Snow studies in Germany

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NATIONAL RESEARCH COUNCIL OF CANADA

ASSOCIATE COMMITTEE ON SOIL AND SNOW MECHANICS

TECHNICAL MEMORANDUM NO. 20

SNOW STUDIES IN GERMANY

by

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A contribution from the Directorate of Vehicle Development,
Department of National Defence, Ottawa

Ottawa
May, 1951

FOREWORD

This report presents a summary of information regarding snow studies in Germany which was obtained during a special visit to Europe made on behalf of the Associate Committee in April, 1946. The information has been specially recorded with reference to its relevance to Canadian conditions. For some time, the original report in which it appeared was a classified document, but the Associate Committee are now glad to make the information available generally with the co-operation of the Directorate of Vehicle Development of the Department of National Defence.

The background of this report is as follows. The Associate Committee was set up in 1945 to investigate a special war problem involving soil mechanics. At the outset, and in the naming of the Committee, the importance of comparable study with snow was recognized. This association of soil and snow, in relation to a study of their physical and mechanical properties, has proved to be most helpful; it is an association which investigators in other countries have developed only after long experience.

It was not until after the end of hostilities, in 1945, that the Committee were able to devote attention to problems of snow. A search was then started for published information on the properties of this most common material but singularly little information was to be found. It soon became clear that Switzerland had pioneered in the field of snow research and, by a fortunate chance, it proved possible to make early contact with Swiss workers in this field. As a result of discussions thus started, it was arranged that Major Bekker and the writer should visit Europe in April, 1946 in order, primarily, to visit the Swiss snow research workers in their laboratories.

This mission was successfully completed; the Swiss proved to be most kindly hosts and a wealth of information was obtained even during a relatively short visit. Upon the return of the writer to Canada, Major Bekker remained in Europe, by arrangement, and in order to follow up some clues which had been uncovered with regard to German work in the same field of snow mechanics. The success of this further mission is clearly shown by the remarkable assembly of vital information now presented in this report. From the information initially uncovered, Major Bekker was eventually able to make personal contact with all the main German workers in the field of snow mechanics.

Fortunately, he was able to bring to Canada a large amount of literature and other printed information regarding German snow work. He has personally translated much of this and examined all of it. This report summarises the result of this long task and constitutes in itself one of the most comprehensive treatments of snow, as a material, yet to be assembled in the English language. It contains much detail, not of general interest, but highly important from a technical point of view and as a basis for further study in Canada.

The Associate Committee wishes to acknowledge the kind co-operation of Colonel R. L. Franklin, Director of Vehicle Development, in connection with the preparation of this version of Major Bekker's report and particularly in connection with the provision of the illustrations. Miss Margaret Gerard, Assistant Secretary to the Committee, in addition to her usual editorial services in connection with this report, has personally checked most of the references which add so much of value to the complete report.

Robert F. Legget,
Chairman,
Associate Committee on
Soil and Snow Mechanics

Ottawa, Canada.
May, 1951.

TABLE OF CONTENTS

	Page No.
General	1
A. Physical Properties of Snow	3
(i) Specific weight	3
(ii) Crystalline structure	4
(iii) Snow strength	6
(iv) Friction	8
(v) Moisture content	10
B. Theoretical and Practical Problems of Snow Clearing	13
(i) Technique of investigating and assessing:	
snow-ploughs	14
snow-blowers	19
(ii) Systematic investigation of available equipment:	
snow-ploughs	23
snow-blowers	27
(iii) Elaboration of theoretical fundamentals of snow clearing technique:	
snow-ploughs	38
snow-blowers	42
(iv) Results of experimental and theoretical work:	
snow-ploughs	45
snow-blowers	54

TABLE OF CONTENTS CONT'D

		Page No.
C.	Inter-relation Between Snow-Cover and Air Currents	58
	(i) Purpose of research	61
	(ii) Method	61
	(iii) Material tested	63
	(iv) Results obtained	63
D.	Avalanche and Ski Research	67
References		69

SNOW STUDIES IN GERMANY

by M.G. Bekker

The impetus given to motoring by the construction of a vast "Autobahn" network involved the problem of keeping these roads open for traffic in winter. The scale of this enterprise necessitated the exploration of quite new problems and initiated the applied research on snow.

By the annexation of Austria and Czechoslovakia, the problem of road clearing became a "prime requirement" as Lieutenant Colonel Schanze, from the Wehrmacht wrote in July, 1939, in conjunction with the discussions on snow clearing devices (129).

The first organized tests on this subject were conducted in the winter of 1938-39, during which a contest for the best snow-plough took place.

In winter 1939-40 the Reichsminister Todt (former General Inspector) inaugurated in Munich a special Snow Research Station (Schneeforschungsstelle) organized under the auspices of the General Inspector of the German Highways. The direction of the new organization was given to Dipl. Ing. Karl Croce, who was responsible for a vast program including the clearing and protection of roads from snow.

A close co-operation with the industry producing road equipment as well as with the German Society for the Advancement of Road Research (Forschungsgesellschaft für das Strassenwesen) was initiated and a special snow committee under the chairmanship of Herr K. Croce (Untergruppe "Schneeforschung") was formed for that purpose.

After the winter of 1939-40, meetings were held and the experience discussed. Papers presented were published by the Forschungsgesellschaft für das Strassenwesen, under the editorship of Prof. Otto Huber, who was the Scientific Adviser at the Reichsministerium in Berlin.

A second and the last snow-plough contest was organized during the winter of 1939-40. The contest results which reflected the scope of requirements and achievements will be discussed later.

The outbreak of war with Russia had a tremendous effect on snow research in Germany. The problem of costs and man-power did not play much of a rôle, as may be observed in the amount of work done.

Representatives of the Wehrmacht, Reischpost, and Luftwaffe took an active part in finding the solutions of various problems which arose sometimes in quite new circumstances. For instance, during the winter of 1940-41 many newly established armament factories called for help because of snowfalls which hampered their normal operations, especially in mountainous areas.

The direct co-operation of the Heereswaffenamt was responsible for the expanding of the scope of research which also embraced at that time the problem of snow-going vehicles.

The work done by the Snow Research Station during the period 1940-45 comprised both fundamental and applied research, which were carried out after a previous investigation of work performed in foreign countries had been completed.

Herr K. Croce, who personally started the study of snow in 1936, remained in touch with many of the snow workers abroad, among whom the following persons were included:

(1) Dipl. Ing. E. Bucher, Director, Snow Research Institute for Avalanche Prevention, Davos-Weissfluhjoch, Switzerland.

(2) Commendatore del Gaudio e Simeoni, Azienda Autonoma Statale della Strada, Via Nomentana 2, Rome, Italy.

(3) Commendatore Madoini, Azienda Autonoma della Strada, Via degli Amedei 8, Milan, Italy.

(4) Ing. Einar Rosendal at Mnjf Kristiansen 5, Govik Ostre, Norway.

(5) Ing. Ragnab Nokleby at Totenway 119, Govik Ostre, Norway.

(6) Mr. Axel Riis at Dansk Vejlaboratorium Øster-voldgade 6C, Copenhagen, Denmark.

(7) Prof. Dr. Noskkentved at Laboratorium for Bygning Statik Østervoldgade, Copenhagen.

(8) Prof. U. Nakaya, Hokkaido Imperial University, Tokyo, Japan.

(9) Herr K. Croce also exchanged some information with Swedish scientists but could not find their names and addresses during the interview, and promised, if required, to do this later. To the writer's knowledge an authority in this subject in Sweden has been Professor H.W. Ahlmann from Stockholm.

Early discussions which took place in Snow Subcommittee meetings, showed that very little was known in Germany about the properties of snow. Consequently research plans were laid down with the purpose of investigating:

A The physical properties of snow which affect snow removal;

B Theoretical and practical problems of snow removal;

C The inter-relations between snow-cover and air currents; snow fences;

D Avalanche prevention.

The above plan did not materialize as a whole. Only the three first points were investigated and the problem of avalanche prevention was considered in a very general way only.

A. PHYSICAL PROPERTIES OF SNOW

From many physical properties of snow, the following were considered as being intimately connected with the process of economic snow clearing:

(i) Specific weight;

(ii) Crystalline structure;

(iii) Strength (not specified clearly);

(iv) Friction (or rather cohesion and adhesion);

(v) Moisture content.

(i) <u>Specific weight</u> was determined by means of a conventional method, very similar to that used in Canada (84). Equipment, developed for this purpose, was made from a cylindrical snow sampler of 1 litre volume, snow cutter, wooden hammer and a precise balance (Fig. 1). Detailed instructions on testing measurements were issued for use of District Road Supervisors (6).

Tests conducted through Germany revealed that the specific weight of fresh snow varies from 25 to 200 kilograms per cubic metre. The above figures were quoted by Croce (23). Prof. Dr. Ing. W. Koeniger investigated snow of 80 to 350 kilograms per cubic metre and mentioned that fresh snow may be packed by traffic up to a specific weight of 670 kilograms per cubic metre (89).

(ii) Crystalline structure. The nature of such a wide span between the maximum and minimum value of specific weight of snow was investigated by means of a microscope, which directly showed the internal structure of various types. As was expected, the lightest type was usually formed by large crystals spaced by large pores, whereas the heaviest snow was almost always composed from amorphous compact ice particles, which are the result of metamorphosis. The proportion of air and water in the pores had a considerable effect on the specific weight, and was investigated by means of a calorimetric method which will be described later.

In order to understand better the internal snow structure, attempts were made to develop a stereoscopic microscope. The instrument constructed for this purpose was provided with a swinging mirror which enabled one to take pictures of the same crystal from two different angles.

The general view of the microscope is shown in Fig. 2. The glass container in which the snow sample is observed was filled with air at a constant sub-zero temperature to prevent crystals from melting.

Pictures obtained by means of this microscope were observed through a stereoscope and gave a full impression of the spacial configuration of ice particles.

This study was extensively performed by Herr K. Croce and his staff. It was admitted, however, that systematic work by U. Nakaya (106), H. Bader (7) and A.B. Dobrowolski (49) provided a wide basis for study of snow metamorphosis. Stereo-microscope technique proved a valuable refinement of the ordinary microscope technique used by other investigators, but as such did not reveal anything hitherto unknown.

It may be useful to note that the research on snow crystals was done in Germany by Professor Hellman from Berlin University in 1893 (70) who defined and classified various types of snow flakes.

G.F. Schumacher worked in similar lines early in 1874 (133).

In 1889 R. Assmann recorded data on various snow forms including air hoar crystals (4).

Later, Prof. H. Hess studied generally the problem of ice from the point of view of geophysics (72).

A. Wegener made numerous observations of crystals during his Greenland expedition, and gave much valuable information on this subject in his excellent book on Thermodynamics of the Atmosphere (160).

Prof. W. Paulcke published a classification of all crystalline ice forms (111) and worked on snow metamorphosis.

M. Robitsch and M. Dekart investigated the growth of snow flakes (121).

The study of ice crystals, remote from any immediate practical application, was performed by Major D. Hell who himself made more than 3000 pictures of snow crystals and claimed to have the largest collection of this kind in Europe (69).

M.K. Hoffman (Freidberg i. Sa.) developed a method of producing synthetic snow which was described in 1933 in Prof. Weickmann's Transactions from Leipzig (75).

A fundamental physical research on ice crystallization was performed by Prof. G. Tammann in Göttingen, whose work, done between 1930-1935, largely contributed to the explanation of basic phenomena (144), (145), (146).

It may be mentioned that similar work was performed by Nakaya (75) in Japan who also investigated with his co-workers the effect of static electricity on snow crystals, but the General Electric Co. Laboratories under D. Langmuir brought into the picture much more information about the crystalline snow structure and made possible the production of large amounts of snow, as well as the prevention of radio disturbances due to static electricity (188). The new technique by G.E., of producing resin casts of snowflakes (1), (2), (128), (183), was not challenged by the Germans.

At the Berlin University a large cold room existed which was 10 1/2 m. long, 3 m. wide, and 2 1/2 m. high. Temperatures up to minus 45°C. could be easily obtained. Prof. W. Koeniger suggested the use of this cold room for practical experiments (89).

However, this work did not seem to go beyond the fact finding stage at the Schneeforschungsstelle. Hundreds of stereophotographs and a great deal of data were seen by the writer at Traunstein Strassen and Flussbahnamt, without any visible results of correlation between the physics of snow structure and those features of snow which might have any practical significance.

Herr K. Croce explained this by the lack of time and personnel during the war. Although this study did not open any immediate practical prospects and was rather of pure scientific interest, it was considered by the Germans to be as essential in explaining the mechanical properties of snow as the investigation of the crystalline structure of metals is essential for a better understanding of their mechanical properties.

In the book under preparation by Herr K. Croce on snow and its role in road transport problems (the manuscripts of which were reviewed by the writer) the first chapter deals with snow structure and is an introduction to the further chapters. There is the same general tendency in presenting the background of crystallography of snow, as may be seen for instance, in works by Seligman (127), Bentley and Humphreys (12), and there is no special elaboration of some problems as it is illustrated by later papers by Perutz and Seligman (117) or the newest work of Swiss investigators, like de Quervain (118).

(iii) Snow strength. The meaning of "snow strength" and how it affects the efficiency of a snow-plough was not clearly defined. As Herr K. Croce said, "It is the question of forces binding the snow particles together." Although the work by Haefeli (65) was not ignored, an opinion prevailed that the ideas of tensile, compression, and shear strengths do not contribute to the snow clearing technique (23). This is considered rather an underestimation, and suggests that the development of German applied snow research from the scientific point of view was in its preliminary stage.

As in early works on soil mechanics, the German method of investigating the "snow strength" consisted only of measuring the snow penetration under the pressure of a metal cone. Although there are doubts as to what mechanical properties may be measured by this method (104), it was considered that the cone method offers much opportunity in correlating the snow strength and the efficiency of a snow-plough.

Whether these expectations were right or wrong is not known. The fall of Germany interrupted the work and insufficient data were available at the end of the war.

The Croce cone penetrometer developed for snow survey was designed for quantitative determination of certain more or less unknown properties, and as such should not be compared with the Swiss cone penetrometer (66) which has been used for a qualitative survey of snow-cover in conjunction with the study of snow stratification.

There is, however, one interesting point in the German method, namely the range and precision of the measurements. The instrument is shown in Fig. 3. It consists of a rigid stand with a light (210 grams) sheet cone suspended in a special rig. The height of the cone above the snow surface is adjustable, depending on snow hardness. After release, the cone penetrates the snow according to the amount of resistance encountered, the height of fall and the shape of the cone.

The reading of the penetration is very accurate, thanks to a precise sight which enables one to determine the penetration with accuracy up to 0.05 inches.

This, and the variation of the height of cone fall, give the instrument a very wide range of measurements. The conversion of recorded data into the "units" of snow strength is as arbitrary as it is simple.

Let "d" mm. be the diameter of the cone impression in snow, then the index of "snow strength" is:

$$\frac{4x \text{ cone weight (210 grams)}}{d^2}$$

Tests were made with 60°, 75° and 90° cones all having the same weight, 210 grams. It was found that a definite interrelation between these various cones exists with almost all kinds of snow. If, for instance, the depth of penetration of the 60° cone is 100 per cent, then the 75° cone gives 80 per cent and the 90° cone 66 per cent penetration at the constant height of fall.

The graph shown in Fig. 4 refers to the penetration vs. "snow strength" as established for 75° cone at fall heights from 0 to 40 cm. From this diagram "strength" readings may be obtained for the 60° cone by multiplying the respective "strength" figure by 1.77. In the case of a 90° cone, the multiplication factor is 0.59.

With very hard snow, when the penetration of the cone falling down from a 40 cm. height is only 1 to 3 cm. the method should be discarded as the readings are scattered too widely.

An identical method of measuring the snow hardness by an impact cone was developed in Japan in 1936 by M. Kuroda (91). This method, however, was considerably elaborated on by Herr K. Croce who used various types of cones and an adjustable height of cone fall. There is some analogy between this work and the investigations by A. Riis from Denmark (200). As Herr K. Croce was in touch with Mr. Riis it is possible that the latter had some influence in developing the described method of investigating the snow "strength".

Snow removal by a plough is simultaneously compacted and forms a more or less solid mass before it is broken again and thrown away in a granular or pulverized form. An attempt to investigate this problem as well as snow "strength" in general led to the development of an experimental tensile strength apparatus.

This instrument was a copy of Haefeli's centrifugal tensiometer (67), and was improved with a milk separator gear (Fig. 5). It is based on the principle that a tensile stress is applied to the snow under test by means of centrifugal force. For this purpose a cylindrical sample is rotated around an axis vertical to the axis of the cylinder. Centrifugal forces, acting on both ends of the tested snow are gradually increased and at certain r.p.m. break the sample.

The stretching force may be determined from the sample weight, radius of rotation and r.p.m. Also the sample cross-section is known, hence the tensile stress of the snow may be determined.

Although Herr K. Croce was not enthusiastic about the results obtained by means of this instrument, an interesting design of covers which held the sample cylinder was noticed. These covers were fully automatic and closed the cylinder under the action of the centrifugal force exercised by the counter-weights.

Apparently the crudeness and the improvization of the apparatus did not secure very satisfactory results, but the experiment proved the definite possibility of making a portable field instrument of this kind, provided that the stress theory of snow is sufficiently clarified. This had not been done in Germany and again wartime conditions were blamed.

(iv) Friction. Efficiency of snow-clearing devices was found to depend on snow properties which were called "friction". It is admitted that friction is displayed when snow moves on snow surface or on the surface of metal, although in these cases terms "cohesion" and "adhesion" would be more adequate. Herr K. Croce, however, did not seem to make a distinction between frictional and coherent properties along Coulomb's definition, which was recognized by Haefeli in his "Snow Mechanics" (65).

Germans knew the results of tests made in Switzerland with the purpose of determining the coefficient of friction between snow and glass. This coefficient was found to vary from 0.175 to 0.0005 and was a function of unit pressure and of the temperature.

The above figures, however, did not refer to the friction between steel and snow and they were measured at speeds up to 100 mm. per minute. Speeds encountered with the snow-ploughs often reach a value of many metres per second.

In order to investigate the "friction" under these conditions, special apparatus was devised by Herr K. Croce. This is composed of a disc (Fig. 6) running at speeds which can be regulated in a wide range. A snow sample resting on the disc is the subject of frictional force which stretches the measuring spring and indicates the required values.

In the winter of 1940-41 tests on friction between snow and steel were made. It was found that the Swiss experiments with snow and glass have a general meaning and that the same character of relationship between snow and steel may be observed. In the latter case the coefficient of friction also rises with the increase of speed. It seems, however, to have a certain limiting value which varies with the variation of the unit pressure. This limit is never surpassed and is reached sooner when the pressure is high. The decrease of speed is marked by a decrease of friction which is emphasized at speeds over 1 metre per second.

Figures determined during these experiments show the coefficient of friction of snow on steel as varying between 0.03 and 0.16 for a temperature slightly higher than 0°C. Speeds were not specified but included those above a few metres per second. Lower temperatures show higher values of friction, which is in accordance with the tests performed by Klein in Canada (85).

Various explanations were offered by Herr K. Croce with reference to the nature of friction on snow. However, their theoretical and experimental verification was not given. It seems that the Germans did not conduct any research on the mechanism of ice friction and that they did not follow Bowden and Hughes (15) in this subject.

(v) Moisture content. Snow, at temperatures close to 0°C. has a free water content which considerably changes mechanical properties of this material. The effect of pore water, and its relation to cohesive forces binding the solid particles together, has been appreciated since the early works on soil mechanics.

Herr K. Croce spent considerable time in devising a calorimetric method of measuring the moisture content of snow. This method was widely used in the winter of 1943, and is undoubtedly based on similar work done in Japan by Z. Yosida which was published in 1940 (166). The Japanese investigations, as far as it is known, are original ones and used standard laboratory equipment.

Germans improved this method and attempted to develop some sort of a portable field instrument. The principle of the snow moisture calorimeter is based on the known fact that melting of ice at 0°C. requires a definite amount of heat, namely 79.5 calories per kilogram. Consequently the amount of water content of a snow sample may be determined by measuring the amount of heat absorbed during the process of melting it. This may be achieved by mixing in a calorimeter a known volume of snow and warm water, the temperature of the latter having been carefully determined, and by measuring the temperature at the end of the melting process.

The calorimeter used for this purpose is shown in Fig. 7. It has a 1-liter thermos container with a wide opening which may be closed by a cover provided with a thermometer. Snow taken by means of a sampler is taken directly to the calorimeter.

It was found that for weighing the amount of snow and water a scale with the accuracy of 0.01 gram is required. The procedure applied for measuring the moisture content is as follows:

1. Weigh 500 to 600 cu. cm. of water with the accuracy of 0.1 gm. and pour it into the calorimeter. Water temperature: 50° to 70°C.

2. Take a snow sample and weigh it with the sampler. Measure water temperature in the calorimeter (0.1°C. of accuracy). Introduce the snow into the water.

3. Shake the calorimeter. Measure the temperature of the melted mixture and weigh the empty snow sampler with the mixture of snow and water (in order to determine the exact weight of the melted snow).

For dry snow at 0°C. the following formulae may be deduced:

Let: G_B = weight of the warm water (kg.)

G_P = weight of snow sample (kg.)

t_B = initial temperature of the water (per cent)

C_1 = 1 cal/kg/1°C. - specific heat of water

C = 79.5 cal/kg. - latent heat of fusion of ice

Then:

$$C_1 \, G_B \, (t_B - t) = G_P \, (C + C_1 \, t)$$

or

$$G_B \, (t_B - t) = G_P \, (79.5 + t) \qquad (1)$$

For a moist snow, however, this formula must be modified.

If snow contains water, then the weight G_P must be split into:

G_W = weight of water

G_E = weight of ice

Then:

$$G_P = G_W + G_E$$

and

$$G_B \, (t_B - t) = G_E \, (79.5 + t) + G_W \, t \qquad (2)$$

In the above, it was assumed that the heat exchange takes place between ice and water only, which is not correct. The calorimeter also cools and some heat is transferred from its walls to the mixture. This necessitates the determination of a constant for the calorimeter. Let this constant be denoted by X.

Croce proposes to determine this value by using a dry snow at a temperature below 0°C., say t_P°C. Before melting, this snow must be brought to the temperature 0°C. If the specific heat of ice is 0.5 cal/kg/1°C., then from the equation (1):

$$(X + G_B)\ (t_B - t) = G_P(-\ 0.5\ t_P + 79.5 + t) \qquad (3)$$

For a snow at -8°C. the calorimeter constant X is:

$$X = G_P \frac{159 + 2t - t_P}{2\ (t_B - t)} - G_B$$

Once X is know, equation (2) is determined:-

$$(X + G_B)\ (t_B - t) = G_E\ (79.5 + t) + G_W\ t \qquad (4)$$

Let the snow moisture p be defined by the formula:

$$p = \frac{100\ G_W}{G_P}\ \% \qquad (5)$$

By substituting $G_E = G_P - G_W$ into equation (4) the following may be obtained:-

$$(X + G_B)\ (t_B - t) = (G_P - G_W)\ (79.5 + t) + G_W\ t$$

or

$$G_W = \frac{1}{79.5}\ (G_P\ (79.5 + t) - (X + G_B)\ (t_B - t)$$

By substituting the above determined value of G_W into equation (5) the snow moisture may be determined from the formula:

$$P = \frac{100}{79.5} \left((79.5 + t) - (t_b - t)\ \frac{(G_B + X)}{G_P} \right)$$

Calorimeter tests were made in the winter of 1943 and about 500 measurements were taken. The calorimeter constant was determined as X = 0.0523 kg. The average moisture content varied between 5 to 10 per cent. The accuracy of measurement was investigated by more than 100 measurements with dry snow. It has been found that the error was ± 5 per cent mainly due to the fact that at the moment of introducing the snow sample a great deal of heat from the warm water was lost.

Herr K. Croce was dissatisfied with the accuracy obtained and planned an improvement of this method to further decrease the error. He envisaged a calorimeter composed of two bottles with a heat-isolated slide in between (Fig. 8). The lower thermos bottle was supposed to contain warm water and the upper one the snow sample which could be forced into the calorimeter by using a piston and preventing any contact of the mixture with the outside air. Also heating of the water by means of electric current was contemplated.

The results of some tests made in the vicinity of Inzell were published in a special report (24). The Swiss approach to the problem was concentrated on other aspects and was not directly concerned with measurements of moisture content in the field. The German-Japanese method, however, undoubtedly has a definite bearing on snow investigation for practical purposes. A simplified version of this method by Klein (84) proved useful in Canada, although in the light of the German experience it seems to be very approximate.

B. THEORETICAL AND PRACTICAL PROBLEMS OF SNOW CLEARING

Croce first started in the summer of 1941 to investigate snow-blowers and approached the problem from the mechanical point of view (25).

The most striking result of these tests was the fact that the efficiency of various rotative ploughs appeared to be very low and was in the range of 10 to 20 per cent. The necessity of improving the snow clearing technique became urgent. The tremendous amount of snow which was to be removed every year from some of the German highways involved about 20 per cent of the total cost spent for highway maintenance.

Croce estimated that nearly 160,000,000 cu. m. of snow had to be removed in 1938/39 in Bavaria only, which cost the taxpayers 2,400,000 marks (26).

The necessity of doing this work economically became more urgent during the war, when, apart from manpower and material, time was the most important factor.

The trend towards obtaining better efficiency of snow clearing devices embraced both snow-blowers and ploughs. The snow-plough problem was strictly correlated to the problem of vehicle design and preoccupied the Wehrmacht, which had to adapt its military vehicles to be used as plough pushers.

The question of training the drivers was widely discussed. Ing. A. Schmidt, (131), showed how important it is in snow clearing economy. The same problem also was discussed by Ing. Jungel (81).

The work which was performed by the Forschungsstelle under Herr K. Croce may be described under the following headings:

(i) Development of the technique of research and of quantitative assessment of snow clearing;

(ii) Systematic investigation of available equipment;

(iii) Establishing theoretical fundamentals of snow clearing technique;

(iv) Application of results of experimental and theoretical work.

Each of the above-listed paragraphs may be subdivided into two parts, one referring to the snow-ploughs and the second to the snow-blowers.

(i) Technique of investigating and assessing the value of snow-ploughs was not easily determined as the nomenclature customarily used had not been defined. It also was not known at the beginning what units determine the value of a snow-plough, and how they should be expressed and measured.

Innumerable experiments and two contests in which many German and foreign ploughs were investigated slowly clarified many questions and lead to the introduction of some new ideas which later proved very useful. In general, the plough-vehicle unit was assessed after determining:

(1) its conformity to the traffic regulations;

(2) simplicity in operation and in adaption of the plough to the vehicle;

(3) economy.

The first point was determined by means of gauges. Manoeuvrability and steerability were the subjects of a similar procedure. Simplicity in operation and in adaption to the vehicle were easily determined by means of measuring the time required to perform given functions, and/or by means of measuring effort needed for that purpose.

The problem of economy, however, appeared to be more complex, and proved to depend not only on snow clearing efficiency, but also on the exploitation of the vehicle itself.

For instance, the additional load which was acting on the front axle of the truck, due to the attached weight of a snow-plough, usually decreased the manoeuvrability of the vehicle. This reduced the speed of idle course and affected the economy of the whole action. In the same way, the surcharged front axle was subjected to additional wear which increased the maintenance costs.

Therefore, it was considered important to assess the loads on the front axle. To do this, not only the weight of the plough but also its location with reference to the truck wheels was decisive. Herr K. Croce introduced the idea of a "Specific Front Axle Load" (Bezogene Vorderachsbelastung) which was determined from the load distribution between front and rear axles (Fig. 9).

If the distance between these axles is c, the distance between front axle and centre of gravity of the plough a + b and the ploughs weights G then the "SFAL" is:

$$SFAL = G \frac{(a + b + c)}{c}$$

The smaller the value of SFAL the better is the plough, and the better is the vehicle applied.

The value of SFAL was used for comparing various units and seems to be very useful for this purpose as it takes into consideration not only the economy of the plough weight but also the effect of load distribution.

Since the German shortages emphasized saving of materials, the lightness of ploughs was one of the major items in the assessment of their value. For this purpose the plough weight itself was referred to the surface of the horizontal projection of the frontal areas of blades and was introduced by Herr K. Croce as "Specific Plough Weight" (Bezogenes Pfluggewicht):

$$SPW = \frac{\text{Plough Weight } (K_g)}{\text{Frontal Area of Blades } (m)}$$

Further economy of snow clearing depends on movement resistance, which is the result not only of snow properties but also of plough design. If tests are conducted in the same snow conditions the plough design may be assessed by measuring the resistance which is offered during the operation.

First attempts to determine this resistance were made by using the Siemens accelerometer (Fig. 10) which indicates the deceleration or acceleration of a vehicle (134).

A truck provided with a snow-plough was set in motion at a certain speed and subsequently declutched. Deceleration was indicated by the above mentioned instrument. Since the moving mass was known by weight, the instantaneous resistance encountered could be determined by calculation using Newton's Law which defines force as mass times acceleration.

Values obtained by this method include rolling resistance of the vehicle. The latter, however, was determined in a similar manner with the plough out of action. Vehicle resistance was subsequently subtracted from the previously found value of the aggregate resistance. Thus net plough resistance was obtained (26).

Tests repeatedly conducted with declutching at various speeds gave a typical graph shown in Fig. 11, which enabled one to assess the merits of the plough and those of the vehicle.

It is generally known that the deceleration method used for measuring movement resistance is not very accurate unless an elaborate system of recording speed and time is used. The same conclusion was arrived at later by the Germans. The Siemens device was used during the first snow-plough contest in 1938/39. Further work, however, which also dealt with the determination of the distance over which the snow is thrown by a plough at a given speed, required more accurate speed measurements which were in these cases performed by means of the well-known "fifth wheel", (Fig. 13). The same device also was later used by Croce for measuring the movement resistance (27), (87).

The instrument used was provided with an electric speedometer by Hartman and Braun. Time was marked by a contact clock by A. Ott (Kempten). Recording was performed by means of a Siemens 16 mm. camera.

Direct measurement of plough resistance by connecting the blades with the main frame through dynamometers was not mentioned. This method was undoubtedly considered tedious and expensive, as special dynamometers would probably have had to be made for every type of plough tested.

De Forest strain gauges were either not known or were not contemplated. Herr K. Croce was fully satisfied with the "coasting" (deceleration) method. If the investigators from Forschungsstelle had been better informed on tests in automobile research, the discrepancy between the "coasting" and dynamometer methods, especially at higher speeds, would have been considered (9).

Measuring the resistance of various ploughs, even at the same speeds and snow conditions, does not offer any comparable value in assessing the plough economy, because plough resistance depends on the size of the blades, which was not considered at all.

In order to obtain a comparable value for the evaluation of ploughs of various dimensions under the same snow conditions, Croce applied in his work the idea of plough resistance referred to 1 metre of the width of the trace made in snow by the blades.

$$R_w = \frac{\text{Movement resistance of a plough (kg.)}}{\text{Width of the plough trace in snow (m.)}}$$

This unit, however, although useful for comparing ploughs used under the same conditions, does not express the effect of snow depth or snow volume, removed at the cost of the measured resistance. Also tests made by Croce, in order to compare one-and two-blade ploughs, revealed a wide scattering of R_w values.

A more universal unit and a more decisive tool in measuring plough economy was obtained after the plough resistance had been referred to 1 metre of trace width and to 10 kg. of the removed snow on the surface of one sq. metre.

$$R_V = \frac{10 \times R_W}{\text{Weight of snow (kg.) removed from 1 sq. metre}}$$

These units, however, are affected by varying physical conditions of snow and cannot be used as an accurate "measuring rod". They are very valuable in determining the tendency in plough development, but their accuracy lies in extensive experimental work and in a great deal of statistical data (27).

To complete this survey, the writer takes the opportunity of mentioning another unit used in his earlier work, which determines the efficiency of ploughing in terms of the volume of snow (cu. m.) removed, as referred to the work performed (kg. x m.) at a constant distance of snow throwing.

$$C = \frac{\text{volume of snow removed (cu. m.)}}{\text{plough resistance (kg.) x distance (m.)}}$$

These attempts to find a convenient way of measuring economy of snow-ploughing show that the problem is still open although practical progress has been made by Herr K. Croce and his co-workers.

In assessing the efficiency of snow clearing, measuring of the volume of the snow removed is the most frequent operation. It never offered any particular problem and was usually performed by finding the dimensions of the excavation made by a plough. This however, was very tedious and inaccurate when the theodolite and foot tape had to be used. The Germans encountered this problem so often that they developed a very quick method of measuring this volume.

This method consisted of the photographic recording of the snow profile, which was later scaled and used for the computation of volume. For this purpose a rigid beam was placed across the road at the height of 1 m. above the pavement. The beam could be moved along the road on a wooden support and could be fixed at any point where the snow profile had to be measured. Black rods spaced at a distance of 25 cm. were attached to the beam. These rods could be moved vertically so that they might be fixed with their ends touching the snow surface. The outer ends of rods sticking above the cross beam automatically determined the snow profile.

The whole installation was then photographed. The scale painted on the beam enabled the experimenter to determine the scale of the picture and finally the dimensions of the profile. Thus the volume of snow could be determined very accurately.

More advanced study of snow-ploughing included movie recording of the movement of snow particles along the plough blade, and in the air. A rectangular grid traced on the blade (Fig. 14) enabled the observer to compute path, speeds, accelerations, etc. This work proved to be very useful in determining the right shape of blades and in investigating the snow-throwing effect at an economic speed. The above method required an elaborate system of light signals for photographic recording of various data. It also served Herr K. Croce in the determination of critical plough speeds (87).

The graph in Fig. 12 is a sample of computations performed in solving problems of plough resistance. Curve G/W shows the speed of the plough. K_1 shows the respective resistance of the plough and vehicle. K_2 is the resistance of the vehicle itself. P is the plough resistance. The lowest curve shows the distance to which the snow is thrown at a given speed. The curves were determined from the data obtained by means of the methods mentioned above.

Investigation and assessment of snow-blowers offered more difficulties since these devices are mechanically more complicated and the process of snow clearing depends on more variables. During the first tests made with snow blowers (Peterfräse BER and DEF, Schallert, Fokkerrad and Crosti) in Grossglocknerstrasse in the summer of 1941, the following values were measured:

(1) Volume of snow (in cu. m.) removed in 1 hour;

(2) Number of revolutions (r.p.m.) of the rotating drum;

(3) Distance (m.) at which the snow is thrown.

On the other hand, some of the snow properties also were recorded although they were not successfully correlated to the work of snow-blowers:

(1) Specific weight;

(2) Cone "strength".

It should be noted that the cone "strength" was not measured at that time by means of the apparatus described in pages 6 to 8 of this report.

For the above purpose a rammer made according to Haefeli's data was used (66) and snow "strength" was determined from the formula:

$$W = \frac{n \times R \times h}{t} + G$$

Where n is the number of strokes of the weight R which fell from the height h and forced the cone into the snow to the depth t. G is the weight of the cone with the rod which guided the falling weight.

From the recorded number of revolutions of rotors and from the ratio in the transmission, the r.p.m. of the engines were determined. Since engine characteristics were known, power input N_o (h.p.) developed at a given speed of snow blowing could be approximately determined.

The energy A (m. x kg./sec.) of snow stream blown from the device may be assumed as equal to:

$$A = \frac{M \times V^2}{2}$$

Where M is the mass of snow blown in 1 sec. (kg. x sec^2/m.) and v is the speed of the stream (m./sec.). Accordingly, the power represented by blown snow is:

$$N_1 = \frac{M \times V^2}{2 \times 75} = \frac{M \times V^2}{150} \quad \text{(h.p.)}$$

The ratio of power N_o supplied by the engine to the power N_1 which remains in the snow when leaving the blower is a measure of the efficiency of the device.

$$\eta_1 = \frac{N_1}{N_o}$$

Herr K. Croce called this value the coefficient of internal efficiency (innerer Wirkungsgrad) of the snow-blower (25).

Another coefficient of efficiency was also defined by Croce, who referred the power N_o to the power N_2 which would be required if the snow were to be thrown from the road to the distance blown without any losses due to air resistance or faulty trajectory of fall. It is known that the longest trajectory is obtained at the angle of 45°. The work A (m. x kg.) required to cover this distance is:

$$A = \frac{G_o \times W}{2}$$

Where G_o (kg.) is the weight of the snow thrown, and W (m.) is the distance which it falls.

If the weight G_o (kg.) of snow removed is expressed in G kg. per second, then the corresponding power required is:

$$N_2 = \frac{G \times W}{150} \quad \text{(h.p.)}$$

and the coefficient of total efficiency (gesamte Wirkungsgrad) is:

$$\eta_2 = \frac{N_2}{N_o}$$

This value expresses losses of the whole process including the losses which take place during the flight of snow particles in the air (25).

As has been mentioned before, coefficients of efficiency were found within the limits of 10 to 20 per cent. However, the accuracy of recording various data listed above was not satisfactory, especially as far as the measurement of power input to the snow blowing process is concerned. For instance, not all the power of the engine was used for rotation of blowers. A portion of it was used for moving forward the device which made the calculation of energy consumption more inaccurate. Engines worked at Grossglocknerstrasse at an altitude of 2200 to 2400 metres (7300 to 7500 feet) and did not develop full power due to the decreased air pressure. Mechanical efficiency of some older machinery used was not equal to the new one, etc.

These sources of inaccuracy started new trends toward the further improvement of the technique of measuring of snow-blowers. It was emphasized on several occasions that an economy of one per cent in power used, or the smallest increase of efficiency of the process means a saving of thousands of man-hours or millions of Reichsmark due to the astronomical figures of cubic feet of snow which had to be removed.

It was agreed that accuracy in assessing snow-blowers should be brought up to highest standards and that any amount of money spent for this purpose would pay in the future.

Accordingly the most modern, but probably the most expensive, program was devised. It was arranged that all gas engines in experimental snow-blowers were replaced by electric motors and were supplied with D.C. by an especially built mobile generating unit. Power input was measured by means of electric instruments, thus securing the greatest possible accuracy.

The arrangement of the generating unit is shown in Fig. 15. It was equipped with a 12 cylinder Diesel engine by Humboldt-Deutz developing 275 h.p. at 1500 r.p.m. and with an AEG generator FG5227c/295b of 270 kw. and 500 volts D.C. This generating unit also supplied power for an electric motor which propelled the whole installation.

It may be interesting to note that the importance attached to the new methods of snow-blower investigations was responsible for the designing and construction of this mobile generating station in 5 months. Those who co-operated in this work with the Forschungsstelle were Reichsbahn workshops and Street Car Company in Munich. Electric instruments for measuring the power were those manufactured by Hartman and Braun (Frankfurt). Other installations were supplied by Zettler Co. (Munich).

The instrument panel of the generating unit is shown in Fig. 16, right. Since the readings of various metres were to be made simultaneously, a special camera was installed which took 8 pictures per second of the instrument panel, thus recording the variation of power and speeds at 1/8 second intervals (Fig. 16, left). From the photographed indication of voltmetres, ammetres and clocks, the power was later calculated and subsequently the coefficients of internal and total efficiency (Page 20, 21) were determined.

Pictures of the generator, experimental blower unit and a photograph of instrument records are shown respectively in Fig. 17a, b, c.

Power was supplied to the snow-blowers by means of flexible cables. The arrangement of the electrically driven Peterfräse Schallert is shown in Fig. 18.

The new equipment was used for testing the snow-blowers during the winter of 1941-42. The great amount of data recorded during these tests enabled the investigators to compile many interesting graphs and tables, which will be discussed later.

It may be noted that, at that time, the Germans did not conduct any tests with small scale models, which were originated later in Switzerland by R. Aebi and Co. Although Professor W. Koeniger recommended in 1939 this type of test (89) they never, as far as it is known, materialized at the Forschungsstelle. Only large scale tests were performed by Herr K. Croce who devised a special experimental blower unit provided with electric propulsion and exchangeable rotors (Fig. 17b).

This suggests that the wartime emergency of the snow-clearing problem in Germany favoured a full-scale experiment with an immediate prospect of practical results rather than a long-term scale model research.

The above-mentioned Swiss firm, however, recently inaugurated at the Schneeforschungsinstitut at Davos an investigation of snow-blowing process by using miniature rotors and special measuring installation, which undoubtedly better serves systematic study of the relevant problems.

Herr K. Croce was acquainted with the progress made by the Swiss and hoped soon to return to further research in this subject at the Bavarian Strassen and Flussbauamt in Traunstein. At the time of the writer's visit in Germany he was busy finishing his previously mentioned book in which he discusses in detail all the methods of measuring and assessing the value of snow-clearing equipment.

(ii) A systematic investigation of available equipment was preceded by tests on snow removal performed since 1935/36 after the Autobahn Munich-Salzburg had been constructed. For this purpose existing equipment was used, and the history of experience gained was described by Oberreichsbahnrat Saurler, who gave in his paper a good picture of the difficulties encountered (123).

An organized study, however, independent from daily routine and from the necessity of keeping the autobahn open for traffic started early in the winter of 1938-39 when the General Inspector organized the first contest of snow-ploughs.

In July, 1939, a meeting was called in the Reichsministerium in Berlin with the purpose of exchanging ideas between the Highway Departmental officials, scientists and the representatives of the industry producing the necessary equipment. The experience gained during the contest was discussed, and conditions for a new contest planned in the winter of 1939-40 were set.

General Inspector Dr. Todt was not satisfied, especially with the results obtained by the snow-ploughs classified in Class A (shallow snow, flat country ploughs). He insisted that new ploughs be developed which would be able to throw snow on the sides of a road without forming vertical embankments at a snow depth of 25 to 30 cm. and at speeds of about 30 km./hr.

As Ministerialrat Auberlen emphasized the new ploughs should be able to throw the snow further without forming a snow deposit on the sides of a road, especially at small snow depth (5).

Equipment admitted to the contest in 1939-40 was divided into four classes and was tested near Inzell and on the Autobahn Munich-Salzburg.

Class A: Ploughs devised for flat country and small snow depth (up to 50 cm.); suitable for use on the Autobahn and country roads at speeds up to 30 km/hr.

Class B: Ploughs for a hilly country with large snow precipitations, and steeper slopes.

Class C: Snow removers for remnants of a snow-cover and ice crust that remains on highways after thaw periods.

Class D: Special devices enabling one to attach any type of plough to any type of vehicle.

Under the chairmanship of Herr K. Croce, the following judges assessed the merits of the machinery during the contest: Jungel, (responsible for snow-clearing in annexed territories in Eastern Europe called Ostmark), Schanze and Rische (from the Obercomando der Wehrmacht), Kleiber (from Ministry of Interior), Doll and Dlee (from Highway Dept.) and Wallack (Hochalpen-Strassen Co.).

From 27 snow-ploughs and devices tested, the following were praised:

Class A: "Rampel Pflug" by J. Kronbichler Rosenheim, Obb.

Weight	2640 kg.
Width of removed snow	8.5 m.
Max. snow depth	0.45 m.
SPW (See p. 15)	1065 kg/m.^{2}

"Flugelgestell München" by W.U.J. Scheid Limburg a.d. Lahn

Weight	2070 kg.
Width of removed snow	7.50 m.
Max. snow depth	0.65 m.
SPW	710 kg/m.^{2}

Class B: Vorbaupflug Type MSR by Miag Co. Abt. Wartungsmaschinen, Oberramstadt bei Darmstadt

Weight	700 kg.
Width of removed snow	0.70 and 0.80 m.
SPW	323 and 377 kg/m^2
SFAL (See p.15)	980 and 1015 kg.

Tests of equipment in classes C and D were considered unsatisfactory. The results as compared with the contest of 1938-39 showed, however, an improvement especially in B class. As the survey of the contest states (171), there was a tendency toward a lighter plough design. None of the equipment, however, satisfied requirements with respect to the snow throwing capacity. The most significant progress was made in reduction of types of ploughs. New tendencies, like a trend toward using hydraulic or electric installations for blade adjustment were welcomed, but not considered quite satisfactory. No further contests were contemplated and the Forschungsstelle took over the development and the elaboration of the experience gained.

Although tests conducted in the winter of 1938-39 were considered unsatisfactory, it may be useful to quote a few graphs which illustrate the pre-war tendency of German manufacturers in plough design.

The graphs reproduced in Fig. 19 show the specific plough weight (SPW) of various equipment tested at that time. The variety of types and the large difference in weight between the lightest and heaviest plough even in the same class is striking. The full characteristics of ploughs denoted on the graphs by numbers may be found in the Croce report on results of the 1938-39 contest (26).

As will be later discussed, the variety of types listed in the above diagrams were ultimately reduced to one universal plough unit as a result of research performed by the Forschungsstelle. One of the most important items of this research was probably the measurement of the economy of snow removal by means of the methods described on pages 14-18.

Since the data obtained has a certain comparative value, it may be advisable to quote a few measurements which were made during the tests carried out at the end of 1940 (27).

Table I shows the movement resistance of various V-type and one-blade type ploughs with reference to the speed and snow characteristics.

TABLE I

V-TYPE PLOUGHS									
Plough No.	Plough Width m	Snow Depth Cm	Snow Spec wt. g/l	Movement Resistance in kg. at Speeds: 5	10	15 (km/hr)	20	25	30
1	3.15	16	280	540	640	820			
	4.40	16	280	990	1090	1110			
2	2.95	16	200	250	315	440	520	520	
		16	200	235	330	450	535	910	930
		20	200	300	410	505	550	540	
		21	200	240	345	365	590	655	
3	3.20	17	170	310	500	850	905		
		24	193	430	480	700	880	1060	
		21	193	640	660	830	1020	1250	1370
4	2.40	31	77	300	370	430			
		34	77	280	310	360	420		
ONE-BLADE PLOUGHS									
5	2.75	32	60	670	620	570			
6	2.80	7	335	490	500	520	550		
7	5.00	20	102	320	390	490	600		
8	3.70	31	102	270	240	180			
		21	102	80	110	190	280		
9	2.70	39	77			360	420	500	

Data shown in the above table, when referred to 1 metre of plough width are plotted in Fig. 20a and b. The average values of R_w (see p.17) extrapolated on these graphs show a definite difference between the character of resistance increase with the increase of the speed for V-blade and one-blade ploughs.

The curve shown in Fig. 20b is, however, to be considered as less certain than that shown in Fig. 20a, because each point is based on six measurements only.

When the resistance is referred to 10 kg. of the removed snow on 1 square metre of the road then the respective R_v value (see p. 17) gives a clearer picture of differences between various types of ploughs (Fig. 20c and d).

The above measurements do not reflect the local differences in snow structure. Herr K. Croce admits that specific weight of snow and the width of a plough do not determine the economic conditions of ploughing. He stressed the necessity of further elaboration of existing methods in order to obtain more accurate data.

Graphs shown in Fig. 20 illustrate the various tendencies. More knowledge of the economy of snow-ploughing had to be sought in basic research, which preoccupied the staff of the Forschungsstelle at an increasing rate.

From many observations, perhaps one of the more interesting fundamental facts is the question of snow compacting during the process of its removal.

As Herr K. Croce found out, snow is usually compressed by ploughing to a state 3 to 4 times more dense than the original one. This process of snow packing is a source of energy losses, which are proportional to the work used for compacting snow from its initial to the final state. The above problem was investigated on many occasions and lead to some interesting theoretical conclusions, which will be discussed later.

Investigation of snow-blowers was performed at the same time as that of ploughs. H. Jungel gave a survey of experience gained with American, French, Italian, Swiss, Norwegian and German equipment from which the following machinery was described in detail: "Snow King" "Snogo" "Crosti" "Saurer" "Thune" "Krause" "Henschel" "Peter-Raco" "BER" "DEP" "Schallert" "Rieder" (82).

The first systematic investigation of snow-blowers was performed, however, in June and July of 1941 on the Grossglocknerstrasse, with the purpose of determining the value of some newly developed German and Italian equipment (25).

Old snow covered the Grossglocknerstrasse up to the height of 3 m. which created very difficult conditions of work. This terrain, which was often used for tests, was the subject of a special study of snow removal by H. Wallack who supervised that district. The paper by Wallack on the methods used may be especially useful in studying the technique of snow removal in high mountains (154).

Equipment tested in the summer of 1941 had the following characteristics:

(1) Peterfräse "BER" by A. Schmidt, St. Blasien model 1939 as shown in Fig. 21. Two V8 Ford 78 h.p. engines produced by Opel-Ford Works propelled one shaft from which power was supplied to the rotors and to a generator. This latter propelled the tracked chassis. Electric track propulsion was devised for the purpose of obtaining a smooth regulation of speeds, which appeared very important for economic snow removal. Rotors shown in Fig. 21 are 2.5 m. wide and are 1.2 m. in diameter. They turn at a speed of 250 r.p.m. if the engines rotate at 2500 r.p.m.

(2) Peterfräse "DEP" by A. Schmidt, St. Blasien model 1940 is shown in Fig. 22. The main difference between this blower and the BER machine, as described above, is that it was built on a wheeled chassis. The tracked BER could climb on deep snow drifts, whereas DEP should operate on a firm basis only and the height of snow-clearing could not surpass the rotor diameter.

Power was supplied by a 165 h.p. Diesel engine, which was directly connected with the rotors. Chassis was propelled by means of an electric transmission. The dimensions of the rotors were the same as those of BER but the r.p.m. was a little higher (280 r.p.m.).

(3) Peterfräse system Schallert was devised in general lines by a machinist named Schallert and Dipl. Ing. Grasser. This device was developed under the direction of Herr K. Croce in M. Beilhack Works at Rosenheim and was manufactured in 8 weeks early in 1941.

The main feature of this equipment is that it has two pairs of rotors. The front one with an axle vertical to the road served the purpose of cutting and loosening snow. The second pair of rotors located behind the first one (Fig. 23) on two axes parallel to the road, were provided for throwing snow outside. This idea by Herr Schallert was supposed to enable one to design the front rotors, so that the snow cutting would be performed with the highest economy, whereas the blowing rotors could be applied efficiently for the purpose of snow throwing only.

Four V8 Ford engines (of German make) were provided for propelling the device. Three engines supplied power to the rotors and the fourth one moved the chassis, by means of a multi-speed mechanical transmission. Width of front rotors was 2.7 m. and the diameter was 1.2 m. R.p.m.'s varied from 180 to 1100 at 3700 r.p.m. of the engine according to the selected speed in a gear box.

The rear rotors were 1.2 m. in diameter and rotated at the same speeds reversed which enabled the device to throw snow on the selected side of the road.

(4) Snow-blower Crosti of Italian make S.A. La Motomeccanica, Milan, is an older type tracked machine with two 4-blade rotors located at the front of the chassis in a V-shaped nose (Fig. 24). A Diesel engine of 65 h.p. rotates the blades. Another Diesel engine of 45 h.p. propels the device. More details are given in a description by H. Jungel (82) and in the report by Croce (31).

(5) Fokkerrad was built by the Feldkirch Road Construction Office (Fig. 25). An 80 h.p. gasoline engine was located on the platform of a truck and propelled, through a 4-speed gearbox, a rotor fastened to a swinging arm. The diameter of the rotor is 0.75 m. It makes 240 to 940 r.p.m. according to the selected speed. The device is supposed to remove snowbanks which remain after plough use.

All this equipment was tested by using mechanical methods previously described. Since these methods were applied for the first time in this type of research, the results obtained were considered as preliminary only.

They indicate, however, the magnitude of economy obtained, and may guide any similar research. For this reason some of the values are reproduced from an official report (25) in Table II. A check-up of figures quoted in this Table with the data obtained by means of improved electrical methods enables one to evaluate the errors, which may be committed in assessing the economy of snow removal by means of less accurate methods. It seems to be quite obvious that errors were very significant and that the cost of scientific investigation was well rewarded.

TABLE II

Model	Test No.	t/hr.	kg/sec.	Distance Thrown m.	Supplied Engine Power No. h.p.	Power of Snow Stream N_1 h.p.	Coefficient of Internal Efficiency N_1 %	Power of Ideal Trajectory N_2 h.p.	Coefficient of Total Efficiency N_2 %
BER	V	141	39.2	6	90	7.1	7.9	1.6	1.78
	5	198	55.0	6	90	7.9	11.0	2.2	2.45
DEP	6a	534	148.2	10	104	31.2	30.0	9.9	9.5
	6b	495	137.6	10	104	29.0	27.8	9.2	8.9
	7	530	147.2	10	104	31.0	29.8	9.8	9.4
	8	423	117.8	10	104	24.8	23.8	7.8	7.5
Schallert	I	427	118.8	8	132	10.3	7.8	6.3	4.8
	II	742	202.0	8	138	17.6	12.8	10.8	7.8
	III	330	91.7	18	166	23.7	14.3	11.0	6.6
	IV	379	105.2	18	166	27.2	16.4	12.6	7.6
	1a	486	135.0	18	166	34.9	21.0	16.2	9.8
	1b	529	147.0	8	166	12.8	7.7	7.9	4.8
	2a	322	89.5	18	166	23.1	13.9	10.7	6.5
	2b	185	51.4	26	166	41.8	25.2	8.9	5.4
	3a	131	36.4	8	166	3.2	1.9	2.0	1.2
	3b	493	137.0	18	166	35.4	21.3	16.4	9.9
Fokkerrad	4a	354	98.4	5.5	60	6.0	10.0	3.6	6.0
	4b	199	55.2	14	60	9.2	15.3	5.2	8.7
	4c	202	56.1	21	60	20.2	33.7	7.9	13.2

A second, larger investigation of snow-blowers was carried out in the winter of 1941-42, when, in addition to the already described Peterfräse Schallert, Crosti, DEP and BER the following devices were tested: Grossmodel der Hochschleuder, and Pendershaab Bronderslev.

The history of development of the Hochschleuder has its origin in tests performed in 1940-41. It appeared at that time that ploughs mounted on trucks are suitable for light snow in a country of small precipitations, and cannot be used on roads with a grade of more than 4 per cent.

The Peterfräse proved to be good in clearing hard snow but was not successful when used in fresh snow. The problem of snow containing large quantities of air proved to be very difficult and was a subject of special investigations (31). All tests made in this field with axial turbine-like blowers were unsuccessful, or rather lead to the solution which worked satisfactorily with one selected type of light snow (80). Radial turbines seemed to be better adapted to the throwing of an air-snow mixture, because both the air and the ice particles passed through the same mechanical process. They entered the device axially and left it tangentially, after having been subjected to the same sort of movement. Experimental work done in this field early in 1941 by means of a special full scale rig (Fig. 17b) was very successful.

In the summer of 1941 the Forschungsstelle constructed a device based on this experience. Herr Schallert and Herr Friedel, the chief of the Feldkirch Road Construction Office were credited with a prompt completion of a new snow-blower shown in Fig. 26. Two drums with turbine-like blades were propelled by means of a 130 h.p. gasoline engine. The installation was mounted on a standard 85 h.p. Cletrac tractor.

The result of preliminary tests carried out in light snow 1 m. deep (250 g/l of specific weight) showed a coefficient of total efficiency of 35.5 per cent which was three times more than the efficiency of the Peterfräse as previously measured. Such an outstanding result was obtained by an elaborate study of the shape and of the location of turbine blades (31).

The new device was supposed to be an intermediary link between snow-ploughs and heavy snow-blowers of DEP or BER type. The diameter of the rotors was 1.2 m. and their speed of rotation was 225 r.p.m.

The Pendershaab snow-blower tested in 1941-42 was of American origin (Snogo) as far as the design is concerned. This device was found to be suitable for fresh snow only and was adapted for use with the 3/4 track vehicle of the Wehrmacht (Fig. 27). Characteristics of this equipment were as follows: diameter of snow throwing rotor 0.9 m. engine - Ford; r.p.m. of the rotor - 800 (direct gear) and 473 (third gear) at 2400 r.p.m. of the engine. The whole installation was mounted on small wheels and could be adjusted by means of an hydraulic installation.

The Germans were very interested in this equipment and in order to investigate it with the highest possible accuracy, provided it with an electric motor. Power output and input were then measured electrically.

As far as the writer knows, this was probably the first and maybe the only American snow-blower tested by means of an electric method as described on pages 20-21 This method was also applied to the investigation of the Grossmodel Peterfräse Schallert (Fig. 18). Other equipment could not be converted from gasoline to electric propulsion due to the lack of time and was assessed again by means of a mechanical method, i.e. by evaluation of the input according to the engine revolutions with atmospheric pressure corrections (30). From the seventy-four individual tests made, a great deal of information was collected. It was later digested and summarized in a special report (31), from which some of the more interesting findings are stressed below.

Among others it was experimentally established that the output of removed snow increased with the increase of the number of revolutions until a certain maximum was reached. This maximum value of snow output was called the Schluckfähigkeit, which in a free translation means the "bottle-neck capacity". The above value will be referred to in this report as critical snow output and will be denoted by the letter S. It means the maximum amount of snow which can be removed in a unit of time by a given snow-blower. The critical snow output depends on the design of the equipment and on the smallest "bottle-neck" size of various components of the machinery. Figure 28 shows how snow is stopped in a too small outlet, which impairs higher output of other elements.

The distance to which the snow is thrown depends on the number of revolutions of blowers (circumferential speed). This distance also is affected by the form of snow cakes which leave the equipment. Fresh snow encounters more air resistance than does old snow. In order to obtain the same distance, blowers designed for a light snow must rotate faster.

The distance to which the snow is removed was measured in a direction at right angles to the road, and equipment which has rotors located at an angle to this direction (like Crosti) showed a definite disadvantage.

A comparative measure of various equipment was obtained by referring the amount of removed snow in tons/hr. to the engine power required:

$$R = \frac{\text{ton}}{\text{hr. h.p.}}$$

This corresponds to the value C, as determined for snow-ploughs (see p. 18.. It appeared that the value R depends on the distance the snow was thrown, and on the "strength" of the snow.

Further assessment of equipment was performed by measuring coefficients η_1 and η_2 which have been described on page 20.

Tests made with the Peterfräse Schallert show that the η_1 values as determined for the cutting rotor vary to a very large extent according to the age of the snow. It is interesting to note that the large output is marked by a low efficiency and vice versa (Fig. 29). The explanation of this fact was sought in the distribution of power required for loosening the snow and for its subsequent acceleration when thrown away. Tests were conducted with the purpose of investigating this problem, but the results are unknown.

The η_2 coefficient was not determined because it has no meaning as the cutting rotor of the Peterfräse did not throw the snow into the air, but supplied it to the throwing blades of the special turbine (Fig. 18). This turbine received snow, already having a certain speed U_f. If the circumferential speed of the rotor was U_w, then the energy spent on the acceleration of snow in the turbine was proportional to the difference of both speeds:

$$U_w - U_f$$

and the power put into the snow stream was not

$$N_1 = \frac{GV^2}{2 \times 9.81 \times 75} \text{ (h.p.)}$$

but should be corrected as follows:

$$N_1 = \frac{G(U_w^2 - U_f^2)}{2 \times 9.81 \times 75} \text{ (h.p.)}$$

If G kg. which is the weight of snow that is thrown in a continuous stream in 1 sec. is replaced by R, which means the same but is expressed in tons and is referred to one h.p. and one hour, then the corrected efficiency η_1 is:

$$\eta_1 = \frac{R\ (U_w^2 - U_f^2)}{5300}$$

Fig. 30 shows η_1 as determined for two different numbers of revolutions of the cutting rotor: n_f = 90 and n_f = 170. Negative value of η_1 at n_f = 170 indicates that at low r.p.m. snow must be slowed down by the throwing blades, as it is supplied by the cutting rotor with too high a speed. This means, of course, an unnecessary loss. The low flat peak of the η_1 curve also indicates an unfavourable blade design. The coefficient of total efficiency η_2, for the throw rotor is shown in Fig. 31.

Both coefficients η_1 and η_2 as determined for BER and DEP are shown in Fig. 32.

The American designed Pendershaab (Snogo) may be evaluated from the efficiency curves shown in Fig. 33.

In order to make all the above-described coefficients comparable, η_1 and η_2 values were referred to the distance of throw of the respective equipments and have been plotted in Fig. 34. It is interesting that the Pendershaab proves its quality again as far as η_1 is concerned.

Another summary of the investigation showing values η_1 and η_2 is drawn in Fig. 35. This figure is self-explanatory. It enables one to assess the merits of snow-blowers and gives an interesting interpretation of the economy of snow-clearing by using various types of equipment.

The graph shown in Fig. 36 was plotted by calculating the theoretical distance the snow could be thrown when assumed that it falls along an ideal trajectory without any losses. For various initial speeds assumed, an ideal curve was drawn (curve I) which may be compared with the real distances the snow was thrown when measured at various speeds of rotors. A curve determined for "DEP" is located below the curve as found for "Schallert", because the first snow-blower deflects the snow stream after it leaves the rotor, which causes an additional loss. Another source of losses is the powderization of the snow-stream. A wide, dusty stream encounters much air resistance which shortens the distance the snow can be thrown.

An interesting evaluation of this distance is shown in Table III which refers to the initial speed of the snow-stream (circumferential speed of the rotor), that is required for obtaining a constant distance of throw of 10 metres.

TABLE III

Model	Speed m/sec.
Schallert	10.75
Hochschleuder	10.75
Pendershaab	11.60
DEP	16.35
BER	17.20
Crosti	20.52

If the snow removal could have been performed without any losses by throwing this material in a compact stream on the ideal trajectory starting at an angle of 45°, an initial speed of only 9.90 m/sec. would be required in order to throw the snow a distance of 10 metres. As it may be noted, the newly developed Schallert and Hochschleuder are very close to this ideal value. The American designed Pendershaab was second after the Schallert and Hochschleuder and was far ahead of the Italian Crosti.

An example of the investigation of the differences in snow driven by the right and left rotor of the Schallert blower is shown in Fig. 37.

The effect of the snow properties on the amount of power consumed, with reference to the r.p.m. of the rotor, is shown in Fig. 38. It will be noted that at high speeds the output is relatively small, and it remains almost the same for practically all types of snow. This was supposed again to be connected with the ratio of the amount of power required for loosening the snow and for accelerating it when thrown away. Phenomena referred to this problem were not sufficiently investigated. It was found that any attempts to correlate the respective data with the indications of a rammer, or cone "strength" meter were unsuccessful.

Herr K. Croce mentioned that a new device for determining snow resistance against cutting and loosening by rotors had been under consideration, but it must have been unsuccessful as no further information was available.

In a further test, an investigation of the Schallert snow-blower was performed by measuring the amount of snow removed (ton/h.p. hr.) and the average r.p.m. of the snow throwing rotor at a constant r.p.m. of snow cutting blades (Fig. 39).

A very similar graph determined for the Pendershaab (Fig. 40) shows the relationship between the r.p.m. of the thrower and the amount of snow removed. Herr K. Croce, when discussing the above graphs, called attention to the fact that it enables one to evaluate the economy of clearing fresh snow on the basis of tests with clearing old snow.

Power required for propelling the feeding screws and the throw rotor was not measured separately as Pendershaab's design did not allow the installation of pick-up for this purpose. Design changes, however, were considered, and a separate electric propulsion of screws and blower blades was planned, so that the distribution could be determined. As far as it is known, however, this work was never done.

The relationship between the variable r.p.m. of the rotor and the out-put of snow removed as determined for the DEP is shown in Fig. 41. This could not be done for the Hochschleuder and Crosti, because they worked at constant r.p.m.

Another comparison of the investigated equipment may be made with the help of the graph shown in Fig. 42. This graph is plotted on thrown distance - snow output co-ordinates and shows a definite superiority of Hochschleuder and Pendershaab over the remaining devices.

The relationship between the distance of throw and the amount of cleared snow at various specific weights of snow is shown in Fig. 43. The respective data as obtained for the DEP were plotted together with the curve defining the critical snow output S. It can be seen from this graph that for a distance of throw of 6.25 m. the value S is about 1840 cu. m/hr. at a snow spec. weight of about 424 kg./cu.m. With the lighter snow this output cannot be surpassed because the blower will not "swallow" it. This was checked and it was found that the cause of such insufficient capacity lies in the very narrow outlet of the rotor.

It is worthwhile to note that the electric transmission of the DEP was found impractical. It was thought that a gradual and smooth regulation of the driving speed of the blower might also be obtained by using an internal combustion engine, provided that the rotors have another source of power.

Characteristics of the Schallert device are shown in Fig. 44. They are given in a different way and refer the distances of throw to the snow output and to the r.p.m. of the thrower.

A more complete picture of the economy of snow-clearing is shown in Fig. 45 as drawn for Pendershaab. It enables one to evaluate the effect of an additional gearbox installed between the engine and the throwing rotor. It is evident that at small distances of throw, the critical snow output limits the capacity of the device, especially when the snow is very light. Since this device was found to be well adapted for clearing fresh snow, the investigation of the effect of specific weight upon the economy was carefully investigated. It was found that the best conditions exist where the outgoing snow weighs about 300 kg/cu. m. Further improvement of Pendershaab was contemplated and will be described later.

Apart from testing the above-mentioned equipment, the Forschungsstelle investigated an item which was brought into the picture due to the initiative of Hofrat Wallack who was responsible for clearing the Grossglocknerstrasse District (154).

Herr Wallack proposed a new type of rotor which was called a "cylinder plough". Advantages claimed by the inventor are described in detail in Herr K. Croce's report (32). In brief, the "cylinder plough" was supposed to loosen snow by means of knives which were secured to a rotating drum. Special guiding surfaces provided proper clearing of the snow from the cylinder.

A pilot model of this device equipped with a throw rotor was installed on the chassis of the Schallert blower. Efficiency was measured by means of the electric method at various positions of the guiding surfaces. Results of tests made during the winter of 1941-42 were not quite conclusive. Some improvement was done during the summer of 1942 and further investigation was conducted in the winter of 1942-43.

An exhaustive study of the equipment was described in a special report (33) which may be regarded as an example of a technical approach to the problem. As this report was completed on July 30, 1944, it may be considered as a sample of work which embraces a great deal of experience and knowledge gained in the field of snow-clearing during the period of a continuous research between 1939 and 1944. Although the above-mentioned report does not give any conclusions with reference to the development of Herr Wallack's device, it summarizes the findings for further research. This research, however, was not carried out. Herr K. Croce was rather sceptical when explaining the final results obtained with this equipment.

Among the original equipment tested was a giant 1000 h.p. snow-blower, which was built on the order of Reichsminister Speer. A significant lack of enthusiasm to this project on the part of Herr K. Croce seems to suggest that this was another invention which materialized because it was sponsored by a high-ranking official. Nevertheless, the 1000 h.p. snow-blower is a unique example of this kind. It has a definite correlation with other smaller equipment and it may be worthwhile to describe briefly the background and the results achieved with this device.

As a consequence of tests conducted in April 1943, Munitions Production Minister Speer ordered that the 1000 h.p. giant be made. Until the end of that year nobody could be found who would tackle this problem. Finally the Hubert Zettelmeyer Works in Konz near Trier made a contract with the Forschungsstelle (34).

A Panzerkraftwagen No. 4 chassis was used as the basis, on which the 750 h.p. Tiger engine and the blowers were installed (Fig. 46). General characteristics of this device were as follows:

Chassis	PZKW4
Engine I (chassis)	265 h.p.
Engine II (blowers)	750 h.p.
Total weight	26 tons
Width of snow clearing	3.2 - 4 m.
Crew	2

The blower installation was developed according to the Hochschleuder principle and was constructed under Herr K. Croce's direction by Beilhack Works, Rosenheim. Preliminary tests were conducted in Inzell in March, 1944. They were not conclusive. The end of the war interrupted further work. Herr K. Croce expressed the opinion that such a giant, although mechanically sound, does not compete with smaller equipment, which from the economy point of view is more advisable.

Generally speaking it may be said that the snow-clearing devices have certain economic limits in size and capacity. The 1000 h.p. giant seemed to be one which surpassed that limit. Where this border actually lies is not known. It depends on many local conditions and on general purposes. The Germans were rather inclined to admit that in their conditions a device of Hochschleuder size should be about an ideal.

(iii) Elaboration of theoretical fundamentals of snow-clearing technique became more necessary as more complex problems were revealed. For instance, attempts to make the power case more economical involved an analysis of phenomena which take place between the snow and the plough blade.

As was mentioned before, the main trend in improving snow-ploughs was marked by an endeavour toward increasing the distance of throw and getting the road sides clear from high snow embankments. For this a knowledge of the kinematics of the snow entering and leaving a blade was required. Therefore the study of relevant problems started in the early days of the existence of the Forschungsstelle. The starting point was an observation which revealed that a cohesive layer of ploughed snow moved along the blade without breaks following a definite path. This process was considered by Croce in an analysis outlined in the so-called "Aufwicklungstheorie".

The main problem of this theory was to determine the speed of snow particles moving on the plough blade. Once the speed magnitude and direction is known, the investigator is in a position to determine the distance of throw, and the forces involved. Kinematics of a snow-plough was then a logical approach to its dynamics. Both have been considered useful in problems of the economics of snow removal (28). A few simple cases of this theory applied to the edge-like plough blade will be considered below. An analysis of more complicated problems, like that of a blade formed by a portion of a cone was seen by the writer in the manuscript of the forthcoming book by Croce on snow. The method of reasoning applied was the same in all cases, and it may be explained in the following example.

Let us consider an edge-like plough blade as shown in Fig. 47a. The direction of movement is marked by an arrow. The lower edge of the blade is at right angles to the direction of the road. Point P of a snow layer originally located on the road surface takes a position marked by point P" on the surface of the blade. In order to determine the new position P it is sufficient to assume that the distance s which the plough moved on the road equals the distance s' which the snow moved on the blade:

$$s = s'$$

Then the new location of point P can be determined by the intersection of the blade surface with an arc having the radius s.

From Fig. 47a it becomes obvious that, when ploughing, snow originally located at P is lifted to the height y and is simultaneously shifted forward the distance x. It can be seen from this figure that:

$$y = s \sin\alpha$$
$$x = s\,(1 - \cos\alpha)$$

Respective speeds of snow at point P" are:

$$u_y = c \sin\alpha$$

$$u_x = c \cos\alpha$$

where c is the speed of the plough.

If the blade surface is not at right angles to the road direction, but turned at an angle β, then the process is the same, but it must be considered in three-dimensional co-ordinates. This case is especially interesting because it usually takes place when snow is removed on one side of a road.

Triangle ABC (Fig. 47b) shows the outline of a blade having its cutting edge at AC. Line BD, vertical to this edge, lies on the road surface and forms an angle α with line DB' located on the surface of the blade. Direction of movement at speed c is shown by an arrow.

Point P of snow originally located on the road will be found in position P" on the blade, which is determined by co-ordinating x, y and z. From Fig. 47b it may be found that:

$$y = s \sin\beta \sin\alpha$$
$$x = s \sin^2\beta\,(1 - \cos\alpha)$$
$$z = s \sin\beta \cos\beta\,(1 - \cos\alpha)$$

where s is the distance which the blade moved along the road during the period considered.

Speed of the snow layer located at point P" may be resolved in directions x, y and z as follows:

$$u_y = c \sin\beta \sin\alpha$$
$$u_x = c \sin^2\beta\,(1 - \cos\alpha)$$
$$u_z = c \sin\beta \cos\beta\,(1 - \cos\alpha)$$

The same problem referred to a plough blade which is formed by a portion of a cylinder (Fig. 47c) and which is tilted to the direction of plough movement, was solved in the following manner:

$$s = r \sin\beta\,(\alpha - \sin\alpha)$$
$$y = r\,(1 - \cos\alpha)$$
$$z = r \cos\beta\,(\alpha - \sin\alpha)$$
$$u_x = c \sin^2\beta\,(1 - \cos\alpha)$$
$$u_y = c \sin\alpha \sin\beta$$
$$u_z = c \sin\beta \cos\beta\,(1 - \cos\alpha)$$

On the basis of this theory, Croce found that the path of snow particles removed by cylindrical or conical blades is a cycloid. A relationship between the direction of throw and the geometry of a blade, as well as the effect of blade height on snow throwing were also established.

It should be noted, however, that the "Aufwicklung" theory is based on an assumption that snow forms a continuous layer which adheres to the road and to the blade. Such a layer must be relatively thin, so that any changes in its structure do not affect the movement. Usually, this condition is satisfied but it does not exist with a thick snow-cover. The theory is also not to be applied to a dry powdery snow which does not form continuous layers.

Herr K. Croce was fully aware of these deficiencies and has been working on a new theory in which loose non-cohesive snow was considered. The "Aufwicklung" theory, however, worked satisfactorily in most cases with thin fresh snow. Experiments made with blades marked by rectangular grids (see Fig. 14) proved the practical soundness of his assumptions, and led to the development of efficient equipment.

Further research in this field has been contemplated by testing a stationary plough blade which was acted upon by a moving snow-cover. Incidentally this idea was realized 6 years later by a Swiss firm, which constructed such a rig for investigating snow-blowers. Herr K. Croce did not mention whether similar tests were made by the Forschungsstelle, or if any installation of this type was seen at Inzell.

From the research performed it was learned that snow removal is more economic the faster the plough and the heavier the snow. If the speed of a plough drops below certain limits then the inertia of the snow mass is not sufficient to clear the blade. Snow piles up instead of flowing along the plough. Instead of being a subject of a regular movement determined by the above quoted equations, snow particles get mixed and move chaotically. This involves unnecessary losses and unsatisfactory clearing. The phenomena described above had been observed when tests with movement resistance were made. The speed at which the plough action becomes unco-ordinated was observed, and was called by Croce the critical speed of snow-ploughing. As results from the theory indicate, this speed depends on plough blade design (28).

In the light of these considerations, the problem of using high speed vehicles for snow-ploughing was stressed. But it proved difficult too, because the steerability of trucks used as plough movers appeared to be highly affected by the unbalanced movements of a plough.

For this the following solution was offered: the location of the blades and the snow pressure exercised upon them should be so selected that the respective moments which upset the straight line driving of the plough mover eliminate themselves.

Two possible solutions are shown in Fig. 48 a and b. If a truck is provided with a front plough which gives a reaction P_V (Fig. 48a), then the moment M_V may be nullified by a moment $-M_H$ exercised by a side plough, which is acted upon by a reaction P_H. In order to get this effect, the angle must be experimentally adjusted according to the existing snow conditions.

An alternative is offered by applying a side blade (Fig. 48b) to the front plough acted upon by a reaction W. In this case, as in the previously described one, moments M_V and M_W reduce themselves and assure safe steering conditions.

Elaboration of fundamentals of snow-blowers referred chiefly to the design of rotors. The previously mentioned idea of critical snow output S played an important rôle in assessing equipment by an experimental or theoretical method. The following is a brief description of determining S at the rotor outlet.

Let it be assumed that the snow volume contained in a thrower during one r.p.m. must be emptied through the outlet in the same time. This means that the volume of snow covering a blade must be removed in the time during which points B and A consecutively approach the outlet opening (Fig. 49).

When A reached point C, then the snow layer d_m must clear the rotor completely. The motion of point A may be determined from the circular movement of the blade, and from the resulting centrifugal force. During the time in which point B reached point C, point A must cover the distance d. Accordingly, the calculation has been made for straight blades neglecting all losses such as friction, air resistance, etc. Let

P = centrifugal force
m = mass of a snow particle
r = radius of a polar co-ordinate determining the position of a snow particle
ω = respective angular speed
γ = gravity acceleration
t = time
v_r = radial speed of a snow particle
v_t = tangential speed of a snow particle;

other denotations as marked in Fig. 49. In this condition

$$P = mr\omega^2$$

and $$\frac{d^2r}{dt^2} = r\omega^2$$

or $$\left(\frac{dr}{dt}\right)^2 = 2\int r\omega^2 \, dt + C_1$$

but $v_r = 0$ for $r = a$ and $C_1 = -a^2\omega^2$, hence

$$\frac{dr}{dt} = \omega\sqrt{r^2 - a^2}$$

and $$\omega\, dt = \frac{dr}{\sqrt{r^2 - a^2}}$$

or $$\omega t = \ln\left(r + \sqrt{r^2 - a^2}\right) + C_2$$

for $r = a$, $t = 0$ and $C_2 = -\ln a$, hence

$$\varphi = \omega t = \ln\left[\frac{1}{a}\left(r + \sqrt{r^2 - a^2}\right)\right]$$

If the radius of a rotor is denoted by b then the outlet angle β is:

$$\beta = \ln \frac{1}{a}\left(b + \sqrt{b^2 - a^2}\right)$$

The same may be expressed in a different form when it is assumed that $a = c \times b$ then

$$\beta = \ln\left(\frac{1}{c} + \sqrt{\frac{1}{c^2} - 1}\right)$$

Values of β are plotted in Fig. 49 which shows the relationship between this angle and the a/b ratio. It is a purely geometrical relationship and is fully determined by the dimensions of the rotor.

Once the thickness of snow layer, dm, is determined with reference to the outlet dimension β, then the critical snow output S may be determined for a given rotor.

Let the r.p.m. of the thrower be denoted by n, e be the width of the rotor, axially measured; y = 0.75 is the coefficient which increased the theoretical angle β in view of various losses, then

$$S = 140\, neb^2 (1 - c^2)\ m^3/hr.$$

Value c may be found from Fig. 49 if β has been previously determined.

More detailed considerations with regard to the design and calculation of rotors were not published in the reports of the Forschungsstelle. They were nevertheless elaborated and Croce frequently referred to them. In his book of snow problems some space was provided for discussing such general questions as snow removal considered as a transportation problem. This question was closely related to the problem of compacting snow during removal and offered great possibilities in the application of mathematical analysis. For instance the value S hitherto referred to the volume of snow leaving the rotors, but the volume of snow that entered the machine was different. Since snow had not been at that time a subject of centrifugal force, the respective value of S was quite different and also could be calculated.

Although theoretical and experimental investigations of this important problem were not conclusive, Croce expressed an opinion that snow-blowers compact fresh snow to a density 3 times greater than its original state. Even old snow is supposed to compact 1 1/2 times. The above fact cannot be over emphasized as far as the economy of snow removal is concerned and offers a wide field for a theoretical investigation of S.

How some of the theoretical considerations were applied to the practical work may be explained by the following examples.

Peterfräse Schallert had a throw rotor with the radius $b = 0.6$m. and width $e = 0.5$ m. angle $\beta = 67°$. From Fig. 49 it will be found that $c = 0.56$, hence the critical snow output S is:

$$S = 2 \times 140 \times n \times 0.5 \times 0.6^2 (1 - 0.56^2) = 34n \ (m^3/hr).$$

Figure 50 shows this equation plotted for both rotors (line 1). The other limitations of the snow output are also shown. Line 2 determines the max. S as plotted for 100 h.p. input and for snow specific weight of 500 kg/cu.m. This line was determined from Fig. 37 in order to get a comparable basis for assessment of other equipment. The third limitation of S results from minimum r.p.m. which gives the smallest distance of throw. This distance was assumed to be 6m. at 120 r.p.m. (Fig. 50). It is at this distance that the given type of snow is still removed without packing rotors and outlets.

The cutting rotor of the Schallert device had a diameter 1.2 m. and $\beta = 67°$. The corresponding value of c is 0.56 (Fig. 49). Then the thickness d of the removable snow may be determined as follows:

$$d = b - bc = 0.6 (1 - 0.56) = 0.26 \text{ m.}$$

Since the rotor has d = 0.2 m. it becomes evident that it is too small and S is not limited by opening angle β, but by a too short dimension d of the rotor.

Peterfräse DEP has the following dimensions: b = 0.27, β = 43° hence c = 0.77 and

$$d = 0.60 - 0.60 \times 0.77 = 0.14 \text{ m.}$$

which is less than the depth of the snow collector. Hence again the error in design is discovered.

Snow-blower Pendershaab has b = 0.45 β = 63° e = 0.26, and c = 0.6, therefore:

$$S = 140 \times n \times 0.26 \times 0.45^2 \,(1 - 0.6^2) = 4.7n \text{ (m}^3\text{/hr)}$$

Figures 50 and 51 have been determined and checked for old snow and should not be extrapolated for fresh snow. In the cases, discussed above, snow output which can be obtained with 100 h.p. while working on 500 kg/cu. m. snow, may be determined as follows:

Schallert (thrower)	4300 cu. m/hr. at n =	127 r.p.m.
Schallert (cutter)	2320	90
DEP	1360	216
Pendershaab	1430	304

In this condition the distance of throw would not be smaller than 6 m.

(iv) The result of experimental and theoretical work was the development of pilot models and standards by the Forschungsstelle as it took over the co-ordination and control of the production of snow removing equipment.

After the discussions with Croce were held, the writer tried to reproduce a complete picture of ideas, and opinions in the field of snow removal. The above was not easy, however, as a tremendous amount of work was performed by the Germans in a relatively short time without being thoroughly summarized. This work faced shortages which resulted from wartime restrictions and for this reason might not be as conclusive as it would have been if performed under normal conditions.

It seems logical, therefore, that many opinions and conclusions reported in this paper may be subject to further revision. They may also be altered under different climatic conditions, and should not be taken as final.

The value of the German interpretation of problems connected with snow removal lies, above all, in the scientific approach, and in the systematic organization of a research, which, undoubtedly, has not been very attractive for private initiative. The above remark does not, however, exclude the fact that the privately owned snow equipment industry has not been interested in the improvement in economy of snow removal. The costly experiments with scale models of snow-blowers performed at Davos in Switzerland by a private company whose representatives were interviewed by Prof. R. F. Legget and the writer is the best example of this initiative. It seems, however, that this initiative was indirectly encouraged by the work done on the other side of the Swiss-German border. From that point of view, the merit of German applied snow research may be unquestionable although many results are pending further verification. The status of German views as described below may be interesting not as such, but rather as a detailed introduction to the vast field of complexities of snow removal which were in many cases unrecognized and underestimated.

The problem of snow-ploughs was the first one which was tackled both by military and civilian organizations. The variety and great difference in the characteristics of equipment in the same class as produced in Germany before 1939 (Fig. 19) needed some standardization which was dictated primarily by the military-minded rulers of the Third Reich. However, the economic significance of this work could be denied. Herr Croce mentioned in the lecture delivered on 3rd July, 1939, (26), that the problem of designing a university hooking device for snow-ploughs "is very important in the case of the outbreak of war" (31). But this problem also had been a subject of great interest to the Railway Department and to the Post Master General.

Large-scale tests with snow-ploughs performed by the Wehrmacht in 1938 were very fruitful in conclusions and recommendations with regard to future plans. According to opinions expressed by Lieutenant-Colonel Schanze (129) many commercial trucks used in Germany were liable to be used as plough movers. He favoured Diesel engines because of fuel economy, but the relatively low h.p./ton ratio was the source of many troubles. It was recommended that vehicles which had more than 10 h.p./ton of available power be used.

The problem of the quick wear of clutches and gear boxes also was stressed but the F and S (Fichtel and Sachs) clutch was supposed to be adequate. Proper selection of speeds in a gear box was considered and, in conjunction with this, the requirement of economic engine regulation in low and middle speeds was put forward.

The average speed of snow-ploughing was initially assumed as 25 km/hr. which was much lower than standard speeds for which the vehicles were originally designed. It is obvious that the complete economy of a slow running truck equipped with a plough could not be achieved but might have been corrected to a certain degree. For this, trucks with five or more speeds in their gearboxes were favoured.

The question of a steering mechanism was previously mentioned. It may be added that many German vehicles were the source of trouble from that point of view. The above situation led to the question of whether standard or specially built vehicles should be used for snow removal. To this Schanze replied "utility vehicles always, never special ones" (129). The standard 4 by 4 or 4 by 6 vehicles were supposed to be the most suitable. Tracked vehicles were not recommended for the following reasons:

(1) Poor performance on icy roads;
(2) More complicated maintenance;
(3) Packing of snow between track and suspension.

Some full and 3/4-track vehicles were, however, successfully used, which rather denies the validity of the above opinion.

The Wehrmacht recommended as wide ploughs as possible. However, an opinion prevailed that 2.5- to 3 m.-wide plough is the best possible when applied to a 3-ton truck.

The standardization of the various systems of attaching the plough to a vehicle was a problem for a long time, until it was brought to the attention of the General Inspector. The original project started by the Wehrmacht was finally developed by the Forschungsstelle in 1940-41. This project practically solved the principle of using any vehicle as a pusher of any type of plough, and was introduced for use in the Army.

The device consisted of a standard plate shown in two versions in Fig. 52 which was fastened to the given vehicle. Any plough was provided with a similar type of a plate. The fitting and securing of both plates was, of course, greatly simplified and completely standardized.

Generally speaking, standardization was a big problem of the Wehrmacht. The so-called "speed program" was outlined first in 1939 in order to formulate these requirements by testing the following equipment:

5 trucks 1 1/2-ton (3 gas, 2 Diesel engines)
6 trucks 3-ton (Diesel)
4 trucks 4 1/2-ton (Diesel)
4 trucks 6 1/2-ton (Diesel)

Trends toward the standardization of snow-ploughs may be observed in Norway (124). The same was noted at Michigan State College during the First Central Snow Removal Conference in a paper by C.L. Motl (102), who ventured an idea that 24 models would cover all United States' requirements. However, the existing variety of types does not suggest much progress in this direction and the number 24 is much larger than the few standardized German plough types.

The question of truck design with reference to snow removal also does not seem to have been considered on this continent. Shannon from F.W.D. Corp. states that as far as it is known the "Four Wheel Drive Auto Co. is the only truck manufacturers employing a full-time engineer assigned to the improvement of snow removal methods, the design of snow removal equipment and its application to motor truck", (143).

The second German plough contest previously described increased the importance of snow research. Now, the Forschungsstelle could effectively co-ordinate the work and perform the research more systematically than the Wehrmacht did at the Winter Proving Ground at St. Johann (175).

Before formulating any requirement with regard to trucks used as plough movers, a general classification of requirements referred to ploughs themselves were made. It had been originally assumed that the blades mounted in the front of a vehicle were mainly to be considered. Subsequent development of a snow throwing plough changed this idea. Snow-ploughs were classified in three general groups with weights varying from 500-1200 kg.:

(1) Light weight
(2) Middle weight
(3) Heavy weight

When referred to the design, ploughs were classified as:

(1) One-blade
(2) V-blade

Some equipment was universal and could be used as a one-or a V-blade type.

V-blade ploughs had an angle of 80° or 105°. The angle between the blade edge and the road surface was 50° to 60°. One-blade ploughs could remove a strip 2.6 to 3.5 m. of snow width.

Some medium V-blade ploughs could be converted into one-bladers by removing the nose portion of the edge (e.g. MSR 3, model by MIAG, Ober Ramstadt).

A special type of plough was later designed for work in the eastern part of territories occupied by the Germans. This model was called "Nashornpflug" and had a flexible mounting which enabled it to adjust itself to ground unevenness. Final shape of this development is not known, aside from the information that it was used with tracked vehicles in order to secure the necessary belly clearance for army vehicles. For the same purpose, snow compacting devices were developed in a form of big drums pushed by tracked vehicles.

The following is the list of ploughs used in 1942 and mentioned in official instructions (6).

TABLE IV

TYPE	WEIGHT (kg.)	WIDTH OF REMOVED SNOW STRIP (m.)
<u>Schmidt and Rieder</u>		
One-Blade:		
Light	580	2.6
Medium	780	3.0
Heavy	980	3.5
V-Blade:		
Light	400	2.2
Medium	620	2.6
Heavy	980	3.0
<u>Grasmuck</u>		
V-Blade:	890	2.7
<u>Scheid</u>		
V-Blade		
Radstadt	519	2.6
Inzell	618	3.0
One-Blade		
Schwarzback	724	2.8

Detailed description of these ploughs is given in "Strassenwinterdienst" 2nd volume which, however, was not available when this report was compiled.

Experience gained indicated that the movement resistance of ploughs as encountered in German conditions should not be higher than 2000 kg. whereas the plough width should not be greater than 4.5 m. and the speed 30 km/hr. The above was supposed to satisfy economical snow removal for depths varying between 5 and 40 cm. This corresponds to the approximate 20 to 150 kg. of push required of a plough mover as measured in R_V units.

The necessity of using commercial trucks as plough movers was stressed again in view of the fact that special vehicles used for this purpose would work 500 to 600 hours per year only. This was considered extremely uneconomical. The above refers to the German snow conditions, and the economy of special equipment used in more severe climates would be, of course, different.

A special mounting device developed later by the Forschungsstelle for side ploughs (Fig. 53) put an additional load on the bodies of standard trucks. The front axle also had to be adapted for carrying an extra load which, resulting from plough weight, might have gone up to 2000 kg. In conjunction with this, tire capacity had to be revised. Minimum engine power was finally set at 100 h.p. Additional electric power for better illumination and heating as well as attempts to operate some ploughs by means of electric motors, resulted in the requirement of a more powerful generator and battery. In general, the standardization of vehicle types in Germany by Schell (176) was supposed to be satisfactory as far as snow removal was concerned.

The side ploughs which were developed later as a consequence of a long research were recommended as snow-throwers only. This type of plough was supposed to satisfy the requirement of the General Inspector with regard to snow-throwing. As has been mentioned before, the above requirement, although strongly emphasized, was not satisfied by the contests of 1938-39 and 1939-40.

Probably the most important item in the original development of snow-clearing equipment by the Forschungsstelle, was the universal mounting which served the purpose of securing a standard plough to the commercial truck.

The pilot model developed under the direction of Croce in accordance with the requirements laid down by the General Inspector of German Highways was subject to several alterations. At the end of the war, however, it was supposed to be completed and was intended to be introduced as standard equipment. The main idea of this structure is shown in Fig. 53. It fits all trucks of 3-ton capacity which have body dimensions varying as follows:

width from 2.10 to 2.50 m.
height from 1.10 to 1.45 m.

The main frame was composed of two halves A and B (Figs. 54, 55 and 56) which are connected by adjustable cross members D, so that the required clearance, b, for the truck body may be achieved.

The frame halves A and B were provided with columns G connected in between by a structure H. Legs J are adjustable and serve as a stand when the structure is mounted on the truck. Afterwards they are withdrawn. The procedure of mounting the device is shown in Fig. 57 which is self-explanatory. The details of clamps and jigs are shown in Fig. 58.

The development of a 2-wing plough (Fig. 53) for far distance throwing of snow necessitated designing an additional structure. This was attached to columns G, one of which is shown in cross-section in Fig. 59. The side plates S, were provided with a sliding bracket T, supporting the pin U, to which the side plough frame was secured. The adjustment of the height of this frame was performed by turning drums X, (Fig. 60) through which cables W, move bracket T up and down. More elaborate mechanisms were later developed on the basis of this scheme.

The side plough frame A is shown in Fig. 55a. The way in which it is secured to the truck is shown in Fig. 58. The plan of the whole installation is shown in Fig. 61.

A special blade developed for removal of the top layers (Wallkopfer) of snow embankments is shown in Fig. 62. This device may be adjusted hydraulically and was secured to the standard plate A (Figs. 55a and 58). The cross-section, showing the Wallkopfer in action is shown in Fig. 63.

The blade for far-distance snow-throwing was applied to the above-described mounting and was effective at speeds above 20 km/hr. which requires trucks with engines above 120 h.p. The snow layer removed should not be thicker than 20 cm. and road slopes should not be steeper than 4 per cent.

The scheme of this installation is shown in Fig. 64. It is provided with an hydraulic jack for adjustment and may be operated from the driver's cab.

The universal mount as described above was also adapted to a heavy side plough designed for removal of snowbanks (Fig. 65). This device was secured to the mount by means of a flexible parallelogram (Fig. 66), which prevented any damage to the plough in case it encountered a hard obstacle, such as stone, ramp, etc.

Instructions for throwing snow by means of the abovementioned ploughs are shown in Fig. 67a and b. If the road slopes more than 4 per cent (Fig. 67a) so that the speed required for throwing snow cannot be reached, then the snow-clearing operation should start slowly in direction I, by removing snow to the left. When returning downhill in direction II, higher speeds may be obtained and snow may be thrown far away. If the operation starts while climbing a hill according to the scheme shown in Fig. 67b, a third course is required which is not desirable, but which cannot be avoided.

In general, ploughs were put in action when snow precipitation was higher than 10 cm. In countries where there were no strong winds, snow clearing was allowed on both sides of a road. In windy regions, the selected side of a road where the removed snow was deposited was the object of a study from a meteorological standpoint.

The use of front snow-ploughs was recommended for snow precipitations which were 0.5 to 0.8 m. high. It was advised that one-blade front ploughs with which snow could be removed on one side only should be used for those roads.

Snow removal with V-blade ploughs was subject to other regulations. The action of such a plough consists principally in compressing snow toward the road sides, and it requires a great deal of power. Therefore V ploughs were restricted in use for snow depths up to 0.30 to 0.50 m.

Recommended schemes of snow removal by means of ploughs are shown in Figs. 68 to 71.

Detailed instructions were compiled in special hand books (6) and also described:

(1) Snow removal by hand;
(2) Use of sand and salts for slippery roads;
(3) Traffic regulations.

As these instructions illustrate the trends and conditions under which the work was performed it may be useful to stress some of these points:

"Winterservice" on roads was practically extended over the whole year:

(1) At the end of a winter - a general meeting was held of personnel involved and discussions on experience gained. Selection and posting of personnel for the next winter. Changes in

organization with regard to the required improvements. Check-up of equipment and assessment of repair required. Storage of equipment which does not require any overhaul. Procurement of additional equipment and material if necessary.

(2) In the summer time - establishing a snow removal plan (Raumplan) and final check-up of information service and meteorological station. Securing local additional manpower, needed in the case of emergency. Winterization of equipment.

(3) In the autumn - acquainting personnel with plans and organization. Transportation of all equipment to places of their location. Mechanical check-up. Location of required sign posts for traffic and snow removal. If necessary, preparation of additional temporary winter roads.

An information service was organized in survey zones which reported to the Information Collecting Posts (Nachrichtensammelstellen). The latter sent their reports to the district stations which transferred them subsequently to the office of the General Inspector (in peacetime). All roads were marked by numbers. Any report contained the description of the road surface. For this the following code was used:

Nothing to report	x
Normal condition	o
Local snow precipitation	1
Slush ice	2
Snow and ice skin	3
Snow height below 15 cm.	4
Snow height above 15 cm.	5
Snowdrifts	6
Snow ruts	7

Trafficability on the road was reported in another code:

Nothing to report	x
Unhindered	o
Little hindered	1
Difficult	2
Not for the use of heavy veh.	3
Not for the use of heavy and medium vehicles	4
For tracked vehicles only	5
For horse and mules	6
Detour	7
Impassable	8

Development of snow-blowers was based on previously described tests. It has been found that two types of machinery are required:

(1) Snow-grinders (Schneefrase) for removal of old snow (DEP, BER, Schallert).

(2) Snow-throwers (Schneeschleuder) for clearing fresh snow (Pendershaab, Crosti, Hochschleuder).

As far as snow grinders are concerned, the required distance for German road and autobahn gauges is 26 m. The smallest distances were set up at 7.5 m.

It appeared necessary to have this distance adjustable so that the device could work with the best efficiency in the most frequently encountered conditions. This led to the necessity of having throw rotors turning at variable speeds. BER and DEP did not satisfy the above requirements and could not be adapted to them. An introduction of a gearbox between the cutting rotor and propelling shaft of the DEP blower would be required in order to get the adjustability of the distance of throw. As shown, however, from the investigation of critical snow output, the advantages of an additional gearbox would be limited by a too small value of S.

The electric transmission also was not found to be convenient. It required well-trained personnel and a great deal of critical metals which were badly needed by other German war industries (copper). It was agreed that an internal combustion engine could provide the same smoothness of propulsion and r.p.m. regulation, provided that an adequate transmission is designed. In general, development of equipment in line with BER and DEP was discarded.

Schallert had the advantage of an independent propulsion of the cutting and throwing rotors. The device worked with almost 30 per cent efficiency at a speed of 90 r.p.m. for the rotor with the thrown speed adjusted to suit. It was found that in order to fulfil the requirement of an adjustable throw distance a 5-speed gear regulation would have to be devised. At speeds $n = 134, 157, 175, 192, 318$ r.p.m. the following throw distance would have been reached: $\mathbf{w} = 6.25, 8.5, 10.5, 17.75, 26.0$ m.

This was easily obtained. In comparison with DEP it was calculated that the snow output of Schallert blower would have been 138 per cent higher at 12.15 m. of throw distance. Consequently, the final plan was that further development of snow grinders should follow this principle.

Snow-throwers designed for work in deep fresh snow were investigated, as was mentioned before, on two types, Pendershaab and Crosti. Crosti, however, proved so unsatisfactory that it was not contemplated after the preliminary tests had been completed. Pendershaab (Snogo) was found to be a very interesting device and was susceptible to the alterations required by the adjustability of the distance of throw. This was because it already had a 2-speed gearbox between the engine and the thrower.

The data on tests conducted with an improved device (Fig. 72) are shown in Fig. 45. From this graph it is shown that the improved version of Pendershaab had an output of:

578 620 625 336 ton/hr.

at the respective distances of throw:

6.25 8.5 10.5 12.75 m.

However, the value S, as well as the engine power, was too small to satisfy further requirements. A complete reconstruction of this snow-thrower was contemplated and a theoretical specification of the new device is shown in Fig. 73. It is not known whether the above results have been achieved, or if Pendershaab was ever reconstructed.

From the discussion with Herr Croce it was evident that the Hochschleuder type equipment was the subject of a most intensive development. Previously described tests with this device supplied a great deal of information which led to the development of the 1000 h.p. giant. The same experience, however, served for designing a small model which is shown in Fig. 74. It represents undoubtedly the latest trend in development of snow-blowers by the Forschungsstelle and was discussed by Herr Croce with some pride. Its overall efficiency is aimed to reach a value of 40 per cent. It was adapted for use on a Raupenschlepper Ost chassis. Two 80 h.p. engines propelled the rotors through a multi-speed transmission, which secured the highest known efficiency.

A detailed description of this device will supposedly be published in Croce's forthcoming book but was not available for compiling in this report. The development was finished shortly before the end of the war and is probably under further consideration by the Bavarian Strassen and Flussbauamt in Traunstein, with whom Croce was associated in the summer of 1946.

Among the originally developed equipment, one item, although small, deserves some attention. During numerous tests it had been found that snow dust obscured the visibility by covering the windshield of the pushing vehicles. Tests with standard wind shield wipers proved unsatisfactory and finally a rotating glass disc was devised which proved extremely effective. A picture showing this device is produced in the Strassenwinterdienst (6).

Snow-blowers were to be used for snow depths of 1.0 to 1.5 m. Equipment mounted on wheels served for removal of the lowest snow layers of a drift. Tracked blowers coped with the top layers. In many cases hand work with snow blowers, pick and shovel was required. The general scheme for an action of this kind is shown in Fig. 75.

Snow-clearing in special conditions was the subject of a careful study, and instructions were originated for military operations in eastern Europe (6).

Special mobile squads were provided for emergency cases. Their organization varied in accordance with the task prescribed. For instance:

i)	Team No. 1	Task	- Snow-clearing of heavy snow drifts. Heavy snow falls.
		Equipment	- 5 snow-blowers and 5 trailers with spare parts; 1 truck with a trailer equipped with heater, tools, 1 transporter for snow-blower, 1 light tank for team commander.
		Personnel	- 15 men.
ii)	Team No. 2	Task	- Snow-clearing of medium snow drifts. Medium snow falls.
		Equipment	- 2 snow-blowers and 2 trailers with spare parts, 1 truck with heater and tools.
		Personnel	- 7 men.
iii)	Team No. 3	Task	- Snow-clearing of country with light snow-falls but heavy drifts.
		Equipment	- 2 trucks with heavy snow-ploughs and trailer carrying spare parts, 1 truck with light snow-plough and spare parts. 1 street plough transported on the trailer. 1 KOM (with a snow-plough) and spare Pendershaab blower as a trailer, 1 truck for tools, equipment and food, 1 field kitchen, 1 light tank for the team commander.
		Personnel	- 47 men.

Details of equipment and specifications of material have been listed in the "Der Strassenwinterdienst" (6). Special lists of personal equipment for the alloted German crews and for the locally drafted man-power also were quoted. Some typical tools are shown in Fig. 76.

The above organization was undoubtedly based on the investigation of snow conditions encountered in Russia. First impressions in this field were published by Wehner in 1942 (162). At the same time Saller described Russian snow conditions (126) with reference to the railway traffic. Later the same was published by Sasse (125).

It is not known to the writer how the above teams worked during the war, and whether the organization as quoted above was changed or not. The magnitude of the preparations, however, indicates how much importance was attached to the snow-clearing problems.

A survey of relevant references in Canadian and American publications stress the same point: (3) (16) (18) (19) (41) (44) (48) (52) (56) (59) (61) (66) (71) (76) (78) (84) (86) (92) (93) (95) (98) (100) (102) (109) (115) (122) (135) (137) (139) (140) (147) (152) (153) (155) (157) (158) (164) (165) (168) (170) (173) (174) (177) (180) (182) (188) (190) (191) (192) (196) (198) (199). The magnitude of the problem is emphasized when it is learned that several millions of dollars are spent annually on snow removal. Various ideas are proposed and a greater variety of means of snow clearing is contemplated. The idea of melting snow, for instance, has been tried, as far as is known only on this continent (138) (185) (186) (187).

The available information clearly indicates that our methods and equipment for snow removal are effective. Whether it is efficient from a mechanical and an economic point of view one cannot say because of lack of relevant information. If the German claim is true that the Hochschleuder is twice as efficient as the best of existing devices, then this means that 200 h.p. engine of an average American snow-blower could be replaced by a 100 h.p. engine. Whether any investigations have been made in order to check this possibility it is not known. Some American manufacturers refer to scientific research but they do not specify its nature. It seems that this problem has been neglected.

The only available information on organized comparative tests of various equipment is that published in Roads and Bridges (193). On March 4th, 1942, tests were carried out at Fairchild Airport, Longueuil, Que., under the direction of Major R.L. Franklin and Captain G.F. Bradbury, from Army Engineering Design Branch, Department of Munitions and Supply. Canadian-made snow-blowers were investigated but mechanical efficiency and the relevant economic problems were not considered.

C INTER-RELATION BETWEEN SNOW-COVER AND AIR CURRENTS

Study of snow transport by air currents was initiated a long time ago. It has much in common with sand transport by desert winds and this analogy was quoted by some authors, who often referred to the paper written on this subject by Bagnold (8).

The action of wind flowing over terrain obstacles was discussed by Seligman (127), Cornish (42) and Dobrowolski (50) (51). It was very seldom studied however on the basis of aero-dyamic theories, although a few attempts in this field may be recorded. Wasik elaborated some problems of eddy currents which were commented on by Dobrowolski in conjunction with snowdrifts (156), whereas Seligman referred to work by Riabouschinsky (119) who applied a laboratory method of investigating waves of lycopodium deposited by air. Herr Bucher, Director of the Swiss Snow Research Institute, disclosed during the visit of Prof. R.F. Legget and the writer, that similar research is planned with the help of scientists trained in aerodynamics.

The existing knowledge, however, did not give a scientific approach to the problem of fighting snowdrifts. This was always solved by trial and error methods, which were not considered satisfactory by the General Inspector of the German Highways, who asked the Forschungsstelle to investigate snow drifting and snow fences on a more scientific basis.

An adviser in this work was Prof. W. Paulcke whose reputation in snow research was well established throughout the world (127). Paulcke's activity was initially tied up with the work of another German investigator Welzenbach, who worked chiefly on avalanches. They both published a paper on snow-cover as early as 1928 (110). Later Welzenbach obtained his Ph.D. by writing a thesis on Snow Stratification and on the Mechanics of Snow Movement (161). Paulcke, apart from work on avalanches, which will be discussed in part "D" was interested in snowdrifts. His ideas and achievement in this field were broadly outlined in the paper published in the Forschungsarbeiten (112) at the moment when he became the scientific adviser to the Forschungsstelle. Another authority in this field was A. Becker (11). The handbook of Strassenwinterdienst (6) deals with basic explanations and information on snow drifting and snow fences. The above may be briefly outlined as follows:

Snow transport by wind may be schematically presented as shown in Fig. 77a. Thicker and heavier snow particles move on the snow-cover surface and are much slower than the light particles driven freely by the wind. From this it may be learned that snow drifting is more complex than usually admitted. When the wind is slowed down by an obstacle, Fig. 77b, heavy snow particles drifted on the surface are stopped before the obstacle, whereas the lighter particles drop down behind it. The snow deposits built up in this way decrease the efficiency of the obstacle and cease after a certain period to slow down the wind. The duration of the period before a fence loses its efficiency is very important for snow protection.

A similar process takes place in ground excavations (Fig. 77c) or slopes (Fig. 78a). The collisions of snow particles and the wind packing make the drift compacted. This causes the removal of such snow to be more difficult. How the snowbanks grow up with continuous road clearing is shown in Fig. 78b. It becomes evident that bank-free snow removal is a prerequisite for avoiding new snowdrifts. Roads built in a cutting may be a source of constant trouble as, similarly, a road on a hill slope (Figs. 78c, 79a and 79b).

The most simple, although not always effective, means of preventing snowdrifts are snow fences or hedges. The main problem is to locate the fences as far from the protected area as is necessary in order to prevent the snow deposit from reaching that area (Fig. 79c). Examples of fences originally considered are shown in Figs. 80 and 81. Use of walls made from snow also was advised.

However, the lack of quantitative data on the effectiveness of various types of snow fences necessitated a vast research program which embraced:

(1) Special study of the terrain surface in conjunction with air currents. In this, measuring of profiles of terrain as well as those of snowdrifts was planned. The results were to be plotted on maps 1:5000. An assembly map with all positions of fences recorded was to be made to the scale 1:100,000;

(2) Observations of existing fences. Search for uniformity in various circumstances;

(3) Scientific research in wind tunnels by means of small scale models and of all methods available in aerodynamics.

The errors which resulted from the present insufficient knowledge of laws governing snowdrifts were stressed as follows:

(1) Use of too many fences, or

(2) Use of too few fences

(3) Application of an improper snow fence height, and generally,

(4) Insufficient protection of given areas.

The importance of solving the relevant problems was stressed by the fact that a solution of existing questions will affect:

(1) Tracing of new lines of communications;

(2) Selection of slopes in new earthworks;

(3) Improvement of existing conditions of snow drifting;

(4) Planning of snow protective installations.

In the program outlined above, an interesting item was brought up by A. von Kreudener. He referred to his many years of work as Chief of Forestry at the Russian Imperial Court and advocated a long-term policy in planning new forests so that they would provide adequate snow-cover in thos regions which usually are not sufficiently protected in the wintertime (90).

Herr Kruedener quoted that such a policy proved very useful in flat, steppe-like country, and raised the standard of crops and cultivated soil. During his 18 years' career in Russia, a net of forest strips were planted which spread the required snow-cover over a total area of more than 10,000 hectars.

The preliminary work required for the selection of territories and for planting new forests was estimated as requiring 3 to 5 years. It was advocated that Germany may gain very much in this way by improving agricultural production.

The research work performed at the Forschungsstelle in the winters of 1940-41 and 1941-42 may be described in the following points:

(1) General purpose
(2) Method
(3) Material tested
(4) Results of test

1. The general purpose of this project, as has been mentioned before, was to determine quantitatively the value of different types of snow fences and of the different methods of their use. It was also aimed at establishing some general rules and at unifying various procedures which would eliminate waste and inconvenience of haphazard actions, hitherto based on custom and rules of thumb.

2. Method applied consisted of recording data which described terrain, the state of snow, characteristics of the given fence, and its efficiency in preventing snowdrifts.

Terrain selected for tests was supposed to have uniform meteorological conditions as well as the same snow drifting characteristics of all equipment tested. Preliminary tests were made in 1940-41 in Lindenberg bei Buchloe (Schwaben) whereas the main test was carried out in 1941-42 in Oberjoch, Hindelang (Allgau). Topographic and climatic features of the proving grounds were carefully investigated and were recorded on charts and photographs.

Snow state was defined by measuring the "cone resistance" specific weight and moisture content. Also microscopic observations of snow crystals were made. In addition to this meteorological observations were performed including recording of:

(1) temperature
(2) humidity
(3) wind speed
(4) precipitation

The way in which meteorological data, speed and direction of wind were recorded is shown in Figs. 82a and 82b.

Snow fences used were described in detail as far as their manufacture is concerned. Dimensions, and photographs supplemented each report. Location of fences and of measuring instruments were plotted on a plan made to the scale 1:1000.

The following are definitions used in fence description:

(1) Fence height - was determined as the distance between the ground and the highest point of the structure. For fences made from trees this dimension was determined as the average tree height.

(2) Fence length - fabricated fences did not require any definition. For tree fences, however, it was impossible to define the length exactly. Average fence length was determined as the length of a fence which gives at its centre that size of deposited snowdrift which would be deposited by an indefinitely long fence.

(3) Total fence surface - was the product of (1) and (2).

(4) The width of a gap between a fence and the ground was often defined as the average distance measured from the ground to the lower edge of a fence.

(5) Fence "density" - was measured in the same value which otherwise is defined as hole-percentage. The measure of fence "density" is the ratio "f" between the surface covered by fence material and the total surface of a given fence (3). Thus a plain wall has f = 1 and a fence made from a net has f close to 0.

The effectiveness of protection from snowdrifts was determined by careful measurement of profiles of deposited snow during various test periods.

There is no room to describe here the way in which all data were collected. Some examples, however, may be useful in general description of the methods applied.

As the whole observation time was divided into three periods, the respective data were recorded at the end of each period. The amount of deposited snow was plotted on graphs one of which is shown in Fig. 83. This gave a full picture of the whole test or of specific period with reference to each fence.

The surface of cross-sections of various snow deposits was measured at each period and was tabulated in a general record. Also, the length and height of deposited layers were recorded. As it was interesting to compare various fences from various points of view, the height and length of deposited snow was plotted with reference to the fence height and to its density f.

This method enabled one to draw many conclusions with reference to the way in which different types of fences worked. It was agreed, however, that so many factors are involved in the process that only general trends and regularities could be observed. More detailed study was referred to special laboratory work, which, however, could not be satisfactorily developed due to wartime shortages.

3. Material tested during the two winters of 1940 to 1942 is shown in Fig. 84. Its general characteristics are specified in Table V.

TABLE V

No.	Type of fence	Fig.	Height m	Density "f"	Gap between ground and fence	Material
0	Staudingen	1	1.2	0.7	0.2	Wood scrap
1	Garland	2	1.7	0.4	0.45	Pine branches
2	Russian	3	1.75	0.47	0.35	Wooden sticks
3	Paper	4	a 1.60	0.35	0.20	Impregnated
			b 1.70	0.35	0.35	Paper net
4	Bayrisch	5	1.73	0.74	0.30	Wooden planks
5	Norwegian	6	a 2.00	0.50	0.30	
			b 2.00	0.65	0.30	Wood
			c 2.00	0.34	0.30	
6	Hedge		a 2.50	0.20	0	Pine
			b 2.20	0.70-0.10	0	
			c 4.00	0.5 -0.10	0.08	

4. Results and conclusions which were published in a special report by Herr Croce (35) may be stressed briefly in the following lines.

As has been mentioned before, the test from 1940 to 42 proved to be conclusive in a very general way only. This was realized during the above research which was consequently concentrated on a very few general items.

Attempts to find an interrelation between the fence height and the height of snow deposit are shown in Fig. 85a. Results of this figure indicate that there is no regularity at all. Conclusion: there are other unknown factors besides the height of a fence which affect the height of deposited snow. However, the height of deposit when referred to the fence "density" shows a clear-cut regularity (Fig. 85b). It was then concluded that dense fences leave higher deposits than open ones.

The second item interpreted from this data was the relationship between the length of snow deposit, measured at right angles to the fence, and the fence structure. As the length of deposited snow determines the distance between the fence and the area which is to be protected, the problem was considered very important. In Fig. 86a the length has been referred to the fence height. As in the case represented by graph 85a, lack of regularity indicates the existence of other unknown factors. However, the deposit length when plotted as a function of the fence density shows a tendency of increasing with the increased density (Fig. 86a).

In order to eliminate from the discussion the effect of the fence height, the graph shown in Fig. 87a has been compiled, and refers to the density and to the length of snow deposit measured in fence height units. Points thus determined show a definite relationship between the two values in question. They also show, however, the effect of some other factors. In order to investigate the latter, graph 87b was computed for Norwegian fences Nos. 6a, b, c, (Table IV) which have the same height and structure but different density "f". The result is striking, and shows the effect of "f" upon the deposit heights.

Graphs in Figs. 86 and 87 indicate how fence design as well as their density affect the snow deposits. If one assumes that all fences show the same relationship between deposit length and density as those determined for Norwegian fences, then it is possible to calculate deposit lengths of other fences at the same density "f" and subsequently, to refer these lengths to the respective fence heights.

The calculation factors "k" determined from the curve as obtained for Norwegian fences and plotted for a fence with average density f = 0.5 are:

f	=	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75
k	=	0.79	0.80	0.86	0.93	1.00	1.07	1.14	1.22	1.29	1.35

The same may be determined from the average curve as extrapolated in Fig. 86b. In this case respective "k" values are:

k	=	0.70	0.77	0.85	0.92	1.00	1.08	1.15	1.22	1.27	1.31

which is almost the same as in the preceding case. The above proves the soundness of the assumed generalization.

Values "k", defined in the above way are plotted in Fig. 88a and enable one to find the length of snow deposit of a fence with any density once this length is known for f = 0.5, or vice versa. For instance, a fence with f = 0.7 deposits a snowdrift 20 ft. long. What will be the length of a drift if the fence is more open, and has f = 0.5 only? The answer is shown in dotted lines in Fig. 88a. Value for f = 0.70 is about 1.28. The new length of snow deposit will be 20/1.28 or 15 feet.

Fig. 88b shows the length of deposited snow at various fences reduced to f = 0.50 and referred to the fence height. Points are scattered fairly widely. However, it is justifiable to extrapolate an average value which is marked by a straight line.

This line determines the deposit length "L" with reference to the fence height for f = 0.50. The equation of the above line may be easily determined from the graph and is:

$$L = 11 + 5h$$

where h is the height of the fence.

It is obvious that for various values of fence density f, this becomes,

$$L = \frac{11 + 5h}{k}$$

The above formula shows the magnitude of the relation involved between the fence height and the length L. For practical purposes it is advised to add a safety margin of 5 metres (35) in order to determine the required distance A between a fence and a protected area.

$$A = \frac{11 + 5h}{k} + 5$$

In the manual on Strassenwinterdienst (6) a wider safety margin was quoted, namely 10 metres, and the formula was written as,

$$A = \frac{11 + 5h}{k} + 10$$

This discrepancy and the relatively high value of the safety factor indicate that there is still much to be don in order to determine numerical values for the relation between fence design and the length of snow deposits. However, the above reasoning seems to be very useful. The graph in Fig. 89 shows various required distances A with reference to fence height and fence density.

The third point of interest in investigating the action of snow fences was the relationship between the volume of deposited snow and the fence structure. From many investigated relations this one is probably of major interest. It determines that the volume of snow deposited by two fences having the same structure but different height are proportional to the square of the height ratio, i.e. a fence twice as high will deposit 4 times as much in cu. ft. of snow. The above relation was to be the subject of further research which was planned for 1943-44. It is not known by the writer whether it has been performed.

The effect of fence density upon the surface of cross-section of the deposit is shown in Fig. 90. It refers to the fences Nos. 1, 2 and 4 which are almost of the same height (see Table V). It may be said that the paper net fence 3a (f = 0.35) gave the best results although it would be impossible to judge this from the density only. This problem was a subject of further study.

Comparison between snow fences and hedges was also studied on the basis of the tests performed. In general, it was established that snow deposits as obtained by hedges were much larger than those obtained by fences. However, a strict comparison could not be made.

Herr Croce spoke very favourably about hedges and expressed an opinion that they have been working very well although in some cases their density was less than f = 0.20.

It was very difficult to get general estimates on the distance required between a hedge and a protected area. The whole problem was considered as closely related to the relevant studies in botany and further work was planned in conjunction with the Biology Research Dept. (Forschungsstelle für Ingenieur Biologie) of the General Inspector of German Highways.

The simplified rules determined by the above discussed research with reference to the use of snow fences were published in Strassenwinterdienst. Instruction for applying a plain fence is shown in Figs. 91a and 91c which refers to the dimensions of the snow deposit and those of the fence. Figure 91b shows the installation of several rows of fences. Fences which have a gap between their lowest edge and the ground are shown in Fig. 92a.

The placement of snow fences for protecting a given road portion with two possible varying directions of wind is shown in Fig. 92b. The same with reference to the protection of a curved road is drawn in Fig. 92c.

An example of fence installation at a place where a road approaches a forest and highway crossing and where it goes out from a cut and enters an embankment is shown in Figs. 93a, 93b and 93c.

Much similar research on snow fences is being planned in Switzerland by the Snow Research Institute at Davos. The Institute which was originally dealing with avalanche prevention is slowly extending its activity not only in the field of civil engineering (67), snow physics and crystallography (118) but also in the field of snow protection.

One cannot say what may be compared **as** similar work in Canada and the United States. A survey of available information on snow fences (10) (13) (14) (47) (79) (94) (96) (101) (116) (120) (138) (148) (150) (181) (197) indicates that a great deal of observations were made. This information, however, cannot be a basis of general conclusions as no scientific methods were applied. An exception, however, is the work done by Finney in the U.S. (56) (57) who developed the technique of investigating snowdrifts on scale models by a wind tunnel much earlier than the Germans did. Finney determined the length of snow drift as equal to 6 1/2 times the height of a fence, which is very close to the results of German full scale tests.

D AVALANCHE AND SKI RESEARCH

The study of snow problems in Germany expanded greatly due to the war. Even the avalanche investigations had a definite military aspect and this influenced Swiss wartime avalanche research.

During the first world war, Army casualties in the Tyrol and Carpathian mountains due to avalanches, were higher than those resulting from direct military operations. Paulcke, an excellent student of this problem, estimates that on winter operations, during the period of 1914-1948, avalanches caused 60,000 casualties.

Protection of mountain passages required preventing avalanches. Research in this field was performed as mentioned before, by Welzenbach and Paulcke (110). The latter was known as an expert in this subject. In 1936 and 1938 Paulcke took part in the meeting of the International Commission of Snow in Edinburgh and Riga (113). He also is the author of an excellent book on Snow and Avalanches (114).

Another expert on snow problems was Prof. W. E. Fauner from Berlin. However, other than the fact that he co-operated with German railways, very little is known of his activity. Another author who worked on snow problems in conjunction with railways was S. Schubert (132). Croce also named W. Flaig an outstanding German avalanche investigator (58) but no more information on his work was available besides the note by Prof. P. Niggli (7) who mentions Flaig's work on avalanches. Niggli gives also a brief outline of research performed by Paulcke and other German and Swiss workers.

Some of them are quoted by Haefeli (65) as authors of articles on avalanches published in the Swiss paper Die Alpen (20) (21) (22) (53) (62) (73) (74) (130) (142). Also some work by Herr Zdarsky should be mentioned (167). The avalanche research in Germany, however, was not developed beyond the descriptive and fact-finding work on snow and its metamorphosis and cannot be compared with the work done in Switzerland (7) (65).

The same practical application of observed phenomena and practical rules for skiers, and mountaineers that are included in German publications may be found in English snow literature whose best known representative is G. Seligman (127). Some additional information of the same kind may be found in any of the excellent Swiss publications (184).

Croce officially admitted that "the Swiss are far ahead of us" (36) and nothing original was found which would be comparable to Haefeli's "Snow Mechanics" (65) or even to Japanese research on skiis (107).

The Forschungsstelle, as far as is known, dealt with regulations for reporting and preventing avalanches. In a report "Lawinenkataster" (36) in addition to general definitions, some rules on how to forecast avalanches and how to record this information were described.

Another paper (39) standardizes the procedure of firing mortars in order to precipitate the fall of dangerous snow layers. Fig. 94 gives the idea of the nature of these instructions. Similar problems were considered by F. Weber (159).

In order to make the picture of German snow research more complete, the general investigation of snow precipitation should be mentioned. This problem was also tackled by Paulcke (113) and many others. As the writer's visit in Germany was of a very short duration practically no information on this subject was collected. The Flussbauamt in Traunstein has been dealing with this problem whose nature is widely known and has been popularized in English literature. The International Commission of Snow and Glaciers (97) is responsible for stimulating the wide program of studies in hydrology (172) (40) and air physics (43) (108) (163). The work by J.E. Church who is known as the Chairman of the International Snow Commission has gained a wide reputation on this subject (45) (46). The Germans took an active part in co-operation with the International Commission prior to the war (113).

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SNOW TESTING KIT

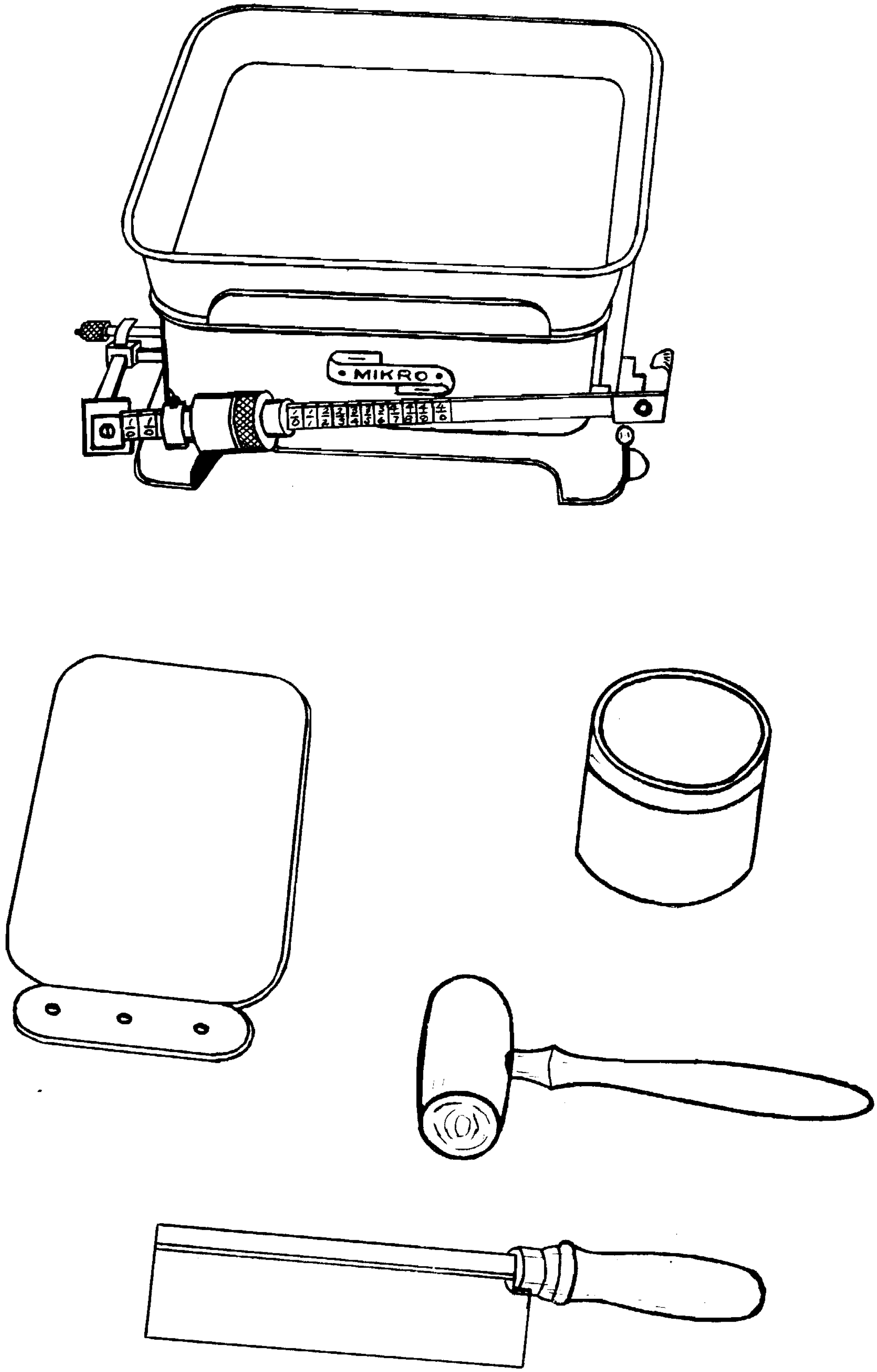
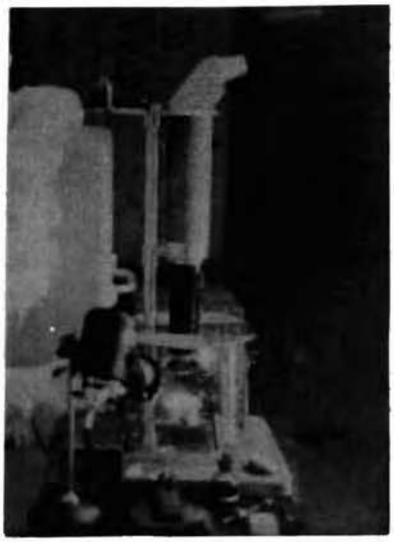
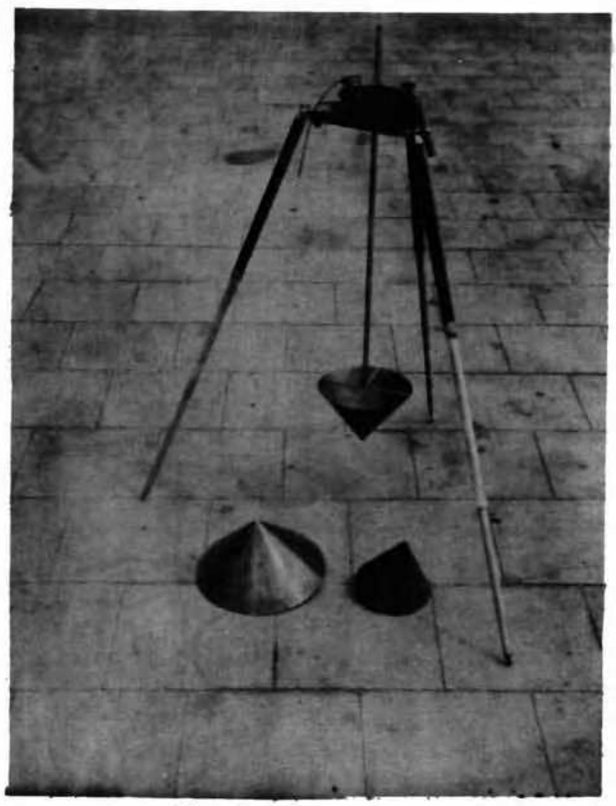


FIG. 1

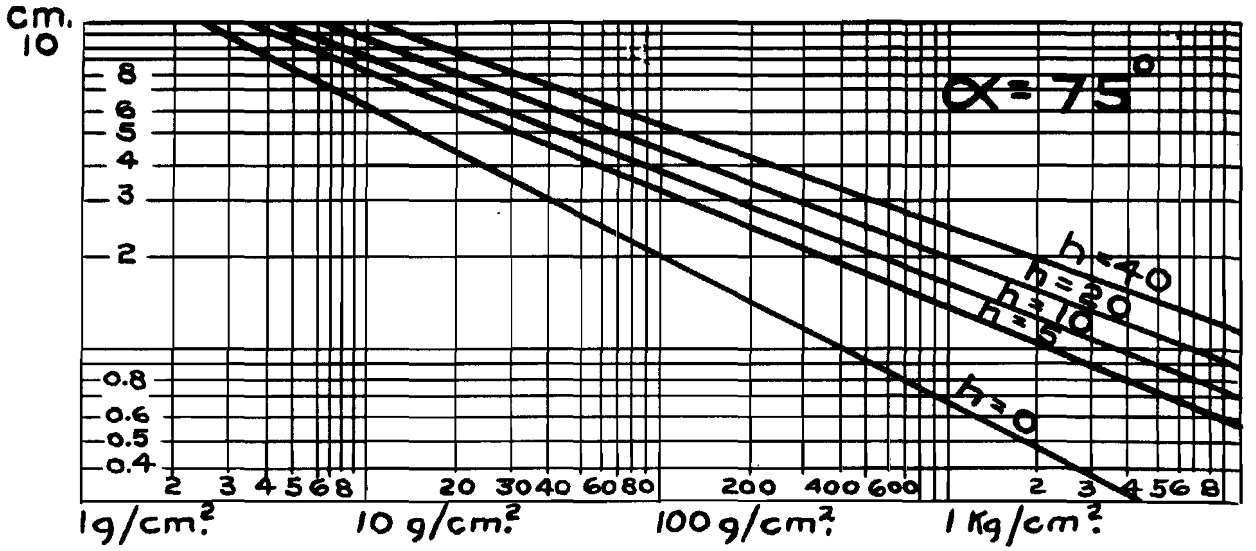


STEREO - MICROSCOPE

FIG. 2

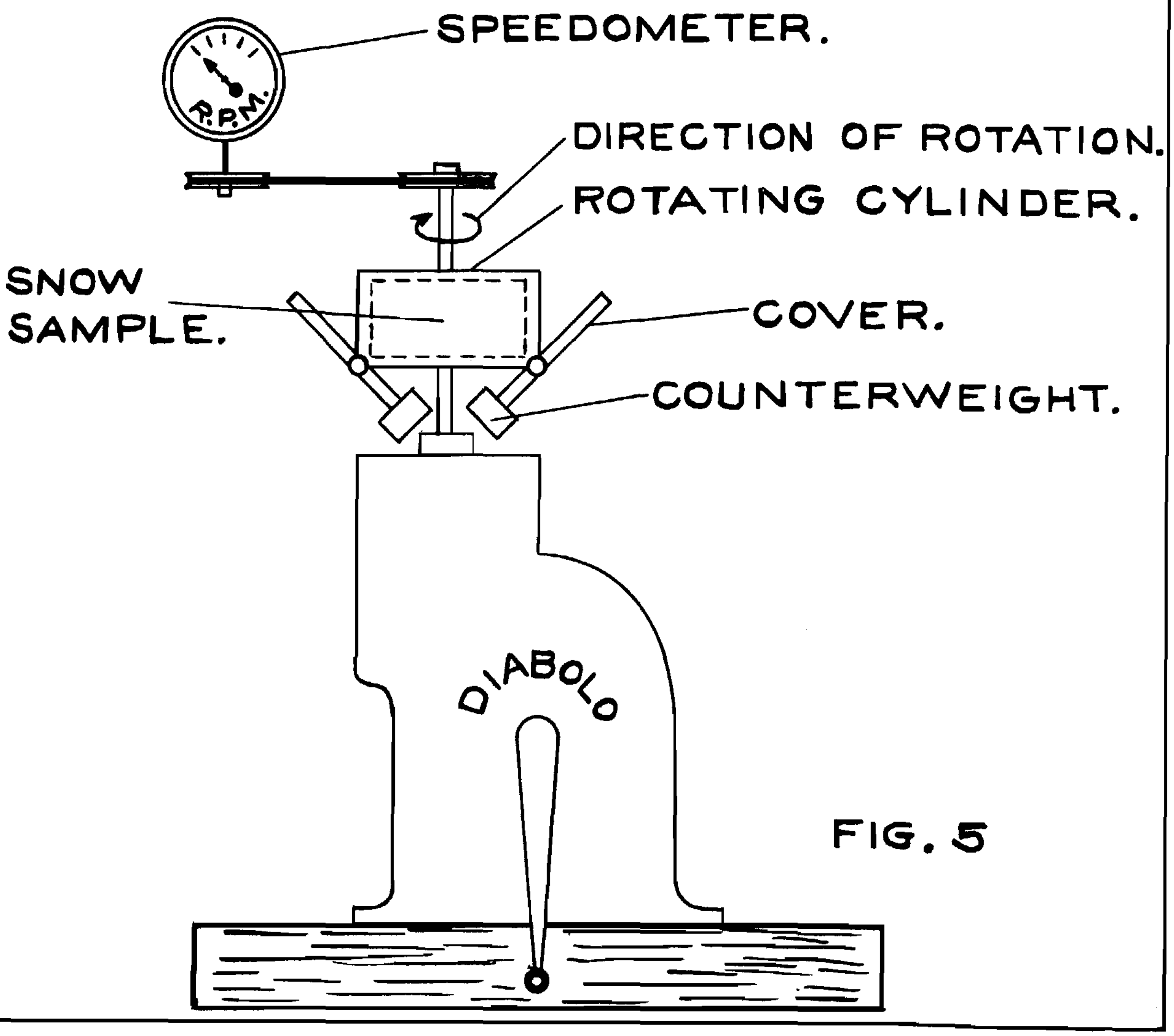


IMPACT CONE
FIG. 3



cm.
10
8
6
5
4
3
2
0.8
0.6
0.5
0.4
α = 75°
h=40
h=20
h=10
h=5
h=0
2 3 4 5 6 8
20 30 40 60 80
200 400 600
2 3 4 5 6 8
1g/cm²
10 g/cm²
100 g/cm²
1 Kg/cm²

FIG. 4



SPEEDOMETER.
R.P.M.
DIRECTION OF ROTATION.
ROTATING CYLINDER.
SNOW
SAMPLE.
COVER.
COUNTERWEIGHT.
DIABOLO

FIG. 5

FRICTION MEASURING DEVICE

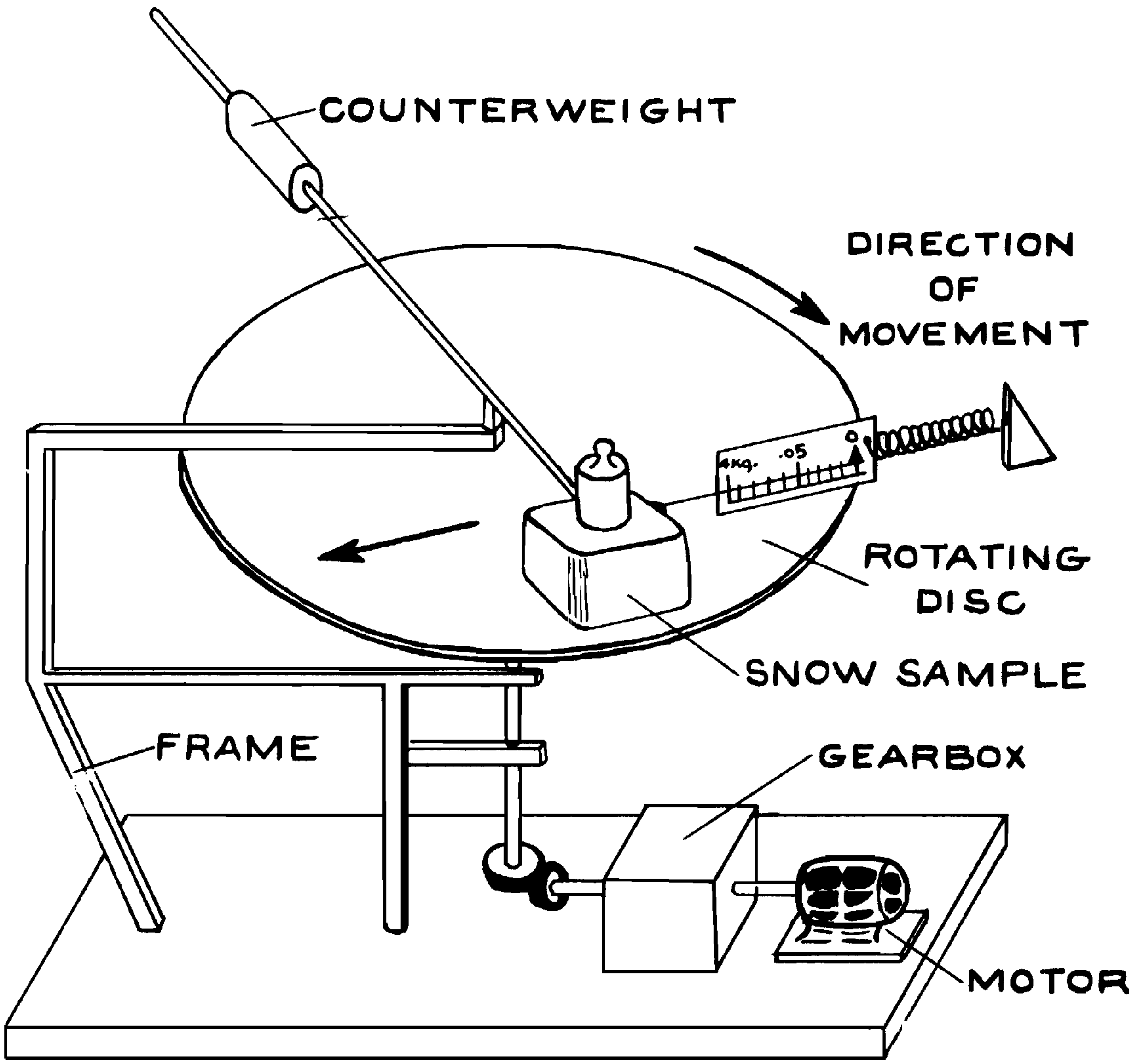


FIG. 6

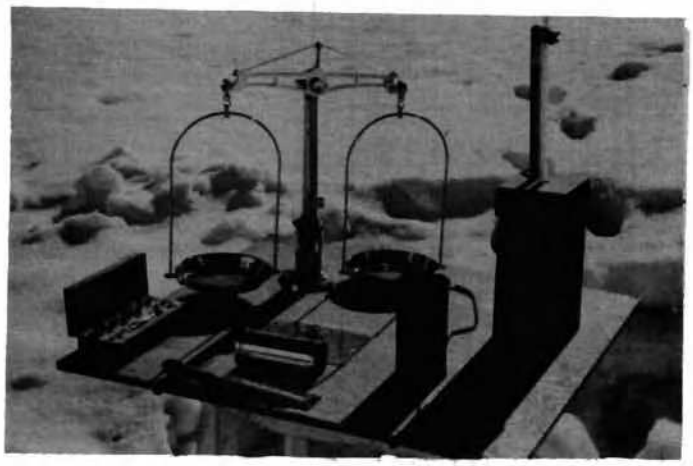


FIG. 7a

MOISTURE CONTENT KIT
FIG. 7b

MOISTURE CONTENT CALORIMETER

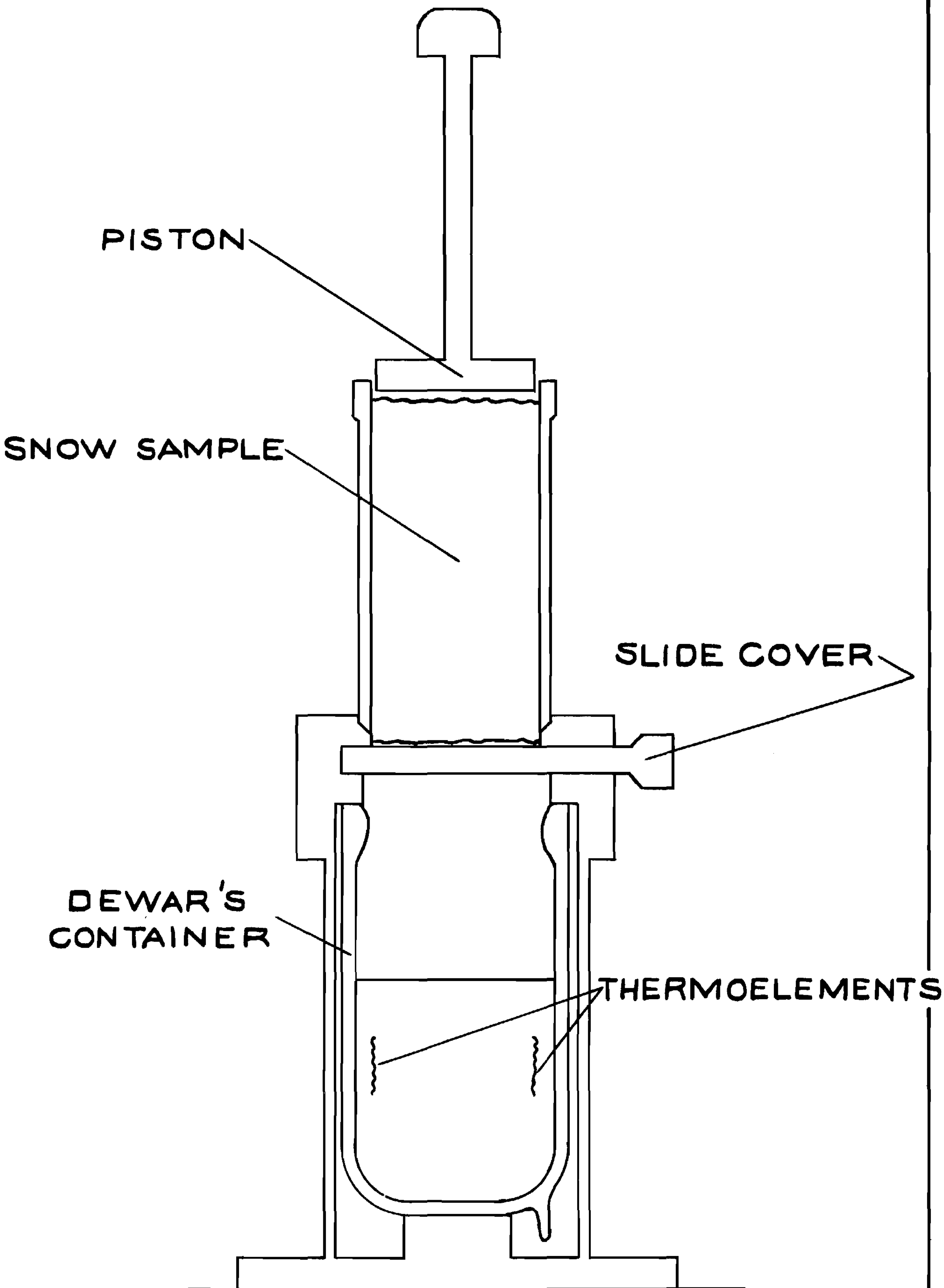
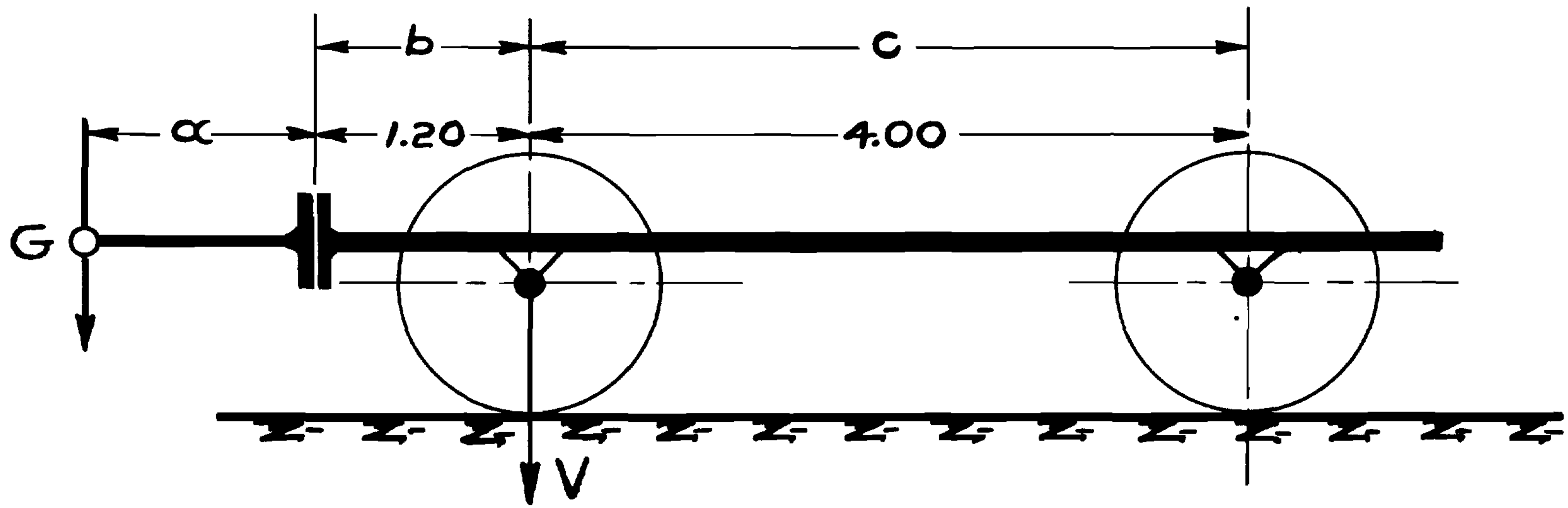


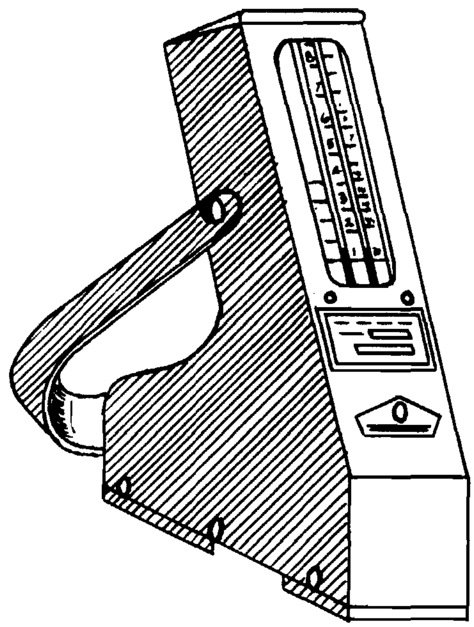
FIG. 8

DISTRIBUTION OF LOADS
ON CHASSIS OF A PLOW MOVER



$$V = \frac{G(a+b+c)}{c}$$

FIG. 9



ACCELEROMETER

FIG. 10

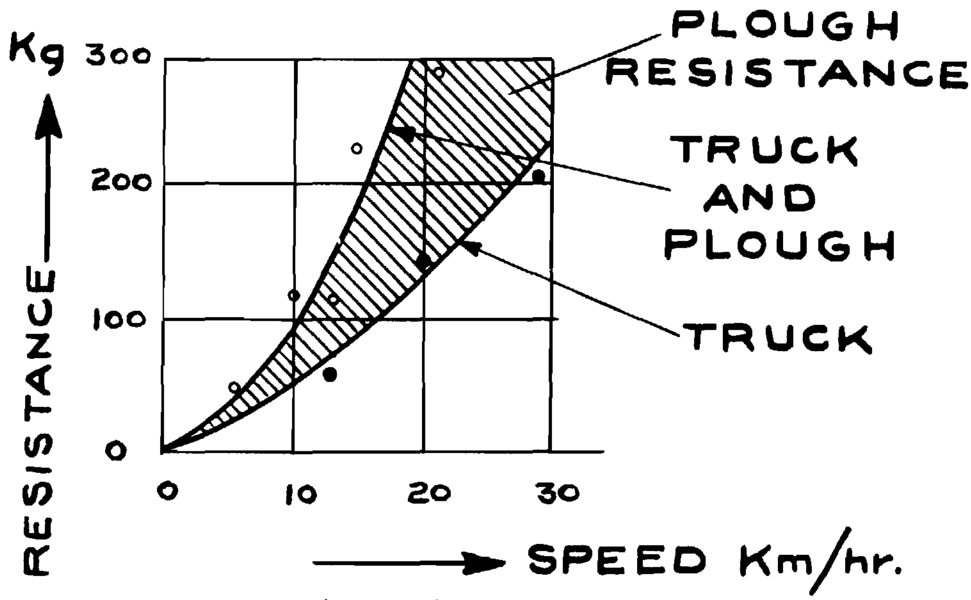


FIG. 11

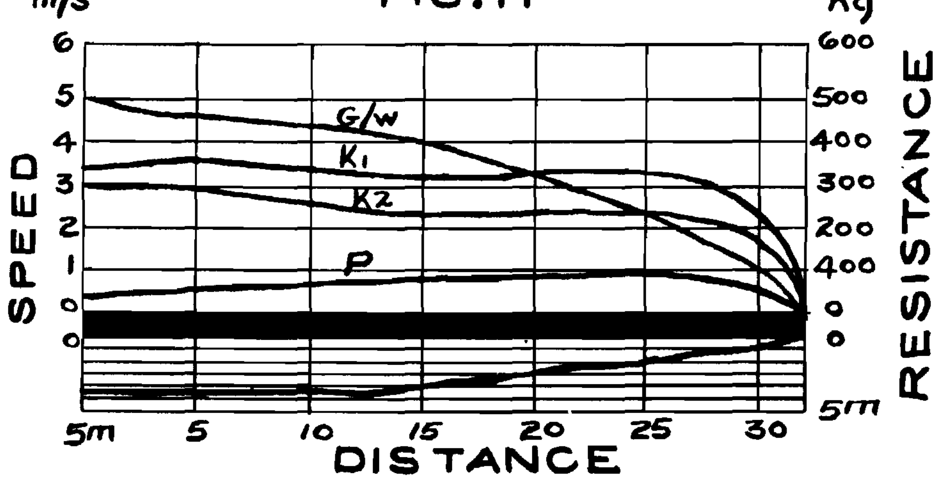
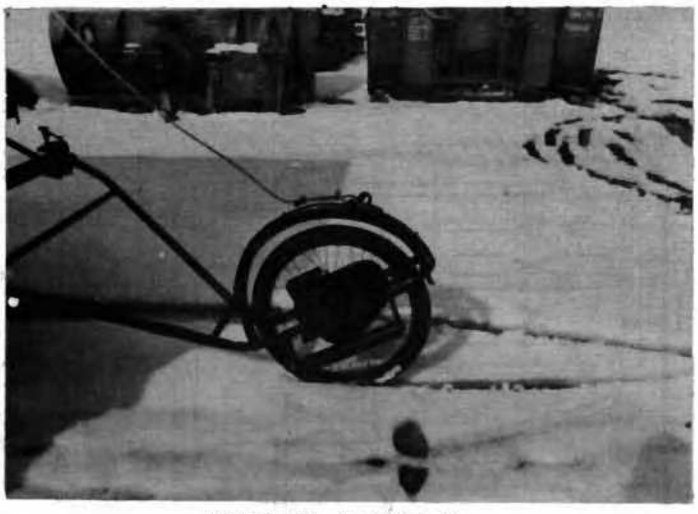
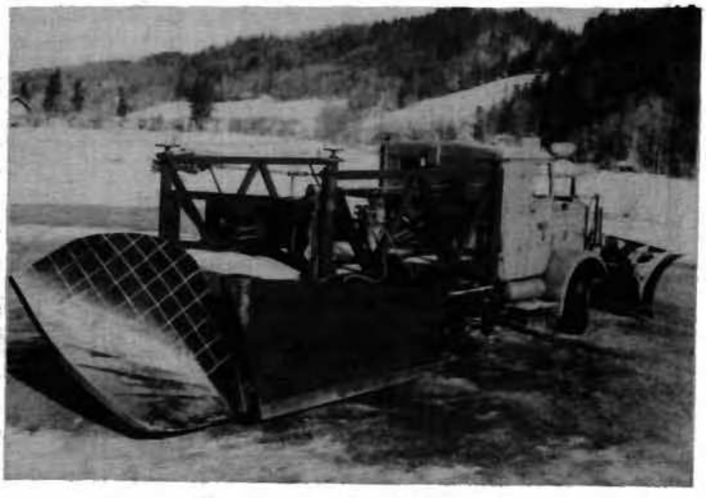


FIG. 12



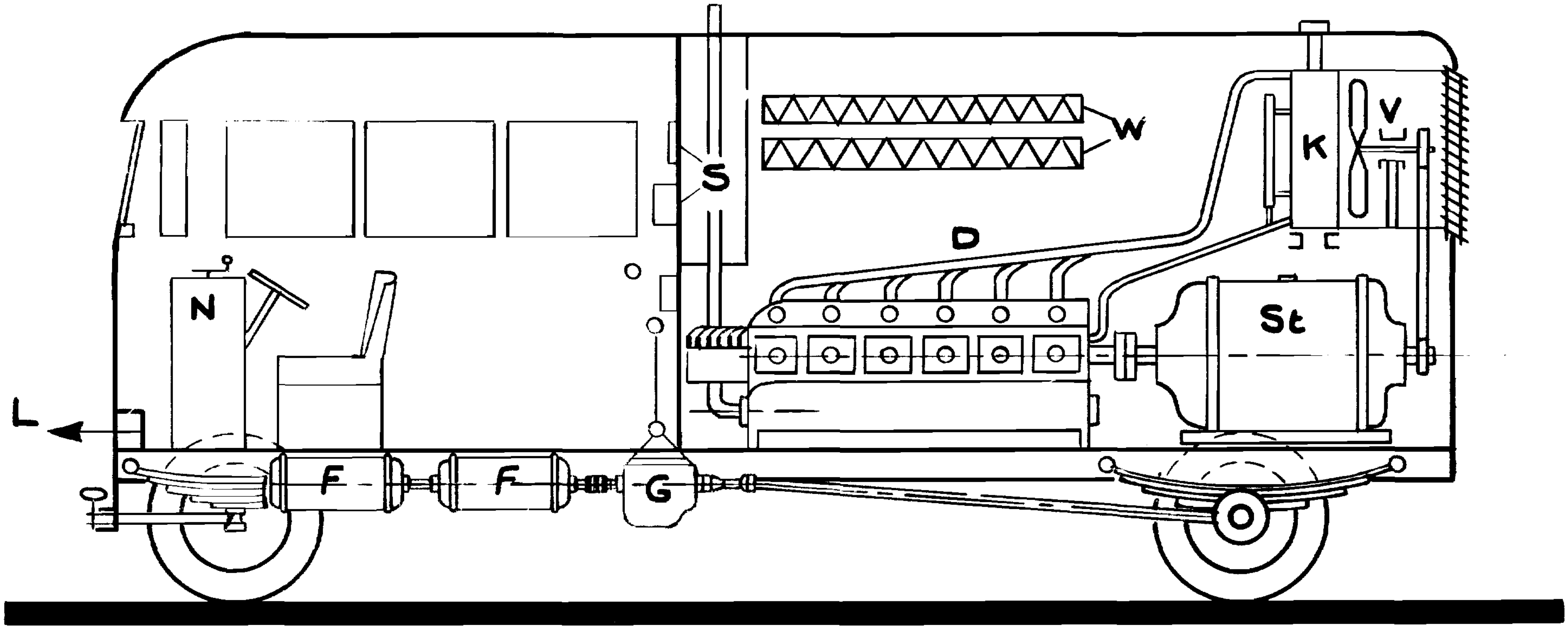
FIFTH WHEEL
FIG. 13

FIG. 14 a



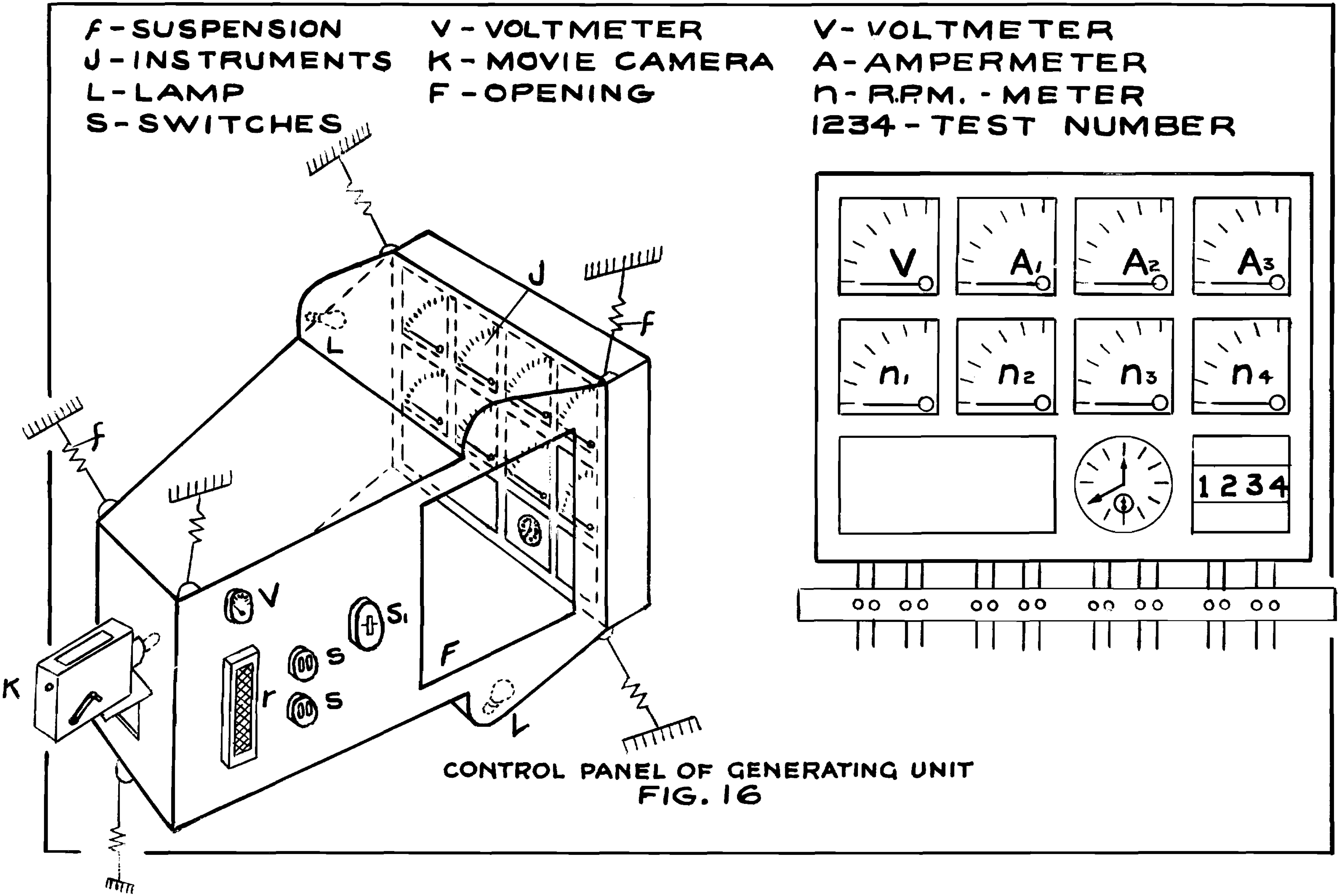
EXPERIMENTAL BLADES
FIG. 14 b

W – RHEOSTAT
N – CONTROLS
F – ELECTRIC MOTOR
G – GEARBOX
S – INSTRUMENT PANEL
D – DIESEL MOTOR
S^t – GENERATOR
K – RADIATOR
V – VENTILATOR
L – PLUGS



MOBILE GENERATING UNIT

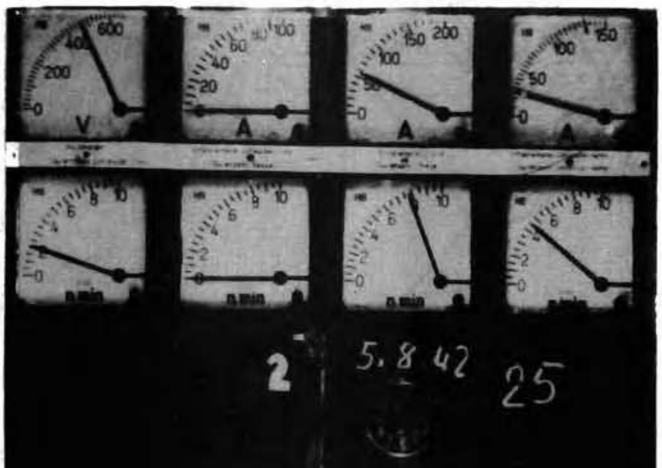
FIG. 15



CONTROL PANEL OF GENERATING UNIT
FIG. 16

MOBILE GENERATING UNIT
FIG. 17 a

EXPERIMENTAL SNOW BLOWER
FIG. 17 b

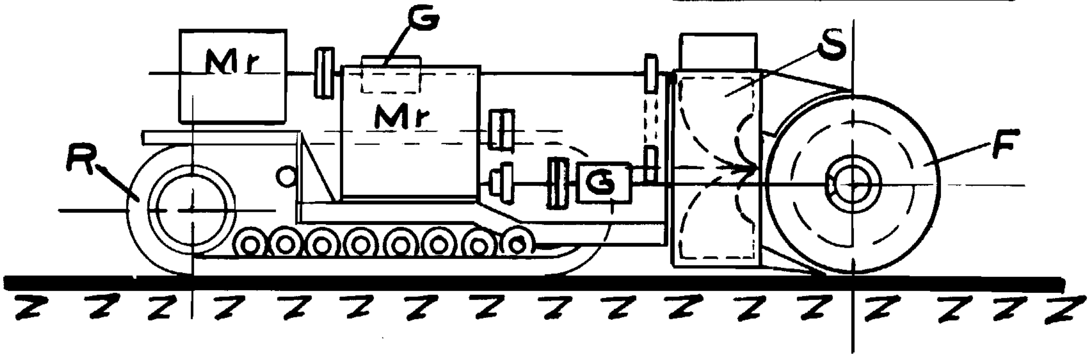


INSTRUMENT PANEL
FIG. 17 C

SCHALLERT

M_l & M_r - ELECTRIC MOTORS (THROWING ROTORS)
M_f - ELECTRIC MOTOR (CUTTING ROTOR)
G - GEARBOX
S - THROW ROTOR
F - CUTTING ROTOR
R - TRACK

SECTION A-B



PLAN

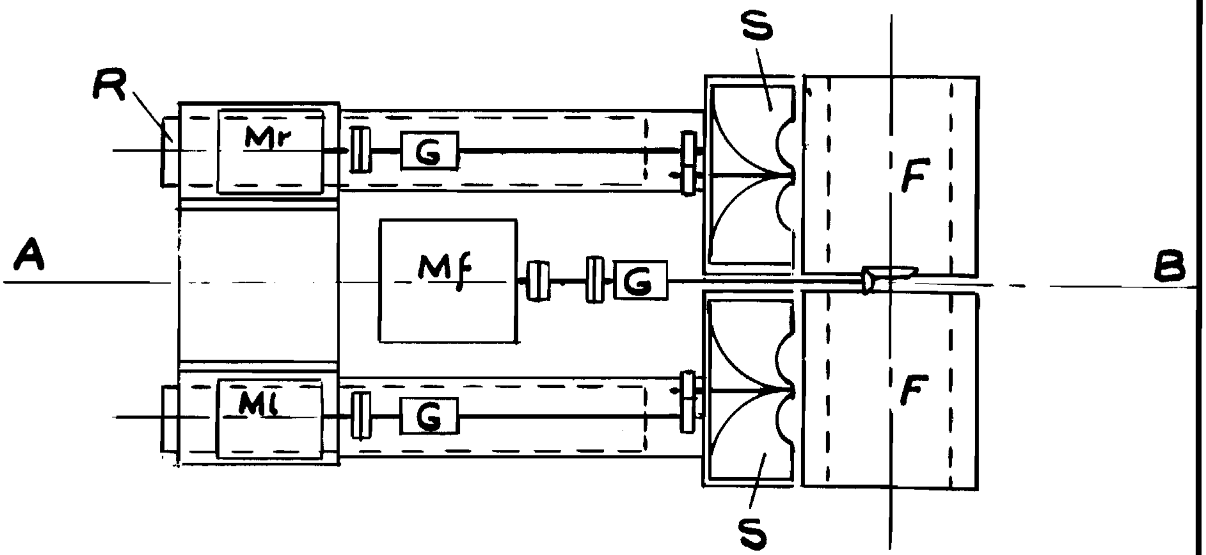
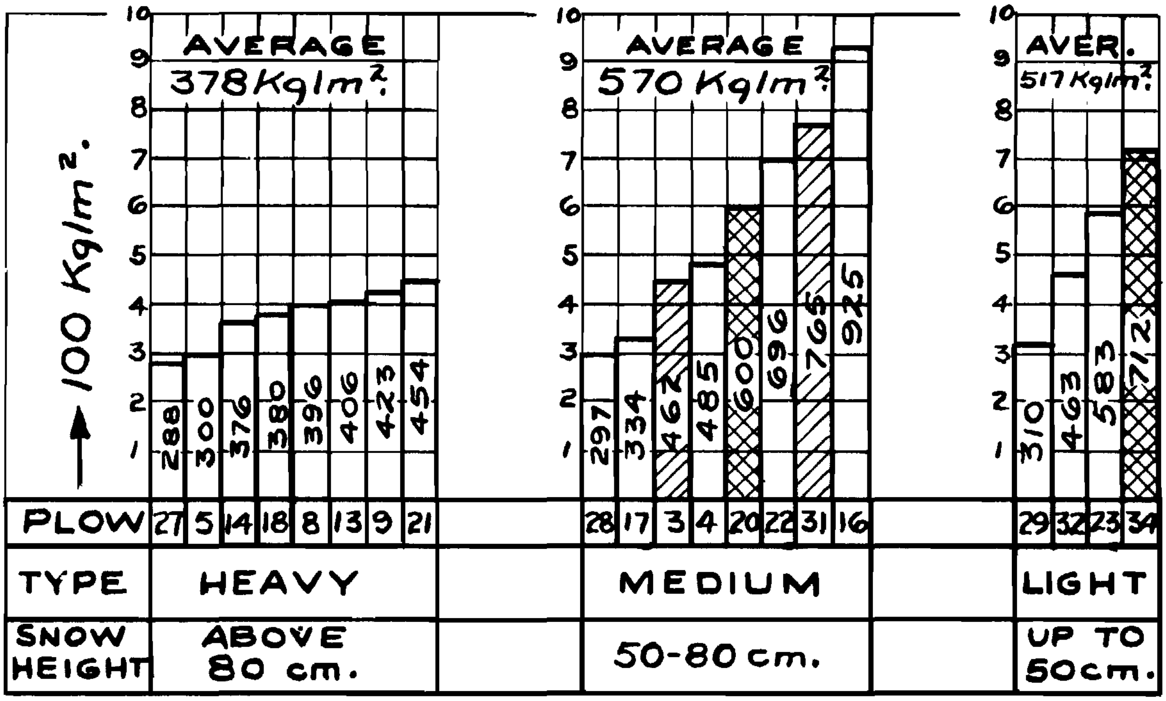
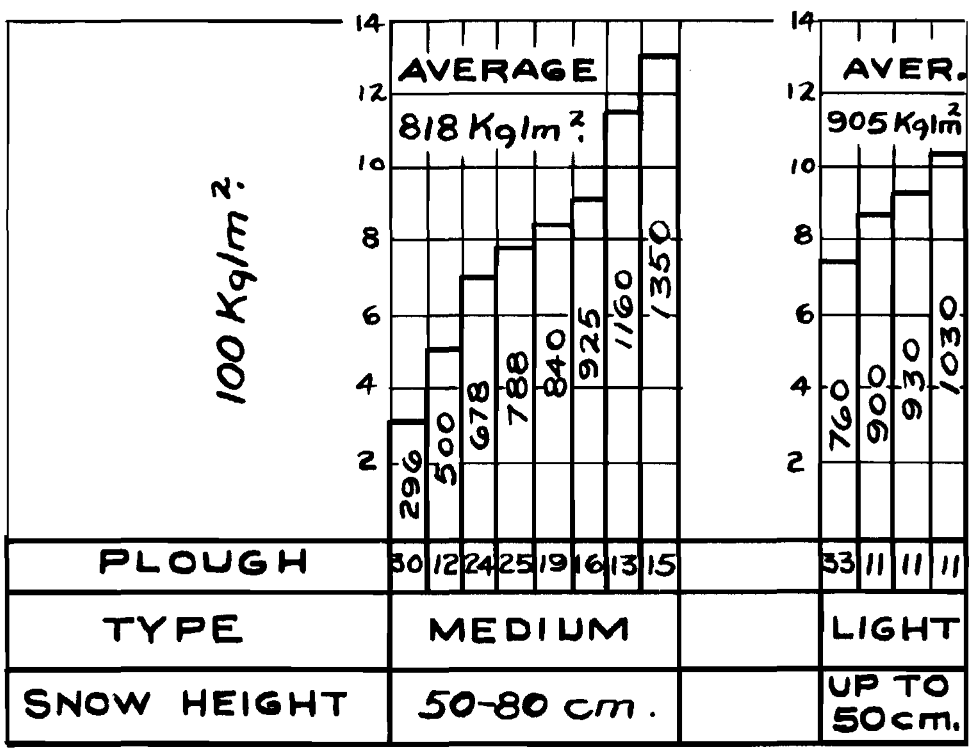


FIG. 18



SPW OF V-BLADE PLOUGHS



SPW OF ONE BLADE PLOUGHS

FIG. 19

MOVEMENT RESISTANCE REFERRED TO 1m OF PLOW WIDTH.

Kg ONE BLADE PLOWS 2,40-440 m. WIDE.

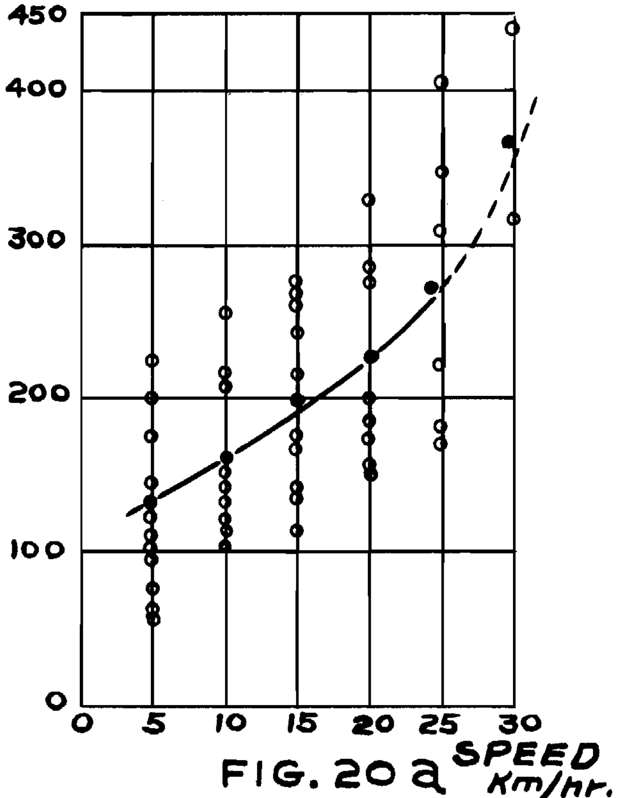


FIG. 20 a

Kg. V-PLOWS 2.70-50 m. WIDE.

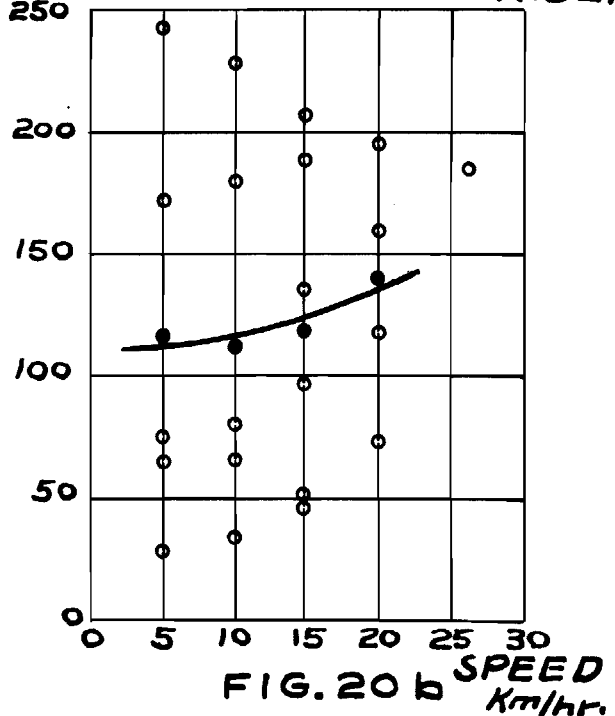


FIG. 20 b

MOVEMENT RESISTANCE REFERRED TO 1m. OF PLOW WIDTH, TO m^2 OF ROAD SURFACE AND TO 10 Kg. OF SNOW.

Kg. V-PLOWS.

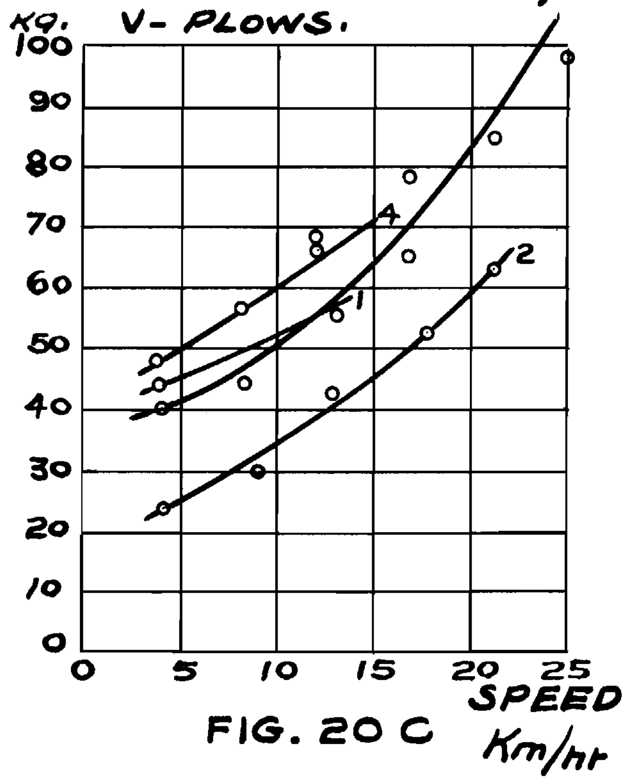


FIG. 20 C

Kg. ONE BLADE PLOWS.

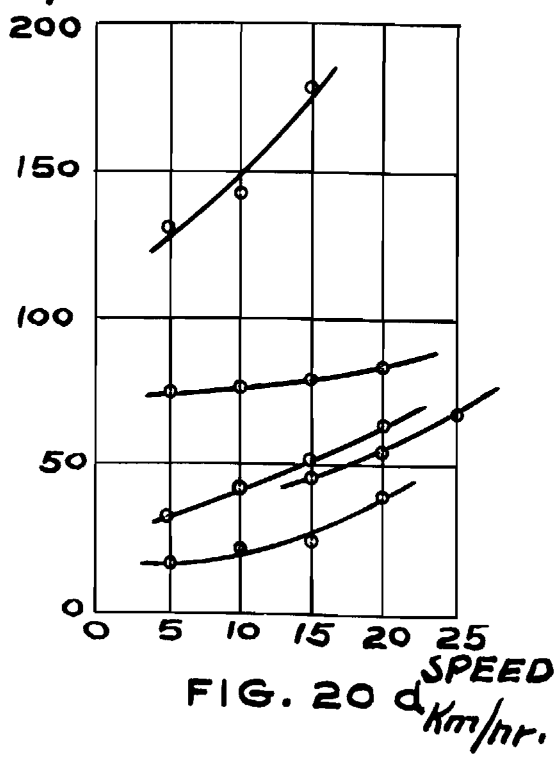
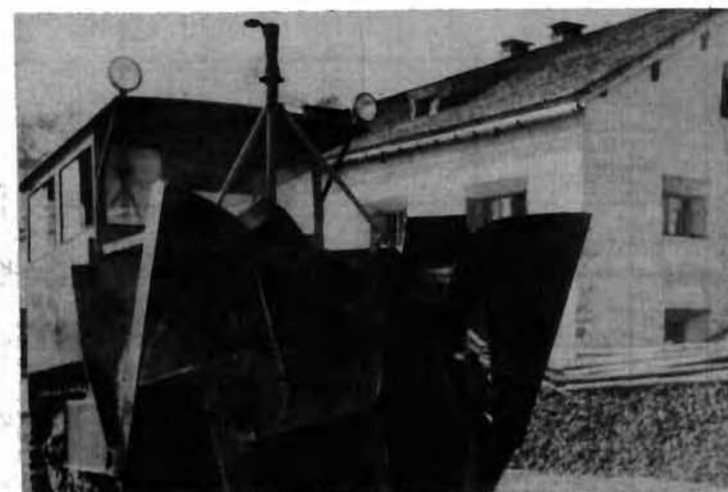


FIG. 20 d

BER
FIG. 21

DEP
FIG. 22

SCHALLERT
FIG. 23

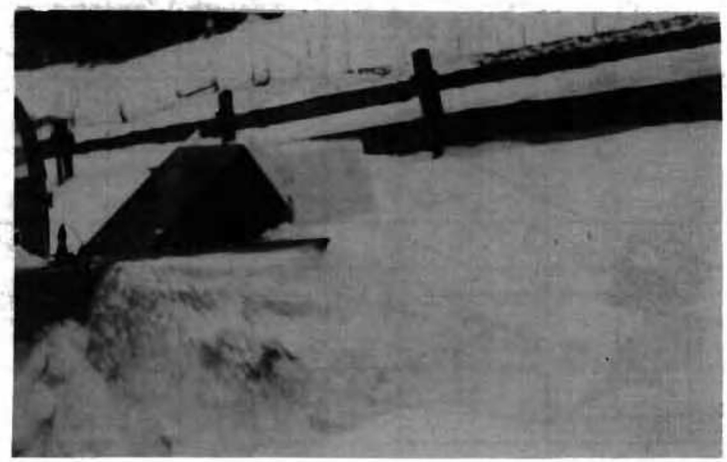


CROSTI
FIG. 24

FOKKERRAD
FIG. 25

SCHALLERT II
FIG. 26

SNOGO
FIG. 27



SNOW PACKING AT THE ROTOR OUTLET
FIG. 28

CHARACTERISTICS OF SCHALLERT BLOWER

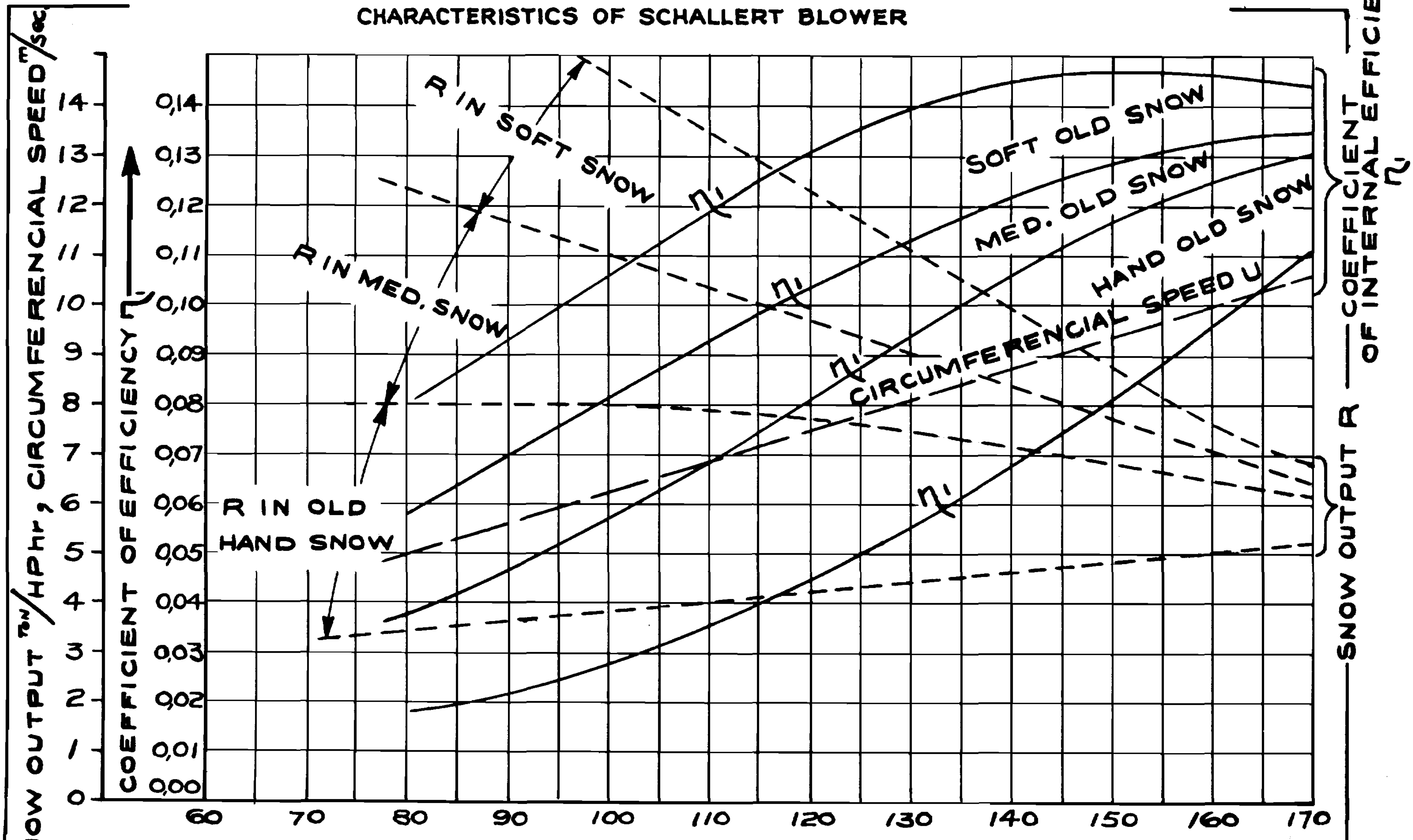


FIG. 29

COEFFICIENT OF INTERNAL EFFICIENCY
PETERFRÄSE SCHALLERT

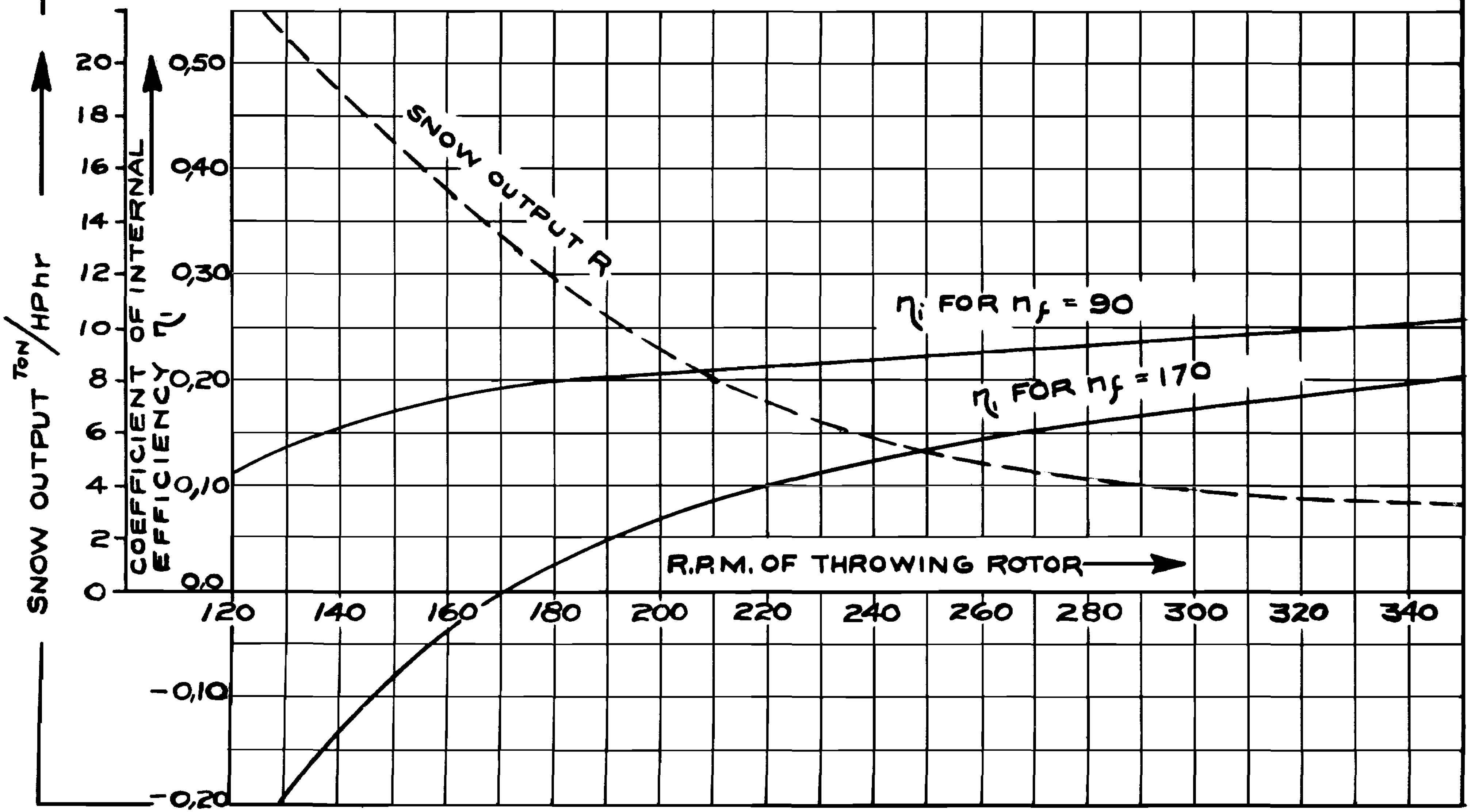


FIG. 30

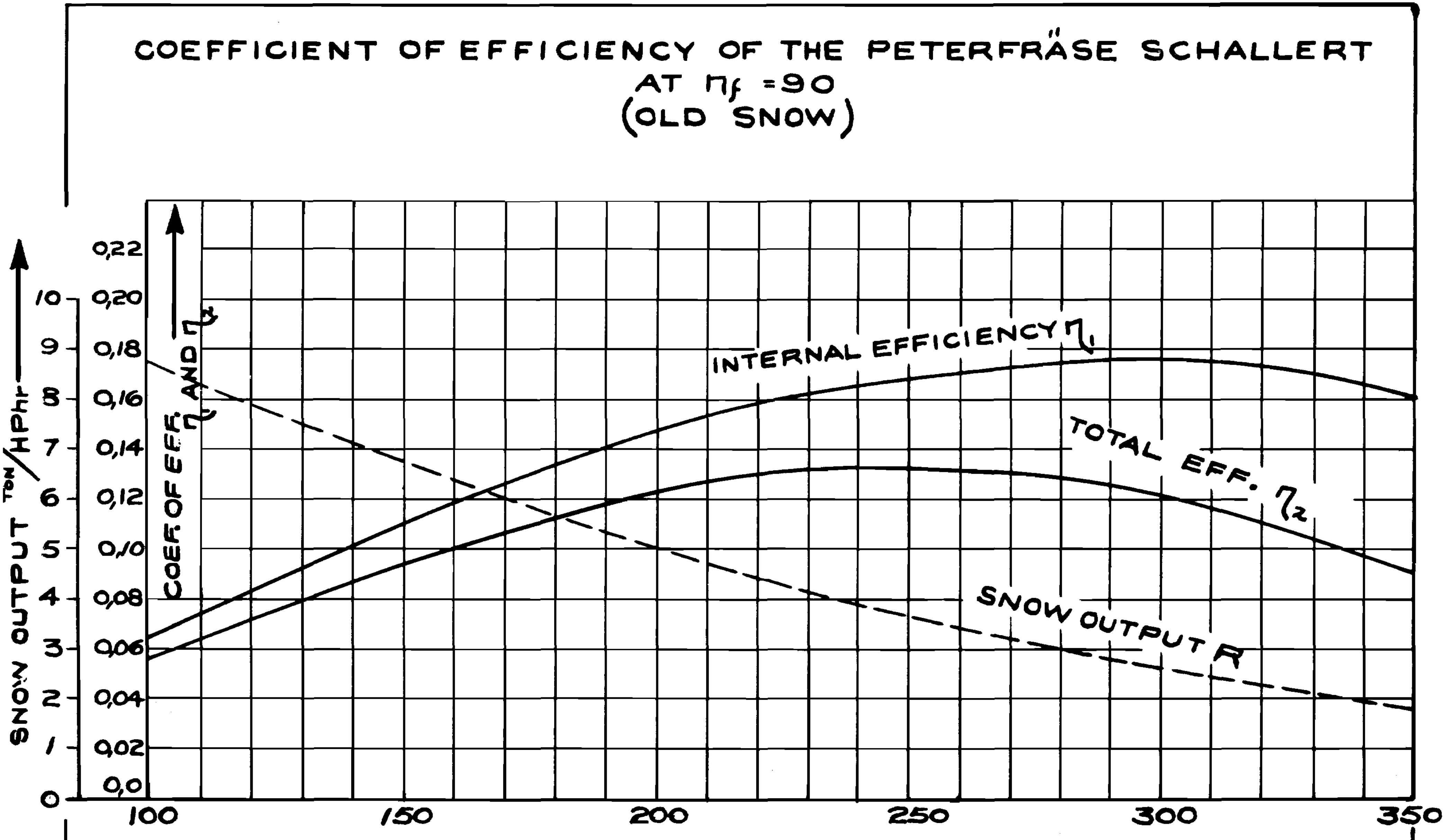

COEFFICIENT OF EFFICIENCY OF THE PETERFRÄSE SCHALLERT
AT η_f =90
(OLD SNOW)
SNOW OUTPUT TON/HPhr
COEF. OF EFF. η_1 AND η_2
INTERNAL EFFICIENCY η_1
TOTAL EFF. η_2
SNOW OUTPUT R
0,22
0,20
0,18
0,16
0,14
0,12
0,10
0,08
0,06
0,04
0,02
0,0
10
9
8
7
6
5
4
3
2
1
0
100
150
200
250
300
350

FIG. 31

COEFFICIENT OF EFFICIENCY OF THE DEP AND BER BLOWERS

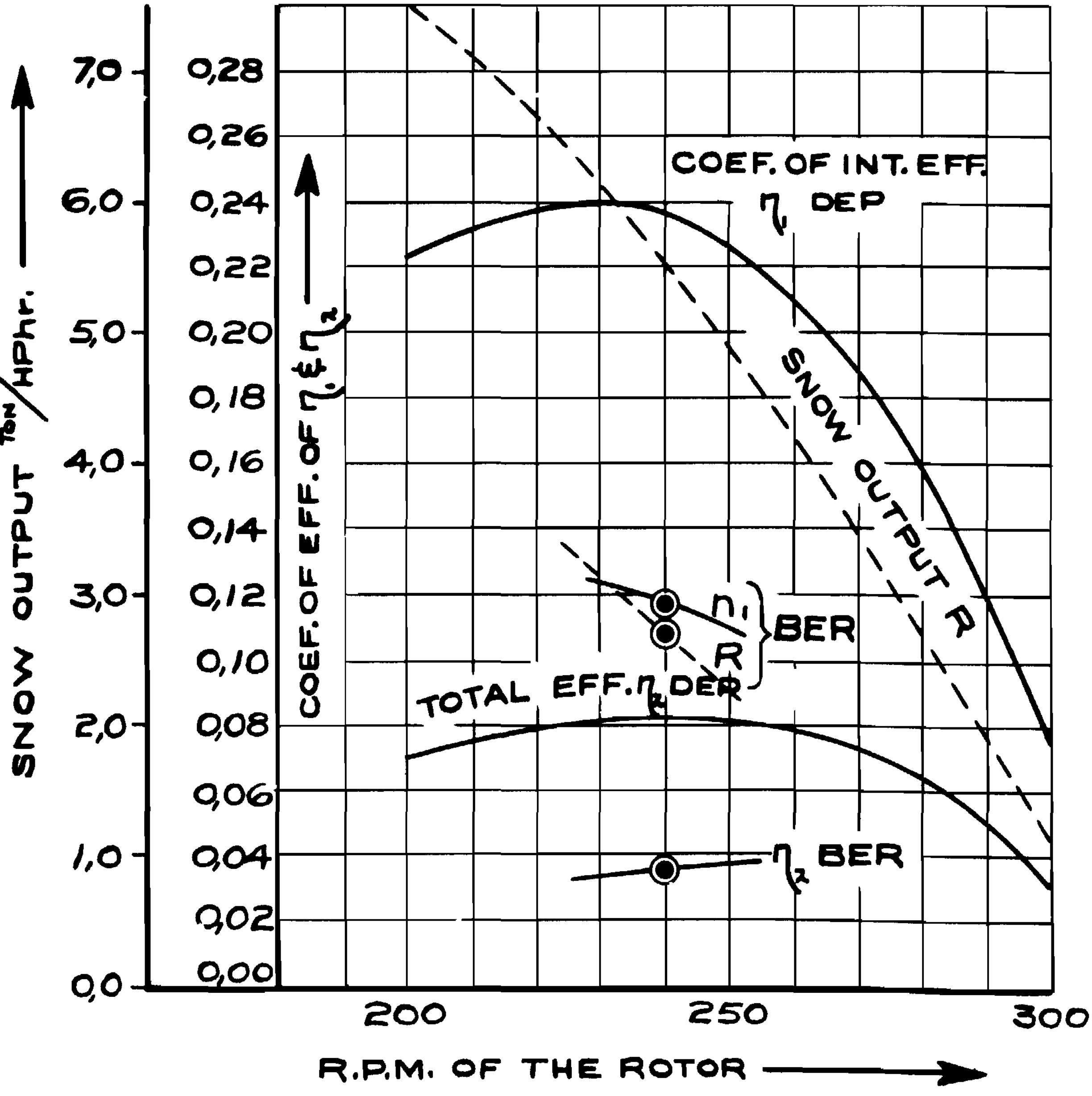


FIG. 32

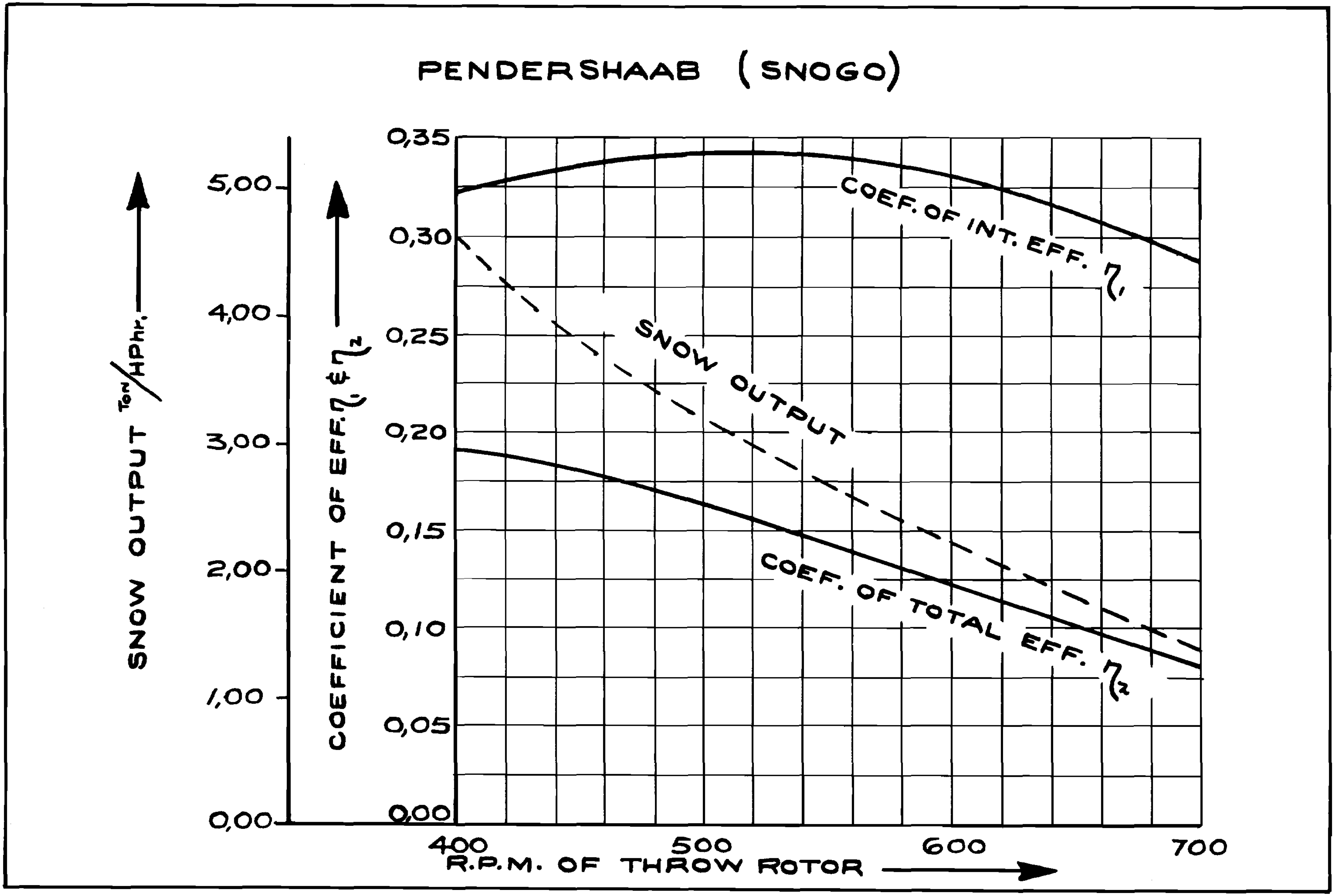
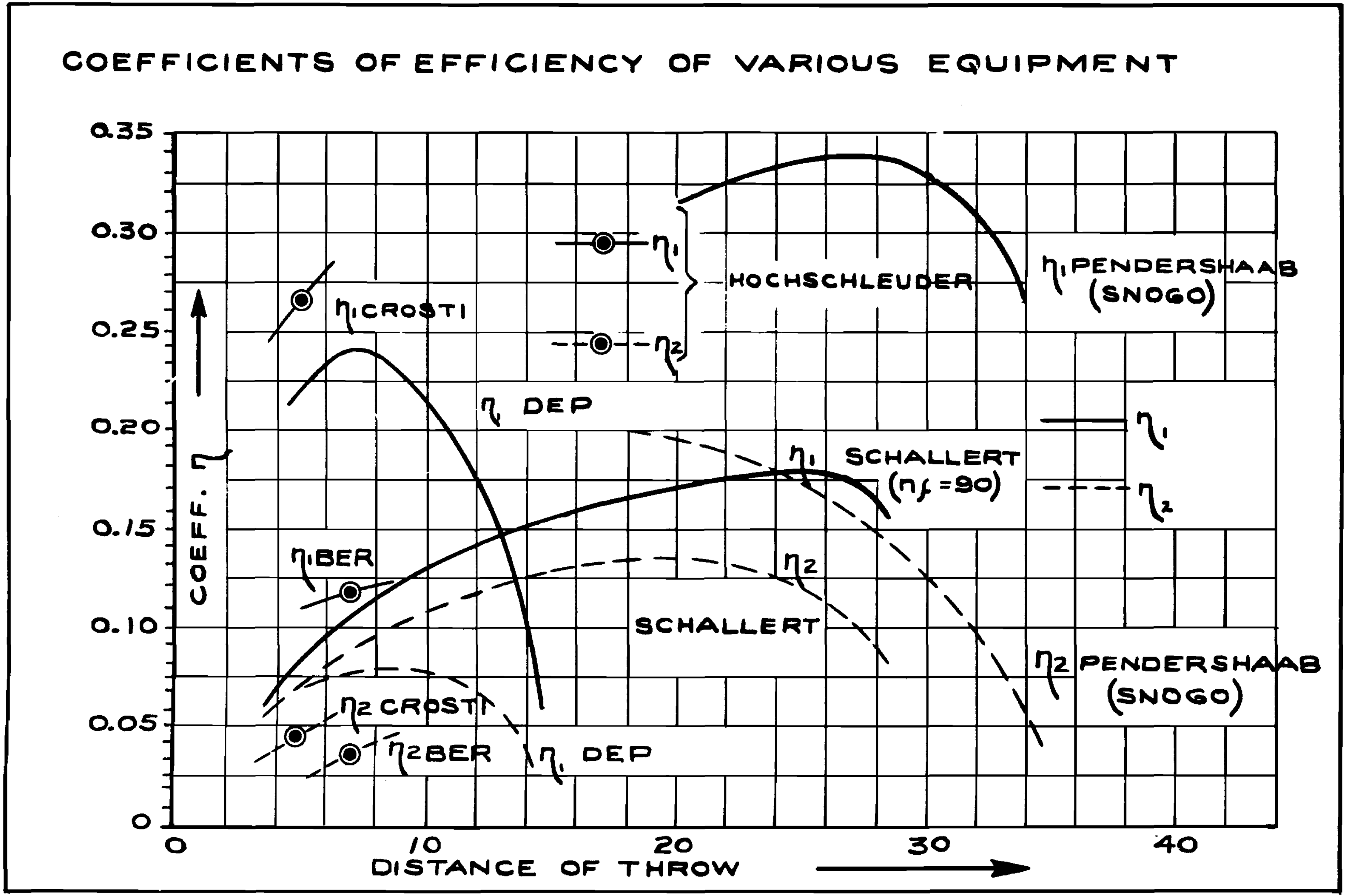

PENDERSHAAB (SNOGO)
SNOW OUTPUT Ton/HPhr.
5,00
4,00
3,00
2,00
1,00
0,00
COEFFICIENT OF EFF. η1 & η2
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0,00
COEF. OF INT. EFF. η1
SNOW OUTPUT
COEF. OF TOTAL EFF. η2
400
500
600
700
R.P.M. OF THROW ROTOR

FIG. 33



COEFFICIENTS OF EFFICIENCY OF VARIOUS EQUIPMENT
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
0
10
20
30
40
DISTANCE OF THROW
COEFF. η
η1
η2
HOCHSCHLEUDER
η1 PENDERSHAAB (SNOGO)
η1 CROSTI
η1 DEP
η1
η2
η1 SCHALLERT (nf =90)
η1 BER
η2
SCHALLERT
η2 PENDERSHAAB (SNOGO)
η2 CROSTI
η2 BER
η1 DEP

FIG. 34

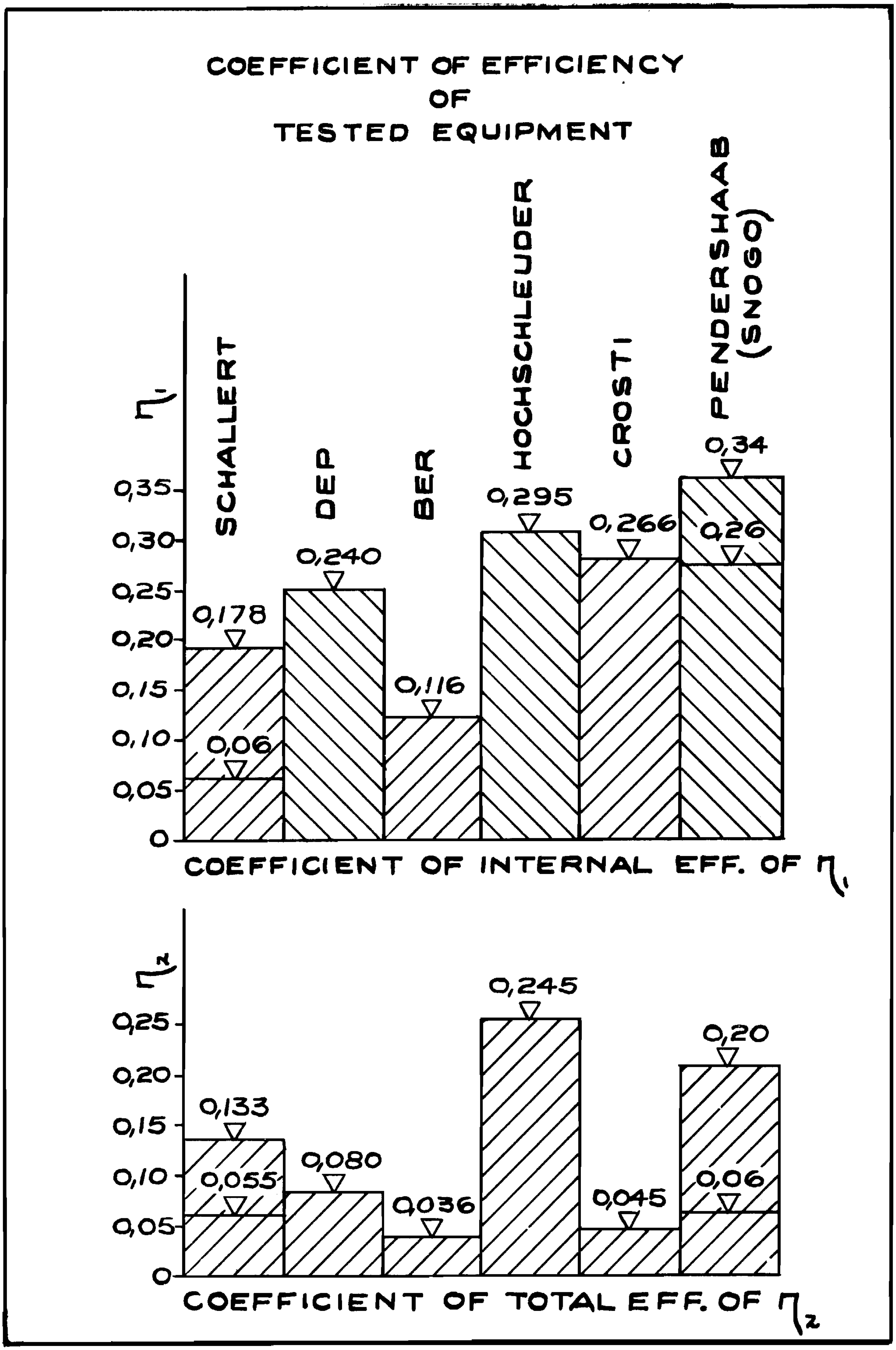

COEFFICIENT OF EFFICIENCY
OF
TESTED EQUIPMENT
SCHALLERT
DEP
BER
HOCHSCHLEUDER
CROSTI
PENDERSHAAB (SNOGO)
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0
0,178
0,06
0,240
0,116
0,295
0,266
0,34
0,26
COEFFICIENT OF INTERNAL EFF. OF η_1
0,25
0,20
0,15
0,10
0,05
0
0,133
0,055
0,080
0,036
0,245
0,045
0,20
0,06
COEFFICIENT OF TOTAL EFF. OF η_2

FIG.35

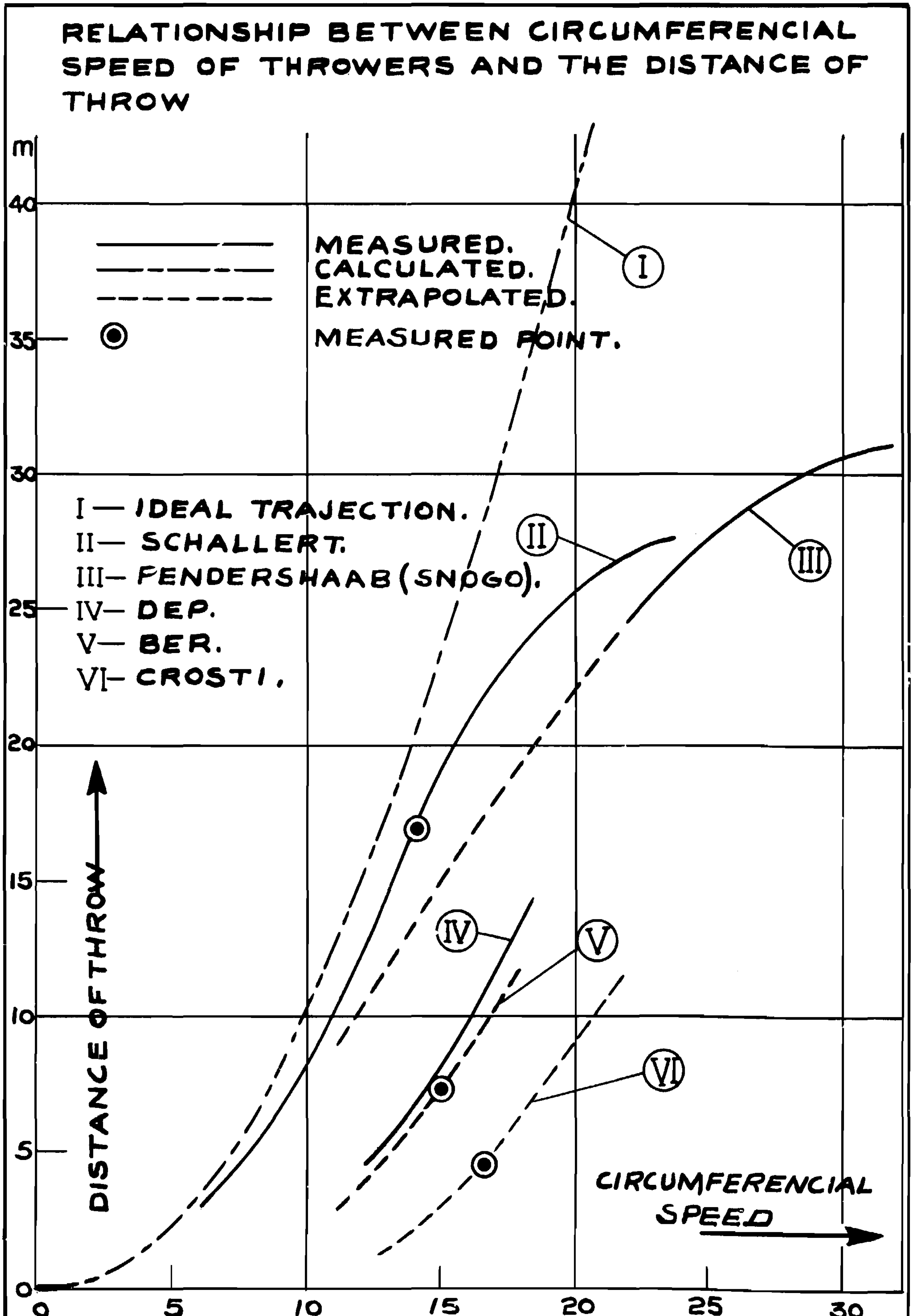
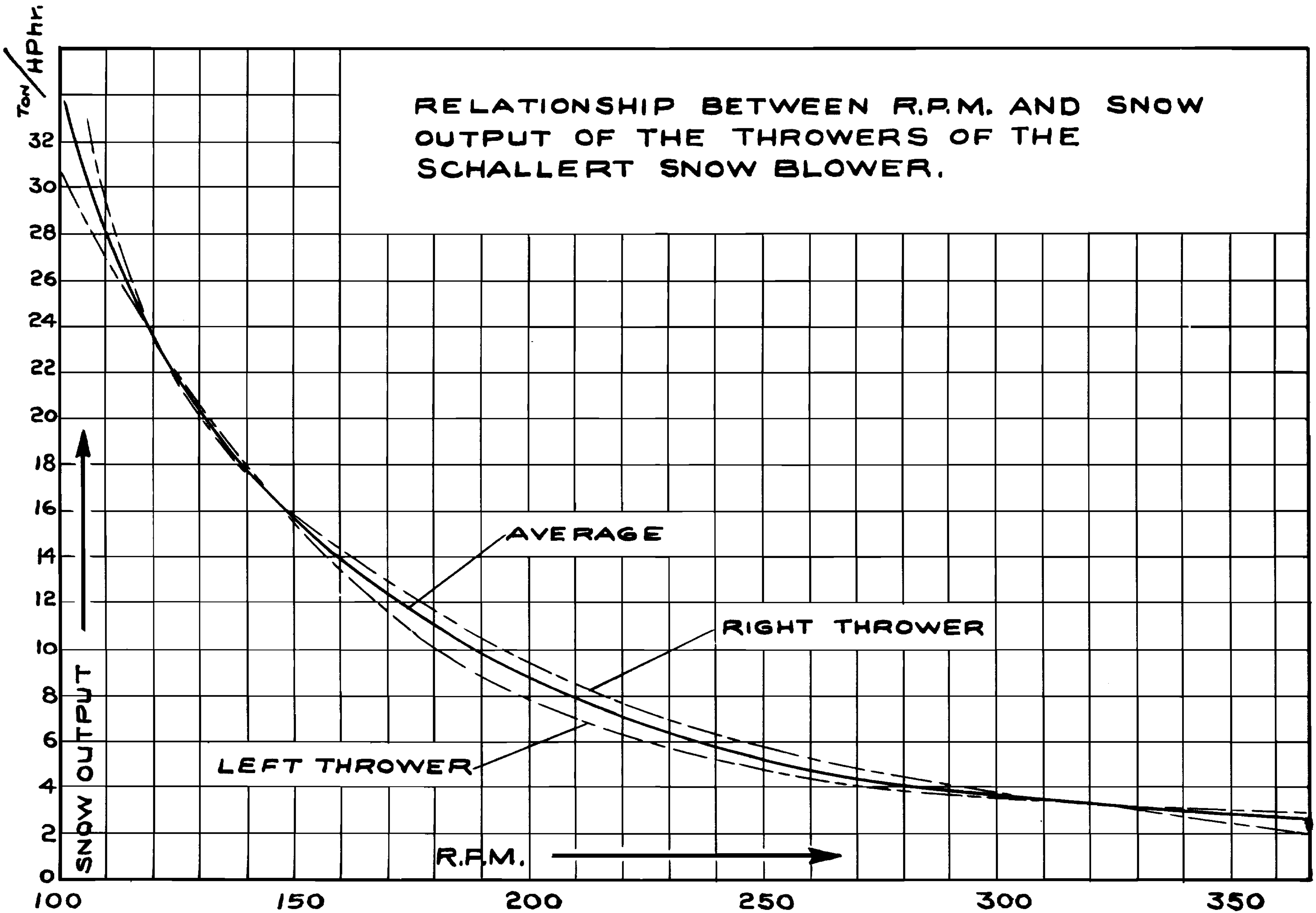

RELATIONSHIP BETWEEN CIRCUMFERENCIAL SPEED OF THROWERS AND THE DISTANCE OF THROW
MEASURED.
CALCULATED.
EXTRAPOLATED.
MEASURED POINT.
I — IDEAL TRAJECTION.
II — SCHALLERT.
III — FENDERSHAAB (SNOGO).
IV — DEP.
V — BER.
VI — CROSTI.
m
40
35
30
25
20
15
10
5
0
DISTANCE OF THROW
CIRCUMFERENCIAL SPEED
0
5
10
15
20
25
30
m/sec.
I
II
III
IV
V
VI

FIG. 36



RELATIONSHIP BETWEEN R.P.M. AND SNOW OUTPUT OF THE THROWERS OF THE SCHALLERT SNOW BLOWER.
Ton/HP hr.
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
SNOW OUTPUT
AVERAGE
RIGHT THROWER
LEFT THROWER
R.P.M.
100
150
200
250
300
350

FIG. 37

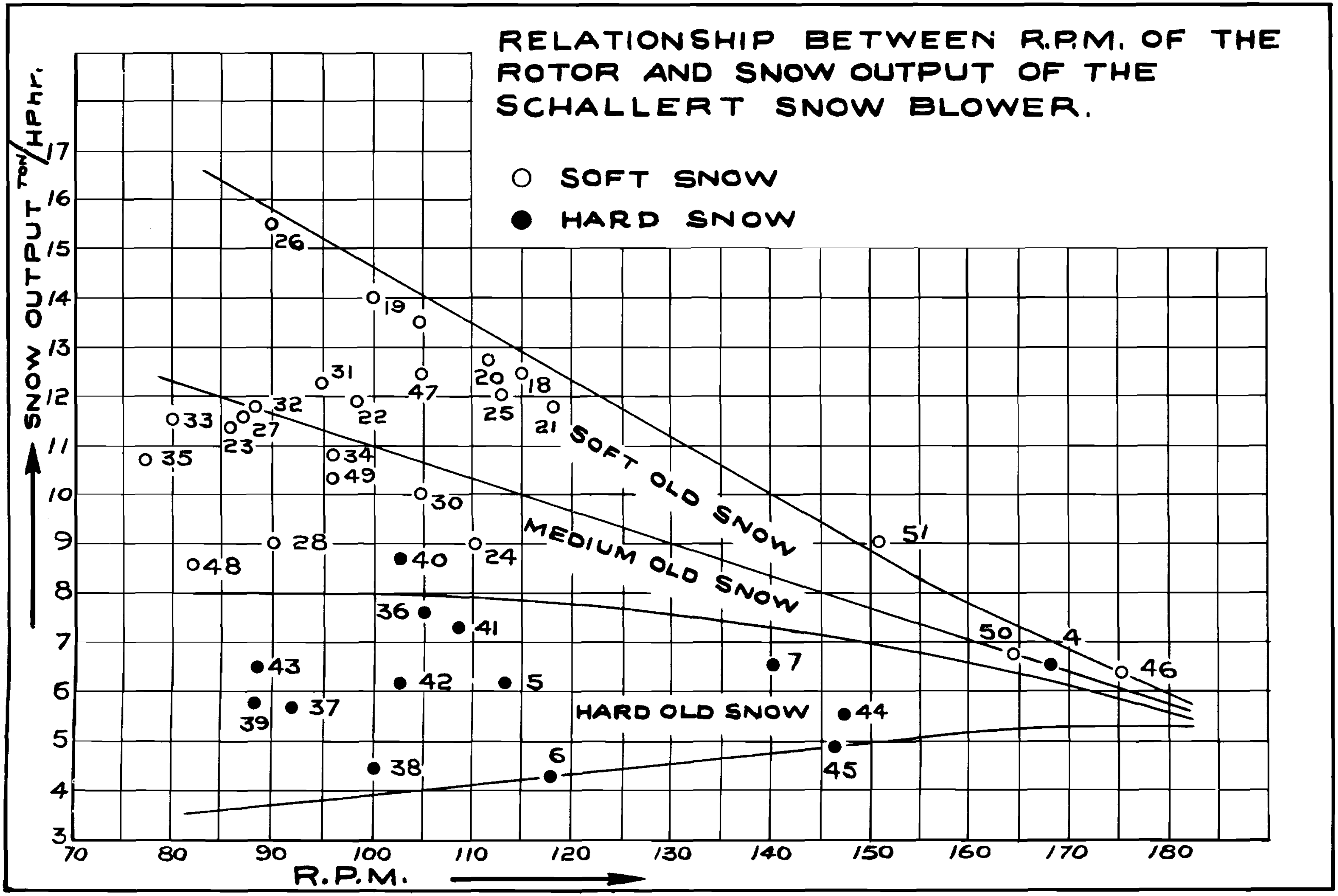
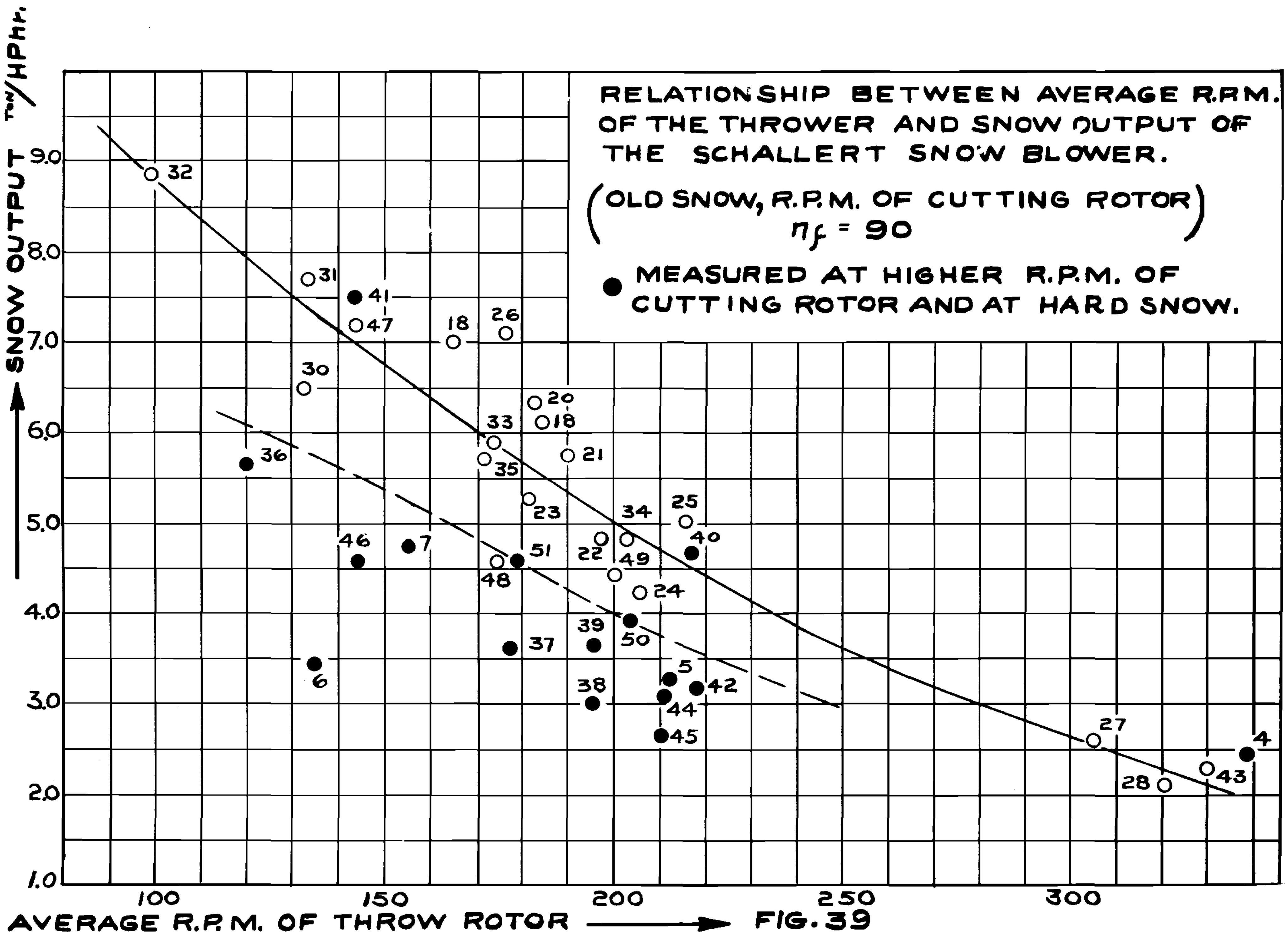

RELATIONSHIP BETWEEN R.P.M. OF THE ROTOR AND SNOW OUTPUT OF THE SCHALLERT SNOW BLOWER.
SOFT SNOW
HARD SNOW
SOFT OLD SNOW
MEDIUM OLD SNOW
HARD OLD SNOW
SNOW OUTPUT TON/HP hr.
R.P.M.

FIG. 38



RELATIONSHIP BETWEEN AVERAGE R.P.M. OF THE THROWER AND SNOW OUTPUT OF THE SCHALLERT SNOW BLOWER.
(OLD SNOW, R.P.M. OF CUTTING ROTOR n_f = 90)
MEASURED AT HIGHER R.P.M. OF CUTTING ROTOR AND AT HARD SNOW.
SNOW OUTPUT Ton/HPhr.
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
100
150
200
250
300
AVERAGE R.P.M. OF THROW ROTOR
32
31
41
47
18
26
30
20
18
33
21
36
35
23
34
25
46
7
51
22
40
48
49
24
39
50
37
6
5
42
38
44
45
27
4
43
28

FIG. 39

RELATIONSHIP BETWEEN R.P.M. OF THE THROWING ROTOR AND THE SNOW OUTPUT OF THE PENDERSHAAB (SNOGO) BLOWER.

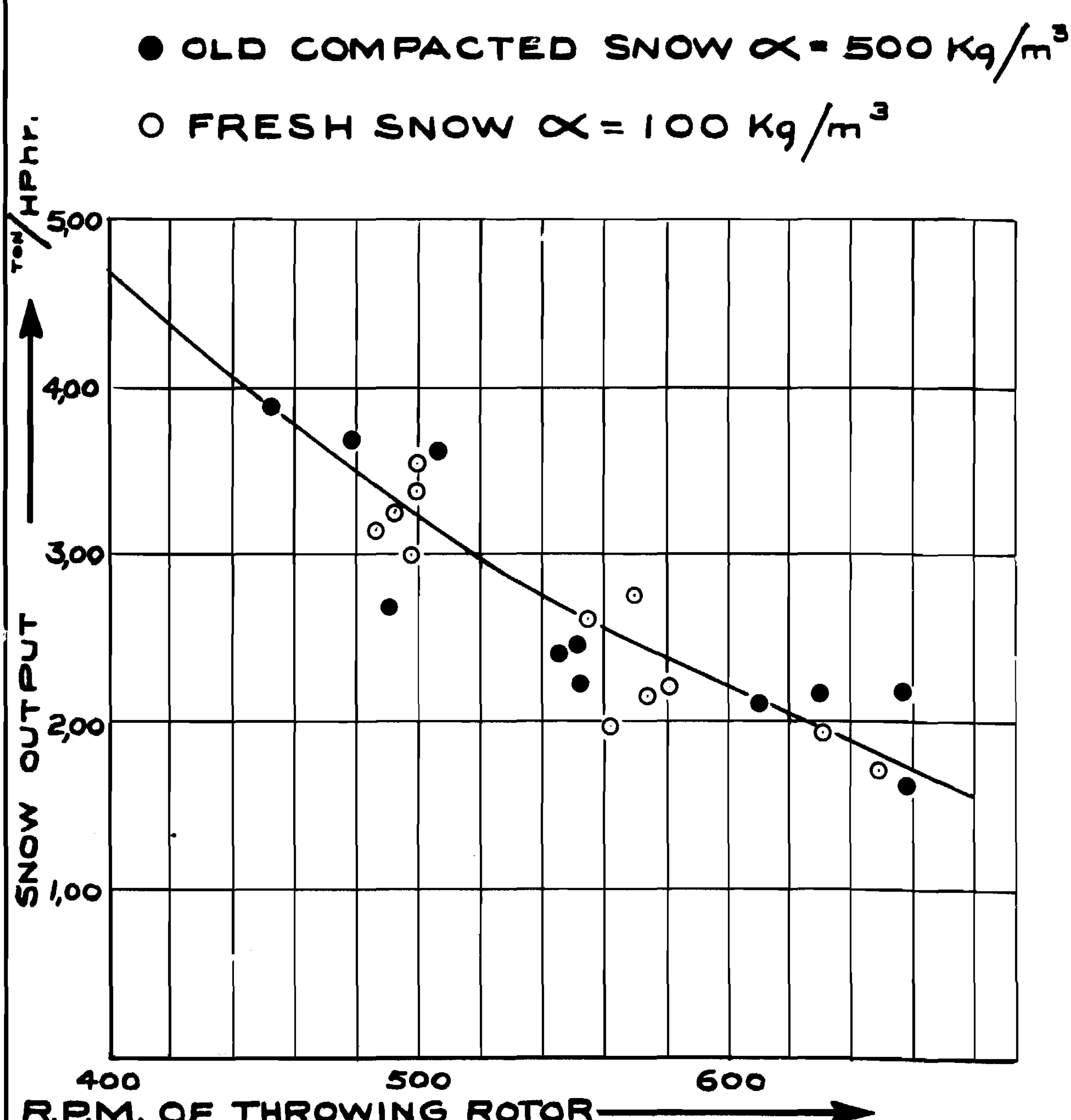


FIG.40

RELATIONSHIP BETWEEN R.P.M. OF THE CUTTING ROTOR AND SNOW OUTPUT OF THE DEP SNOW BLOWER.

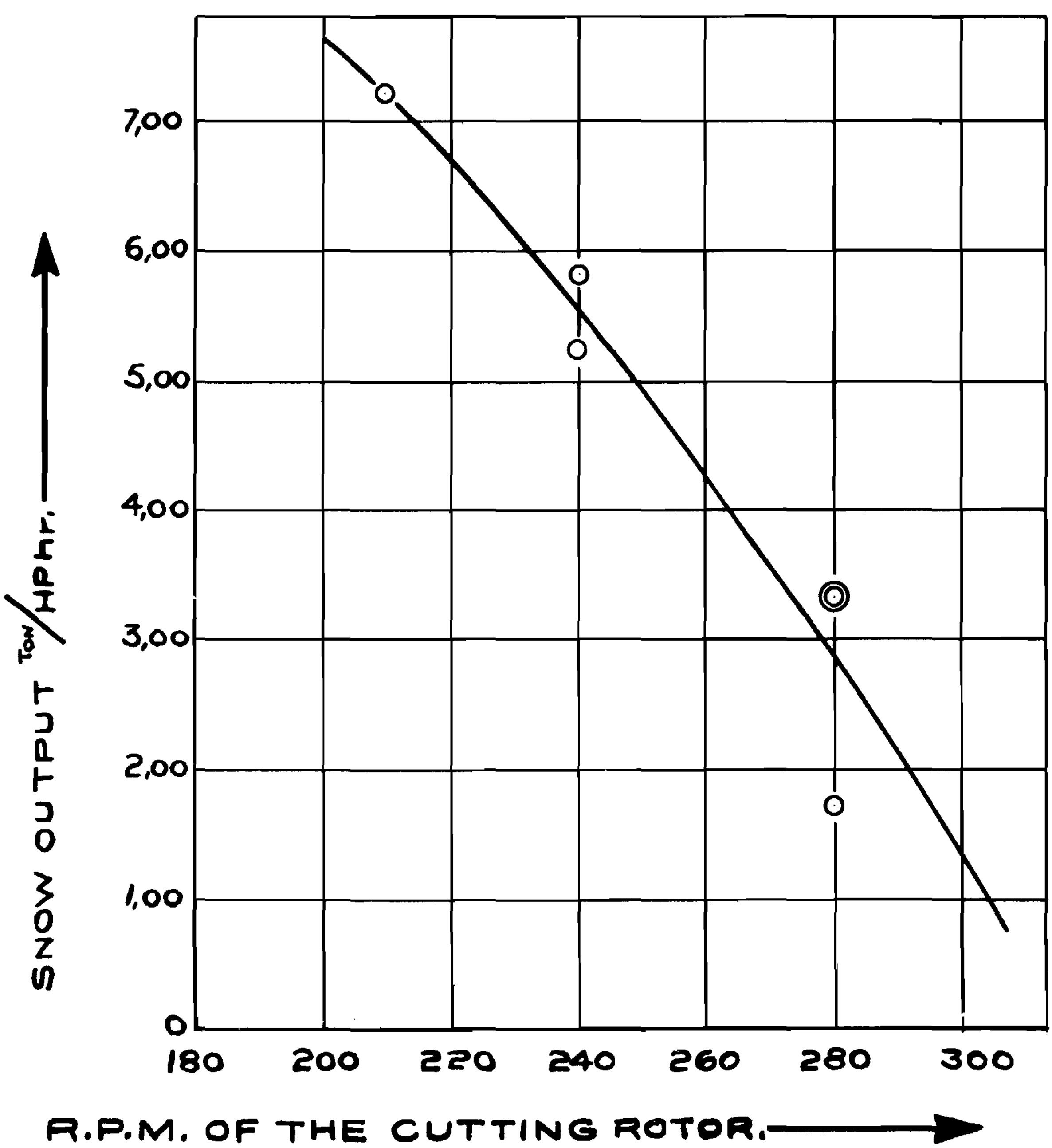


FIG. 41

RELATIONSHIP BETWEEN DISTANCE OF THROW AND SNOW OUTPUT OF VARIOUS EQUIPMENT.

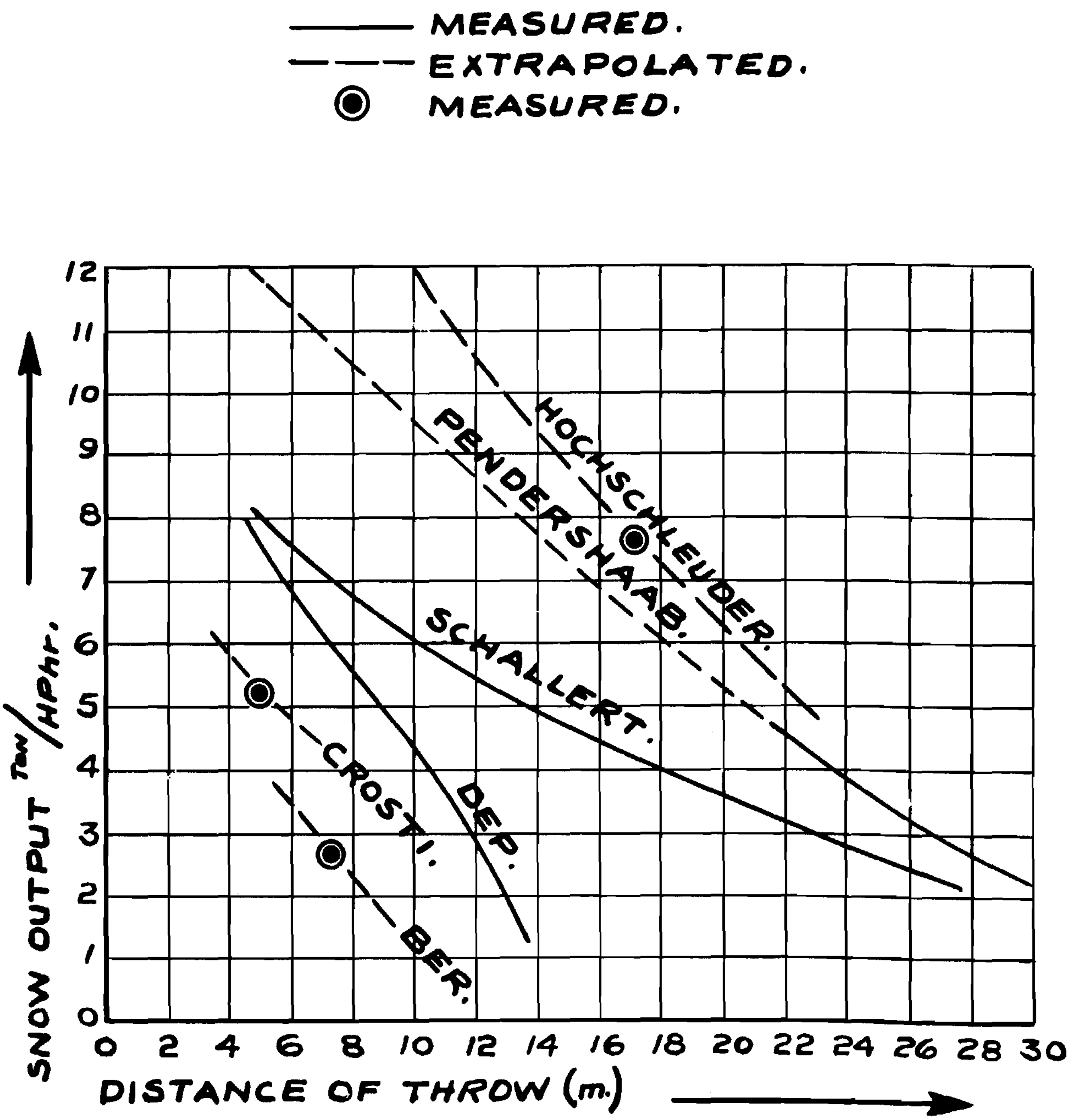


FIG. 42

AMOUNT OF REMOVABLE SNOW FOR DEP SNOW BLOWER WITH VARIOUS KINDS OF SNOW AND DISTANCES OF THROWER.

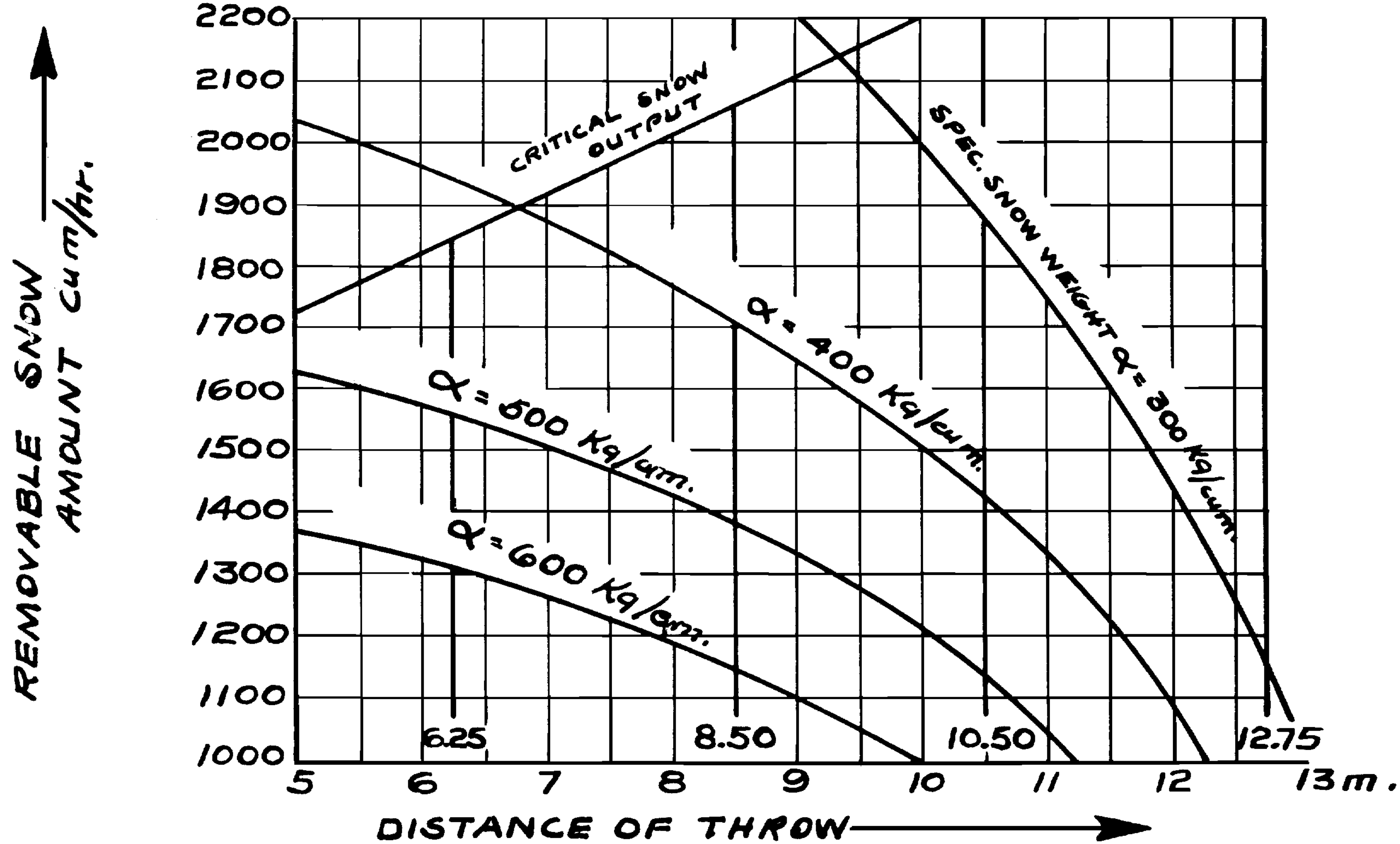


FIG. 43

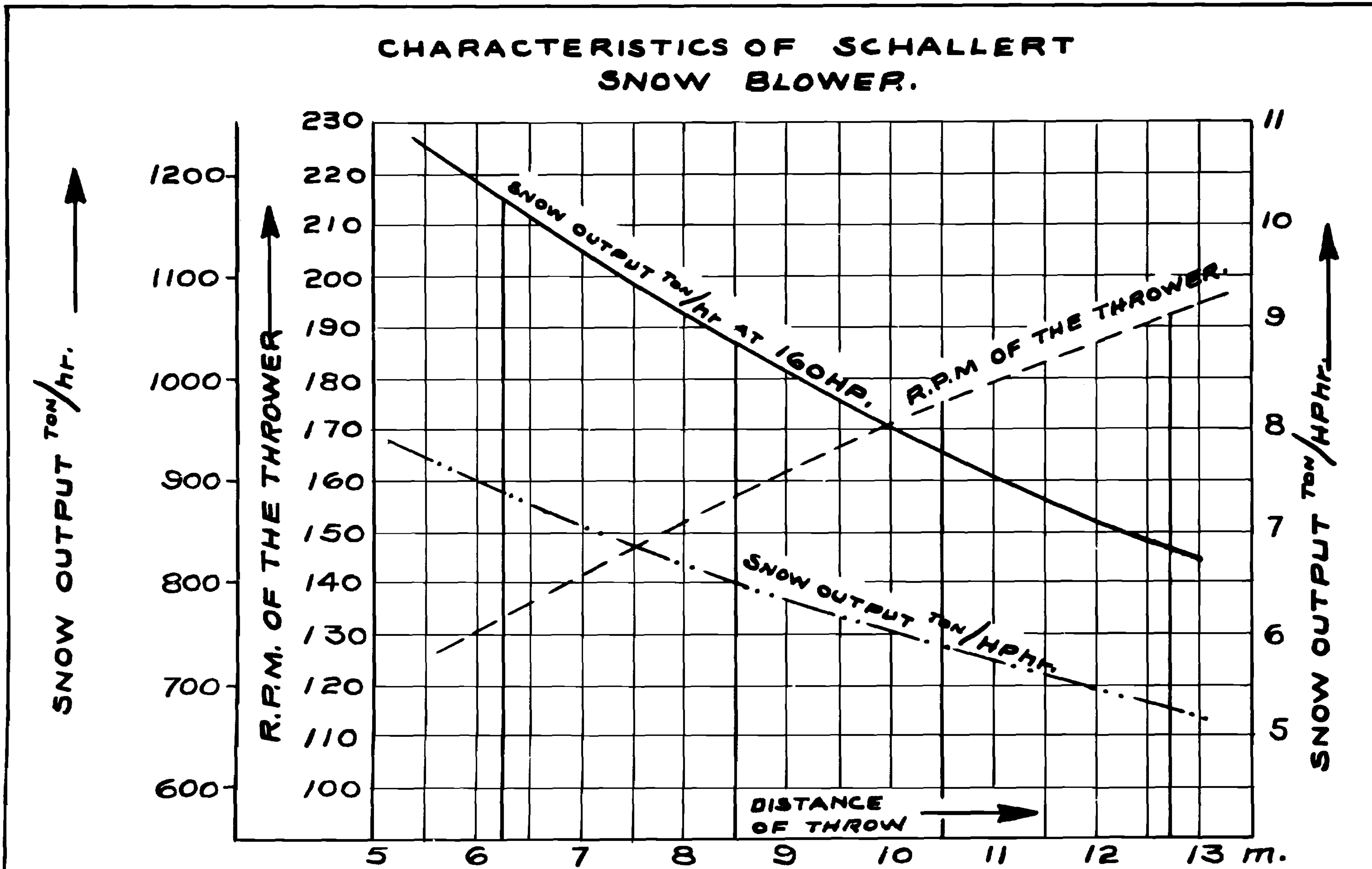
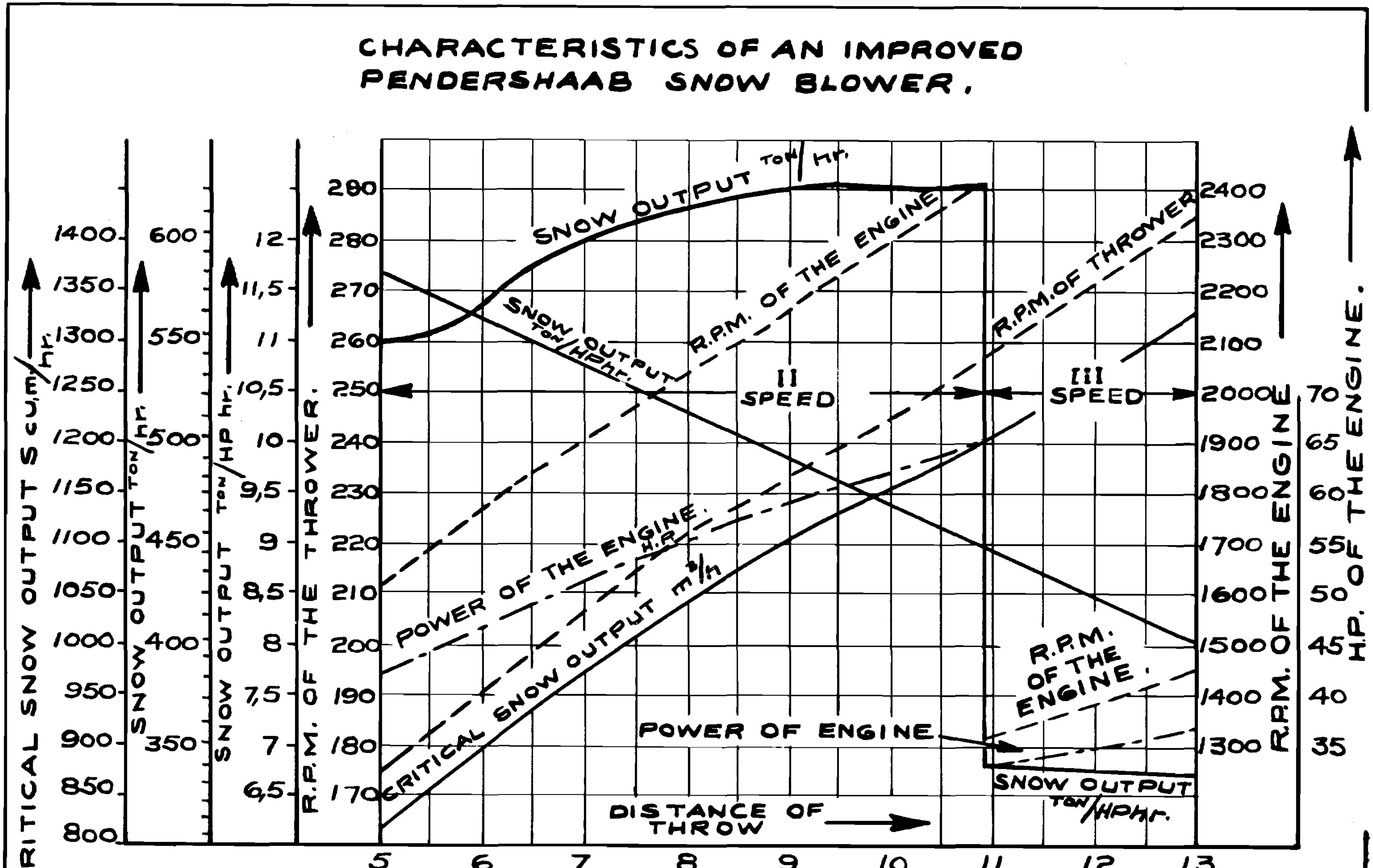
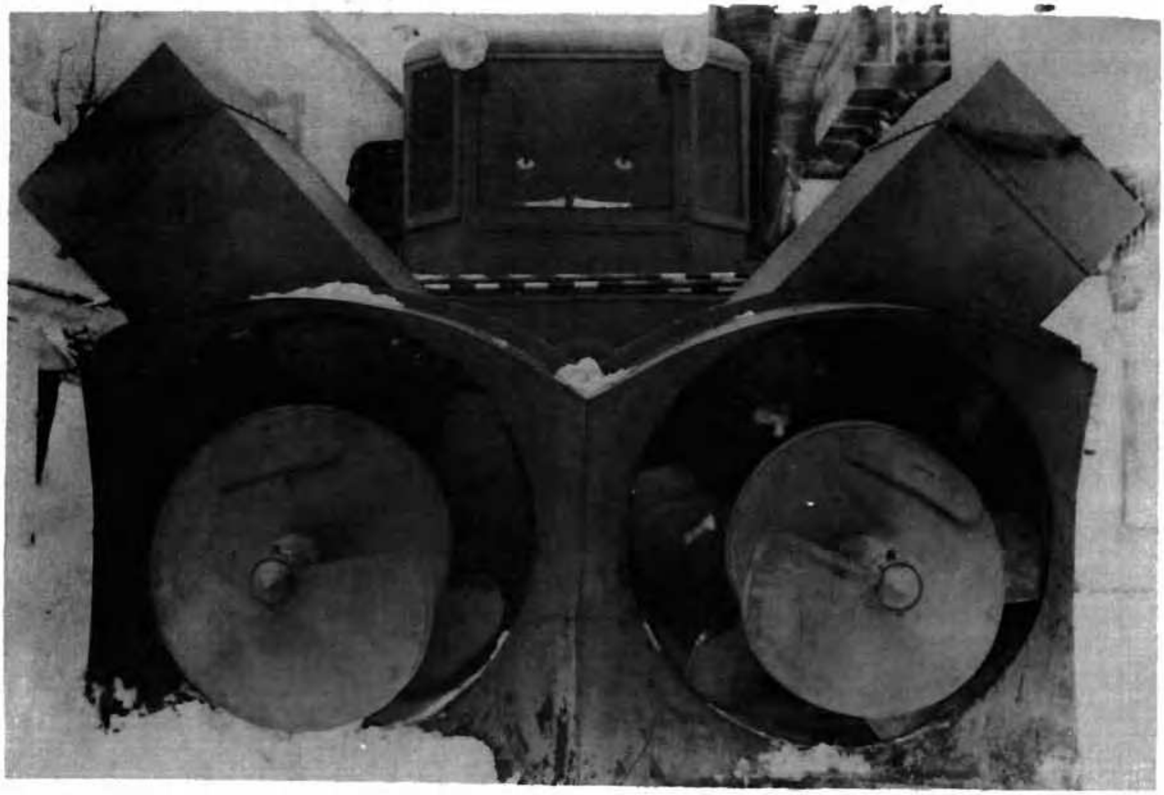
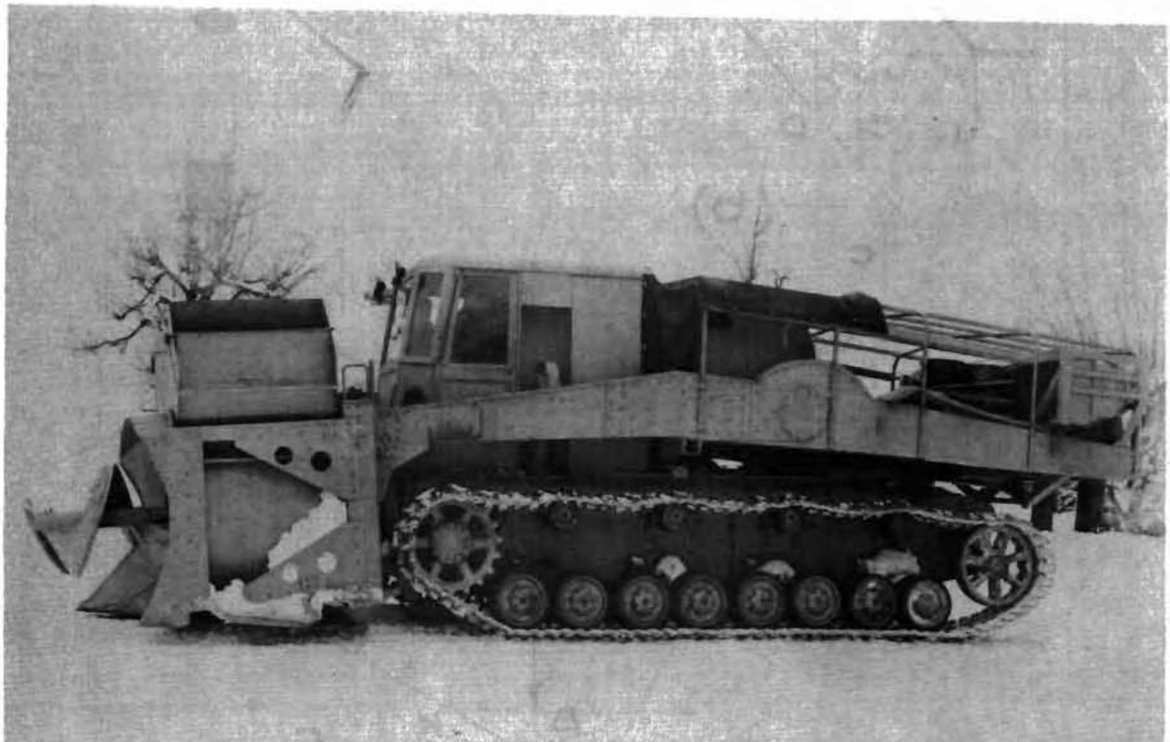

CHARACTERISTICS OF SCHALLERT SNOW BLOWER.
SNOW OUTPUT TON/hr.
R.P.M. OF THE THROWER
SNOW OUTPUT TON/HPhr.
1200
1100
1000
900
800
700
600
230
220
210
200
190
180
170
160
150
140
130
120
110
100
11
10
9
8
7
6
5
SNOW OUTPUT TON/hr AT 160HP.
R.P.M OF THE THROWER.
SNOW OUTPUT TON/HPhr.
DISTANCE OF THROW
5
6
7
8
9
10
11
12
13 m.

FIG. 44

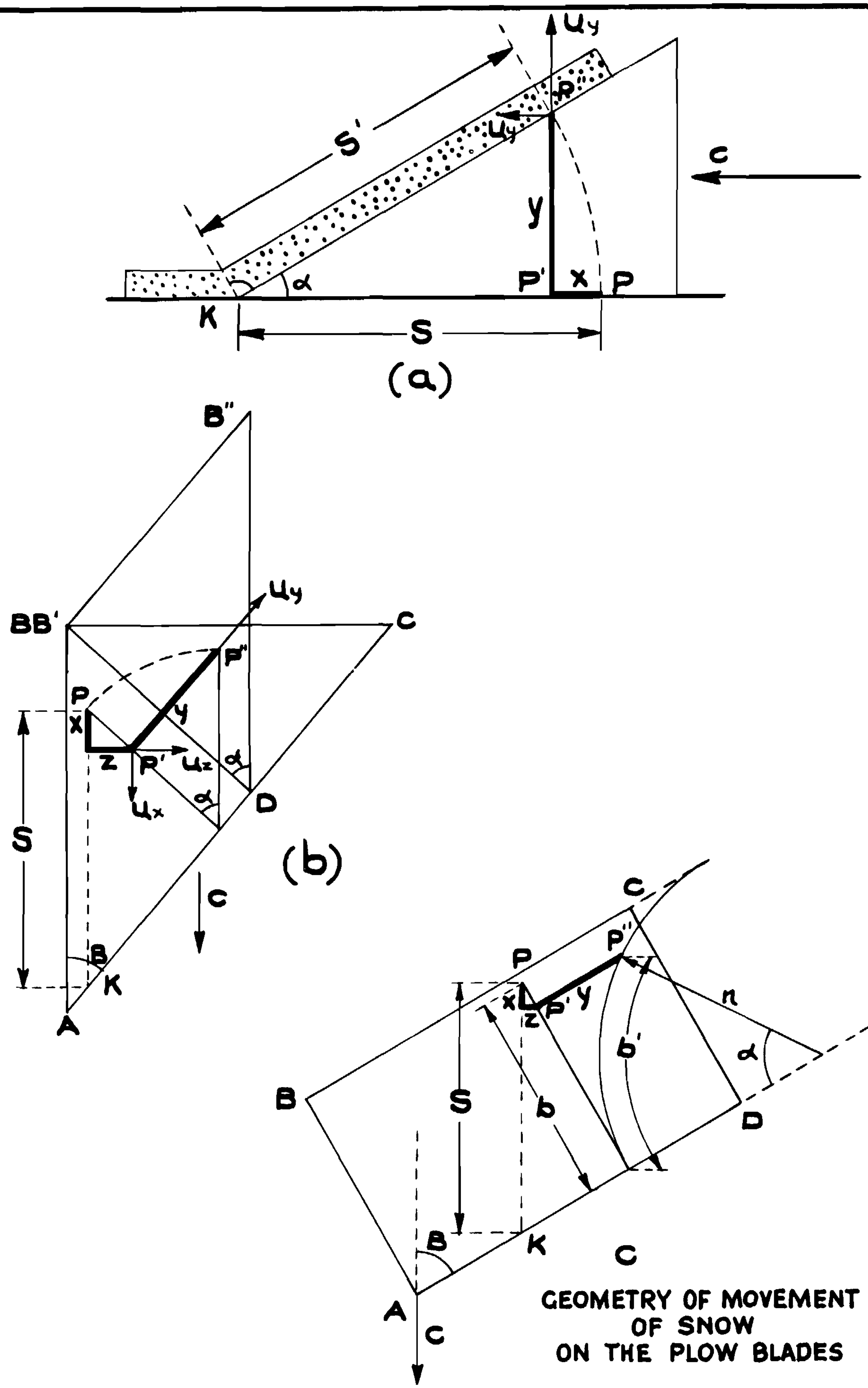

CHARACTERISTICS OF AN IMPROVED PENDERSHAAB SNOW BLOWER.
SNOW OUTPUT TON/Hr.
SNOW OUTPUT TON/HP hr.
R.P.M. OF THE ENGINE
R.P.M. OF THROWER
II SPEED
III SPEED
POWER OF THE ENGINE. H.P.
CRITICAL SNOW OUTPUT m³/h
R.P.M. OF THE ENGINE.
POWER OF ENGINE
SNOW OUTPUT TON/HPhr.
DISTANCE OF THROW
CRITICAL SNOW OUTPUT S cu.m/hr.
SNOW OUTPUT TON/hr.
SNOW OUTPUT TON/HP hr.
R.P.M. OF THE THROWER.
R.P.M. OF THE ENGINE
H.P. OF THE ENGINE.
1400 1350 1300 1250 1200 1150 1100 1050 1000 950 900 850 800
600 550 500 450 400 350
12 11,5 11 10,5 10 9,5 9 8,5 8 7,5 7 6,5
290 280 270 260 250 240 230 220 210 200 190 180 170
2400 2300 2200 2100 2000 1900 1800 1700 1600 1500 1400 1300
70 65 60 55 50 45 40 35
5 6 7 8 9 10 11 12 13
FIG.45



1000 H.P. SNOW BLOWER
FIG. 46 a

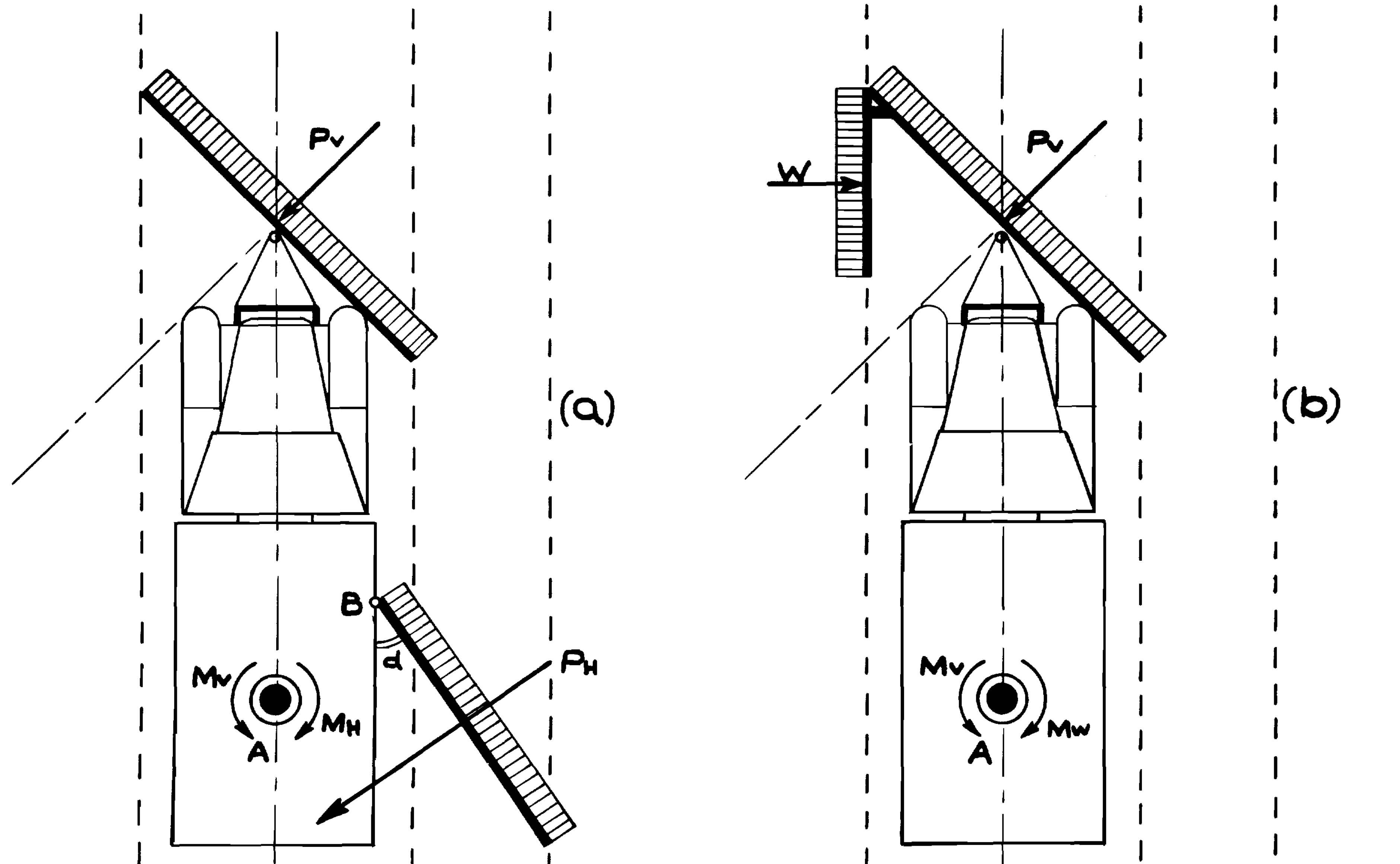


1000 H.P. SNOW BLOWER
FIG. 46 b

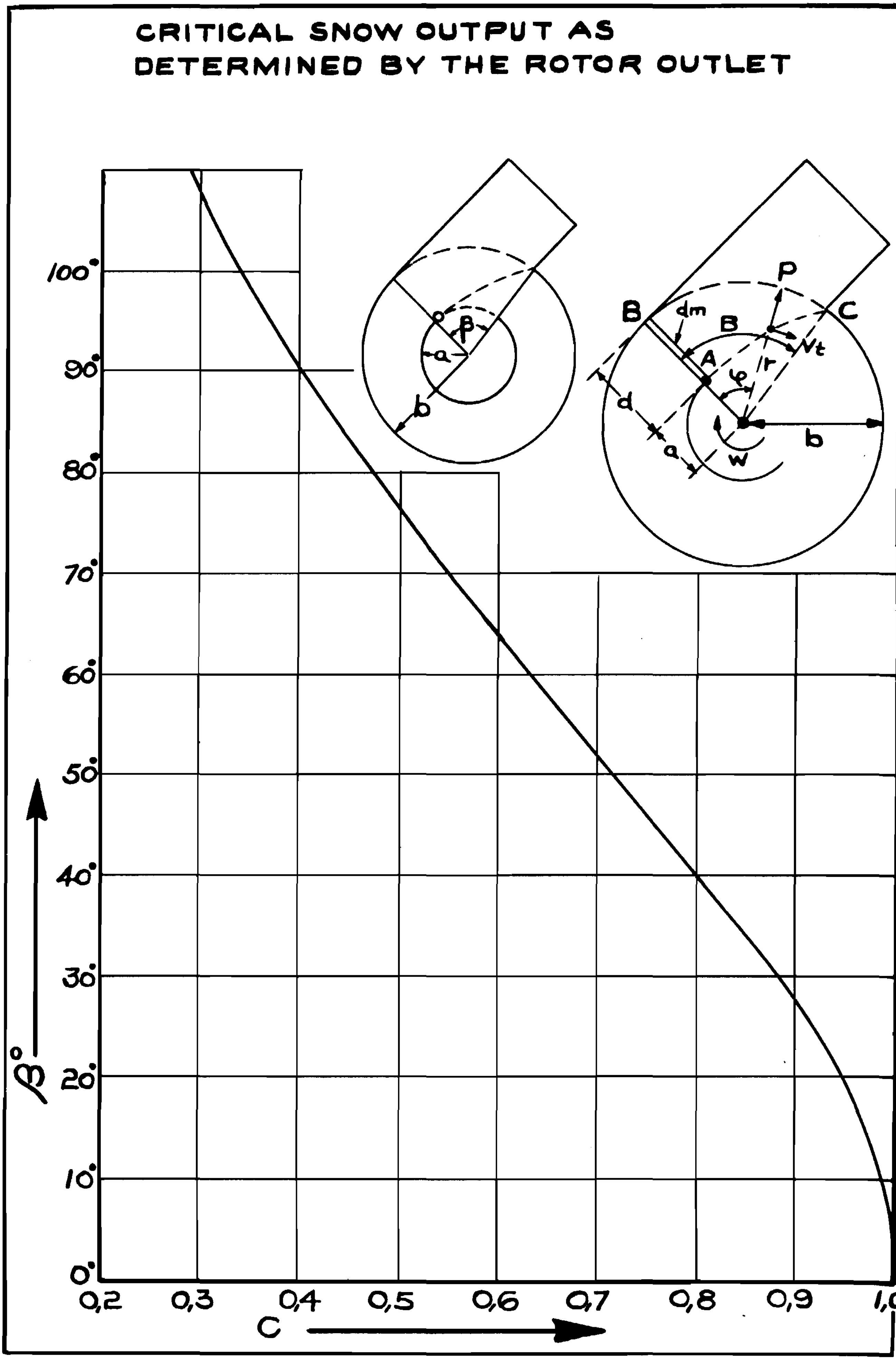


GEOMETRY OF MOVEMENT OF SNOW ON THE PLOW BLADES

FIG. 47

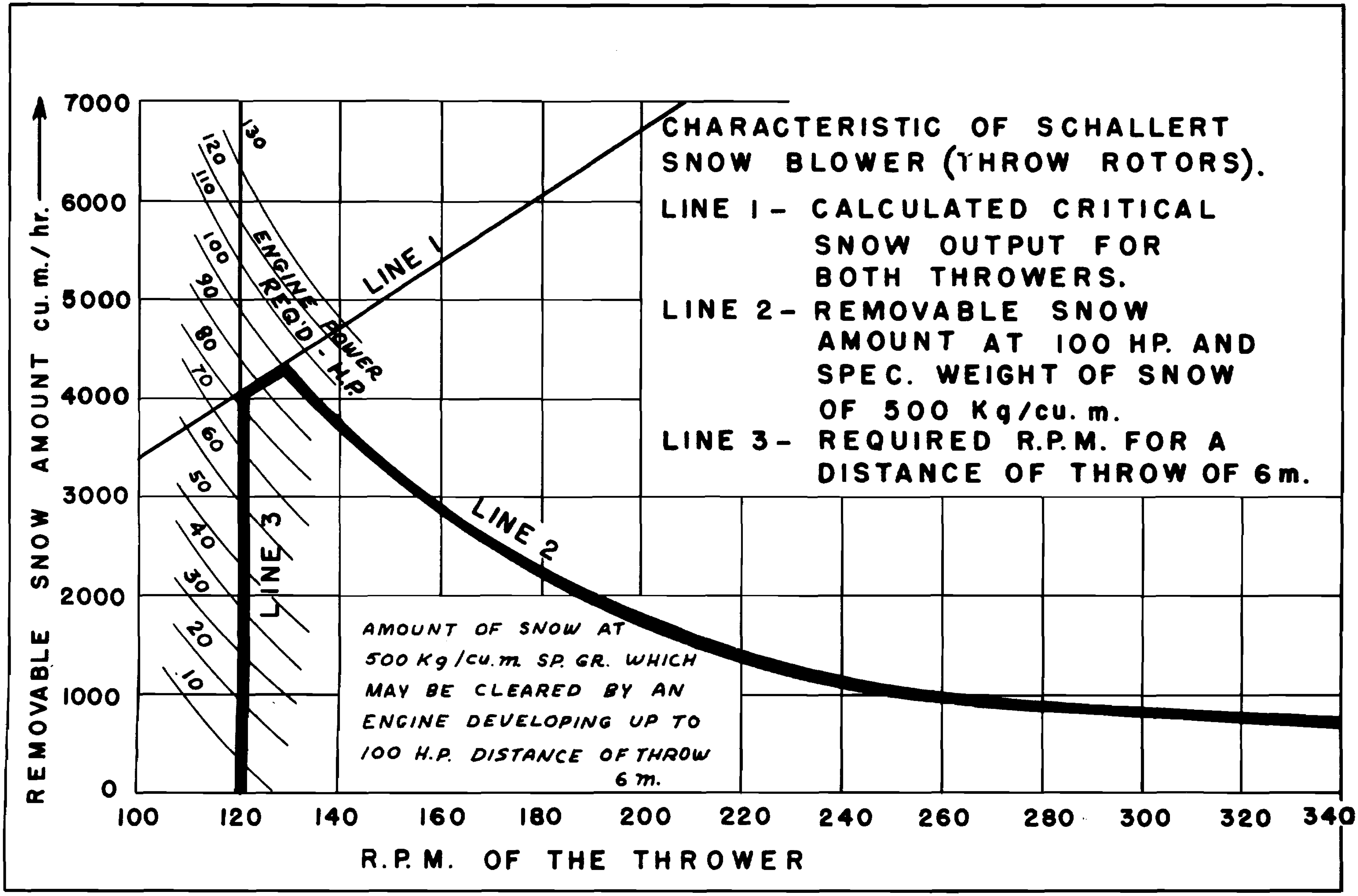


BALANCING THE PLOW MOMENTS
FIG. 48



CRITICAL SNOW OUTPUT AS DETERMINED BY THE ROTOR OUTLET
100°
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
β°
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
C
a
b
β
B
dm
B
P
C
A
φ
r
Vt
d
a
w
b

FIG. 49



CHARACTERISTIC OF SCHALLERT SNOW BLOWER (THROW ROTORS).
LINE 1 - CALCULATED CRITICAL SNOW OUTPUT FOR BOTH THROWERS.
LINE 2 - REMOVABLE SNOW AMOUNT AT 100 HP. AND SPEC. WEIGHT OF SNOW OF 500 Kg/cu. m.
LINE 3 - REQUIRED R.P.M. FOR A DISTANCE OF THROW OF 6 m.
AMOUNT OF SNOW AT 500 Kg/cu.m. SP. GR. WHICH MAY BE CLEARED BY AN ENGINE DEVELOPING UP TO 100 H.P. DISTANCE OF THROW 6 m.
ENGINE POWER REQ'D. - H.P.
LINE 1
LINE 2
LINE 3
130
120
110
100
90
80
70
60
50
40
30
20
10
REMOVABLE SNOW AMOUNT cu. m./hr.
7000
6000
5000
4000
3000
2000
1000
0
100
120
140
160
180
200
220
240
260
280
300
320
340
R.P.M. OF THE THROWER

FIG. 50

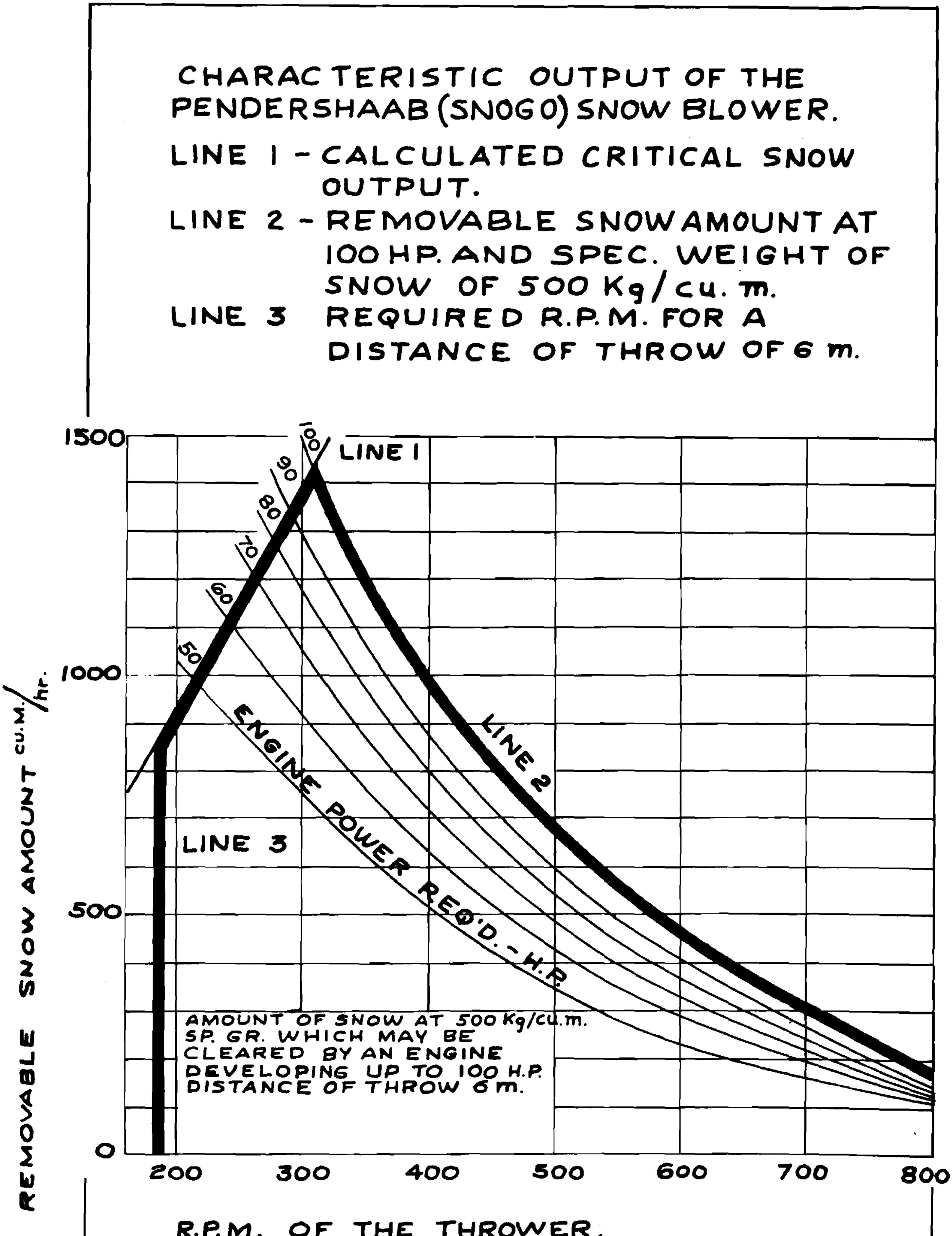

CHARACTERISTIC OUTPUT OF THE PENDERSHAAB (SNOGO) SNOW BLOWER.
LINE 1 - CALCULATED CRITICAL SNOW OUTPUT.
LINE 2 - REMOVABLE SNOW AMOUNT AT 100 HP. AND SPEC. WEIGHT OF SNOW OF 500 Kg/cu. m.
LINE 3 REQUIRED R.P.M. FOR A DISTANCE OF THROW OF 6 m.
1500
1000
500
0
100
90
80
70
60
50
LINE 1
LINE 2
LINE 3
ENGINE POWER REQ'D. - H.P.
AMOUNT OF SNOW AT 500 Kg/cu.m. SP. GR. WHICH MAY BE CLEARED BY AN ENGINE DEVELOPING UP TO 100 H.P. DISTANCE OF THROW 6 m.
REMOVABLE SNOW AMOUNT cu.M./hr.
200
300
400
500
600
700
800
R.P.M. OF THE THROWER.

FIG. 51

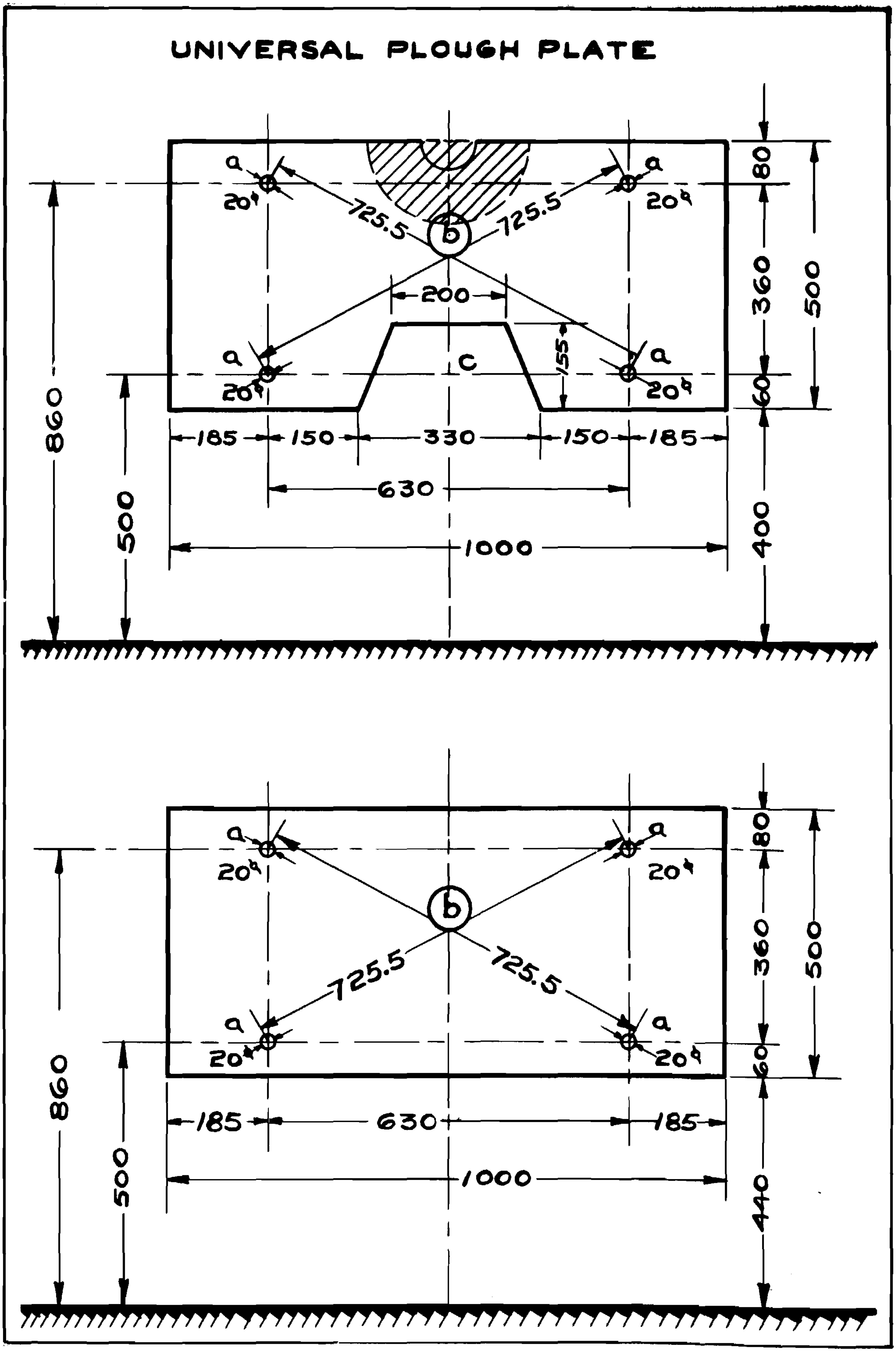
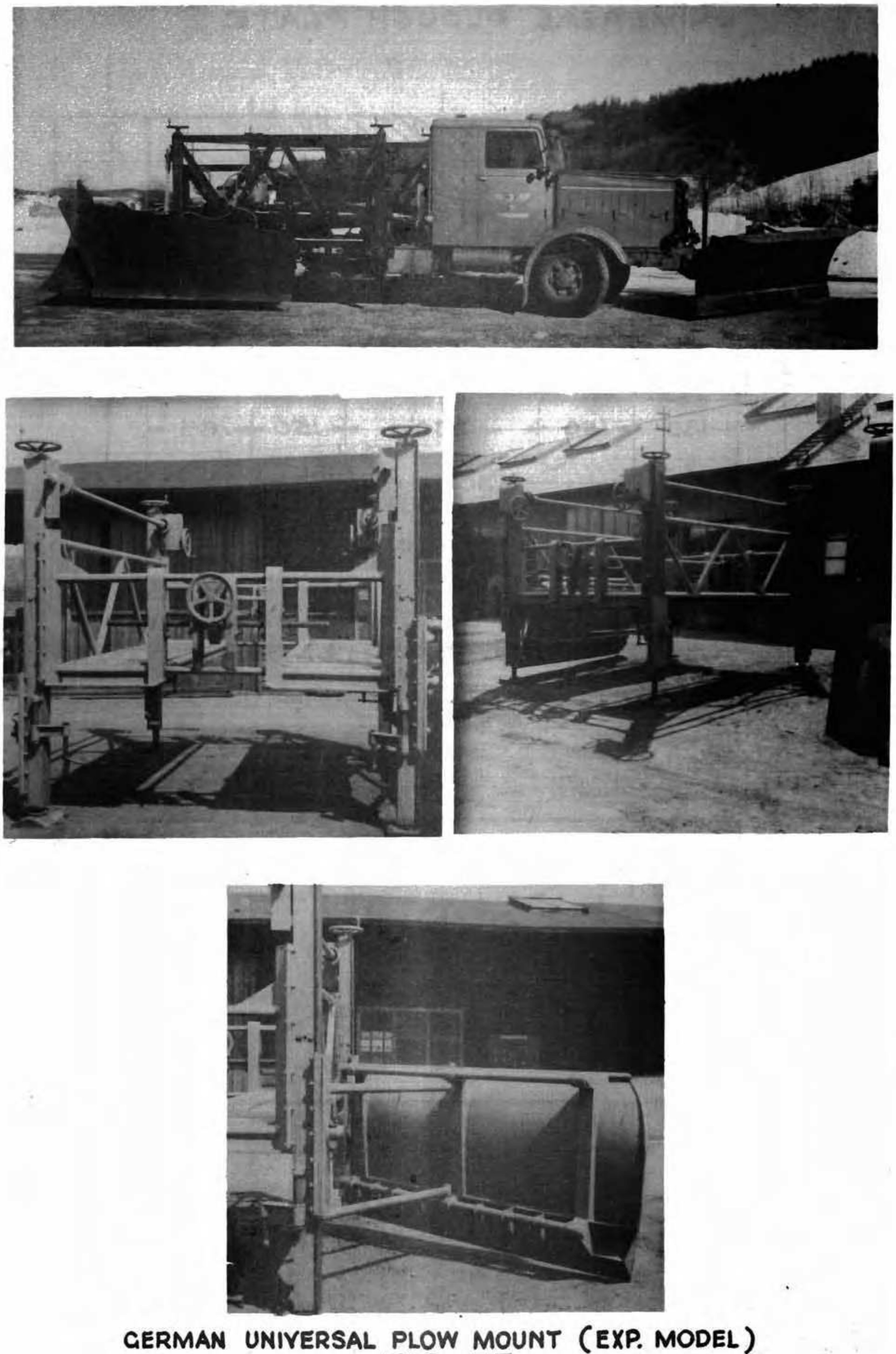

UNIVERSAL PLOUGH PLATE
a
20ᶲ
725.5
b
200
155
c
80
360
500
60
860
500
400
185
150
330
150
185
630
1000
440

FIG. 52



GERMAN UNIVERSAL PLOW MOUNT (EXP. MODEL)
FIG. 53

UNIVERSAL PLOUGH MOUNT

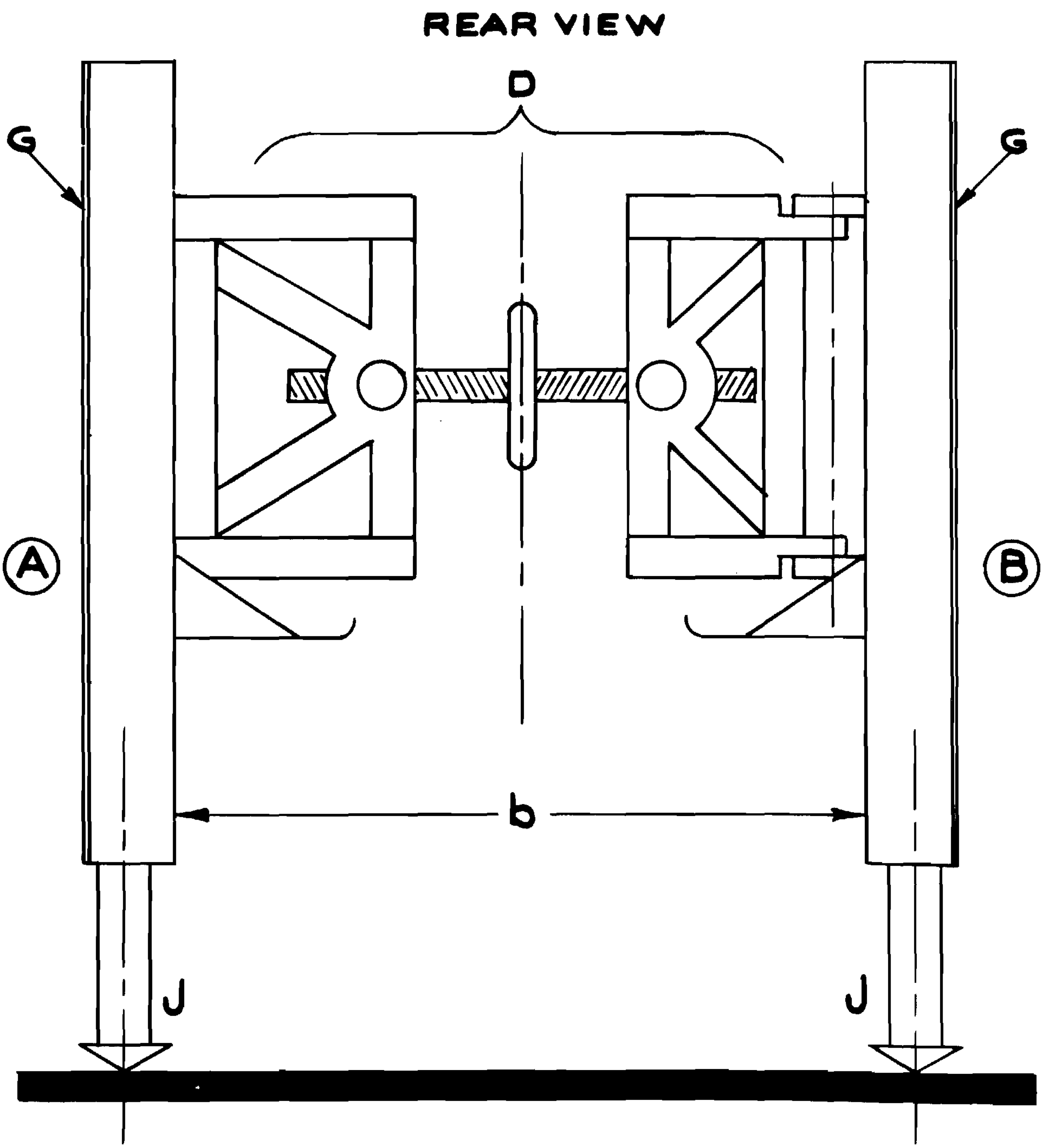


FIG. 54

UNIVERSAL PLOUGH MOUNT

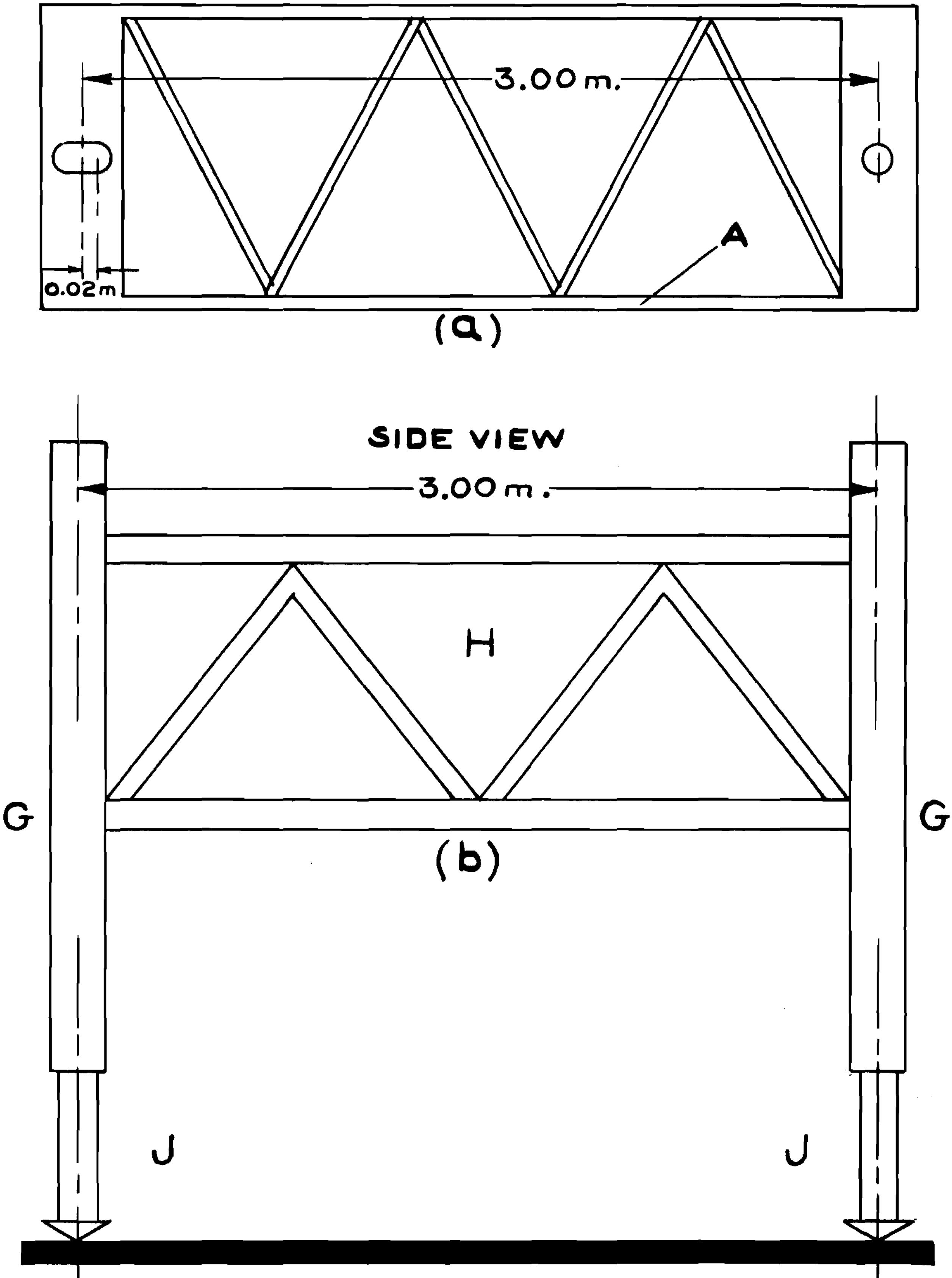


FIG. 55

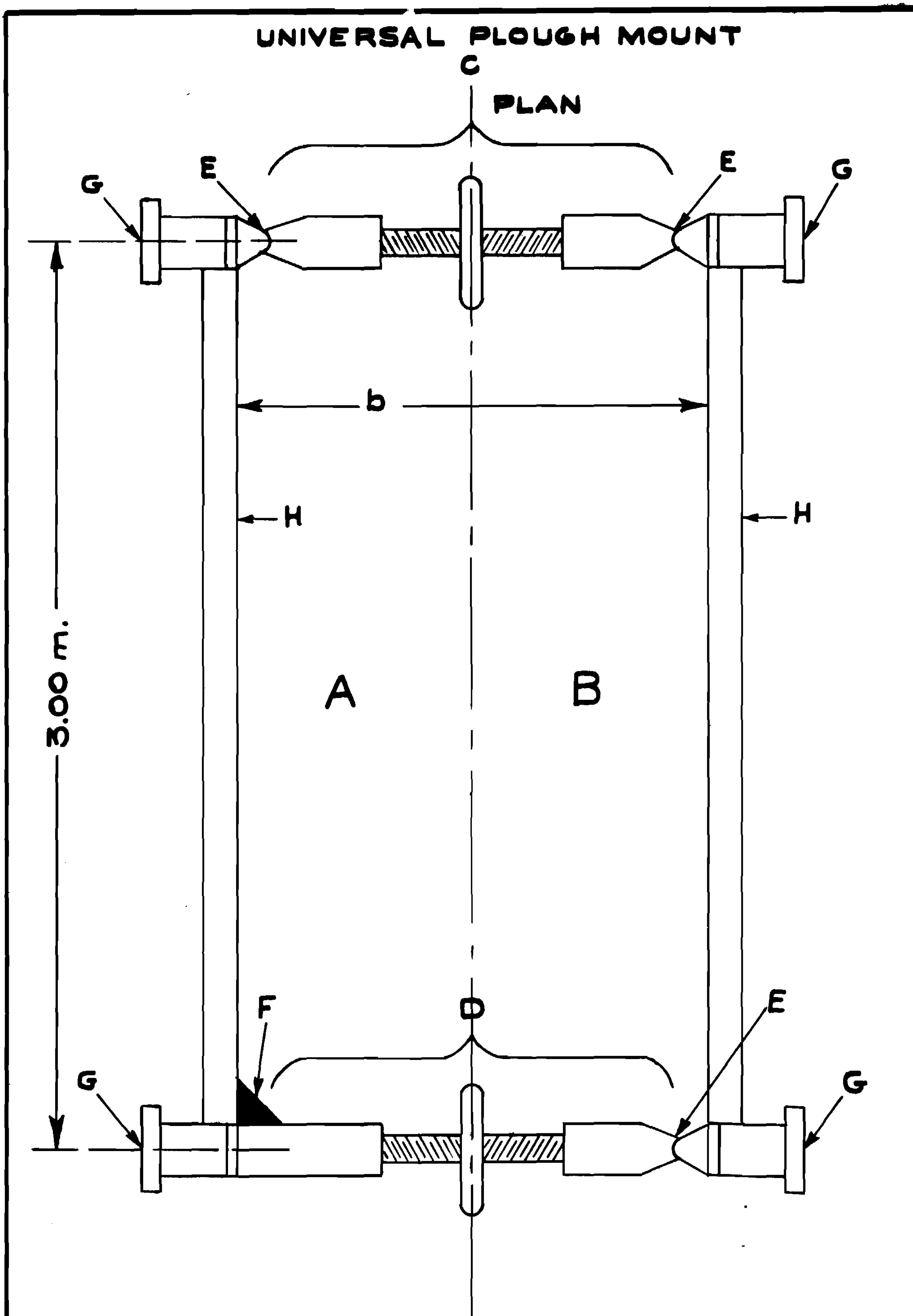


FIG. 56

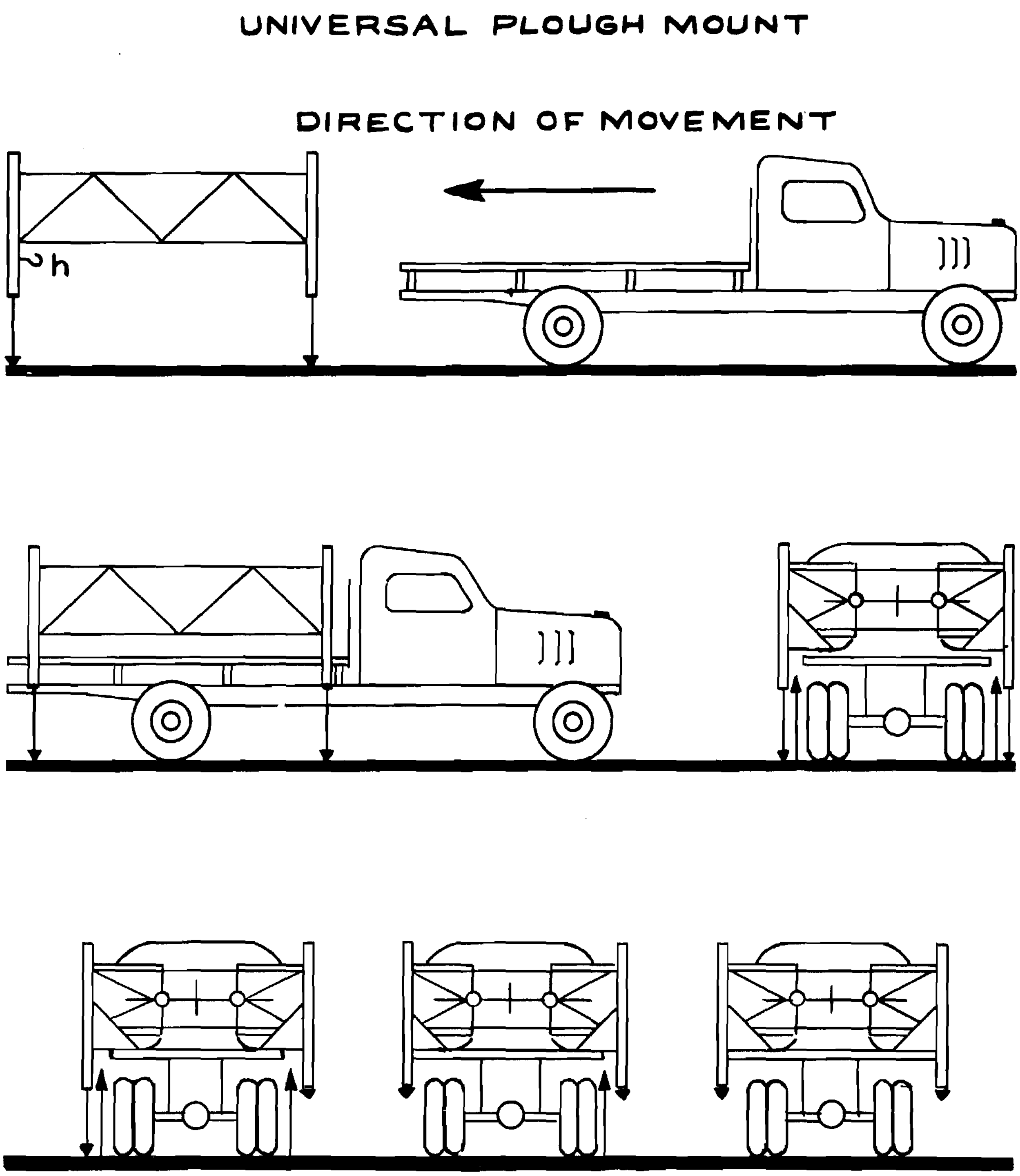


FIG. 57

UNIVERSAL PLOUGH MOUNT

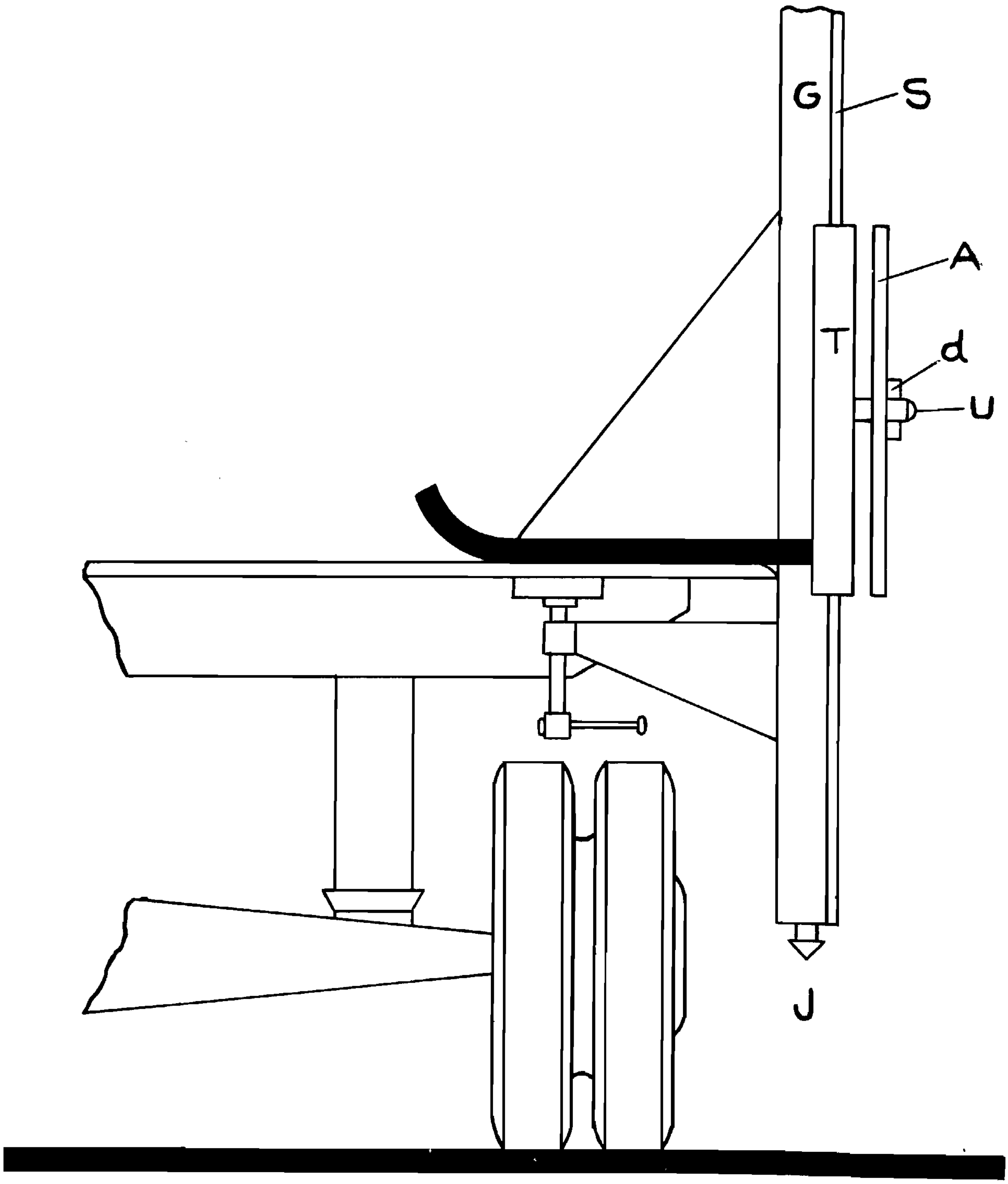


FIG. 58

WING PLOUGH ATTACHMENT

DETAILS

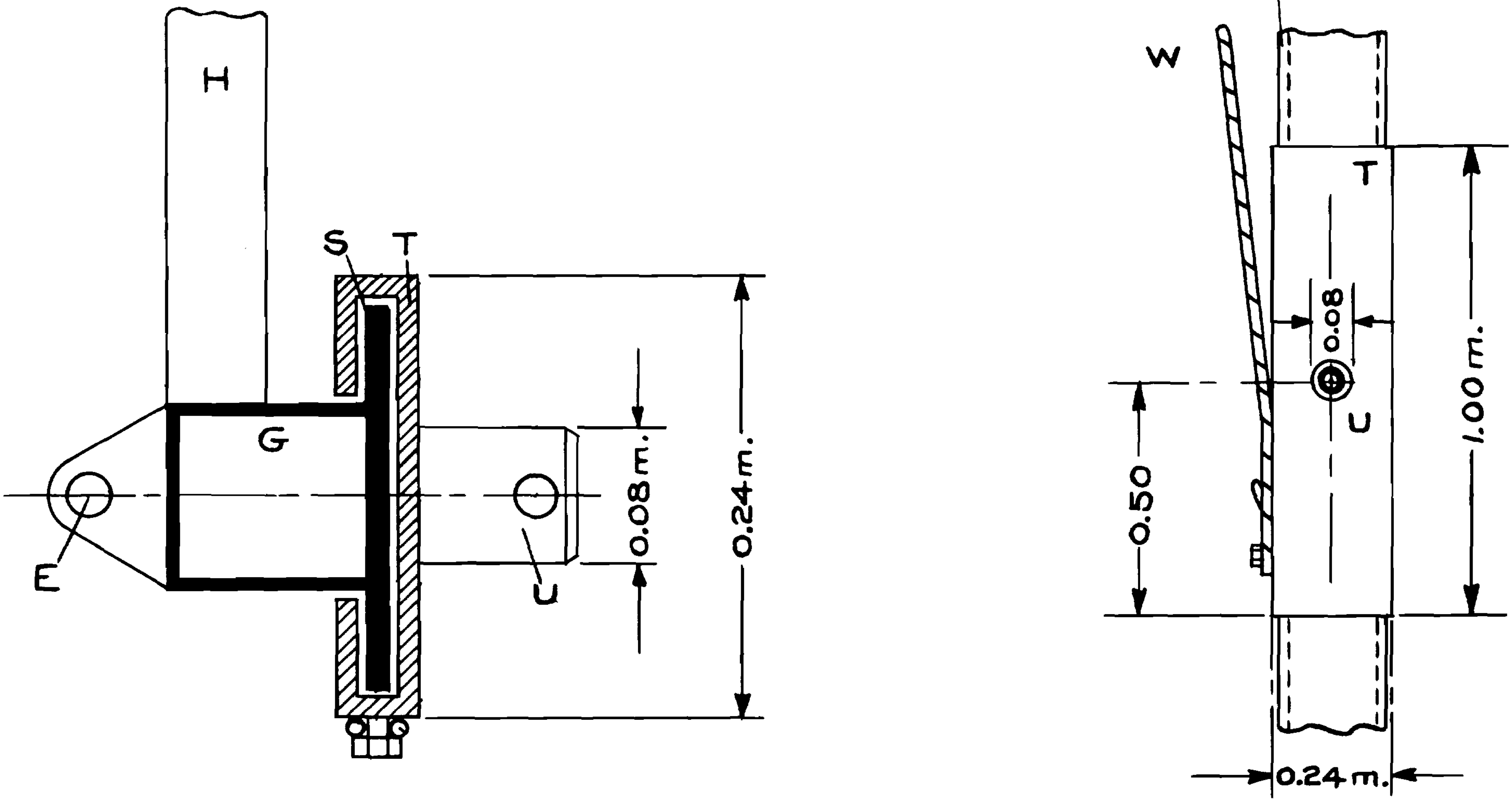


FIG. 59

WING PLOUGH ATTACHMENT
REAR VIEW

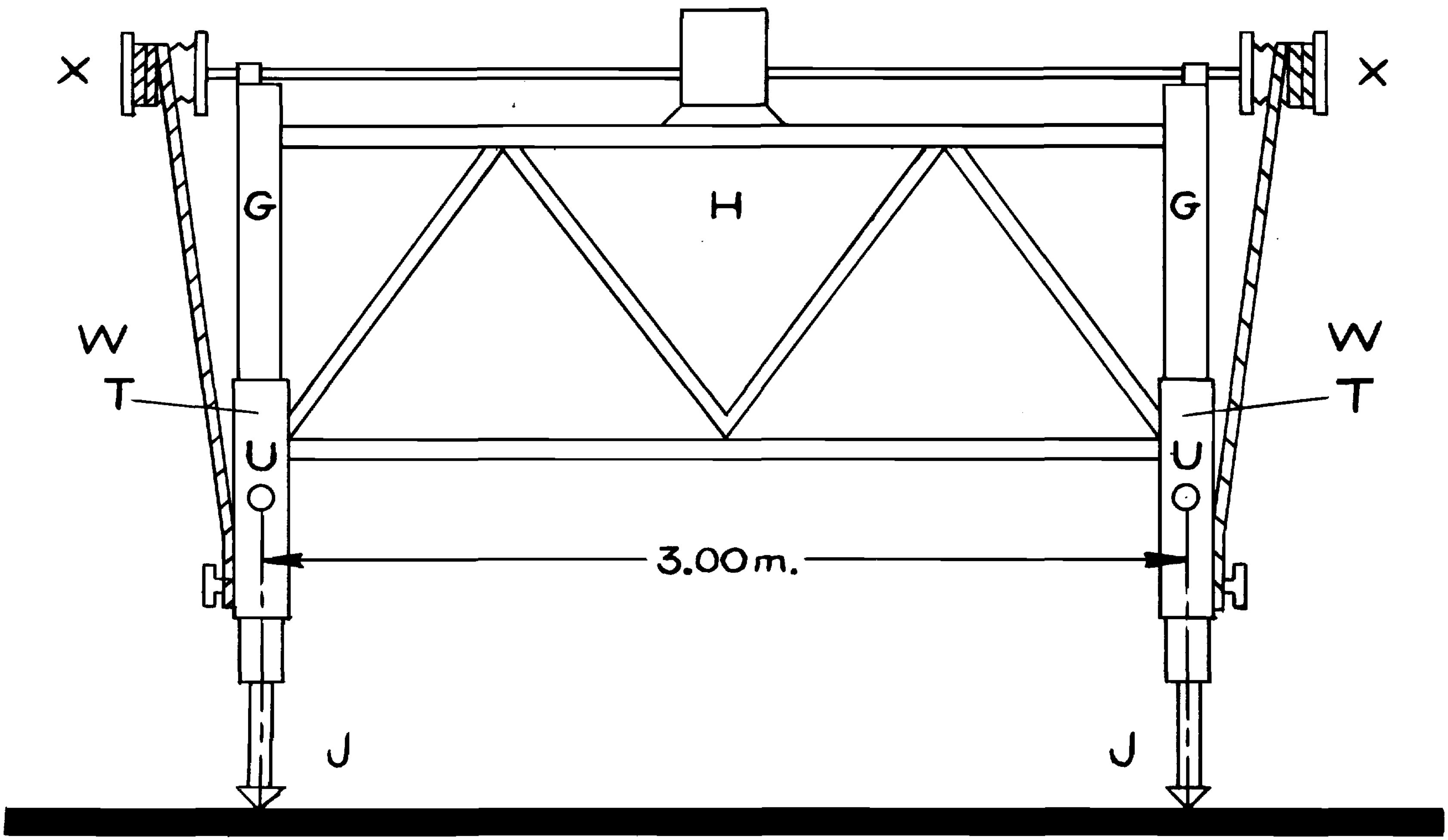


FIG. 60

WING PLOUGH

PLAN

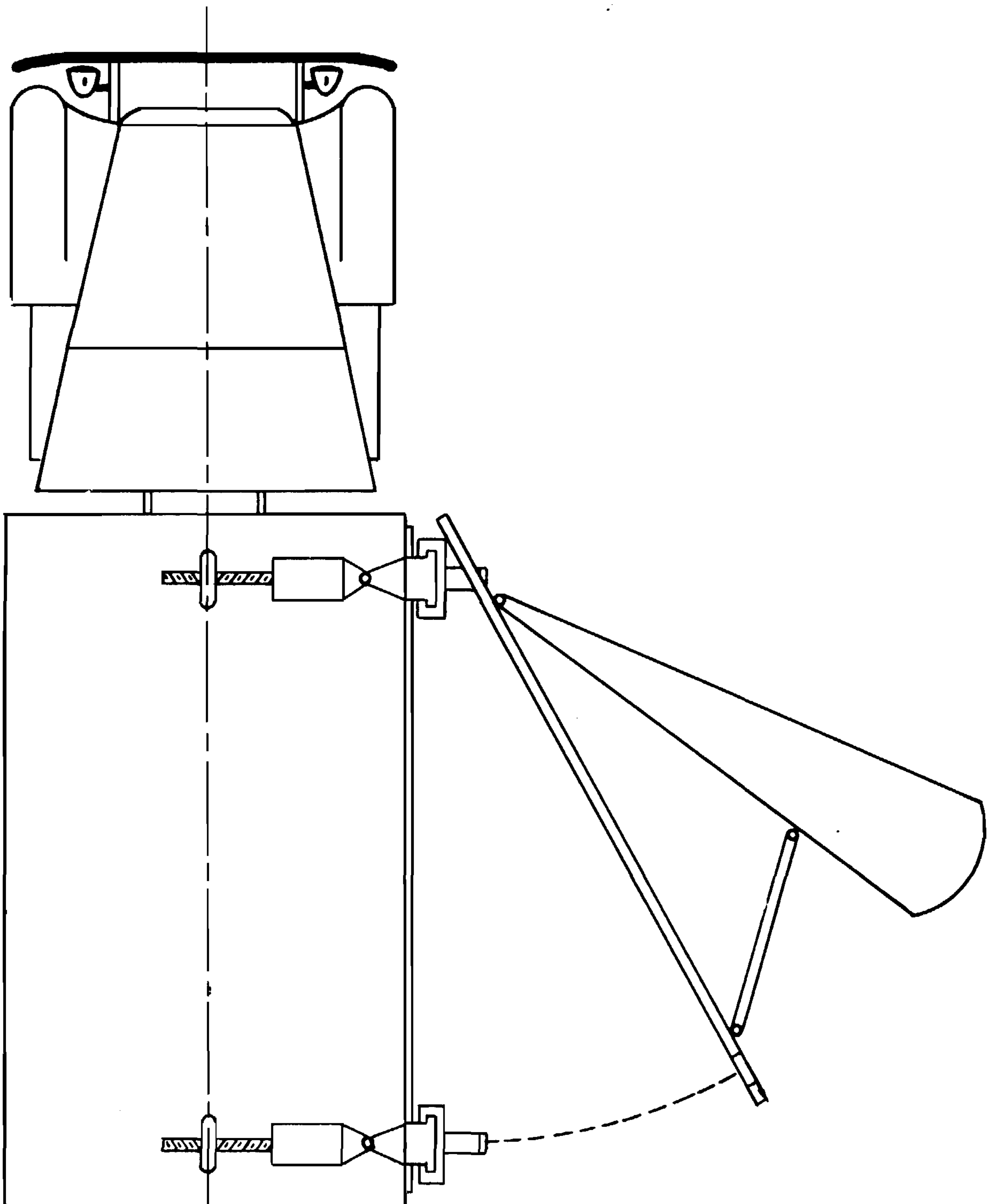
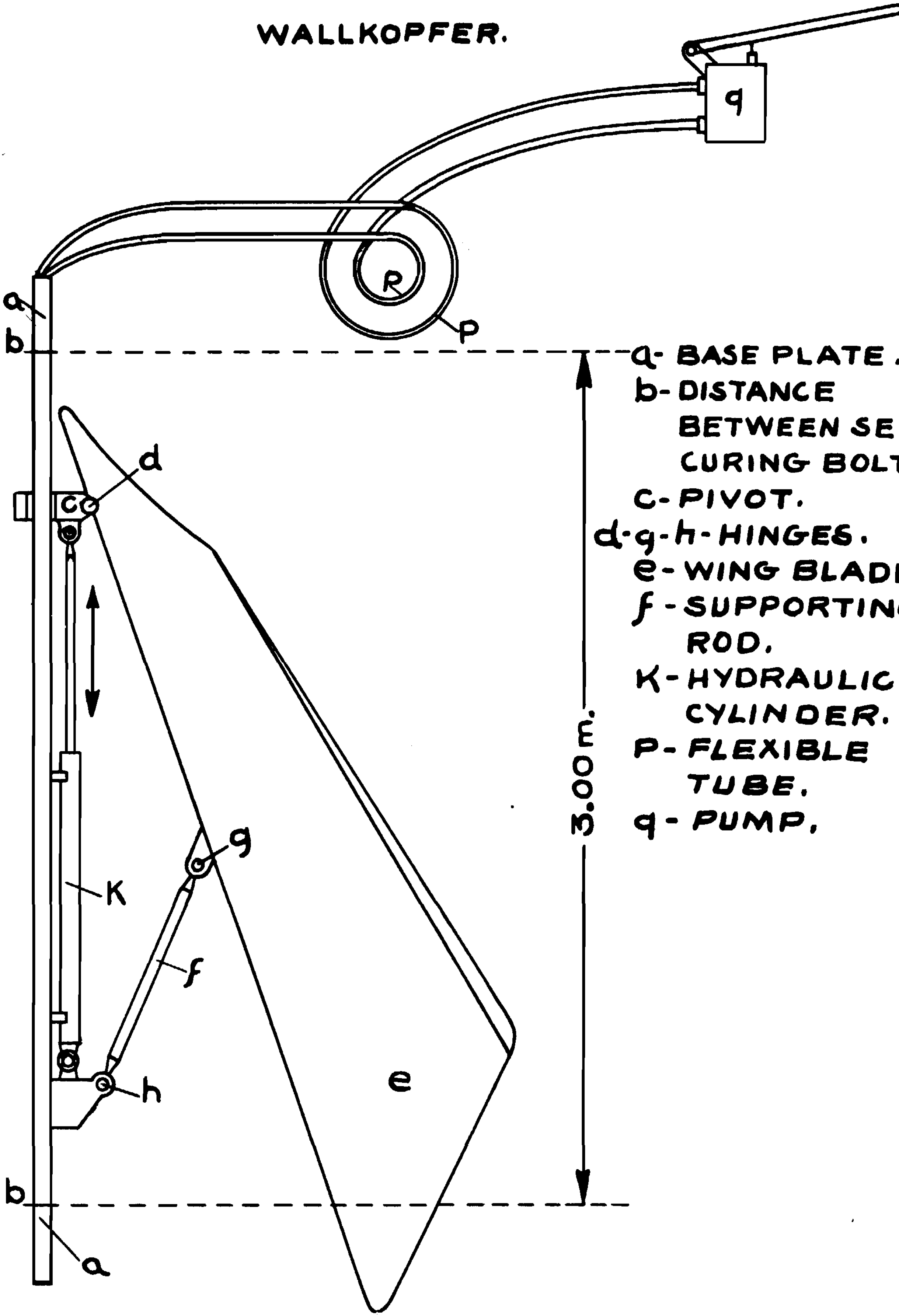


FIG. 61

WALLKOPFER.



a- BASE PLATE.
b- DISTANCE BETWEEN SECURING BOLTS.
c- PIVOT.
d-g-h- HINGES.
e- WING BLADE.
f- SUPPORTING ROD.
K- HYDRAULIC CYLINDER.
P- FLEXIBLE TUBE.
q- PUMP.

FIG. 62

WALLKOPFER.

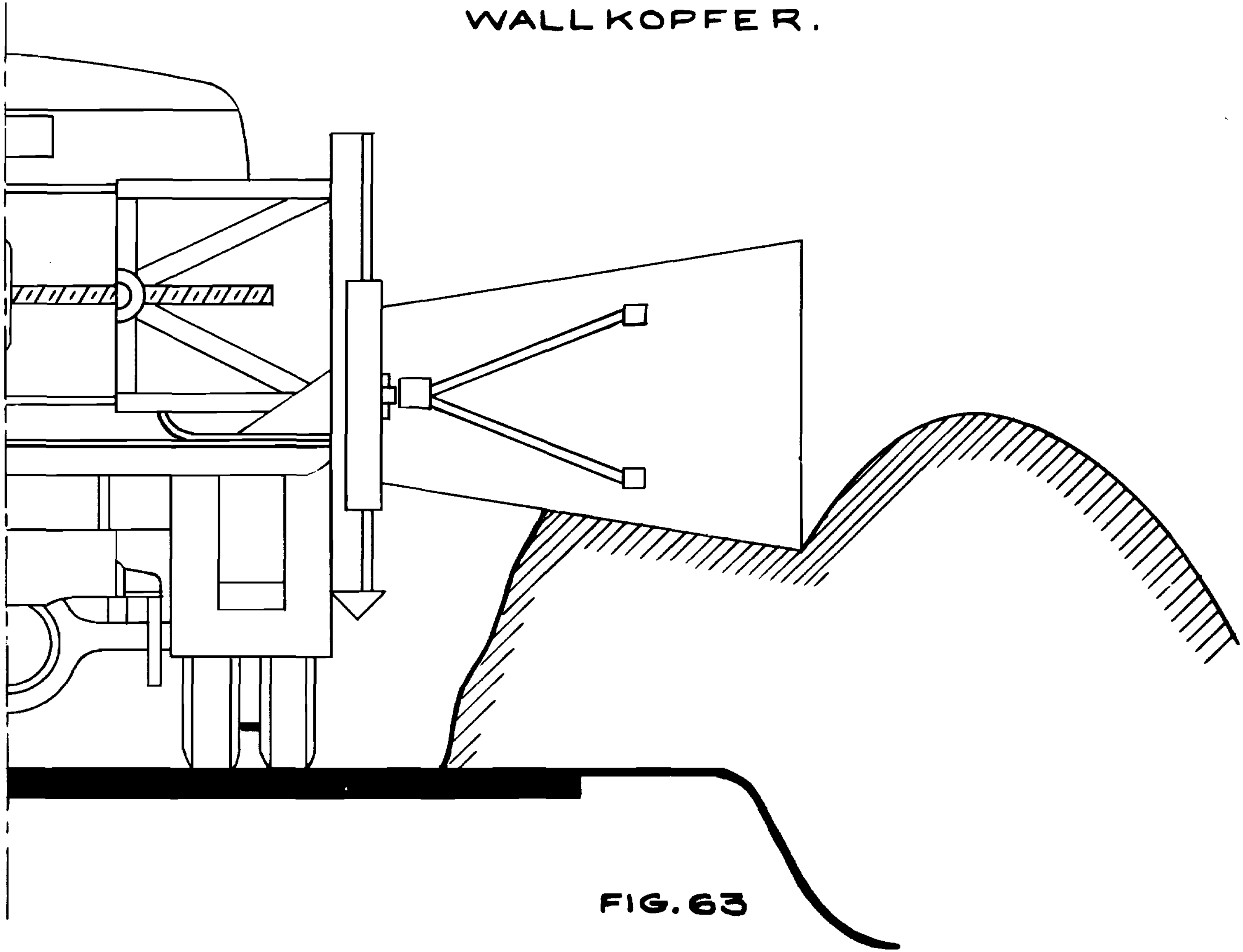
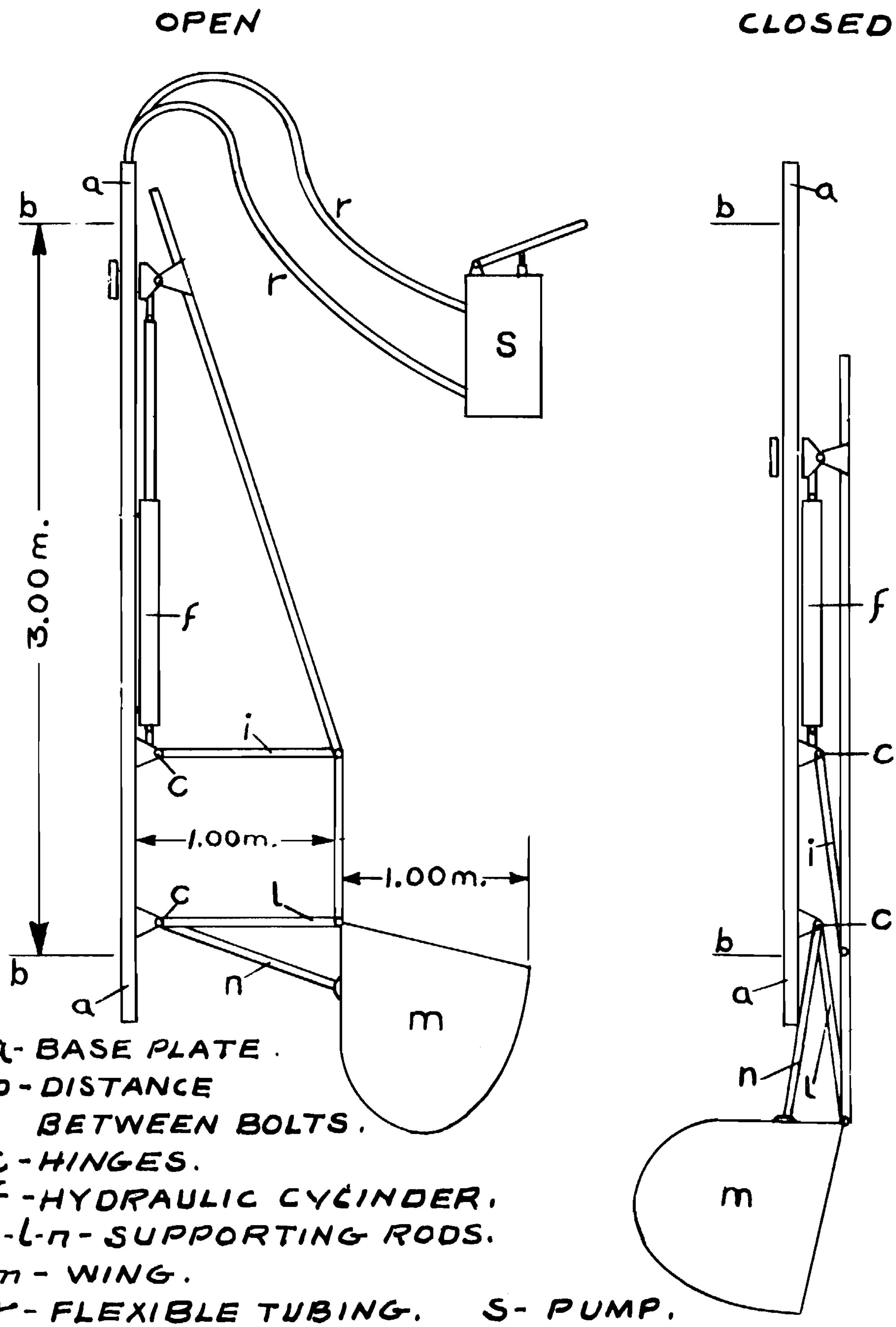


FIG. 63

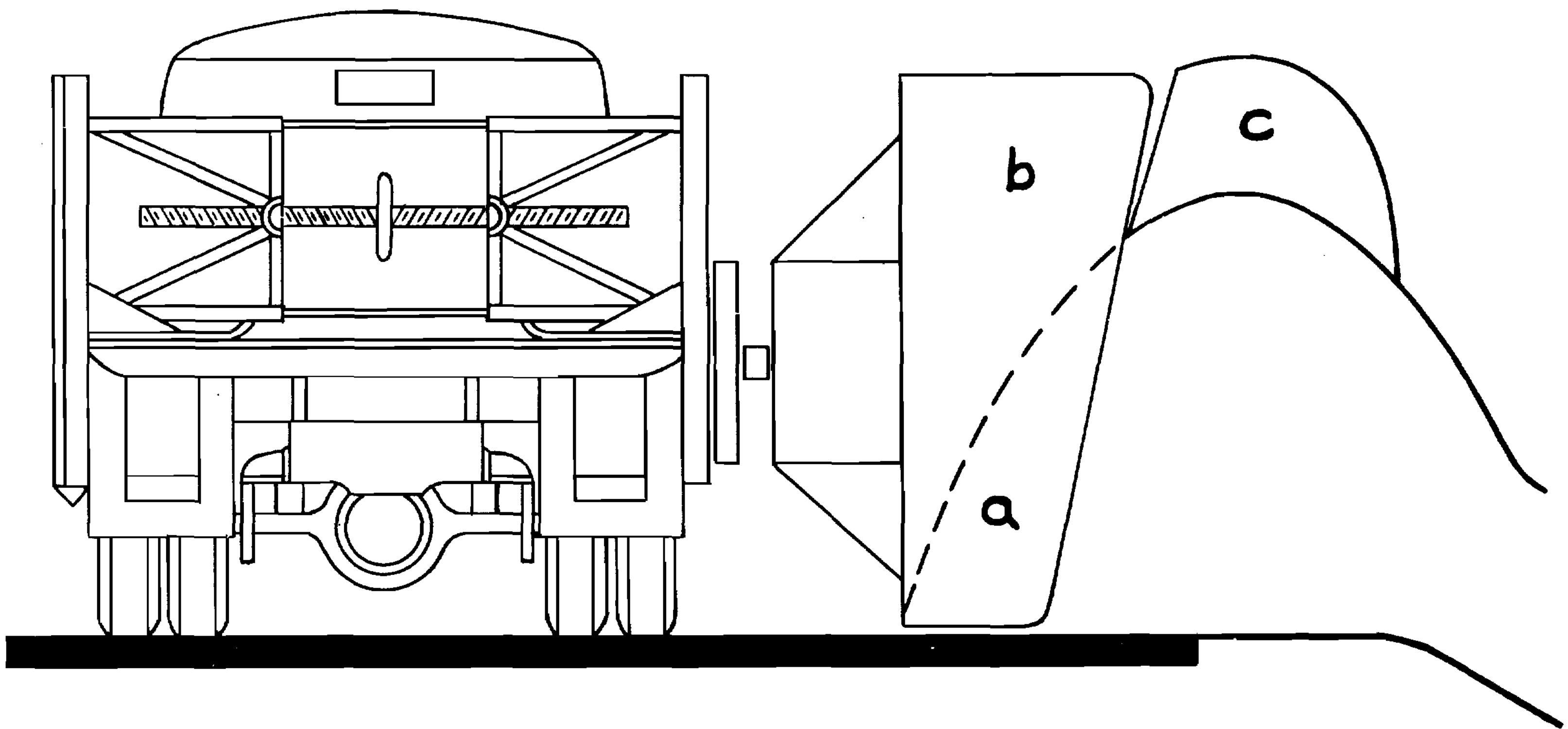
DISTANCE THROWING WING.



a - BASE PLATE.
b - DISTANCE BETWEEN BOLTS.
c - HINGES.
f - HYDRAULIC CYLINDER.
i-l-n - SUPPORTING RODS.
m - WING.
r - FLEXIBLE TUBING. S - PUMP.

FIG. 64

SNOW CUTTER



a - BOTTOM OF SNOW BANK.
b - BLADE.
c - SNOW REMOVED.

FIG. 65

SNOW CUTTER.

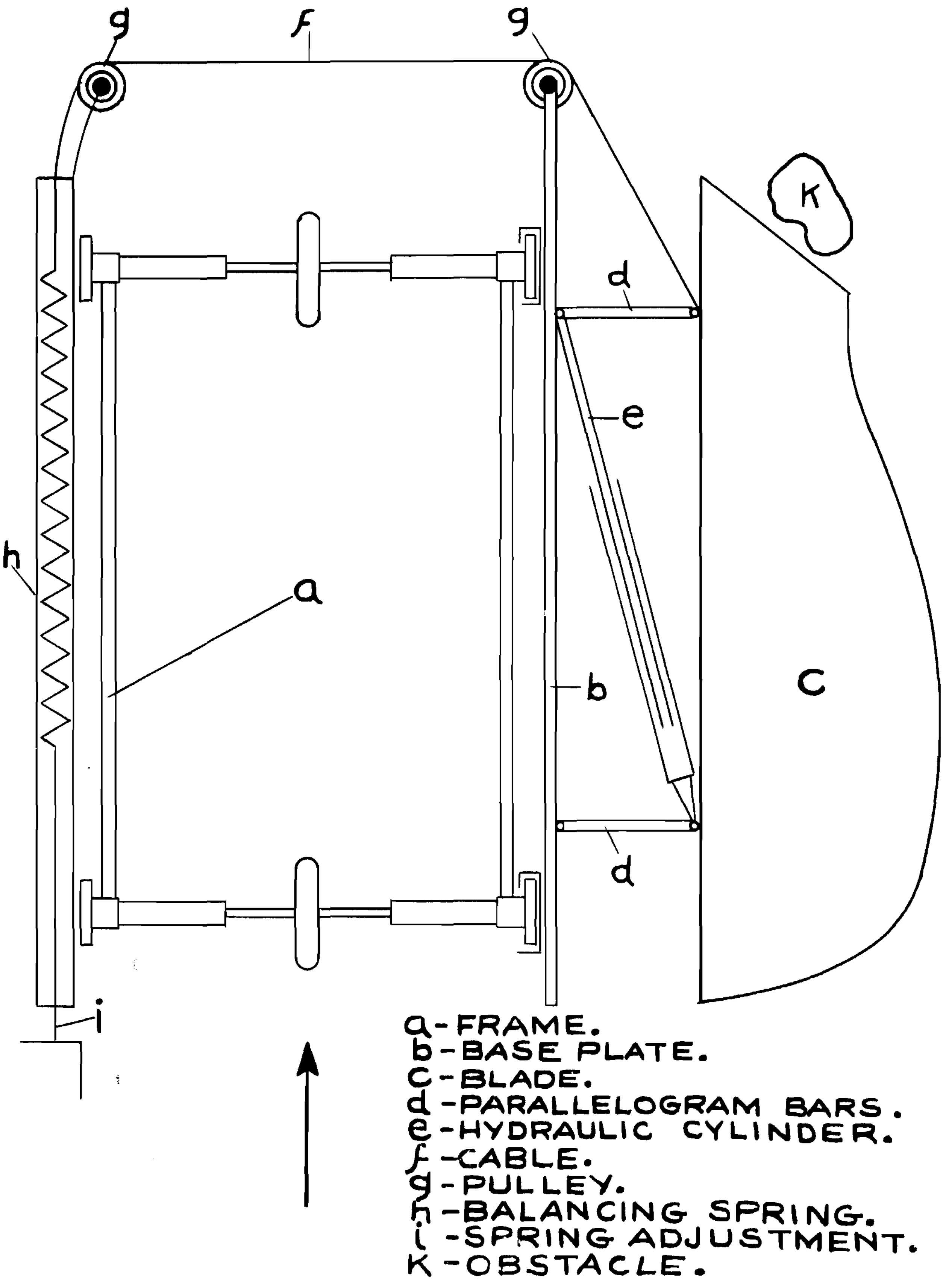


FIG.66

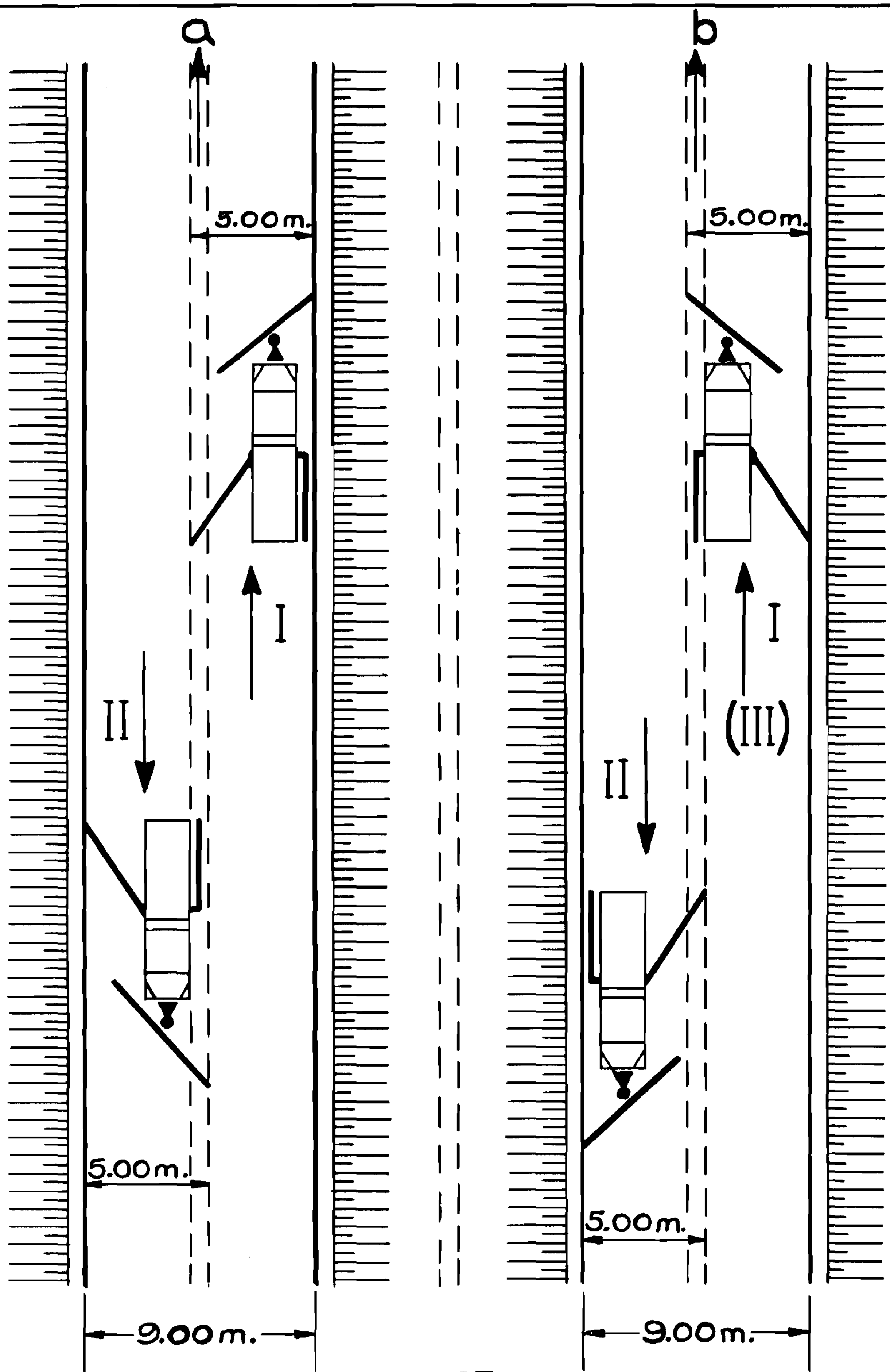


FIG. 67
INSTRUCTION FOR PLOW OPERATION

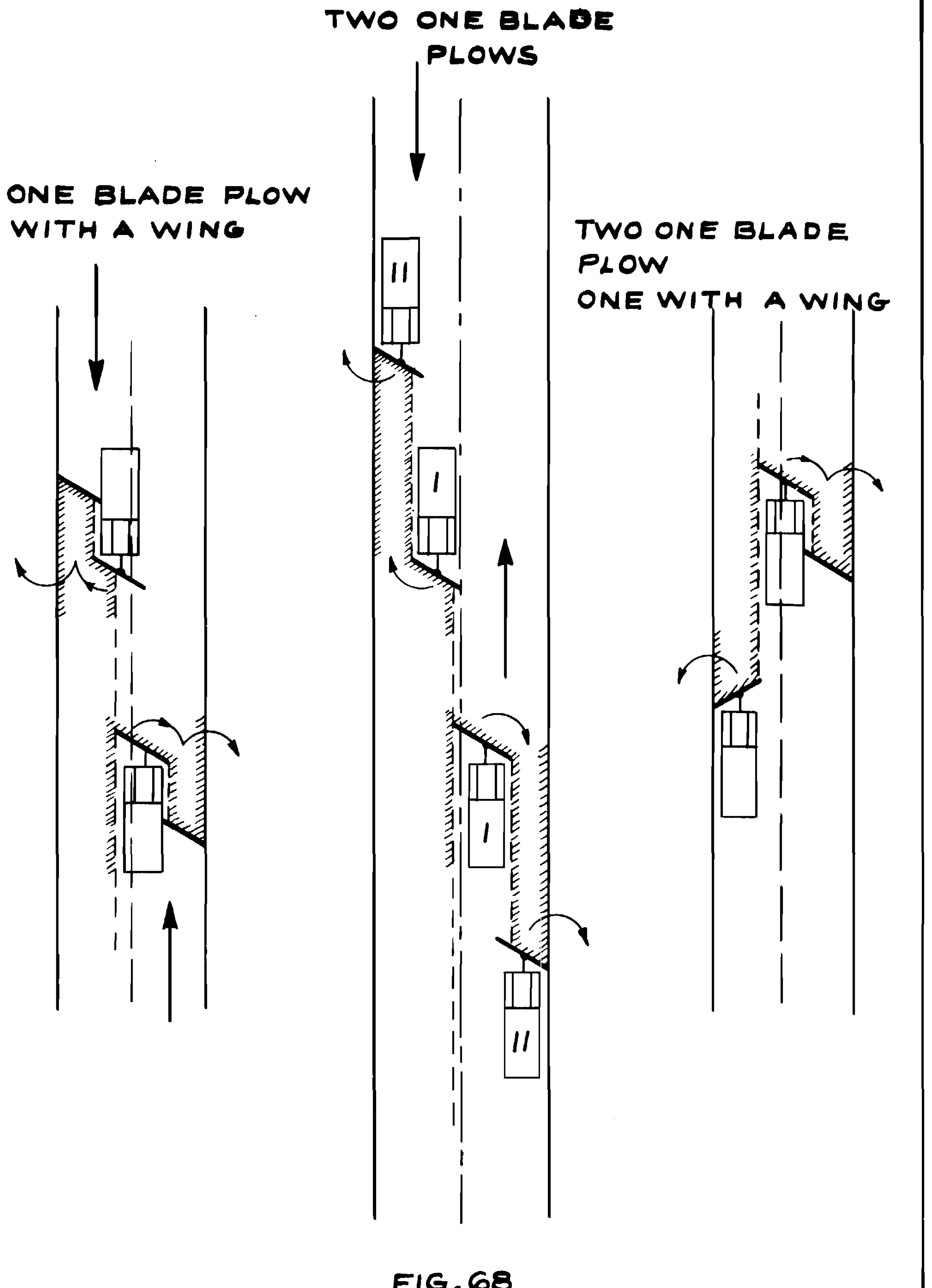
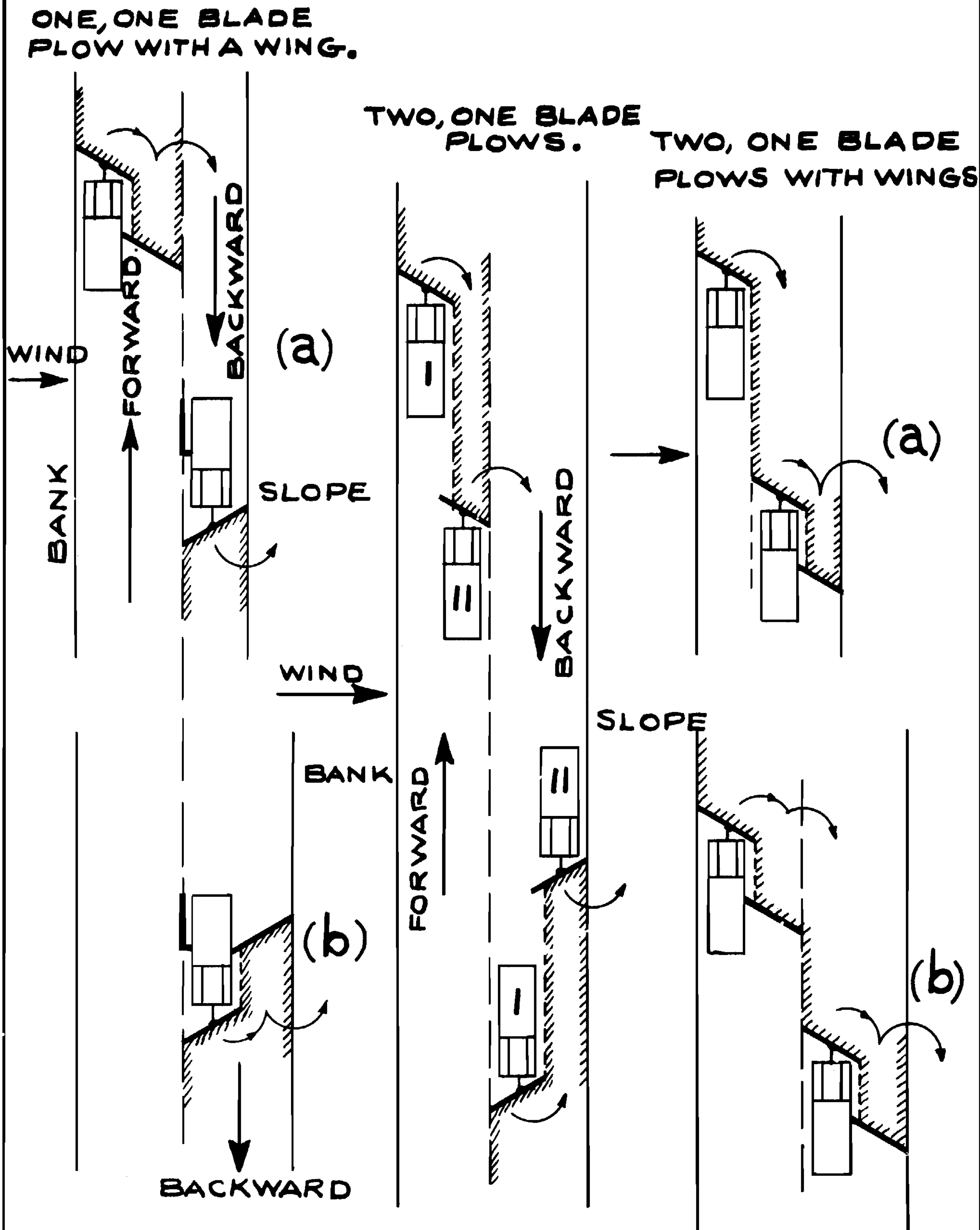


FIG. 68

INSTRUCTION FOR PLOW OPERATION



(a)- CLEANED STRIP 7m. WIDE.
(b)- CLEANED STRIP 9m. WIDE.

FIG. 69
INSTRUCTION FOR PLOW OPERATION

V- AND ONE BLADE PLOUGHS.

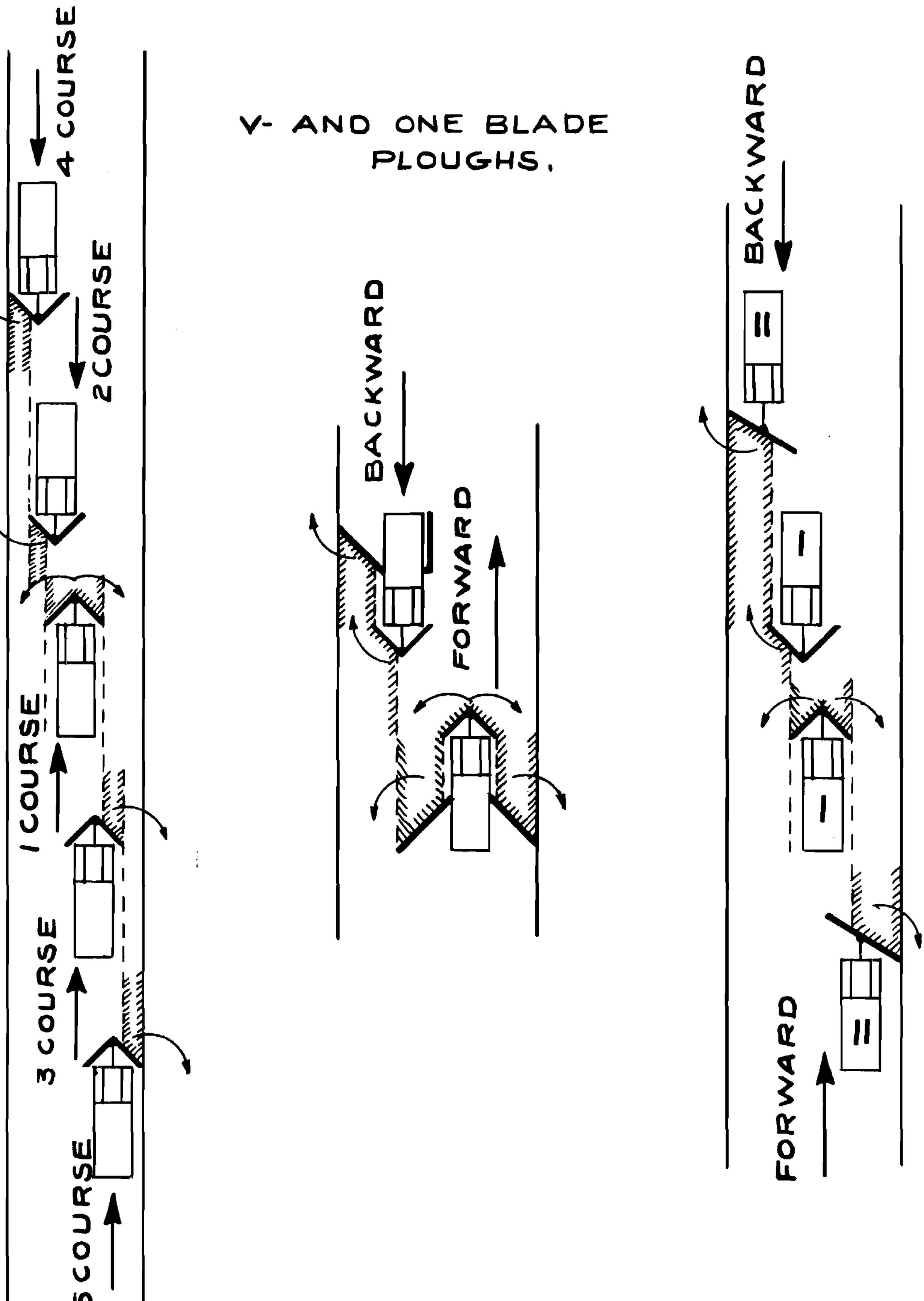


FIG. 70
INSTRUCTION FOR PLOW OPERATION

ONE V- AND TWO
ONE BLADE PLOUGHS

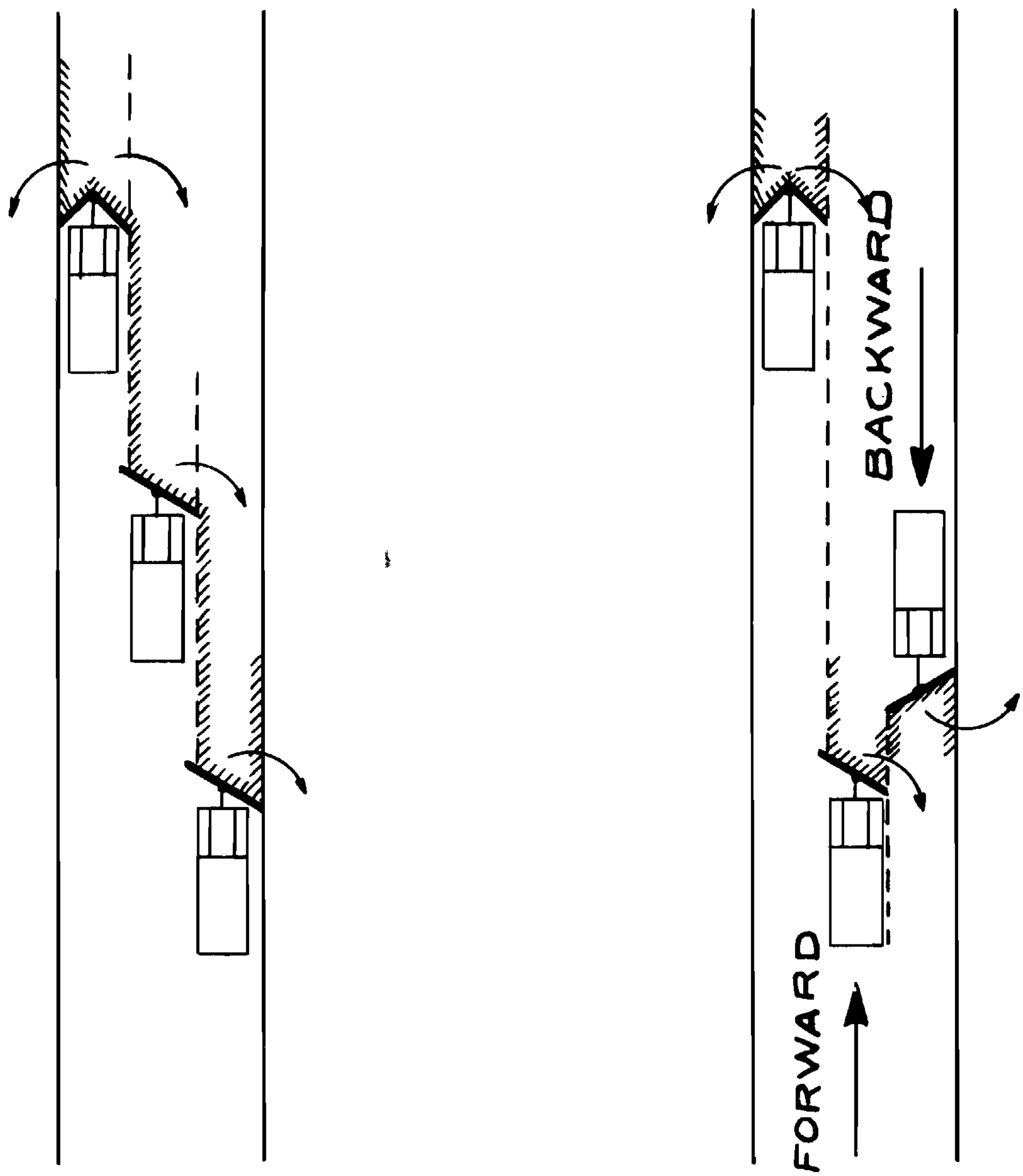


FIG. 71
INSTRUCTION FOR PLOW OPERATION

PENDERSHAAB (SNOGO)

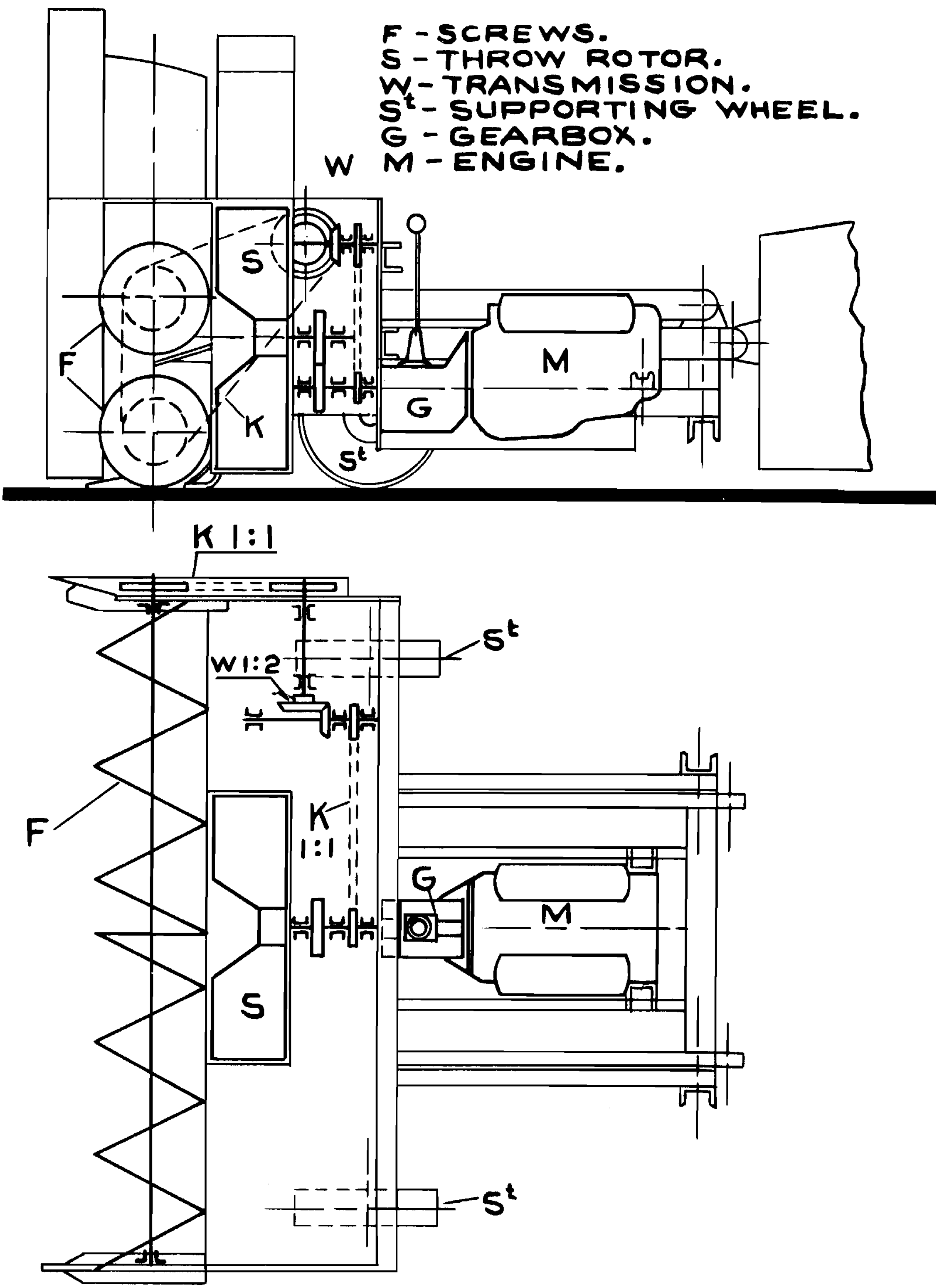


FIG. 72

RELATIONSHIP BETWEEN SNOW OUTPUT AND THE DISTANCE OF THROW AT VARIOUS SPEC. GRAVITY OF SNOW, AS DETERMINED FOR AN IMPROVED VERSION OF PENDERSHAAB (SNOGO) SNOW BLOWER.

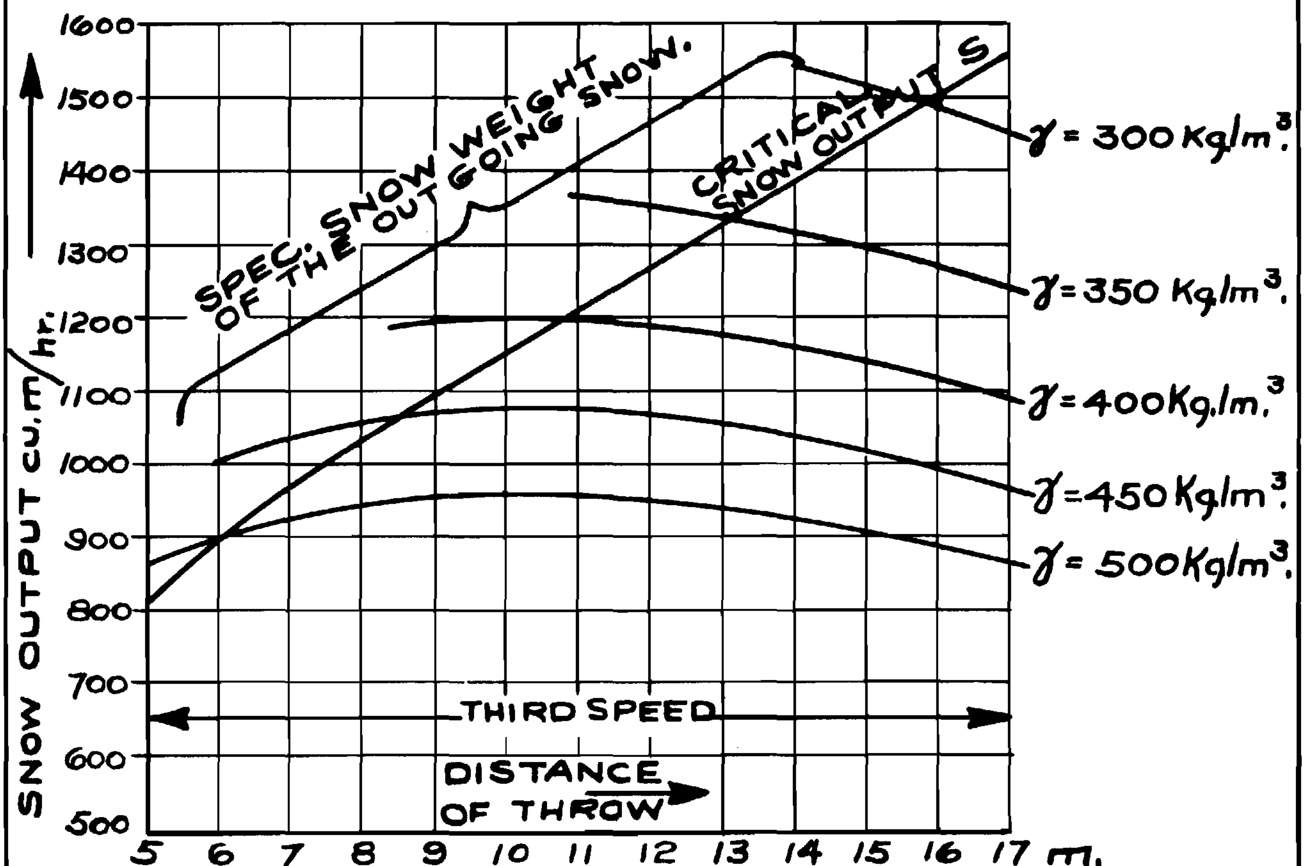


FIG. 73

EXP. MODEL OF THE NEWEST GERMAN SNOW BLOWER

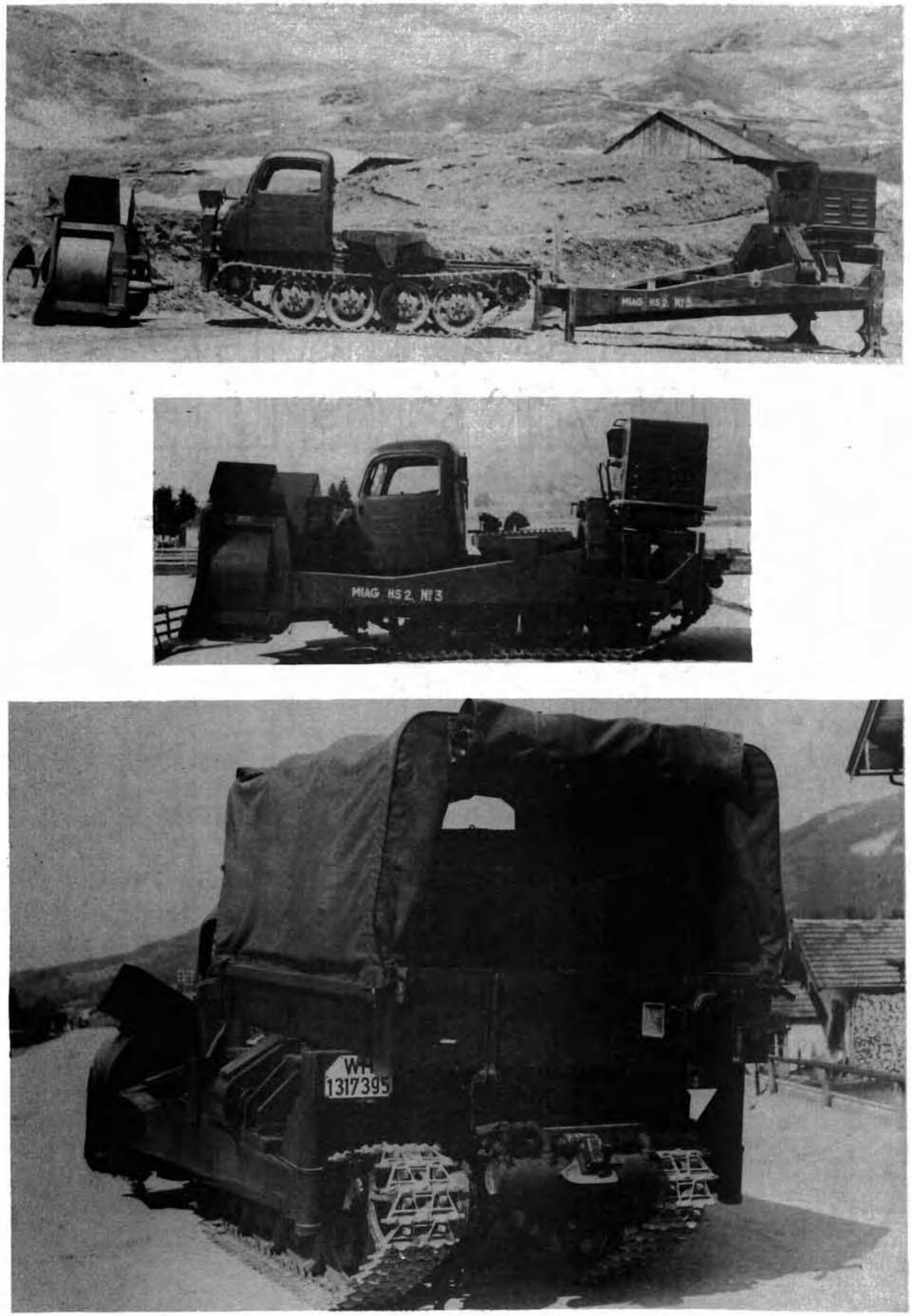
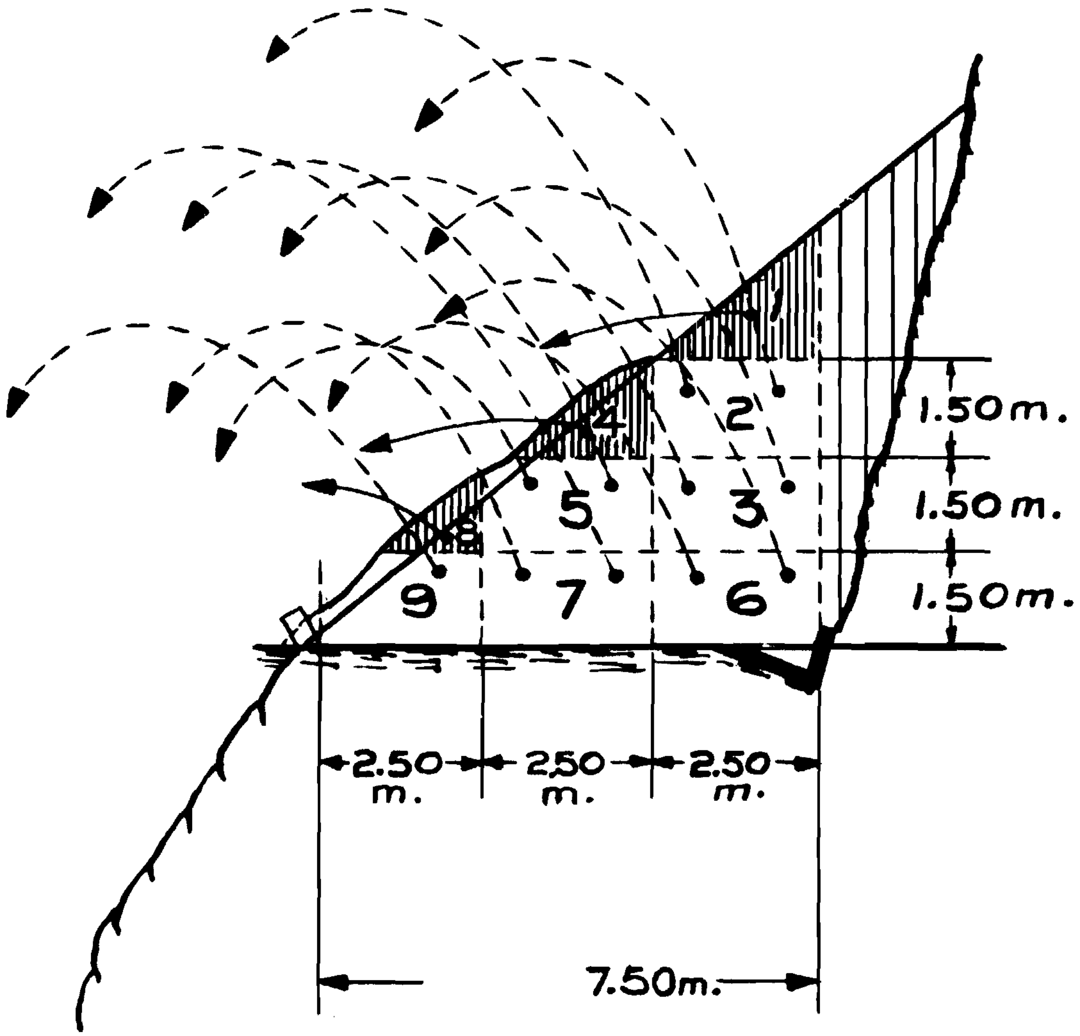


FIG. 74

USE OF TRACKED AND WHEELED EQUIPMENT.



SECTION - 1, 4, 8 — CLEANED BY A SHOVEL.
2, 3, 5 — SNOW BLOWER ON TRACKED CHASSIS.
6, 7, 9 — SNOW BLOWER ON WHEELED CHASSIS.

FIG. 75

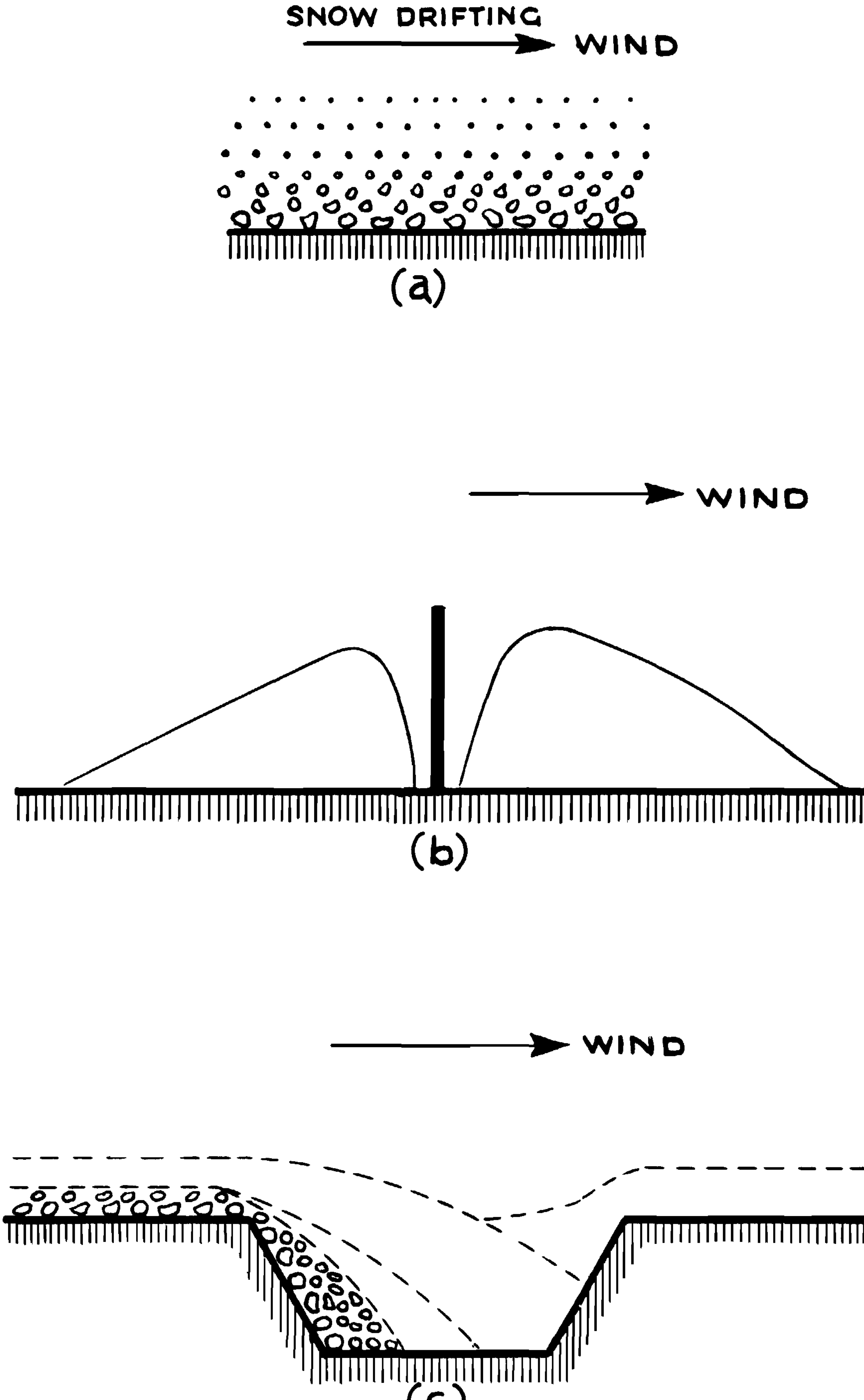


FIG. 77

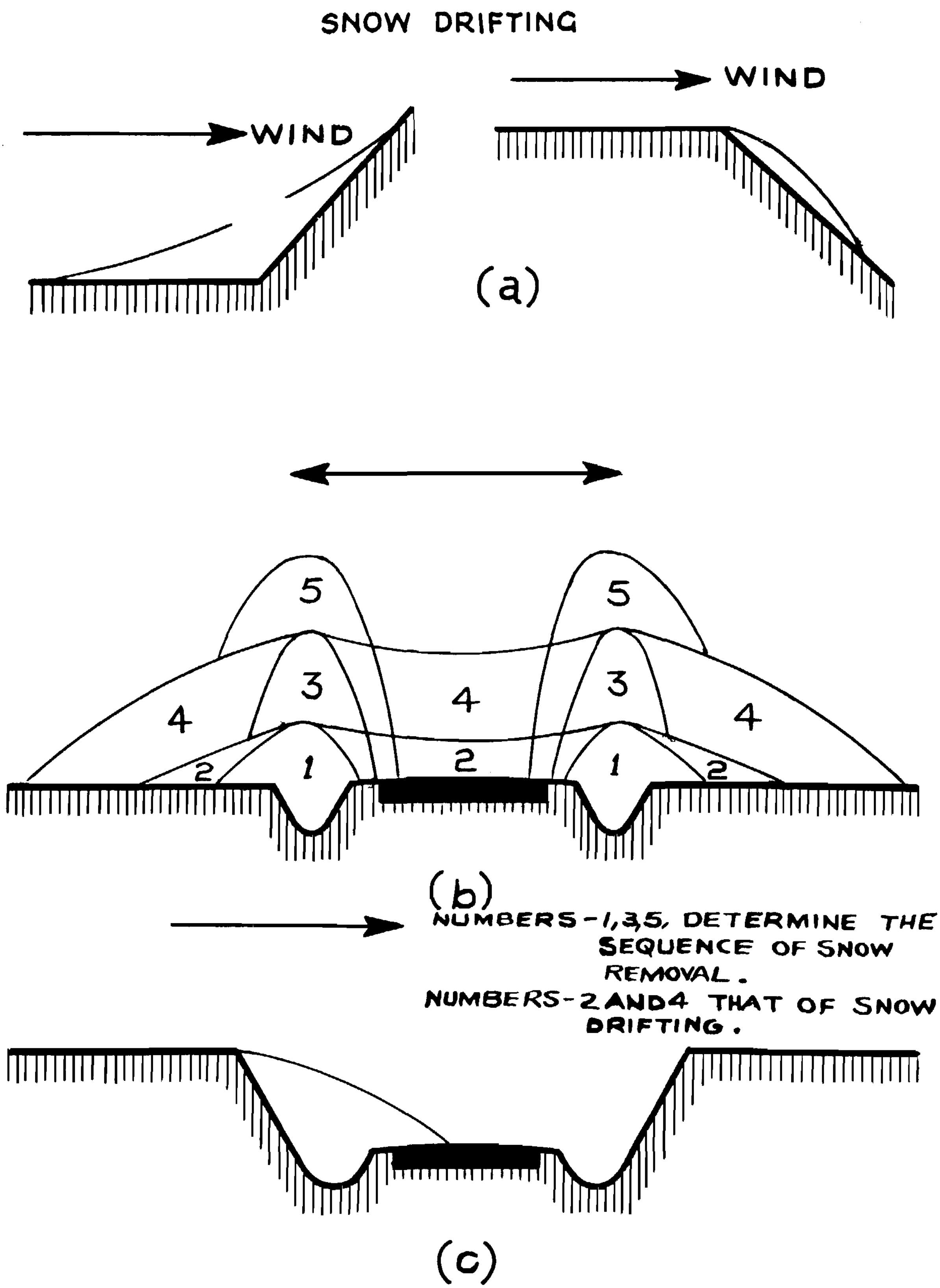

SNOW DRIFTING
WIND
WIND
(a)
5
5
3
4
3
4
4
2
1
2
1
2
(b)
NUMBERS-1,3,5, DETERMINE THE SEQUENCE OF SNOW REMOVAL.
NUMBERS-2 AND 4 THAT OF SNOW DRIFTING.
(c)

FIG. 78

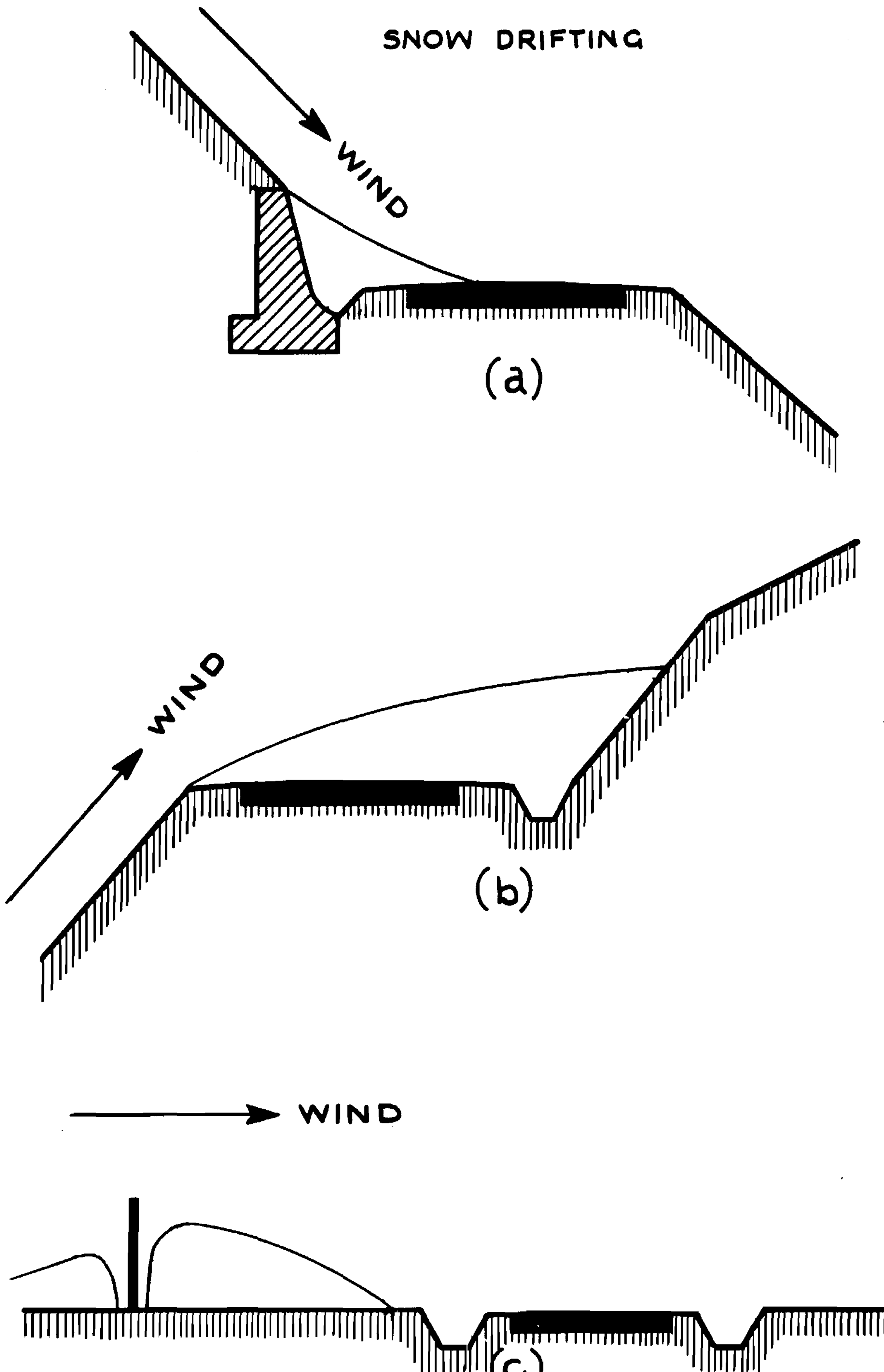


FIG. 79

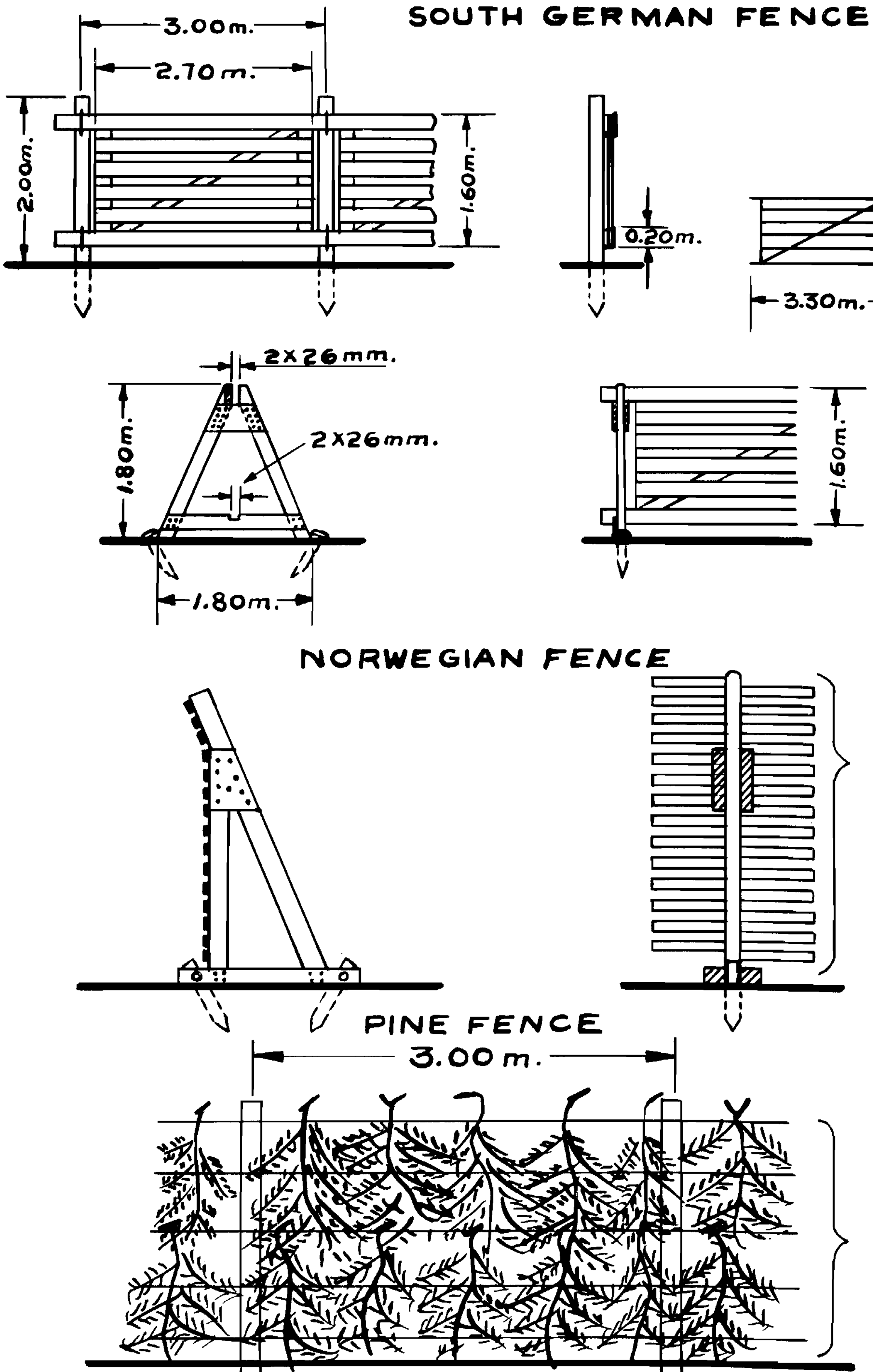

SOUTH GERMAN FENCE
3.00m.
2.70m.
2.00m.
1.60m.
0.20m.
3.30m.
2X26mm.
2X26mm.
1.80m.
1.80m.
1.60m.
NORWEGIAN FENCE
PINE FENCE
3.00m.

FIG. 80

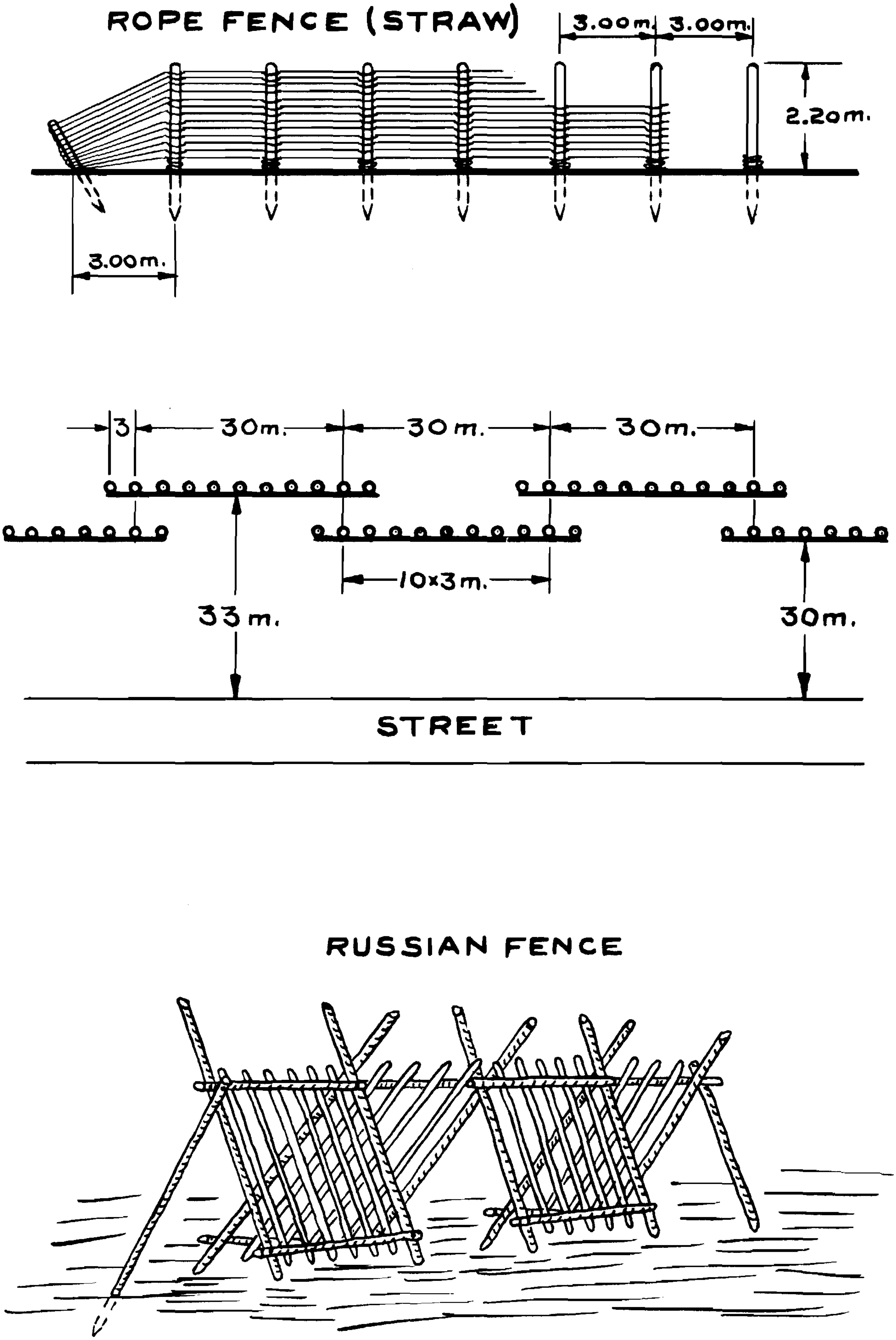

ROPE FENCE (STRAW)
3.00m.
3.00m.
2.20m.
3.00m.
3
30m.
30m.
30m.
10×3m.
33m.
30m.
STREET
RUSSIAN FENCE

FIG. 81

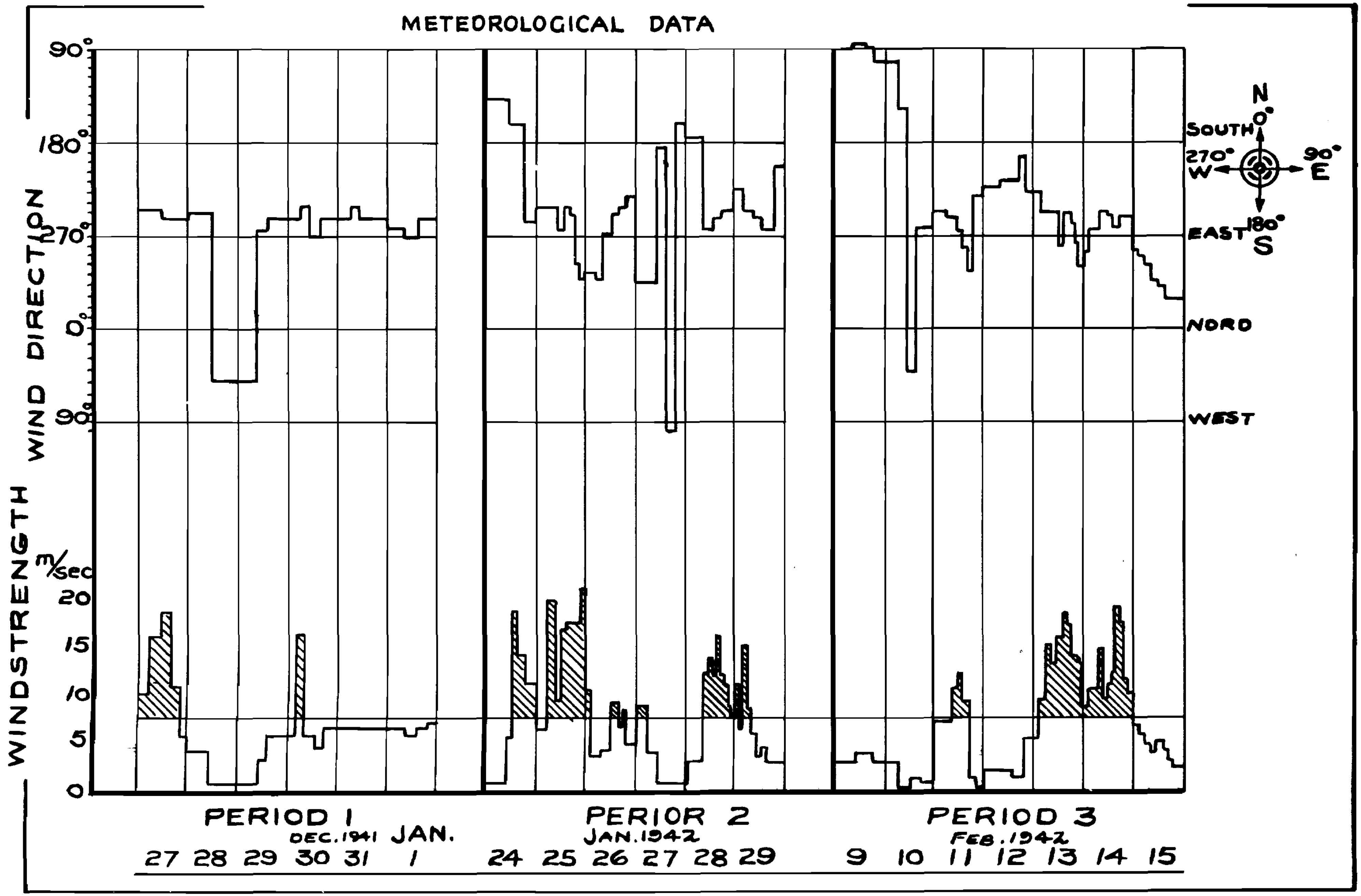

METEOROLOGICAL DATA
90°
180°
270°
0°
90°
WIND DIRECTION
WINDSTRENGTH
m/sec
20
15
10
5
0
SOUTH
EAST
NORD
WEST
N
0°
270°
W
90°
E
180°
S
PERIOD 1
DEC. 1941 JAN.
27 28 29 30 31 1
PERIOR 2
JAN. 1942
24 25 26 27 28 29
PERIOD 3
FEB. 1942
9 10 11 12 13 14 15

FIG. 82a

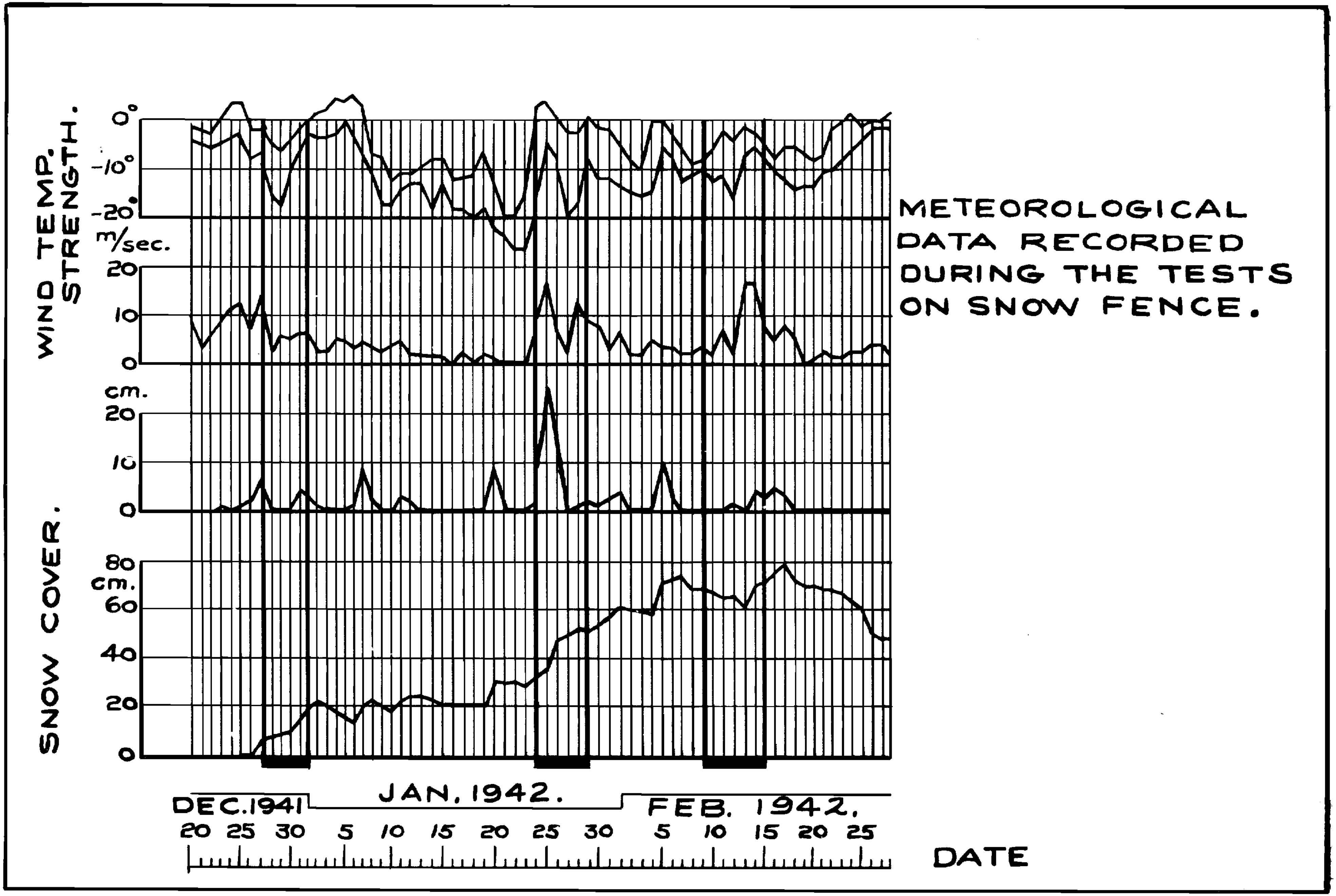
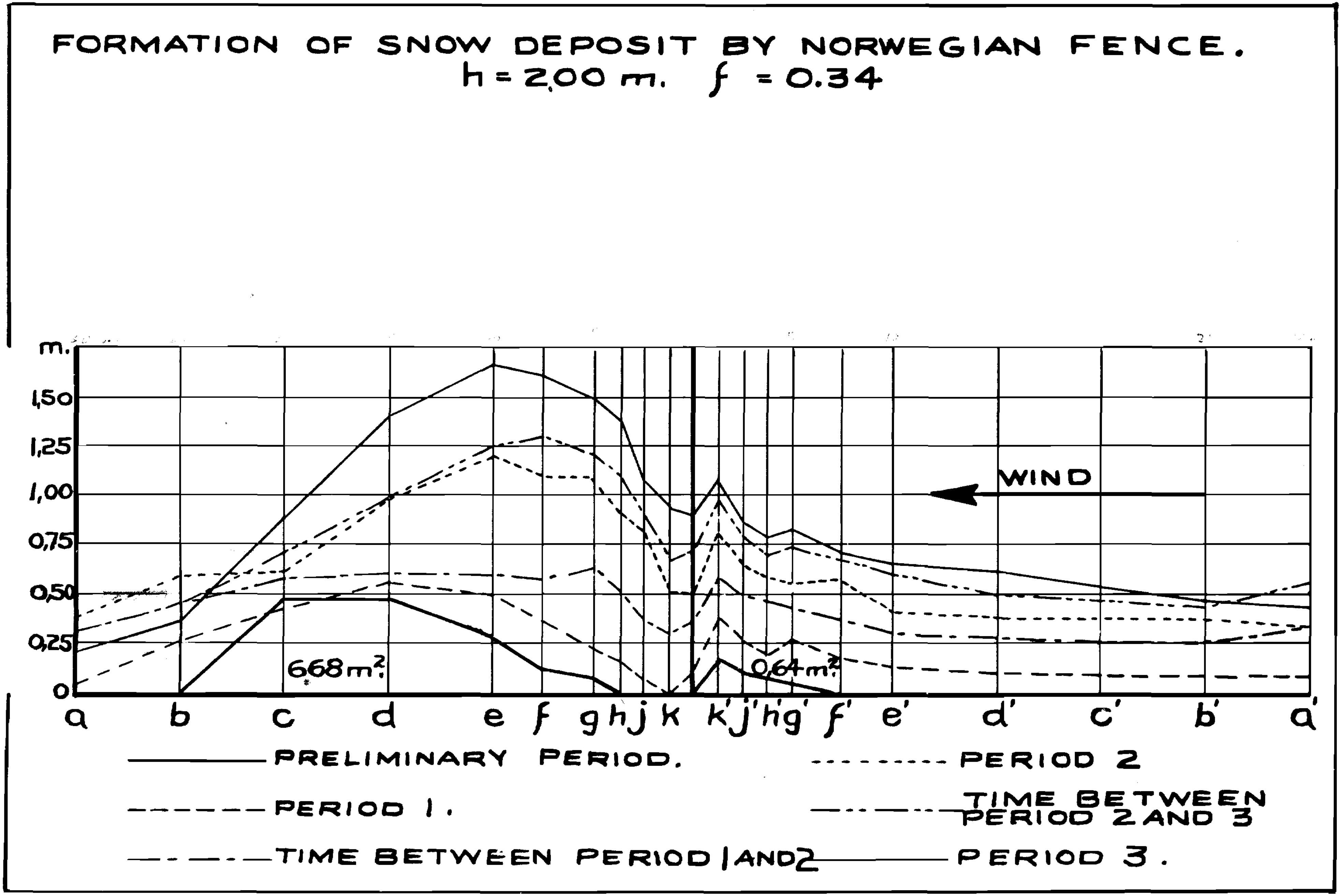

WIND TEMP.
STRENGTH.
SNOW COVER.
0°
-10°
-20°
m/sec.
20
10
0
cm.
20
10
0
80
cm.
60
40
20
0
METEOROLOGICAL DATA RECORDED DURING THE TESTS ON SNOW FENCE.
DEC.1941
JAN, 1942.
FEB. 1942.
20 25 30 5 10 15 20 25 30 5 10 15 20 25
DATE

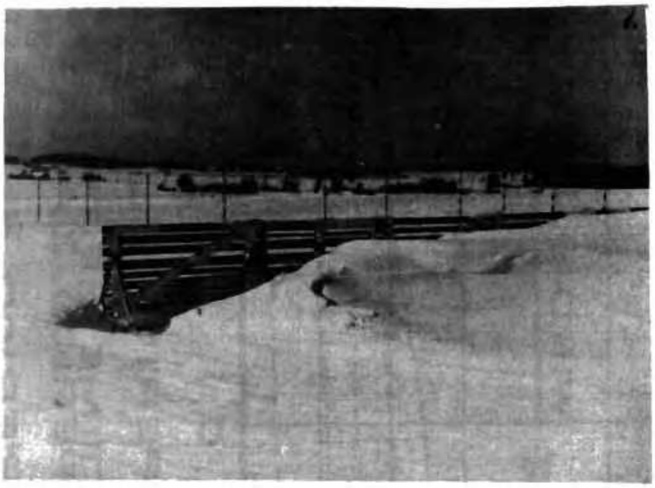
FIG. 82 b



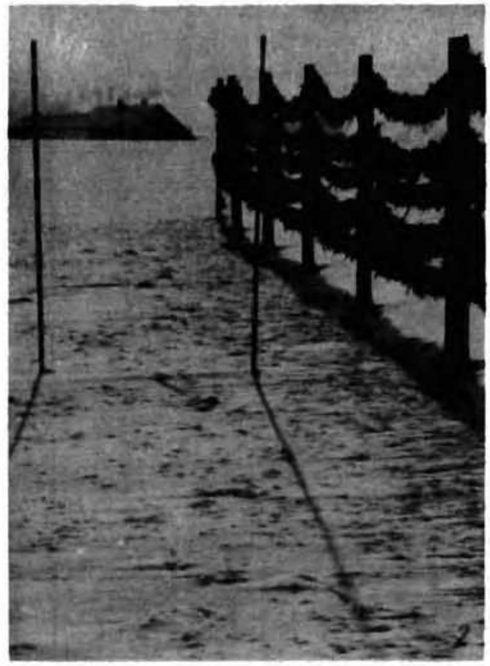
FORMATION OF SNOW DEPOSIT BY NORWEGIAN FENCE.
h = 2,00 m. f = 0.34
m.
1,50
1,25
1,00
0,75
0,50
0,25
0
WIND
6,68 m².
0,64 m².
a b c d e f g h j k k' j' h' g' f' e' d' c' b' a'
PRELIMINARY PERIOD.
PERIOD 2
PERIOD 1.
TIME BETWEEN PERIOD 2 AND 3
TIME BETWEEN PERIOD 1 AND 2
PERIOD 3.

FIG. 83

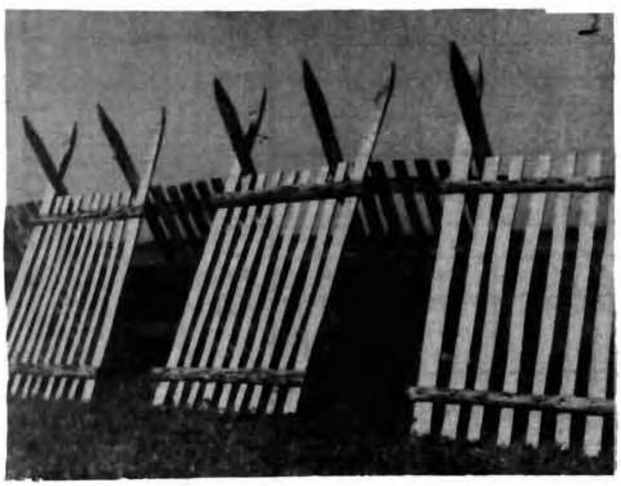
TESTED SNOW FENCES



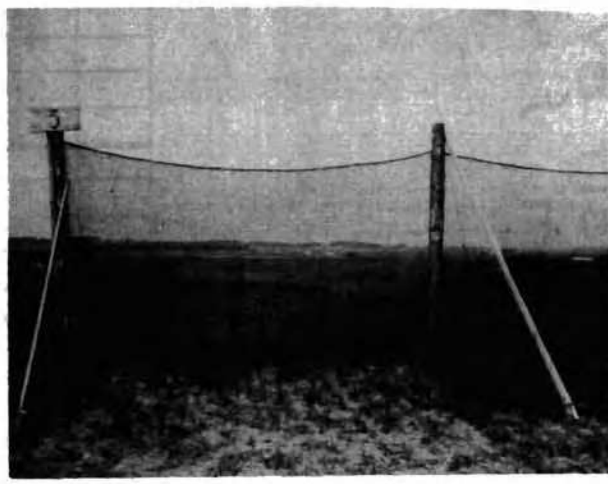
FENCE 0



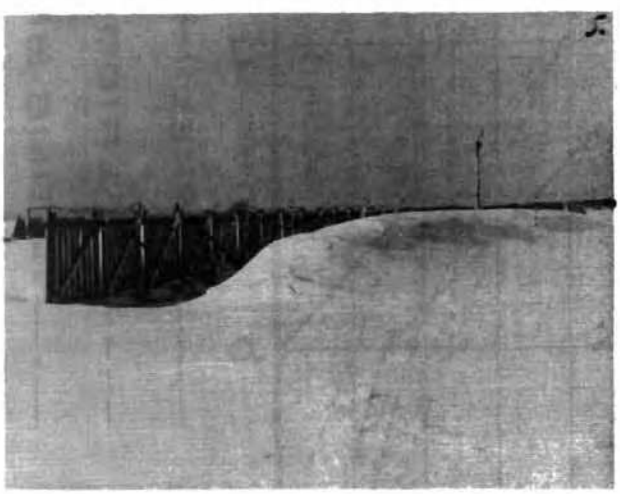
FENCE 1



FENCE 2



FENCE 3



FENCE 4

FENCE 5

FIG 84

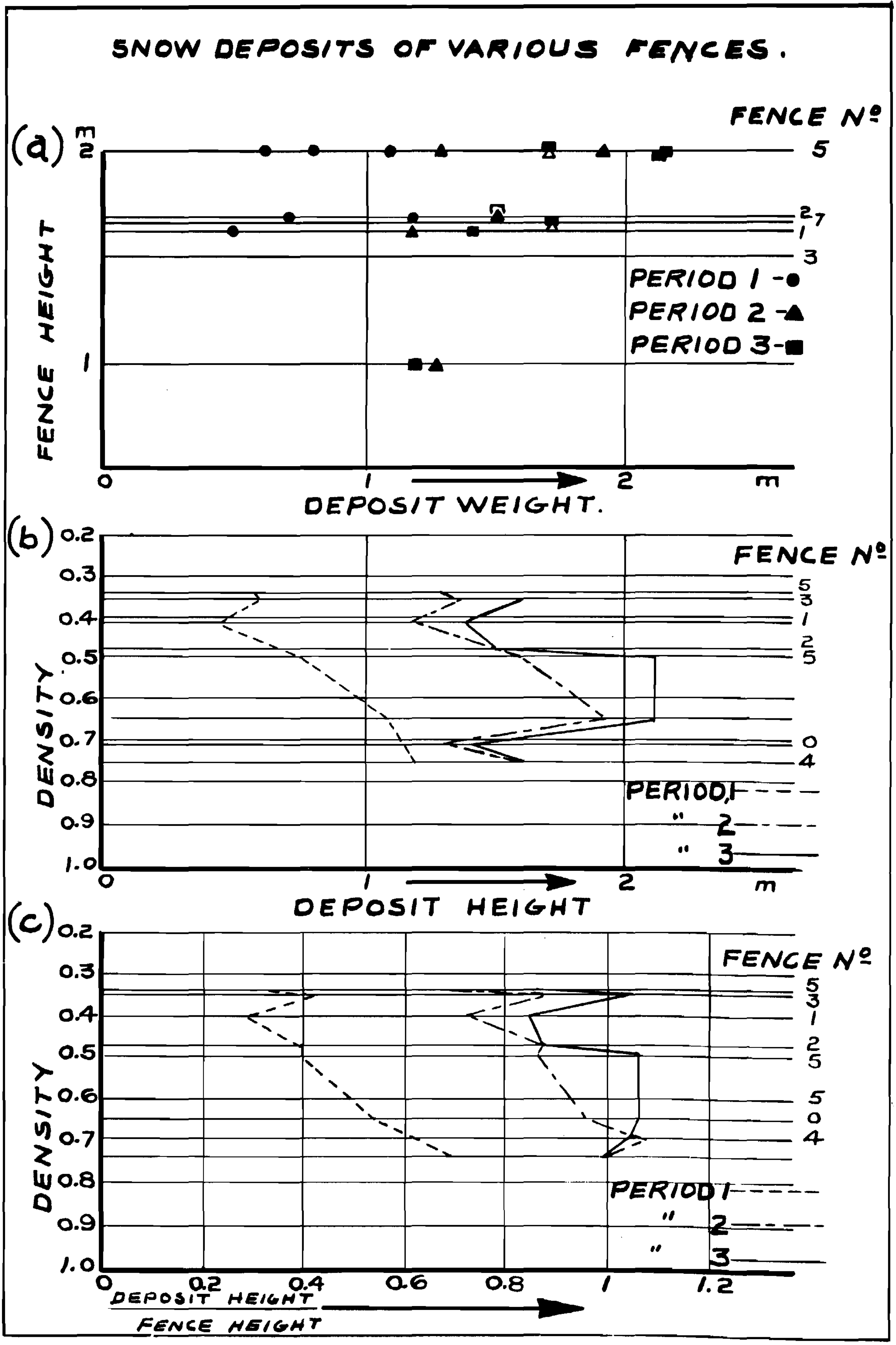

SNOW DEPOSITS OF VARIOUS FENCES.
(a)
FENCE No
FENCE HEIGHT
DEPOSIT WEIGHT.
PERIOD 1 -●
PERIOD 2 -▲
PERIOD 3 -■
(b)
FENCE No
DENSITY
DEPOSIT HEIGHT
PERIOD 1
" 2
" 3
(c)
FENCE No
DENSITY
DEPOSIT HEIGHT
FENCE HEIGHT
PERIOD 1
" 2
" 3

FIG. 85

LENGTH OF REAR SNOW DEPOSITS OF VARIOUS FENCES

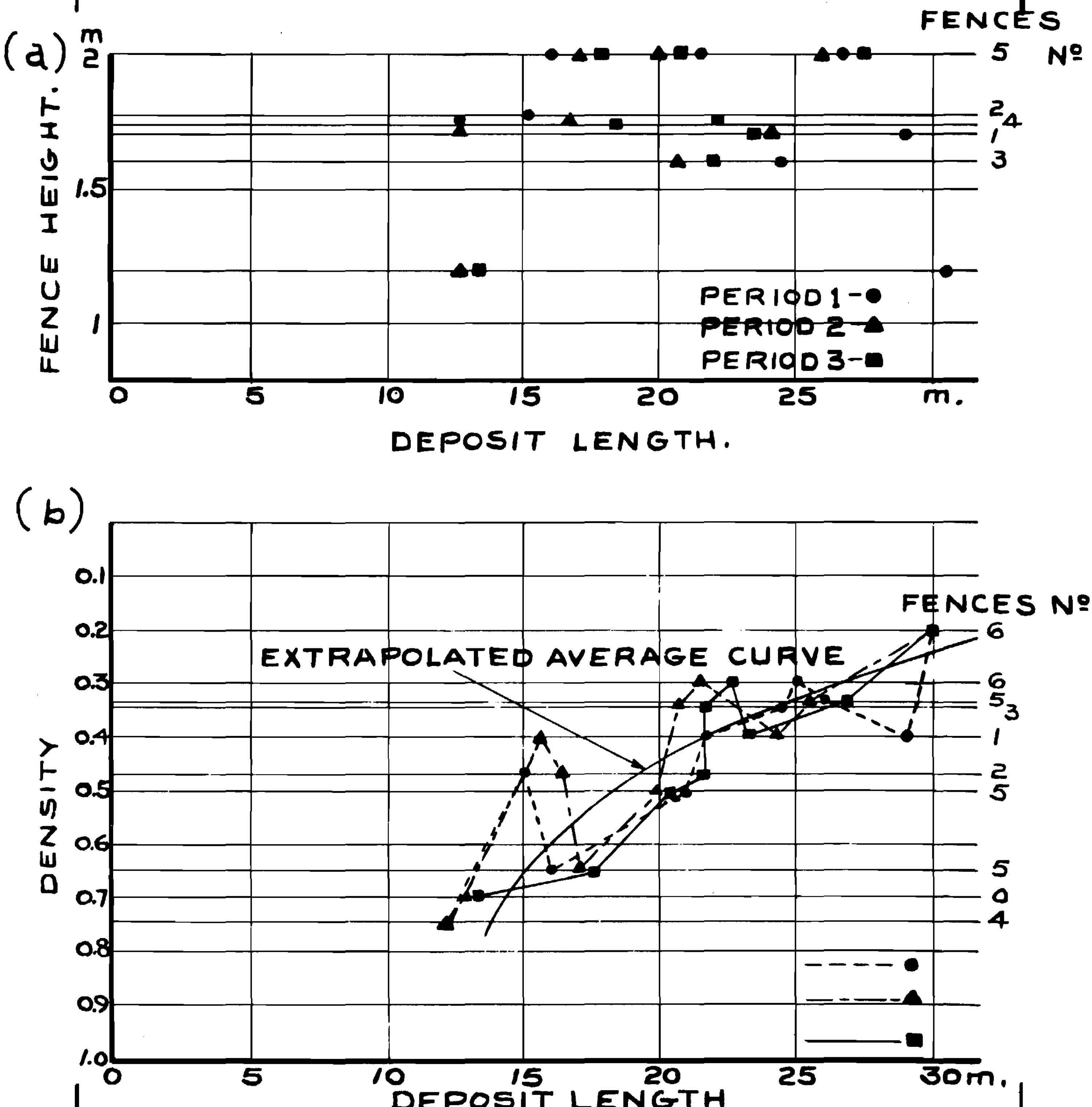


FIG 86

DETERMINATION OF THE LENGTH OF SNOW DEPOSIT.

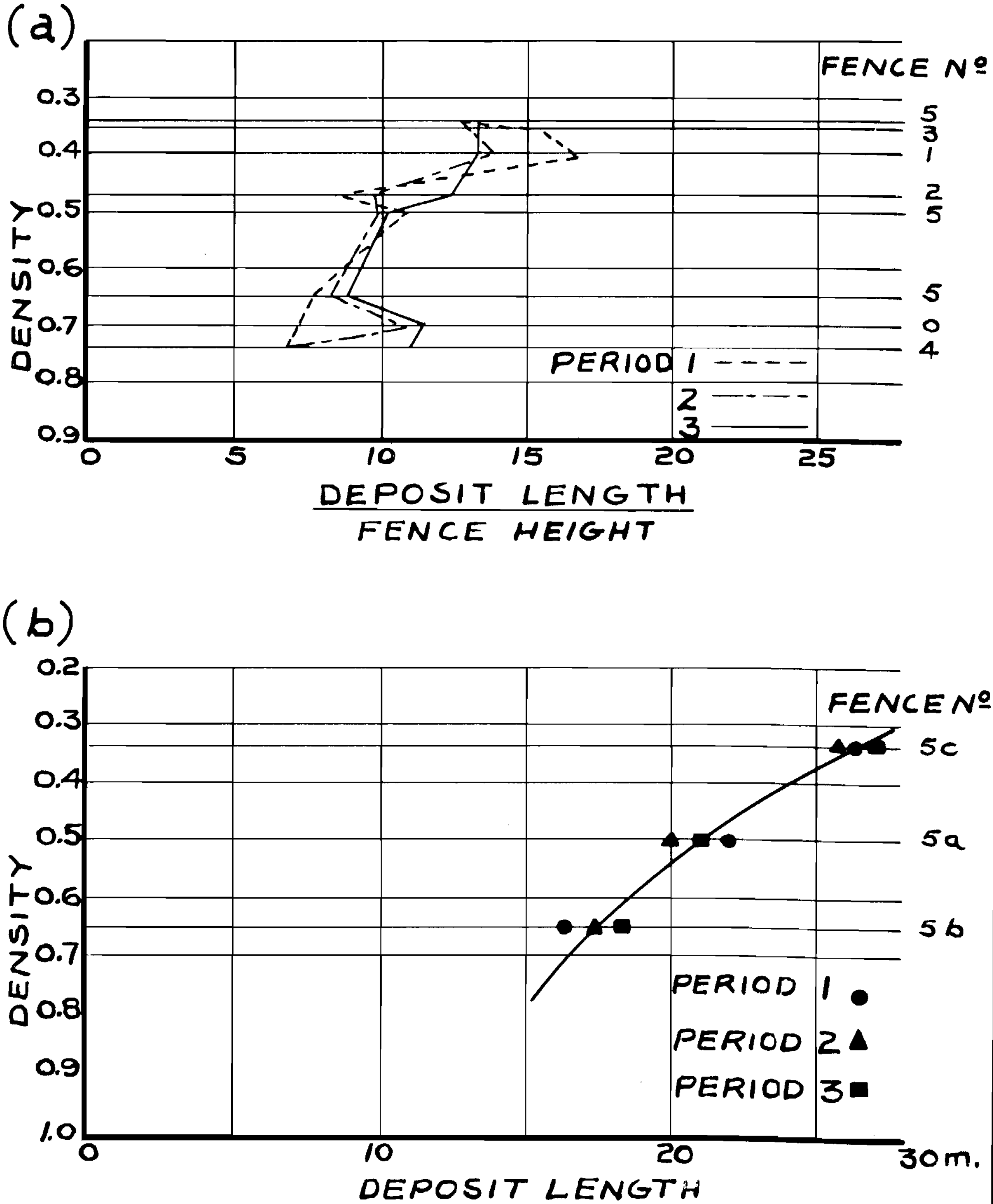
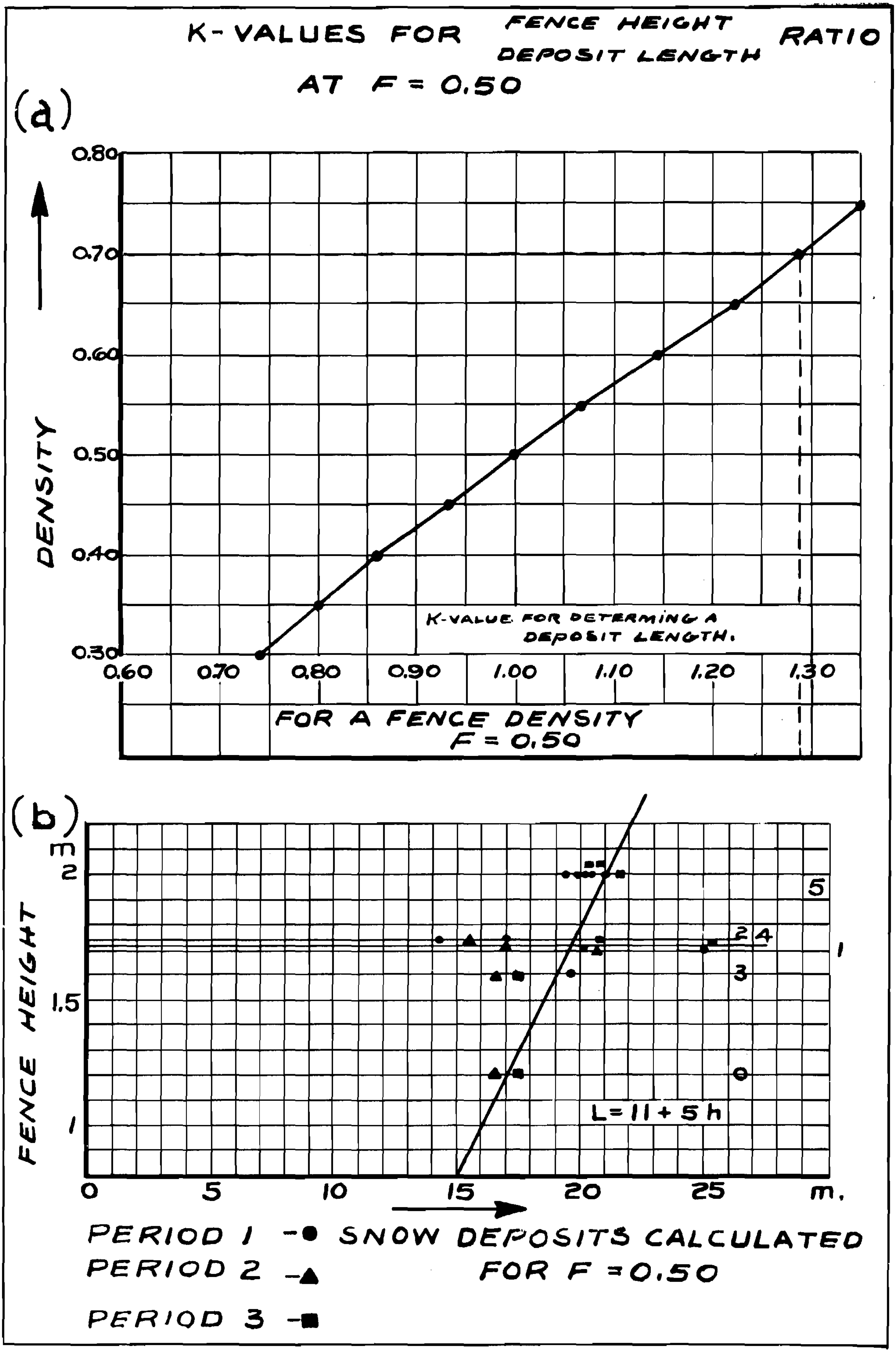


FIG. 87



K-VALUES FOR FENCE HEIGHT / DEPOSIT LENGTH RATIO
AT F = 0.50
(a)
DENSITY
0.80
0.70
0.60
0.50
0.40
0.30
0.60
0.70
0.80
0.90
1.00
1.10
1.20
1.30
K-VALUE FOR DETERMING A DEPOSIT LENGTH.
FOR A FENCE DENSITY F = 0.50
(b)
FENCE HEIGHT
m
2
1.5
1
0
5
10
15
20
25
m.
5
2
4
1
3
0
L=11+5h
PERIOD 1 –●
PERIOD 2 –▲
PERIOD 3 –■
SNOW DEPOSITS CALCULATED FOR F = 0.50

FIG. 88

DISTANCE REQUIRED BETWEEN SNOW FENCES AND PROJECTED ROADS.

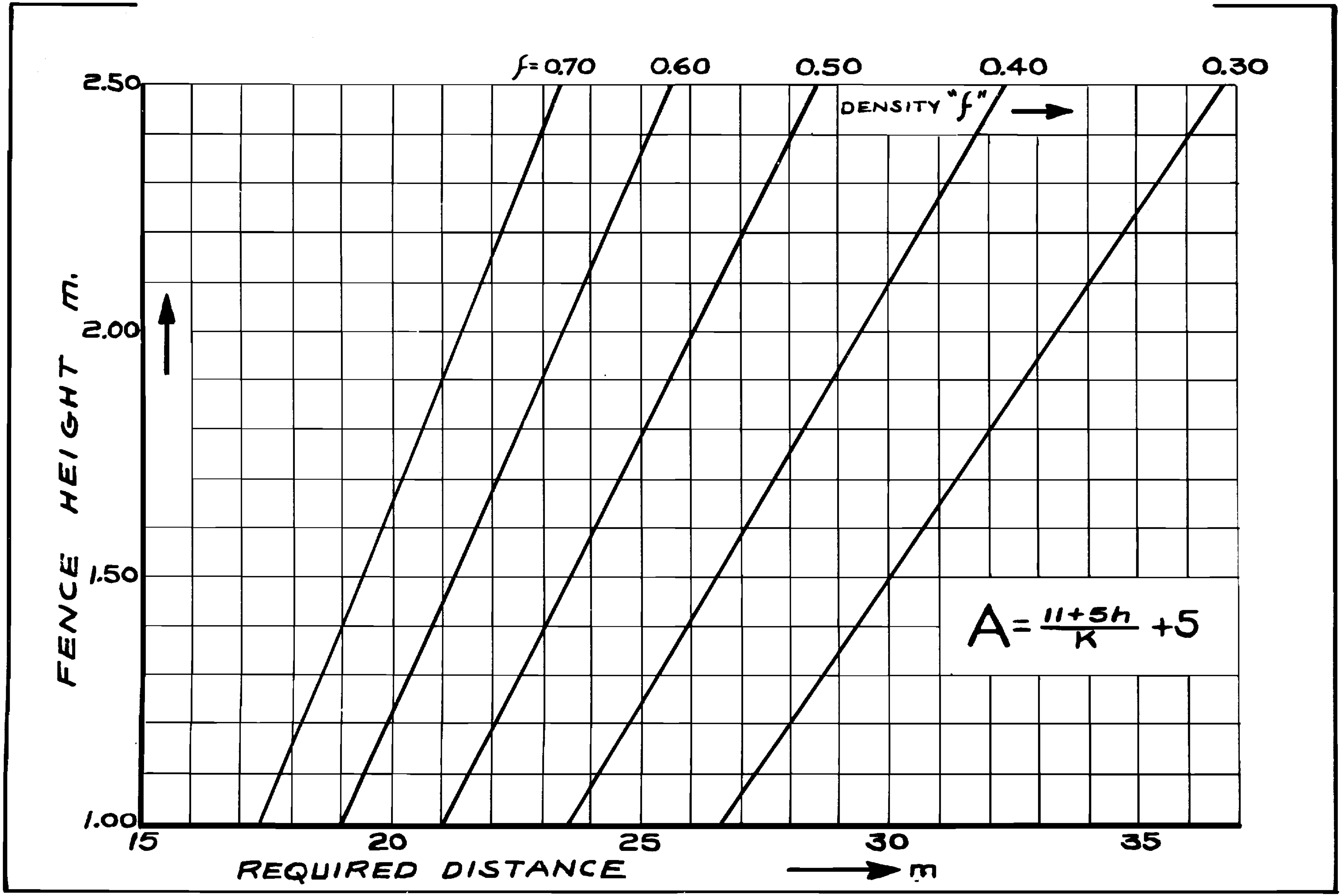
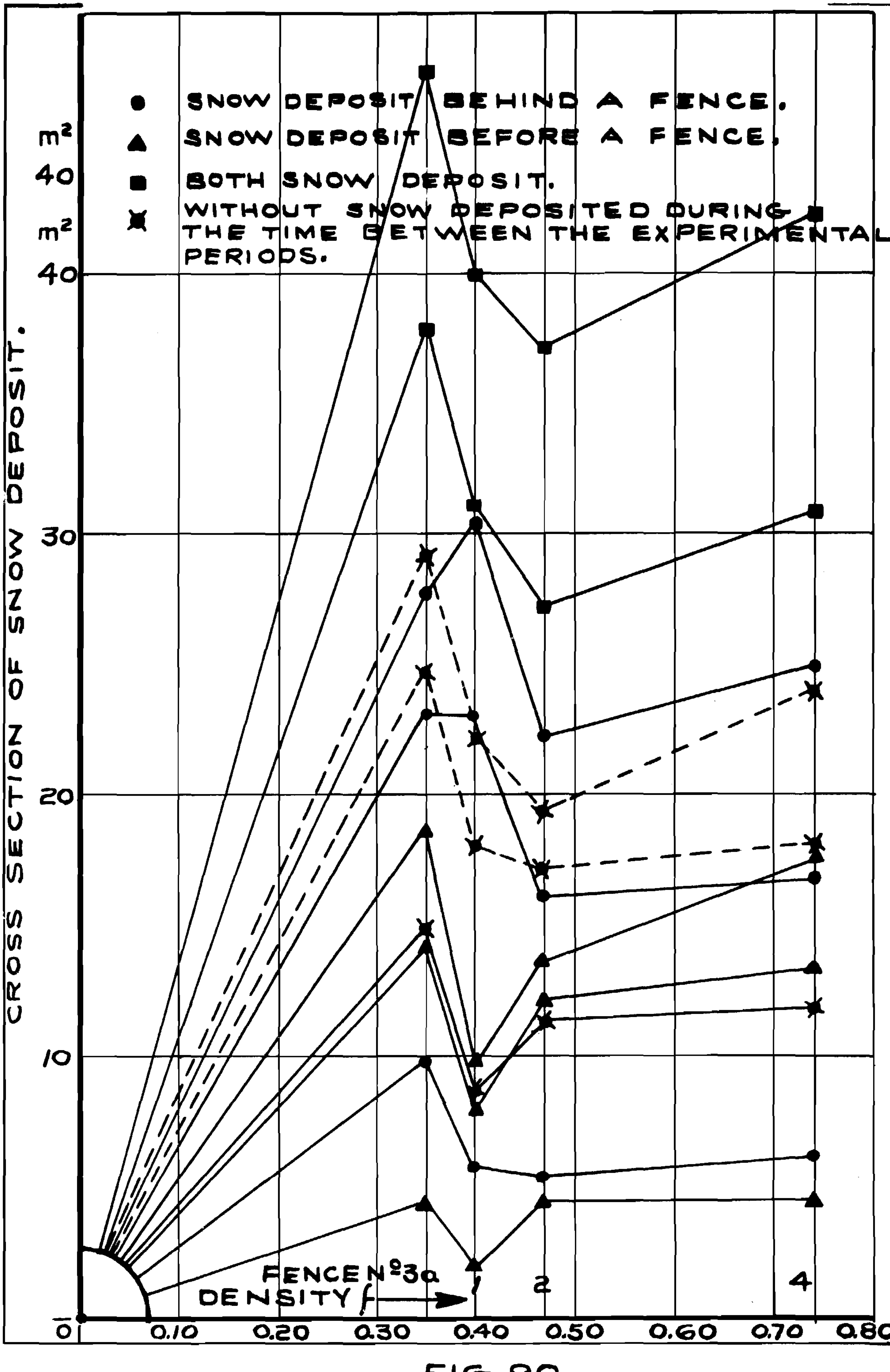


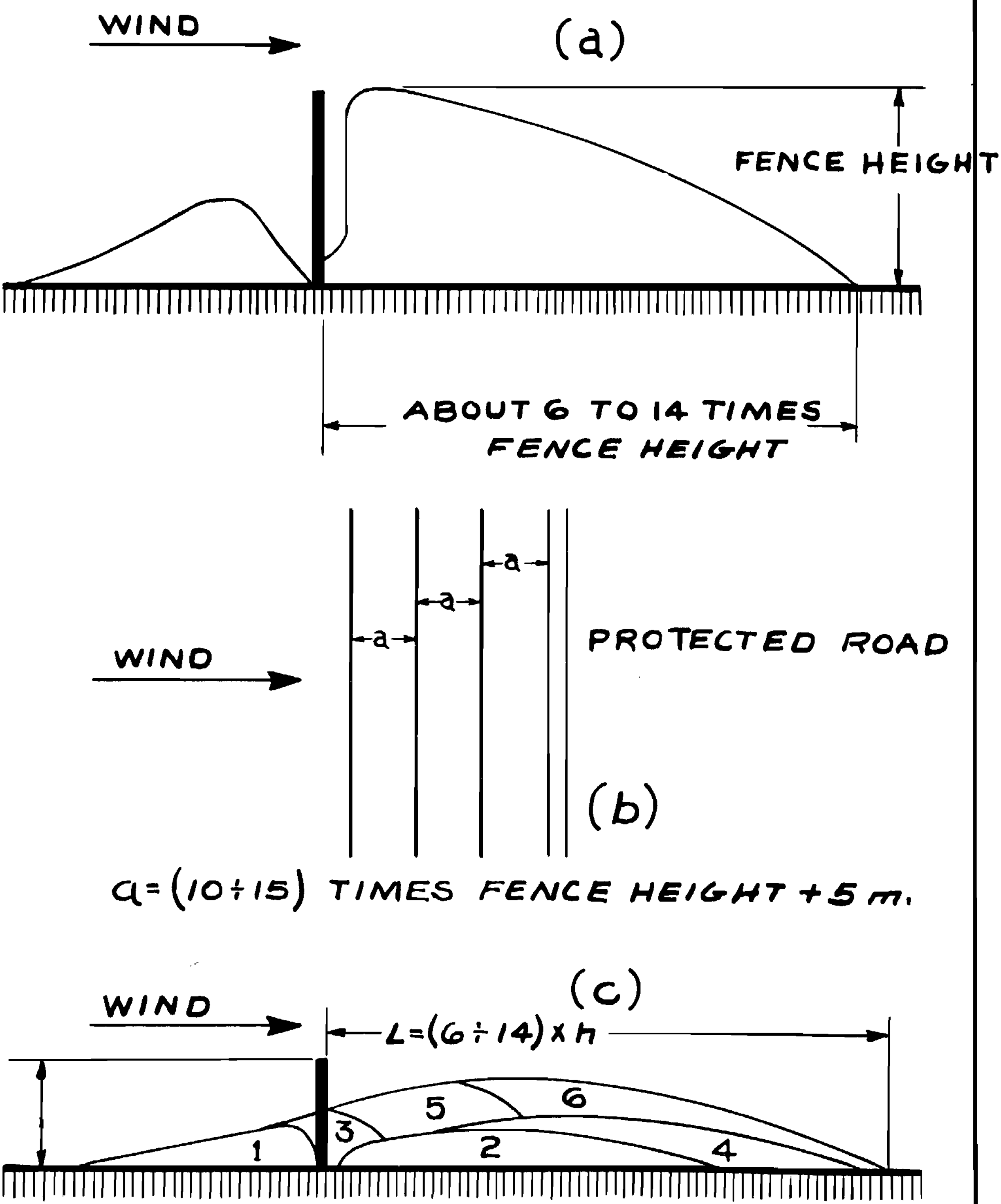
FIG. 89



● SNOW DEPOSIT BEHIND A FENCE.
▲ SNOW DEPOSIT BEFORE A FENCE.
■ BOTH SNOW DEPOSIT.
✱ WITHOUT SNOW DEPOSITED DURING THE TIME BETWEEN THE EXPERIMENTAL PERIODS.
m²
40
m²
40
30
20
10
0
CROSS SECTION OF SNOW DEPOSIT.
FENCE Nº 3a
1
2
4
DENSITY f
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80

FIG. 90

SNOW DRIFTING



NUMBERS 1, 2, 3, 4, 5, 6, INDICATE THE SEQUENCE OF THE FORMATION OF A SNOW DEPOSIT

FIG. 91

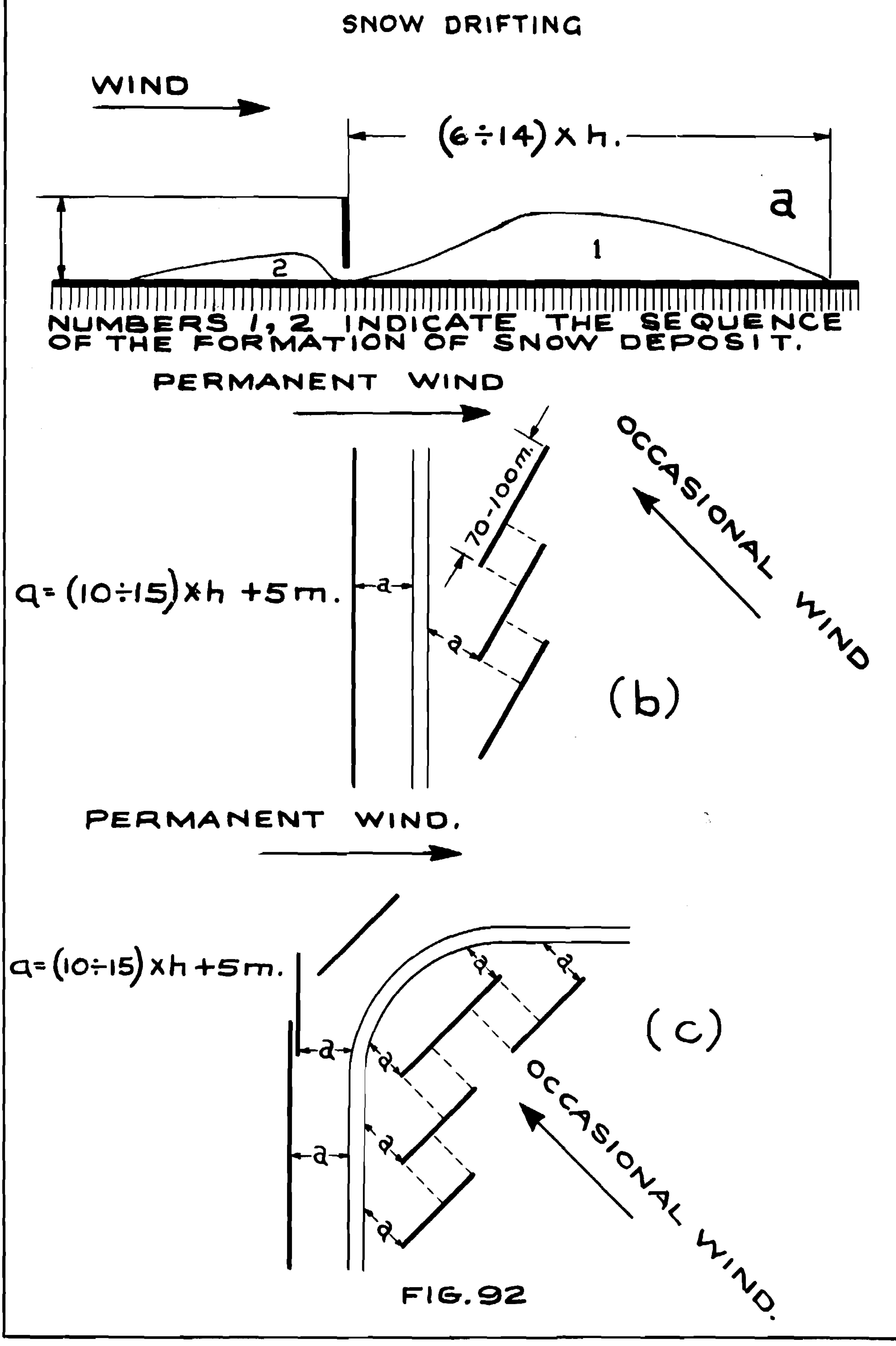

SNOW DRIFTING
WIND
(6÷14) x h.
a
1
2
NUMBERS 1, 2 INDICATE THE SEQUENCE OF THE FORMATION OF SNOW DEPOSIT.
PERMANENT WIND
70-100m.
OCCASIONAL WIND
a = (10÷15) x h + 5 m.
a
a
(b)
PERMANENT WIND.
a = (10÷15) x h + 5 m.
a
a
a
a
a
a
a
(c)
OCCASIONAL WIND.

FIG. 92

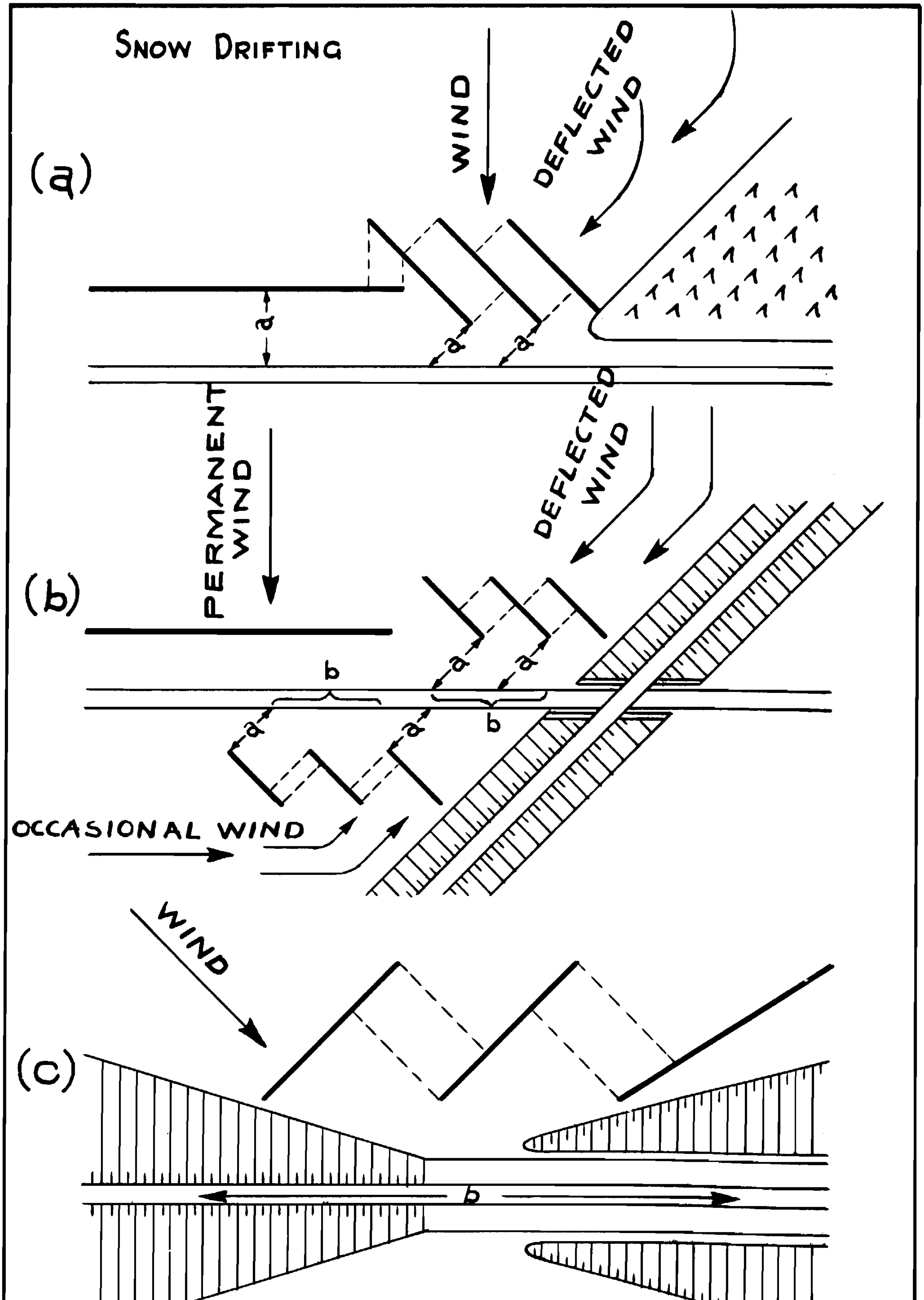

SNOW DRIFTING
(a)
WIND
DEFLECTED WIND
a
a
a
PERMANENT WIND
DEFLECTED WIND
(b)
b
a
a
a
a
b
OCCASIONAL WIND
WIND
(c)
b

FIG. 93

MORTAR TRAJECTORIES FOR SHOOTING AT PENDING AVALANCHES.

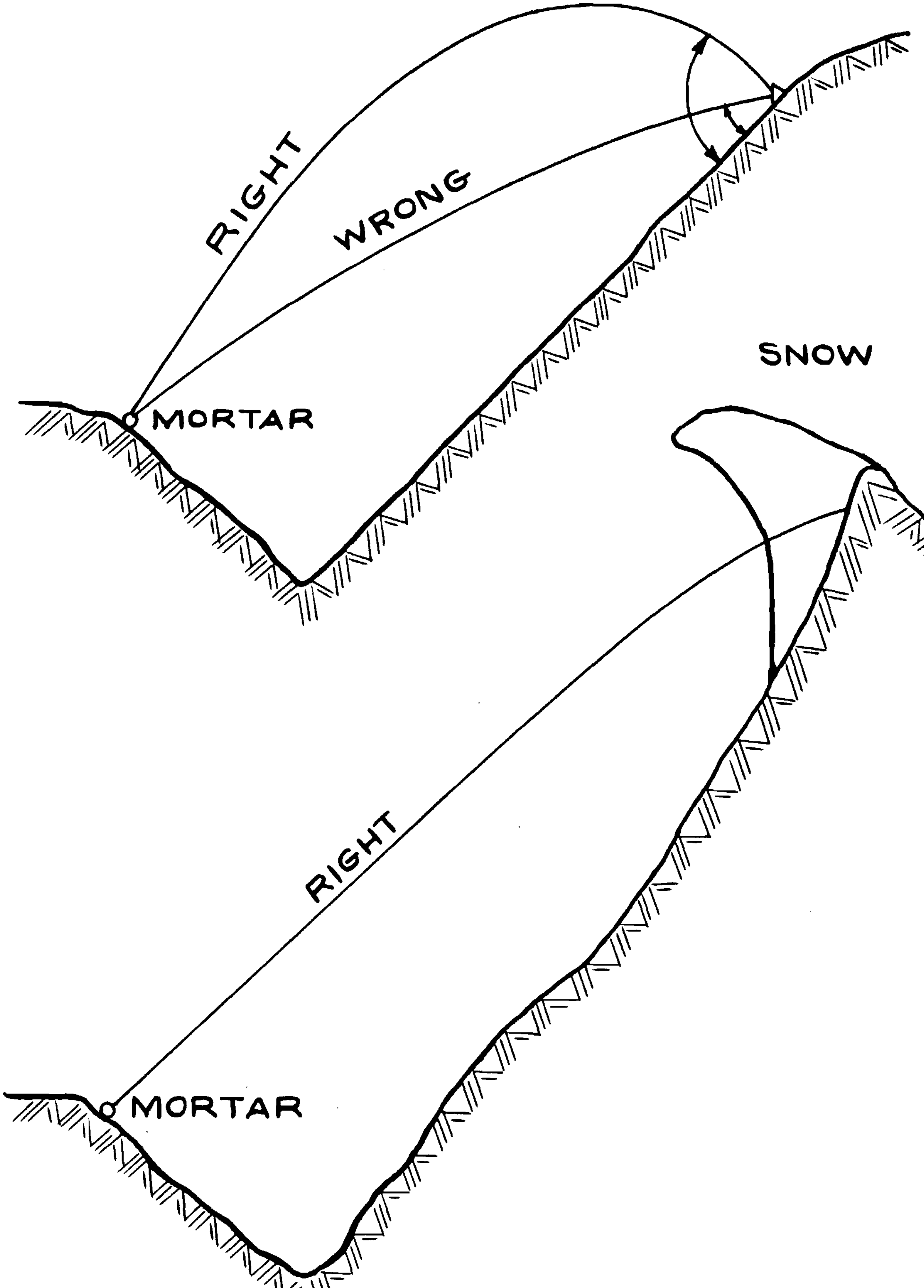


FIG. 94

NATIONAL RESEARCH COUNCIL

ASSOCIATE COMMITTEE ON SOIL AND SNOW MECHANICS

LIST OF TECHNICAL MEMORANDA

No.	Date	Title
1	August, 1945	Proposed field soil testing device. ★
2	September, 1945	Report classified "restricted"
3	November, 1945	Report classified "confidential"
4	October, 1945	Soil survey of the Vehicle Proving Establishment, Ottawa. ★
5	November, 1946	Method of measuring the significant characteristics of a snow-cover. G. J. Klein. ★
6	November, 1946	Report classified "confidential"
7	March, 1947	Report classified "restricted"
8	June, 1947	Report classified "confidential"
9	August, 1947	Proceedings of the 1947 Civilian Soil Mechanics Conference.
10	October, 1947	Proceedings of the Conference on Snow and Ice, 1947.
11	March, 1949	Proceedings of the 1948 Civilian Soil Mechanics Conference.
12	May, 1949	Index to Proceedings of Rotterdam Soil Mechanics Conference. (Soil Mechanics Bulletin No. 1).
13	June, 1949	Canadian papers: Rotterdam Soil Mechanics Conference.
14	December, 1949	Canadian papers presented at the Oslo meetings of the International Union of Geodesy and Geophysics.
15	April, 1950	Canadian survey of physical characteristics of snow-covers. G. J. Klein.
16	April, 1950	Progress report on organic terrain studies. N. W. Radforth.
17	August, 1950	Proceedings of the 1949 Civilian Soil Mechanics Conference.
18	November, 1950	Method of measuring the significant characteristics of a snow-cover. G. J. Klein, D. C. Pearce, L. W. Gold.
19	April, 1951	Proceedings of the 1950 Soil Mechanics Conference.

★ Out of print