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Progress in the Study of Organic Protective Finishes for Plywood Airplanes and Gliders

NAVAL RESEARCH LABORATORY

WASHINGTON 20, D. C.

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NAVY DEPARTMENT

First Report On

# Progress in the Study of Organic Protective Finishes for Plywood Airplanes and Gliders

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

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ABSTRACT

This is the initial report of a contemplated exhaustive study of finishing systems for plywood aircraft. Plywood panels, coated with products of five reputable manufacturers have been subjected to test. On the basis of results obtained, certain changes in the finishing systems appear desirable. These are as follows:

1. Omission of the primer surfacer coat.
2. Application of filler as the initial coat.
3. Use of at least two sealer coats for added protection and smoothness.

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INTRODUCTION

(A) Authorization

1. This study was authorized by Bureau of Aeronautics letters Aer-E-2571-MVS-L2-5/F38 091963 dated 10 July 1942 and Aer-E-2571-MVS-F38-2 090781 dated 8 July 1942.

2. References

(a) Memorandum Aer-E-2571-MVS, L-2-5/F38, JJ39, F38-3, 30 June 1942.

(b) U. S. Army Specification: Protective Coatings (for Aircraft Wood Surfaces)

(B) Background

3. An Army-Navy Aeronautical conference on wood finishing schemes for Military aircraft was reported in reference (2a). The purpose of the meeting was to consider the applicability of the proposed Army Air Force Specification for wood finishing to Naval aircraft and to recommend to the Working Committee of the Aeronautical Board the changes deemed necessary for a joint Army-Navy specification.

4. One change that was suggested applies to paragraph (E-1c) of reference (2b), the finishing of exterior wood surfaces. Paragraph (2g) of reference (2a) is quoted herewith.

> "Change paragraph E-1c to read as follows:
> 'The minimum finishing system for exterior wood surfaces shall consist of one coat of aluminized sealer, plus one coat of primer surfacer, plus finish of the required color which may be either two coats of lacquer or one coat of enamel. The finish after 48 hours air drying shall weigh between 0.035 and 0.050 pounds per square foot. Dr. Browne presented data indicating that the smoothness added to the final finish by primer surfacer was at the expense of a large increase in weight, without a corresponding increase in water resistance. It was agreed that, if slightly less smoothness was found to be acceptable, a system consisting of one coat of filler, plus one coat of aluminized sealer plus finish coats of the required color should be substituted for the above system."

The study reported here has been made in accordance with the letters of Authorization, and Action-4 of reference (2a).

(C) Discussion of Problem

5. The use of plywood for the construction of military aircraft is rapidly expanding. This is due partly to metal shortages.

The intrinsic merit of the material itself must be acknowledged for great progress in plywood technology has been made recently. The most noteworthy strides are the introduction of phenolic and urea formaldehyde resins in place of glues as binders for the veneers and the newer molding methods for shaping the laminae to precise contour.

6. The finishing problems which attend plywood aircraft are centered around the following considerations:

1. Weight
2. Smoothness
3. Durability and protection
4. Production speed

The fourth item must be reckoned with in all types of military aircraft. The first and second are of more importance to combat planes than to other classes of aircraft. Durability of the film and protection of the underlying structure are primary considerations in the manufacture of trainers, and other craft of reasonably long life expectancy. As a matter of practical consideration, no finishing system can be optimum for all four factors. The selection of any given finishing system represents, to a certain extent, a compromise, and the choice must be governed by the role of each coat to the resultant paint film and its relation to whatever of the four points that happen to be of greatest importance.

7. The drawbacks of a heavy coating are, of course, lower speeds, increased fuel consumption and a decrease in the effective load that can be carried. A rough air foil offers these handicaps also. In addition, a rough film will deteriorate more rapidly.

8. The third point "durability and protection" connotes a surface film capable of insulating the wood from the extreme fluctuations of atmospheric moisture and the evils of warpage, grain raising, checking, and the rupture of wood fibers from the freezing of absorbed moisture.

9. The desirability of speed in output requires no discussion. The paint shop must not be a "bottle neck."

10. At the present time in this country, most of the plywood aircraft are trainers and gliders where the primary requisites of the paint film are durability and speed of application, with weight and smoothness secondary, but by no means negligible, considerations.

11. Excepting construction in which the wood is given a covering of doped fabric the following materials are commonly employed for the finishing of exterior surfaces.

(a) A penetrating sealer. This is an alkyd or phenolic type varnish usually thinned to 18% to 20% solids to facilitate penetration of the wood. The penetrating sealer may be applied either by dip, brush or spray. It is believed by some that this material functions simply as a good bond between the wood and the next coat, and that the sealer of itself contributes very little to the moisture resistance of the film. Occasionally, two successive coats of sealer are applied. In this event the second coat is probably only partially absorbed and thus forms a true surface film. This is certainly the case when the sealer is pigmented with aluminum.

(b) Wood filler. This material is of essentially the same composition as the penetrating sealer with the addition of about 50% magnesium silicate, silica, or other similar material. Current usage prescribes its use on porous, open grained woods like mahogany. The filler is applied liberally by spray or brush, and the volatile solvent allowed to evaporate. After the surplus filler has been wiped off, a relatively smooth surface is presented. Wood filler is not now employed on close grained, non-porous woods.

(c) Primer surfacer. This is a pigmented varnish applied in 1 or 2 heavy coats immediately preceding the top coats. The primer surfacer is usually sanded in order to provide a maximum smoothness for the top coat. The principal drawbacks of the primer surfacer are its great weight and excessive time for the coat to dry sufficiently for sanding. Add to these handicaps the belief of some that the primer surfacer contributes neither durability nor moisture resistance to the films and the need for a critical evaluation of the primer surfacer becomes apparent.

(d) Top coat. This is an important coat but it is mentioned only briefly because its merits are only a subordinate part of this study. It is usually a phenolic or alkyd enamel or a lacquer, applied in one or more coats.

12. The Army Air Force Specification, reference (2b, paragraph E-1a) requires at least two coats of clear sealer for the protection of interior enclosed surfaces. The procuring agency may require a coat of aluminized sealer in addition. The Army-Navy Aeronautical Conference (reference 2a, paragraph 2e) suggests one coat of clear sealer plus one coat of aluminized sealer as the minimum interior finishing system. For external surfaces, the specification establishes a minimum finishing system consisting of one coat of sealer, one coat of surfacer and two top coats. The change proposed by the conference has already been quoted.

13. The principal objectives of this study have been as follows:

(a) An evaluation of the importance of the primer surfacer to the resultant film.

(b) A determination of the adequacy of filler as replacement for primer surfacer, as suggested by the conference (reference 2a, paragraph 2n).

(D) Methods

(a) Material

14. Clear sealers, wood fillers, primer surfaces and enamels were supplied by five manufacturers as complying with the appropriate A.A.F. or AN specifications. Each item was thinned in accordance with manufacturer's directions.

15. Plywood panels, 12" x 12" x 7/32", five plies thick, complying with AN-NN-P-511a were used in all cases.

(b) Experimental

16. A number of plywood panels of different woods were chosen. Those having outer plies of mahogany were selected as exemplifying porous, open grained wood, while poplar and birch were chosen as representative of the smooth, nonporous types. Three panels of each wood type were sprayed on one side with the complete finishing system prescribed by the manufacturer. As alternatives, the coat of primer surfacer was omitted and filler applied, either before or after the seal coat. The few exceptions to this general procedure are noted at the appropriate places. The top coat, of course, was applied as usual. With a few exceptions, the back surfaces of the panels were sprayed with the interior finishing system recommended by the Army-Navy aeronautical Conference (reference 2a), namely, one coat of clear sealer plus one coat of aluminized sealer. The latter was prepared by adding aluminum pigment (AN-TT-A-401) at the rate of one pound per gallon of clear sealer. The panels were then air dried and sawed into smaller pieces for the individual tests. The edges of these small panels were then sealed with two dip coats of aluminized varnish. This was done to eliminate the capillarity of the sawed edges as a factor in the behavior of the paint film.

17. After aging for a minimum of two weeks in the laboratory, panels were subjected to the following tests:

1. Roof exposure
2. Accelerated weathering
3. Moisture absorption
4. Salt spray

As already stated, the 12 x 12" panels were prepared in triplicate, sawed, and three pieces, one from each panel, were selected for each of the tests mentioned above.

18. The spraying was done by an experienced operator, using a De Vilbiss spray gun Type CV-604 at a nozzle pressure of 30 pounds.

19. The sequence of coats representing exterior finishes is given in Table I below.

TABLE I

Preparation of the External Surfaces of Plywood Panels

| Group | Manufacturer | Wood | Sequence of Coats | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|
| 1 | A | Mahogany | filler | surfacer | top | top | | (a) |
| 2 | A | " | sealer | filler | " | " | | |
| 3 | A | " | filler | sealer | " | " | | |
| 4 | A | Birch | sealer | surfacer | " | " | | (a) |
| 5 | A | " | " | filler | " | " | | |
| 6 | A | " | filler | sealer | " | " | | |
| 7 | B | Mahogany | sealer | filler | prim. surf. | " | top | (a) |
| 8 | B | " | " | " | top | " | -- | |
| 9 | B | " | filler | sealer | " | " | | |
| 10 | B | Birch | sealer | surfacer | " | " | | (a) |
| 11 | B | " | " | filler | " | " | | |
| 12 | B | " | filler | sealer | " | " | | |
| 13 | C | Mahogany | filler | alkyd sealer | surfacer | | top | (a) |
| 14 | C | " | " | phenolic sealer | " | | " | (a) |
| 15 | C | " | " | alkyd sealer | top | | -- | |
| 16 | C | " | " | phenolic sealer | " | | -- | |
| 17 | C | " | alkyd sealer | filler | " | | | |
| 18 | C | " | phenolic sealer | " | " | | -- | |
| 19 | C | Poplar | alkyd sealer | surfacer | " | | | (a) |
| 20 | C | " | phenolic sealer | " | " | | | (a) |
| 21 | C | " | alkyd sealer | top | -- | | -- | |
| 22 | C | " | phenolic sealer | " | -- | | -- | |
| 23 | D | Mahogany | sealer | filler | surfacer | | top | (a) |
| 24 | D | " | " | " | sealer | | " | |
| 25 | D | " | filler | sealer | top | | -- | |
| 26 | D | Poplar | sealer | surfacer | " | | -- | (a) |
| 27 | D | " | sealer | top | " | | | |
| 28 | D | " | " | " | -- | | -- | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 29 | E | Mahogany | sealer | sealer | filler | surfacer | top (a) |
| 30 | E | " | filler | " | sealer | top | |
| 31 | E | " | sealer | " | filler | " | |
| 32 | E | Poplar | " | " | surfacer | " | – (a) |
| 33 | E | " | " | " | filler | top | |
| 34 | E | " | filler | " | sealer | " | |

(a) Sequence recommended by manufacturer.

20. The interior finishing systems were applied to the reverse sides of the panels. Here the standard spray procedure was one coat of clear sealer plus one coat of aluminized sealer. Except where noted, the latter was prepared by adding aluminum powder (for standard varnish #321) to the clear sealer at the rate of 1 pound per gallon. The inner finishes which were tested are summarized in Table II. As in Table I, each group refers to three panels. There is no necessary correspondence of the group numbers between the two tables.

TABLE II

Preparation of Inner Surfaces of Plywood Panels

| Group | Manufacturer | Wood | Sequence of Sealer Coats | | | Remarks |
|---|---|---|---|---|---|---|
| 1 | A | Mahogany | Clear | Al | | Al sealer prepared with mfr's. Al paste |
| 2 | A | Birch | " | " | | " |
| 3 | B | Mahogany | " | " | | |
| 4 | B | Birch | " | " | | |
| 5 | C | Mahogany | " | " | | Alkyd |
| 6 | C | " | " | " | | Phenolic |
| 7 | D | " | " | Clear | | |
| 8 | D | " | " | Al | | |
| 9 | E | Poplar | " | " | | |
| 10 | E | " | " | " | Al | |
| 11 | E | " | " | Clear | | |

21. Each coat was allowed to air dry before the next coat was applied. Each finished panel was then sawed to the following approximate sizes for individual tests:

1 – 4"x 12" for normal weather resistance
1 – 3"x 9" for accelerated weathering
3 – 4"x 4" for moisture absorption
1 – 3"x 4" for salt spray

22. After sealing the edges with a double dip coat of alumunized varnish the panels were set aside until the films had aged at least two weeks before the tests were begun.

(a) Normal Weathering - This test was limited to the films for outside exposure (Table I). The 4 x 12" panels were placed in exposure racks on the laboratory roof at a 45° angle, facing south. They were then inspected periodically.

(b) Accelerated Weathering - The 3"x 9" panels were exposed in a "National" Accelerated Testing Unit Type X-1-A. The weathering process consists of continuous exposure to a 60 ampere twin carbon arc, plus 15 minutes of water spray every two hours. The panels were subjected to 300 hours of this treatment, which sufficed to produce evidence of deterioration in practically all panels.

(c) Moisture absorption - (1) The standard technique for measuring moisture absorption involves immersion of the painted panel in water for a definite period. The gain in weight is taken as the index of the permeability of the paint film. In the present study, this method was rejected for two reasons. The capillarity of the sawed edges seemed to offer opportunity for serious error. Although the edges were sealed with aluminized varnish, assuming the integrity of this film along a relatively rough surface seemed unwarranted. Secondly, an immersed panel absorbs water through both surfaces which requires that either the test finish be applied to each side or that the reverse side be protected with a film of negligible permeability. Since some of the test finishes were expected to be highly resistant, a practically impervious film would be required.

(2) Another method consists in sealing the painted panel across the mouth of a vessel containing calcium chloride or a similar desiccant. The gain in weight of the assembly as the hygroscopic material absorbs moisture from the air, indicates the permeability of the panel. This method has the merit of uniformity in that the paint is subjected to a relatively constant vapor pressure gradient. However, by this technique the film is always dry and as such does not approximate service conditions. Further, it must be recalled that the five plywood veneers comprising the panel are bonded with a phenolic resin of high moisture resistance. It was feared that the impedance of the four layers of adhesive might be high enough to place the additional impedance of the paint film dangerously close to the limit of error of the measurements.

(3) For this study glass rings ½" high were cut from ordinary soft glass tubing 3" inside diameter. The rings were affixed to the 4 x 4" panels of the surfaces being studied. Thus, the paint film formed the bottom for a vessel about 45 sq. cm. in area. At first, sealing wax was used to cement the rings in place. Later, a molten mixture of rosin and beeswax was employed. For test, the prepared panels were brought to moisture equilibrium by storage at 25° C in the constant temperature room where all the weighings were to be made. After the panels had come to approximately constant weight, the rings were filled with tap water and a cover applied to each. After 24 hours each unit individually was drained, wiped dry, weighed, and refilled with water. The operation was repeated for five consecutive days, the

daily increments in weight representing the moisture absorbed.

(4) The principal advantages of this method are as follows: First, it permits study of a single surface, with no complications from edge effects. Secondly, the absorption occurs through a definite area. Repetition of measurements on the same panels serves to disclose certain cases of films that are initially satisfactory but which deteriorate by prolonged contact with water.

(d) Salt spray - In this device the panels maintained at 29°-36°C are subjected alternately to 15 minutes of spraying with 6% sodium chloride solution, and 15 minutes of a warm air current. Eight hours daily the panels are illuminated by a G.E. (S-1) lamp through a corex filter.

(E) Experimental Results

23. (a) Normal Weathering -

TABLE III

Normal Weathering by Roof Exposure.

Symbols G - good, F - fair, T - trace, P - poor, S - slight, M - marked, VM - Very marked, 11 - parallel, 0 - none

| Group | Exposure Period from 10/17/42 | to 2/1/43 | days 107 | Hiding | Color | Cleanliness. | Chalking | Checking | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| 1 | " | " | " | G | G | F | T | S(11) | |
| 2 | " | " | " | G | G | F | T | | |
| 3 | " | " | " | G | G | F | T | | |
| 4 | " | " | " | G | G | F | T | | |
| 5 | " | " | " | G | F | F | T | (VM11) | 1 panel unchecked |
| 6 | " | " | " | G | F | F | T | | |
| 7 | 10/19 | " | 105 | G | F-P | G | M | 0 | pinholes |
| 8 | " | " | " | G | F-P | G | M | 0 | 1 panel S checked |
| 9 | " | " | " | G | F-P | G | M | 0 | |
| 10 | " | " | " | G | F-P | G | M | 0 | |
| 11 | " | " | " | G | F-P | G | M | 0 | |
| 12 | " | " | " | G | F-P | G | M | 0 | |
| 13 | 11/16 | " | 77 | G | G | P | | 0 | |
| 14 | " | " | " | G | G | P | | 0 | |
| 15 | " | " | " | G | G | P | | (0) | 2 panels unfilled grain, incipient checking |
| 16 | " | " | " | G | G | P | | 0 | |
| 17 | " | " | " | G | G | P | | (0) | 1 panel, checking T |
| 18 | " | " | " | G | G | P | | 0 | |
| 19 | " | " | " | G | G | P | | 0 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 20 | 11/16 | 2/1/43 | 77 | G | G | P | (0) | 1 panel, 1 check at seam |
| 21 | " | " | " | P | G | P | 0 | |
| 22 | " | " | " | P | G | P | 0 | |
| 23 | " | " | " | | | | | |
| 24 | " | " | " | | | | | |
| 25 | " | " | " | | | | | |
| 26 | " | " | " | | | | | |
| 27 | " | " | " | | | | | |
| 28 | " | " | " | | | | | |
| 29 | 12/16/42 | 2/1/43 | 47 | | | | | |
| 30 | " | " | " | | | | | 1 panel pinholes T; unfilled grain |
| 31 | " | " | " | | | | | |
| 32 | " | " | " | | | | | 1 panel T check |
| 33 | " | " | " | | | | | marked grain raising on 1 panel |
| 34 | " | " | " | | | | | |

24. Though judgment must be suspended on most of the panels, it may be noted that some evidences of deterioration are already present. Though the finishes vary in such film properties as hiding, color, cleanliness and chalking, there is no variability among the groups representing a single manufacturer. Groups 21 and 22 are not exceptions to this rule; the hiding of these films was poor from the beginning. It is evident, therefore, that deterioration of the four qualities mentioned is controlled by the top coat. In resistance to checking the underlying coats are of considerable importance.

25. Groups 2, 5, 8, 9, 15, 17, 31 and 33 represent panels in which perceptible weathering has taken place. (Group 21 is here excluded because it contains no filler). Of the eight groups showing deterioration, six of them are instances in which the coating sequence was sealer followed by filler. In two of them (9, 15) the order is reversed. This establishes only the general inferiority of the sequence. Further weathering is required to demonstrate the comparative durabilities of the system containing primer surfacer and the one containing the filler-sealer sequence.

26. (b) Accelerated Weathering. The conditions of the panels after 300 hours in the carbon-arc water-spray device are summarized in Table IV. The symbols have the same meaning as in Table III. The group numbers correspond to those of Table I.

TABLE IV

Accelerated Weathering

Accelerated Weathering of External Surfaces, Three Hundred Hrs.

| Group | Fading | Chalking | Checking | Rating | Remarks |
|---|---|---|---|---|---|
| 1 | S | 0 | S | 1 | |
| 2 | S | 0 | M | 3 | |
| 3 | S | 0 | T | 2 | |
| 4 | S | 0 | S-M | 1 | |
| 5 | S | 0 | M-VM | 3 | |
| 6 | S | 0 | S | 2 | |
| 7 | VM | S-M | 0 | 1 | |
| 8 | VM | S-M | (0) | 2 | 2 sm. checks on 1 panel |
| 9 | VM | S-M | (0) | 2 | 1 check on 1 panel |
| 10 | VM | M | 0 | 1 | |
| 11 | VM | S-M | M-VM | 3 | |
| 12 | VM | M | 0 | 2 | |
| 13 | S | (0) | (S) | 1 | 1 panel only showed M chalking<br>2 panels show S cracking |
| 14 | S | S-M | S | 3 | |
| 15 | S | (T) | S | 3 | 1 panel only showed M chalking |
| 16 | S | S | S-M | 3 | |
| 17 | S | (0) | T-S | 2 | 1 panel only showed S-M chalking |
| 18 | S | S | T-S | 4 | |
| 19 | S | 0 | (S-M) | 3 | 1 crack on 1 panel |
| 20 | S | (0) | (VM) | 4 | 1 panel only showed S chalking. All panels cracked; 1 badly scaled |
| 21 | S | M | T | (1) | Poor hiding, badly raised grain. 1 panel S cracking. |
| 22 | S | T | (T) | (2) | Poor hiding, badly raised grain. |
| 23 | S | T | T | 1 | |
| 24 | S | T | T | 1 | |
| 25 | S | T | S | 2 | |
| 26 | S | S | (M) | 2 | 2 panels show S cracking |
| 27 | S | S | (S) | 1 | 1 panel shows 2 cracks at edge. |
| 28 | | S | M | 3 | |
| 29 | VM | S | 0 | 1 | |
| 30 | VM | S | (M) | 3 | 1 panel OK |
| 31 | VM | S | (0) | 2 | 1 panel sl. checked |
| 32 | VM | S | 0 | 2 | 1 panel-raised grain |
| 33 | VM | S | 0 | 3 | all panels-raised grain |
| 34 | VM | S | 0 | 1 | 1 panel sl. raised grain |

34. (c) Moisture absorption: The daily water uptake of the various test panels is given in Table V. Each figure represents the average of three similar 4" x 4" panels, each from separate 12" x 12" pieces. To illustrate the degree of precision the average deviations for the first day's measurements are included.

TABLE V

Moisture Absorption of External Surfaces

| Group | 24 hrs. | 48 hrs. | 72 hrs. | 96 hrs. | 120 hrs. | Rank |
|---|---|---|---|---|---|---|
| | Water Absorbed, Milligrams | | | | | |
| 1 | 76± 19 | 80 | 80 | 110 | 133 | 1 |
| 2 | 1158± 34 | 1645 | 1916 | 2181 | 2478 | 3 |
| 3 | 130± 14 | 162 | 182 | 227 | 276 | 2 |
| 4 | 98± 8 | 112 | 122 | 150 | 183 | 1 |
| 5 | 1218± 78 | 1791 | 2170 | 2560 | 2823 | 3 |
| 6 | 99± 47 | 151 | 181 | 239 | 298 | 2 |
| 7 | 34± 8 | 63 | 67 | 91 | 114 | 1 |
| 8 | 45± 8 | 328 | 396 | 441 | 470 | 3 |
| 9 | 55± 1 | 97 | 123 | 158 | 188 | 2 |
| 10 | 38± 22 | 44 | 44 | 83 | 111 | 1 |
| 11 | 136± 25 | 156 | 171 | 217 | 248 | 3 |
| 12 | 80± 38 | 87 | 87 | 131 | 161 | 2 |
| 13 | 141± 5 | 264 | 343 | 418 | 487 | (4) † |
| 14 | 124± 6 | 235 | 305 | 368 | 429 | 2 |
| 15 | 145± 6 | 282 | 371 | 450 | 532 | (6) |
| 16 | 95± 2 | 187 | 240 | 284 | 321 | 1 |
| 17 | 150± 8 | 280 | 367 | 449 | 525 | (5) |
| 18 | 132± 17 | 258 | 337 | 414 | 481 | (3) |
| 19 | 197± 10 | 375 | 501 | 627 | 769 | (4) |
| 20 | 157± 9 | 292 | 383 | 465 | 543 | 1 |
| 21 | 183± 12 | 345 | 480 | 620 | 767 | (3) |
| 22 | 172± 22 | 337 | 470 | 609 | 750 | (2) |
| 23 | 109± 4 | 220 | 288 | 350 | 408 | 1 |
| 24 | 198± 12 | 364 | 470 | 567 | 645 | (2) |
| 25 | 223* | 394 | 494 | 584 | 645 | (2) |
| 26 | 166± 25 | 313 | 420 | 518 | 607 | 1 |
| 27 | 764± 201 | 1251 | 1611 | 1897 | 2153 | 2 |
| 28 | 910± 45 | 1411 | 1763 | 2036 | 2249 | 3 |
| 29 | 128± 1 | 246 | 345 | 411 | 494 | 1 |
| 30 | 163± 19 | 316 | 445 | 532 | 637 | 3 |
| 31 | 140± 19 | 281 | 399 | 478 | 575 | 2 |
| 32 | 208± 35 | 394 | 541 | 647 | 769 | 3 |
| 33 | 106± 4 | 211 | 300 | 371 | 455 | 2 |
| 34 | 106± 6 | 209 | 296 | 353 | 427 | 1 |

* This initial observation represents one panel only.
† Rankings in parentheses are somewhat arbitrary due to their closeness.

TABLE VI

Moisture Absorption of Inside Finishes

| Group | 24 hrs. | 48 hrs. | 72 hrs. | 96 hrs. | 120 hrs. | Rank |
|---|---|---|---|---|---|---|
| | Water absorbed, milligrams | | | | | |
| 1 | 199 ± 45 | 350 | 512 | 663 | 808 | 1 |
| 2 | 654 ± 223 | 995 | 1499 | 1774 | 2023 | 2 |
| 3 | 396 ± 54 | 740 | 1052 | 1326 | 1575 | 1 |
| 4 | 1134 ± 20 | 1692 | 2124 | 2488 | 2773 | 2 |
| 5 | 120 ± 23 | 222 | 304 | 356 | 438 | 1 |
| 6 | 263 ± 240 | 453 | 625 | 755 | 883 | 2 |
| 7 | 210 ± 14 | 416 | 597 | 711 | 861 | 2 |
| 8 | 173 ± 48 | 322 | 420 | 485 | 567 | 1 |
| 9 | 1195 ± 308 | 1746 | 2165 | 2431 | 2682 | 2 |
| 10 | 858 ± 89 | 1359 | 1736 | 1929 | 2227 | 1 |
| 11 | 1254 ± 84 | 1786 | 2219 | 2523 | 2819 | 3 |

35. (d) Discussion of moisture absorption. Comparisons of total absorptions afford indices of the average permeabilities of the various films during the five day period. Ratings on the basis of relative resistances are listed in the last column of the respective tables. Inspection of the first column of Table V shows from Group 13 onward a higher degree of precision than that which obtains for the first twelve groups. While the first twelve were under test, the humidity of the room was low and rapid evaporation of water from the surface-dry panels during weighings impaired that measurement somewhat. Further, while the test was in progress, the room was subjected to a severe fluctuation in humidity. The decrease in atmospheric moisture is reflected in the rapid decrease in the daily increment of panel weight. With restoration of normal humidity, the increments are larger. This behavior is at variance with absorption at constant humidity. There, the normal absorption curve shows a gradually decreasing slope, an increasing slope would indicate failure of the paint film, a levelling off, saturation of the panel. Groups 1 to 4 of Table VI were tested simultaneously with Groups 1 to 12 of Table VII so the same limitations of the data prevail. However, all of the groups mentioned were subjected to the same conditions so a simple ranking of the inspection water resistances on the basis of absorption is quite valid.

36. For the balance of the tests the humidity of the room was stabilized in the vicinity of 32%. Under these conditions the evaporation losses during weighing were negligible. One other experimental difficulty remains to be mentioned. On the fourth day of testing groups 29 - 34 of Table V and groups 5 to 11 of Table VI, failure of the temperature control mechanism caused a drop from 25° C to 19° C or lower. The low increments recorded for that day are the result. With restoration of the standard temperature, the higher values for the fifth day followed. As with the first groups tested, this does not invalidate a rating of the finishing systems. In the last columns of Tables V and VI the finishes are ranked in order of decreasing moisture resistance.

37. (e) Exterior Finishes (Table V). The first three groups represent manufacturer A's products applied to mahogany. Here the most resistant finish is that recommended by the manufacturer, i.e., filler, primer, surfacer and two top coats. Group 3 (filler, sealer, 2 topcoats) is second, while group 2 (sealer, filler) is a poor third.

38. Study of the entire table substantiates this general observation though the magnitude of the differences vary. The following groups may be validly compared, one with another.

| | |
|---|---|
| 1, 2, 3 | 13, 15, 17 |
| 4, 5, 6 | 14, 16, 18 |
| 7, 8, 9 | 29, 30, 31 |
| 10, 11, 12 | 32, 33, 34 |

In each group of figures above, the first number refers to the procedure recommended by the respective manufacturers, i.e., inclusion of a primer surfacer. In five instances out of eight, the standard procedure yields the most resistant film. In only two (14, 16, 18 and 32, 33, 34) does the standard procedure yield an inferior film.

40. As two alternatives to the standard procedure first, sealer followed by filler, secondly, filler followed by sealer was adopted, the primer surfacer being omitted altogether.

41. For evaluation of these two alternates, the following groups may be compared.

| | |
|---|---|
| 2, 3 | 16, 18 |
| 5, 6 | 24, 25 |
| 8, 9 | 30, 31 |
| 11, 12 | 33, 34 |
| 15, 17 | |

In six cases out of these nine, the more resistant film is obtained by applying filler to the bare wood followed by a coat of sealer. Of the three cases remaining, two of them (15, 17) and (24, 25) show the two alternatives to be of equal merit. In one (30, 31) the application of a sealer as the first coat appears to be advantageous.

42. It may be remembered that manufacturer "C" supplied two sealers, one an alkyd, the other a phenolic resin type. The higher water resistance of the phenolic is exemplified by comparisons between the members of the following pairs, i.e., (13, 14)(15, 16), (17, 18) (19, 20) (21, 22). In every case, the second member of the pair, the phenolic, shows the least permeability.

43. In three tests, 21, 22, 28, on close-grained wood, the filler and primer surfacer were simply omitted. Comparison of each of these three with their respective standards 19, 20, 26, should afford an evaluation of the primer surfacer coat itself. Its role would seem to vary from somewhat less than insignificance (19, 21) through moderate importance (20, 22) to tremendous stature (26, 28).

44. Groups 27 and 28 differ only in that the former has an extra top coat. Consideration of the high absorption values and the negligible difference between them suggests that in this system, the top coat contributes little to the moisture resistance.

45. (f) Interior Finishes (Table VI). Measurements of groups 1 to 4 of this table were made at the same time as those on groups 1 to 12 of Table V. Group 1 of Table VI represents manufacturer A's inside finish applied to mahogany and is therefore comparable to groups 1, 2, and 3 of Table V. Similarly, Group 2 of Table VI, on birch, may be compared to Groups 4, 5, and 6 of Table V. The inferior resistance of the inside finishes is apparent. In each case, the inside finish excels only the very poorest of the exterior films.

46. Group 3 of Table VI represents manufacturer B's inside finish on mahogany, and should be compared to groups 7, 8, and 9 of Table V. Group 4 of Table VI may be compared with groups 10, 11 and 12 of Table V. In these instances, the inside finish is vastly inferior to any of the comparable outer films.

47. This observation is of special significance. The interior surfaces of an airplane, such as the inside of the wings and fuselage are exposed to practically the same humidity as the exterior surfaces, without the mitigating effect of good ventilation. This means that extreme conditions of atmospheric moisture persist longer in these enclosed spaces than elsewhere and the need for a highly resistant film is greater.

48. Groups (5, 6) and (7, 8) represent films that were considerably older at the time of testing than any of the others. After due allowance has been made for the fact that moisture resistance is normally enhanced with aging, the inferiority of the interior films receives further confirmation. Groups 7 and 8 of Table VI represent two coats of clear sealer, and one coat of clear sealer plus one coat of aluminized sealer respectively. The increased resistance of the latter group indicates the advantage of aluminizing the sealer. Similarly, groups 11 and 9 exemplify the merit of adding aluminum. Groups 9 and 10 may be compared to show the worth of an extra coat of aluminized sealer.

49. The moisture absorption data, as presented enables one to say merely that one film is more permeable or less permeable than another film prepared and tested under like conditions. The methods of determining and expressing moisture resistance are largely empirical. The apparent merit of a paint film will vary with the way the measurements are made and the results expressed.(1) This is especially true of paint films of low moisture resistance.

50. An adequate means of moisture permeability would be afforded by measuring the rate of passage of water through the film under known vapor pressure gradient. In the present study, the former quantity, i.e., the rate of absorption is rather readily calculable. The latter is more difficult, as will be shown presently.

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1. Edwards, J. D., Ind. Eng. Chem. 25, 846-7, 1933

51. Curves of the total water absorbed against time show a general parabolic shape. This is confirmed by plotting the data logarithically, and the resultant straight line shows the absorption to conform to the equation

$$y = at^b$$

where $y$ = milligrams of water absorbed
$t$ = time in hours
$a$ and $b$ are constants

The conformity of the plotted points to the line is excellent. Some typical curves are shown. Only the initial (24-hour) absorption of manufacturer C's products (Groups 13 - 22) were quite consistently low. With a general equation the rate of absorption at any time is easily calculated:

$$y = at^b$$

$$\frac{dy}{dt} = (ab)t^{b-1}$$

In terms of absorbed water, the rate becomes

$$\frac{dy}{db} = ab\left(\frac{y}{a}\right)^{1-\frac{1}{b}}$$

Similarly, unpainted panels conform to the general equation. The rates of uptake of water by painted panels at given times, compared with the respective rates of uptake by the unpainted panels at the same concentrations of absorbed water seemed at first to afford a basis for the criterion sought. Converting the rates per hour to reciprocal milligrams, or impedances, and subtracting those of the painted panels from those of the blank, promised a valid index of moisture resistance.

52. A variation of this mode of attack was calculation of the vapor pressure inside the panel from equilibrium moisture content data at various relative humidities. Here the index of moisture resistance would be the reciprocal of milligrams per hour, per millimeter of vapor pressure difference between the inside and outside of the paint film. The outer pressure, of course, is constant at the vapor pressure of water at 25° C, i.e., 23.8 millimeters.

53. The failure of these criteria is due to the fact that both methods require uniform distribution of absorbed water throughout the panel. A high concentration of water in the first veneer retards absorption, and the error becomes more serious with more permeable films. The phenolic resin adhesive certainly inhibits diffusion, and calculations showing an apparent increase in moisture resistance with soaking tend to confirm the belief that this source of error is present.

54. A listing of the constants, a and b is given in Table VII, some of the logarithmic curves are given in Plates I - VI.

TABLE VII

Typical Values of Constants in Absorption Equation, $y = at^b$

| Group | a, | b |
|---|---|---|
| - Inner Surfaces (cf. Table II) - | | |
| 5 | 9.92 | 0.979 |
| 6 | 23.4 | 0.772 |
| 7 | 9.79 | 0.966 |
| 8 | 25.1 | 0.659 |
| 9 | 246 | 0.505 |
| 10 | 100 | 0.664 |
| 11 | 234 | 0.522 |
| External Surfaces (cf. Table I) | | |
| 13 | 13.18 | 0.759 |
| 14 | 11.27 | 0.767 |
| 20 | 15.81 | 0.750 |
| 23 | 16.40 | 0.670 |
| 29 | 7.86 | 0.883 |
| 30 | 14.25 | 0.797 |
| 31 | 9.79 | 0.897 |
| 32 | 14.99 | 0.833 |
| 33 | 6.22 | 0.903 |
| 34 | 6.58 | 0.887 |

55. In connection with this report it is submitted that the absorption of moisture by plywood is an exponential function of time. This enables the rate of absorption at any moment to be calculated. Proper evaluation of the aqueous vapor pressure inside the panel will afford an absolute method of rating the moisture resistance of a film. Tests in which this internal aqueous tension will be controlled are planned for the near future.

56. (g) Salt Spray. The exterior finishes only were exposed in the salt spray device described above. The condition of the panels after approximately 900 hours is set forth in Table VIII. On Groups 29 - 34 the test is still in progress. To date there are six sets in which comparisons are feasible. Of the six, the standard finish yields the best film in four cases. In the remaining two (1, 2, 3) and (14, 16, 18) application of filler first with no primer surfacer gave the best results. The negligible differences between 23, 24 and 25 indicates the extra sealer to be as adequate as primer surfacer in salt resistance. The use of filler first yields the best coat of the three. Comparison of 26, 27 and 28 indicates a shortcoming of a topcoat in resisting salt water.

## TABLE VIII

Action of Salt Spray on Exterior Finishes

| Group | Fading | Raised Grain | Remarks | Rating |
|---|---|---|---|---|
| 1 | S | O - T | - | 2 |
| 2 | S | M | - | 3 |
| 3 | S | O | - | 1 |
| 4 | S | O | - | 1 |
| 5 | S | S | - | 2 |
| 6 | S | T | - | 3 |
| 7 | O | O - T | - | 1 |
| 8 | O | T | - | 2 |
| 9 | O | T | - | 2 |
| 10 | O | O | - | 1 |
| 11 | O | (S-M) | 2 panels blistered | 3 |
| 12 | O | S | | 2 |
| 13 | O | S | localized discoloration on 2 panels | |
| 14 | O | S-M | | |
| 15 | O | (M) | 1 panel good, 2 blistered | |
| 16 | O | O | | (1) |
| 17 | O | (M) | 1 good, 2 blistered | |
| 18 | O | M | | |
| 19 | O | O | 1 panel discolored | |
| 20 | O | O | 2 panels discolored | |
| 21 | O | O | all 3 discolored | |
| 22 | O | (S) | 1 panel severe reticulate cracking | |
| 23 | O | S | | |
| 24 | O | S | | |
| 25 | O | T | | |
| 26 | O | S | | |
| 27 | O | M | 2 panels cracked ll grain | |
| 28 | O | VM | all panels cracked ll grain | |
| 29 | | | | |
| 30 | | tests in progress | | |
| 31 | | | | |
| 32 | | | | |
| 33 | | | | |
| 34 | | | | |

57. (h) Smoothness. As indicated in the introduction, this property is of prime importance in certain classes of aircraft. The primer surfacer does contribute to surface smoothness, but the panels bearing an extra coat of sealer are indistinguishable from those with primer surfacer.

58. In Table IX are presented data for the weights of the various exterior coatings employed. All values are averages. For primer surfacers and top coats, the deviation of individual measurements is not excessive; the filler coats showed a considerable range, depending on whether the filler was applied directly to the wood or to a sealer coat. Naturally the open grained mahogany took up considerably more filler than the less porous poplar and birch. For bare mahogany, the tabulated weights for filler should be increased one-half. When applied to poplar or to a sealer coat, the filler weights should be decreased by about one-half.

TABLE IX

Weights of Coatings

| Manufacturer | Material | Wt. lbs./sq. ft. | % of Complete system |
|---|---|---|---|
| A | sealer | .006* | 9% |
| | filler | .012 | 19% |
| | primer surfacer | .022 | 34% |
| | 2 top coats | .024 | 38% |
| B | sealer | .002 | 4% |
| | filler | .003 | 6% |
| | primer surfacer | .C23 | 43% |
| | 2 top coats | .025 | 47% |
| C | sealer | .006* | 11% |
| | filler | .004 | 7% |
| | primer surfacer | .032 | 58% |
| | 1 top coat | .013 | 24% |
| D | sealer | .002 | 9% |
| | filler | .004 | 19% |
| | primer surfacer | .006 | 29% |
| | 1 top coat | .009 | 43% |
| E | sealer (2 coats) | .002 | 5% |
| | filler | .004 | 9% |
| | primer surfacer | .016 | 36% |
| | 1 top coat | .022 | 50% |

59. The response of the panel to the sealer coat was quite anomalous in the figures marked by an asterisk (*). In these cases the panels showed a loss in weight and the figures given are estimated from the solids content and the spreading rate. The loss may be chargeable to simple drying out of the panel, but surrounding circumstances render preferential absorption of the sealer with expulsion of capillary moisture a good possibility.

60. Generally speaking, the sealer coat is the lightest of the system and the filler next. The primer surfacer weighs almost as much as, or even more than the top coats. With but two exception (Groups 14, 16, and 32, 34) the presence of the primer surfacer does enhance moisture resistance, but nowhere does it do so in an amount commensurate with its weight. On the other hand, the application of

filler to the bare wood followed by sealer, and omission of the primer surfacer yields a film almost as resistant and weighing only 50% to 75% as much. In the exceptions noted above, this lighter film is actually superior to the one containing primer surfacer.

61. The same applies to the other tests. The inclusion of primer surfacer in the finishing system generally gives a superior film, but there are exceptions. The advantage, where present, is no greater than that which might be expected from an extra coat of sealer. A fortiori, the justification of primer surfacer becomes difficult.

62. The general inferiority of the sealer followed by filler sequence is probably best explained as due to the inability of the filler vehicle to penetrate the dry sealer film and possible damage to the latter when the filler is wiped down.

General Conclusions:

63. Most unpigmented films of moderate permeability show improved resistance upon the addition of pigment, up to a certain point. Beyond that, the permeability increases. An unpigmented film of considerable imperviousness is usually adversely affected by the addition of pigment. (The many valid reasons for adding pigment, such as durability and hiding, are here ignored for the moment).

64. It is likely that primer surfacers as a class belong in the first category and that their pigment content is in the critical zone. This would serve to explain some of the variabilities in the behavior of the primer surfacer. The reason for pigmenting this coat is, doubtless, the desire to build a thick film that can be sanded. The question of weather resistance of the coat as such is not a factor, because it is invariably protected by a top coat.

65. It has been shown that a finish lacking primer surfacer but of closely comparable properties can be devised simply by a proper sequence of the underlying coats. This is the application of filler to the bare wood followed by sealer. The means by which filler enhances a film on close grained wood remains to be proven. Probably it is due to absorption of the vehicle in which case it has the role of a penetrating sealer, and the subsequent sealer forms a true surface coating. When the sealer is applied first, the filler cannot penetrate, and subsequent wiping down impairs its integrity. This would explain the superiority of the filler-sealer sequence and the inferiority of the reverse order.

66. The same holds true for open grained wood. In addition, the filler is here a true filler. The uneven surface is made smooth and the succeeding coats are adequately supported, there being no depressions for them to bridge.

67. The primer surfacer coat is a burden to the plane because of its excessive weight. It is also a drag on production because it is a slow drying coat that must be thoroughly hardened before it can be sanded. Moreover, the contribution of the primer surfacer to the properties of the film does not warrant the drawbacks it entails. Application of filler, followed by sealer yields a film comparable in every

property except possibly smoothness. An additional coat of sealer will remedy this deficiency and augment the other desirable film qualities at the same time.

Recommendations:

It is recommended that:

1. That paragraph E-1c of the proposed Army-Navy Specification "Protective Coatings (for Aircraft Wood Surfaces)" be amended as follows:

E-1c. Exterior-Exposed Surfaces - The minimum protective finishing system shall consist of one coat of wood filler, two coats of clear sealer and a top coat . . . .

2. That paragraph E-1a of the same proposed specification be amended as follows:

E-1a. Interior Enclosed Surfaces - The minimum protective finishing system for these surfaces shall consist of two coats of clear sealer conforming to Specification AN-S-17 and one coat of aluminized sealer in the order stated.


## ACKNOWLEDGMENTS

The courtesy of the following manufacturers who supplied the finishes used in this study is hereby acknowledged.

E. I. duPont de Nemours & Co., Philadelphia.
The Sherwin-Williams Co., Chicago
Roxalin Flexible Finishes, Inc., Elizabeth, N. J.
Ault and Wiborg Corporation, New York
Wipe-On Corporation, New York

## Identification of Manufacturers

Manufacturer A - Wipe-on Corporation, New York

B - Roxalin Flexible Finishes, Inc. Elizabeth, N. J.

C - E. I. duPont de Nemours & Co., Philadelphia

D - Ault & Wibourg Corporation, New York

E - The Sherwin-Williams Co., Chicago

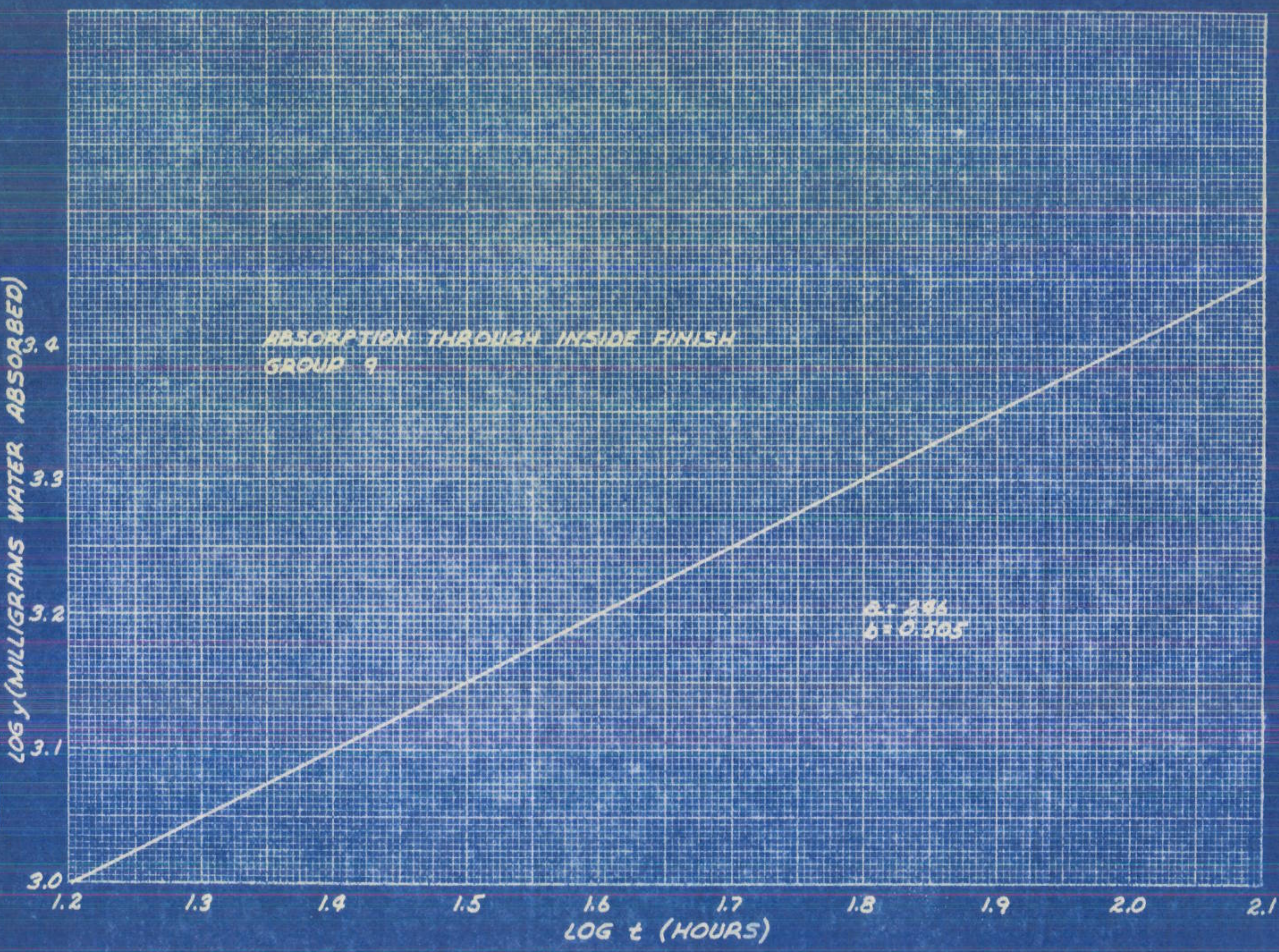
ABSORPTION THROUGH INSIDE FINISH
GROUP 9
a = 286
b = 0.505
LOG y (MILLIGRAMS WATER ABSORBED)
3.0
3.1
3.2
3.3
3.4
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
LOG t (HOURS)

PLATE 1

N. R. L. 34A

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

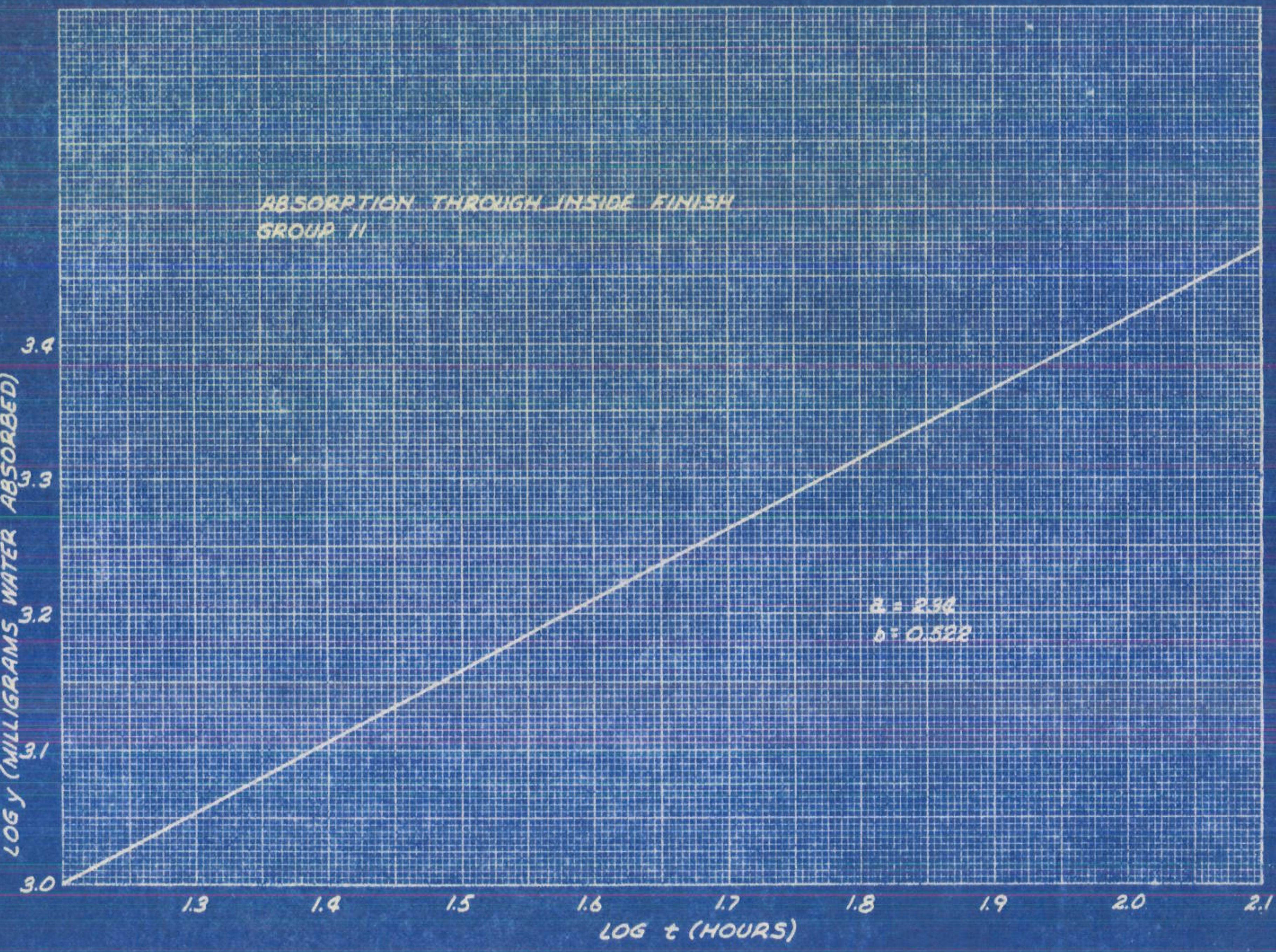


PLATE 2

N. R. L. 31A

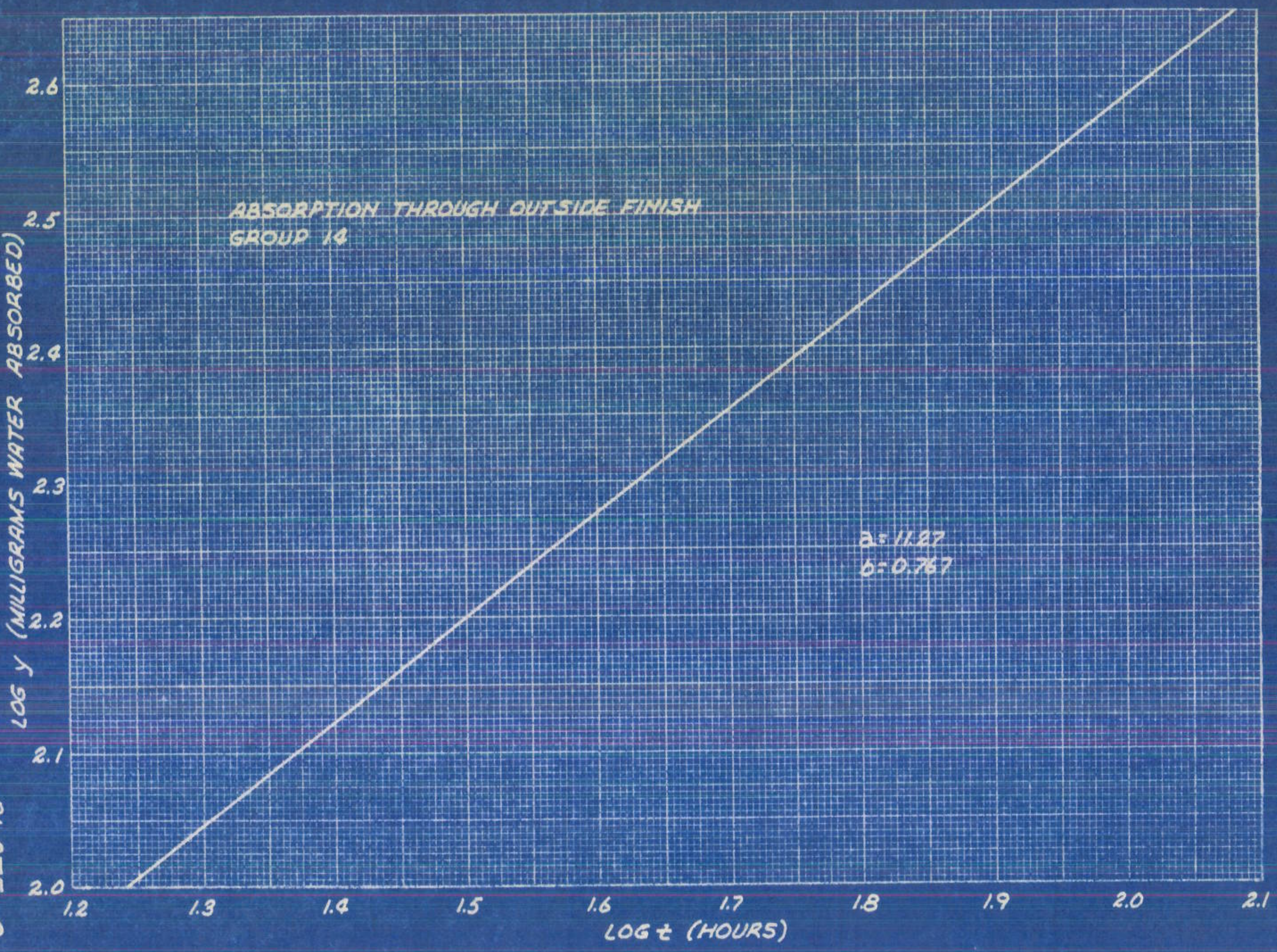


PLATE 3

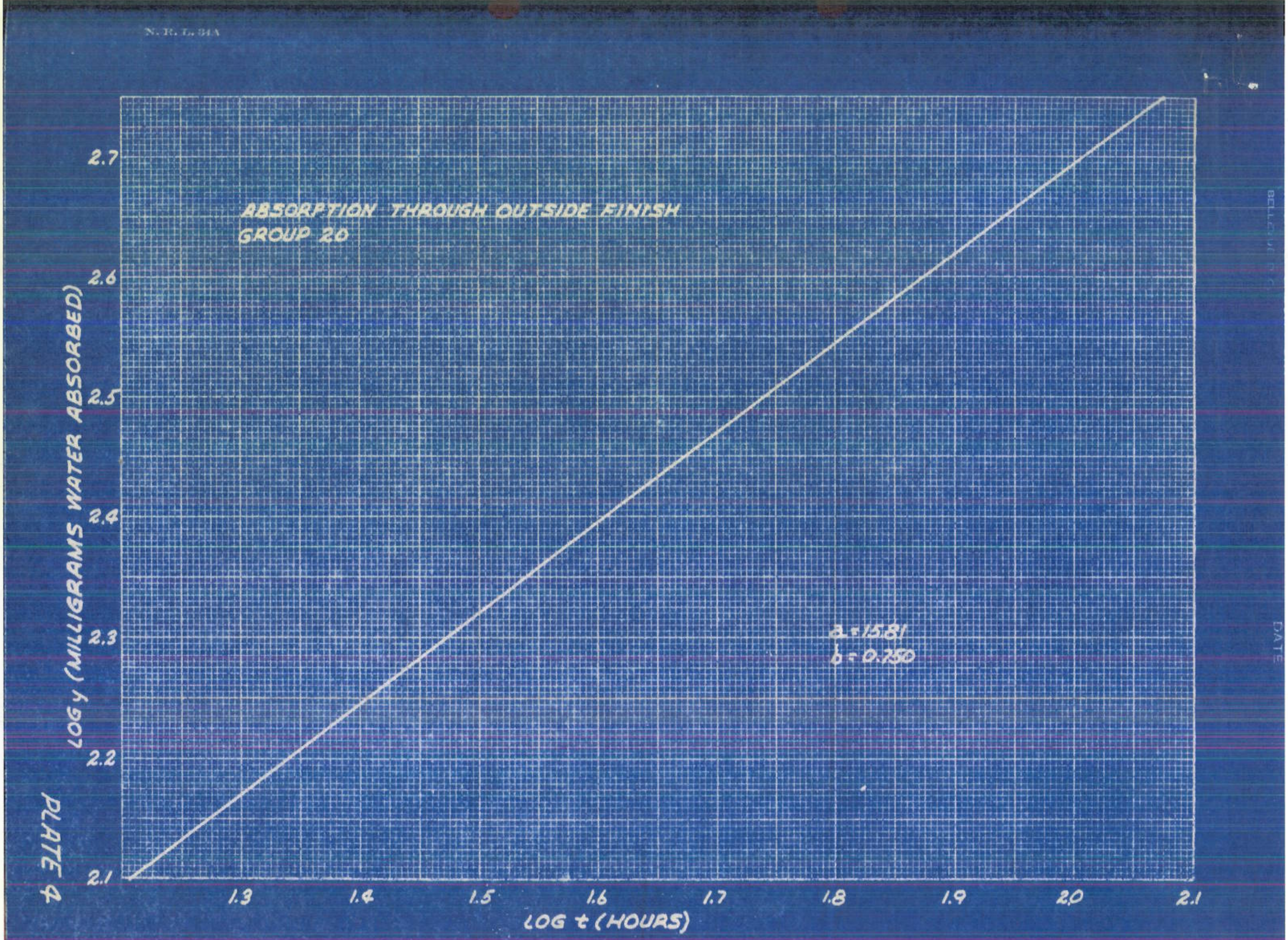
N. R. L. 34A
ABSORPTION THROUGH OUTSIDE FINISH
GROUP 20
a = 15.81
b = 0.750
2.7
2.6
2.5
2.4
2.3
2.2
2.1
LOG y (MILLIGRAMS WATER ABSORBED)
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
LOG t (HOURS)
DATE

PLATE 4

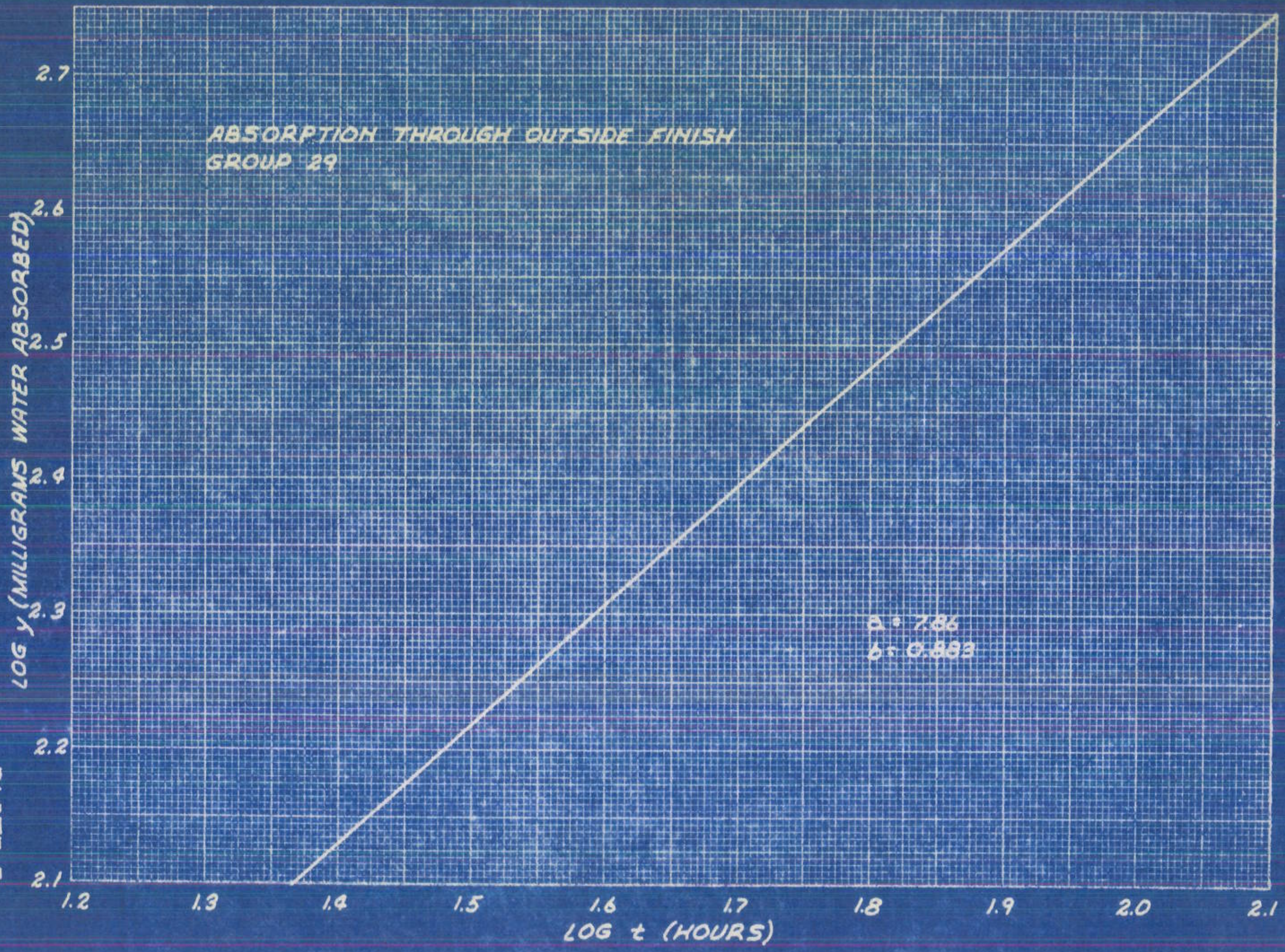
ABSORPTION THROUGH OUTSIDE FINISH
GROUP 29
a = 7.86
b = 0.883
LOG y (MILLIGRAMS WATER ABSORBED)
LOG t (HOURS)
2.1
2.2
2.3
2.4
2.5
2.6
2.7
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1

PLATE 5

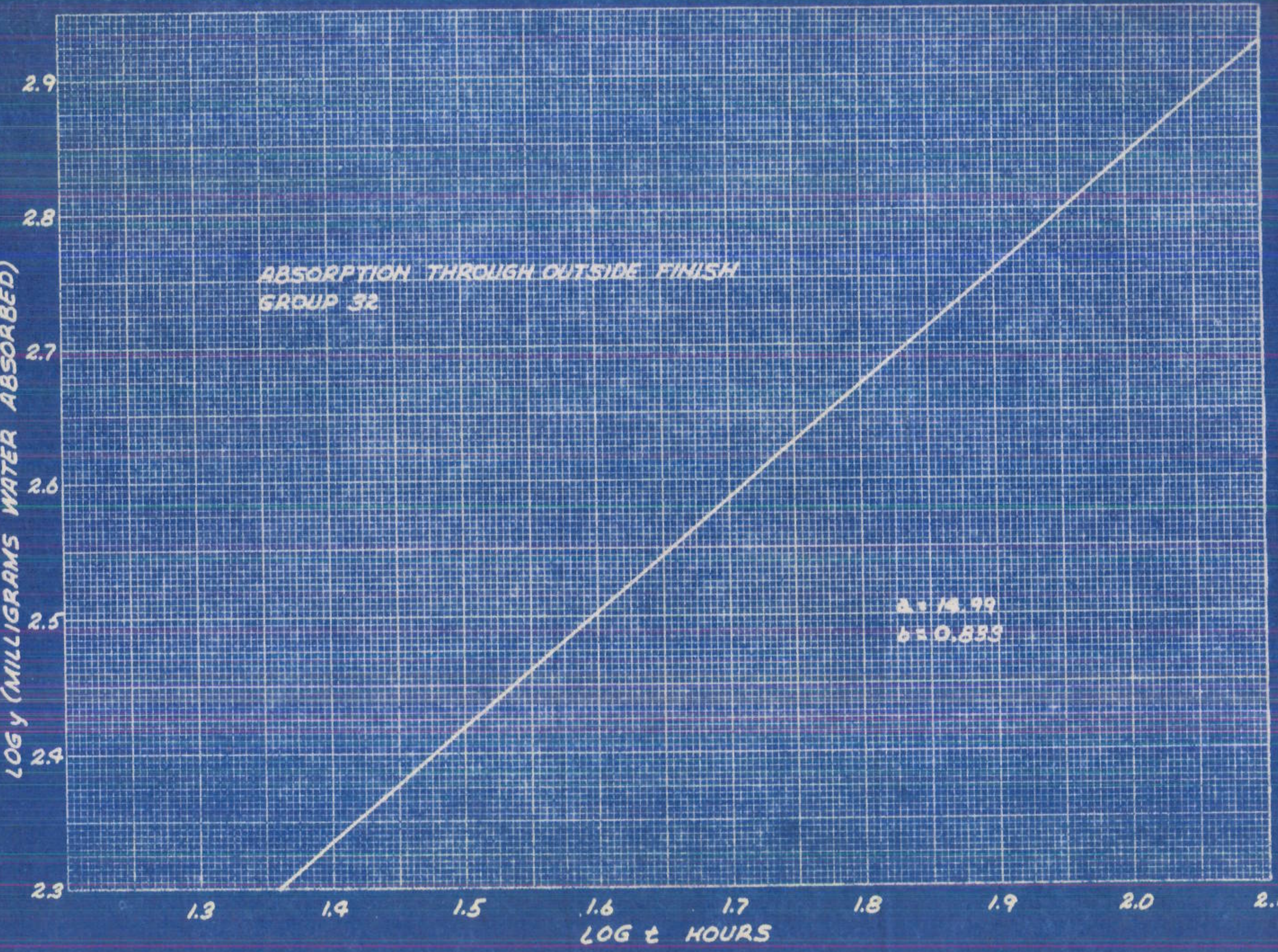
ABSORPTION THROUGH OUTSIDE FINISH
GROUP 32
a = 14.99
b = 0.833
2.9
2.8
2.7
2.6
2.5
2.4
2.3
LOG y (MILLIGRAMS WATER ABSORBED)
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
LOG t HOURS

PLATE 6