in the pitching plane, and angular acceleration in the rolling plane. A sled-mounted cine-camera, which could be located wherever landings were being made, was used for the measurement of vertical velocity at impact. The camera was placed on the approach path and photographed the aircraft from astern during landing. The camera installation is shown in Figure 3(b).

Guidance for the pilot in making certain impacts at specified rates of descent was provided by a type of visual glide-path control.

Recording equipment within the aircraft was a 5000 c.p.s. carrier system feeding into 375 c.p.s. galvanometers with 60 per cent critical damping. Simultaneous time histories for the three accelerations and four component loads from each ski were obtained on the same film. The operator's position and location of recording equipment are shown in Figure 3(a).

Aircraft attitude was not recorded within the aircraft but can be determined where necessary from cine-camera films. It has been found in many cases that irregularities in the snow surface are of greater significance than small angles of roll at the instant of contact.

## 4. SNOW MEASUREMENTS

A record was kept of changes in snow condition taking place from day to day in the course of tests at Arnprior. The snow measuring equipment and procedure described in Reference 2 were used for this purpose. Snow characteristics for the days on which flying took place are given in Tables V and VI.

A few of such measurements were also made at Churchill. It is considered that in this area the factors influencing ski loads result primarily from changes in surface form due to wind erosion and drifting, rather than from variations of temperature and snow grain structure. Conditions encountered are given in Table VII.

## 5. PRESENTATION OF RESULTS

### 5.1 Tests at Arnprior, Ontario

During each flight approximately three normal landings and six initial impacts without subsequent landing runs were recorded. The data obtained was thus arranged to give roughly the same number of samples for each particular snow condition. In the majority of cases recordings were also made during two taxi runs and two take-offs.

#### 5.1.1 Normal Landings

The maximum load recorded by each channel during the landing process, without reference to the time at which it occurred, has been measured for all landings made following entirely normal procedure.

Results obtained with each pair of skis are plotted in the form of histograms in Figures 7 and 8.

#### 5.1.2 Initial Landing Impacts

Recordings were terminated at the end of the first landing impact.

Values of peak drag are plotted against peak vertical load in Figures 14 to 18, each figure representing impacts carried out on one snow condition over a range of vertical velocities.

Side and torque loads during the impact are dependent upon the degree of asymmetry in addition to the velocities parallel with and normal to the snow surface. For convenience, these loads have also been plotted as histograms in Figure 9, although their significance is reduced by the amount by which side and torque loads are influenced by the unusually high mode of vertical velocities.

The relation between vertical velocity and normal acceleration at the centre of gravity is plotted in Figure 12. In the presence of the wide scatter evident in this figure, there is no distinguishable difference in slope for the two pairs of skis.

Normal acceleration at the centre of gravity is plotted against the sum of the port and starboard peak loads at impact for both pairs of skis in Figure 13. Mean slopes of the experimental data for the two types of ski are also coincident.

In Figure 21 peak vertical load occurring at each ski is plotted against the measured vertical velocity at impact. The experimental upper limit for the vertical load on one ski is shown as an envelope to the test data.

Figure 22 shows the data of Figures 14 to 18 superimposed to provide a basis for similar envelopes indicating the maximum drag load experienced by each type of ski over the range of applied vertical loads.

### 5.1.3 Cross-Wind Effects

The effect of excluding landings and impacts made in the presence of appreciable cross-wind is shown in the histograms. Results indicate that none of the extreme side and torque loads experienced can be attributed to the effects of cross-wind, nor is there any effective raising of the mode by including cross-wind cases.

### 5.1.4 Take-Offs into Wind

From inspection of recordings, peak loads experienced are in every case of lower order than those recorded during landings. The only measurements included are values of adhesion and sliding resistance obtained at the start of the take-off runs. These values are given in Table IX.

### 5.1.5 Taxi Runs and Turns while Taxiing

Adhesion and sliding resistance measurements are included in Table IX with those measured during take-off runs. Maximum turning loads are regarded as being the sum of:

(a) A steady load originating from the curved path of the aircraft.

(b) The maximum random peak load arising from irregularities in the snow surface.

The values measured are given in Table X.

5.1.6 Ground Handling Loads

A few tests were made to assess the effects of applying a transverse load at the tail of the aircraft to obtain a break-out of the main skis.

Table XI shows the results of two such tests made on unrolled and rolled snow under conditions for which a high value of adhesion could be expected.

5.2 Tests at Churchill, Manitoba

In this region snow conditions are characterized by the size and distribution of hard snow hummocks.

Selection of areas which could be regarded as typical of the surface normally encountered by ski-equipped aircraft was made with the assistance of pilots experienced in Northern operations.

It was found that on most lake surfaces landing and take-off paths could be chosen which avoided the largest snow hummocks.

Figures 4(a) and 4(b) show typical surface conditions.

5.2.1 Normal Landings

Loads encountered during normal landings carried out at points within a radius of seventy miles from Churchill are presented as histograms in Figure 10, with the reservation that two of the landings were deliberately made on a particularly severe area. During one of these landings the largest hummocks were still avoided. During the second landing run a large hummock, unnoticed by the pilot, was struck approximately 100 yards after first touching down. This momentarily threw the aircraft out of control and produced the very severe vertical loads of 15,620 lb. on the starboard ski at the instant of impact and 23,390 lb. on the port ski after the subsequent bounce. Part of the time history of this landing is shown in Figure 25.

Figure 5(b) is a side view of a similar hummock. Figures 5(c) and 5(d) show the effect of ski impact on the leeward (drifted) side.

On completion of the ski tests at Churchill, failures were found to have occurred at the inboard lugs attaching the port pedestal to the ski (see Fig. 6). It is thought that failure occurred during the particularly severe landing reported.

It should be pointed out that the vertical load recorded by the port ski on this occasion is approximately 18 per cent greater than design ultimate based on ICAO Doc. 1548. It is possible that this load was taken principally on the outboard edge of the port ski, thus shearing the inboard lugs in the downward direction.

5.2.2 Take-Offs

Histograms of drag, torque, and side loads during take-offs are shown in Figure 9. The corresponding histogram for vertical loads is not included. For all four load components both the mode and extreme values are lower than those obtained during landings.

5.2.3 Taxi Runs and Taxiing Turns

Maximum turning loads recorded are included with results obtained at Arnprior, in Table X.

Some measurements were made of the angular travel of skis while taxiing slowly over irregular surface conditions.

The maximum ski-angle measured while traversing large hummocks (see Fig. 5(a)) was twenty-two degrees.

5.3 Effects of Ski Shape and Unit Loading

5.3.1 On Ski Drag

Whenever possible, both pairs of skis were flown on similar snow conditions.

Direct comparison of results obtained on the same day (see Fig. 20) are rather inconclusive, although slightly lower values of the ratio peak drag/peak vertical load at impact are shown by the MS 7500 type skis.

Figure 22 indicates that if the overall results are considered, this is generally the case; the maximum drag loads recorded being of order 10 to 20 per cent higher for the Bear Paw type skis. This figure also indicates a general

tendency for the ratio peak drag/peak vertical load for each set of skis to fall with increasing (momentary) unit loading. No consistent trend is apparent in the results of separate flights plotted in Figures 14 to 18.

5.3.2 On Side Load and Torque

Reference to Figures 7, 8 and 9 shows that the mode and extreme values of side load and torque are considerably lower in the case of the parallel-sided skis.

5.4 Effects of Variation in Snow Characteristics

The purpose of Tables V and VI is to provide a means of assessing the extent to which the snow conditions encountered at Arnprior can be considered as representative.

The degree of scatter present in Figures 14 to 18 prevents separation of any but the broadest controlling features.

The influence of air temperature on the drag obtained for a given vertical load during impact is indicated in Figure 23. The mean values obtained from Figures 14 to 18 are shown together with the upper and lower limits recorded on each day.

Variation of the degree of scatter in the relation between peak drag and peak vertical load may be attributed to some extent to local differences in snow condition at the points at which successive landings were made and to differences in the nature of drag and vertical load development. Two different forms of drag development are illustrated in Figure 24.

The influence of surface hardness and depth of ski penetration is also present but not indicated in Figure 23. The lower points in this diagram in all cases refer to results obtained on hard surface conditions. The higher values were obtained in the presence of loose snow and breakable crust.

6. CONCLUSIONS

The maximum component loads recorded throughout the tests are summarized in Table XII. It is thought that the range of snow conditions covered is sufficient to allow the maximum values quoted, with the exception of drag, to be treated with confidence.

Test data is rather lacking on very soft, deep snow but it is considered that the major effect of deeper snow would be in producing higher drag loads. In view of the trends already evident it is unlikely that the maximum value of drag at impact would ever exceed 3500 pounds.

Tests at Arnprior indicate the superiority of narrow parallel-sided skis in incurring lower drag, torque, and side loads. The adhesion of these skis was also found to be the more easily overcome. External assistance while breaking-out using engine was seldom necessary. When required it was sufficient to rock the wings of the aircraft and kick the tails of the skis.

It was noted, however, that at Churchill, a similar aircraft equipped with narrow, bakelite-surfaced skis, and parked close to the test aircraft, always required considerably greater effort to establish break-out. This was usually achieved by the use of full throttle and elevator and the assistance of two men pulling laterally at the tail with a rope.

The torque applied to the main skis in this way is thought to be of about the same order as that recorded in Table XI, Test 1. It is not doubted that under even more unfavourable circumstances higher torque loads could be applied deliberately to the main skis by vicious ground handling. It is suggested that the values quoted are of the order likely to be encountered by the particular combination of skis and aircraft, while landing, taking off, or taxiing, in overcoming adhesion or during normal ground handling. The extent to which allowance should be made for more severe handling of the aircraft on the ground, such as continued rotation about its vertical axis while being manoeuvred by tractor on wet snow, is not within the scope of this report.

The possible influence of ski-bottom material on the drag loads quoted may be inferred from Reference 3.

The maximum values of vertical and side loads obtained with the narrow skis occurred while landing on undulating snow. While the maximum side load figure is not excessive, the magnitude of the maximum vertical load recorded is disturbing.

From the test data no realistic estimate can be made of the probability of incurring a load of this order, since it depends entirely upon the presence and distribution of large hummocks on the landing surface chosen. It is considered likely that during prolonged operations north of the tree-line a small proportion of all landings will be made on hummock conditions of about this degree of severity and that an occasional vertical load of the order quoted can be expected.

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Method of Measuring the Significant Characteristics of a Snow-Cover.
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The Snow Characteristics of Aircraft Skis.
Aeronautical Report No. AR-2, 1947,
National Research Council, Ottawa.

# TABLE I

## CLASSIFICATION OF SKI TESTS

| Nature of Test | Comments on Test Method and Application |
|---|---|
| 1. Landings into wind. | Aircraft generally in the three-point attitude at contact. No deliberate attempt made to obtain high impact vertical velocities. Peak loads during complete landing process considered. |
| 2. Initial landing impacts. | Vertical velocity at impact varied up to approximately 10 ft. per sec. Aircraft generally in the flying attitude at contact. Peak loads during initial impact considered. |
| 3. Landings and impacts in the presence of a cross-wind. | Normal procedures used for reducing drift at contact to a minimum. Peak loads as for 1 and 2 considered. |
| 4. Take-offs into wind. | Recordings made from the stationary position to include loads incurred during break-out. Full use of engine and main controls and external assistance where necessary in overcoming adhesion resistance. |
| 5. Taxi runs and turns while taxiing. | Turns made as sharp as considered permissible to the pilot and within the capabilities of the aircraft. |
| 6. Ground handling loads. | Resistance of skis to sliding in the direction of an applied torque. |
| 7. Effects of ski shape. | A proportion of all tests made using skis of tapered plan form and lower unit loading. |
| 8. Effects of snow condition. | Separation of any evident controlling features from overall data. |

# TABLE II

## AIRCRAFT CONFIGURATION

| | |
|---|---|
| Wing span, ft. | 51.5 |
| Overall lengths, ft. | 31.75 |
| Wing area, sq. ft. | 296.3 |
| Mean aerodynamic chord, ft. | 7.25 |
| Wing section | NACA 2412 |
| $V_{s_o}$, m.p.h. | 68 |
| Gross weight at take-off, lb. | 6300 |
| Longitudinal position of centre of gravity, per cent MAC | 16.75 |
| Height of centre of gravity above ground, aircraft in the flying attitude, ft. | 7.05 |
| Distance between centre lines of port and starboard skis, ft. | 9.53 |
| Distance of centre of gravity aft of ski axles, aircraft in flying attitude, ft. | 1.48 |

# TABLE III

## SKI CHARACTERISTICS

1. North-West Industries Type MS 7500

   Length: 98.25 in.

   Width: 21 in.

   Contact length (approximately): 68 in.

   Contact area (approximately): 10 sq. ft.

   Plan form: Parallel sides.

   Bottom material: Brass.

2. Noorduyn Aircraft Company Model 4-15 (Bear Paw) Type Ski

   Length: 116 in.

   Max. Width: 32 in.

   Contact length (approximately): 87 in.

   Contact area (approximately): 15.1 sq. ft.

   Plan form: Tapered from 32 in. to 18 in. at the rear.

   Bottom material: Brass.

## TABLE IV

CHARACTERISTICS OF MEASURING EQUIPMENT

| Quantity | Measuring Equipment | | Measuring Accuracy |
|---|---|---|---|
| | | Natural Frequency | |
| 1. Vertical load at pedestal. | Strain gauge ski pedestal (see Ref. 1) | 0.043 sec. | ± 400 lb. |
| Drag load at pedestal. | | 0.014 sec. | ± 50 lb. |
| Side load at pedestal. | | 0.014 sec. | ± 100 lb. |
| Torque at pedestal. | | 0.055 sec. | ± 50 lb. ft. |
| 2. Normal acceleration at C.G. | 90 c.p.s. accelerometer. Fluid damping 0.6 critical. | | ± 0.1 g. |
| 3. Rolling acceleration at C.G. | 13 c.p.s. angular accelerometer. Fluid damping 0.6 critical. | | ± 0.5 rads/sec$^2$ |
| 4. Pitching acceleration at C.G. | 18 c.p.s. angular accelerometer. Fluid damping 0.6 critical. | | ± 0.5 rads/sec$^2$ |
| 5. Vertical velocity at instant of contact. | Cine-camera. | | ± 1/2 ft. per sec. |
| 6. Indicated airspeed. | Pilot's indicator. | | ± 3 m.p.h. |
| 7. Wind velocity and direction. | Cup anemometer and wind vane. | | ± 3 m.p.h.<br>± 10°. |

TABLE V - SNOW CHARACTERISTICS MEASURED DURING SKI TESTS AT ARNPRIOR

| Date | Total Depth in. | Snow Temp. °C. | Air Temp. °C. | Top Layer | | | | | | Second Layer | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Depth in. | Hardness gm./cm.2 | Grain size, mm. | Grain type | Free water content, % | Specific Gravity | Depth in. | Hardness gm./cm.2 | Grain type | Specific Gravity | |
| 11.1.49 | 12 | -10 | -10 | 4 | 225 | 1.5 | Settled | | 0.306 | | | | | Smooth with firm crust. |
| 14.1.49 | 12 | | - 8 | No Snow Measurements | | | | | | | | | | 4" new snow on crust. |
| 18.1.49 | 14 | - 5 | - 6 | 3 | 500 | 0.5 | Old | | 0.36 | 3 | 50 | Old | 0.34 | Crust at surface and at 3". |
| 20.1.49 | 11 | -13 | -14 | 1.5 | 5250 | 2.5 | Old | | 0.36 | 4 | 3500 | Old | 0.34 | Firm old snow. Rain crust at surface. |
| 25.1.49 | 10 | - 8 | -10 | 1 | | 1.5 | Old | | 0.30 | 2 | | Old | 0.32 | 1" loose snow on layers of crust. |
| 27.1.49 | 11 | - 6 | - 1 | 1.5 | 125 | 2.5 | Settling | | 0.26 | 3 | 350 | Old | 0.36 | Settling snow on firm crust. |
| 31.1.49 | 11 | | - 8 | No Snow Measurements | | | | | | | | | | 1" new snow on crust. |
| 1.2.49 | 12 | -2.5 | - 4 | 3 | 15 | 0.5 | Settling | | 0.14 | 3 | 60 | Hail | 0.20 | Patches of top snow up to 8" in depth. |
| 2.2.49 | 13 | - 7 | -10 | 2.5 | 25 | 1.0 | Settled | | 0.27 | 3.5 | 250 | Old | 0.30 | Settled snow on crust. |
| 9.2.49 | 14 | 0 | + 1 | 5 | 300 | 2.0 | Old | | 0.34 | 4.5 | 28 | Old | 0.30 | 5" layer of settled snow. |
| 10.2.49 | 14 | -4.5 | - 4 | 5 | 450 | 1.0 | Old | | 0.34 | 4 | 25 | Old | 0.30 | Surface crust. |
| 11.2.49 | 15 | -14 | -16 | 5 | 650 | 0.5 | Old | | 0.34 | 4 | 35 | Old | 0.28 | 1/2" new snow on surface. |
| 16.2.49 | 15 | +0.5 | + 4 | 4 | 7000 | 2.0 | Old | 21 | 0.38 | 5 | 50 | Old | 0.29 | Firm crust over old snow. |
| 18.2.49 | 14 | -4.5 | - 4 | 3 | 5000 | 2.5 | Old | | 0.42 | 4 | 48 | Old | 0.34 | Crust at surface and at 3". |
| 21.2.49 | 13 | -2.5 | - 6 | 3 | 3750 | 2.5 | Old | | 0.42 | 4 | 70 | Old | 0.32 | Firm surface crust. |
| 23.2.49 | 14 | -0.5 | + 2 | 1.5 | 2.5 | 2.0 | New | | 0.21 | 7 | | Old | 0.38 | 1-1/2" settling snow on crust. |
| 24.2.49 | 13 | 0 | + 2 | 2 | 200 | 3.0 | Settled | 24 | 0.43 | 5 | 2500 | Old | 0.38 | 2" settled snow on crust. |
| 28.2.49 | 11 | - 4 | -3.5 | 3 | 9000 | 3.0 | Old | | 0.43 | 5 | 5500 | Old | 0.40 | ) Several layers of coarse- |
| 1.3.49 | 11 | - 5 | -7.5 | 3 | 9000 | 3.0 | Old | | 0.42 | 5 | 6000 | Old | 0.44 | ) grained crust at surface. |

## TABLE VI

## PENETROMETER TESTS AT ARNPRIOR, ONTARIO

Measurements of Static and Dynamic Penetration following Procedure Described in Reference 2

| Date | Penetration Pressure lb. per sq.in.:- | 1 | | 2 | | 4 | |
|---|---|---|---|---|---|---|---|
| | Penetration in.:- | Static | Dynamic | Static | Dynamic | Static | Dynamic |
| 11.1.49 | | 0 | 3.75 | 0 | 5.5 | 0 | 8.25 |
| 14.1.49 | No penetrometer measurements. | | | | | | |
| 18.1.49 | | 0 | 3.0 | 0 | 1.5 | 0 | 9.0 |
| 20.1.49 | | 0 | 1.0 | 0 | 1.5 | 0 | 2.5 |
| 25.1.49 | | 0.25 | 1.25 | 1.0 | 2.5 | 1.0 | 3.75 |
| 27.1.49 | | 1.5 | 3.0 | 1.75 | 4.0 | 2.0 | 6.0 |
| 31.1.49 | No penetrometer measurements. | | | | | | |
| 1.2.49 | | 2.5 | 6.0 | 4.0 | 6.0 | 6.0 | 6.5 |
| 2.2.49 | | 1.0 | 4.75 | 1.5 | 6.0 | 5.25 | 7.0 |
| 9.2.49 | | 0 | 4.75 | 0 | 6.25 | 6.5 | 8.25 |
| 10.2.49 | | 0 | 2.5 | 0 | 7.75 | 0.25 | 10.25 |
| 11.2.49 | | 0 | 1.0 | 0 | 6.0 | 0 | 8.0 |
| 16.2.49 | | 0 | 6.25 | 0 | 8.0 | 1.75 | 8.5 |
| 18.2.49 | | 0 | 1.5 | 0 | 2.0 | 0 | 8.0 |
| 21.2.49 | | 0 | 1.25 | 0 | 2.0 | 0 | 4.25 |
| 23.2.49 | | 1.0 | 2.0 | 1.25 | 2.5 | 1.5 | 3.5 |
| 24.2.49 | | 1.0 | 2.0 | 1.0 | 4.0 | 1.0 | 9.0 |
| 28.2.49 | | 0 | 0.25 | 0 | 1.25 | 0 | 1.5 |
| 1.3.49 | | 0 | 0.5 | 0 | 1.0 | 0 | 1.5 |

# TABLE VII

## SNOW CONDITIONS ENCOUNTERED NEAR CHURCHILL, MANITOBA

1. General Nature of Test Areas

Terrain: Lake surfaces on flat, open country.

Vegetation: Scattered groups of small trees at lake borders.

Form of surface: Irregular from wind action. Average depth of snow approximately 6 in., distributed to form:

(1) hard snow hummocks varying in size from 5 yd. in diameter and 10 in. high to 25 yd. in diameter and 20 in. high

(2) drifted snow

(3) patches of glare ice.

Hummocks are often roughly crescent-shaped with drifted snow in the hollow of the crescent. Average separation of small hummocks is approximately 25 yd.

2. Snow Characteristics (measured on 18.3.49, at Farnsworth Lake)

Air temperature: -20°C.

Snow temperature: -20°C.

| | Hummock | | Drift | |
|---|---|---|---|---|
| Snow hardness, gm. per cm.$^2$ | 1000 | | 200 to 400 | |
| Grain size, mm. | 0.25 to 0.5 | | 0.25 to 0.5 | |
| Grain description | Old snow | | Old snow | |
| Specific gravity | 0.46 | | 0.27 | |
| Penetrometer Pressure lb. per in.$^2$ | Penetration in. | | | |
| | Static | Dynamic | Static | Dynamic |
| 1 | 0 | 0.25 | 0 | 1.0 |
| 2 | 0 | 0.5 | 0 | 2.0 |
| 4 | 0 | 0.75 | 1.0 to 2.5 | 3.0 |

# TABLE VIII

## SIGN CONVENTION

The following sign convention is used for loads applied to a ski:

| Component Load | Positive Direction |
|---|---|
| Vertical | Upwards |
| Drag | Aft |
| Side | From inboard |
| Torque | Nose out |

## TABLE IX

RESISTANCE MEASUREMENTS DURING TAKE-OFF AND TAXI RUNS AT ARNPRIOR, ONTARIO

Approximate static vertical load on starboard ski: 2675 lb.
Approximate static vertical load on port ski: 2825 lb.

| Date | Ski Type | Flight No. | Run No. | Adhesion Drag, lb. | | Adhesion Coeff., $\mu_A$ | | Sliding Drag, lb. | | Sliding Coeff., $\mu_S$ | | Mean Value of $\mu_S$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Stbd. | Port | Stbd. | Port | Stbd. | Port | Stbd. | Port | |
| 11.2.49 | 7500 | 12 | 7 | 630 | 320 | 0.24 | 0.11 | 205 | 205 | 0.08 | 0.07 | 0.075 |
| 11.2.49 | Bear Paw | 13 | 10 | 685 | 525 | 0.26 | 0.19 | 184 | | 0.07 | | 0.07 |
| 18.2.49 | Bear Paw | 15 | 8 | 265 | 245 | 0.10 | 0.09 | 205 | 175 | 0.08 | 0.06 | |
| 18.2.49 | Bear Paw | 15 | 12 | 290 | 205 | 0.11 | 0.07 | 225 | | 0.08 | | 0.08 |
| 18.2.49 | Bear Paw | 15 | 13 | | 465 | | 0.17 | | 230 | | 0.09 | |
| 18.2.49 | 7500 | 16 | 8 | 285 | 500 | 0.11 | 0.18 | 180 | 205 | 0.07 | 0.07 | 0.065 |
| 18.2.49 | 7500 | 16 | 12 | 290 | 350 | 0.11 | 0.12 | 135 | 200 | 0.05 | 0.07 | |
| 23.2.49 | 7500 | 18 | 8 | 325 | 345 | 0.12 | 0.12 | 305 | 320 | 0.115 | 0.115 | |
| 23.2.49 | 7500 | 18 | 10 | 565 | 475 | 0.21 | 0.17 | 210 | 240 | 0.08 | 0.085 | |
| 23.2.49 | 7500 | 18 | 12 | 715 | 590 | 0.27 | 0.21 | 250 | 210 | 0.09 | 0.07 | 0.095 |
| 23.2.49 | 7500 | 18 | 13 | 600 | 1120 | 0.22 | 0.40 | 270 | 320 | 0.10 | 0.11 | |
| 23.2.49 | 7500 | 18 | 15 | 665 | 690 | 0.25 | 0.24 | | | | | |

N.B. 1. Peak adhesion loads measured irrespective of whether one ski broke free before the other.

2. Sliding drag measured within 8 seconds after breaking free.

## TABLE X

SIDE LOAD AND TORQUE MEASUREMENTS DURING TAXI RUNS AND TURNS WHILE TAXIING

| Date | Ski Type | Flight No. | Run No. | Ground Speed m.p.h. | Random Peak Load | | Steady Turning Load | | Maximum Load while Turning | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Side lb. | Torque lb.ft. | Side lb. | Torque lb.ft. | Side lb. | Torque lb.ft. |
| TESTS AT ARNPRIOR, ONTARIO | | | | | | | | | | |
| 11.2.49 | 7500 | 12 | 7 | 0 - 70 | 745 | 925 | | | | |
| 11.2.49 | Bear Paw | 13 | 10 | 0 - 70 | 905 | 1030 | | | | |
| 18.2.49 | Bear Paw | 15 | 12 | 30 | 815 | 1145 | 315 | 180 | 1130 | 1325 |
| 18.2.49 | Bear Paw | 15 | 13 | 30 | 1000 | 1305 | 565 | 710 | 1565 | 2015 |
| 18.2.49 | 7500 | 16 | 12 | 30 | 385 | 420 | 505 | 350 | 890 | 770 |
| 23.2.49 | 7500 | 18 | 12 | 40 | 575 | 870 | 575 | 370 | 1150 | 1240 |
| 23.2.49 | 7500 | 18 | 13 | 40 | 430 | 630 | 625 | 280 | 1055 | 910 |
| TESTS AT CHURCHILL, MANITOBA | | | | | | | | | | |
| 19.3.49 | 7500 | 23 | 27 | 30 | 1275 | 705 | 650 | 335 | 1925 | 1040 |
| 19.3.49 | 7500 | 23 | 28 | 30 | 1055 | 1050 | 720 | 385 | 1775 | 1435 |

# TABLE XI

## GROUND HANDLING LOADS

Date: 23 February 1949.

TEST 1.

Snow Condition: 1.5 in. settling snow on crust. Skis not penetrating crust. Temperature at skis: +1°C.

Procedure: Aircraft tail lifted and swung to starboard in two stages.

EFFECT:

Stage 1: Tail moved approximately 12 in. Both skis adhering.
Stage 2: Tail moved approximately 18 in. Port ski adhering, starboard ski shifted forward. Test discontinued.

Maximum Recorded Loads:

| Stage | Starboard Ski | | | Port Ski | | |
|---|---|---|---|---|---|---|
| | Drag lb. | Side lb. | Torque lb.ft. | Drag lb. | Side lb. | Torque lb.ft. |
| 1 | +690 | Small | + 795 | | +600 | -1260 |
| 2 | | Small | +1475 | -1430 | +960 | -3360 |

TEST 2.

Snow Condition: Rolled snow. Temperature: +1°C.

Procedure: Aircraft tail lifted and swung to starboard approximately 30 degrees.

EFFECT: Starboard ski shifted forward. Port ski shifted.

Maximum Recorded Loads:

| Starboard Ski | | | Port Ski | | |
|---|---|---|---|---|---|
| Drag lb. | Side lb. | Torque lb.ft. | Drag lb. | Side lb. | Torque lb.ft. |
| +510 | Small | Small | -1115 | +336 | -1990 |

# TABLE XII

## SUMMARY OF MAXIMUM COMPONENT LOADS RECORDED

1. MS 7500 SKIS - ARNPRIOR TESTS

| Component Load | Maximum Value Recorded | Circumstances |
|---|---|---|
| Vertical | 11190 | Initial impact. (Vertical velocity 8.2 ft. per sec.) |
| Drag | 2390 | Initial impact. (Vertical load 10550 lb.) |
| Side | 1740 | Initial impact. (Vertical velocity 4.8 ft. per sec.) |
| Torque | 1860 | Initial impact. (Vertical velocity 4.8 ft. per sec.) |
| | 3360 | Ground handling. (See Table XI.) |

2. BEAR PAW SKIS - ARNPRIOR TESTS

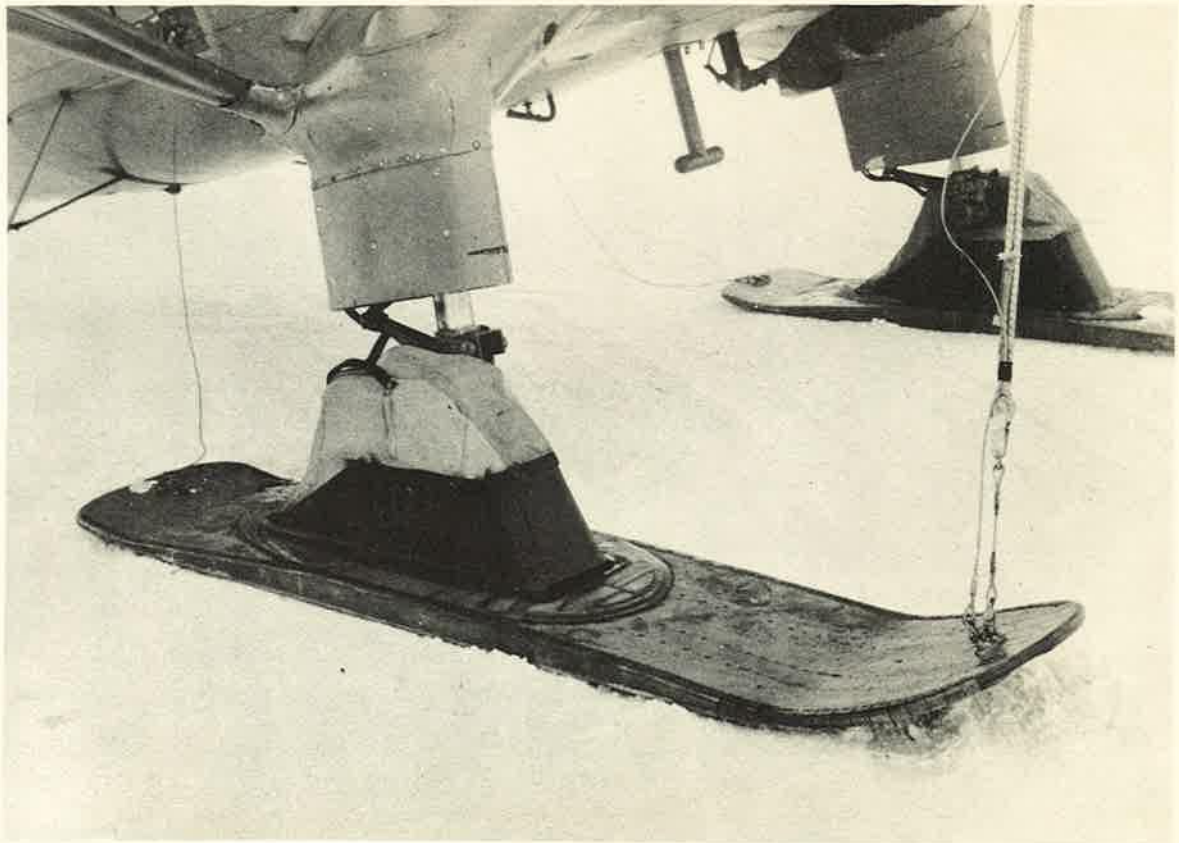
| Component Load | Maximum Value Recorded | Circumstances |
|---|---|---|
| Vertical | 13590 | Initial impact. (Vertical velocity approximately 10 ft. per sec.) |
| Drag | 2630 | Initial impact. (Vertical load 7280 lb.) |
| Side | 3480 | Initial impact. (Vertical velocity 9.8 ft. per sec.) |
| Torque | 3020 | Initial impact. (Vertical velocity 9.8 ft. per sec.) |

3. MS 7500 SKIS - CHURCHILL TESTS

| Component Load | Maximum Value Recorded | Circumstances |
|---|---|---|
| Vertical | 23390 lb. | Impact with large snow hummock during landing run. |
| Drag | 1775 lb. | Impact with large snow hummock during landing run. |
| Side | 3360 lb. | Impact with large snow hummock during landing run. |
| Torque | 3110 lb.ft. | Normal landing on severe hummock conditions. |

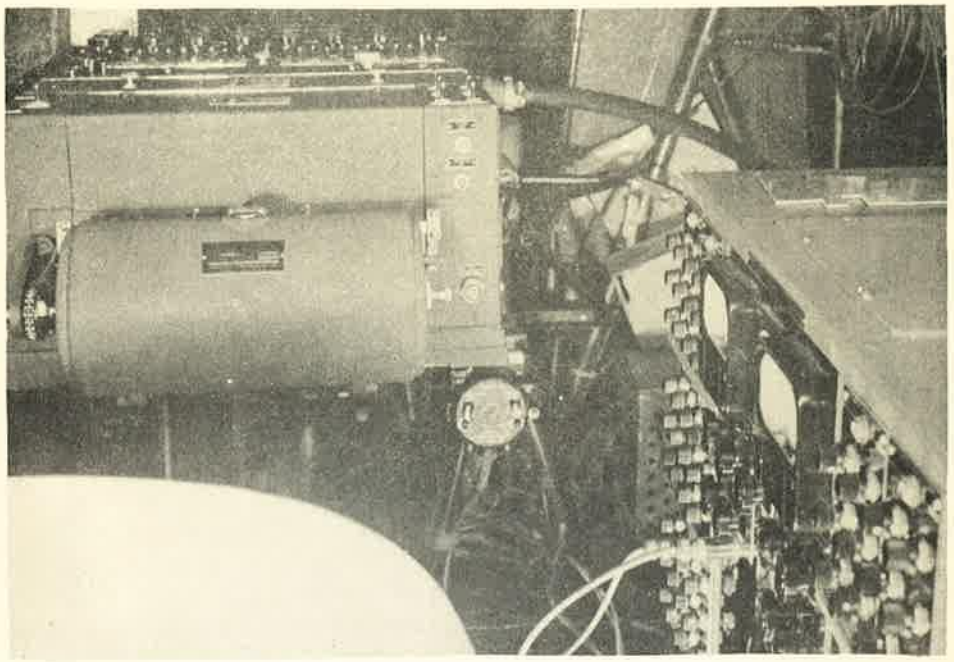

NOORDUYN NORSEMAN MK VI

FIG I
MR-7



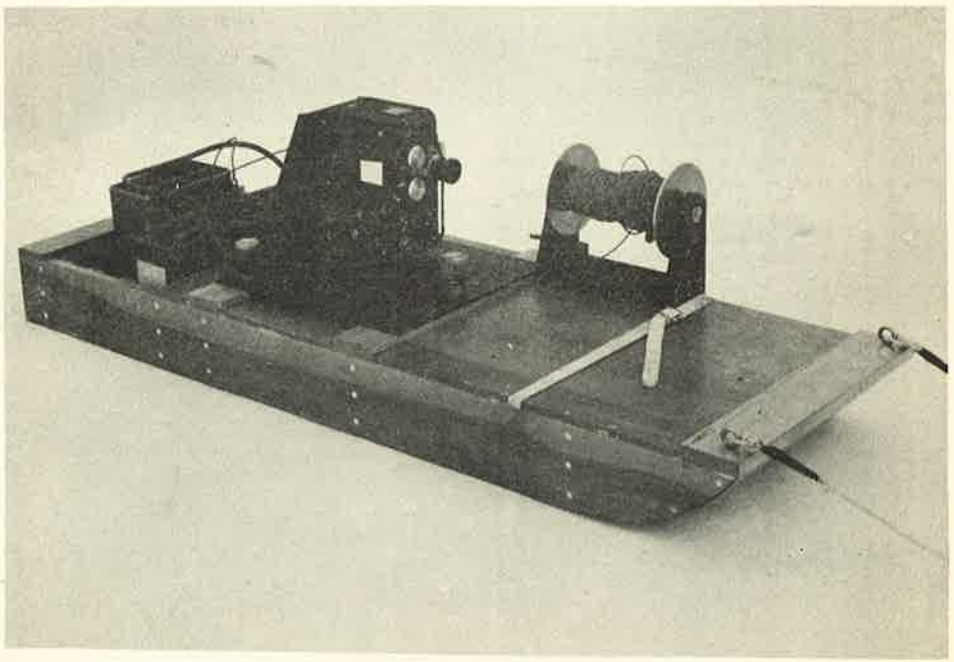
TEST INSTALLATION OF M. S. 7500 TYPE SKIS

FIG 2
MR-7



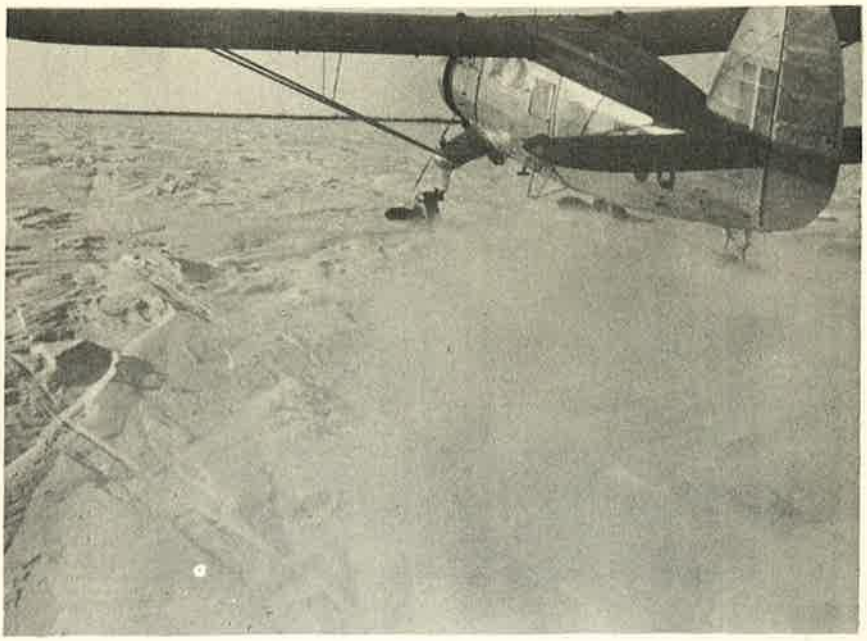
"A"

RECORDING EQUIPMENT



"B"

CINÉ-CAMERA AND SLED



"A"

TYPICAL LAKE SURFACES NEAR CHURCHILL MANITOBA

"B"

"A"

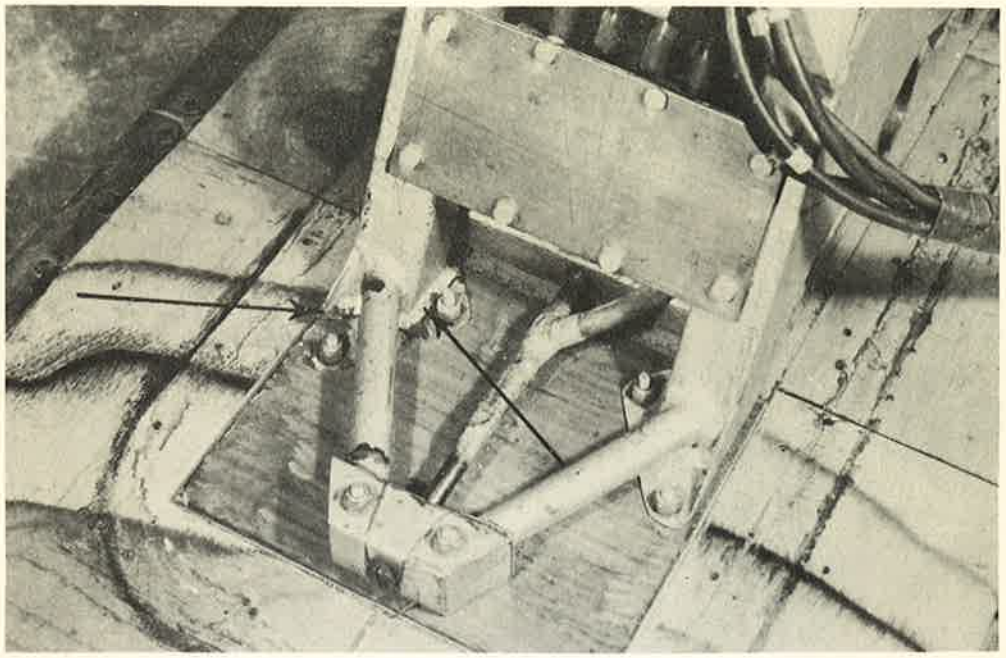

"B"

LARGE SNOW HUMMOCKS NEAR
CHURCHILL MANITOBA

"C"

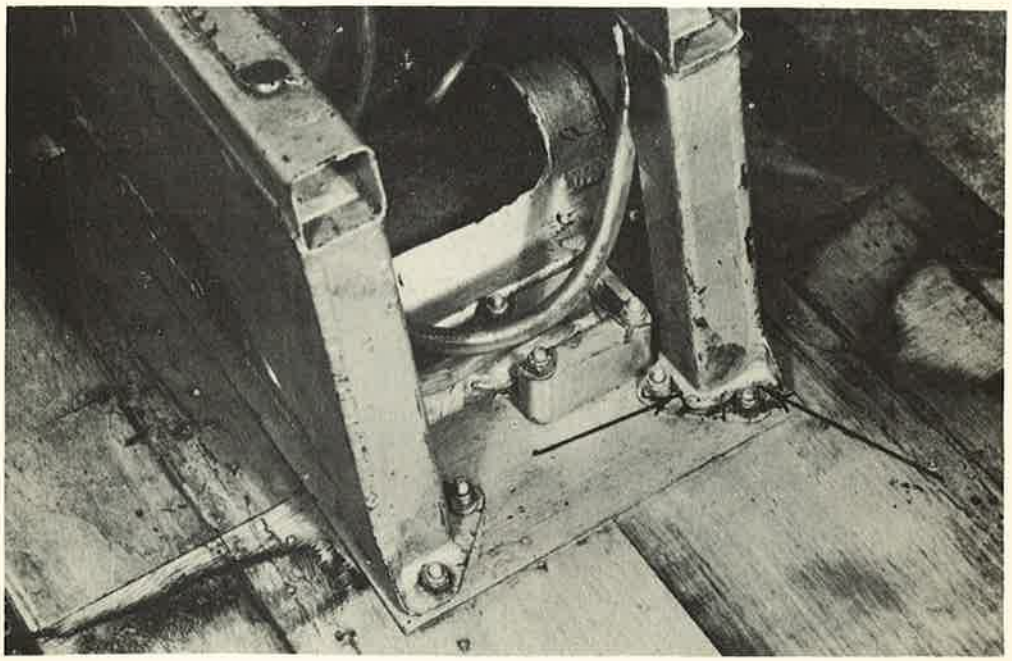
"D"

EFFECT OF SKI IMPACT
ON THE DRIFTED SIDE OF
A SNOW HUMMOCK



"A"

LOAD MEASURING PEDESTAL AFTER FRACTURE ( INDICATED BY ARROWS )



"B"

FIG 7
MR-7

# MS 7500 SKIS

## PEAK LOAD HISTOGRAMS FOR NORMAL LANDINGS AT ARNPRIOR ONT

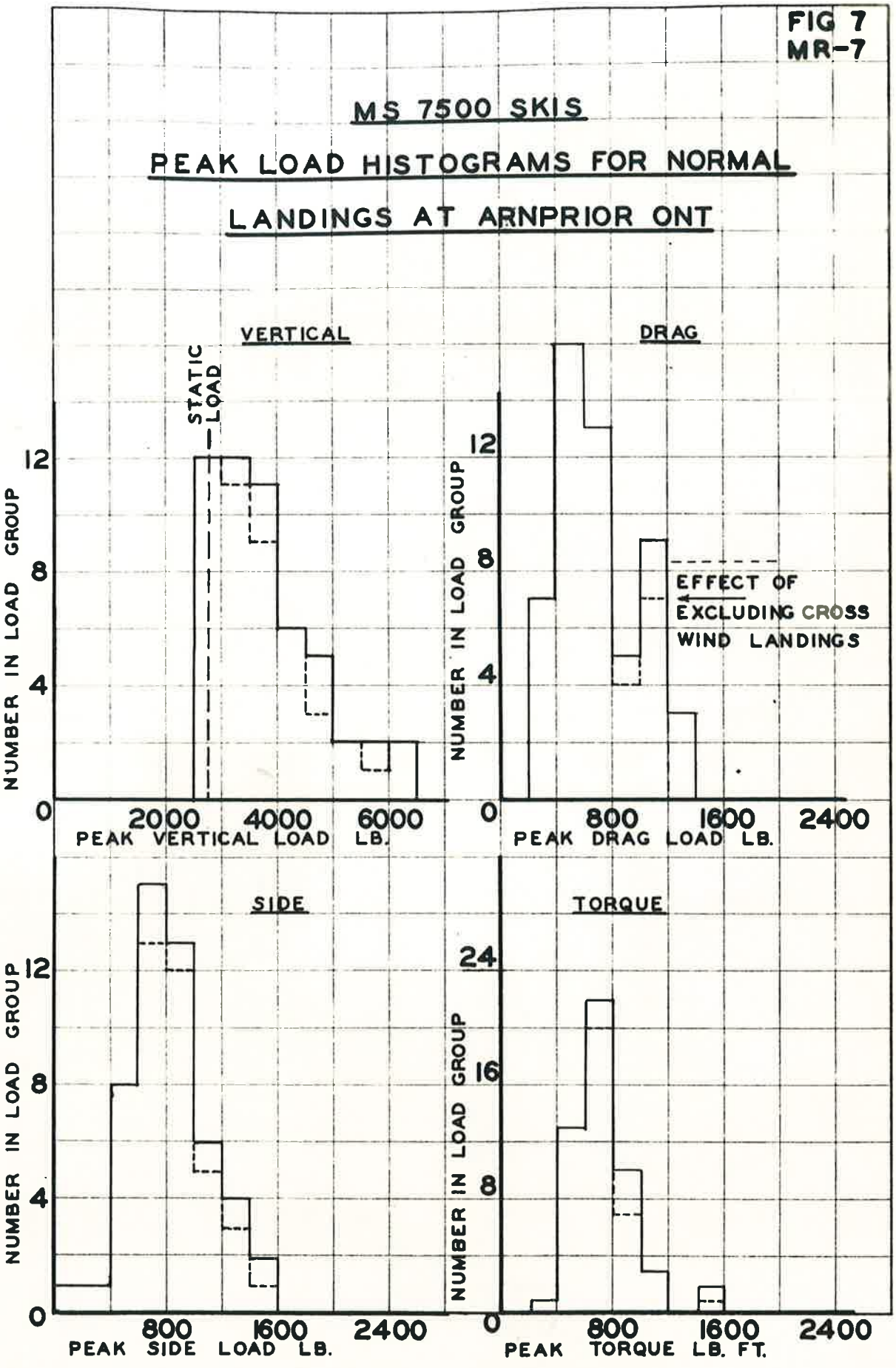
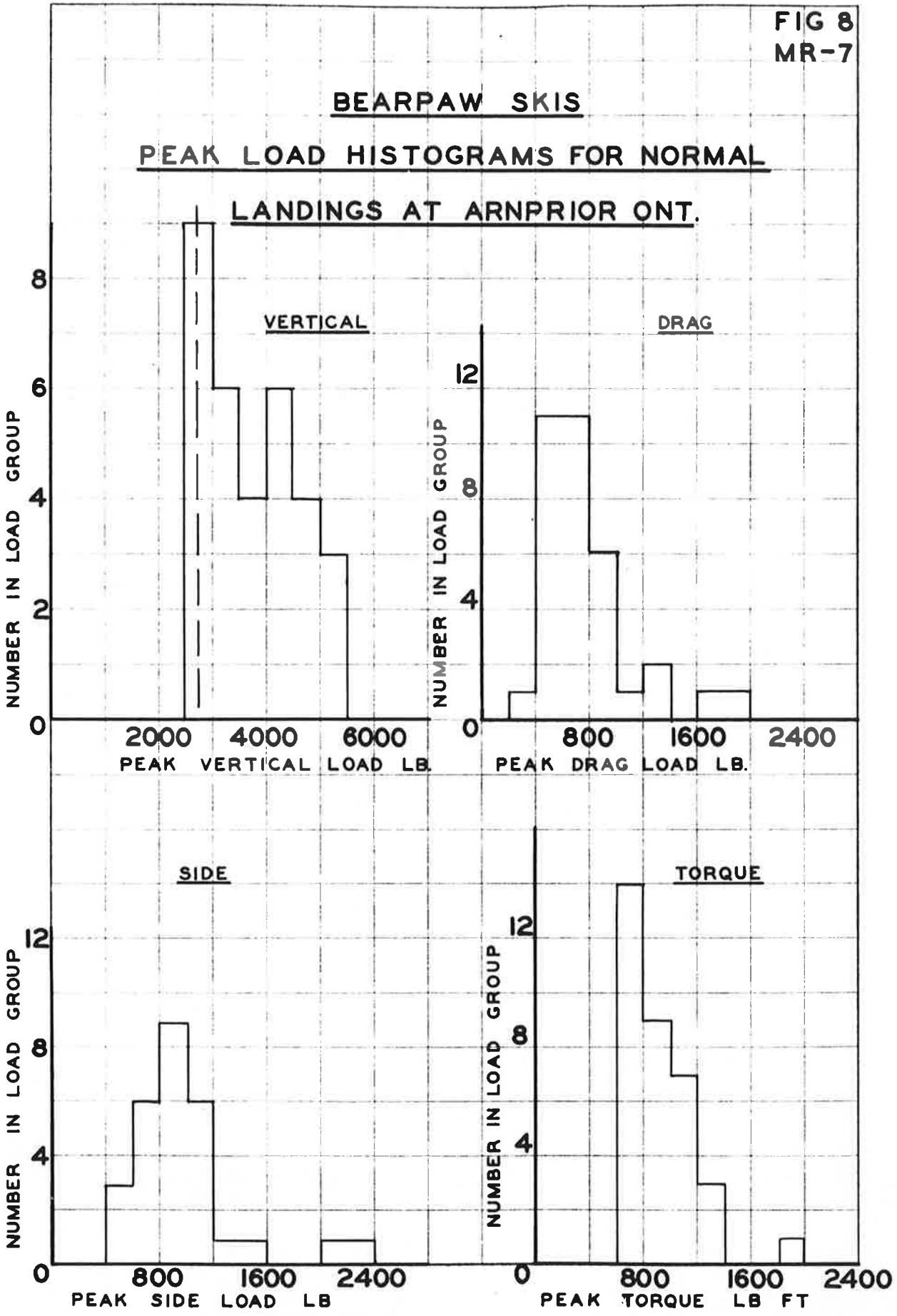
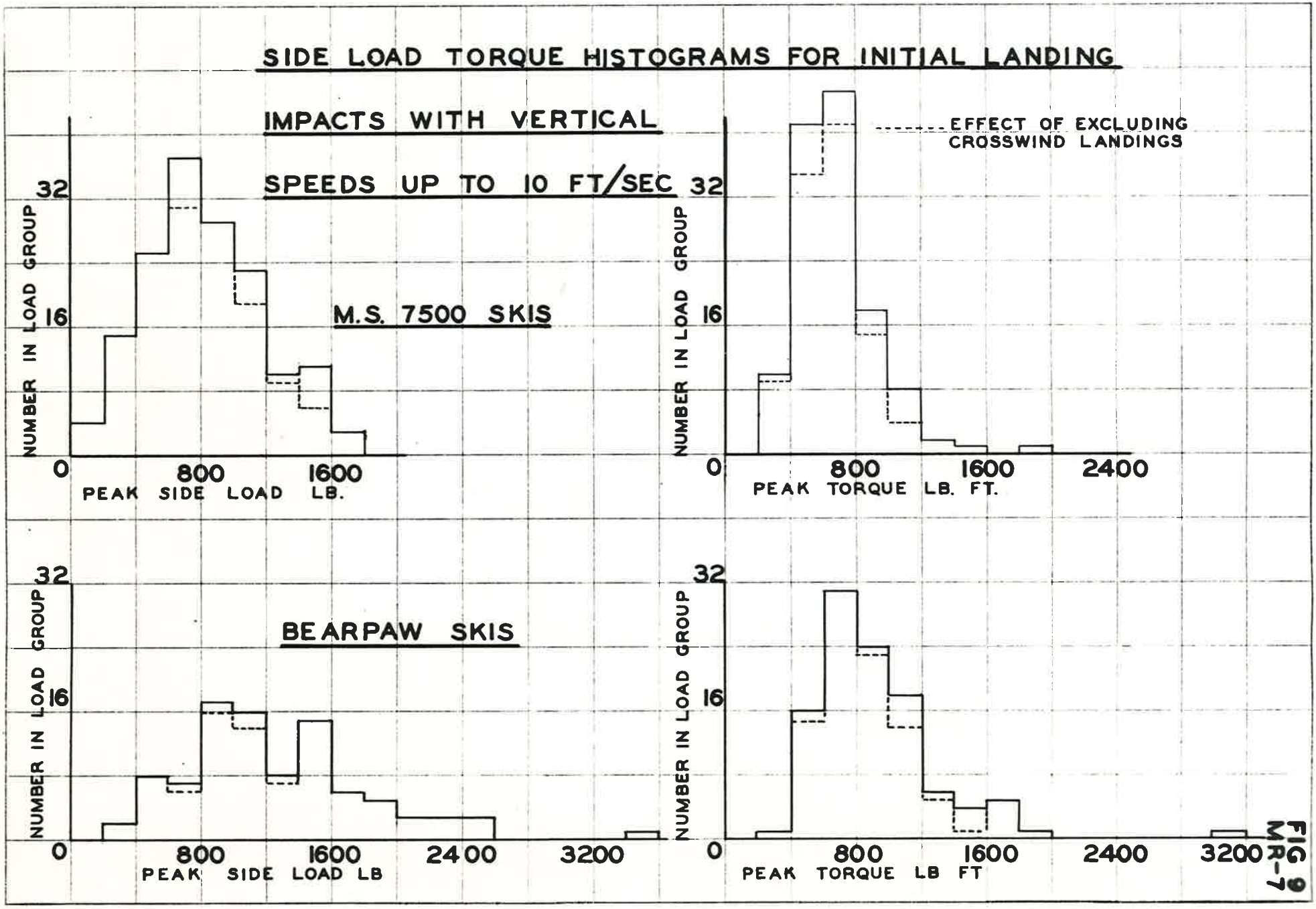


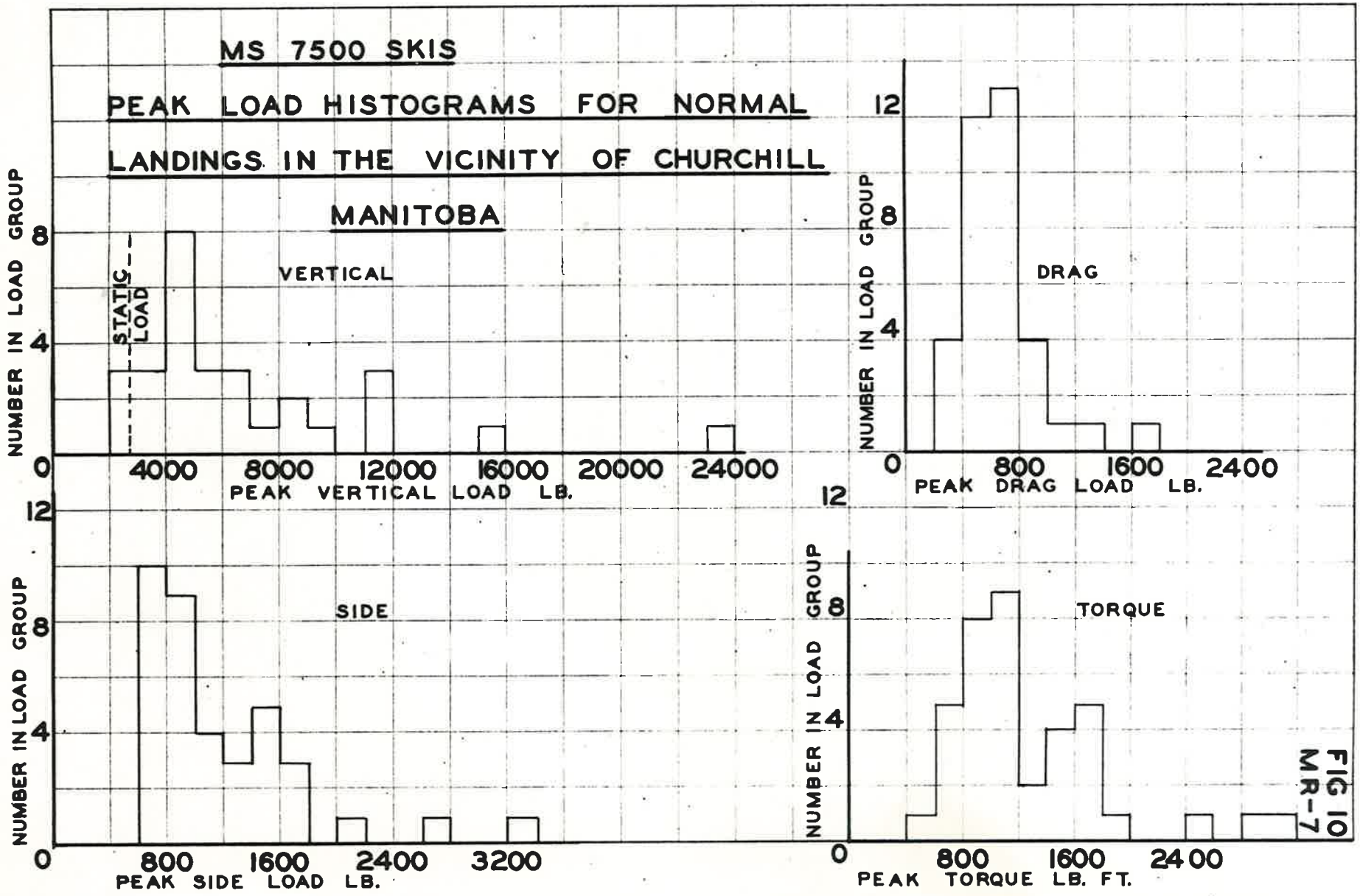
FIG 8
MR-7

# BEARPAW SKIS

## PEAK LOAD HISTOGRAMS FOR NORMAL LANDINGS AT ARNPRIOR ONT.




SIDE LOAD TORQUE HISTOGRAMS FOR INITIAL LANDING
IMPACTS WITH VERTICAL
SPEEDS UP TO 10 FT/SEC
M.S. 7500 SKIS
EFFECT OF EXCLUDING CROSSWIND LANDINGS
NUMBER IN LOAD GROUP
32
16
0
800
1600
2400
3200
PEAK SIDE LOAD LB.
PEAK TORQUE LB. FT.
BEARPAW SKIS
PEAK SIDE LOAD LB
PEAK TORQUE LB FT
FIG 6
NR-7


MS 7500 SKIS
PEAK LOAD HISTOGRAMS FOR NORMAL LANDINGS IN THE VICINITY OF CHURCHILL MANITOBA
VERTICAL
STATIC LOAD
NUMBER IN LOAD GROUP
0
4
8
4000
8000
12000
16000
20000
24000
PEAK VERTICAL LOAD LB.
DRAG
12
800
1600
2400
PEAK DRAG LOAD LB.
SIDE
3200
PEAK SIDE LOAD LB.
TORQUE
PEAK TORQUE LB. FT.
FIG 10
MR-7

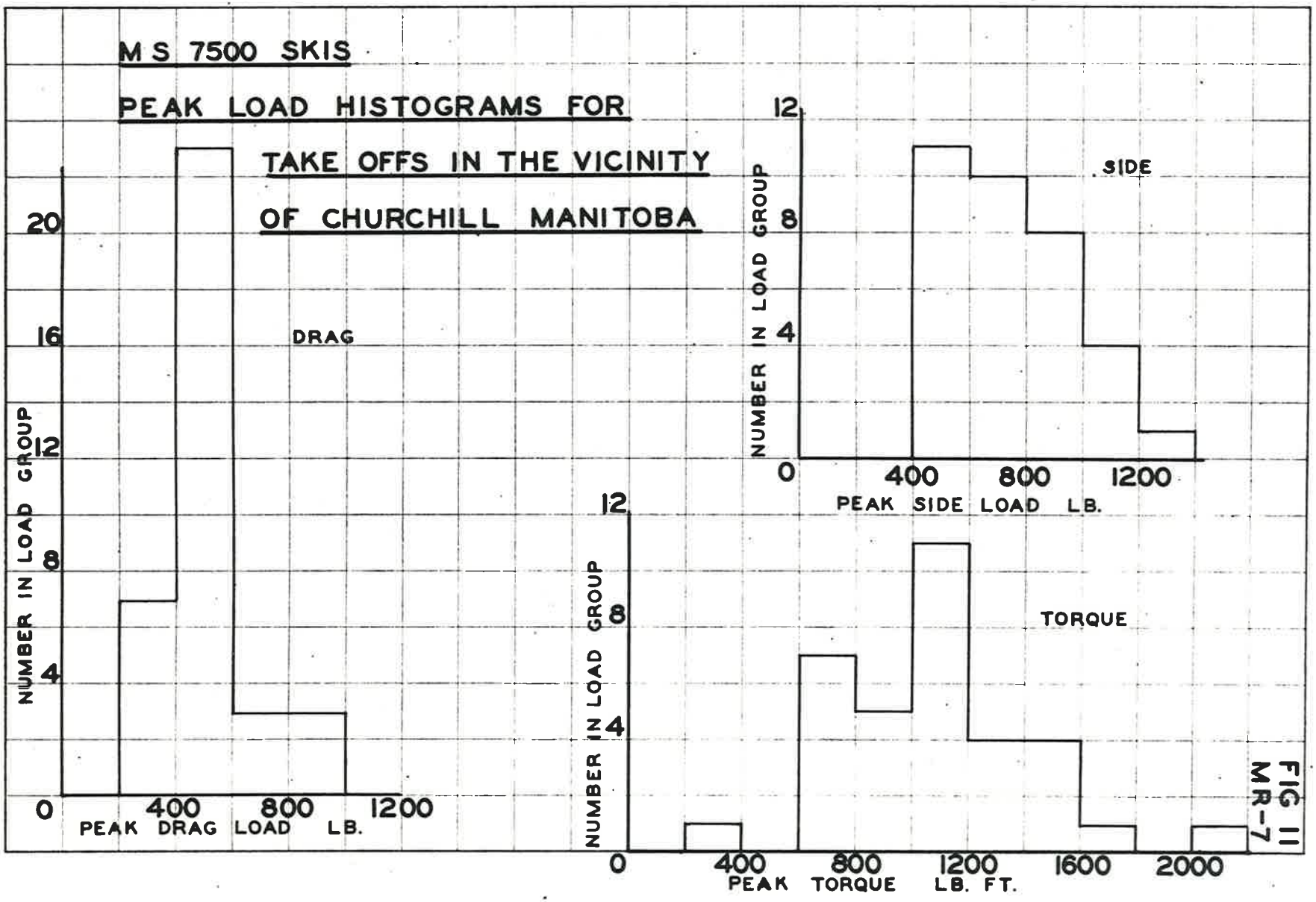

M S 7500 SKIS
PEAK LOAD HISTOGRAMS FOR
TAKE OFFS IN THE VICINITY
OF CHURCHILL MANITOBA
DRAG
NUMBER IN LOAD GROUP
0
4
8
12
16
20
400
800
1200
PEAK DRAG LOAD LB.
SIDE
PEAK SIDE LOAD LB.
TORQUE
1600
2000
PEAK TORQUE LB. FT.
FIG 11
MR-7

FIG 13
MR-7

# RELATION OF NORMAL ACCELERATION TO TOTAL VERTICAL IMPACT FORCES

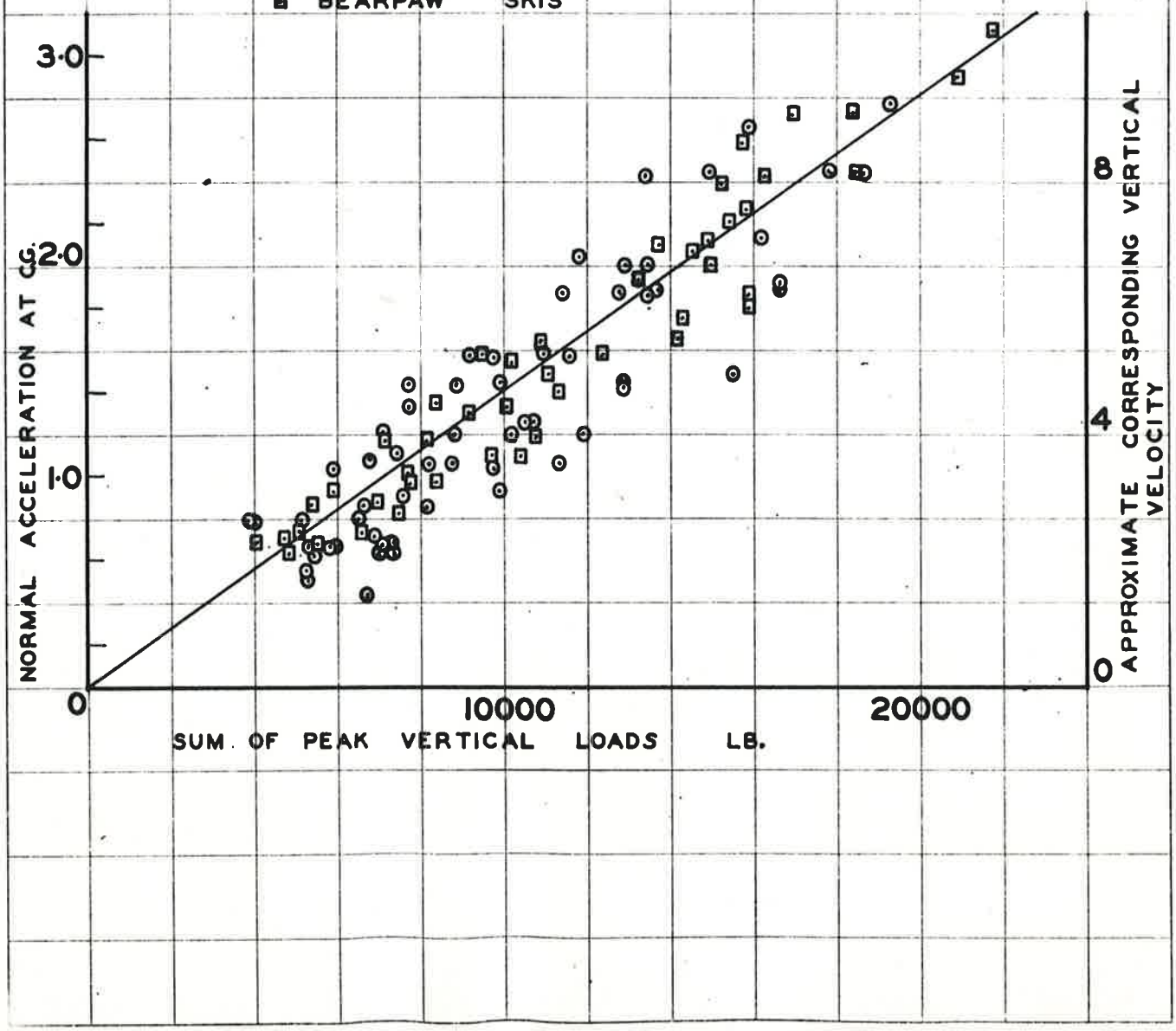


FIG 14
MR-7

# RELATION OF PEAK VERTICAL LOAD TO PEAK DRAG WITH VARYING SNOW CONDITIONS

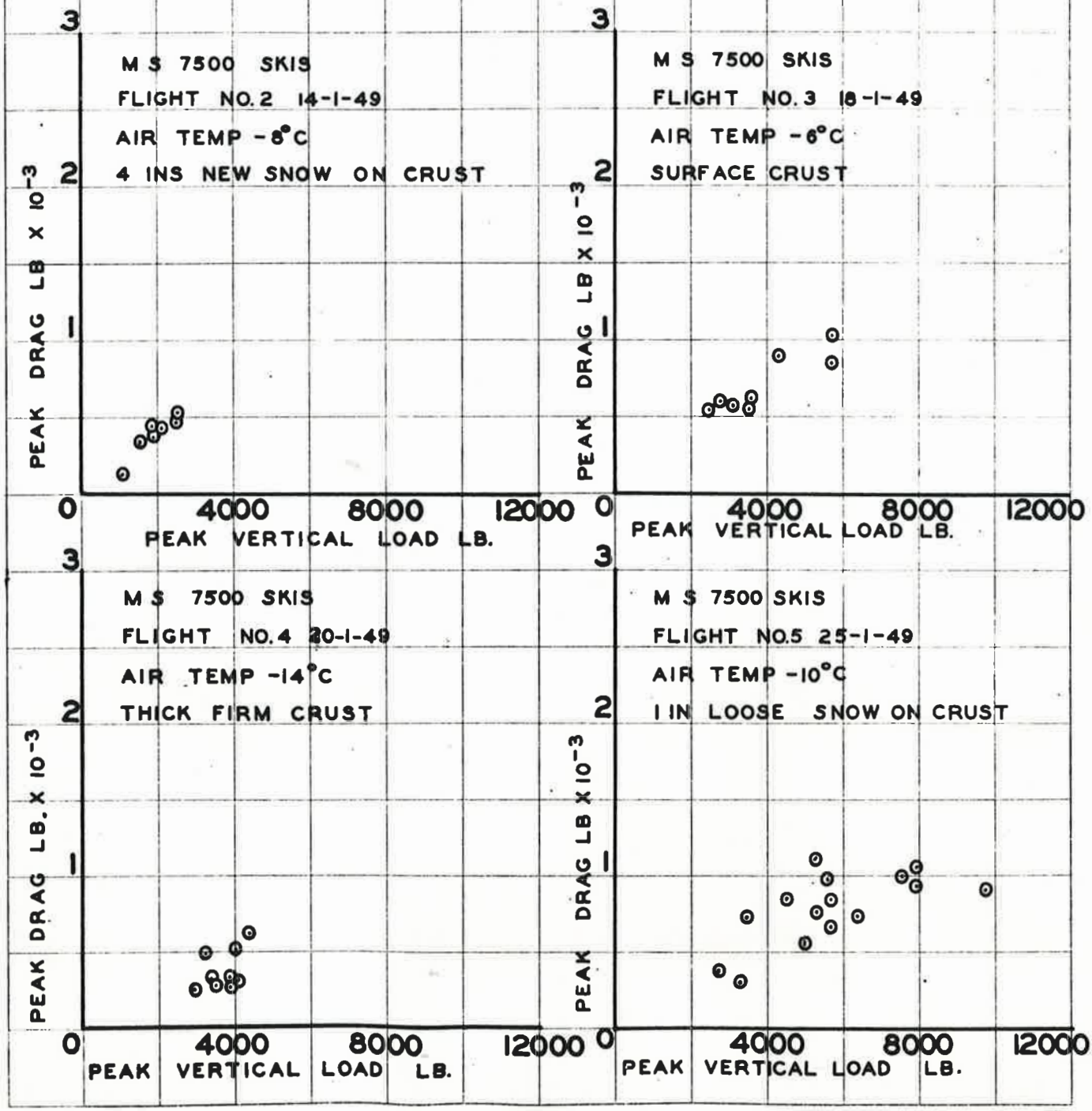


FIG 15
MR-7

# RELATION OF PEAK VERTICAL LOAD TO PEAK DRAG WITH VARYING SNOW CONDITIONS

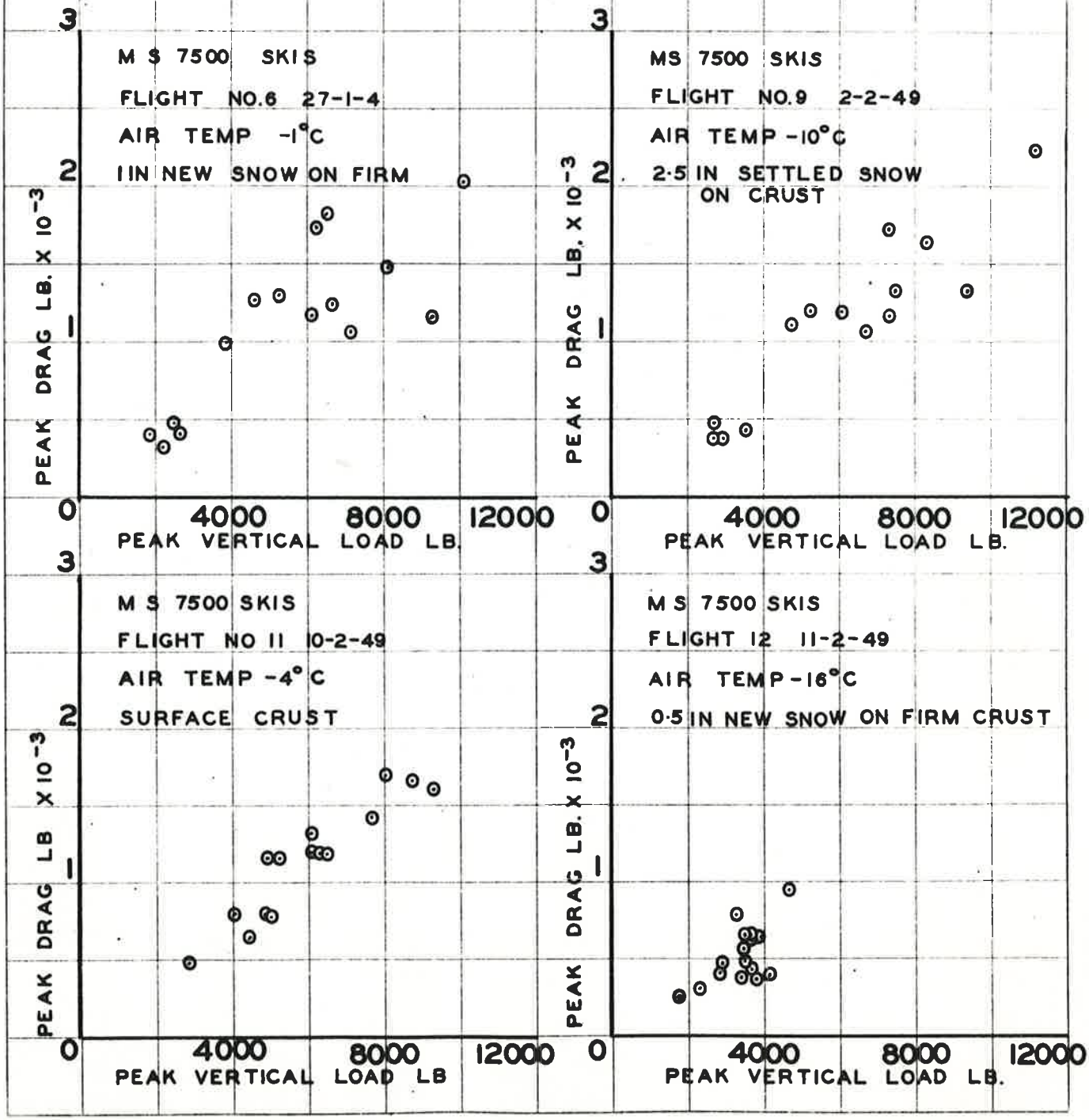
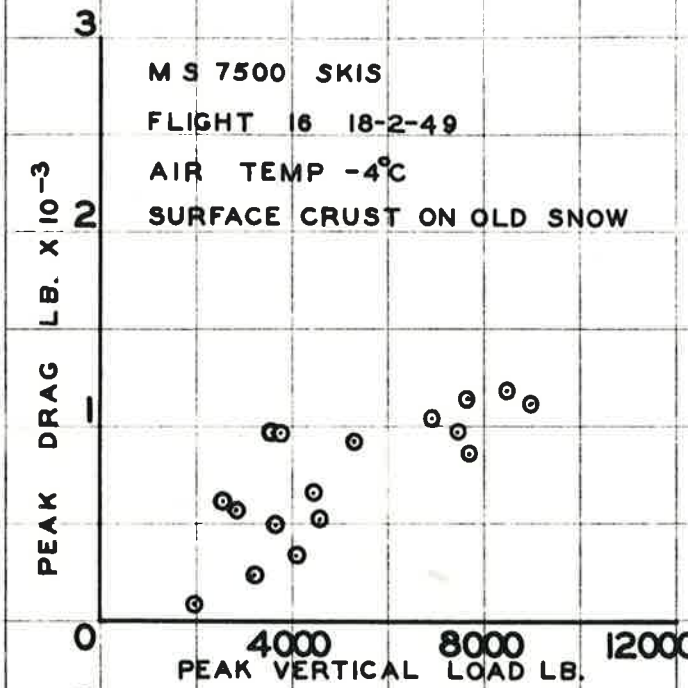
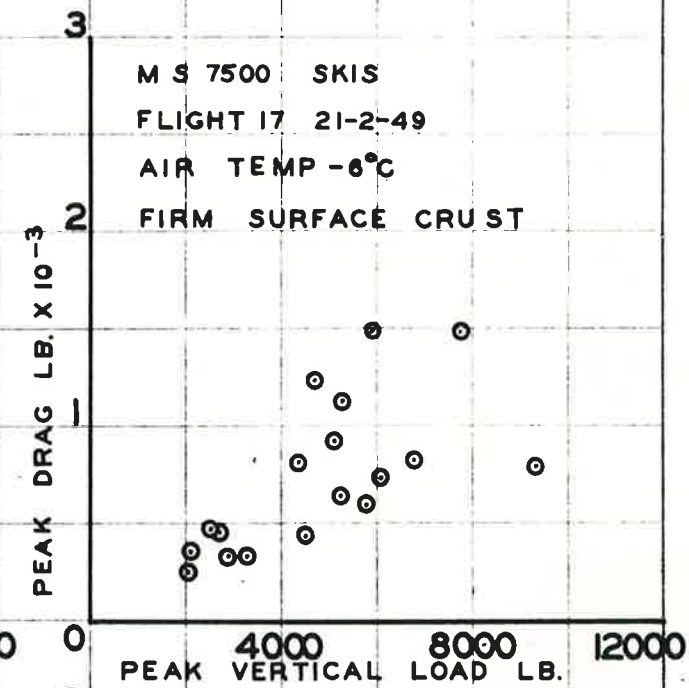
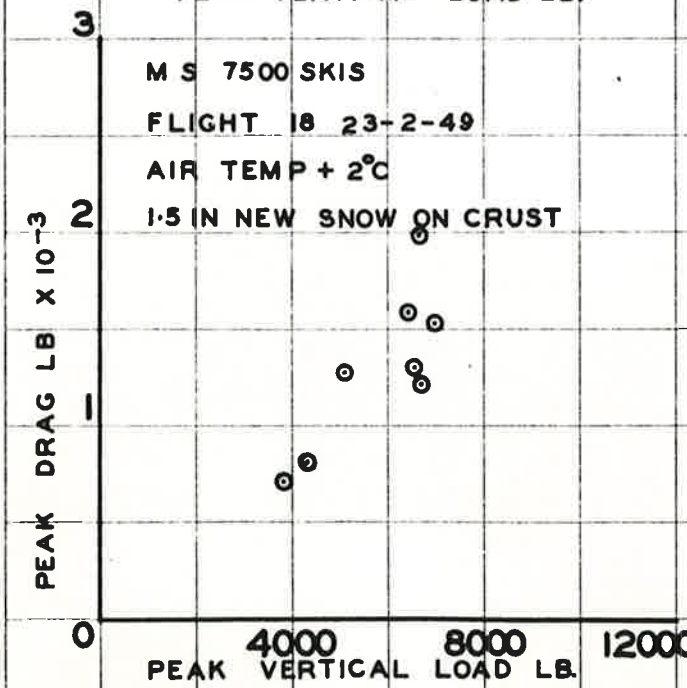


FIG 16
MR-7

# RELATION OF PEAK VERTICAL LOAD TO PEAK DRAG WITH VARYING SNOW CONDITIONS



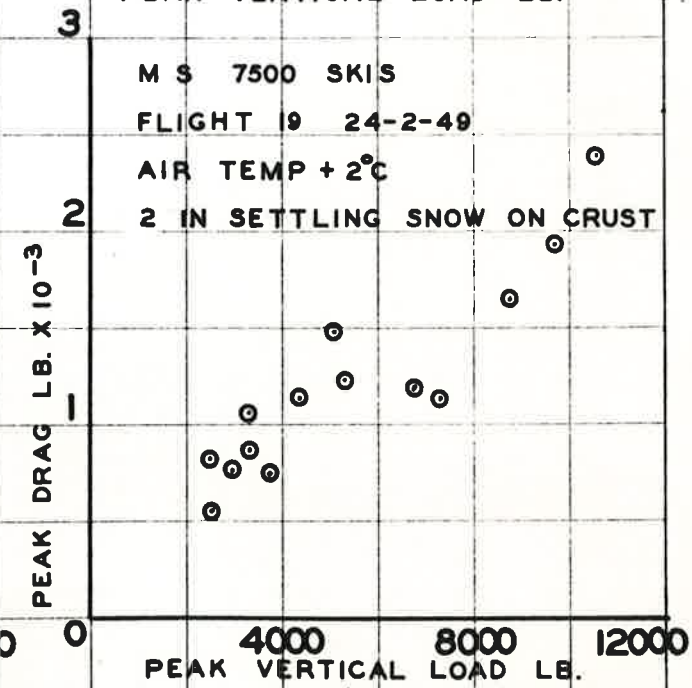



FIG 17
MR-7

# RELATION OF PEAK VERTICAL LOAD TO PEAK DRAG WITH VARYING SNOW CONDITIONS

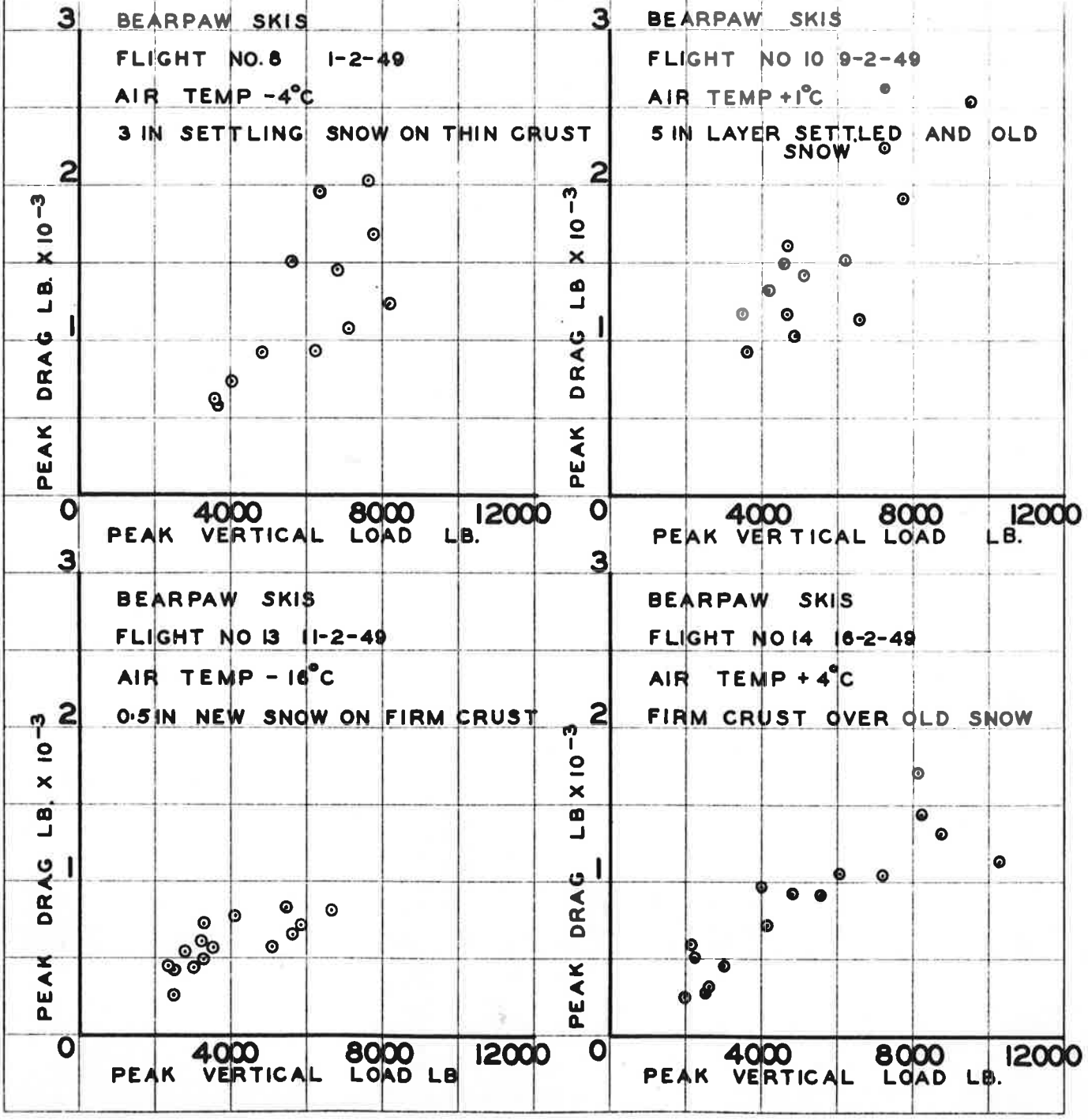


FIG 18
MR-7

# RELATION OF PEAK VERTICAL LOAD TO PEAK DRAG WITH VARYING SNOW CONDITIONS

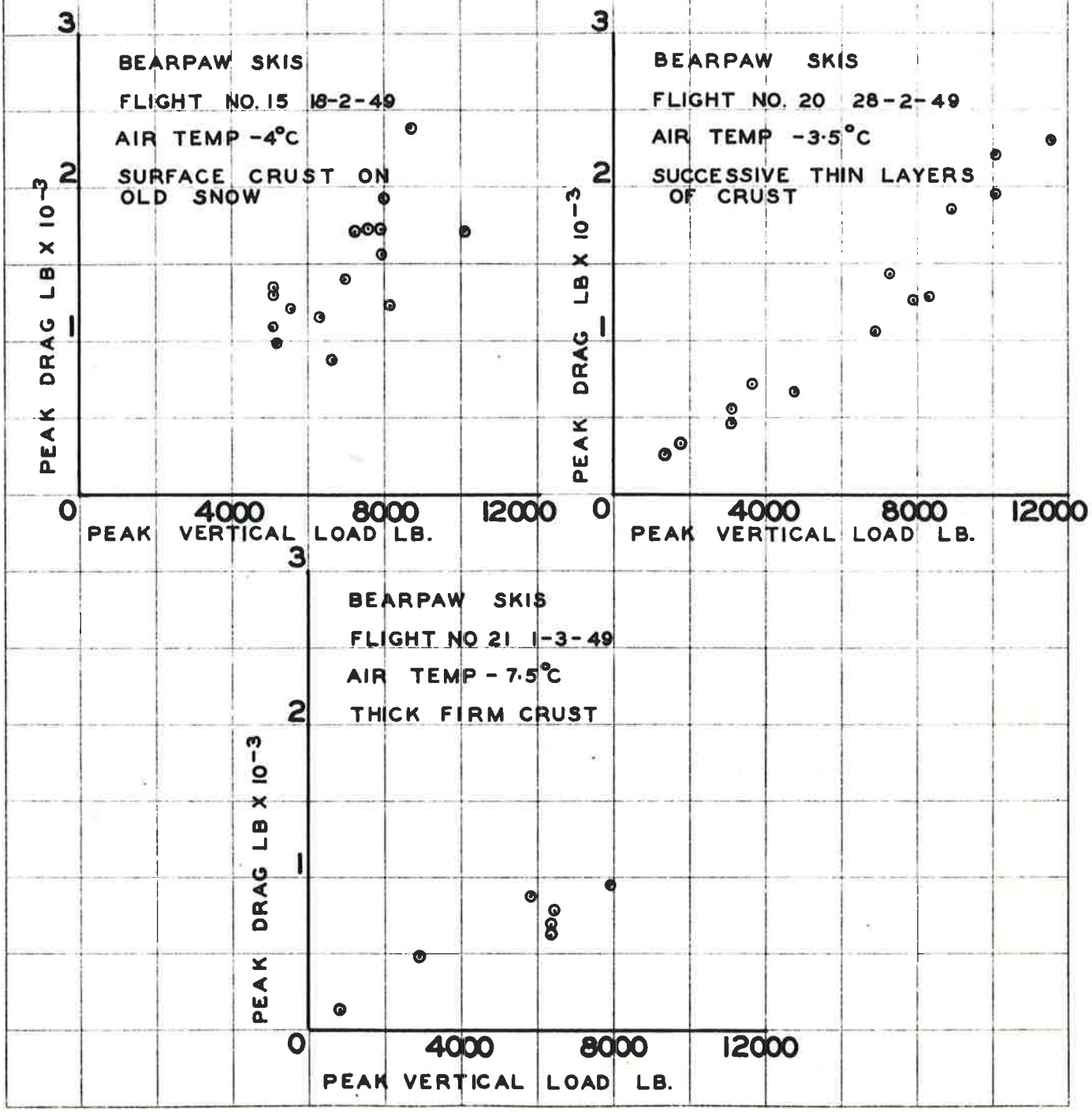


FIG 19
MR-7

# RELATION OF PEAK VERTICAL LOAD TO PEAK DRAG AT IMPACT

FOR TYPICAL SNOW CONDITION AT CHURCHILL MANITOBA

M S 7500 STARBOARD SKI

FLIGHT NO 22 18-3-49

AIR TEMP -20°C

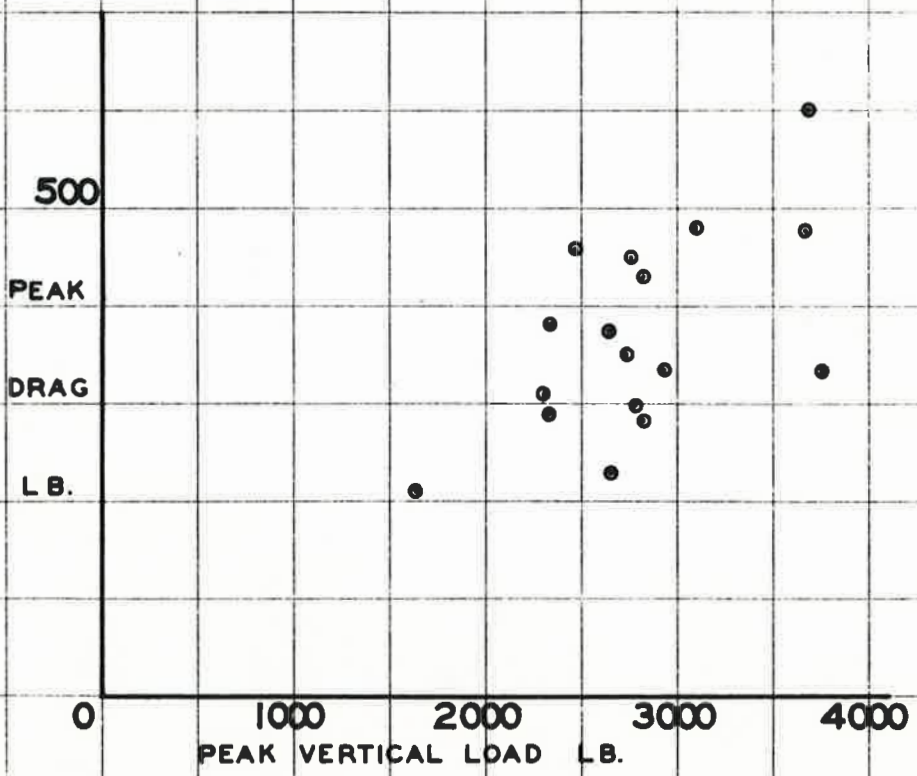
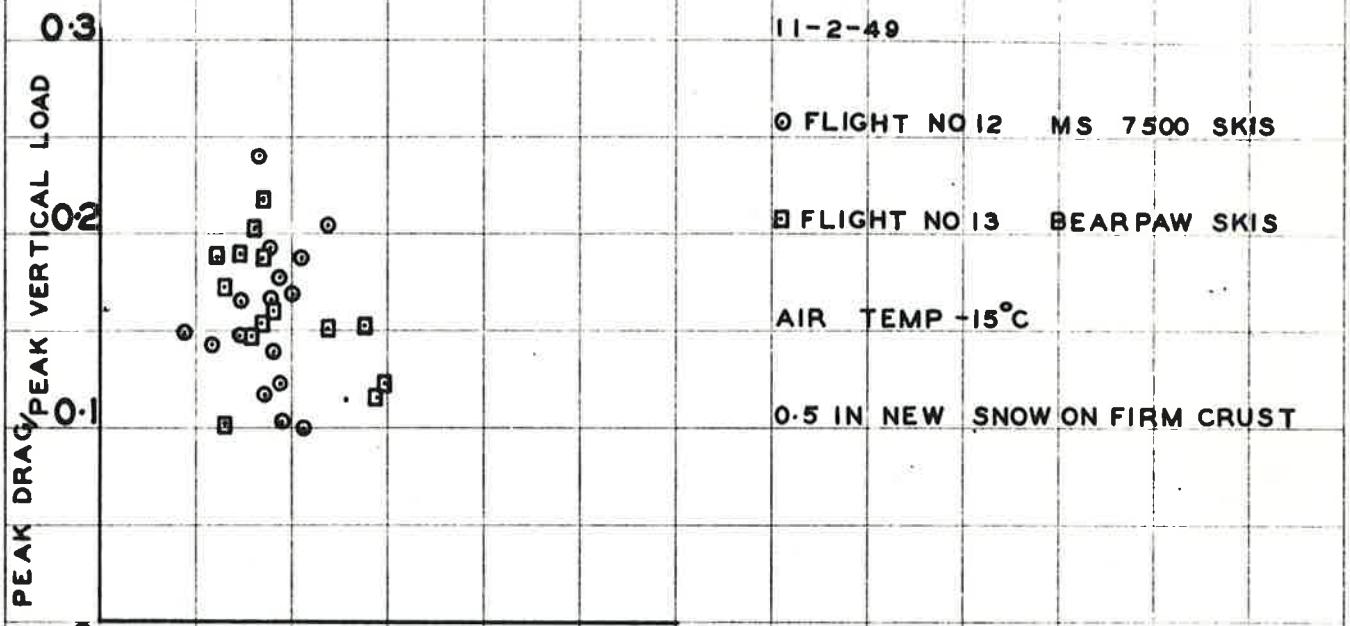


FIG 20
MR-7

# COMPARISON OF PEAK DRAG/PEAK VERTICAL LOAD RATIO AT IMPACT FOR MS7500 AND BEARPAW SKIS ON SIMILAR SNOW CONDITIONS



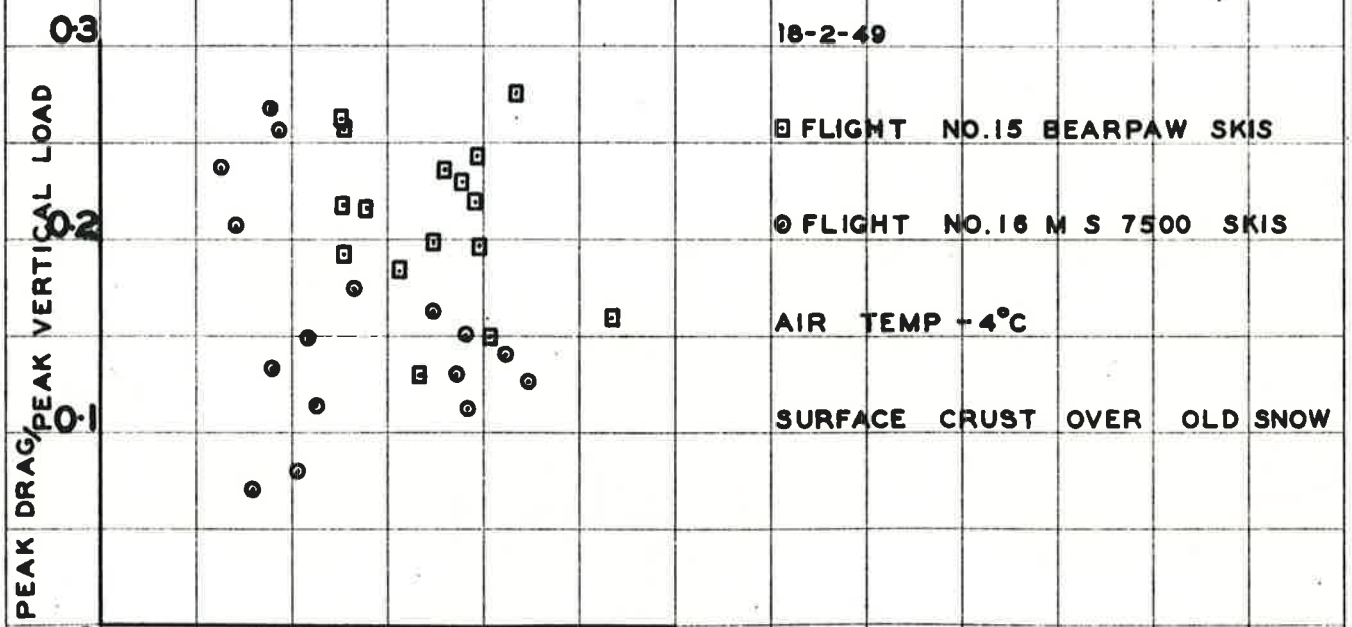



FIG 21
MR-7

# PEAK VERTICAL LOAD ON ONE SKI DURING INITIAL LANDING IMPACT

## ARNPRIOR TESTS

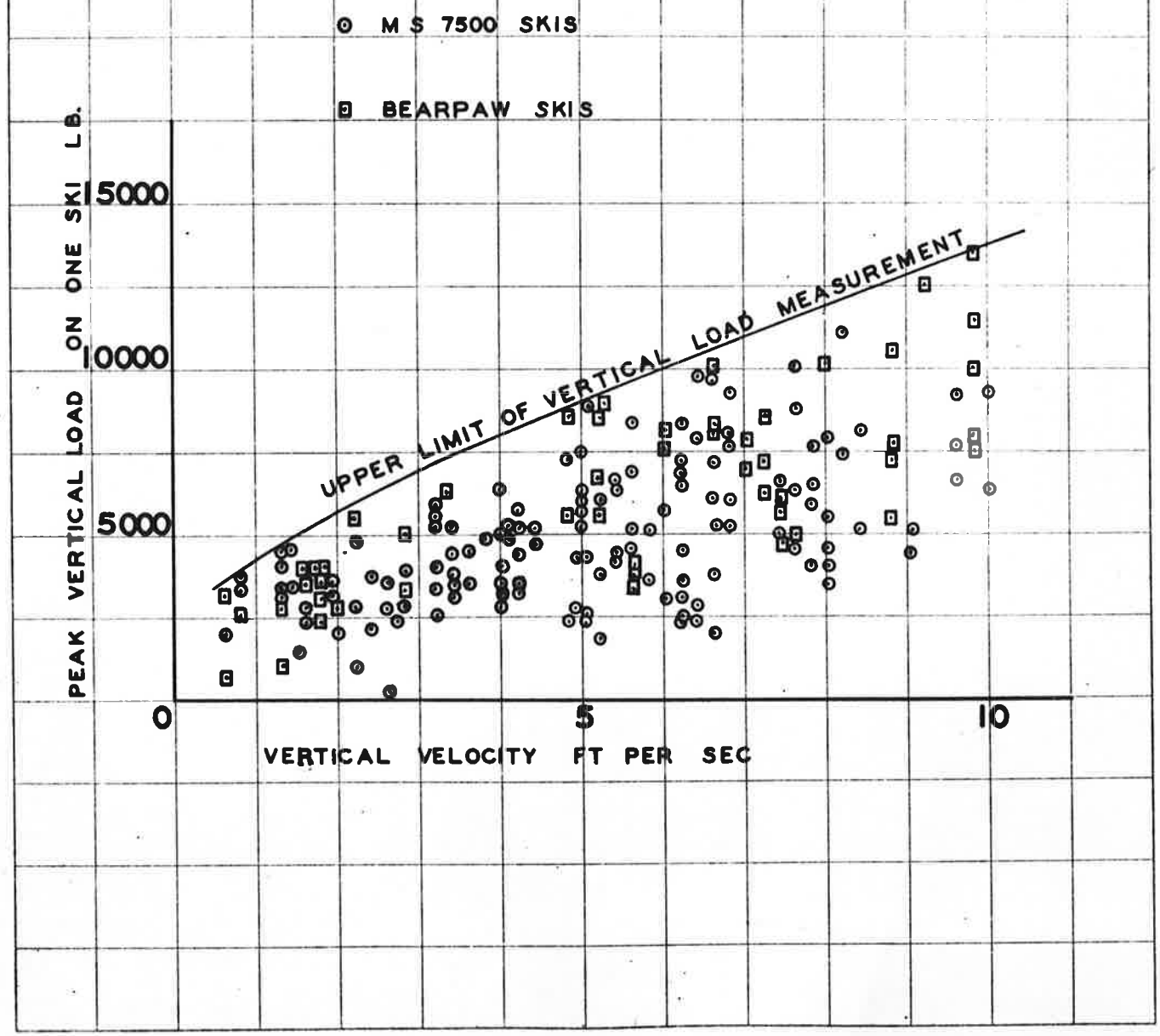
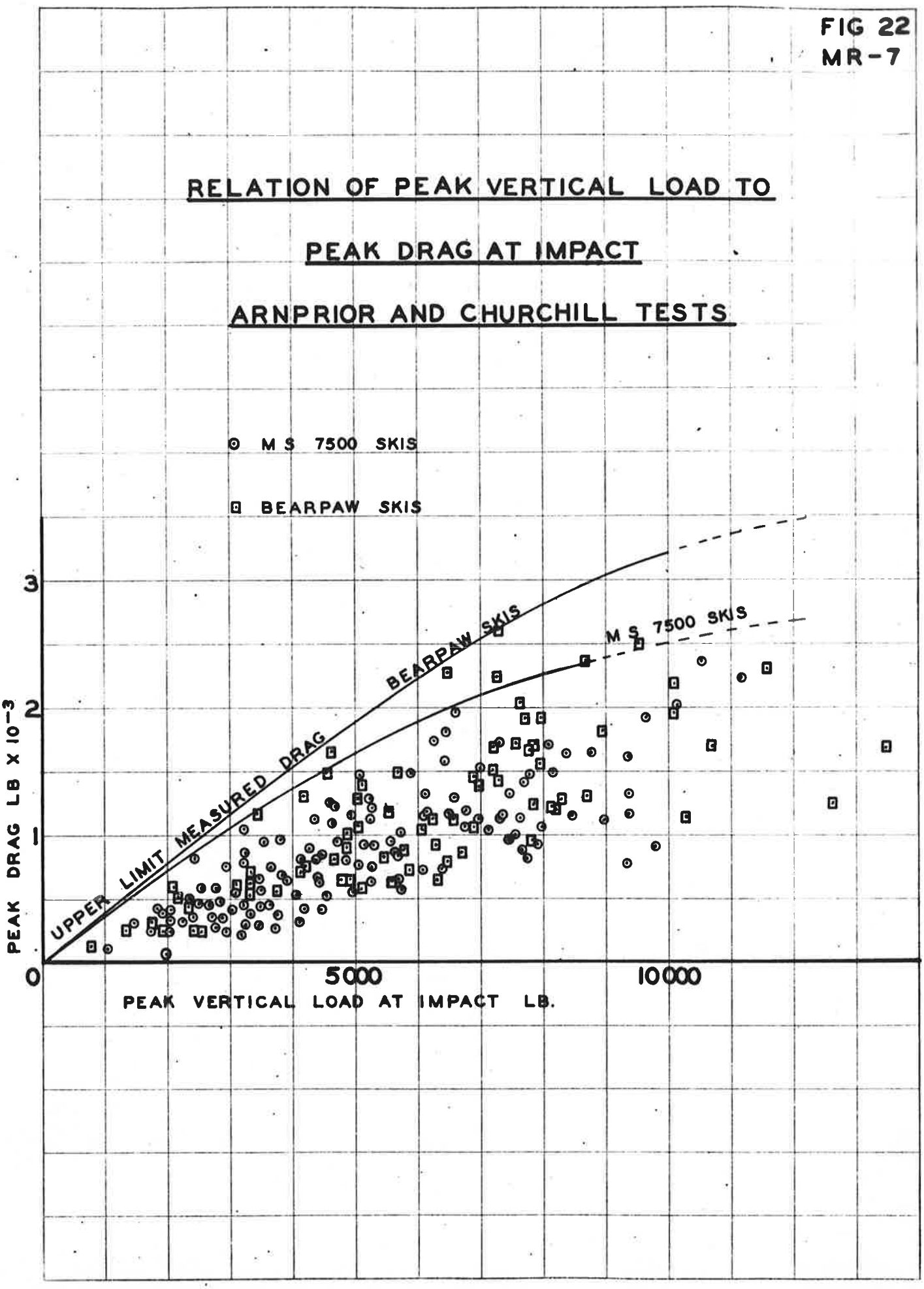


FIG 22
MR-7

# RELATION OF PEAK VERTICAL LOAD TO PEAK DRAG AT IMPACT ARNPRIOR AND CHURCHILL TESTS



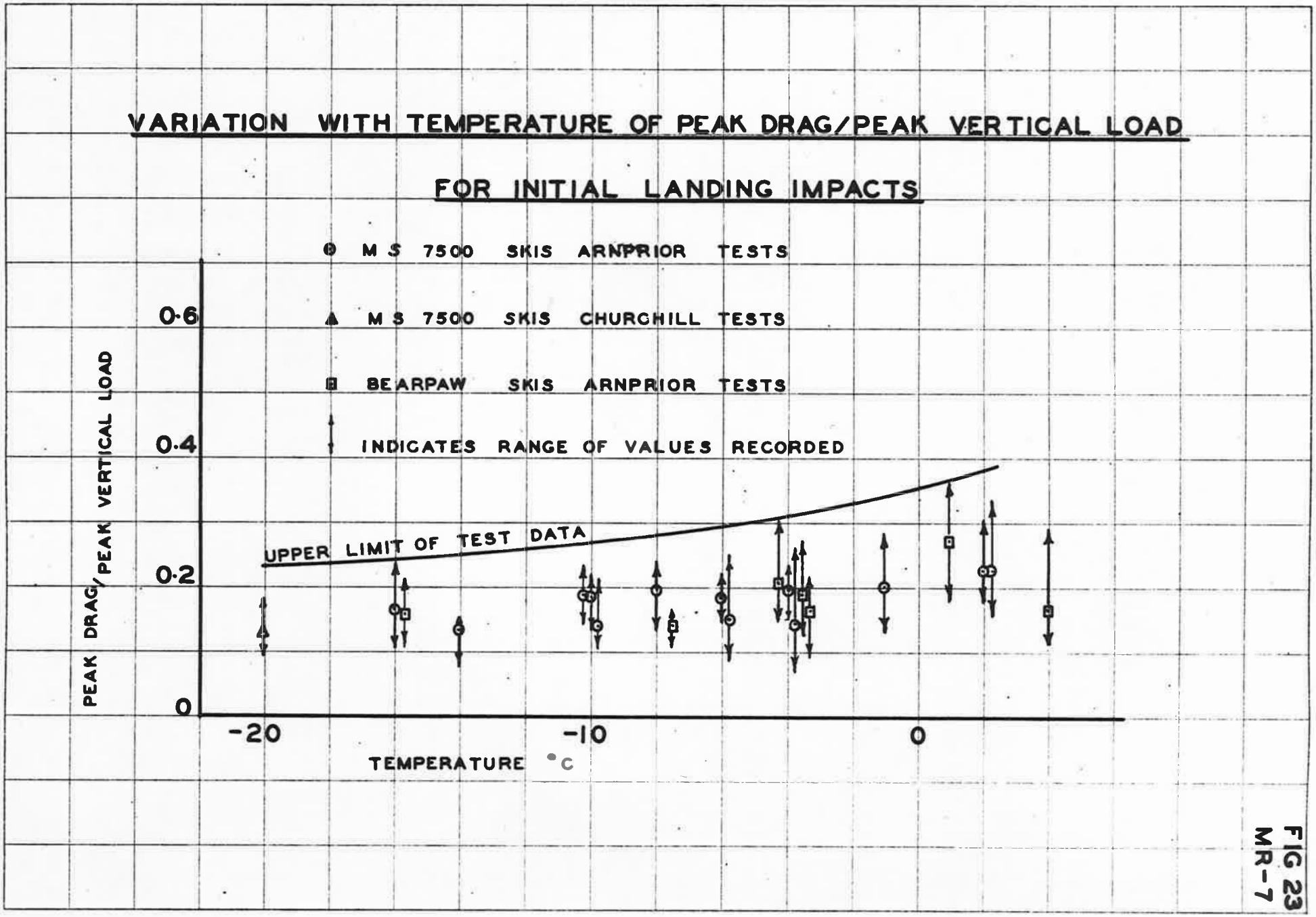
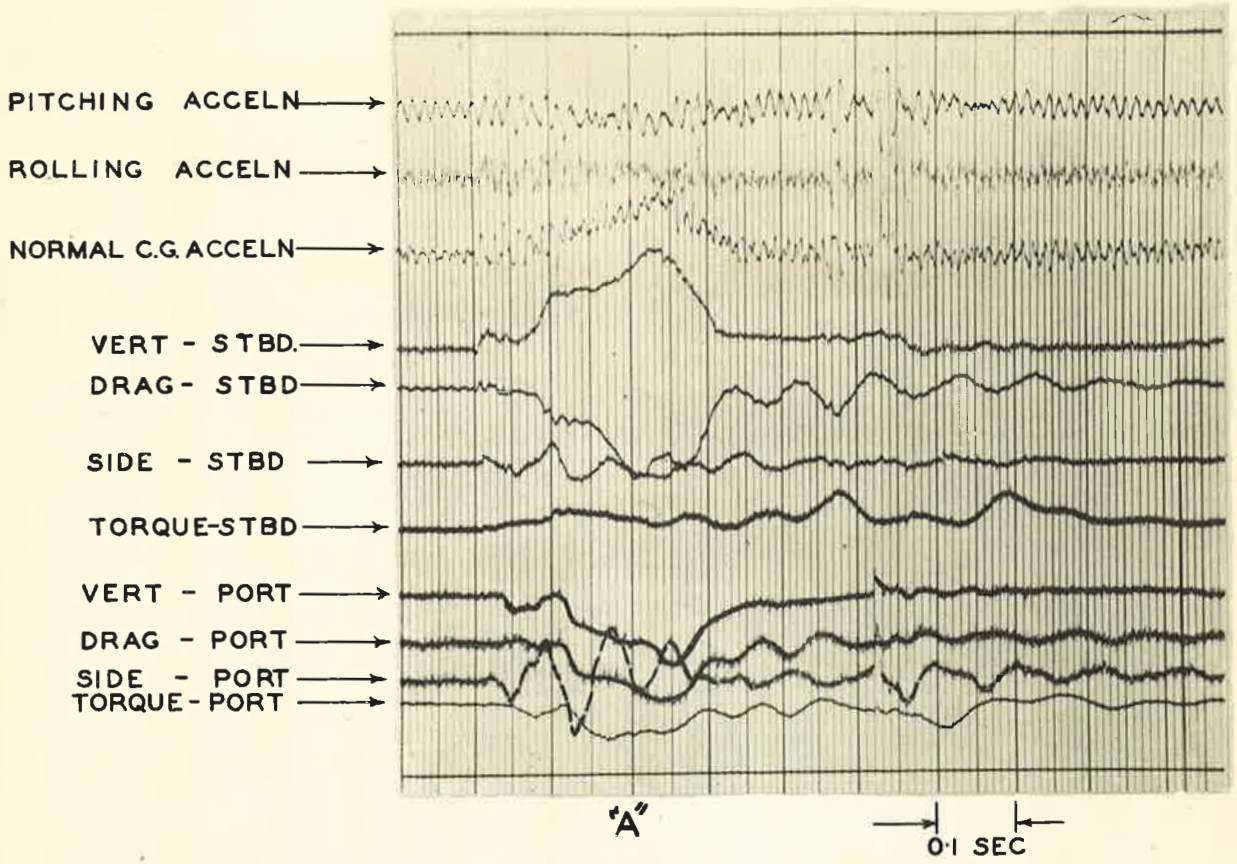

VARIATION WITH TEMPERATURE OF PEAK DRAG/PEAK VERTICAL LOAD
FOR INITIAL LANDING IMPACTS
M S 7500 SKIS ARNPRIOR TESTS
M S 7500 SKIS CHURCHILL TESTS
BEARPAW SKIS ARNPRIOR TESTS
INDICATES RANGE OF VALUES RECORDED
UPPER LIMIT OF TEST DATA
PEAK DRAG/PEAK VERTICAL LOAD
0·6
0·4
0·2
0
-20
-10
0
TEMPERATURE °C

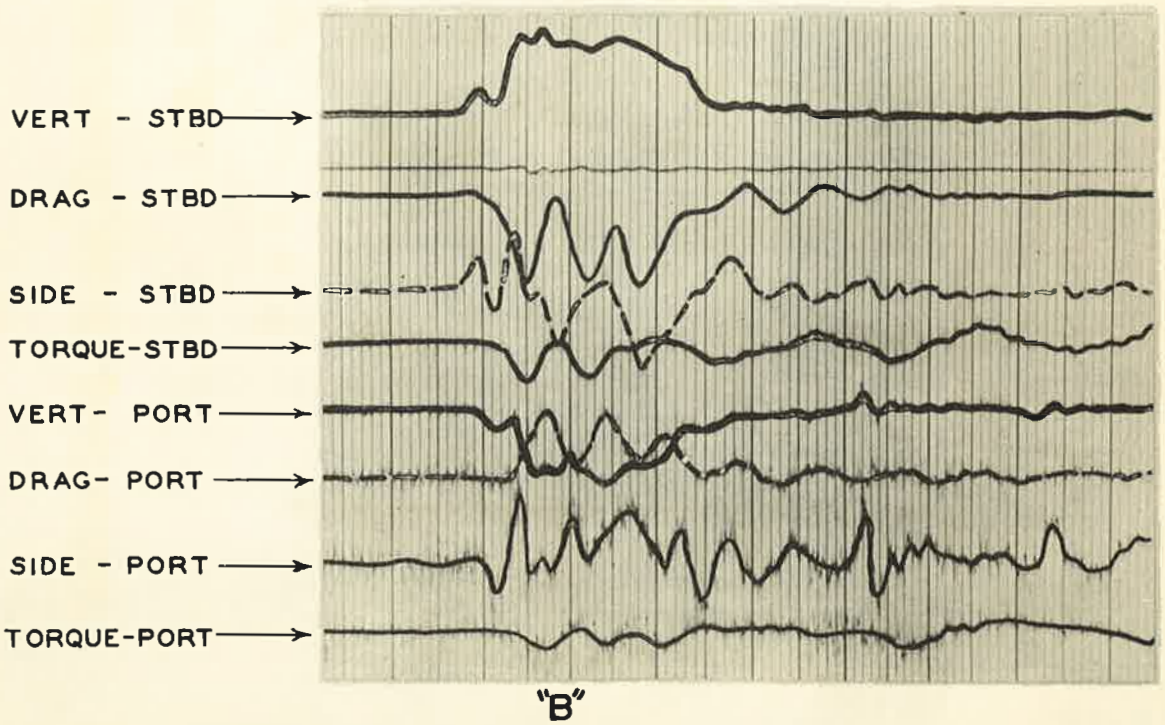
FIG 23
MR-7

FIG 24
M.R-7

# TYPICAL FILM RECORDS OF INITIAL LANDING IMPACT
## ARNPRIOR ONTARIO

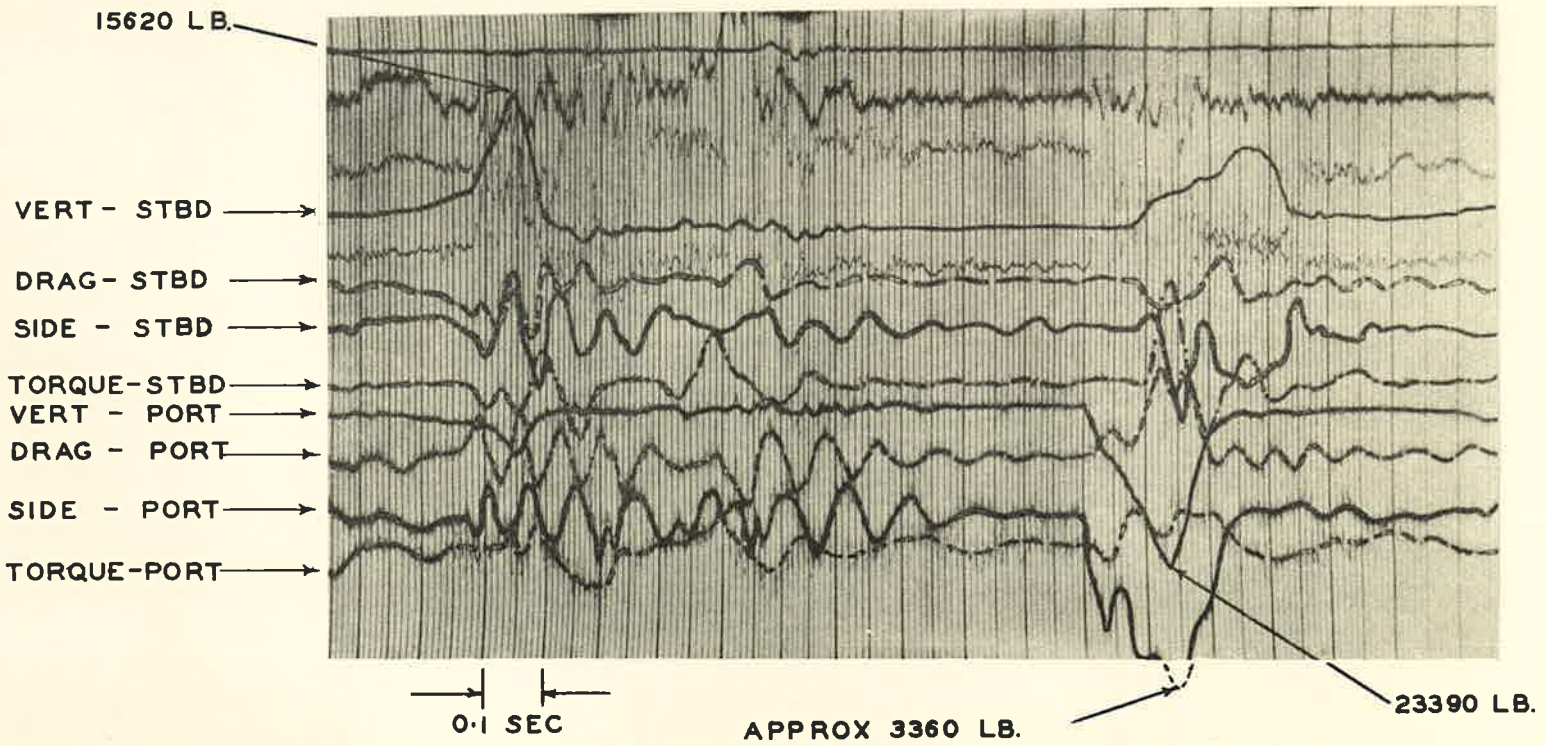



FLIGHT 8 RUN 8 BEARPAW SKIS




FLIGHT 17 RUN 4 M.S. 7500 SKIS

## SECTION OF LANDING RUN RECORD ON SEVERE SNOW HUMMOCK CONDITIONS CHURCHILL MANITOBA




FLIGHT 25 RUN 3 M.S. 7500 SKIS

FIG 25
MR-7