SECTION XXVII

Icing Nomenclature

Introductory Remarks

During the past five years numerous geometric shapes, especially cylinders, have been exposed to icing at the Mount Washington Observatory for the purpose of studying the ice which has accumulated on them. As early as the first year certain definite types of ice were observed to be common on rotating cylinders, and at the end of the second year other types were considered to be characteristic of deposits on stationary cylinders and were studied by Langmuir(1). Since that time over 2000 ice deposits on rotating cylinders have been examined as well as many hundreds on stationary cylinders, cones, spheres, flat ribbons, and airfoils. As a result of this extensive examination of ice formations at the Mount Washington Observatory, it has been found that not only have few exceptions to the original classifications been observed but also that all of the stationary objects which were exposed collected ice of the types observed on the rotating cylinders and in shapes observed on the stationary cylinders. Moreover, all photographs of ice encountered by aircraft in flight which have come to the attention of the writer have revealed ice formations of the types and shapes observed at the Mount Washington Observatory.

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(1) Langmuir, Irving, "Super cooled Water Droplets in Rising Currents of Cold Saturated Air", Part II. Aug. 1944.

In view of these considerations, it is the purpose of this report to describe and illustrate with photographs the various shapes and types of ice which have been observed at the Mount Washington Observatory, and to propose that this report be considered as a preliminary Ice Atlas. In the future, it is hoped that it may be strengthened, revised, or replaced by the contributions of other icing observers. In any case, it is hoped that it may provide at least a small step in the direction of standardization of icing nomenclature.

General Consideration of the Classification.

In the same manner in which a single cloud layer may contain two different cloud types with areas about which two observers will argue as to the type, so in the case of a single ice deposit there may be found two or more distinct types of ice with dispute as to where one type stops and the next begins. Then, as in the case of disputes over the proper classification of certain isolated clouds, there are disputes over the proper classification of certain isolated ice deposits. Nonetheless, there are enough strikingly different characteristics both in appearance and conditions of formation which are typical of each of the types to be proposed to warrant the establishment of a standard classification.

In appearance, ice deposits on both rotating and stationary objects may vary in their ability to transmit light from virtually clear ice with no air entrapped and a high degree of light transmissivity to opaque "ice" with a considerable amount of air entrapped and virtually no light transmissivity in thinnest layers. Further, it appears that close to the point of opacity in this gradation the ice loses a certain shininess which may be caused by either a frozen or unfrozen film of airfree deposit at this surface. Deposits with this shininess are classed in the family of glazes, while those which lack it and feature complete opacity are referred to as types of "rime" rather than just "ice".

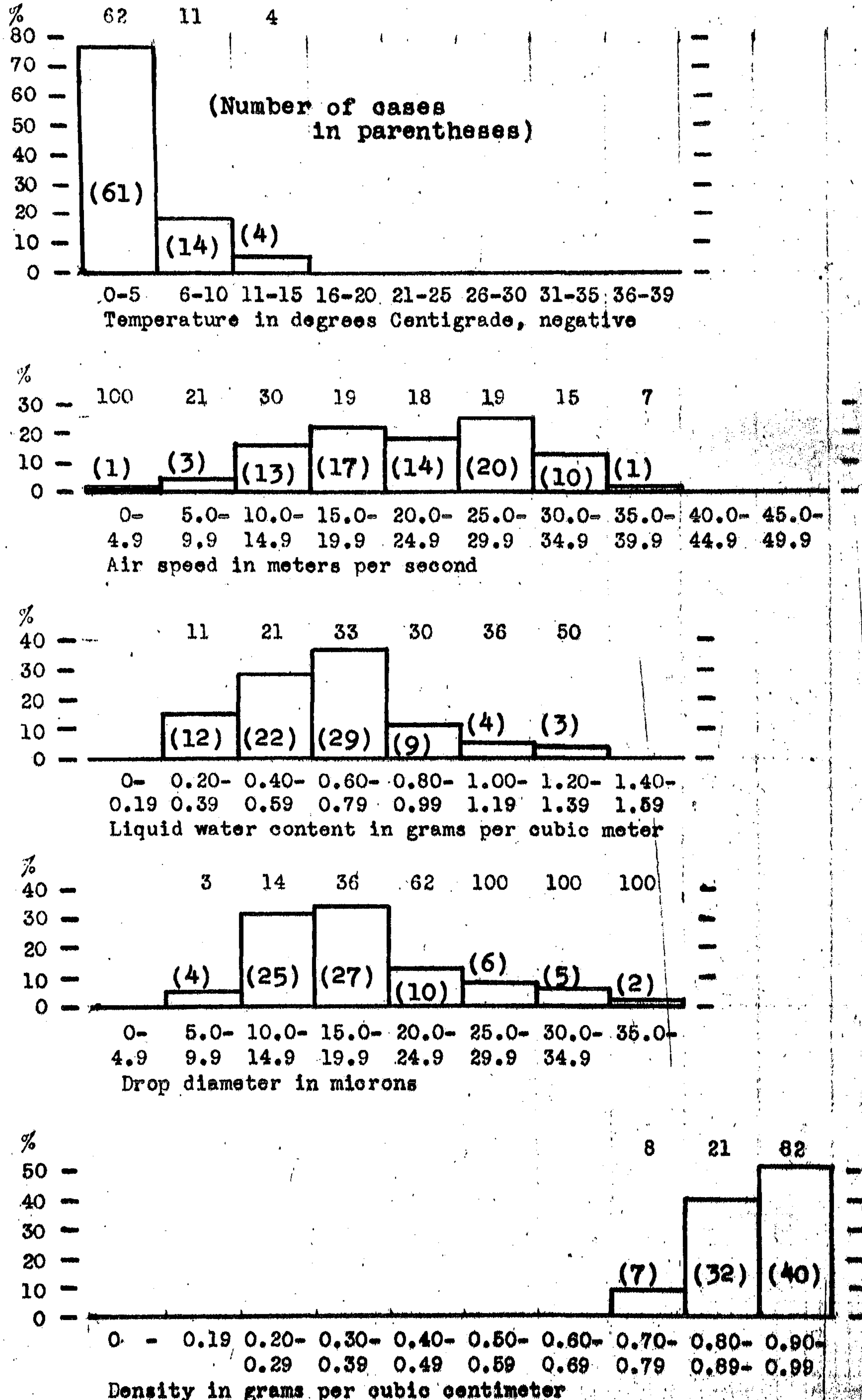
Following are listed the 6 primary and 2 secondary classifications of all ice:

Primary:

1) Clear Ice 2) Transparent Ice 3) Milky Ice	Family of Glazes
4) Opaque Rime 5) Kernel Rime 6) Feathery Rime Secondary: 1) Enamel Ice 2) Powder Rime	Family of Rimes

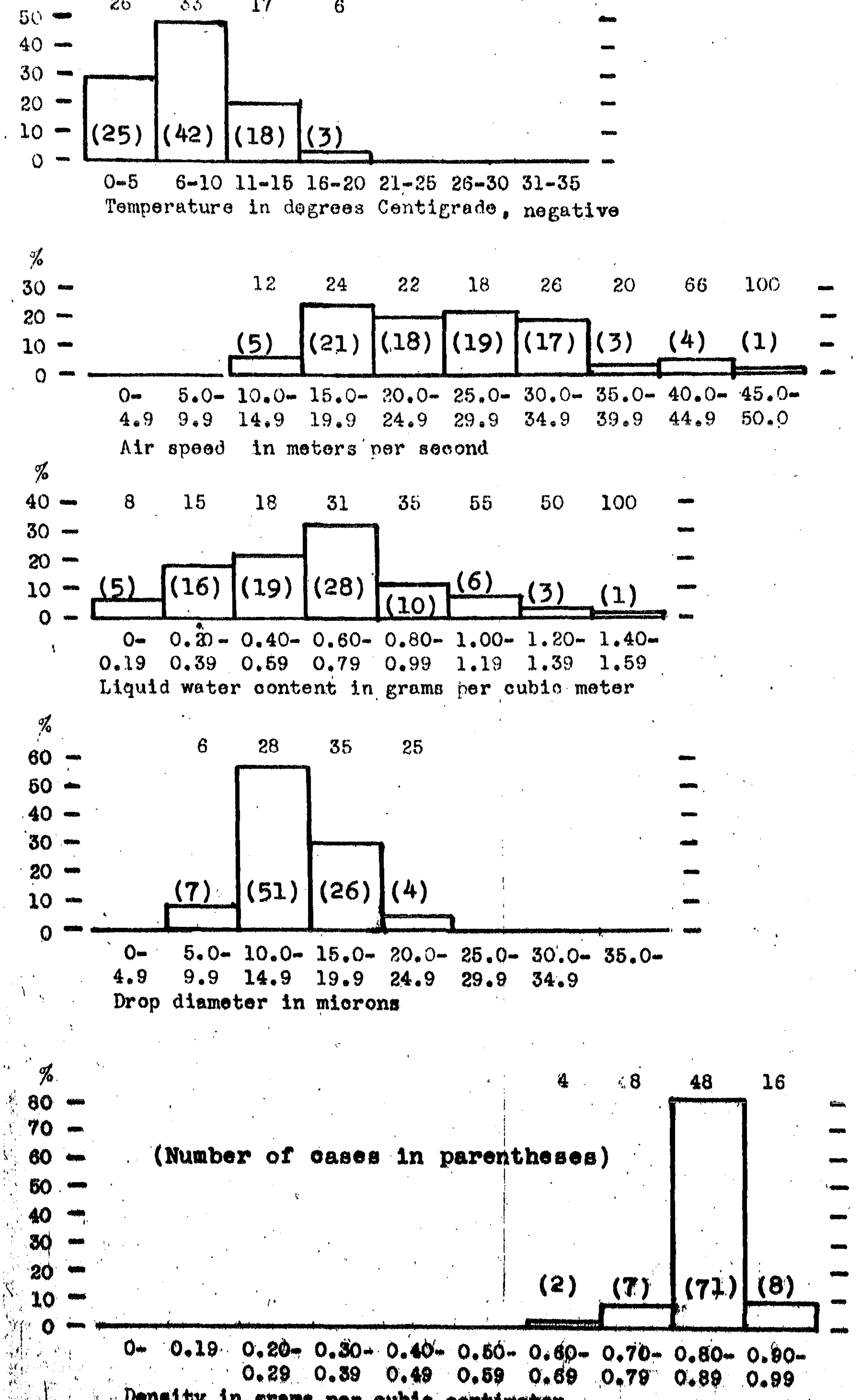
CLEAR ICE PERCENTAGE DISTRIBUTION OF OCCURRENCE

(79 cases)



The numbers across the tops of the columns give the ratio (%) of occurrence of clear ice to all icing under the conditions represented by the columns

TRANSPARENT ICE — PERCENTAGE DISTRIBUTION OF OCCURRENCE
(88 cases)



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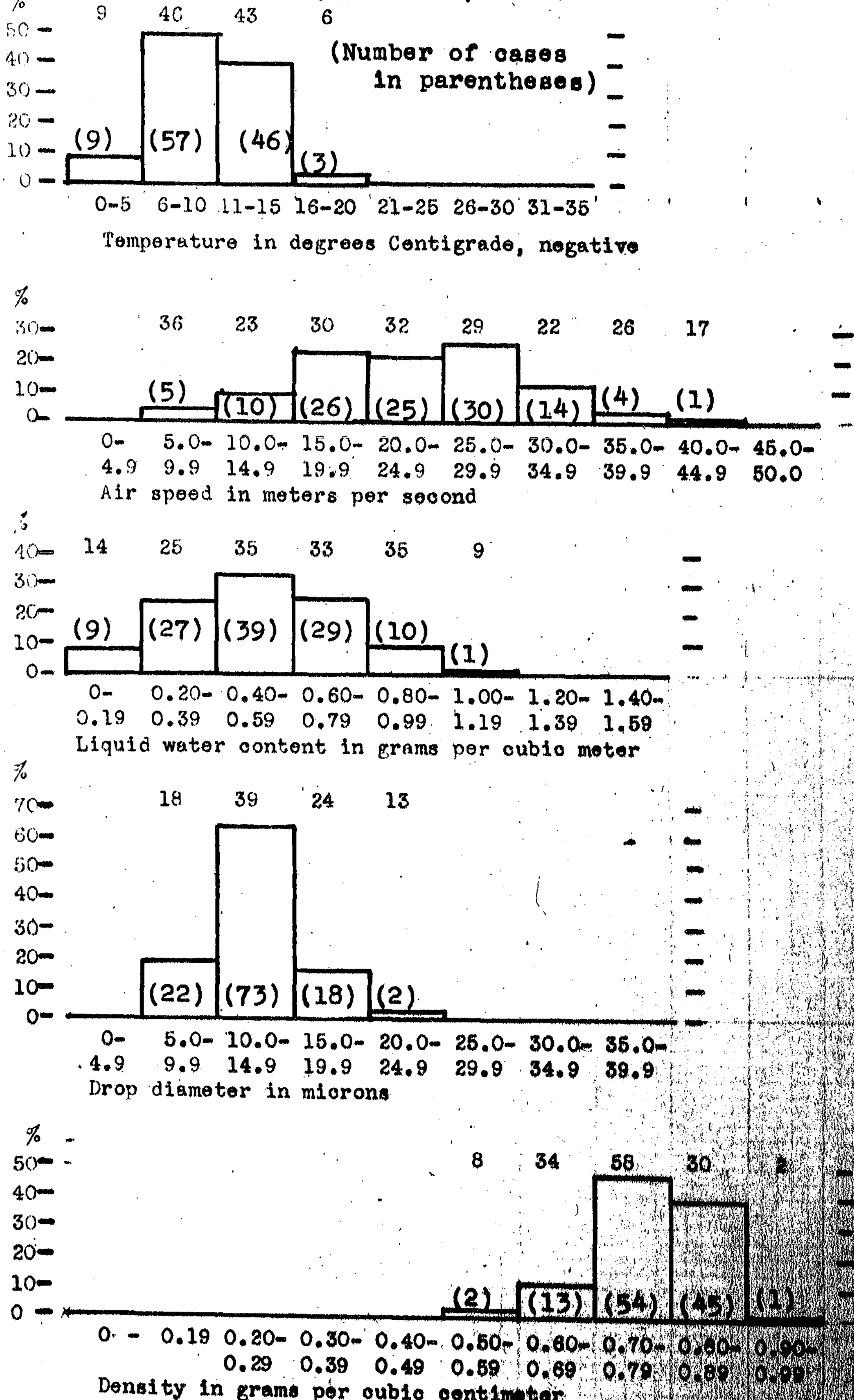
MILKY ICE PERCENTAGE DISTRIBUTION OF OCCURRENCE
(115 cases)



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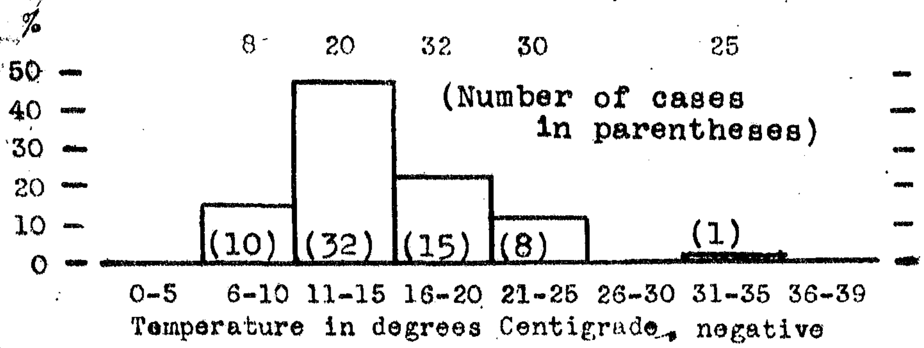
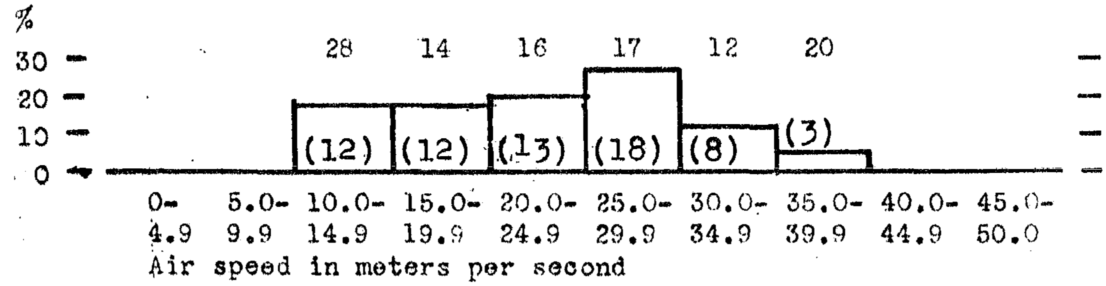
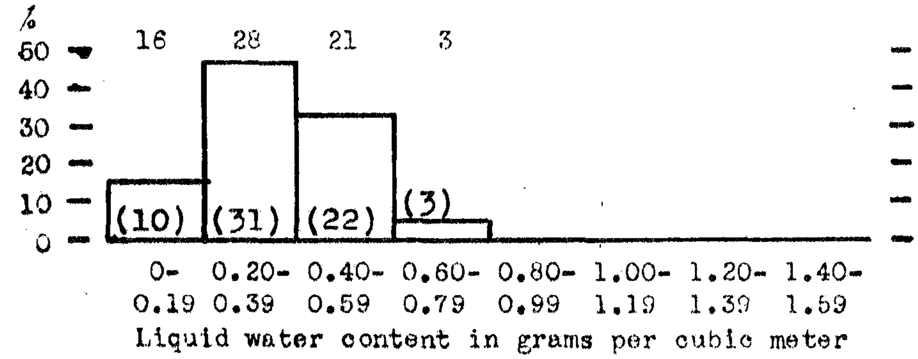
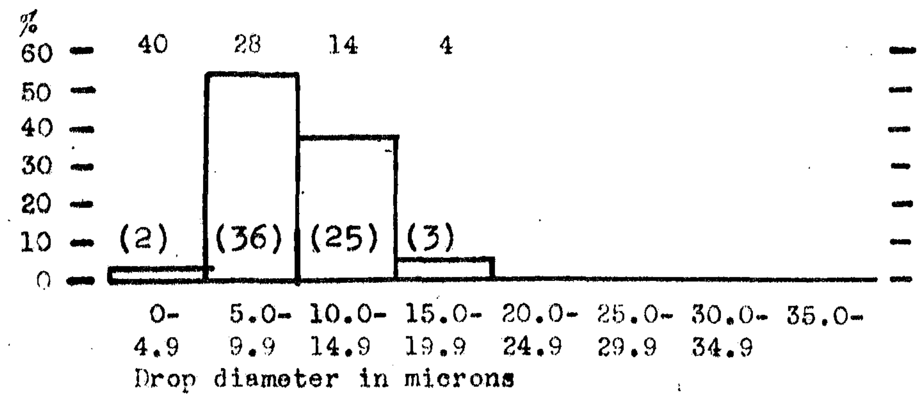
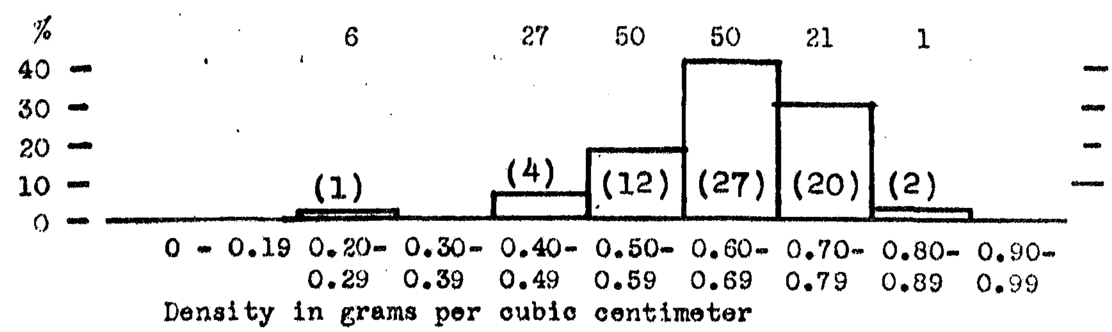
OPAQUE RIME PERCENTAGE DISTRIBUTION OF OCCURRENCE
(66 cases)





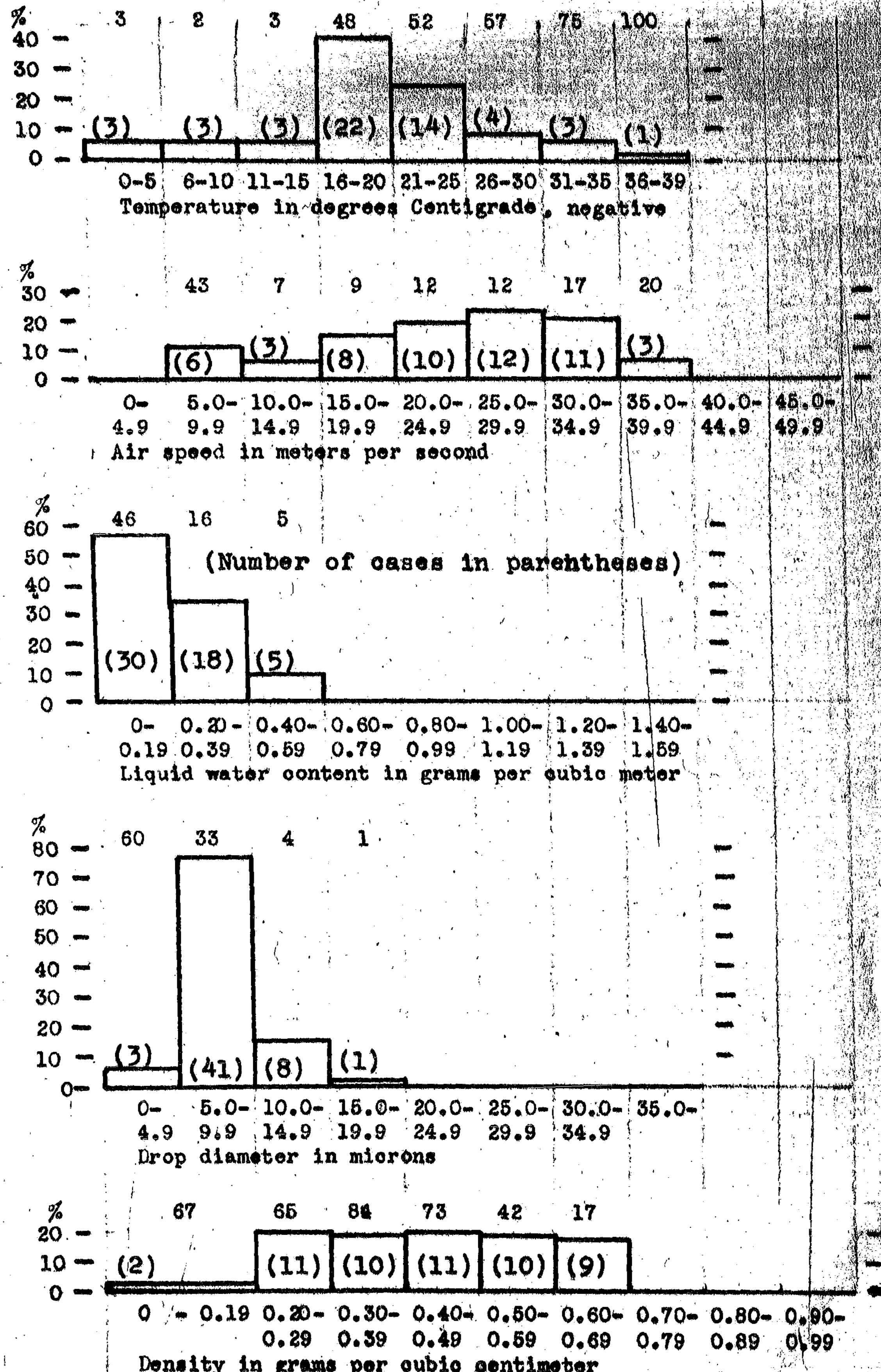






The numbers across the tops of the columns give the ratio (%) of occurrence of opaque rime to all icing under the conditions represented by the columns.

...DISTRIBUTION OF OCCURRENCE
(53 cases)



The numbers across the tops of the columns give the ratio (%) of occurrence of kernel rime to all icing under the conditions represented by the columns.

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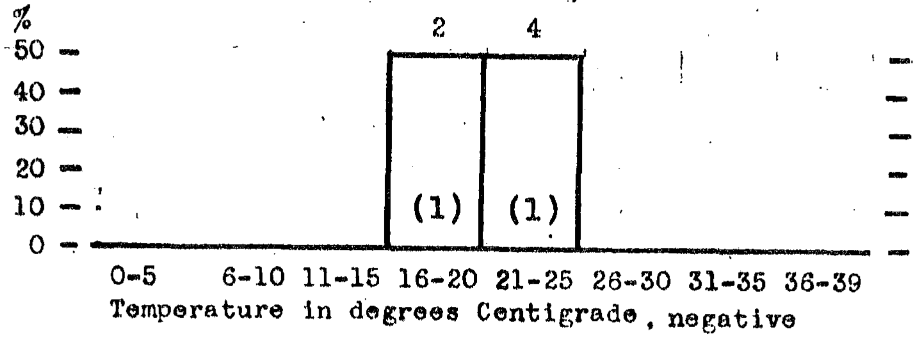
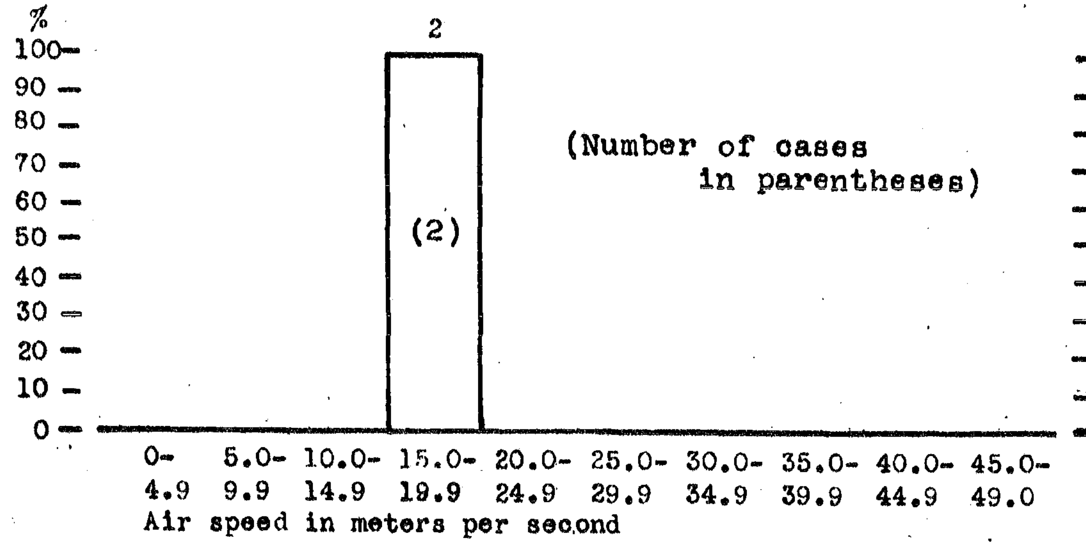
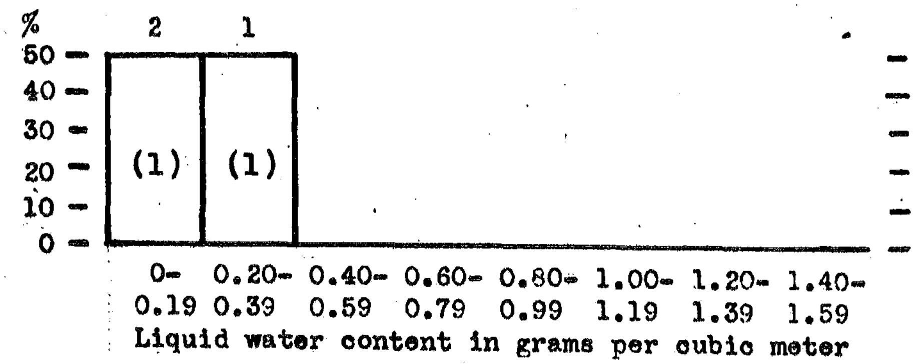
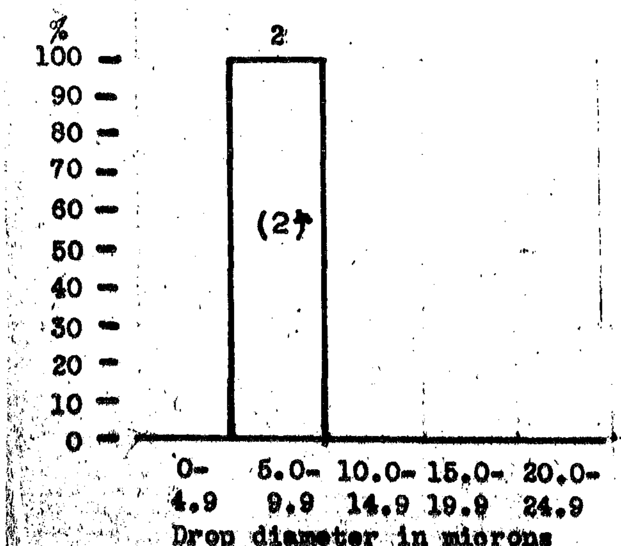
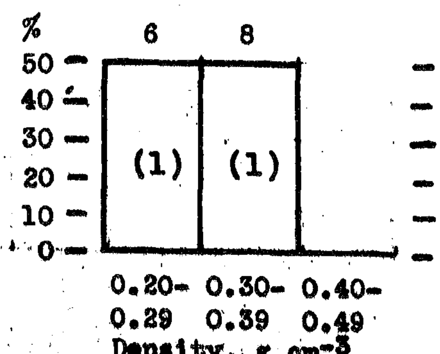
PERCENTAGE DISTRIBUTION OF OCCURRENCE
(2 cases)





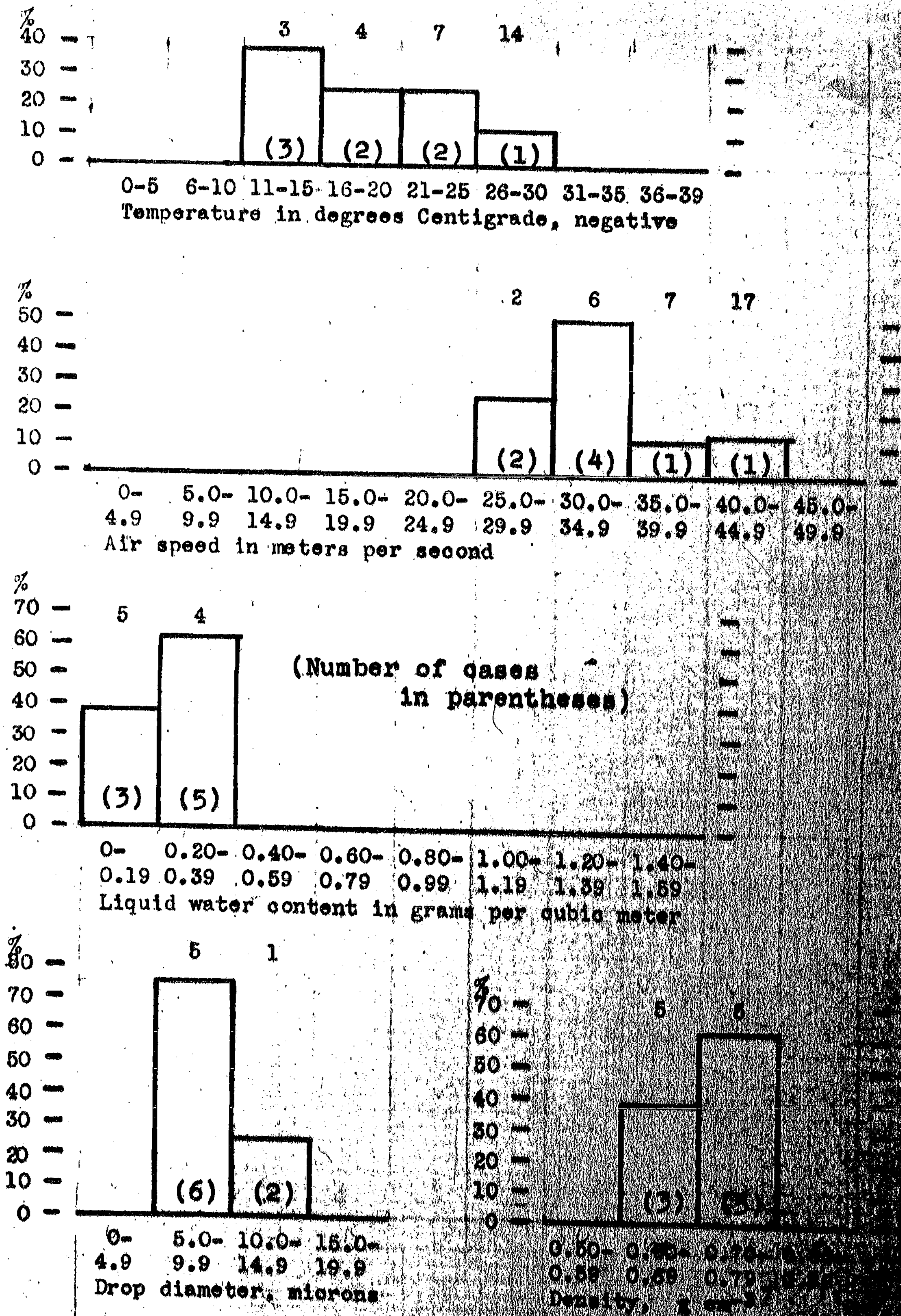






The numbers across the tops of the columns give the ratio (%) of occurrence of feathery rime to all icing under the conditions represented by the columns.

ENAMEL RIME PERCENTAGE DISTRIBUTION OF OCCURRENCE
(8 cases)



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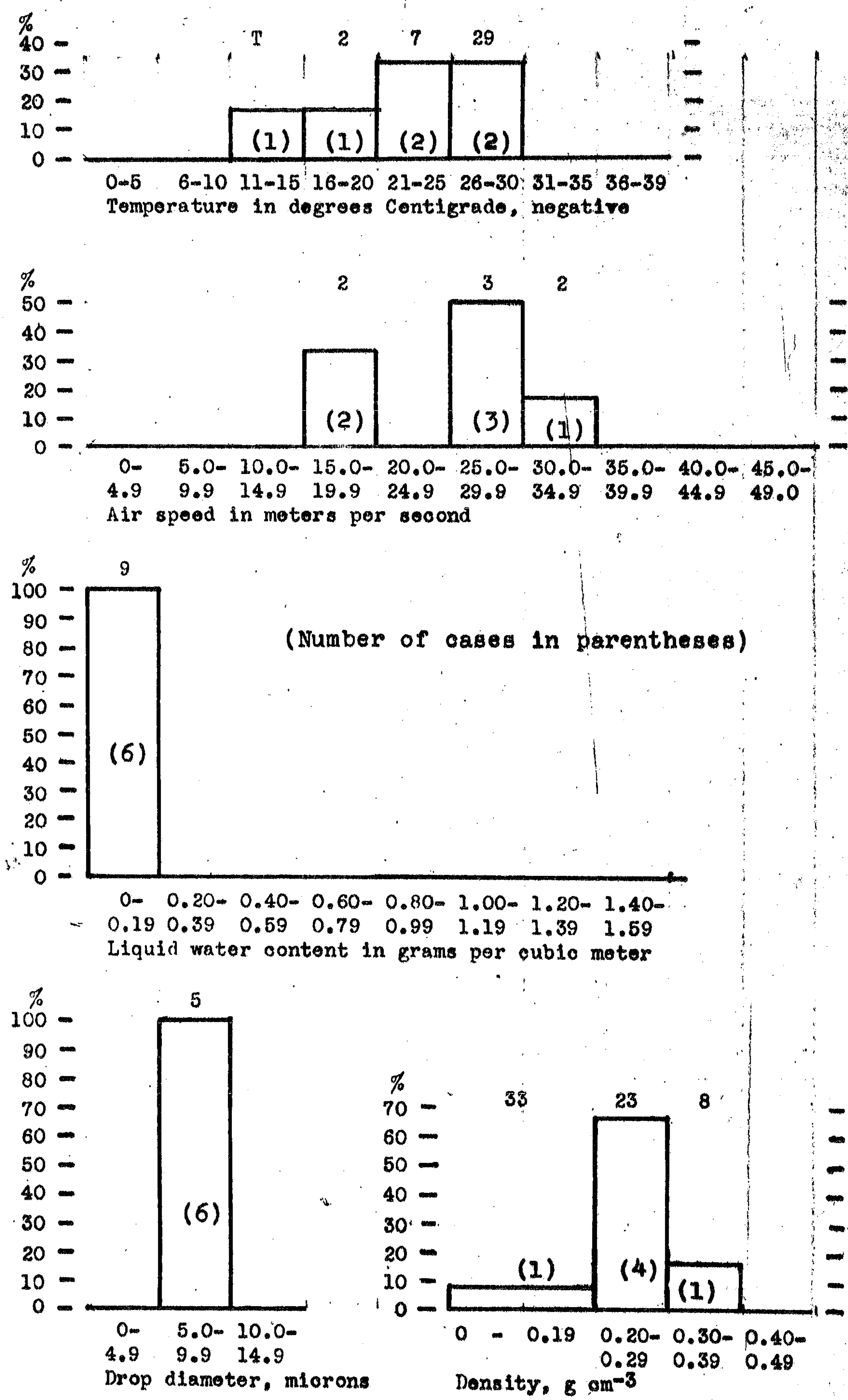
POWDER RIME PERCENTAGE DISTRIBUTION OF OCCURRENCE (6 cases)



The numbers across the tops of the columns give the ratio (%) of occurrence of powder rime to all icing under the conditions represented by the columns.

To further supplement these classifications, "hard", "soft", "rough", and "smooth" are used when the appearance and structure of the deposits call for it. As mentioned, it is not uncommon for different parts of a single deposit to be classified differently. Further remarks on the differentiation of the individual types are included in the discussion of each type.

While the above classification holds for deposits on both rotating and stationary collectors, and is primarily descriptive of the appearance of the ice, the classification now under discussion is used to describe stationary deposits only and is descriptive of the shape of the deposits. Listed below are the four primary and two secondary types of shape classification which are used:

Primary:

1) Ridged Type
2) Curved Type
3) Flat Type
4) Grooved Type

Secondary:

1) Double Ridged Type
2) Knife Type

With several exceptions which will be discussed later, each of one of these types has been observed with each one of the appearance classifications. Again, certain of these types may grade off into other types in the same ice specimen. Further remarks on each of these types is included in the individual descriptions in the body of this report.

Section I - Appearance Classification
(for stationary and rotating collectors)

1. Family of Glazes

A) Clear Ice:

Description: virtually no air entrapped. If a noticeable amount of air is visible in the ice, it is classified as Transparent Ice, although clear ice itself is very transparent. When at high temperatures the supercooled water is slow in freezing, it may move about and produce a very rough surface. The density of this type will normally be very close to $0.917 g/cm^3$.

Weather conditions: Clear ice is most likely to occur when the temperature is close to freezing, the particles are large, the water content is high, the collector is small, and the airspeed is high. Snow or sleet may be found to be embedded in the deposit when either is occurring. Due to the higher airspeed, aircraft in flight should experience clear ice and especially rough clear ice more often than at mountain tops.

Common Ice Shapes: When the droplet freezing time is short, the Curved Type is most common with Ridged Type in evidence on the smallest objects. When the droplet freezing time is long, the Double Ridged Type is common, especially on aircraft in flight. Grooved and Knife Types are non-existent with Clear Ice, while the Flat Type is rare with Clear Ice.

CLEAR ICE WITH MILKY ICE EDGES.

Photograph Number 1:

April 19, 1946, 7 AM; Exposure: 15 minutes
Precipitation: None
Temperature: -12°C; Airspeed: 26.4m/s
Water Content: 0.66g/m^3; Drop Diam: 16.9 mic.
Scale: Diam of Cone Base = 5.08 cm.
Scale: Diam of Largest Sphere = 10.16 cm.

Note the borders of all deposits have considerable air entrapped and would be classified as Transparent or Milky Ice. The whiteness near the apex of the cone should not be construed to reveal a lower density, since it is believed to be merely the result of the glare from the flood light.

CLEAR ICE WITH MILKY ICE EDGES.

Photograph Number 2:

April 26, 1946, 1 PM; Exposure: 24 minutes
Precipitation: Snow
Temperature: -30°C; Airspeed: 15.6m/s
Water Content: 0.43 g/m^3; Drop Diam : 16.7E mic.

This photograph is similar to Photograph #1, but the milky ice edges are more striking than in the previous case. Although the temperature is higher in this case the airspeed is considerably less.

CLEAR ICE BASE WITH FEATHERY RIME RIDGE.

Photograph Number 3:

April 5, 1946, 4 AM; Exposure: 60 minutes
Precipitation: Sleet and Rain
Temperature: -6°C; Airspeed: 11.2 m/s
Water Content: 0.74 g/m^3; Drop Diam : 20.6E mic.
Scale: Max. Airfoil Thickness = Approx. 25 cm.

This photograph illustrates an unusual ice deposited on a 1/4 scale model of a DC-3 wing which formed from a mixture of fog, rain, and sleet. As can be seen, the rain drops formed on the entire windward side back to the tangent point, while the smaller fog particles formed a fairly fragile feathery rime ice strip along the stagnation line.

ROUGH CLEAR ICE.

Photograph Number 4:

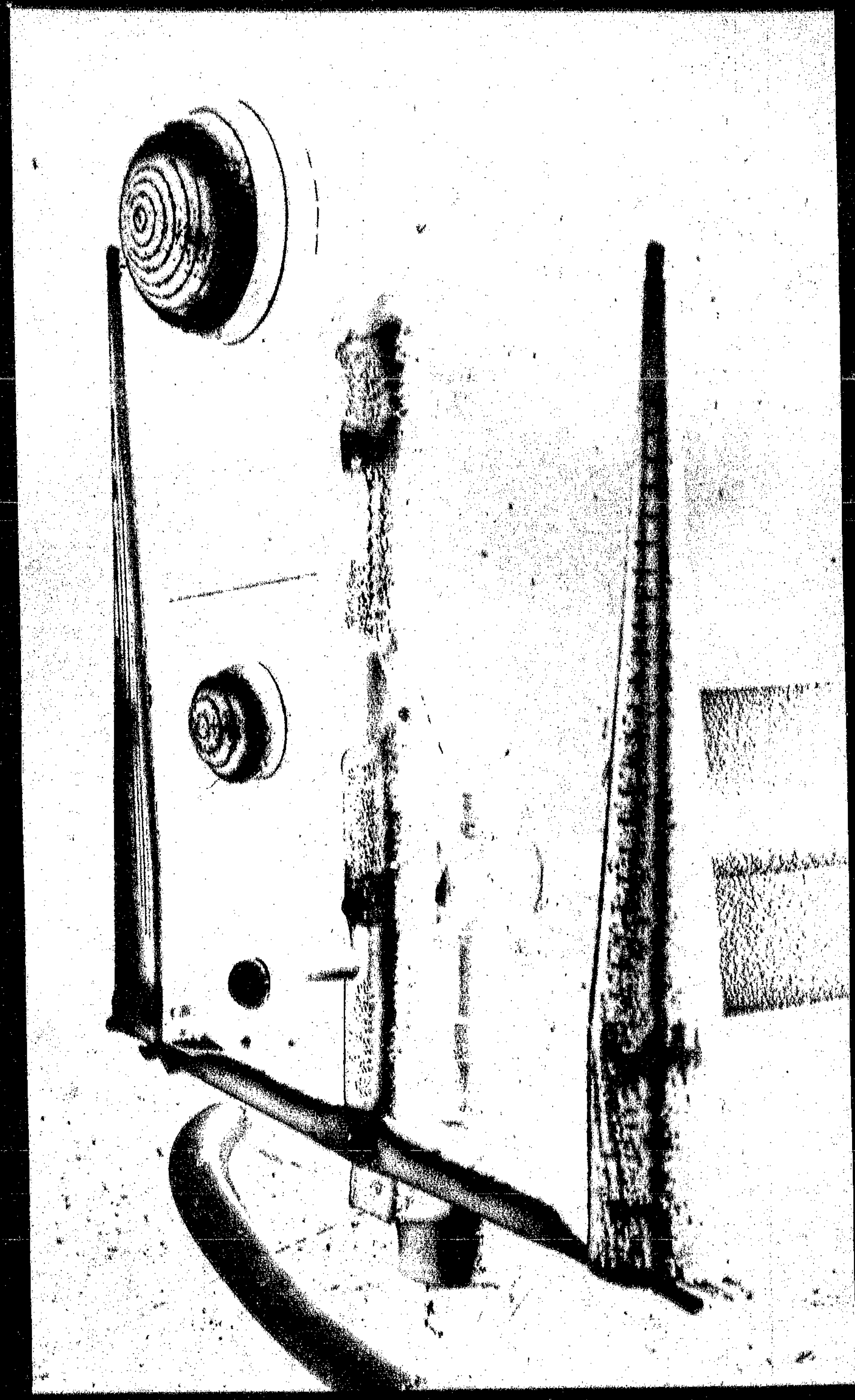
April 3, 1946, 7 AM; Exposure: 20 minutes
Precipitation: Freezing Rain
Temperature: -4°C; Airspeed: 13.4 m/s
Water Content: 0.86 g/m^3; Drop Size: > 21.3 mic.

This photograph is an extreme case of rough clear ice for Mount Washington, but is believed to be typical of rough clear ice encountered by aircraft in flight.

B) Transparent Ice:

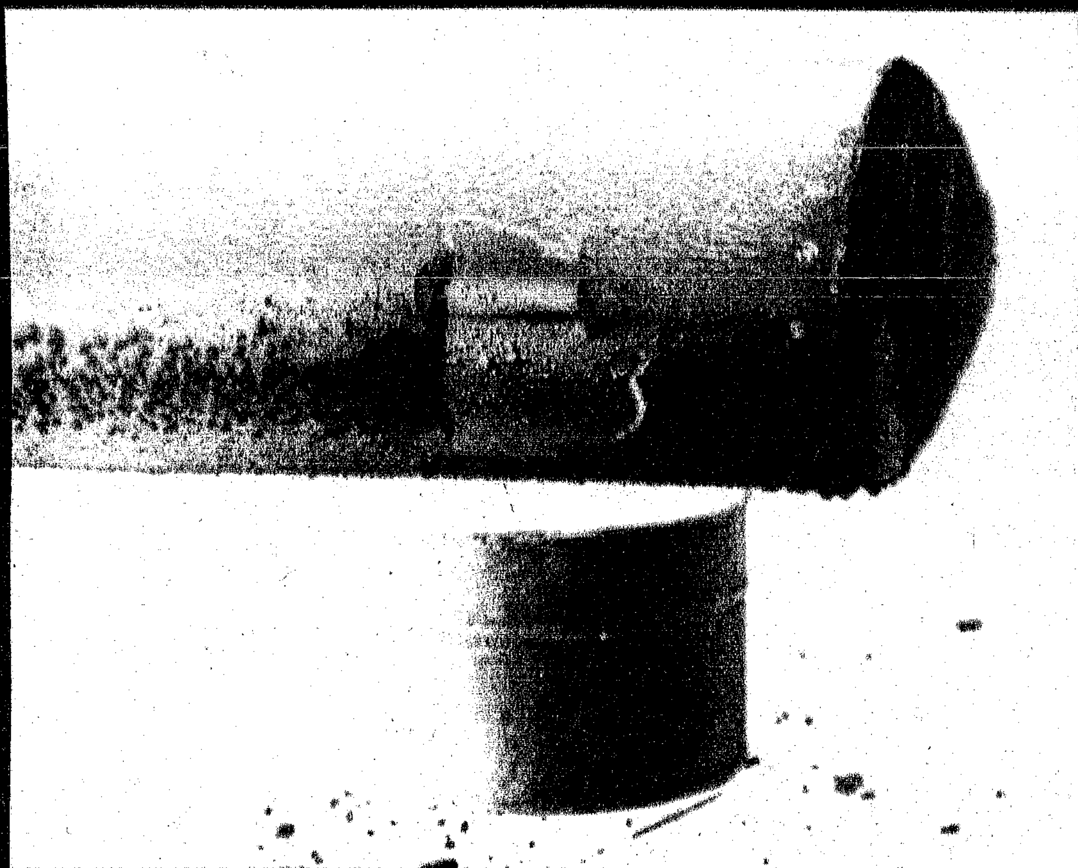
Description: moderate amount of air entrapped, but still definitely transparent. This type is similar in appearance to Clear Ice, but for this type a noticeable amount of air in fairly large bubbles will be seen despite the transparency of the ice. If the ice becomes translucent due to entrapped air, the ice is classified as Milky Ice. The ice density typically will be 0.85 g/cm^3.

Weather Conditions: Transparent ice is favored by high values of temperature, water content, drop size, airspeed, and small collector size. In each of the 1st 4 items the values will be slightly less than those favorable for clear ice. Often the larger parts of collectors and edges of deposits will be transparent ice while the main body is clear ice.

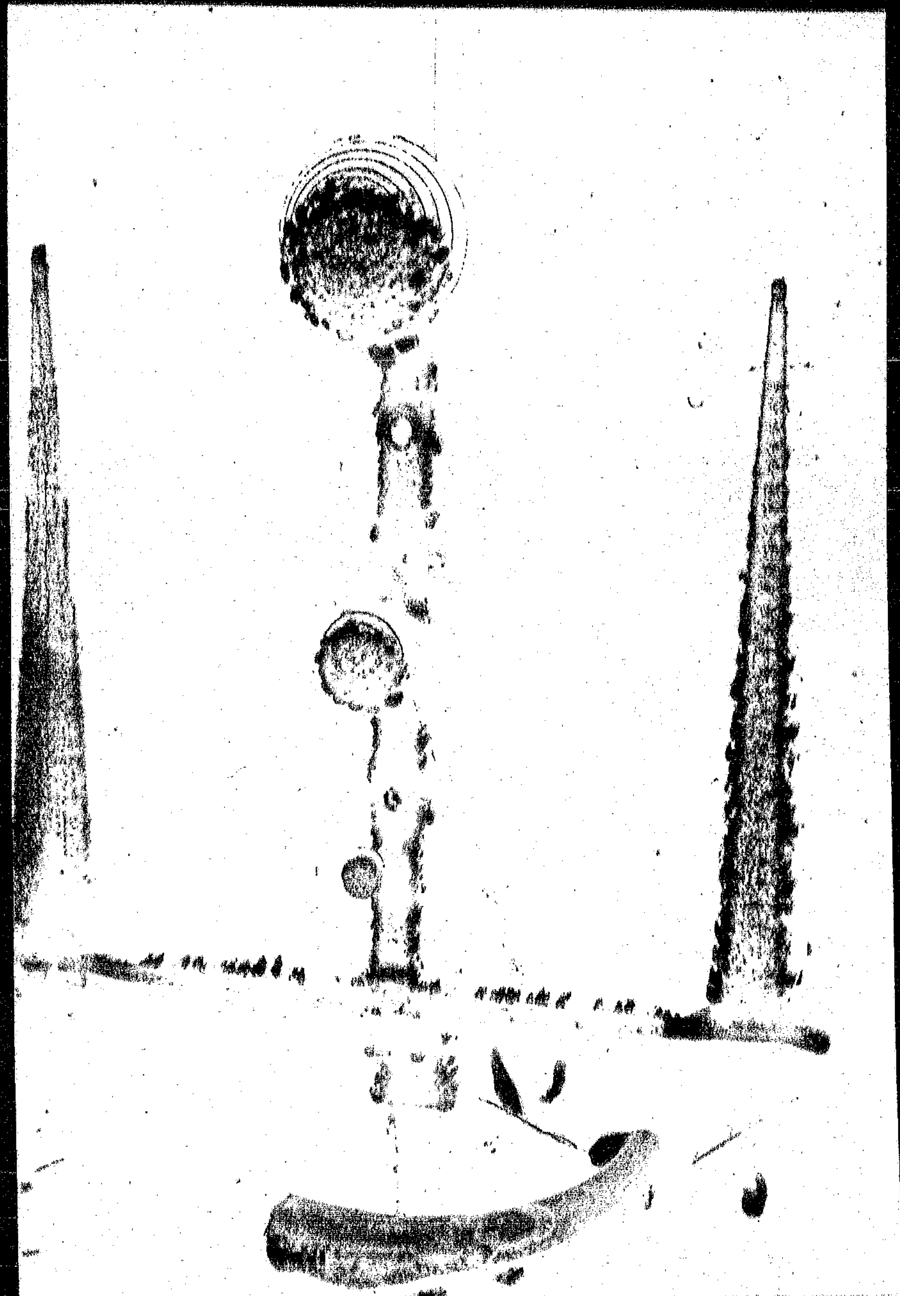


Photograph #1. Clear Ice with Milky Ice Edges.

Photograph #2. Clear Ice with Milky Ice Edges.



Photograph # 3. Clear Ice Base with Feathery Rime Ridge.



Photograph #4. Rough Clear Ice.

Common Ice Shapes: Ridged, Curved, and Doubled Ridges types are most common with the Flat Type occurring on occasion with Transparent Ice.

TRANSPARENT ICE AND MILKY ICE.

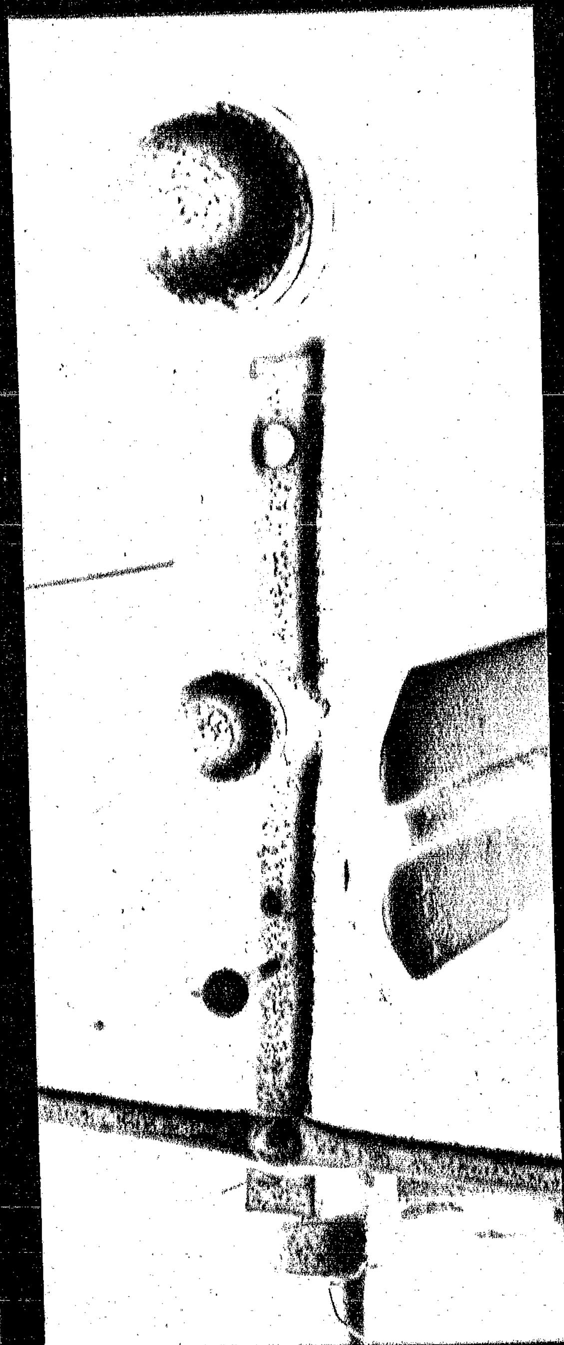
Photograph Number 5:

April 19, 1946, 10 AM; Exposure: 15 minutes
Precipitation: Snow
Temperature: $-11^{\circ}C$; Airspeed: 26.8 m/s
Water Content: 0.56 g/m^3; Drop Diam. 12.7C mic.

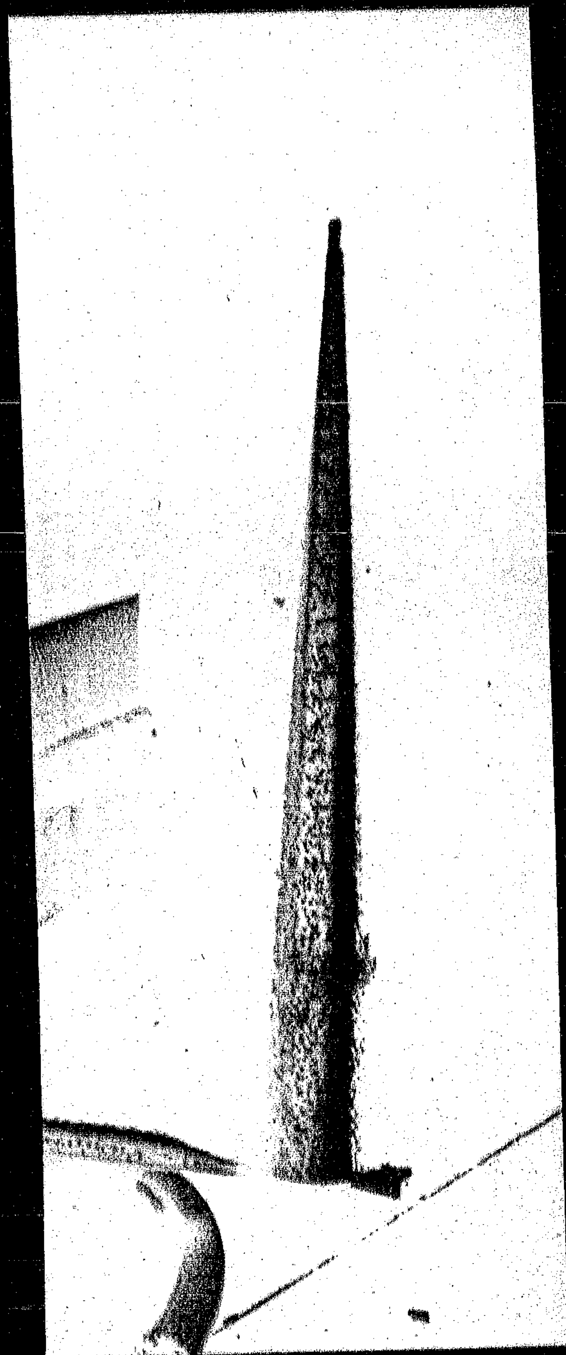
This photograph illustrates Transparent Ice well only in the center section midway down the cone, where the horizontal white lines on the collector can be seen dimly but sharply through the ice. In on the spheres the centers are clear ice with snow and blowing rime embedded, while the edges grade through Transparent to Milky Ice.

C) Milky Ice:

Description: considerable air entrapped in small bubbles, but translucent and shiny. Because of the translucent nature of this ice, the task of distinguishing it from transparent ice is not difficult. On the other hand, because it may be close to opaque in thick layers, it often is confused with opaque rime. However, in appearance, its translucence gives it a grey look in contrast to the white of opaque rime. In addition, it will appear to have a glossy or shiny surface due to an airfree surface film which is absent in the case of opaque rime. When broken, Milky Ice will crack revealing a smooth surface, while Opaque Rime will crumble



Photograph #5. (a) Transparent Ice



Photograph #5. (b) Transparent Ice

revealing a rough non-uniform interior. The density of Milky Ice will usually be less than that of Transparent Ice and more than that of Opaque Rime.

Although no photographs are available stationary deposits of Milky Ice often may have an ice core whose axis coincides with the stagnation line of the collector. Again, it may appear to be formed in laminations of different densities of Milky Ice or of Milky and Transparent Ice.

Weather Conditions: The values of temperature, airspeed, water content and drop size, which are typical of Milky Ice, are somewhat less than those for Clear and Transparent Ice but more than those for the Rimes.

MILKY ICE.

Photograph Number 6:

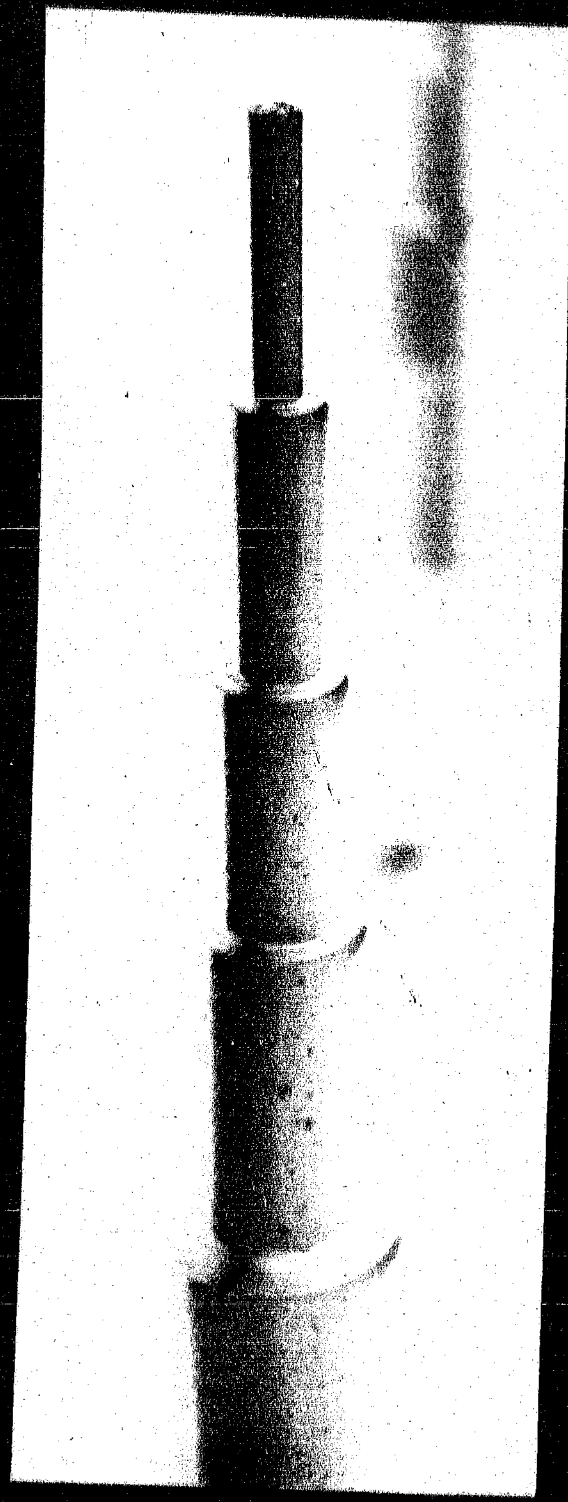
April 16, 1946, 7 AM, Exposure: 1 1/2 minutes
Precipitation: Blowing Snow and Ice only
Temperature: -12°C, Airspeed: 33.5 m/s
Water Content: 0.61g/m^3; Drop Diam : 16.0D mic.
Scale: Largest Cylinder Diam = 3.81 cm.

This photograph is considered to be an excellent illustration of Milky Ice. The greyness of the ice is clearly revealed. Spotted throughout the deposit may be seen small bits of blowing snow and rime.

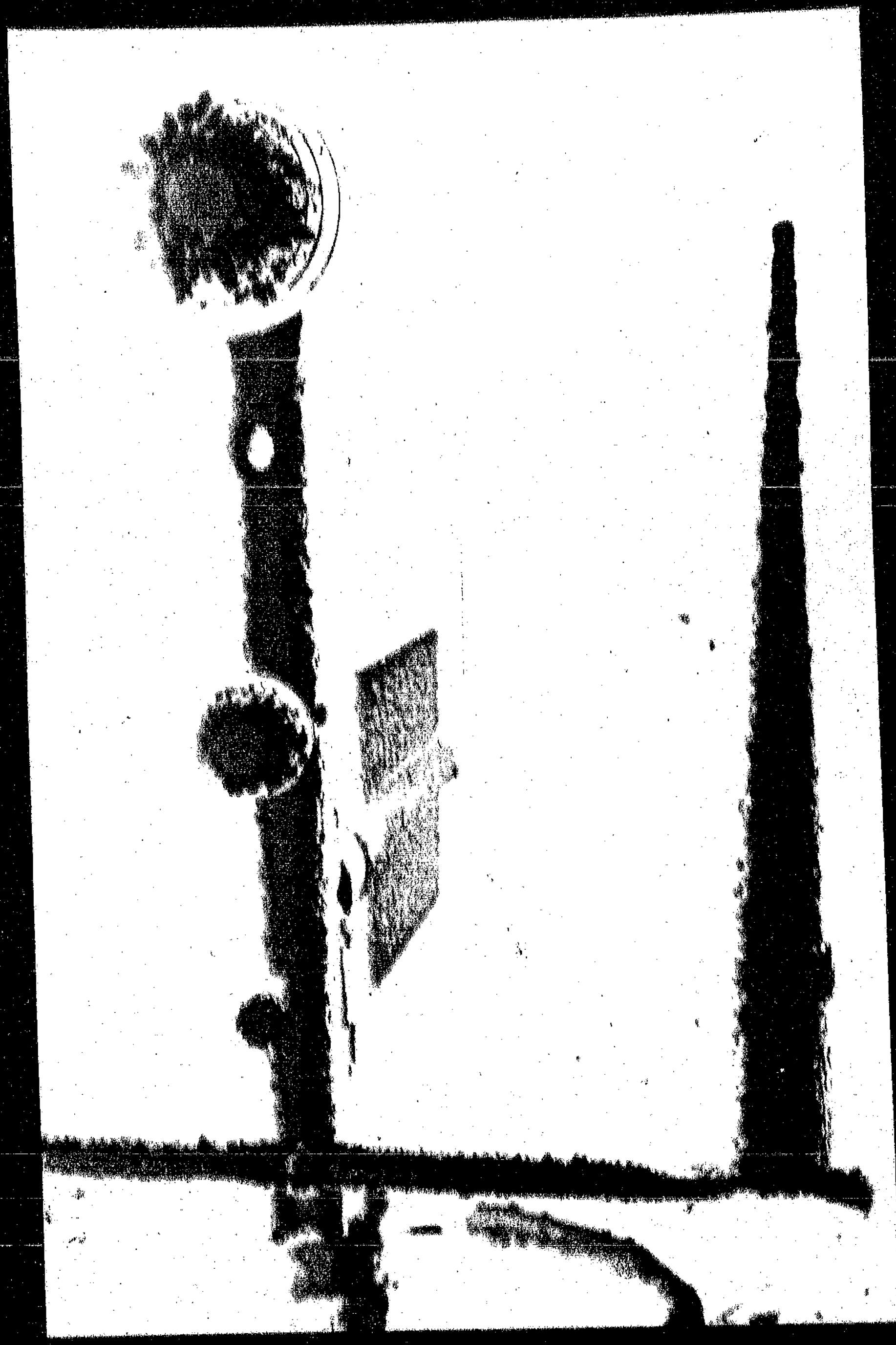
MILKY ICE CENTER WITH OPAQUE RIME EDGE.

Photograph Number 7:

April 26, 1946, 7 AM; Exposure: 27 minutes
Precipitation: Snow
Temperature: -1°C; Airspeed: 17.4 m/s
Water Content: 0.56 g/m^3; Drop Diam : 13.5A mic.



Photograph #6. Milky Ice.



Photograph # 7. Milky Ice Center with Opague Rime Edge.

This photograph clearly shows circular knobs of Milky Ice in the center of the spheres with Opaque Rime periphery. A similar strip of Milky Ice is barely visible on the cone on the right. The difference in color and appearance between Milky Ice and Opaque Rime is well illustrated. It should be mentioned that this phenomenon has been observed only once at Mount Washington. Ordinarily, the gradation from one ice type to the other is much more gradual.

2. Family of Rimes

B) Opaque Rime

Description: usually dull, very white, and opaque when compared with Milky Ice. When broken, Opaque Rime crumbles in contrast to Milky Ice which cracks open baring smooth homogeneous fracture surfaces. In contrast to Kernal Rime and Feathery Rime, Opaque Rime presents a fairly smooth uniform dense surface. While all Rimes are opaque, the term Opaque Rime is chosen to designate a rime which in appearance is void of any other distinguishing characteristics other than its opacity. The density of this type has a mean near $0.6 g/cm^3$, although it often may be equally as dense as Milky Ice.

Weather Conditions: While Opaque Rime has been observed at Mount Washington on large objects at temperatures close to freezing it is more common when the temperature is at least $10^{\circ}C$ below freezing. At very low temperatures, other Rime forms will be found unless the drop size is large or airspeed is high.

Common Ice Shapes: Most common with Opaque Rime are Ridged, Curved, and Flat Types of formation. Knife Type and Grooved Type may be found occasionally, while Opaque Rime with Double Ridged Type is unknown.

OPAQUE RIME.

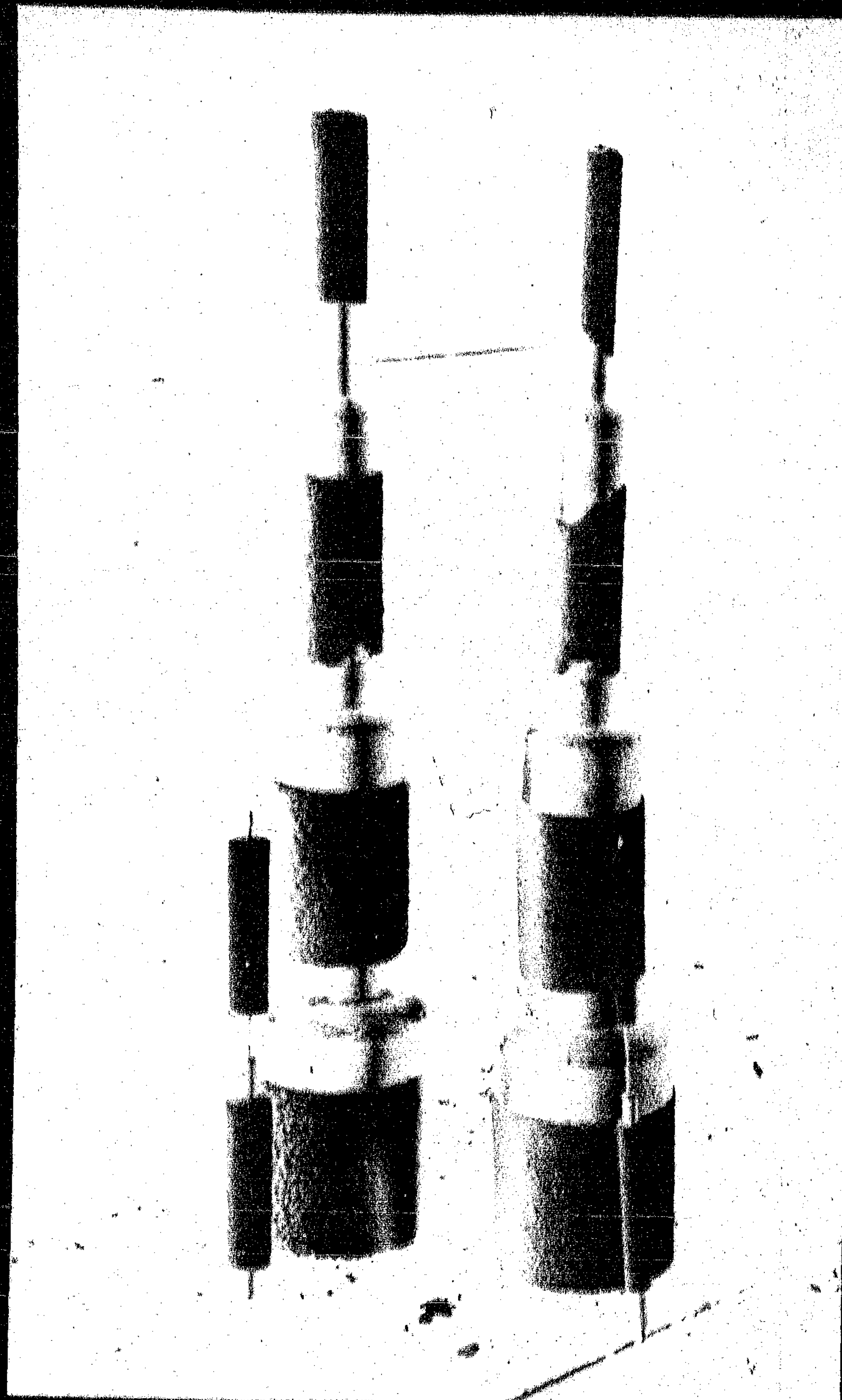
Photograph Number 8:

April 5, 1946, 10 PM; Exposure: 30-9 minutes
Precipitation: Snow
Temperature: $-11^{o}C$; Airspeed: 19.6 m/s
Water Content: 1.04 g/m^3; Drop Diam : 16.2E
Scale: Largest Cylinder = 7.60 cm.

This photograph of deposits on two sets of rotating multicylinders illustrates Opaque Rime especially well on the two largest cylinders on the right. The smaller cylinders on the right appear to have been melted on the surface during handling which has resulted in giving them the greyish appearance of Milky Ice. The largest cylinder on the left has developed a kernal appearance as the rsult of irregularities introduced by impinging snow.

E) Kernel Rime and Feathery Rime.

Description: Kernel Rime may best be described as feathery rime in which the feathers are so closely packed that only the points of each feather are visible, in which case they appear to be similar to kernels of corn on a cob. When large areas without ice deposit exist all around each "kernel"; the feathery character of each entity is apparent, and the whole deposit is classified



Photograph #8. Opaque Rime.

as Feathery Rime. Densities of 0.3 to 0.4g/cm^3 are most common for these formations.

At Mount Washington these two types usually are soft and fragile, while on aircraft in flight it is doubted if ice densities would be less than 0.6g/cm^3.

Weather Conditions: Low airspeed, water content, drop size, and temperature are typically found with this type of formation, although on large collectors these types may be found with moderate values of these elements.

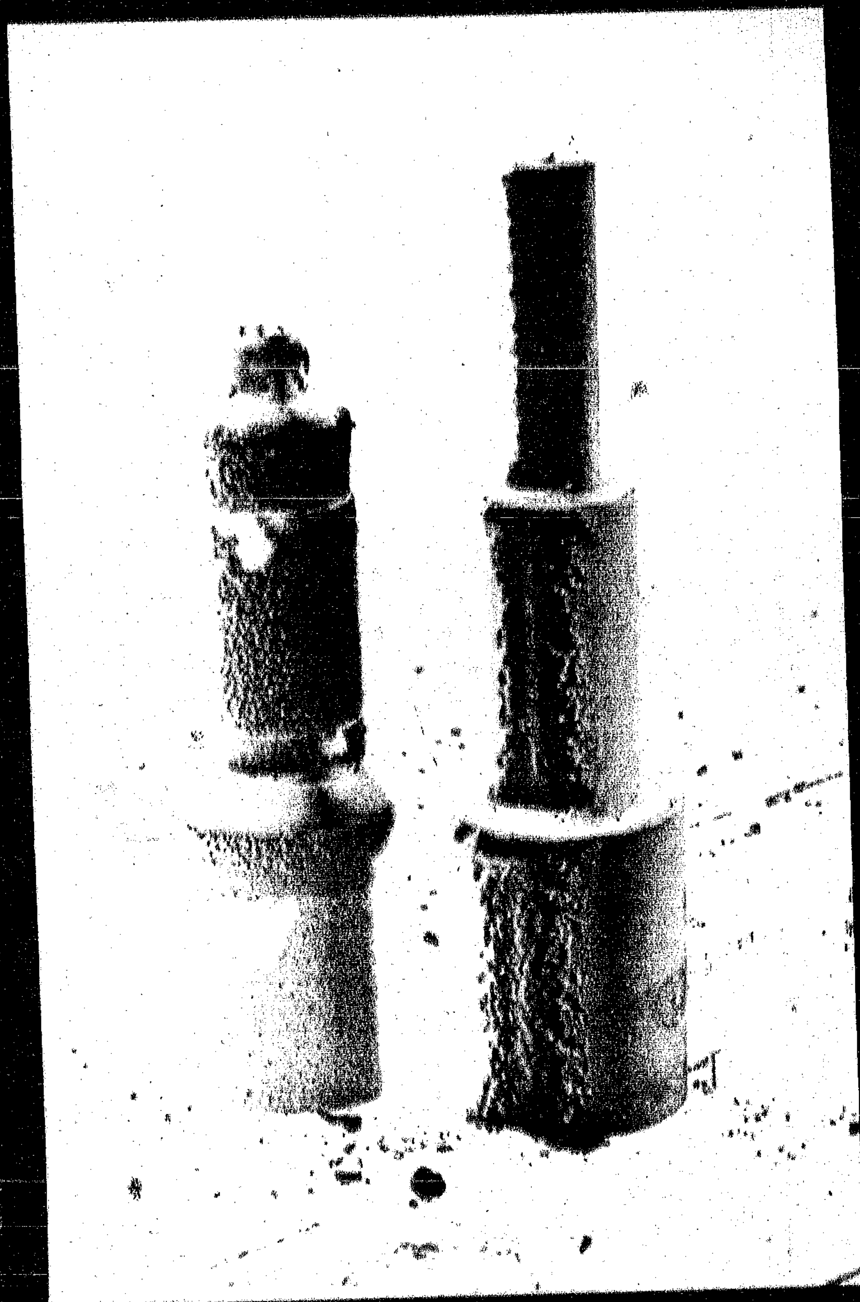
Common Ice Shapes: The Grooved Type is most commonly associated with these types, although the Flat Type and Knife Type may also occur. On thin wires, the Ridged Type almost always predominates no matter what weather conditions are found.

KERNEL RIME AND FEATHERY RIME

Photograph Number 9:

April 5, 1947, 7A; Exposure: 25 minutes
Precipitation: Snow
Temperature: -7^{o}C; Airspeeds: 11.6 m/s
Water Content: 0.49g/m^3; Drop Diam: 16.9A mic.
Scale: Largest Cylinder Diam = 7.60 cm.

The top cylinder on the left is a good example of Kernel Rime, while the bottom cylinder on the left illustrates Feathery Rime in its uppermost sections. The same types are revealed on the comparable stationary deposits on the right, although the edges of both deposits on the right are distinctly feathery.



Photograph #9. Kernal Rime and Feathery Rime.

KERNEL RIME AND FEATHERY RIME.

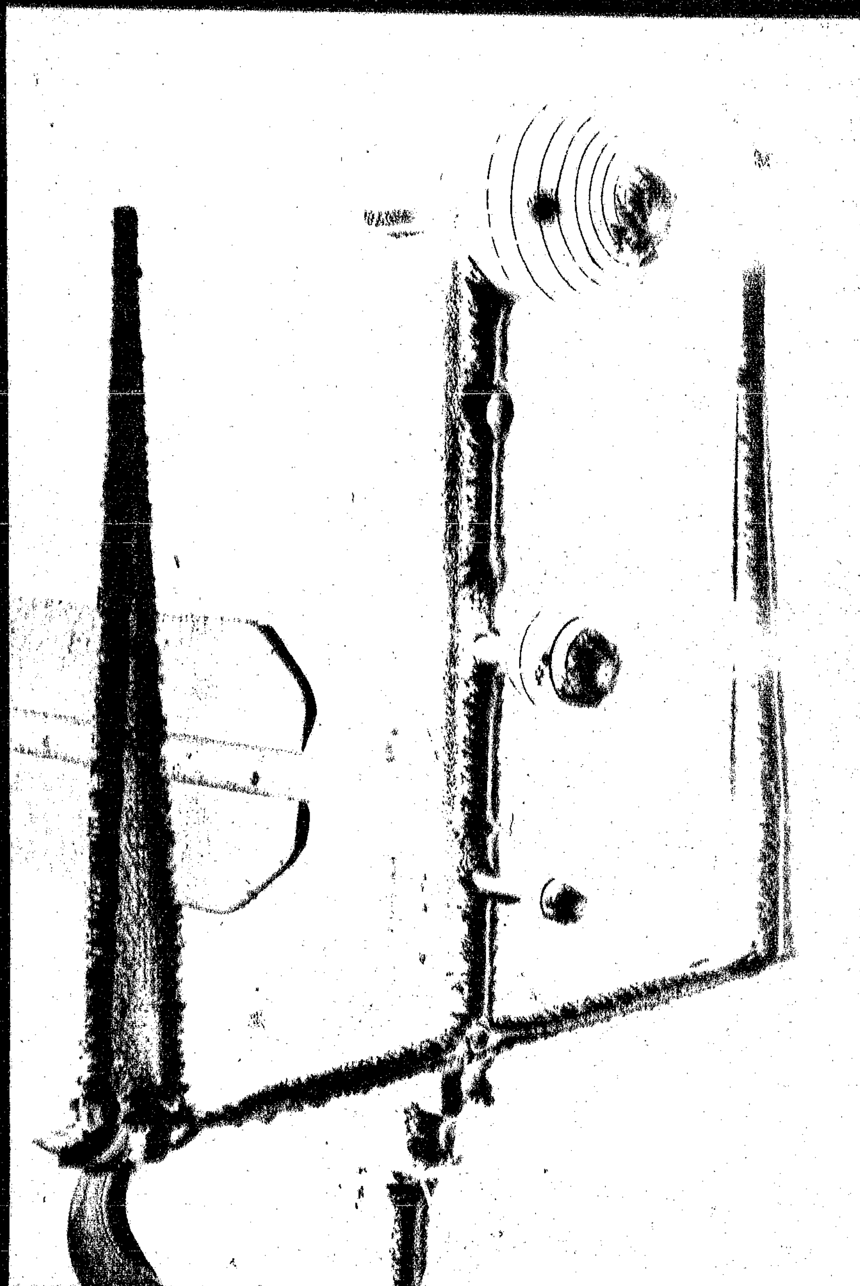
Photograph Number 10:

April 4, 1946, 7 PM; Exposure: 38 minutes
Precipitation: None
Temperature: -2; Airspeed: 14.3 mph
Water Content: 0.95g/m^3; Drop Diam: 84A mic.

While this photograph is a striking example of the Grooved Type formation, it serves well in illustrating Kernal Rime in the center of the metal ribbon on the left and Feathery Rime on the periphery of all of the deposits.

F) Secondary Classifications:

1) Enamel Ice: While no photographs are available of Enamel Ice, it is certain that a separate classification should exist for the type under consideration. In appearance, it has the opacity and whiteness of a rime even in thinnest layers, and at the same time it has the shininess of Milky Ice. It is extremely hard, and chips like enamel when thin layers are pried from the collector. Densities of 0.6 to 0.7g/cm^3 are most are most common. The weather conditions conducive to this formation appear to be high airspeed and moderate temperatures. It is worth speculating that this type is common of regular Opaque Rime formations at aircraft speeds. Its only observed shapes at Mount Washington are Ridged and Curved Types.



Photograph #10. Kernal Rime and Feathery Rime.

2) Powder Rime: No photograph of this type is available since it differs not at all in appearance from Opaque Rime. Its contrast with Opaque Rime lies in the fact that it powders rather than crumbles under pressure. Low densities are most common with this type. For the most part, low temperatures, water content, and drop size are characteristic of this type. The Ridged, Curved, Flat, and Knife Types are most common shapes, depending on collector size and other factors.

Section II - Shape Classification
(for stationary collectors only)

Preliminary Remarks:

While it often is the case that a single appearance classification, such as Clear Ice or Opaque Rime, may change little with increasing collector size, the shape of a stationary deposit on a very small collector will be invariably the Ridged Type. At the same time, it is seldom at Mount Washington that the type will not change at least from Ridged to Curved as the collector size increases. Often it will also change to Flat and Grooved Types. Double Ridged and Knife Types usually will exist alone. For these reasons, the photographs presented here often will show more than one type, but each will be used to illustrate a particular shape.

A) Ridged Type:

Description: The leading edge of this type forms a sharp to rounded ridge at the line of maximum thickness for a cylinder or airfoil and at the point of maximum thickness for a sphere. In these cases, this ridge or point is directly to windward of the stagnation line or point on the cylinder and airfoil, or sphere. In most cases, the deposit begins close to the line of tangency on the collector relative to the airstream. The deposit then usually widens as it grows to a width greater than that of the cylinder or sphere. From this point of maximum width, the deposit becomes narrower until it meets at the ridge or point. Thus, distinct angles are made by the ice at the two points of maximum width and the ridge or point of maximum thickness. As mentioned in the earlier section, small collector size, high airspeed, and large drop size favor this type of deposit.

RIDGED TYPE

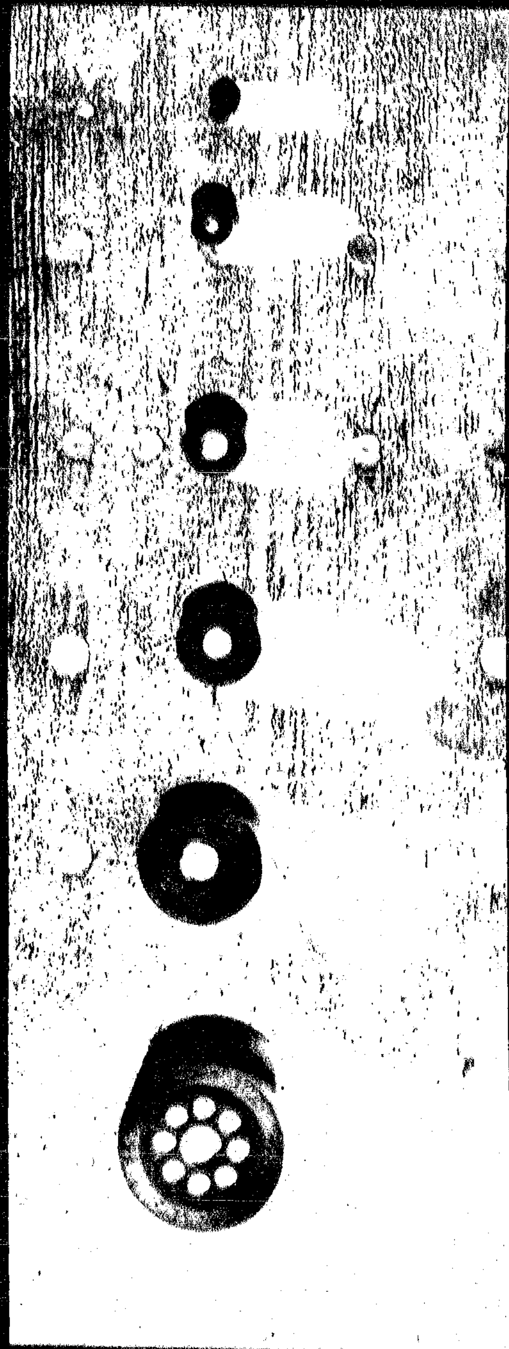
Photograph Number 11:

January 21, 1946 10 PM; Exposure 15 minutes
Precipitation: None
Temperature: -8°C; Airspeed: 19.2 m/s
Water Content: 0.51 g/m^3; Drop Diam.: 30.10 mic.

In this photograph, the smallest cylinder (top of picture) reveals most clearly the Ridged Type, although the next two deposits in line are Ridged Type deposits. The three largest deposits, of course, are good examples of the Curved Type.

B) Curved Type:

Description: The Curved Type is found in two distinct shapes. In the first, the streamlines of the collector are distorted only slightly, since the deposit increases in thickness only very gradually from its periphery to the stagnation point or line. In the second case, the deposit has steep walls which rise sharply from the collector close to parallel to the air streamlines. From the top of these walls the face of the deposit follows closely the curvature of the underlying collector surface. The result is that it



Photograph #11. Ridged Type.

is of equal thickness throughout its face. As far as can be determined, the latter type is characteristic of thick deposits and small collectors. Freezing rain or large droplets usually will produce the former type on a large collector. The Ridged Type usually will blend into the latter type rather than the former type. It should be mentioned that metal ribbons of increasing thickness usually will feature the Ridged Type and then pass to the Grooved Type (really two ridges slightly in from each edge.) Only negligible lengths of Curved or Flat Type deposits have been observed on this type of collector.

CURVED TYPE (WITHOUT WALLS)

Photograph Number 12

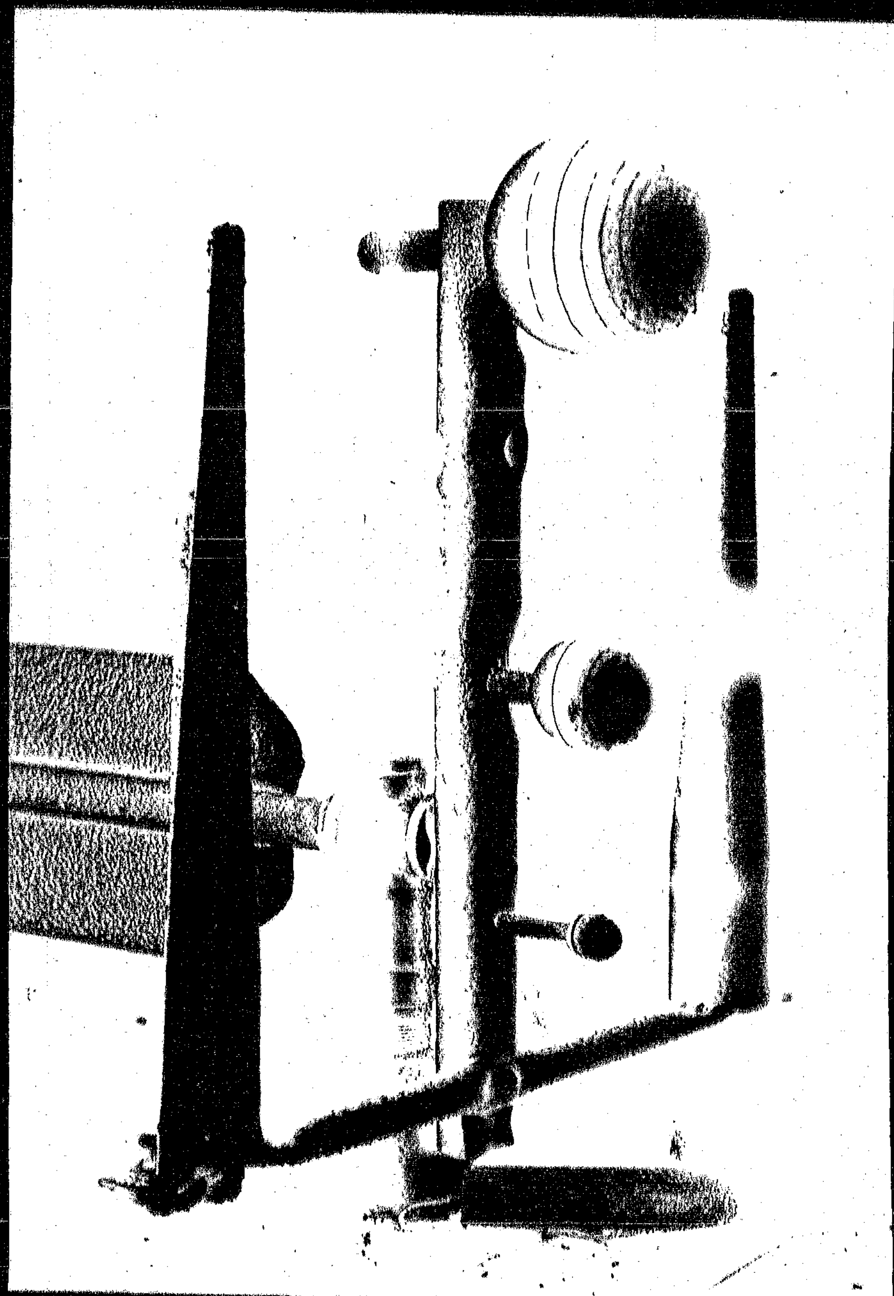
April 2, 1945 7AM; Exposure: 35 minutes
Precipitation: Rain and Snow
Temperature: -11°C; Airspeed: 17.9 m/s
Water Content: 0.54 g/m^3; Drop Diam.: 17.6 E mic.

In this photograph, it can be seen that the largest sphere presents least deformation to the streamlines, although none of the deposits on the three spheres deforms them very greatly. It is worthy of note that freezing rain was occurring at the type deposition.

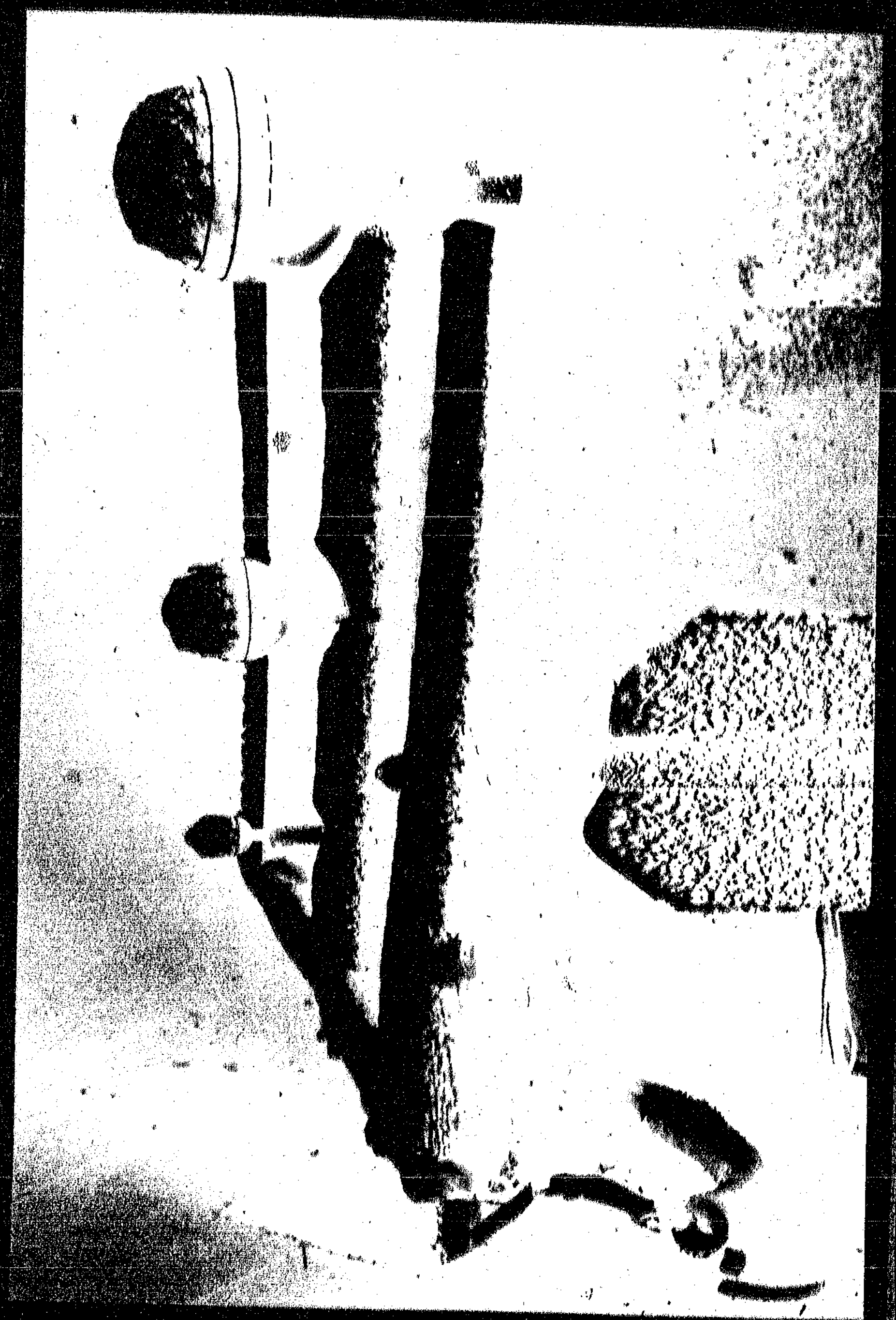
CURVED TYPE

Photograph Number 13: (Side view of collector of photo #7)

April 26, 1946 7AM; Exposure: 27 minutes
Precipitation: Snow
Temperature: -1°C; Airspeed: 17.4 m/s
Water Content: 0.56 g/m^3; Drop Diam.: 13.5 A mic.



Photograph #12. Curved Type (without Walls).



Photograph #13. Curved Type.

Note that in the deposits on all three spheres a sharp wall extends from the collector to the face of the deposit. Only in the case of the largest sphere is the true Curved Type (with walls) present. On the smallest sphere a virtually Ridged Type exists.

CURVED TYPE

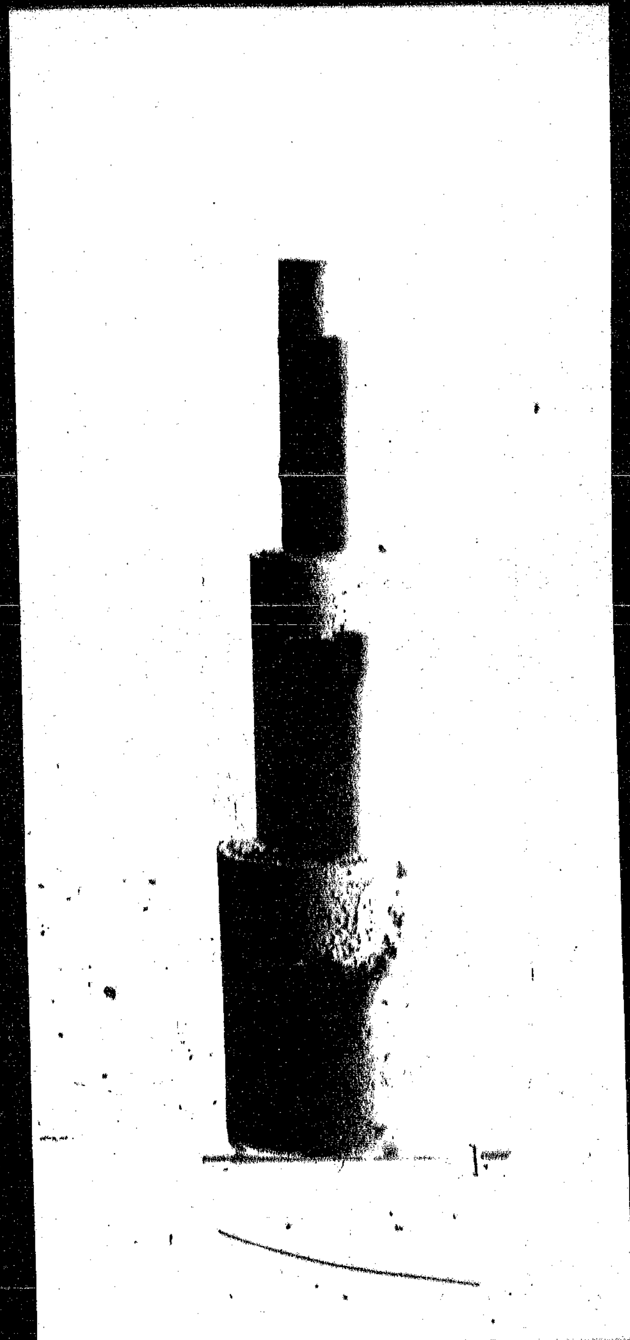
Photograph Number 14:

January 21, 1946 10PM; Exposure: 15 minutes
Precipitation: Snow
Temperature: -8°C; Airspeed: 19.2 m/s
Water Content: 0.51 g/m^3; Drop Diam.: 30.1 C mic.
Scale: Largest Cylinder Diam. = 7.60 cm.

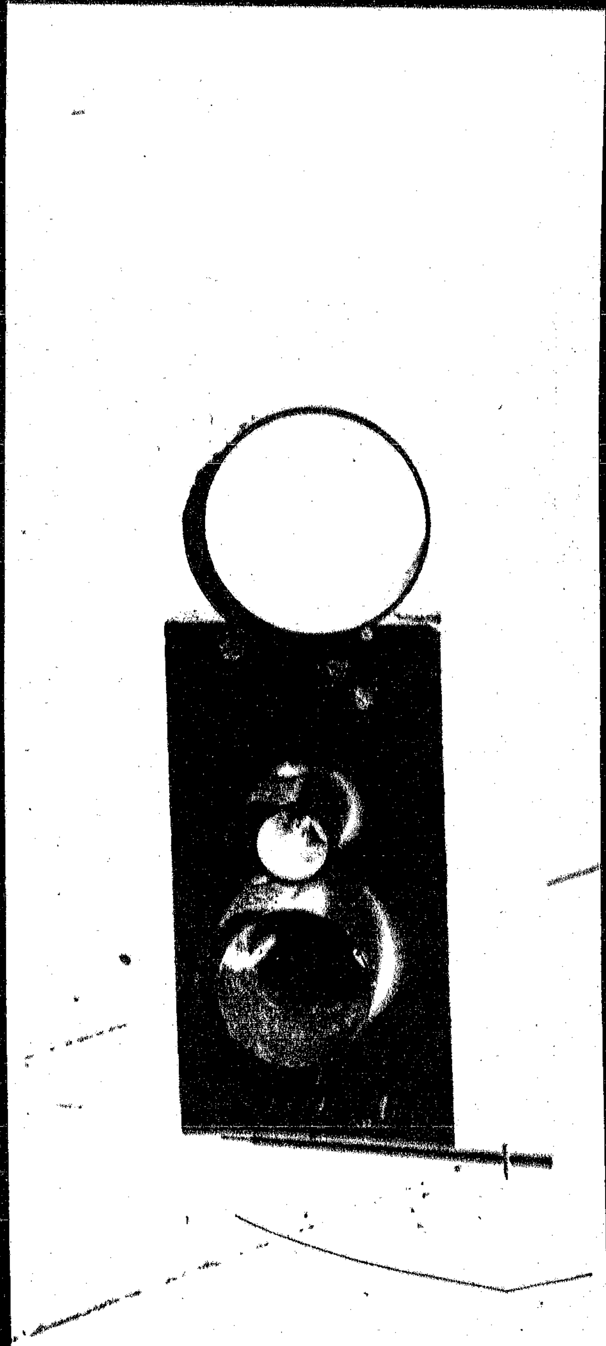
On the largest cylinder, the deposit appears to be midway between the Curved Type with and the Curved Type without walls. The smallest cylinder definitely has the walls, and since the radius of curvature of the face is far less than that of the cylinder, the deposit is more like the Ridged Type than the Curved Type.

C) Flat Type:

Description: As has been seen in most of the photographs, with increasing collector size the leading edge of the ice deposit features an increasing radius of curvature until the Flat Type is found. The Flat Type most typically has walls which appear to approach each other as the deposit grows. If the walls were extended to windward they should meet at a point. On some occasions, these walls have been found to be parallel. At the top of these ice walls the surface is flat, rather than curved concentric



Photograph #14. (a) Curved Type.



Photograph # 14. (b) Curved Type.

with the collector below as in the case of the Curved Type. Because of this flat surface, the thickest part of the deposit is found on both sides of the stagnation line or point rather than at it as is theoretically expected. The Flat Type is the next gradation to be found after the Curved Type as the collector size increases, the airspeed decreases, or the drop size decreases.

FLAT TYPE

Photograph Number 15:

April 6, 1946 1 AM; Exposure: 32 minutes
Precipitation: Snow
Temperature: -12°C; Airspeed: 20.1 m/s
Water Content: 0.84 g/m^3; Drop Diam.: 14.4 E mic.

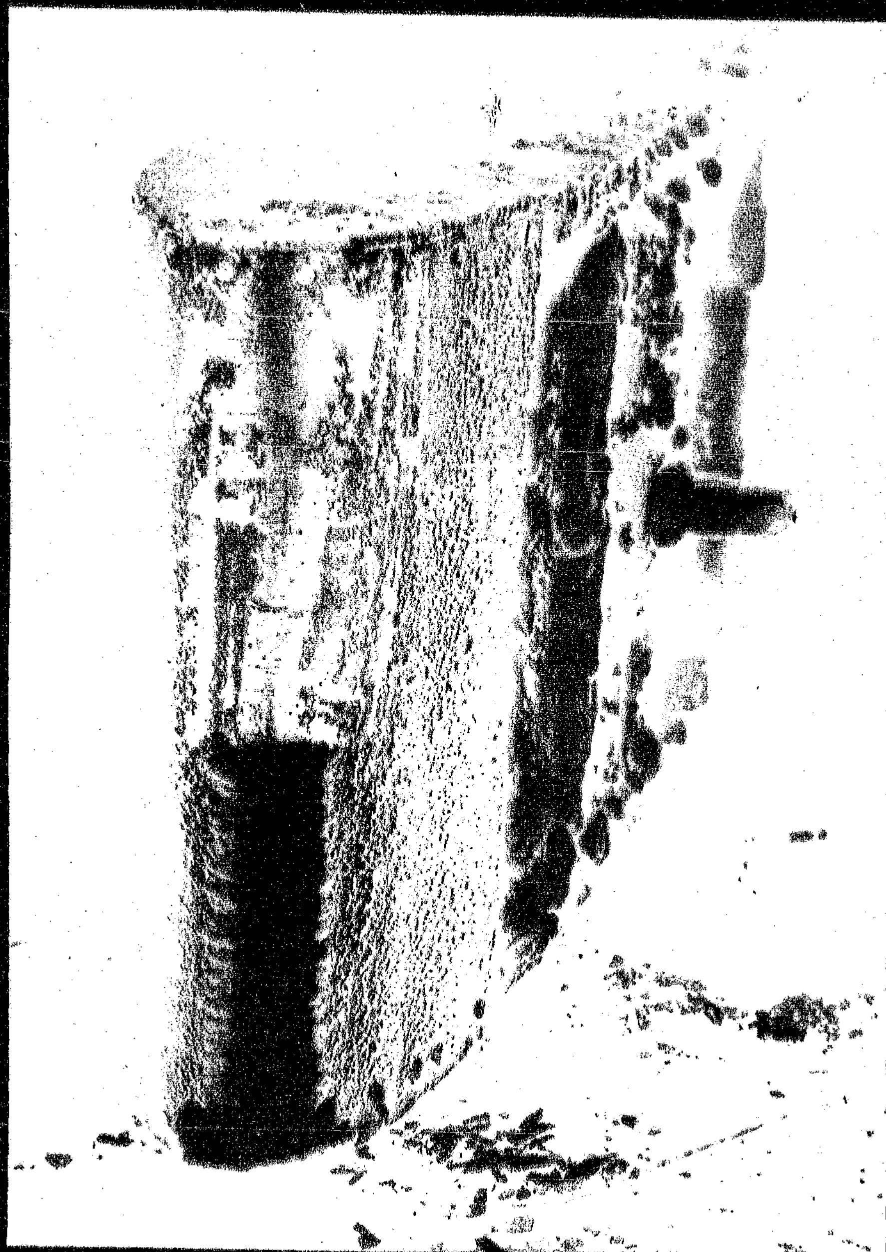
Although this photograph was taken from the windward side of the deposit, it is fairly clear that this ice deposit on the leading edge of a DC-3 quarter-scale model airfoil is of the Flat Type.

FLAT TYPE WITH CURVED AND RIDGED TYPES

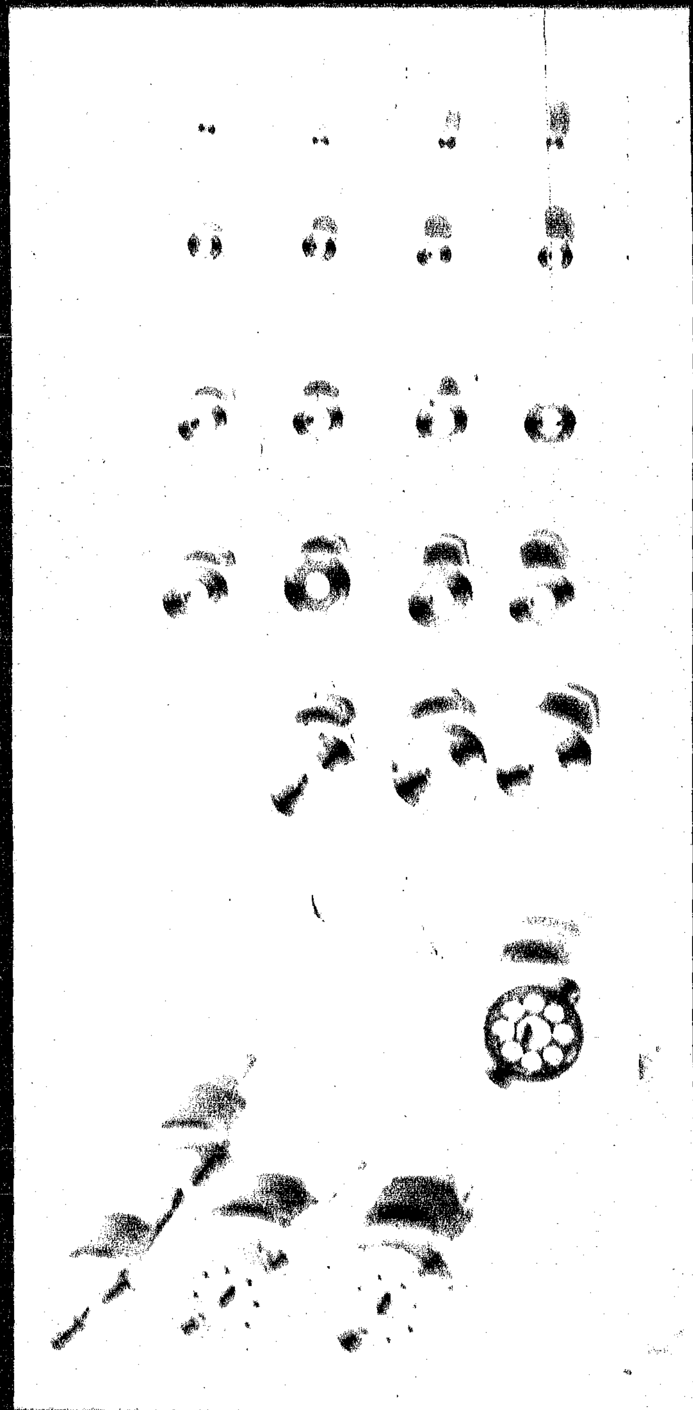
Photograph Number 16:

April 6, 1946 7 PM; Exposure: 5-20 minutes
Precipitation: Snow
Temperature: -11°C; Airspeed: 26.8 m/s
Water Content: 0.49 g/m^3; Drop Diam.: 13.1 A mic.
Scale: Largest Cylinder Diam. = 5.08 cm.

This photograph of deposits on cylinders ranging from 5 to 20 minutes in length reveals a gradation from the Ridged Type to the Curved Type in all but the set of cylinders which have the greatest deposit. In the set on the right side of the picture there is a gradation from Ridged Type to Flat Type, although slight curvature still does exist.



Photograph #15. Flat Type.



Photograph #16.

Flat Type with Curved and Ridged Types.

D) Grooved Type:

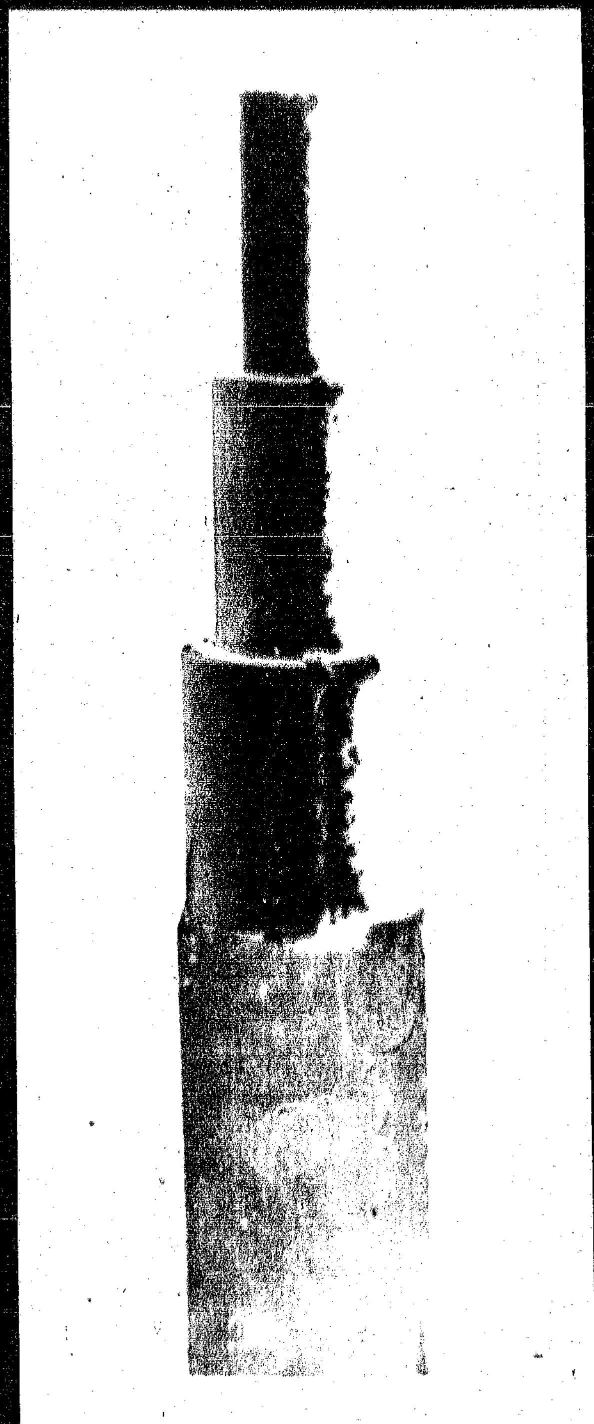
Description: The Grooved Type in the case of cylinders and airfoils consists of ridges of somewhat rough feathery rime on each side of the stagnation line. It usually occurs when the drop size or airspeed are too small for the formation of the flat type, or when the cylinder size is too large for the Flat Type. In the case of Spheres, the Grooved Type takes the form of a circular deposit with a dimple at the stagnation point. Since theory calls for maximum rather than minimum deposit at the stagnation line or point, the explanation for the Flat and Grooved Types would appear to be in the deformation of the streamlines by the initial deposit, such that the collector acts like a plane surface of definite width. The Grooved Type deposit should be clearly distinguished from the Double Ridged Type which is similar in appearance but which is the result of the water running back from the stagnation line and freezing in ridges on either side of the stagnation line.

GROOVED TYPE

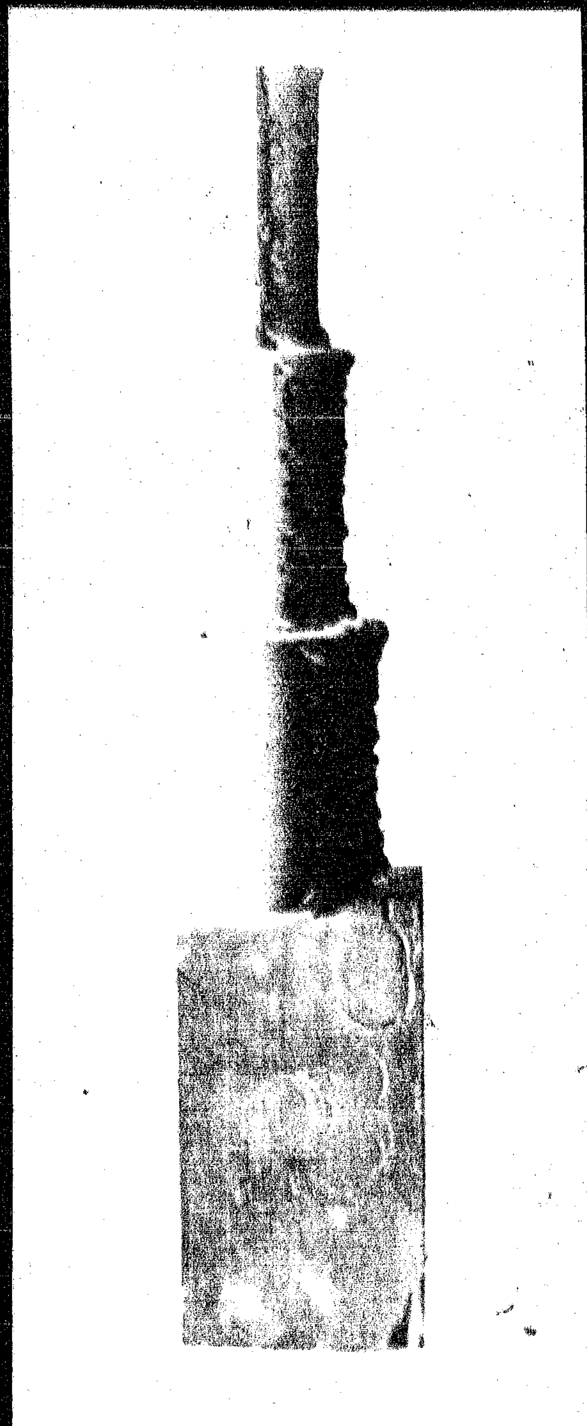
Photograph Number 17:

April 4, 1946 10 PM; Exposure: 33 minutes
Precipitation: Snow
Temperature: -3°C; Airspeed: 15.2 m/s
Water Content: 0.45 g/m^3; Drop Diam.: 14.0 A mic.
Scale: Largest Cylinder Diam. = 7.60 cm.

The front and side views of these Grooved Types deposits reveal clearly the rough feathery nature of the deposit with a distinct groove along the stagnation line.



Photograph #17. (a) Grooved Type.



Photograph # 17. (b) Grooved Type

Photograph Number 18.

In this photograph, the distinct groove in the center of each cylindrical deposit is striking. Also, the dimple or cavity in the center of each spherical deposit should be noted.

E) <u>Secondary Types:</u>

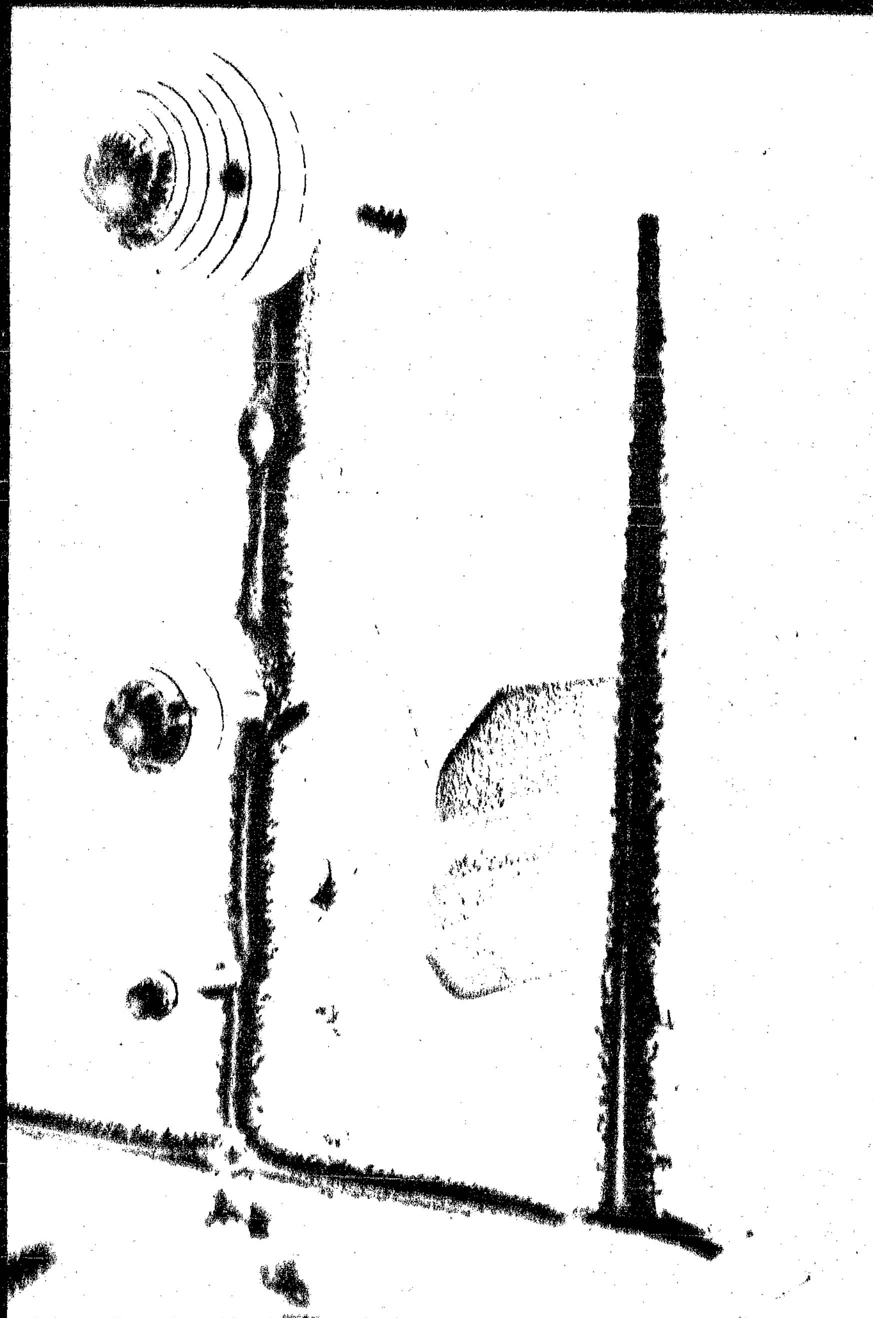
<u>Knife Type:</u> Little is known of the Knife Type deposit other than that its rare occurrence at Mount Washington has been marked by extremely high airspeeds, small particle size, low water content, and low temperatures. While it is featured by a ridge at the stagnation line, it can be distinguished from the Ridged Type by the shape of its sides. Instead of spreading out to a maximum width greater than that of the collector, the Knife Type is widest where it meets the collector and becomes increasingly narrow until it reaches a sharp point (much sharper than that for the Ridged Type) along the stagnation line at point of maximum thickness.

KNIFE TYPE

Photograph Number 19:

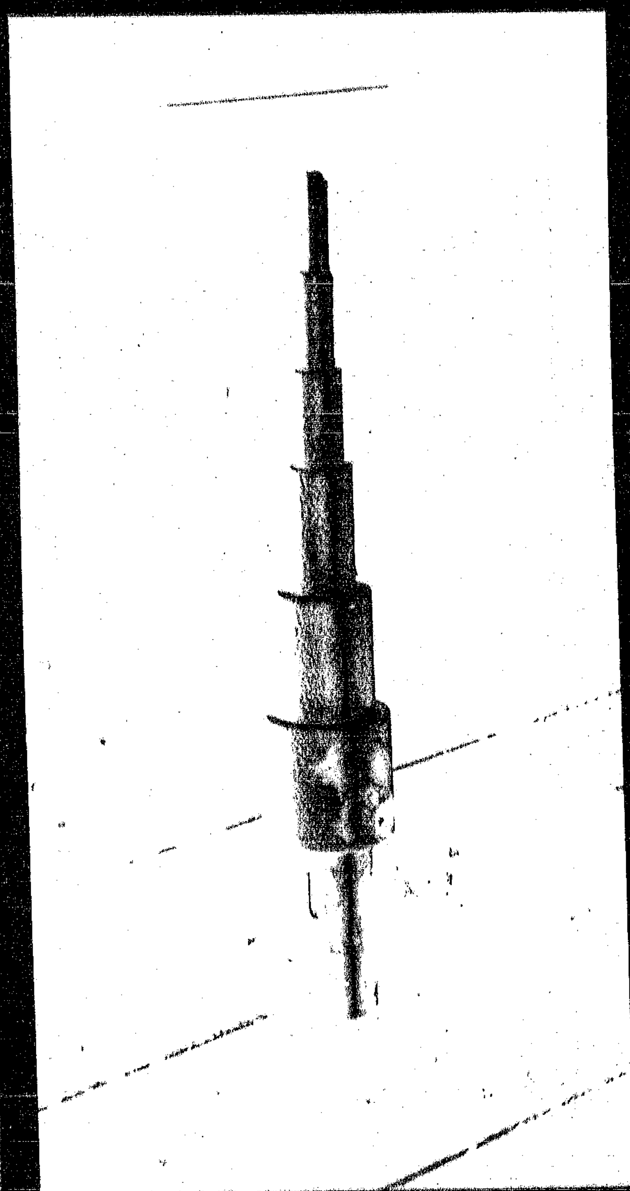
January 25, 1946 10 AM; Exposure: 20 minutes
Precipitation: Heavy Blowing Snow only
Temperature: - 17°C; Airspeed: 44.7 m/s
Water Content: ~0.10 g/m³; Drop Diam.: ~4.0 A mic.
Scale: Largest Cylinder Diam = 5.08 cm.

These photographs give an excellent illustration of the Knife Type deposit both in cross-section and off to one side of exposure position. The third view, which looks like a thin deposit of Feathery Rime, is a

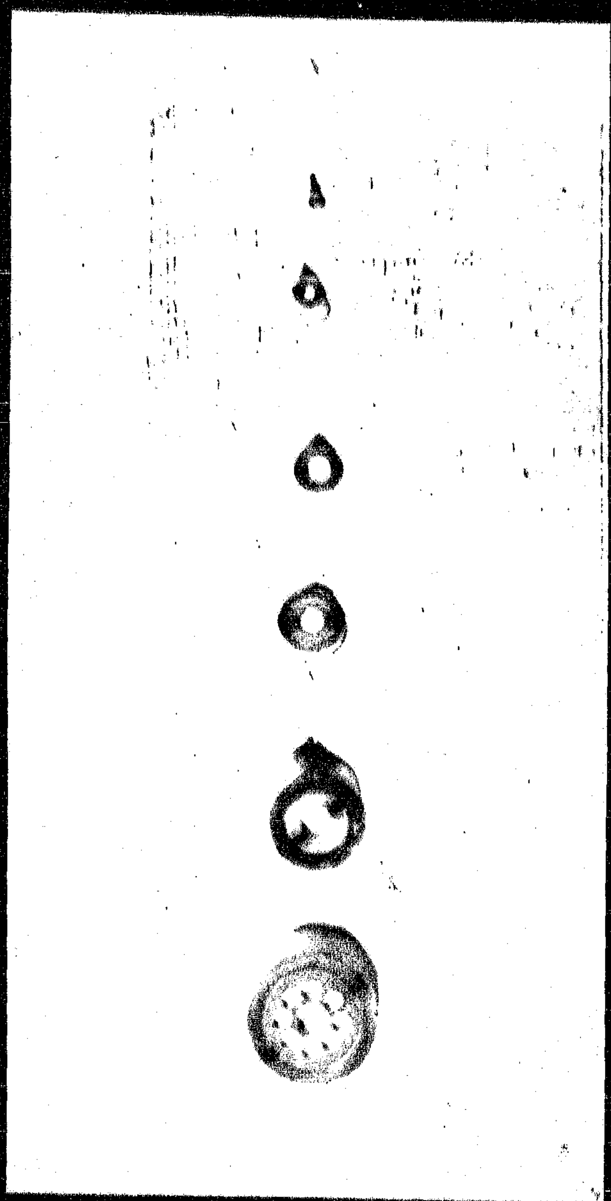


Photograph # 18. Grooved Type.

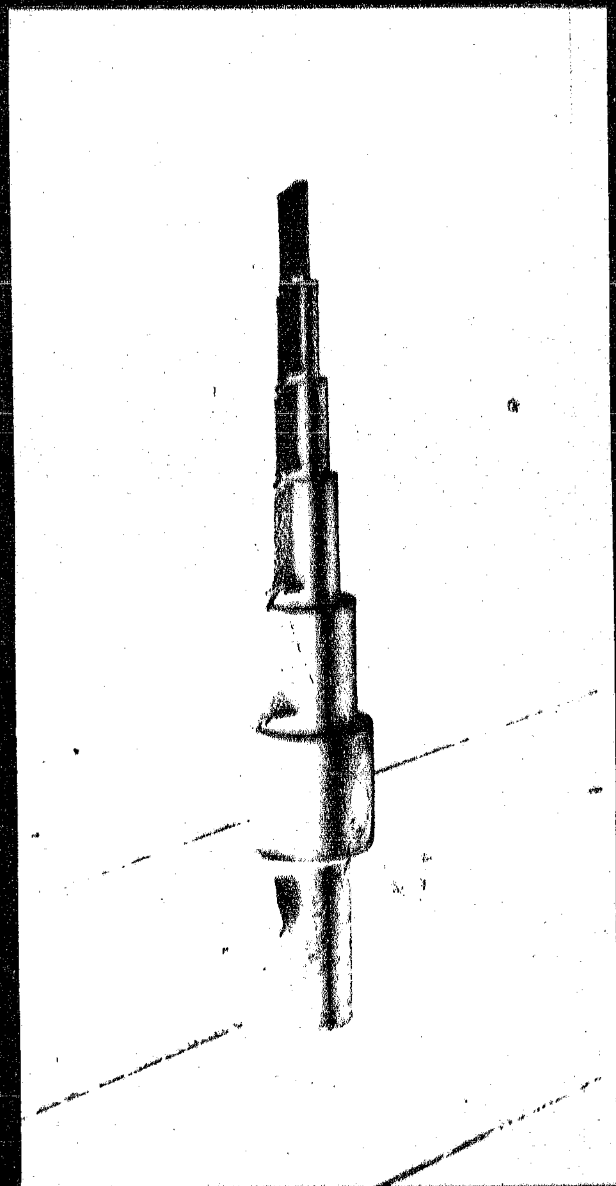
April 4, 1946 7 PM; Exposure: 38 minutes
Precipitation: Snow
Temperature: -2°C; Airspeed: 14.3 m/s
Water Content: 0.95 g/m^3; Drop. Diam. 8.4 A mic.



Photograph # 19. (a) Knife Type



Photograph # 19. (b) Knife Type.



Photograph # 19. (c) Knife Type.

photograph of the leeward side of the collectors. This deposit on the leeward side of stationary collectors is common under certain conditions, although as yet not adequately explained.

Double Ridged Type: In contrast to the Grooved Type, which is formed on Rime types on large collectors where temperature, drop size and other elements are low in value, the Double Ridged Type forms of rough clear ice when these values are high and the droplets run back from the stagnation line before freezing. In appearance, this type usually is much rougher with a wider stagnation line channel than in the case of the Grooved Type. The Double Ridged Type is believed to be much more common at aircraft speeds than at Mount Washington.

MODIFIED DOUBLE RIDGE TYPE ON PROPELLER BLADE

Photograph Number 20:

April 27, 1946 1 AM; Exposure: 2 minutes
Precipitation: Freezing Drizzle
Temperature: -5°C; *Airspeed: 12.1 m/s
Water Content: 0.57 g/m^3; Drop Diam.: 26.8 D mic.
Scale: Large Blade Radius = 17.7 cm.
*Airspeed of Blade Tip During Rotation = $>$100 m/s

This photograph shows the ice deposit on two model propeller blades which were rotated at Mount Washington in fog at top speeds in excess of 200 miles per hour. While this deposit does little to reveal two ridges present in the Double Ridged Type, it can be seen that the water particles have run back from the stagnation line before freezing and that the maximum thickness of deposit probably is somewhere back from the stagnation line.

Photograph #20.

Modified Double Ridge Type on Propeller Blade.

Section III - Fundamental Icing Phenomenon

This section is included first to cover consideration and illustration of the function of the various elements in ice deposition as well as a general consideration of the comparability of ice deposition on airfoils and cylinders.

Function of Various Elements in Ice Deposition: Of the important elements, it may be said that the thickness of ice deposition will increase with:

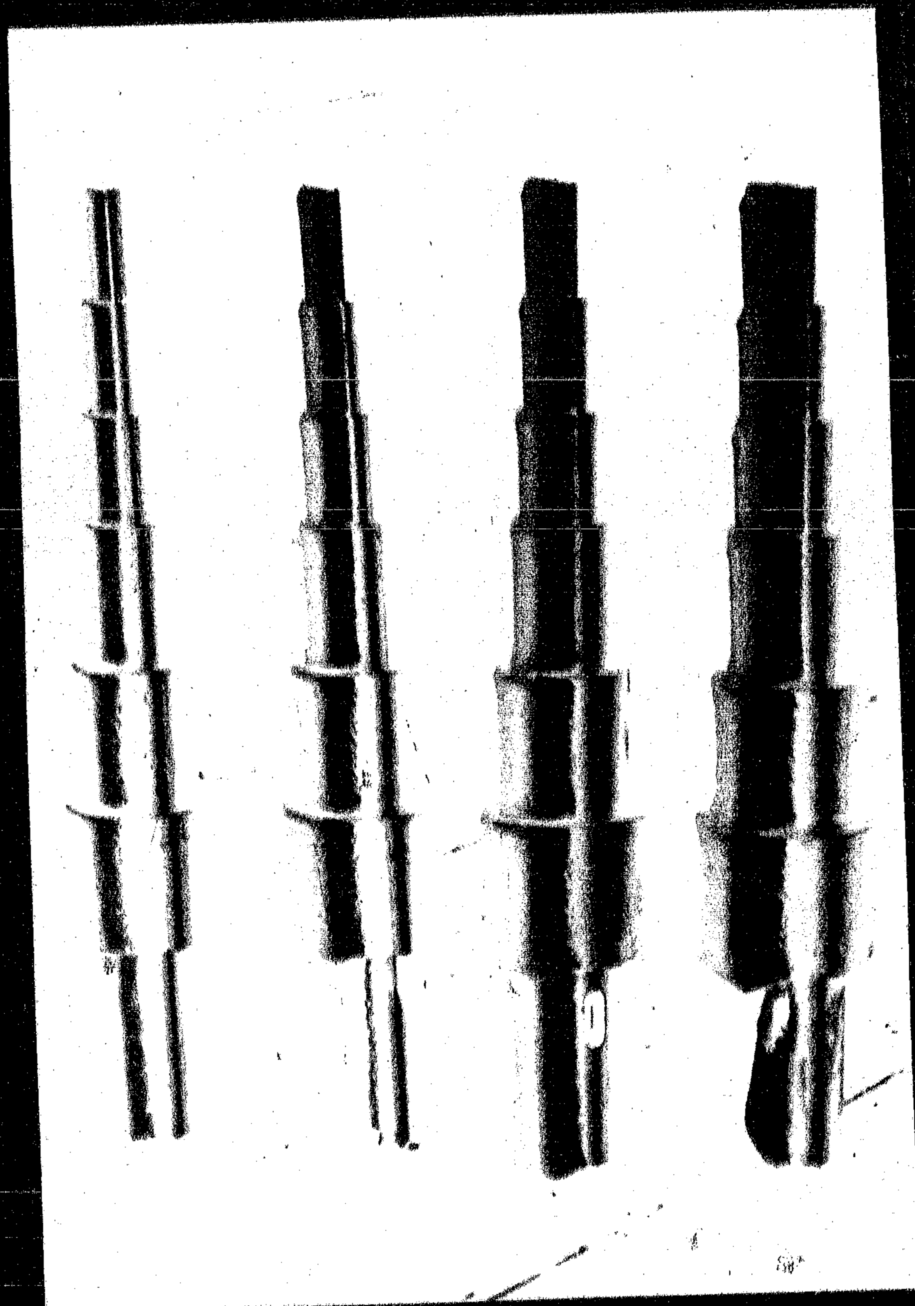
1) Increasing time of exposure
2) Decreasing collector size
3) Increasing water content
4) Increasing drop size
5) Increasing airspeed
6) Decreasing atmospheric pressure

EFFECT OF EXPOSURE TIME

Photograph Number 21:

April 19, 1946, 1 AM; Exposure: 1-19 minutes
Precipitation: Snow
Temperature: -9°C; Airspeed: 33.9 m/s
Water Content: 0.60 g/m^3, Drop Diam.: 16.2 B mic.
Scale: Largest Cylinder Diam. = 5.08 cm.

This photograph reveals the effect of increasing exposure time. The cylinders on the left were exposed 1 minute and those on the right 19 minutes. This photograph also shows that the greatest thickness of ice is collected on the smallest cylinders in each pyramid of cylinders (the smallest cylinder on the set of cylinders farthest to the left should be ignored since the collector turned during exposure.



Photograph #21. Effect of Exposure Time.

EFFECT OF WATER CONTENT AND DROP SIZE

Photograph Number 22:

1) Single Cylinder Set:

January 25, 1946, 10 AM; Exposure: 20 minutes
Precipitation: Heavy Blowing Snow only
Temperature: - 17°C; Airspeed: 44.7 m/s
Water Content: ᵉ0.10g/m^3; Drop Diam: ᵉ4.0A mic.
Scale: Largest Cylinder Diam. = 5.08 cm.

2) Four Cylinder Sets:

April 19, 1946, 1 AM; Exposure: 5-19 min.
Precipitation: Snow
Temperature: -9°C; Airspeed: 33.9 m/s
Water Content: 0.60g/m^3; Drop Diam.: 16.2B mic.

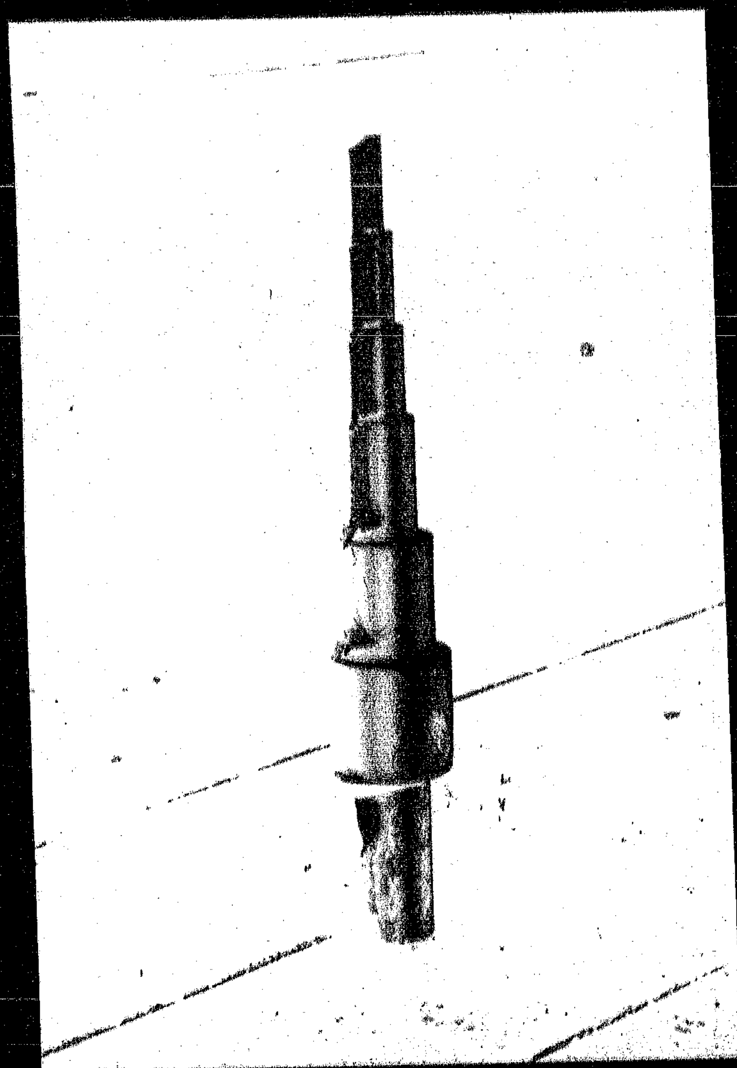
This photograph reveals the influence of water content and drop size on amount of ice deposited. In the single collector picture the deposit is considerably less than in the case of the 4 sets of cylinders due to very low water content and drop size despite a higher airspeed.

EFFECT OF AIRSPEED

Photograph Number 23:

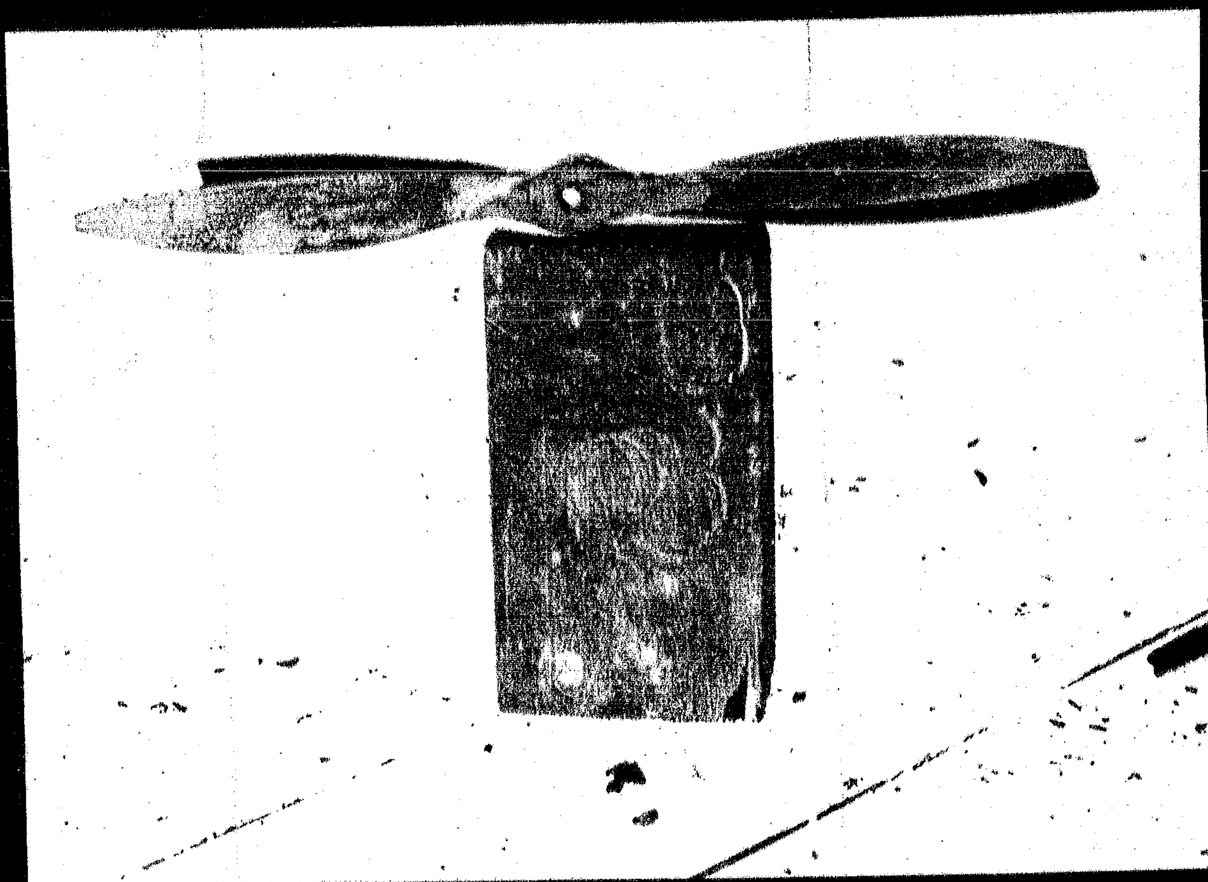
April 5, 1946, 7 AM; Exposure: 4 min.
Precipitation: Snow
Temperature: -11°C; *airspeed: 26.8 m/s
Water Content: 0.68g/m^3, Drop Diam.: 16.0A
*Airspeed of Blade Tip During Rotation = >100 m/s

This photograph shows the effect of increasing airspeed on amount of ice which is deposited. Since this ice deposit was formed during rotation of the model propellor blade, it is clearly seen that the increasing thickness of ice tipwards resulted from increasing airspeed. Illustration of the effect of decreasing pressure are not available because of the small range of pressures experienced



Photograph #22. (a) Effect of Water Content and Drop Size.

Photograph # 22. (b) Effect of Water Content and Drop Size.



Photograph #23. Effect of Airspeed.

at Mount Washington. Decreasing pressure, or, more properly, decreasing density of the air, leads to less deflection of the drops by the curvature of the streamlines and hence to a greater collection efficiency. The values of the critical collector diameter decrease by half in going from a pressure altitude of 5000 feet to one of 12,000 feet due to the pressure effect alone.

COMPARABILITY OF ICE DEPOSITION ON AIRFOILS AND CYLINDERS

Because of convenience of using ice deposits on cylinders to determine the amount of ice that might be expected on an airfoil, it is important to know the comparability of cylinder and airfoil deposits.

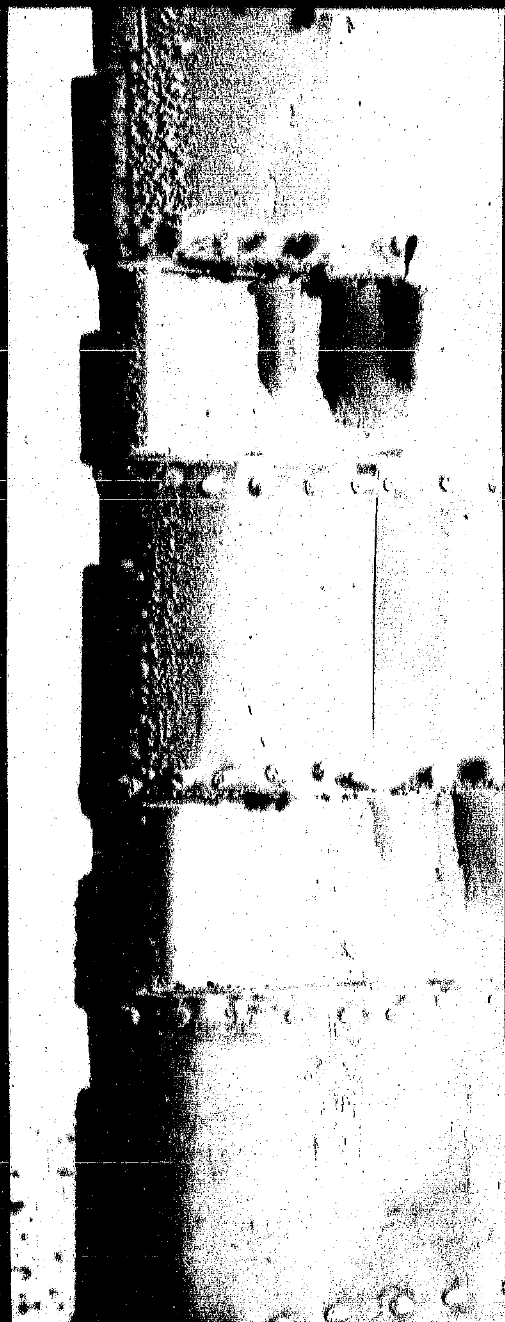
Photograph Number 24:

April 6, 1946, 4 AM; Exposure: 20 minutes
Precipitation: None
Temperature: -12°C; Airspeed: 24.6 m/s
Water Content: 0.67g/m^3; Drop Diam.: 15.2 B mic.
Scale: Largest Cylinder Diam. = 5.08 cm.

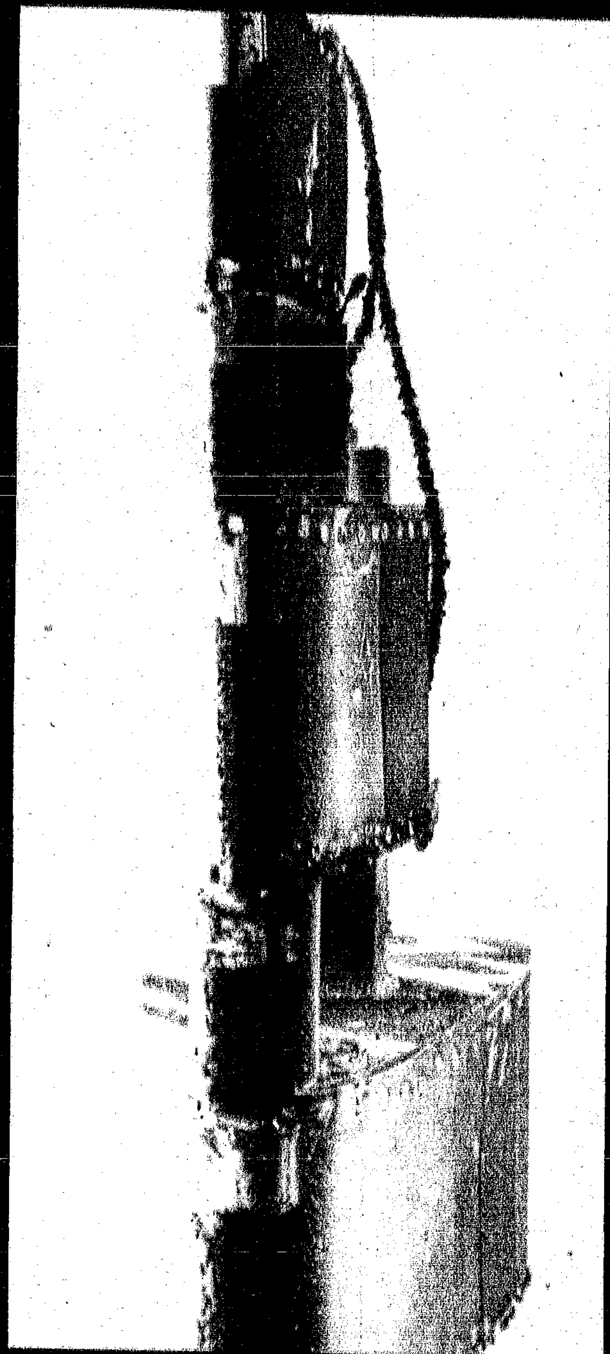
Photograph Number 25:

January 21, 1946, 10 PM; Exposure: 10 minutes
Precipitation: Snow
Temperature: -8°C, Airspeed: 19.2 m/s
Water Content: 0.51 g/m^3, Drop Diam.: 30.1C mic.

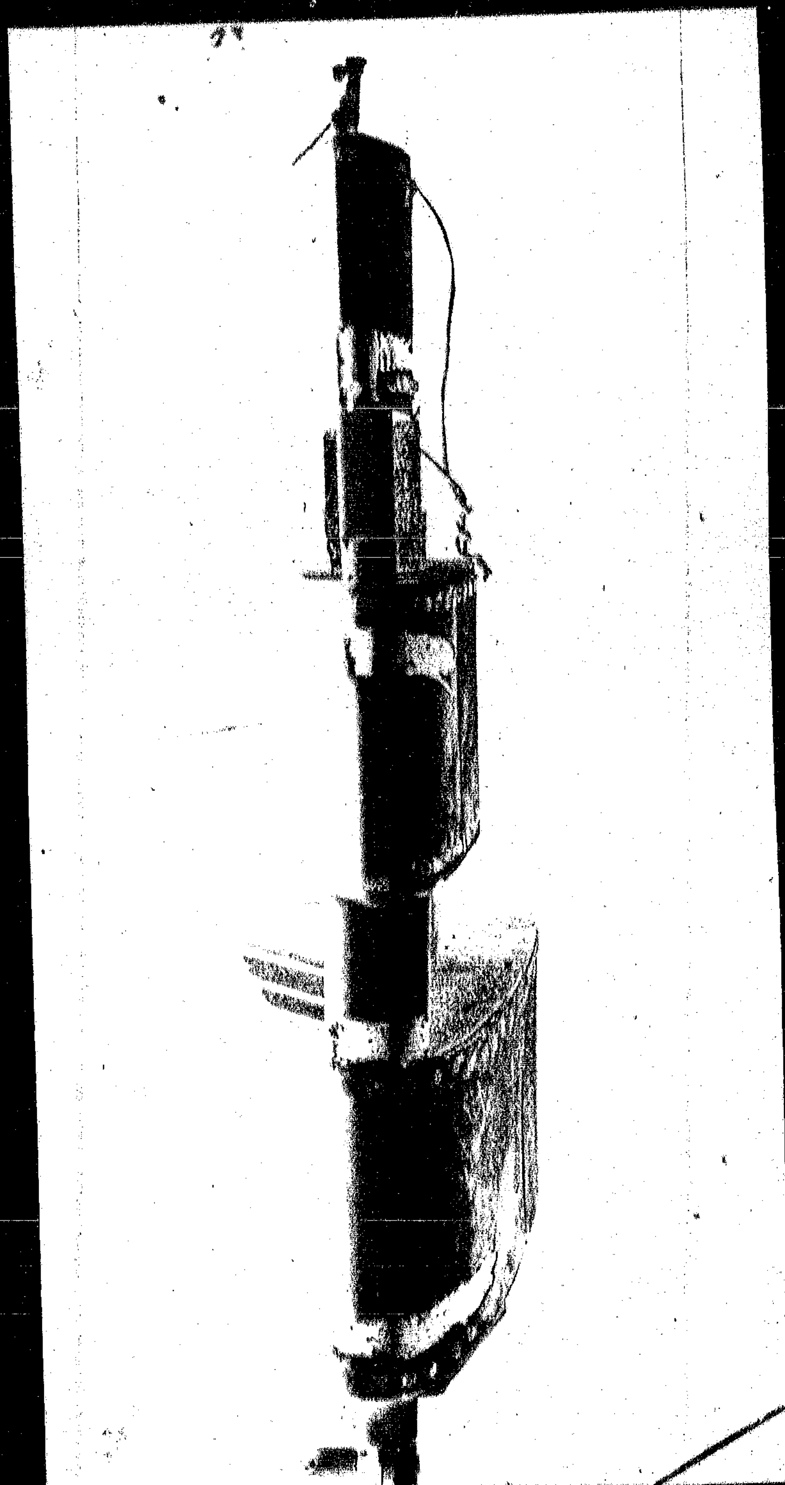
These photographs are presented to show comparability in the former case and noncomparability in the latter case. The comparable cylinders for each scale of the airfoil were chosen by an eye examination of the cylinder size which best fitted the curvature of the leading edge. In both photographs the comparable cylinder is located above its airfoil. In photograph #24, it is seen that no apparent



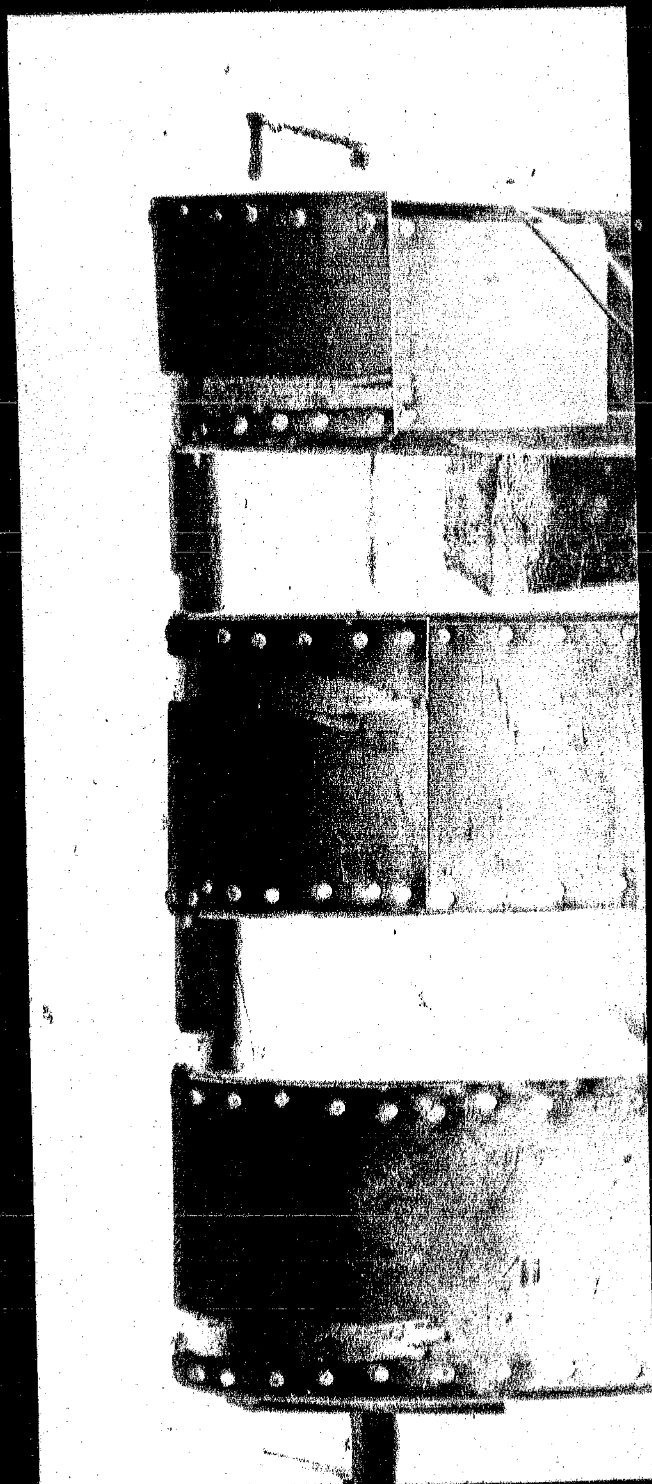
Photograph #24. (a)



Photograph # 24. (b)



Photograph #25. (a)



Photograph # 25. (b)

difference in shape or amount of deposit on the airfoils and their comparable cylinders are revealed. In Photograph #25, the deposit extends to the tangent point on the cylinders and to an airfoil thickness of at least twice the diameter of the comparable cylinder, thus indicating the noncomparability of cylinder and airfoil deposits.