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Fifth Partial Report on the Precipitatic Static Problem.

NAVAL RESEARCH LABORATORY

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NAVY DEPARTMENT

Fifth Partial Report on the Precipitation-Static Problem

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

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ABSTRACT

Using a newly developed apparatus and method, the rates of free electrical charge production on a number of different surfaces moving through a snow storm at high speeds were measured under various controlled conditions. The variables whose effects were sought were speed, temperature, composition of coating, and rate of snowfall. It was found that the charging rate of a surface varied about as the cube of the speed, that the sign of the charge produced on certain surfaces depended on the temperature, and that painted surfaces could be made which charged at approximately 40 percent of the rate of standard Navy non-camouflage airplane finishes. The charging rates of the leading surfaces of a moving body were found to be several times higher than those of the sides or trailing surfaces. The results so obtained are discussed briefly. They add appreciably to the present knowledge of the problem of precipitation-static on aircraft.

All measurements reported were made during actual snowstorms by means of specially developed apparatus located out-of-doors where it was exposed to natural weather conditions closely simulating those of actual aircraft flying through snow. Particular effort was made to operate with only fresh, previously untouched snow. The apparatus is described in the appendix.

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INTRODUCTION

A. Authorization

1. This project is authorized under Bureau of Aeronautics Project Order 832/43, dated 30 June 1943.

B. Statement of Problem

2. Air operations at Minneapolis, Minnesota, employing aircraft fitted with electric field indicators and Faraday Cages, have shown that occasionally the convective charge deposited on the airplane is positive, while the overall charge on the airplane is negative. This and other related data show that tribo-electric phenomena or frictional electrification, due to the impact or sliding of snow particles along the surface of the airplane, are responsible for the observed charging. Such charging may build up the potential on a typical high-speed airplane flying in dry snow to about 350,000 volts,which causes the airplane to break into corona at various places producing serious radio interference. The phenomena need. study, and since the charging conditions in a rapidly moving airplane vary greatly over a given period of time, it seems necessary to set up some equivalent experiment in which conditions may be more carefully controlled. These conditions, however, must closely simulate the actual flight of an airplane through snow. In order to meet the necessary conditions and evaluate the electrical charges produced by the snow sliding at high speeds over various surfaces encountered on aircraft, an entirely new apparatus has been developed and tested by this laboratory. This report gives preliminary results obtained with the above equipment on various natural snows that fell at Minneapolis, Minnesota, and describes the equipment. The data are not as complete as the laboratory would like, but very little snow at low temperatures has fallen at Minneapolis this winter. It is anticipated that more complete results will be available by this time next year.

C. Known Facts Bearing on the Problem

3. Various methods have been used for measuring the surface charging effect by snow. The most direct method of attacking the problem requires the measurement of the charge produced on insulated patch surfaces located at various points on an airplane and under various conditions. Results of direct application can be obtained thereby, but at best, there are many practical difficulties in the way of an extensive study of frictional charging by this means. Two types of indirect method have been used in the laboratory, notably by Professor George of Purdue University. One of these employs a fan to blow snow particles at the test surface, and the other attaches the test surfaces to rotating arms placed underneath a receptacle from which snow or ice particles are sifted. From such experiments much information has been collected, but the methods are open to serious objection. Because the snow particles have been handled or exposed to frictional forces before striking the surface and have frequently been aged for long periods of time, the secured data are open to multiple interpretation. Hence, such tribo-electric experiments introduce a serious element of uncertainty and without corroborative supporting data, the results cannot be trusted. This

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is particularly true because even the sign of the produced charge has reversed in some cases without known cause.

METHODS

4. In an effort to surmount the above difficulties it was decided to build up surfaces in the form of stream-lined bodies, and to arrange to move them on the end of an arm at speeds up to some 300 miles per hour in natural falling snow. The arms are located about ten feet above the ground where fresh, freely-falling snow is always encountered. In other words, the apparatus was designed only for operation outdoors in a snow storm. The stream-lined bodies, themselves, were made similar in size and shape to the ordinary housing for the loop of the ADF receiver used in aircraft but were made of aluminum sheet. Furthermore, each body, or housing, was made in two parts so that the current to the forward section or nose-piece, could be measured separately from the current to the rear section or body-piece. By making the nose-pieces easily interchangeable rapid comparisons between various surfaces on the nose-pieces became possible. The experimental setup was completed by the inclusion of suitable auxiliary and recording apparatus, enabling the recording of nose-piece currents, body-piece currents, relative air-speed, and the measurement of temperature, rate of snowfall, barometric pressure and ground wind speed. Although a complete description of this equipment has been reserved for Appendix I, it may be well at this time, in order better to understand the experimental results, to examine Plate 1 showing the design of the housing, which consists of nose-piece and body-piece, and Plates 2 and 3 which show the whirling machine for rotating the housings.

EXPERIMENTAL RESULTS ON SURFACE CHARGING

5. The surface charging measurements are given under four main headings. These are: (1) the effect of speed, (2) the effect of temperature, (3) the charging rates of various surfaces and coatings, and (4) the charging rates of the nose-pieces relative to those of the body-pieces. All of the experimental work herein reported was done at the Naval Research Laboratory Branch in Minneapolis, Minnesota, during February and the first of March, 1944.

THE EFFECT OF SPEED ON THE FRICTIONAL CHARGING CURRENT

6. The effect of speed on surface frictional charging by snow turns out to be quite large. This may be seen from an examination of Plate 4 where for various speeds, are plotted the charging currents to the nose-pieces for two runs. Note that these runs were made on different days with perhaps much different conditions. It will be seen that the experimental points fall on a curve of the form

$$i = K S^n$$

where i is the charging current in microamperes, K is some constant, S is the speed in miles per hour and n is an exponent giving the effect of speed. This same form of relationship was found to hold for nearly all surfaces in the snow storms where measurements were made. Hence, no need exists for including in this report a charging current-speed graph

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for each run. Instead the observed values of n are listed in Table 1 for the various surfaces. The exponent n has a mean of the average values of 3.2 for all surfaces. For the two standard surfaces on nose-pieces #1 and #2 the mean value of n is 3.1. The speed effect, therefore, is such that the surface charging varies approximately as the cube of the speed. Immediately it becomes evident why the newer, high-speed airplanes have so much more trouble with surface charging and, hence, with precipitation-static than do the older, slow-speed airplanes. Also, it is evident that the propellers, because of their high peripheral speeds (roughly three times that of the airplane), will charge at a maximum rate per unit ares of 3^3 or 27 times the rate of a similar area on the wing of the airplane. The propellers, however, because of their small frontal area, produce only a small fraction of the total charging current to the airplane.

THE EFFECT OF TEMPERATURE ON THE CHARGING CURRENT

7. The evidence may now be presented regarding the importance of temperature to the surface charging rate in snow. Table 1 shows, where the data are available, that the exponent n is greater for temperatures below 20° F than for temperatures above 20° F. The meaning of this is that over a certain temperature range, at least, the speed effect becomes greater as the temperature is lowered. Of even more importance, however, is the change in sign of the charge produced on certain surfaces by snow flakes striking at high speeds, when the temperature is varied sufficiently. Two of the experimental surfaces, namely, that on #3, the chromium-plated nose-piece, and #4, the unpainted 24-ST aluminum alloy nose-piece, charged positively at about 8° F and charged negatively above 20° F. By way of example, these facts are presented for the 24-ST surface in Plate 5. Corroborative evidence that the change of sign occurred with a change in temperature for both the 24-ST surface and the chromium surface was obtained on insulated plates of these materials attached to the nose of our assigned B-25 airplane. The evidence was reported in the Fourth Partial Report, NRL Report No. 0-2271. Of further interest is the fact that only these two surfaces of the seven surfaces which were examined both above and below 20°F exhibited a change in sign.

8. The wide variations seen in the values of n for a given temperature are not believed to be caused by experimental error. On the contrary, it is thought that they result from the great complexity of the frictional surface charging effect. This effect is not a simple one where with a given surface, the charge produced is directly related to the square of the speed, i.e., to the energy available for breakup of the snow flakes. Other factors must be considered such as the size and type of snow crystal involved and the degree of wetness of the flake. Undoubtedly this list of factors is not complete, but a more complete discussion of this matter must await more complete experimental data.

9. Based on the above facts, some speculations may be made concerning the meaning of certain experiences long noted by commercial airline pilots. It has often been reported, for example, that the trailing wire type of discharger was much more likely to be effective in reducing precipitation-static when used in snow at temperatures below 20° F than when the temperatures were above 20° F. Perhaps the reason for this lies in the fact that

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below 20° F the metal (24-ST) surfaces of the airplane charged positively, while the painted surfaces and rubber de-icer-boot surfaces charged negatively. Under such conditions the net charging current would equal the difference between the two charging currents. On the contrary, when the temperatures were above 20° F all surfaces being struck by the snow, including the metal (24-ST) surfaces, charged negatively, and the net charging current would equal the sum of all the charging currents. Therefore, above 20° F a larger charging current would be expected than one would have below 20° F. More trouble would be had in snow, consequently, from precipitation-static at the higher temperatures.

THE CHARGING RATES OF VARIOUS SURFACES

10. Returning now from speculation to fact, it will become evident that the charging rates to the nose-pieces in the various snow storms and flurries have been analyzed from the point of view of (1) relative rates, (2) specific rates, and (3) maximum absolute values observed. The relative charging rates are of greatest use in a study of the different surfaces because they provide direct comparisons between the surfaces. The specific rates would be just as valuable if complete data were available for all surfaces; unfortunately this is not so. Of interest also are the maximum measured values because they show the absolute magnitudes of the charging currents.

11. The relative charging rates are shown in Plate 6. Complete data are available only for the temperatures above 20° F. It will be noted that some nose-piece surfaces were directly compared with nose-piece #1, the two nose-pieces being on opposite ends of the whirling blade during a run. But other nose-piece surfaces were compared with a second nose-piece which in turn was compared with nose-piece #1. Such a presentation was necessary to tie together all the available data that were obtained on different days. A careful study of this figure discloses important facts. First, nose-piece #5 is seen to charge at the lowest rate of any of the painted metal surfaces. Purposely surface #5 had been made to have the highest conductivity of any of the painted surfaces, through the addition of acetylene carbon to the vehicle. Corroborative evidence exists in that surface #10 charges at a lower rate than surface #9, all because of the admixture of acetylene carbon to the ethyl cellulose of surface #10 for the purpose of increasing its conductivity. It is reasonably evident, therefore, that surface charging on a painted surface will be reduced to a minimum by the addition of an agent such as acetylene carbon to the vehicle, the purpose of the additive agent being to increase the conductivity of the paint film. A second fact is that the surface layer is of major importance relative to the underlying layer of primer. As proof, it may be cited that surface #15 which has a primer coat, but is otherwise similar to surface #5, charges at a rate only slightly above that of #5. It is believed, however, that a high resistance primer has a tendency to increase the resistance, and, therefore, the charging rate of a low resistance surface layer. Finally, the metals, namely, the 24-ST aluminum alloy, the chromium-plated surface, and the anodized 2-S aluminum surface, were observed to charge at low negative rates, or even, as in the case of the 2-S surface, at positive rates. It is to be noted that the metal surfaces changed with time and appeared to be relatively unstable; particularly, the anodized 2-S alloy

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changed, as time went on, from a surface which charged positively to a surface which charged negatively.

12. In the beginning it was intended to secure specific charging rates for all surfaces. The specific rate is here defined as the charging current in microamperes to the nose-piece divided by the rate of snow fall expressed in centimeters of water per hour. The latter quantity was determined by weighing the snow collected periodically in a small paper box having a collecting area of about 60 sq.cm. Here trouble was encountered in getting accurate snow fall rates except during storms with little wind. Hence, the available data are few. They are shown in Table 2, where it may be seen that the surfaces are approximately in the same order as in Plate 6. It is also evident in Table 2 that the specific rate is dependent on the temperature of the test. Such is to be expected.

13. Lastly, the maximum values of charging rates are shown in Table 3. It happens that these maximums were noted at a relatively high temperature, 29° F. Very probably the maximum rates observed during these measurements were found during this storm at this temperature rather than at some other temperature because the maximum rate of snowfall occurred at this time. It is to be noted that these charging rates were obtained on a nose-piece, whose frontal cross-section had an area of 53 square inches.

THE RATIO OF NOSE-PIECE TO BODY-PIECE CURRENTS

14. The last matter about which information was sought concerns the ratio of the charging current deposited on the forward surface of a body, to the charging current to the rear or trailing surfaces. For example, this might be the ratio of the charging current to the leading edge of a wing, over the charging current to the top and bottom sections of the wing surface. For this information the ratio of the charging current to the nose-piece over the charging current to the body-piece becomes an acceptable substitute. Such data as are available for strictly comparable tests are given in Plate 7. From this table it may be seen that, in general, the numerical value of the ratio increases with speed, changing from two at 120 m.p.h. to ten at 300 m.p.h. It is also evident that when the temperature is below 20° F, the body-piece of 24-ST alloy charges negatively at slow speeds and positively at high speeds. This explains the peculiar maximum seen in the one curve for the low temperature run, the maximum occurring during the interval when the body surface changes over from a negative to a positive surface. The ratio-speed curve of Plate 7 has considerable bearing on the precipitation-static problem because it shows that as aircraft speeds increase the leading surfaces of the airplane will produce more and more of the total charging current to the airplane. From these data it may be argued that the leading surfaces strike more snow than do the trailing or rearward surfaces. This is reasonable because the air flow over even a streamlined object does not conform exactly to the surface, but tends to bend away from the trailing surfaces, thus carrying the snow flakes out of contact with the latter surfaces. This fact has been well checked by other workers. That the increase in ratio with speed is not caused by a space charge effect may be seen from a study of the lower curve of Plate 7. Here one sees a curve for a negative ratio, which is a reflection of the curve for a positive ratio. In other words, the body-piece charges about the same whether the nose-piece is charging positively or negatively.

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CONCLUSION

15. There are several items as yet unmentioned in this report, but of importance nevertheless. First, no forced rotation of the air caused by the rotating arms, even at high speeds, was noted. For this the clean streamlined design of the arms and the housing is believed responsible. Also, the non-symmetrical outline of the house underneath the rotating arms tended to prevent any appreciable rotation of the air. Second, the whirling machine should have been set up at a high altitude in the mountains in order to duplicate more nearly actual flight conditions. Had more time been available, this would have been done; it is planned to do this at the first opportunity. Last, the work on surface coatings described in this report has been advanced greatly by the close cooperation of Dr. Peter King of the Chemistry Division of the Naval Research Laboratory, who has collaborated in the development of the special coatings described and was responsible for the preparation of each of the surfaces.

RECOMMENDATIONS

16. Recently directives have been issued by both services to reduce the amount of paint or lacquer on aircraft. This practice should be continued because it will reduce the electrical charging rate to aircraft which fly in precipitation.

17. Where paint is necessary for protection to the underlying surface, it is recommended that a paint having a highly conductive surface be used.

18. The best known agent for increasing the conductivity of a paint is acetylene black which makes a black paint when added to a vehicle. In view of this fact it is recommended that the Bureau of Aeronautics investigate the practicability of using a black paint on the leading edges or surfaces of aircraft, if not on all surfaces.

19. It is recommended that the paint or other treatment used on a leading edge or surface of an airplane be examined carefully. These are the principal surfaces where the electrical charges producing precipitation-static originate.

20. Since quantitative measurements show that precipitation-static difficulties will increase with the size of the airplane and approximately with the cube of the speed of the airplane, it is recommended that the Bureau of Aeronautics examine critically the large high-speed airplanes now in use or now under development, in the light of these recommendations.

APPENDIX I

DESCRIPTION OF EXPERIMENTAL APPARATUS

21. In principle the experimental equipment consisted of an arrangement whereby two streamlined loop housings could be rotated through the outside air at speeds up to 300 m.p.h. Each loop housing was on one end of a rotatable blade having a diameter of 20 feet, located outdoors at the top of a small house. The blade was driven from within the house. This apparatus included also, suitable accessory equipment such as an electric power plant, so that it was entirely self-contained and could be used to secure data anywhere that the desired weather conditions could be found.

22. It has already been mentioned that the loop-housing, shown in Plate 1, was made in two parts, a nose-piece and a body-piece. At its widest point the nose-piece had a diameter of 8.2 inches and a depth of 5.0 inches; its frontal cross-section had an area of 52.5 sq. in. The body-piece, however, had a maximum diameter of 9.0 inches, a length of 20-1/4 inches, and a surface area of approximately 868 square inches. Each part was so insulated from ground that even in a wet snowstorm the resistance to ground did not ordinarily fall below 300 megohms. From the two parts of each loop-housing, shielded lead-wires ran through the arms and slip-rings on the shaft to a control panel where selection was made as to which part was to be connected to the recording apparatus.

23. Each arm of the rotatable blade which bore the loop housings was constructed of a streamlined tube and was pivoted at its center support to insure smooth rotation of the parts. At rest the arms were supported by shoes resting on an underlying horizontal ring at the center of the blade. To the blade was attached a vertical driving shaft which extended down through the roof of the house to where it was coupled to a heavy duty gas engine of 40 horsepower located within the house. At the full power output of the engine it was possible to drive the loop housings at a speed of 310 miles per hour. This could be done, too, without excessive vibration. The driving machinery along with the recording apparatus was installed entirely within the house, photos of which are shown in Plates 2 and 3. The necessary accessories to this equipment that were in the engine house, included an amplifier used in conjunction with a photoelectric recorder for measuring charging currents, and a recorder for speed measurements. These records were correlated by a timing device which at known time intervals put marks on each record. Wind speed was recorded, too, but as the wind speed never exceeded 14 miles per hour during the measurements, no use was made of the data so obtained. Power for the recording equipment and for lighting was obtained from a small portable electric-generating plant in a nearby house. The accessories included a good beam balance for measuring the snow fall in a given time, and several thermometers, barometers and the like.

24. In conclusion, it may be said that the performance of the equipment was satisfactory. Little trouble was had from vibration, probably because the engine house was securely fastened down to a concrete foundation.

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That only minor difficulties were met with from a novel set-up of this naturewhere the parts were severely tried is due to the work of F. I. Louckes and W. E. Snyder of this laboratory, who were responsible for the design and construction of the machine.

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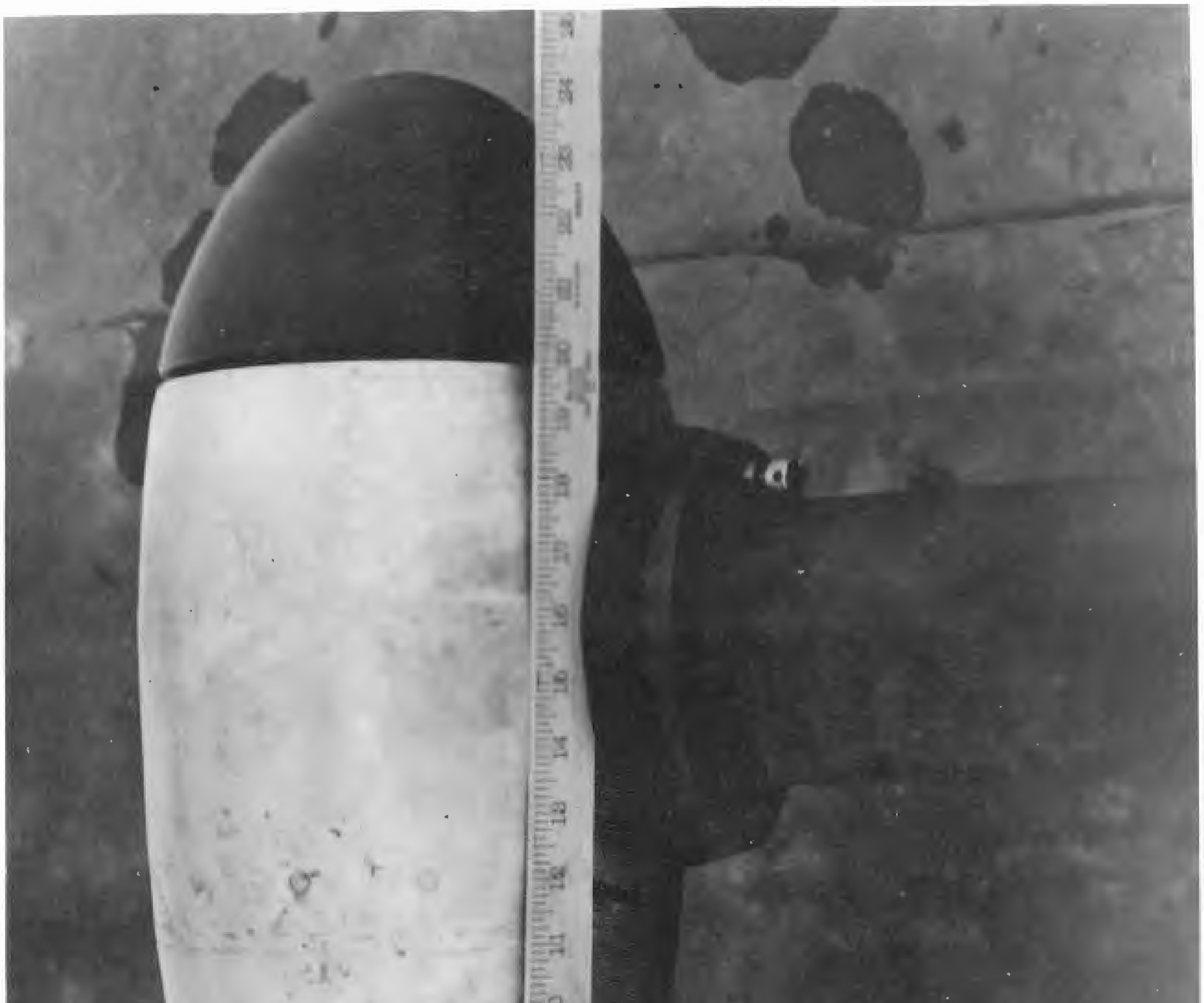

THE HOUSING; NOSE PIECE ABOVE
BODY PIECE BELOW

PLATE I

WHIRLING MACHINE ; SIDE VIEW

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WHIRLING MACHINE; END VIEW

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PLATE 3

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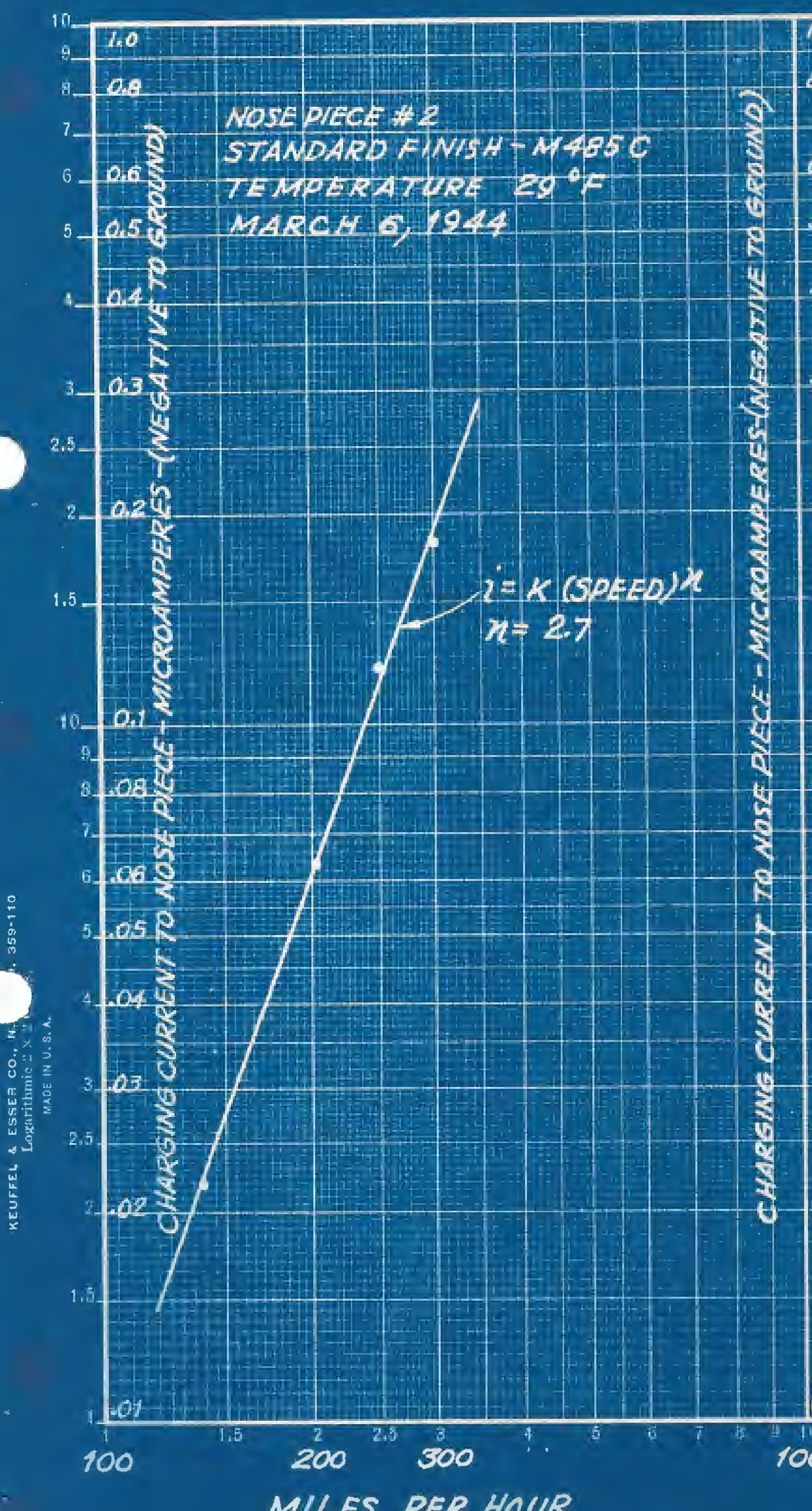

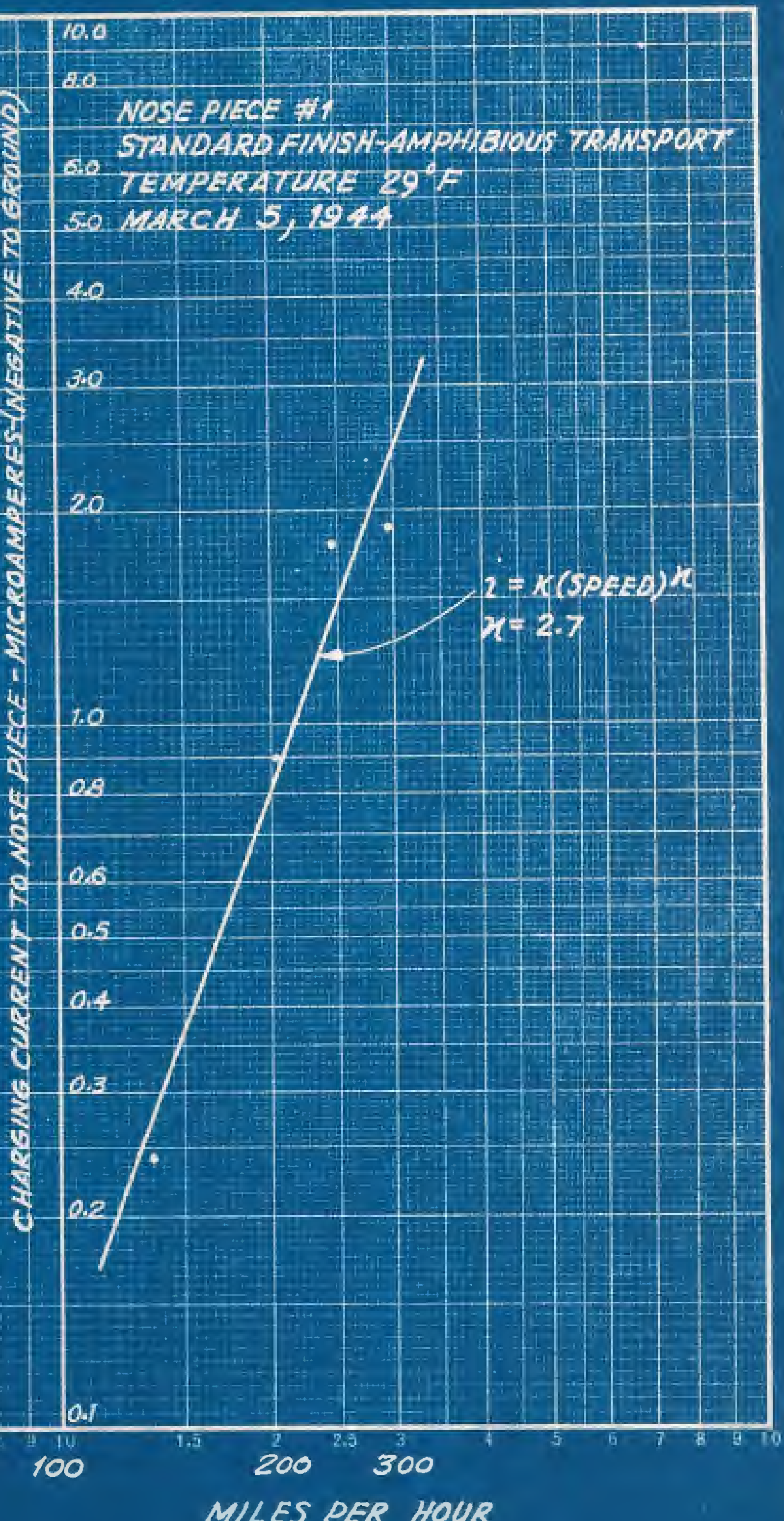

FORM OF CHARGING CURRENT - SPEED RELATIONSHIP

FIG. 4A FIG. 4B

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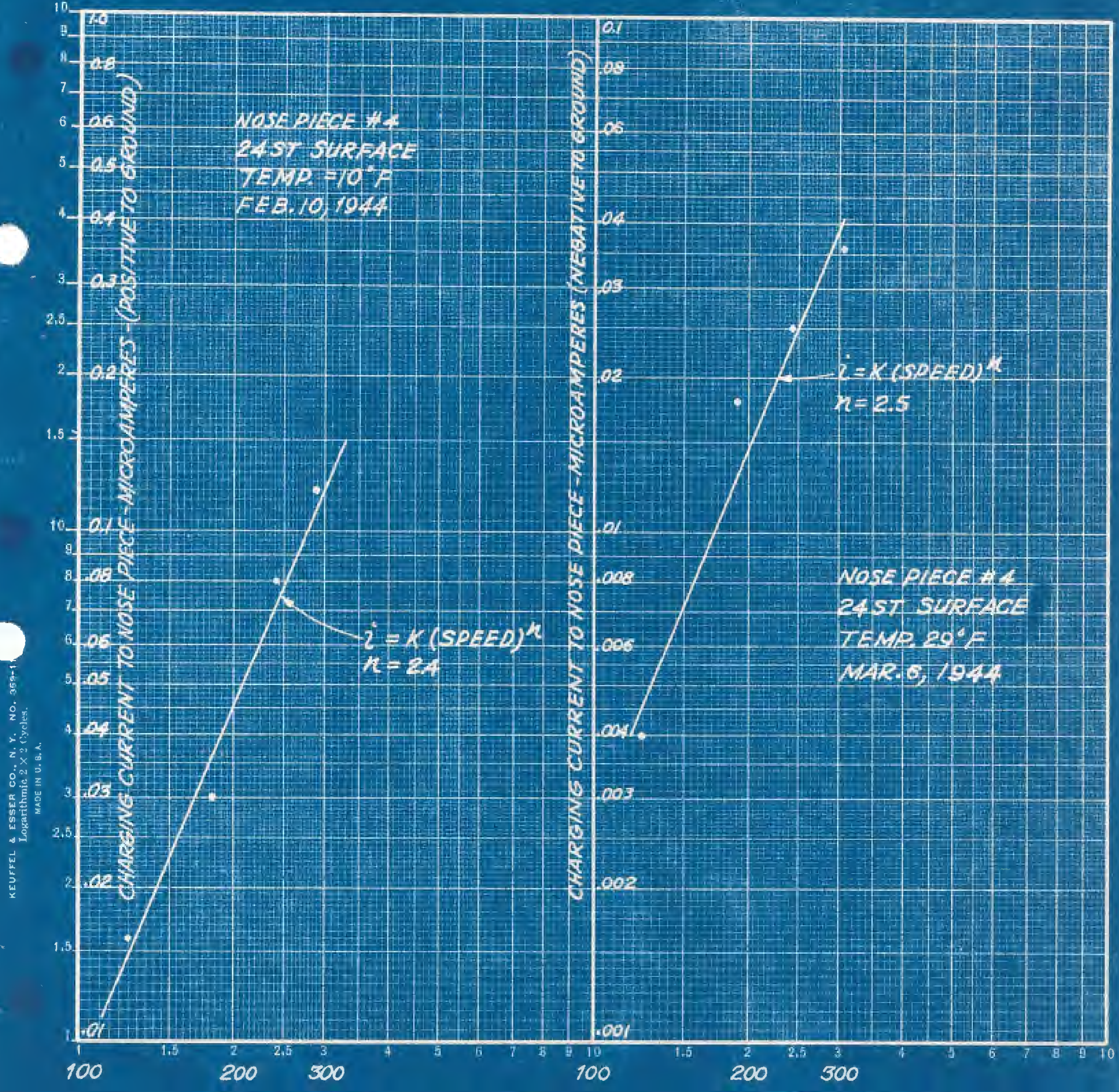

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EFFECT OF TEMPERATURE ON CHARGING CURRENT

FIG. 5 A FIG. 5 B

PLATE 5

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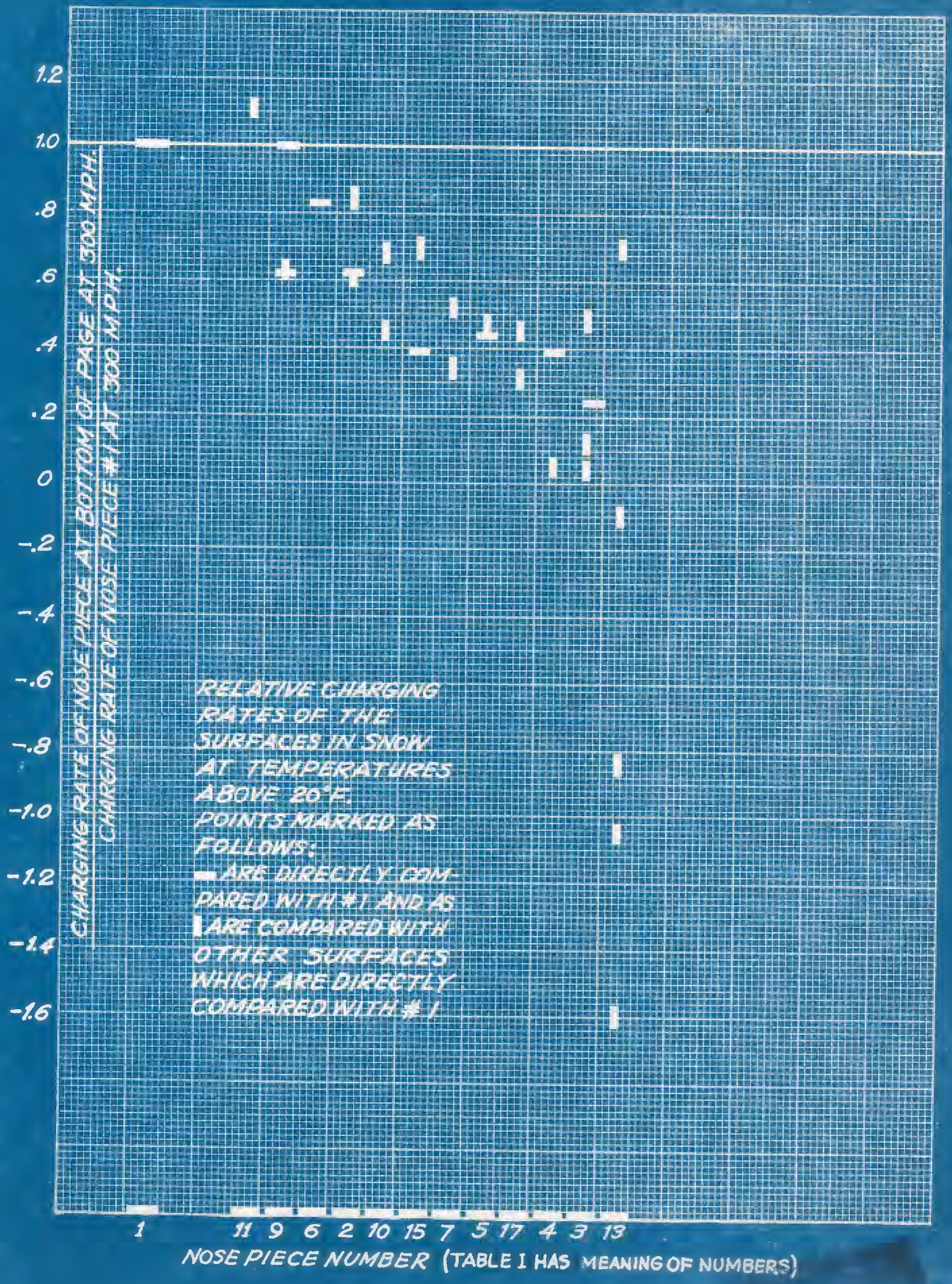
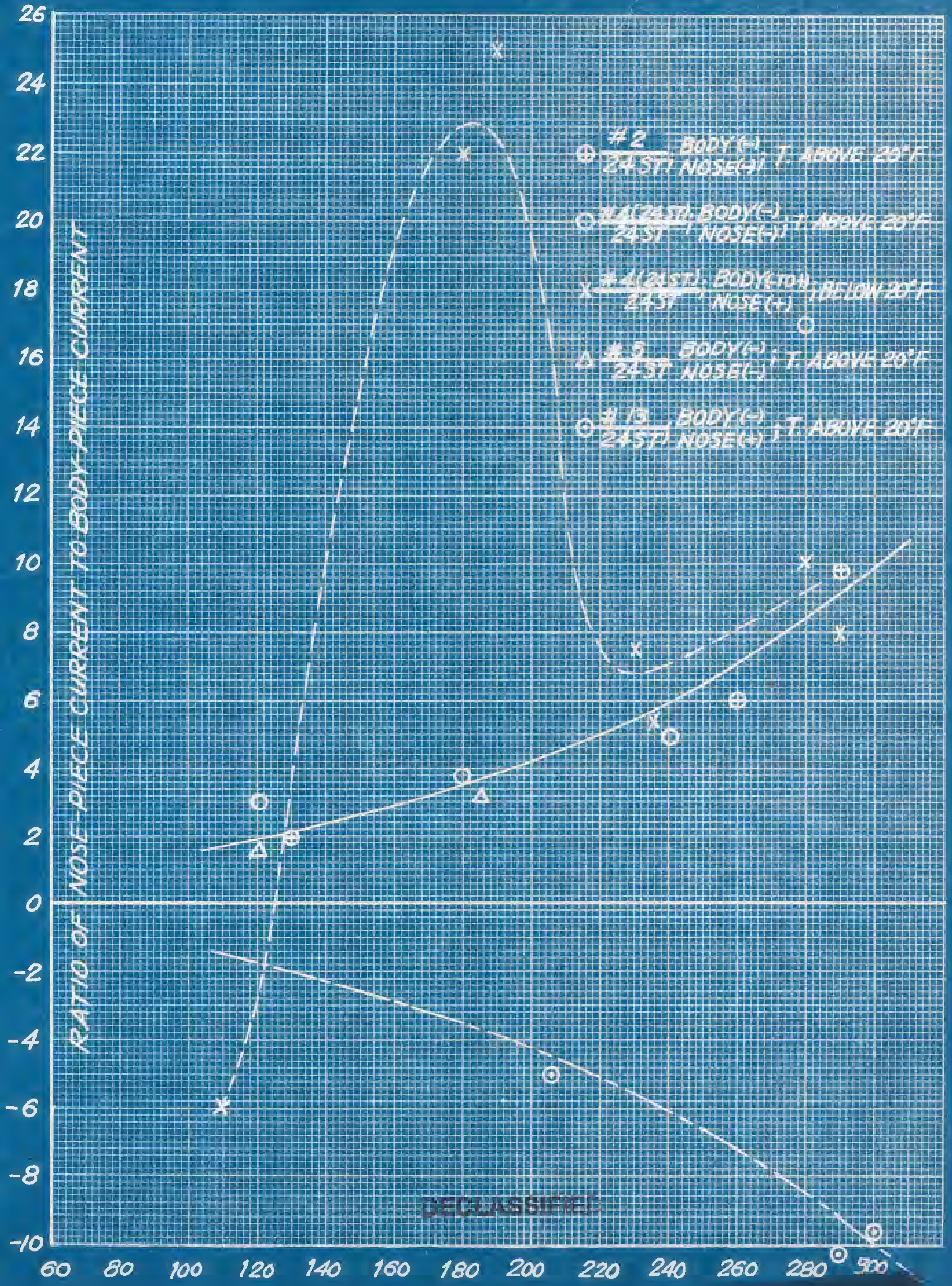


PLATE 6

DATE



MILES PER HOUR [redacted]

RATIO OF NOSE-TO BODY-PIECE CURRENTS

PLATE 7

Table 1

The Effect of Speed on Surface Charging

In this table the column under n lists values of the exponent in the equation $i = K(\text{Speed})^n$.

Surface or Coating				Nose Piece No.	n				Remarks
					Above 20° F		Below 20° F		
Metal	Anodizing Treatment	Primer	Paint		n	T	n	T	
24-ST	Chromic Acid	P27	M485C	1	3.6	25°F	3.5	8.°F	Std. finish Charges Negatively
(Navy standard non-camouflage finish, black)				"	1.9	25°	3.5	10°	
				"	2.2	23			
				"	2.7	24			
				"	2.8	29			
				"	2.1	29			
				Average	2.5		3.5		
24-ST	Chromic Acid	P27	Amphibious Transport	2	2.1	23°	3.6	8° F	Std. finish Charges Negatively
(Navy standard non-camouflage finish, grey)				"	3.1	23°	3.6	8° F	
				"	1.8	25°			
				"	2.4	25°			
				"	3.5	29°			
				"	2.5	29°			
				"	2.7	29°			
				Average	2.6		3.6		
24-ST	---	Chromium Plated		3	2.6	25° F		8° F	At 8° charges positively. At 23° charges negatively.
				"	3.7	29° F			
				"	3.7	29° F			
				Average	3.3				

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Table 1 (con'd)

Surface or Coating				Nose Piece No.	n				Remarks
Metal	Anodizing Treatment	Primer	Paint		Above 20° F n	T	Below 20°F n	T	
24-ST				4	2.5	29°F	2.4	10°F	At 10° charges positively. At 29° charges negatively.
				"			2.7	8°	
				Average	2.5		2.6		
24-ST	- - -	- -	#52	5	2.1	22°F	2.8	8°F	Charges negatively
				"	3.4	22°F	3.7	10°F	
(High-conductivity paint)				"	3.9	29°F			
				Average	3.1		3.2		
24-ST	Boric Acid	- -	#52	6	2.3	23°F	3.6	10°F	Charges negatively.
				"	3.4	29°F			
				"	3.0	29°F			
				Average	2.9		3.6		
24-ST	Chromic Acid	- -	#52	7	4.4	29°F			Charges negatively.
24-ST	- - -	- -	USKON-1	8			3.4	8°F	Charges
(De-icer boot conducting paint)				"			2.6	10°F	
				Average			3.0		
24-ST	_ _ _	_ _	Ethyl Cellulose (Plasticized)	9	3.7	23°F	5.0	8°F	Charges negatively
				"	3.9	29°F	4.7	10°F	
				Average	3.8		4.8		

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Table 1 (con'd)

Surface or Coating				Nose Piece No.	η				Remarks
Metal	Anodizing Treatment	Primer	Paint		Above 20°F n	T	Below 20°F n	T	
24-ST	- - -	- -	Ethyl Cellulose (Plasticized) and carbon	10	4.6	25°F			Charges negatively.
				"	3.8	29°F			
			Average		4.2				
24-ST	Boric Acid	P27	M485C	11	2.2	29°F			Charges negatively.
				"	2.7	29°F			
			Average		2.5				
2S	Boric Acid & Chromic Acid	- -	- - -	13	3.1	29°F			Charges positively at first, negatively later.
				"	1.3	29°F			
			Average		2.9				
24-ST	Chromic Acid	P27	#52	15	3.9	29°F			Charges negatively.
				"	1.9	29°F			
			Average		2.9				
52S	Metal covered by single layer of rubber painted over with USKON-1 paint			17	2.2	29°F			Charges negatively.
				"	2.6	29°F			
			Average		2.4				

[redacted]

Table 2

Specific Charging Rates of Various

Surfaces

Nose Piece No.	Charging Rate µA at 300 MPH	Snow Fall Rate Cm H_2O per hour	Specific Rate $\frac{\mu A}{\text{Cm } H_2O/\text{hour}}$	Temperature °F
1	– 0.09	0.004	– 22	10
2	– 0.08	0.012	– 6.8	10
4	+ 0.12	0.025	4.8	10
5	– .07	0.034	– 2.0	10
6	– .045	0.014	– 3.2	10
	– .045	.012	– 3.7	10
8	– .09	.012	– 7.5	10
9	– .45	.055	– 8.2	10
	– .09	.009	– 10.	10
- - - - - - - - -				
1		Average	– 8	25
2	– .035	.008	– 5.5	25
	– .026	.005	– 5.2	25
3		Average	– 3.3	25
5	– .014	.005	– 2.8	25
	– .027	.008	– 3.3	25
6	– .027	.007	– 3.9	25
9	– .036	.008	– 4.5	25
	– .024	.004	– 6.0	25

(See Table 1 for meaning of nose-piece numbers)

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Table 3

The Maximum Observed Charging

Rate to the Nose-Pieces

(See Table 1 for meaning of nose-piece numbers)
(All of these data were taken at 29°F)

Nose Piece No.	Maximum Charging Current Microamperes	
	300 MPH	200 MPH
1	- 2.6 μA	- 0.8 μA
2	- 0.36	- 0.09
3	- 0.18	- 0.025
4	- 0.04	- 0.015
5.	- 0.9	- 0.18
6	- 0.27	- 0.07
7	- 0.72	- 0.12
9	- 2.6	- 0.5
10	- 0.22	- 0.045
11	- 0.60	- 0.25
13	+ 0.41	+ 0.11
15	- 0.56	- 0.12
17	- 0.10	- 0.035

[redacted] [redacted]