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EXPERIMENTAL STUDY OF FLUID DEICING SYSTEM IN THE NASA ICING RESEARCH TUNNEL

Author Unknown

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16. Abstract

An investigation of the icing of horizontal control surfaces at the VFW in 1970 led them to select the NASA Icing Research Tunnel at LRC for their tests. These tests were performed between March 9-23, 1970, for the VFW 614 aircraft. The TKS ice warning system, the Rosemont ice warning system and the liquid water content indicator were investigated and found to be appropriate for the aircraft.

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REPORT

Subject: Testing of the Fluid De-icing System in the NASA Icing Research Tunnel

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* Numbers in margin indicate foreign pagination.

I. Relevant Documentation (References)

1. Below are presented the documents which are cited in the test report text, in each case only as an index reference [ ]. All of these documents are archived at Eml in the order shown.

    1. File Note Em2-423-70 of 2 April 70.
       Ground System Tests/De-icing Installations
    2. Memorandum Em2-471-70 of 10 April 70
       Ground System Tests/ De-icing Installation Acceptance Levels
    3. Minutes of Meeting Em2-777-70 of 16 June 70
       Results of Tests in the NASA Tunnel
    4. Minutes of Meeting EM2-271-70 of 23 Feb 70
       Ground System Tests/ De-icing Tests at the NASA Lewis Research Center
    5. Minutes of Meeting Em2-310-69 of 28 Mar 69
       Ground Systems Tests in the De-icing Facility
    6. Correspondence and Technical Data from Various De-icing Tunnels
    7. Correspondence with TKS
    8. Drawing No. 614-764540 of 25 Jul 69, Container
    9. Drawing No. 614-037608 of 10 Oct 69
       Control Console for the De-icing Facility, Tunnel Tests
    10. TKS Drawing No P 033 B1 1-3 of June 69
        Model for VFW Icing Tunnel Test
    11. Test Instruction B-S. Em 2-1021-69 of 26 Aug 69
        Production of Models
    12. Drawing No. Ea/7-20 of 6 May 69
        Icing Model HLW VFW 614

13. TKS Drawing No P037 of 2 Oct 69

    Schematic of Pipeline Installation for VFW Icing Tunnel Test

14. Diagram Flowmeter No. 1./.6

15. Documents on the Bimetal Thermometer (Schlummberger Co.)

16. Viscosity Correction Diagram

17. Photography

18. Brochure: "NASA Icing Research Tunnel, General Information"

19. Tunnel Set-up Diagram for the NASA Tunnel (Herr G. Anders, Ea)

20. Test Instruction Em2-1028-69 of 23 Sep 69

    -Tunnel Studies, Ice Warning System -

21. Letter and Documents from the Rosemount Co. on the Icing Warning System IDS-1

22. Instruction Manual J-W Liquid Water Content Indicator, Model LWH Serial 6506

23. Report No.

    Meteorological Icing Conditions

24. Summary of Statistical Icing Cloud Data Measured over the United States and North Atlantic, Pacific and Arctic Oceans During Routine Aircraft Operations NASA MEMO 1-19-59 E 1959

25. VFW 614 De-Icing Tests

26. Report No.

27. AD 690 469 Aircraft Ice Protection- Report of Symposium April 28-30 1969

28. NASA TN 4151 of Feb 1968

    Correlation among Ice Measurements, Impingement Rates, Icing Conditions, and Drag Coefficients for Unswept NACA 65A 0004 Airfoil (Herr Gray).

29. FAA Technical Report ADS-4

    " Engineering Summary of Airframe Icing Technical Data"

30. File Note Em2-222-68 /4/

"Theoretical Derivation of the Ice Accretion on Wings and Control Surfaces of the VFW 614".

31. Report Ea-253 of 11 May 70

"Preliminary Results of De-icing Tests on the HLW* of the VFW 614"

2. The following symbols are used in the report:

F	(ccm/min/panel)	Throughput of de-icing fluid
LWC	(gr/m^3)	Liquid water content (fraction of the fluid supercooled water in the air)
T	(^{o}F or ^{o}C)	Temperature of the blower stream
v	(Kn)	Blower stream velocity
cp	(-)	Static pressure factor, relative to the dynamic pressure of the blower stream
x/1	(%)	Nondimensional wings and/or HLW* chord
α H	(^{o})	Angle of attack on the HLW* model
Droplet Ø	(μ)	average water droplet diameter

* Presumably Höhenleitwerk (i.e. horizontal control surface)—transl. note.

II Summary /5/

1. TKS Liquid De-Icing System

Generally the tests showed that the liquid de-icing system from the TKS firm has the capability to cover all the conditions required in FAR para. 25.1419 and Attachment C throughout the entire meteorological temperature and free-stream range for anti-icing or de-icing (depending on the requirements from the preceding wind tunnel studies), but that the design of the system planned for the VFW 614 at that time required re-working and upgrading with a view to optimization.

2. Rosemount Icing Warning System

The aggregate of studies in the icing tunnel, as well as observations and measurements on the icing warning system from the Rosemount Co., model IDS-1, have shown that a reworking of the VFW requirements for this kind of a facility is needed in order to get to a warning system suitable for the particular attributes of the fluid de-icing system, and further that the IDS-1 type does not meet these specifications.

3. Liquid Water Content Indicator

The Johnson liquid Water Content Indicator planned for flight testing yields sufficiently accurate values within a certain working scope.

III General /6/

In accordance with File Note Em2-423-70 [1], a short evaluation of the tests was carried out in the following form, with a view to the introduction of desireable changes:

1. Deficiencies

All deficiencies which arose or were measured in the course of tests in the NASA tunnel are set down in the deficiency reports, series No. 6-25 inclusive (see also Memorandum Em2(Em1)-471-70). [2]

2. Change Discussions

The actions to be carried out in initiating change discussions are fixed in the Minutes of Meeting Em2-777-70 [3].

IV Test Task /7/

The objective of the tests was: [4]

A. On the fluid de-icing system

1. Determination as to whether the TKS fluid de-icing system is in general in a position to carry out an acceptable anti-icing and/or de-icing function (according to which is required) under all of the meteorological conditions set in the FAR Part 25, and further under the design conditions defined in Paragraph VI.

2. Generation of parameter dependencies in graphic form for the optimizing of the system (for each design condition) consisting of:

- determination of distributor nozzle size
- determination of the required amount of through-put of de-icing fluid (piping system, pump output)
- storage container capacity

B. On the icing warning detector system

Measurement of icing warning detector sensitivity and the functional efficiency of the automatic activation and shutdown of the de-cing system.

C. On the liquid water content indicator

Recording of measurement values on the Johnson liquid water content indicator during the icing conditions employed with a view to determination of the measurement accuracy.

V Test Elements and the Test Set-up /8/

Since, according to wind tunnel studies, the horizontal tail control surface demonstrates at any given time the most sensitive reactions to ice build-up, a 1:1 scale mock-up section from the horizontal tail control surface was selected as the test article. [5]

After a comparison of engineering data from all icing tunnels which are currently in operation [6], the tunnel at NASA Lewis Research Center in Cleveland, Ohio, USA, proved to be the best with respect to the tasks to be carried out. Therefore, the tests of 9-23 March 1970 took place there.

The test set-up is documented using the following topics:

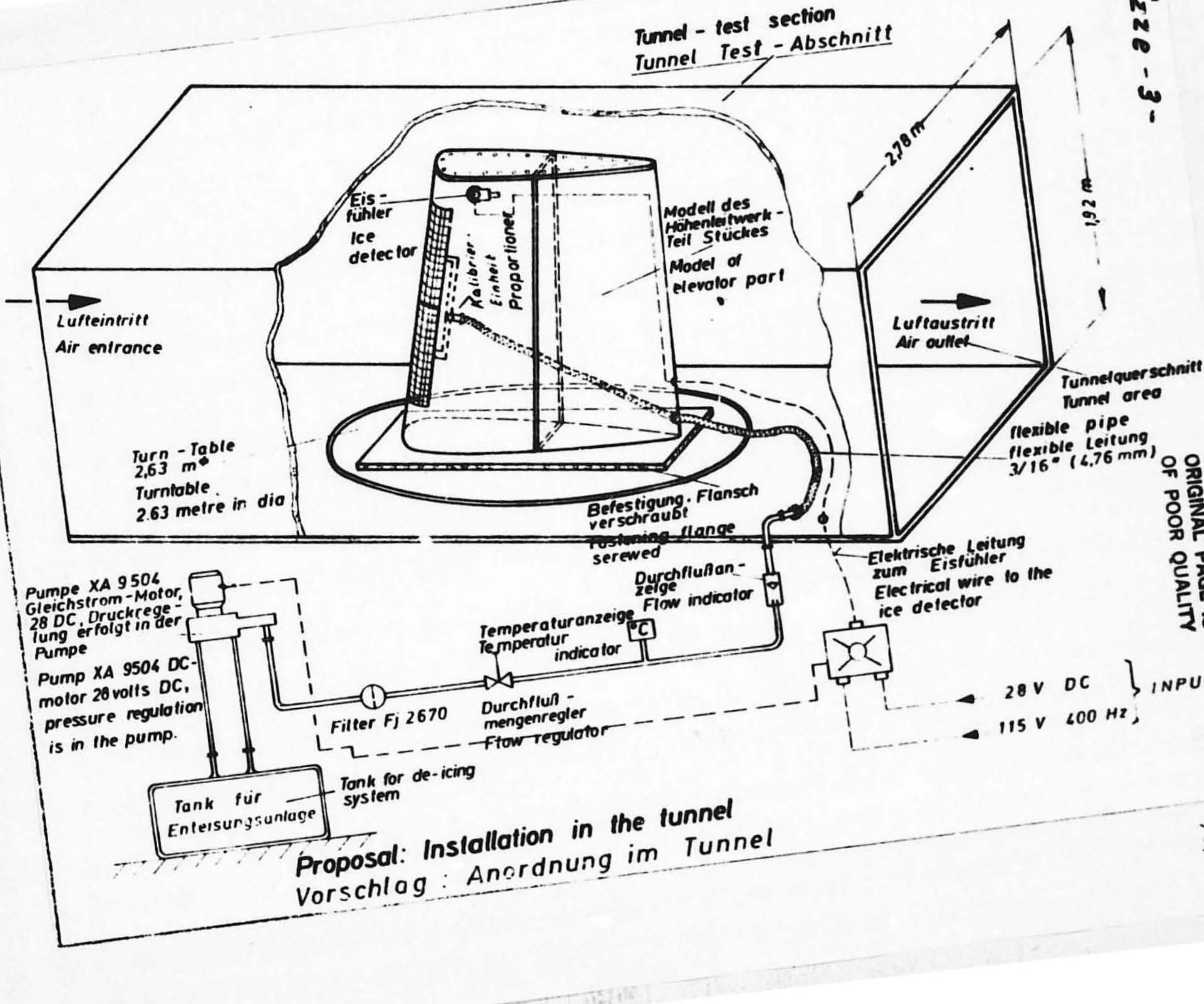
- Overall set-up
- Fluid de-icing system
- Control surface mock-up
- Measuring system
- Icing tunnel
- Icing warning system
- Liquid water content indicator

The overall set-up can be seen in basic principle in the sketch on page 9 and the photographs on page 10/11/12.

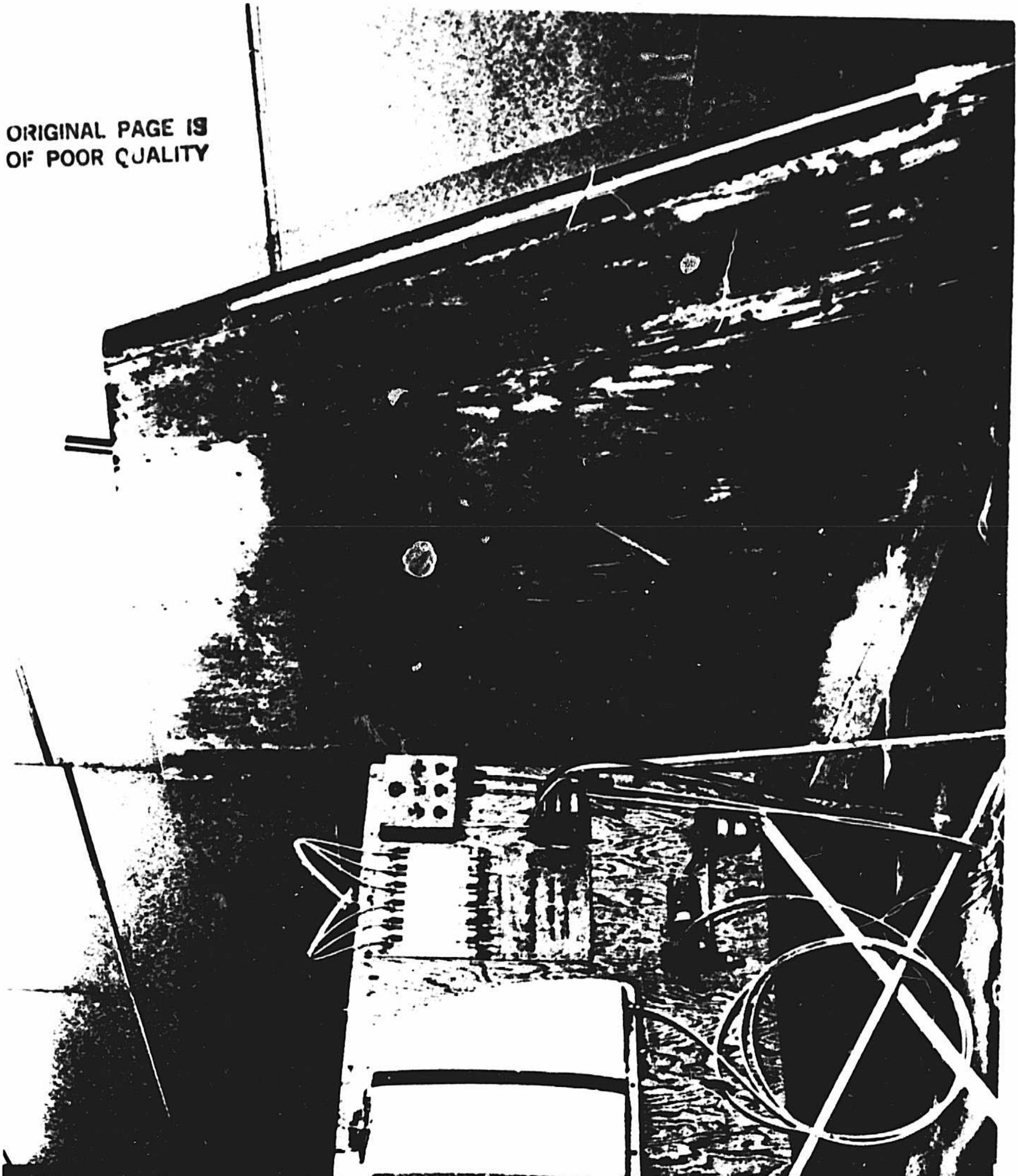
The fluid supply system, the circuitry of the icing warning system, metering devices and the gauges and converter unit of the liquid water content indicator were located in the measuring control room outside the tunnel. (Picture No. PA 2)

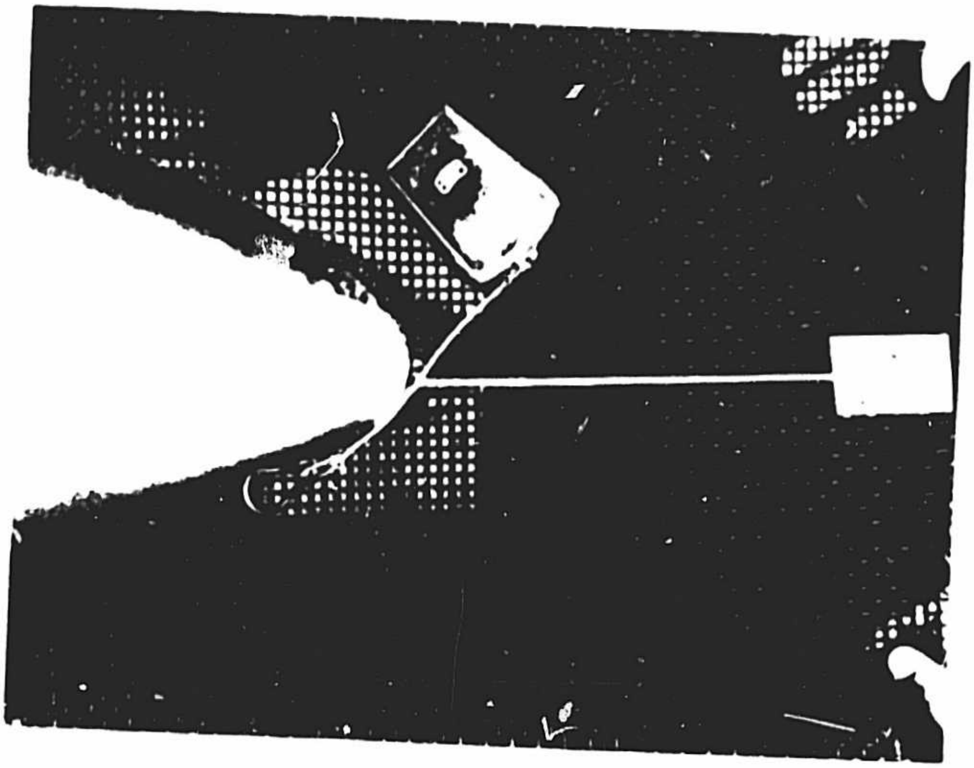
The control surface unit was mounted vertically on a turntable on the floor of the tunnel, and, in addition, fixed into the tunnel cover by means of a pivot pin (in the rotation axis) on the upper side of the model. (Pictures No. 528 and 529)

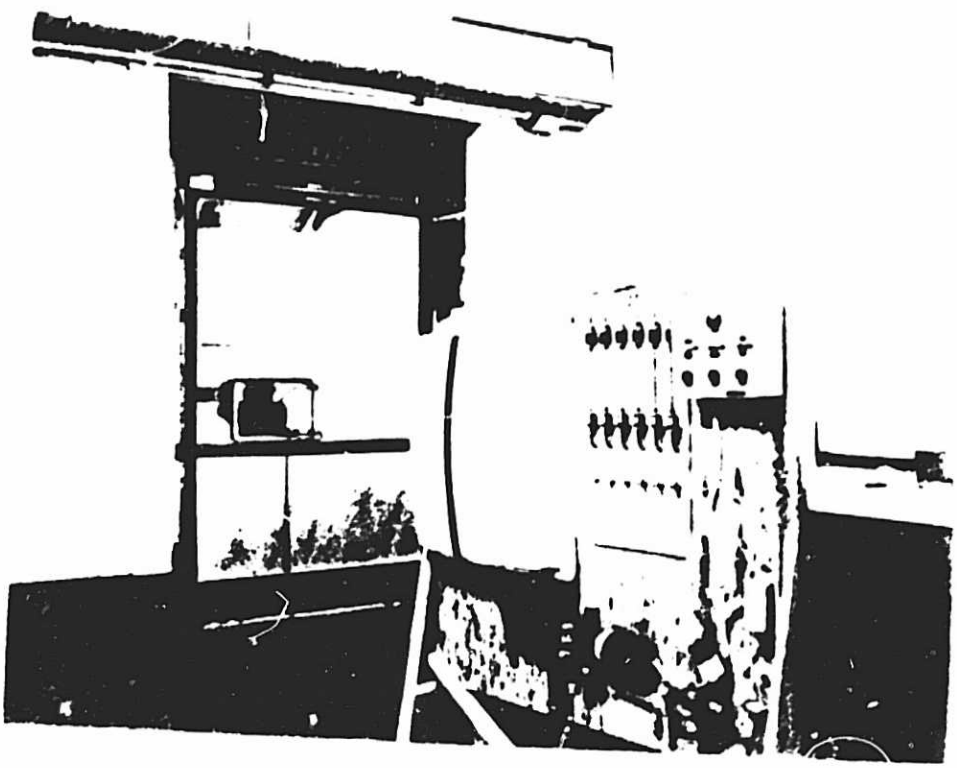
Skizze -3-



Proposal: Installation in the tunnel
Vorschlag : Anordnung im Tunnel







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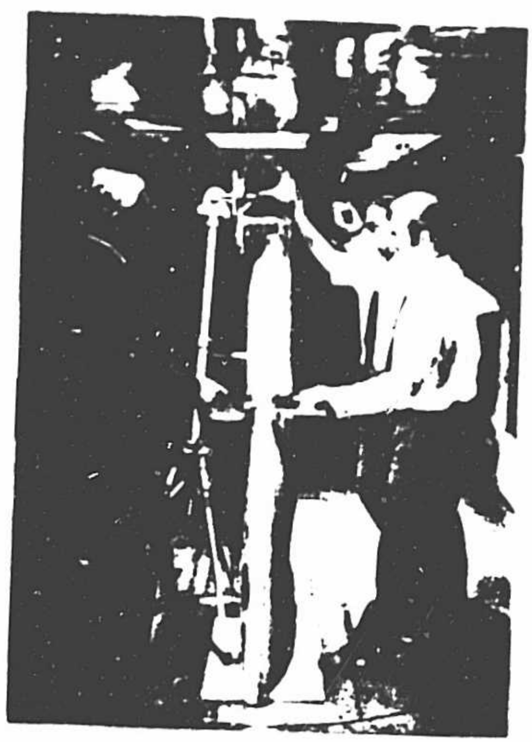


/529

Fluid de-icing system

The scope of the system can be seen in the block diagram on page 14. [7]

The system consisted of:

the supply system - Reservoir as in drawing 614-764540

- Pump, X A 9504 for 28V DC
- Filter unit Fj 2670
- Distribution unit with six branches
- 1 connecting line from the reservoir to the distribution unit. Nylon line 5/16"
- O rings

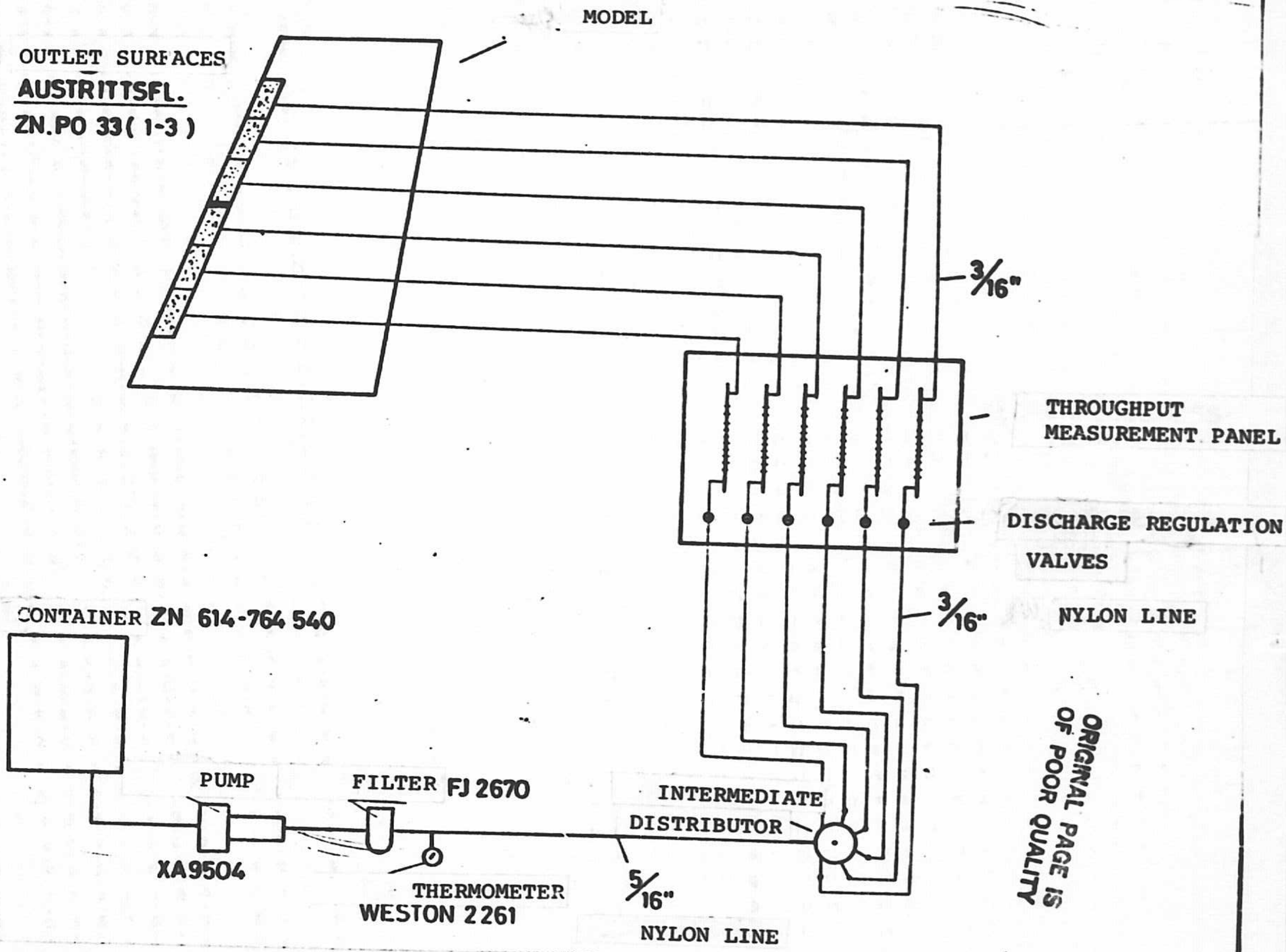
These parts were assembled onto one panel according to picture no. 614-037608 [9].

- 6 connecting lines from the distribution unit to the distribution nozzles. Nylon line 3/16" 10m long.
- On the control surface model the distribution nozzles consisted of two units which were each subdivided into three supply clusters.

  The design of the distribution nozzles may bee seen in drawings no. P 033 Sheets 1-3 [10].
- De-icing fluid DTD 406B, this was permuted with dye-fluid (green). Mixture ratio.

Control surface mock-up [11]

From drawing Ea/7-20 [12] one can see which section of the control surface was employed. The mock-up design can be derived from drawings Ea/7-20.



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NASA requires for the stability design of the model a safety /15/
factor of 5 with respect to aerodynamic forces at a maximum flow of 250 knots.

The pickups for the warning system and the liquid water content indicator were installed on the control surface mock-up (Picture 633).

Measurement system

1. The measurement system for measuring existing values in the fluid supply system consisted of:

- the throughput measurement system (on the immersion tube body principle) [13] which was installed behind the distribution unit and enabled a read-out of the respective flowthrough amounts in each supply cluster.
  Design, calibration curve and viscosity correction can be extracted from the diagram on p. /16/ [14].
  In each flow measurement pathway (Drawing No. P 037) [13], a discharge regulator valve is integrated with which the de-icing fluid amount could be regulated according to the test program.
- a temperature indicator device, bimetal type, thermo/Weston/Mod 2261 [15] before the distributor unit; indicator accuracy 1%. This device shows the temperature of the de-icing fluid passing through. The determination of the temperature is required since the indication furnished by the throughput amount measurement system is very temperature sensitive and thus the measured values require correction (see viscosity correction diagram) [16].

2. For the measurement of the ice build-up a grid coordinate scale was used with 1/4" x 1/4" units (see Photo 1123/630) and during the tests constantly photographed and a film recorded [17].

3. To determine at any given time the location of the stagnation point, a pressure distribution measurement was undertaken (plastic

tubes harnessed together, each having a drill hole at different intervals -- attached to a multiple-tubed manometer).

The Icing Tunnel

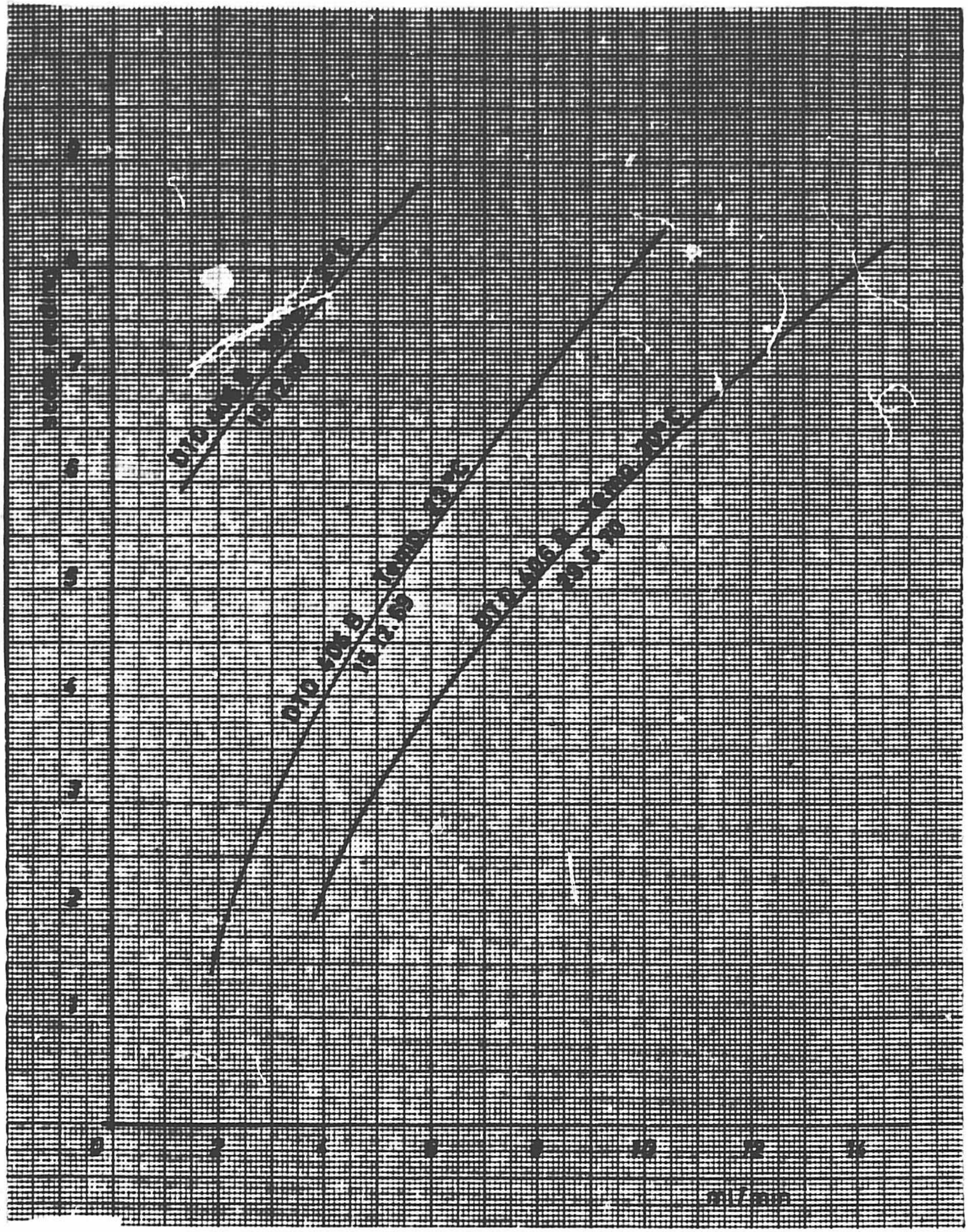
The capabilities of the icing tunnel can be obtained from the brochure "NASA ICING RESEARCH TUNNEL GENERAL INFORMATION" [18] and from the tunnel set-up diagram [19].

Icing Warning System

An icing warning system from the Rosemount Co., Type IDS-1 was studied. [20], [21].

Liquid Water Content Indicator

The measurement quality comparison measurements were carried out with a Johnson liquid water content indicator, Type LWH of the series 6506.



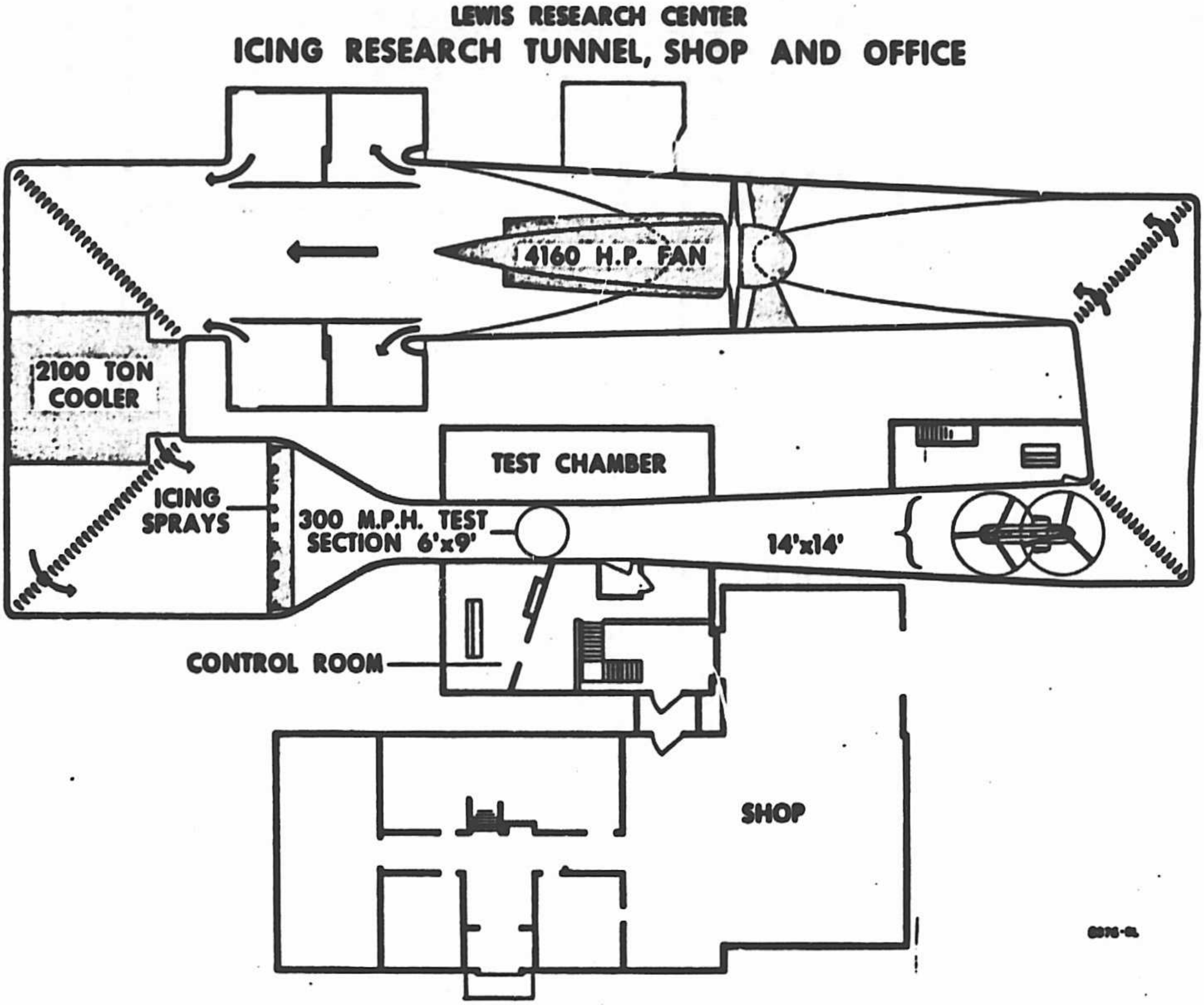
CALIBRATION CURVE

1630

1631

1632

1633



ICING RESEARCH TUNNEL SHOP AND OFFICE

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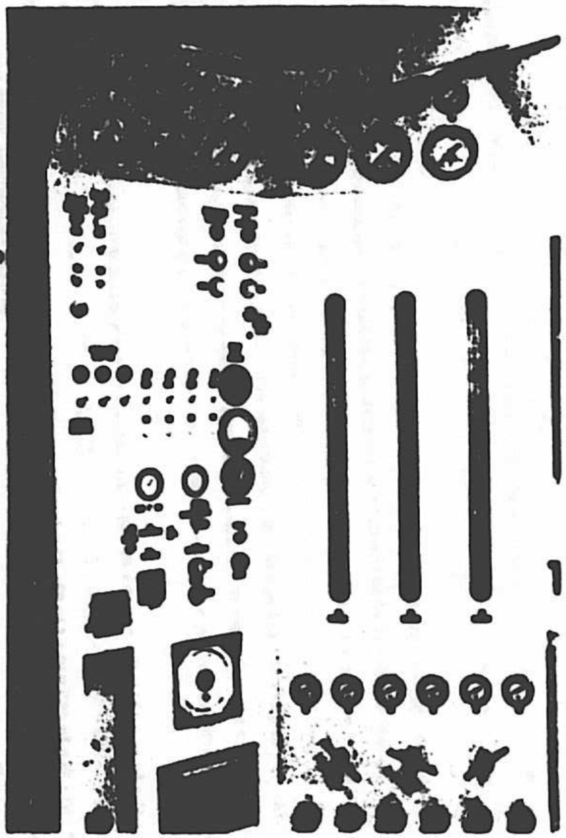

Figure No. F2/27a

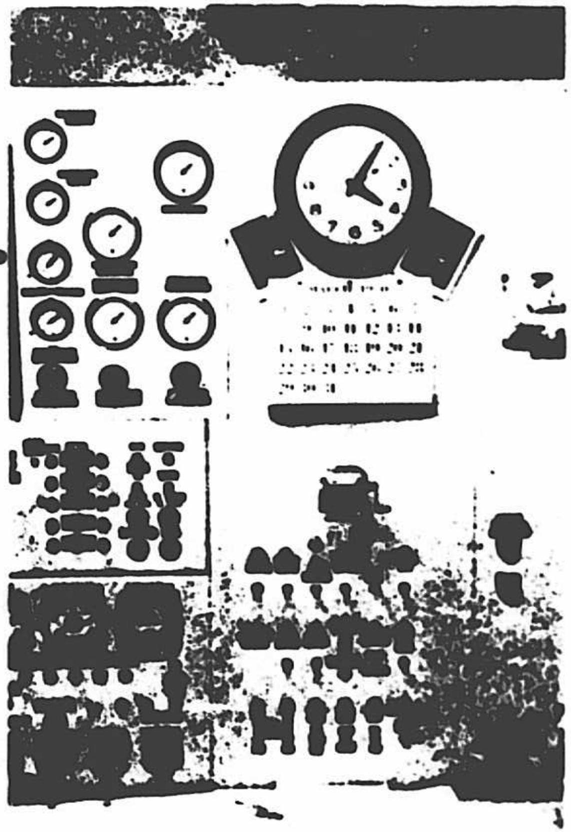

Figure No. F2/27

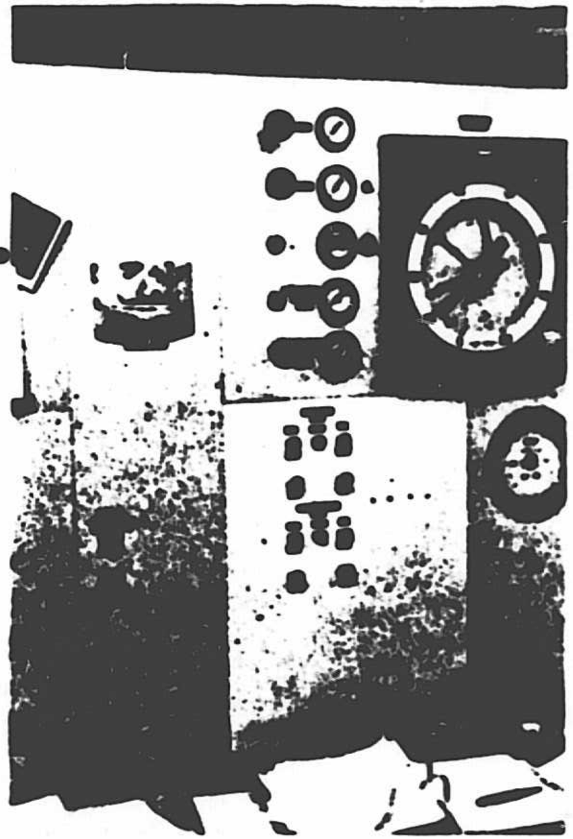

Figure No. F2/25a

VI Design Conditions /21/

1. Meteorological Ambient Conditions

The range of meteorological conditions to be taken into consideration is taken from FAR 25 Para.1419, including Attachment C, and from the FAA Report ADS-4 [22] (sic), which are based on the statistical evaluation of meteorological observations from NACA Reports 1855, 2569 and 2738. (here also see Report (blank)-meteorological icing conditions). [23]

The design cases described below are to be considered purely as extreme cases which statistically very seldom arise, but which nevertheless must be covered in accordance with the structural regulations.

1.1. Design case for the design of the distributor nozzles and sizing the maximum throughput amount (dsistributor nozzle, piping, pump output)

Intermittent maximum (cumulus)

Temperature	$\leq 0^{o}C$
Liquid water content	$= 3.0\ gr/m^3$
Droplet Ø	$= 15\ \mu$

(see diagram on page /26/)

1.2. Design value for the reservoir for storage of the de-icing fluid

Continuous maximun (stratus)

Temperature	$\leq 0^{o}C$
Liquid water content	$= 0.8\ gr/m^3$
Droplet Ø	$= 15\ \mu$
Duration of use	= max. flight time for flights at flight levels to 22,000 feet.

1.3 Functional range in temperature /22/

The system must work satisfactorily over the ambient temperature range of $0^{o}C$ to $-40^{o}C$.

1.4 Actual icing conditions arising

The table following was taken from NASA MEMO 1-19-59E [24].

Evaluation of experiences involving 3200 flights under icing conditions.

Range for 99% of the values

Temperature	= -2^{o} to $-32^{o}C$
Liquid water content	= 0.04 to 0.95 gr/m^3
Cloud extent	= 3-125 miles

2. Free Stream Velocity Conditions

In this test program the free-stream angle, free-stream velocity and de-icing fluid were to be so varied that the working range of the test de-icing systems defined under Paragraph V-Test Elements and Test Set-up- is derived in the form of parametric diagrams.

(Using these diagrams and with appropriate extrapolations, the values of the meteorological conditions under Points 1.1 and 1.2 can be determined for each fixed free-stream condition and the associated profile.)

ATTACHMENT C

(a) Maximum condition for continuous icing

The largest continuing intensity of atmospheric icing conditions (maximum condition for continuous icing) is defined by the variables:

Fluid water content in the clouds; average effective diameter of the cloud droplets, external air temperature, and by the relationships of these three variables to one another shown in Figure 1 of this Attachment. The icing boundary curve as a function of altitude and temperature is reproduced in Figure 2 of this Attachment. The dependency of the fluid water content in the clouds on the droplet diameter and on the altitude is determined from Figs 1 and 2. For a horizontal extension which deviates from the standard extension of 17.4 nautical miles, the fluid water content in a cloud for the maximum condition of continuous icing is determined when the value for the fluid water content in the cloud from Fig. 1 is multiplied by the associated factor from Fig. 3 of this Attachment.

(b) Maximum condition for intermittent icing

The greatest intensity of intermittent atmospheric icing (maximum condition for intermittent icing) is defined by the variables:
Fluid water content in the clouds, mean effective diameter of the cloud droplets, exterior air temperature and the relationships of these three variable with one another given in Fig. 4 of this Attachment. The icing boundary curve as a function of altitude and temperature is reproduced in Fig. 5 of this Attachment. The dependency of the fluid water content in the clouds on the droplet diameter and altitude is determined from Figs. 4 and 5. For a horizontal extension which deviates from the standard extension of 2.6 nautical miles, liquid water content is determined when the value for the fluid water content in the cloud from Fig.4 is multiplied by the associated factor from Fig. 6 of this Attachment.

Fluid water content/ mean effective droplet diameter

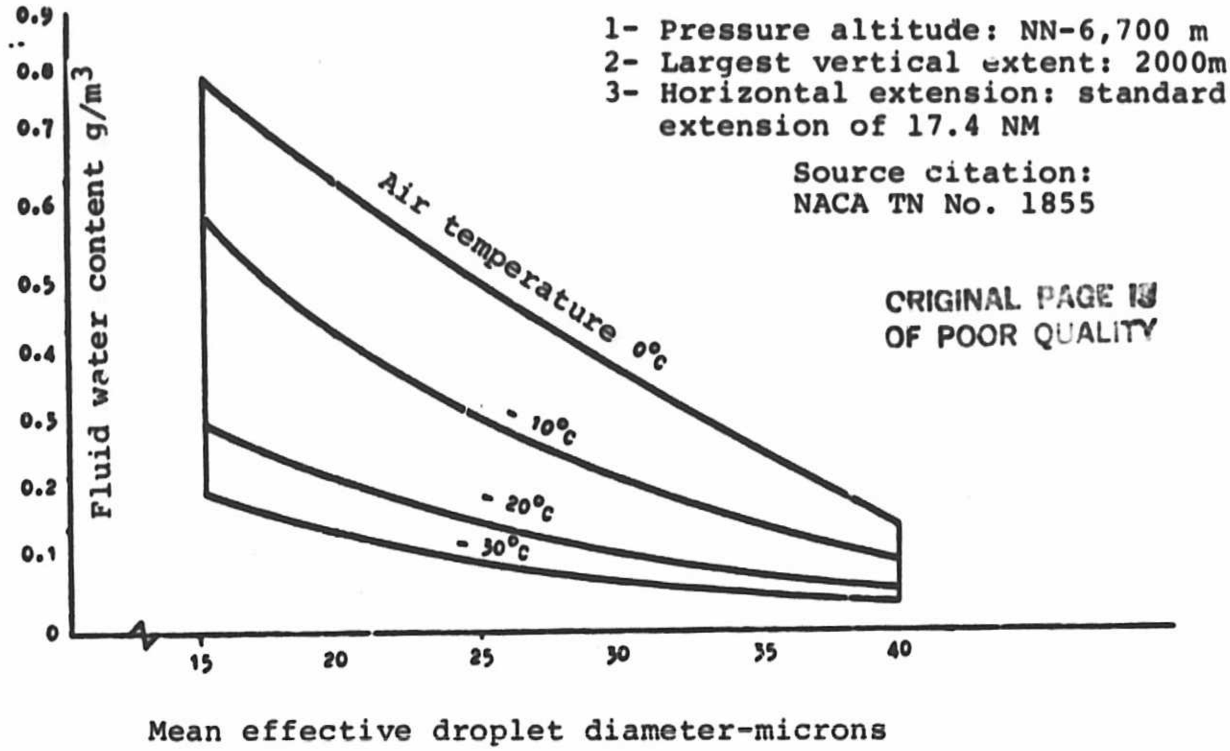

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Figure 1. Maximum condition for continuous icing (Stratocumulus) atmospheric icing condition

Exterior temperature/ Pressure Altitude

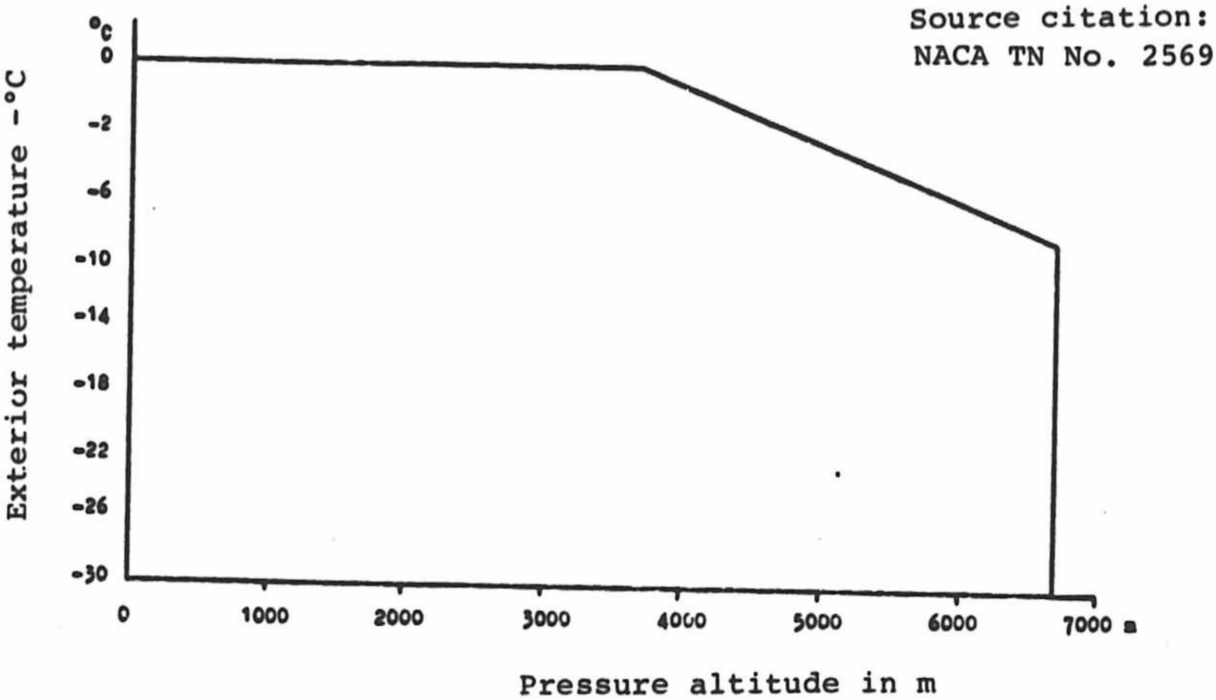

Figure 2. Maximum condition for continuous icing (Stratocumulus) atmospheric icing condition

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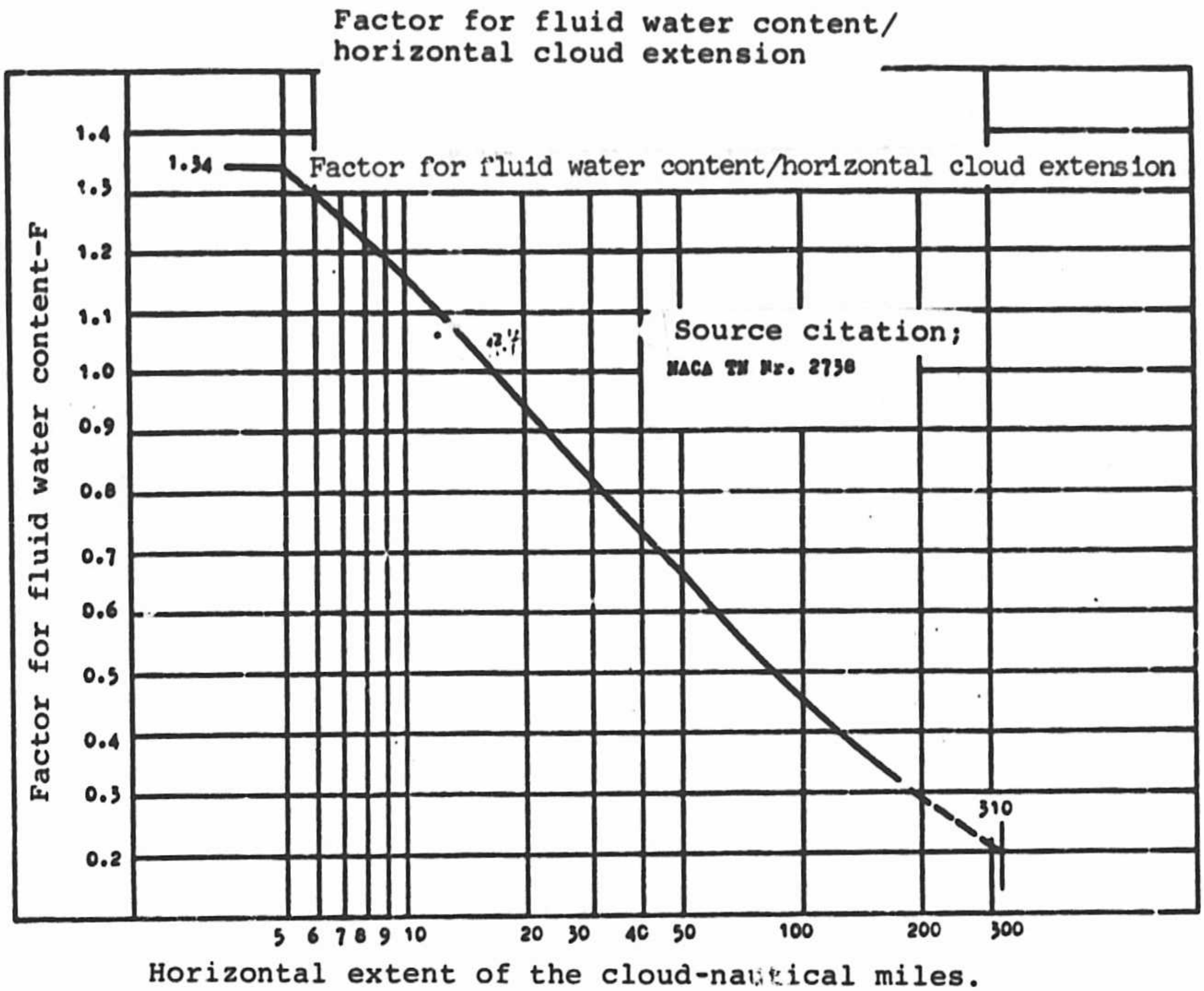

Figure 3. Maximum condition for continuous icing (stratocumulus) Atmospheric icing condition

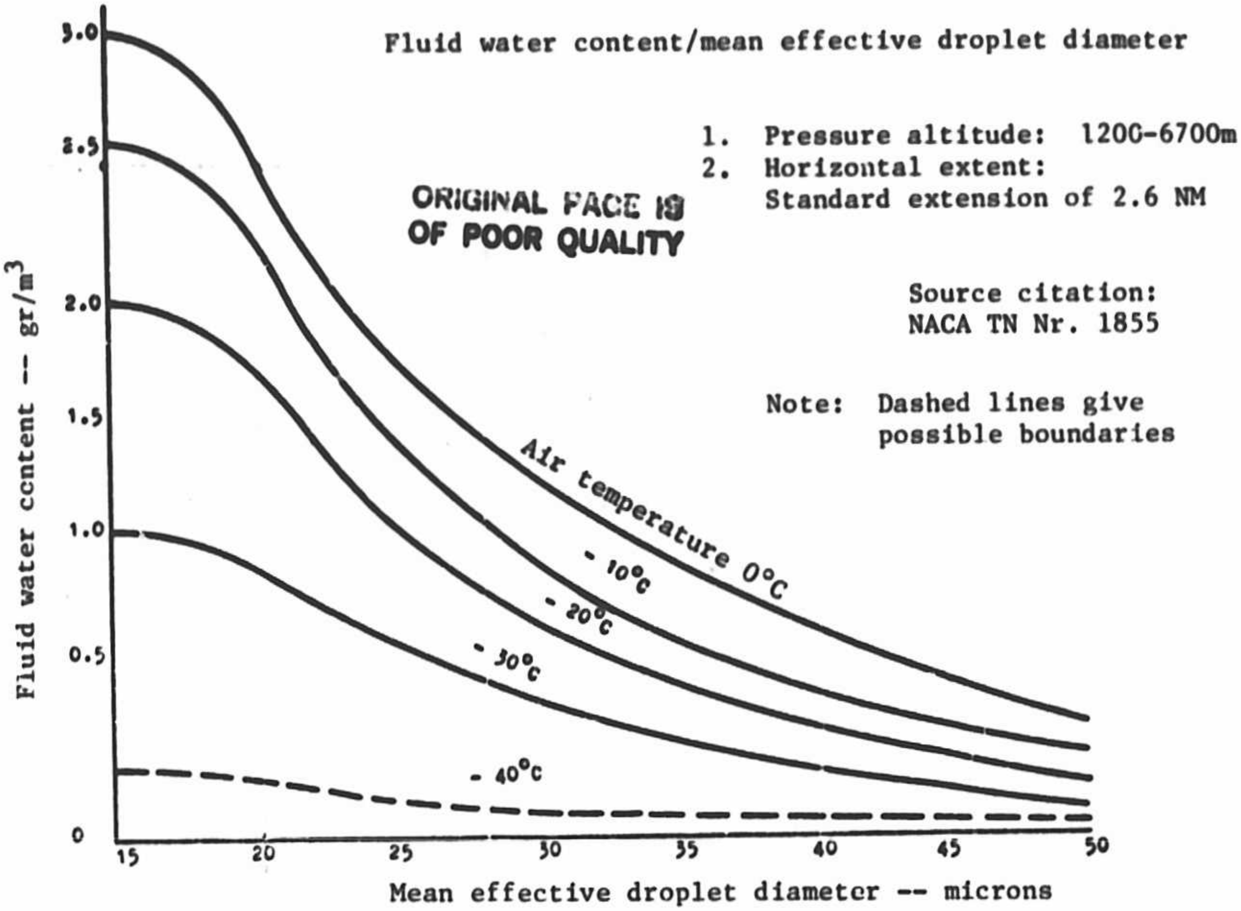

Figure 4. Maximum condition for intermittent icing (Cumulus)
Atmospheric icing condition

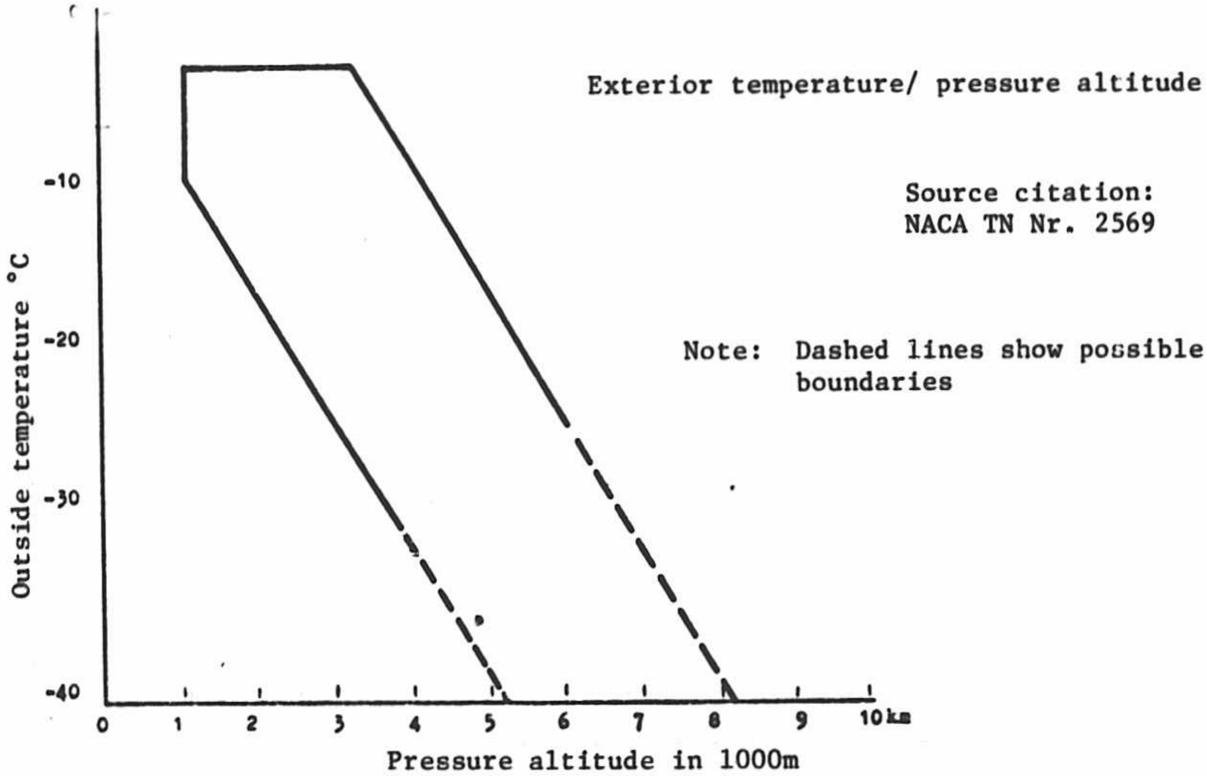

Figure 5. Maximum condition for intermittent icing (Cumulus)
Atmospheric icing condition

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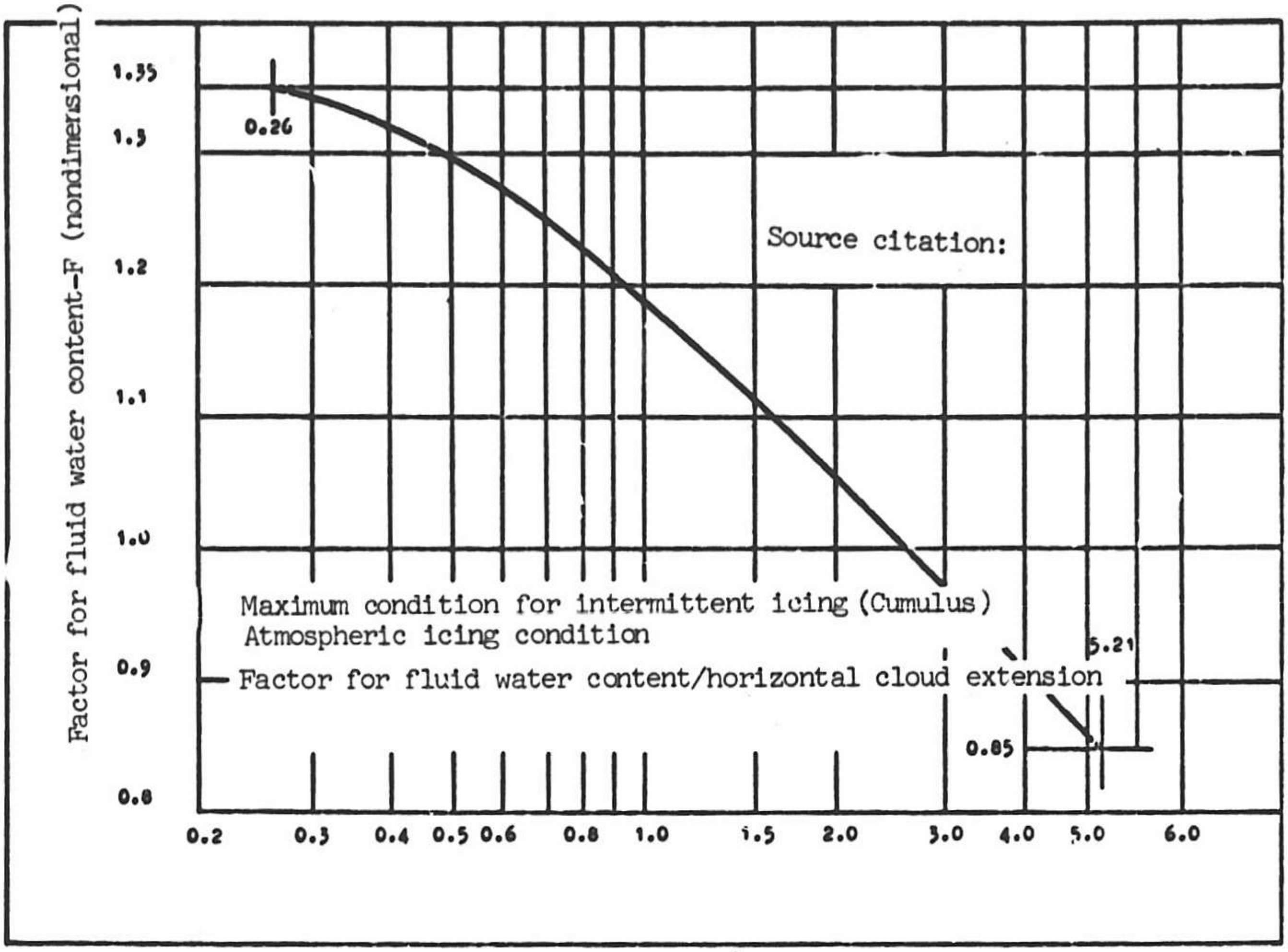

Figure 6. Horizontal extension of the cloud-nautical miles.

VII Test Program [4] /28/

In accordance with the test task (Paragraph IV) and the design conditions (Paragraph VI) the following subjects were investigated one after the other.

1. Stagnation point migration (without icing conditions)

   - determination of the stagnation point as a function of
     - o free-stream angle and
     - o free-stream velocity

2. Measurement of the icing warning detector sensitivity

   - measurement of the time from the onset of icing until the warning and|or turn-on of the pump of the de-icing system as a function of
     - o liquid water content and
     - o free-stream velocity

3. Calibration of the de-icing fluid for anti-icing and de-icing and checking on the de-icing efficiency over the range of angles of attack

   - measurement of ice build-up over time as a function of
     - o free-stream angle
     - o free-stream velocity
     - o liquid water content and droplet ϕ
     - o de-icing fluid

4. Determination of the thawing velocity after occurrence of ice build-up

   - measurement of the ice build-up over time as a function of
     - o time of activation of the de-icing system after onset of icing
     - o free-stream velocity and liquid water content

       (free-stream angle and de-icing fluid were held constant)

5. Icing contour development as a function of time

- measurement of ice contour development over time as a function of
  - o free-stream angle

6. Recording of measurement values of the Johnson liquid water content indicator for derivation of the measurement accuracy

- during the tests under Point 3, the Johnson indicator indicated values were recorded and compared with the cutoff coefficients and measurement values of the tunnel facility

The precisely worked out test program prior to the beginning of the tests [25] which planned for a variation of the values up to the design conditions in accordance with Paragraph VI could not be carried out in this form, since the available adjustment possibilities in the tunnel did not permit the necessary settings.

The modification of the program into the following form took place in Cleveland. The findings must thus be extrapolated to the design conditions.

de-icing tests 614

Test number	Attack angle ∡	Free-stream velocity V_∞		Free-stream temp.T		Liquid water content	Droplet ϕ	De-icing fluid throughput cm^3	Photo No. - after n minutes	Results/Remarks
	* *	V∞	V∞	T	T		ϕ	cm^3		
	o	kn	/s	°F	°C	gr/m^3	μ	Panel		
1	0	100	51.47							
2	2	"	"							
3	4	"	"							
4	[illegible]	"	"							
5	8	"	"							
6	10	"	"							
7	-2	"	"							Pressure disk for stagnation point
8	-4	"	"							
9	-6	"	"							
10	-6	200	10:•94							
11	-4	"	"							
12	-2	"	"							
13	0	"	"							
14	2	"	"							
15	4	"	"							
16	6	"	"							
2.2	0	90	46.3	~ 20	~-7	1.2	15	4		
2.3	c	90	"	~ 20	~-7	1.5	20	4		
2.4	0	90	"	~ 20	~-7	1.9	20	4		Measurement of turn-on times by Rosemount indicator
2.5	0	150	77.2	~ 20	-7	0.8	15	4		
2.6	0	150	"	~ 20	~-7	1.2	15	4	F 1/ 2 a/ 4 /	
2.7	0	150	"	~ 20	~-7	1.5	20	4	F 1/ 4 a/ 8 / 9	
3.1.1	+2	90	46.3	22	-5.5	1.3	15	2		deicing (About 2 min periods)
3.1.2	+2	90	"	22	-5.5	1.3	15	4		antiicing
3.1.3	+2	90	"	20	-7.5	1.3	15	1.5		deicing (2 min periods)
3.2.0	+2	90	"	20	-7.5	2.8	25	2		no deicing
3.2.1	+2	90	"	20	-7.5	2.8	25	4		no deicing
3.2.2	+2	90	"	20	-7.5	2.8	25	6		partly deicing
3.2.2.1	+2	90	"	20	-7.5	2.8	25	8		deicing (2 min periods)
3.3.0	+2	150	77.2	20	-7.5	0.8	15	2	2/8 min 4/10 min (following ice breakup)	no deicing
3.3.1	+2	150	"	20	-7.5	0.8	15	4	6/ following partial de-icing	partly deicing
3.3.2	+2	150	"	20	-7.5	0.8	15	6	8/2 min	straightforward de-icing
3.4.0	+2	150	"	20	-7.5	1.9	25	4	10/9 min 12/12,5 min F2/ 5a/ 7/7a/ 9/ 9a/ 11/	no deicing
3.4.1	+2	150	"	20	-7.5	1.9	25	6	14/10,5 min F2/ 13a/ 15	only very delayed de-icing
3.4.2	+2	150	"	20	-7,5	1.9	25	8	16/15 min.18/20 after 10 min increased to F = 8 cm^3 panel	partly de-icing

Test number	Attack angle ∢	Free-stream velocity V_∞		Free-stream temp. T		Liquid water content	Droplet ⌀	De-icing fluid throughput cm^3	Photo No. - after n minutes	Results/Remarks
	* *	V_∞	V_∞	T	T		ϕ	cm^3		
	o	kn	/s	°F	°C	gr/m^3	μ	Panel		
3.4.3	+2	150	77,2	20	-7,5	1,9	25	10	22/ After ice breakup	Deicing auf P1 / 2 / 3 /
.4	+2	150	"	20	-7,5	1,9	25	12	24/6 min 26/14 min 28/19 min	Deicing
.0	+2	200	102,9	20	-7,5	0,6	<15	2	31/6 min 33/12 min	partly Deicing
.1	+2	200	"	20	-7,5	0,6	<15	4	35(without spray) 37/4.5 min 35/7.5 min	Deicing (3,5 min Periods)
.2	+2	200	"	20	-7,5	0,6	<15	6	Straightforward de-icing-bound./b, 8 cm³/Panel ke	
.1	+2	200	"	20	-7,5	1,4	20	4	41/0,5 min 43/4 min 45/6,5 min	partly Deicing
.2	+2	200	"	20	-7,5	1,4	20	6	48/2 min 50/4 min 52/6 min 54/8 55 - 59 (without spray)	partly Deicing
.3	+2	200	"	20	-7,5	1,4	20	8	61/2 min 63/4 min 65 - 72 (thereafter)	Deicing (partly antiicing)
4.1.0	+10	200	"	20	-7,5	0,6	<15	2	77/7 min 79/9 min	Deicing (partly)
.1	+10	200	"	20	-7,5	0,6	15	4	$\boxed{82}$/without spray 84/2 min 86/3,5 min 88 - 92 (thereafter)	Deicing / antiicing
.2	+10	200	"	20	-7,5	0,6	15	6	94/2 min 95/4 min 96/6 min 98/7,5 min	
4.2.0	+10	200	"	20	-7,5	1,4	20	6	100/2 min 101/4 min 102/6 min 103/7 min 105/8 min	Deicing (with fluid decel.)
4.2.1	+10	200	"	20	-7,5	1,4	20	6	107/2 min 108/4 min 109/6 min 110/8 min	De-icing/partly antiicing (without fluid decel.)
4.3.0	+10	150	77,2	20	-7,5	0,8	15	4	112/2 min 113/8,5 min	Deicing / partly antiicing
.1	+10	150	"	20	-7,5	0,8	15	2	115/2 min 116/5 min	partly Deicing
4.4.0	+10	150	"	20	-7,5	1,9	25	4	118/2 min 119/6 min 120/6 min	Deicing/ partly antiicing
.1	+10	150	"	20	-7,5	1,9	25	2	122/2 min 123/4 min 124/6 min 125/6 min 127/6,5 min	no Deicing
.	+6	150	"	20	-7,5	0,8	15	4	131/2 min	antiicing
5.	+6	150	"	20	-7,5	0,8	15	2	133/2 min 134/7 min	Deicing
.	+6	150	"	20	-7,5	1,9	25	4	137/3 min 138+139/6 min	Deicing / partly antiicing
5. .1	+6	150	"	20	-7,5	1,9	25	2	141/2 min 142/4 min 143 + 144/6 min	no Deicing
5.3.0	+6	200	"	20	-7,5	0,6	<15	4	146/2 min 147/4 min	De-icing/partly antiicing (almost anti-icing)
3.1	+6	200	"	20	-7,5	0,6	<15	2	149/2 min 150/6 min 151/10 min 152/12 min	partly Deicing
4.0	+6	200	102,9	20	-7,5	1,4	20	4	155/2 min 156/4 min 157/6 min 158/8 min	partly Deicing
.1	+6	200	"	20	-7,5	1,4	20	6	160/2,5 min 161/4 min 162/8 min	Deicing
5.5.0	+6	200	"	-15	-26	0,6	<15	4	164/1 min 165/3 min 166/6,5 min 167/9 min	Just antiicing
.1	+6	200	"	-15	-26	0,6	<15	2	169/2 min 170/4 min 171/7 min 172/8,5 min	Deicing
.0	+6	150	77,2	-15	-26	0,8	<15	2	174/2 min 175/4 min	Deicing
.1	+6	150	"	-15	-26	0,8	<15	4	177/2 min 178/4 min	antiicing
.0	+6	150	"	-15	-26	1,4	20	2	179/4 min 180/6 min	Deicing
.1	+6	150	"	-15	-26	1,4	20	4	182/3 min 183/4 min 184/6 min	Deicing
.2	+6	150	"	-15	-26	1,4	20	6	134 min	antiicing
8.0	+6	200	102,9	-15	-26	1,4	20	6	195/2 min 196/3 min 197/4 min 198/6 min	Deicing
5.8.1	+6	200	"	-15	-26	1,4	20	4	199/1 min 200/3 min 201/4,5 min 202 min 203/5,5 min	partly Deicing
6.1.0	±0	200	"	20	-7,5	0,6	<15	4	206/2 min 207/3 min 208/6 min 209/9 min	partly Deicing
6.1.1	±0	200	"	20	-7,5	0,6	<15	6	213/5 min 214/6 min	partly Deicing

Test number	Attack angle	Free-stream velocity V_∞		Free-stream temp. T		Liquid water content	Droplet ϕ	De-icing fluid throughput cm^3	Photo No. - after n minutes	Results/Remarks
	* *	V_∞	V_∞	T	T		ϕ	cm^3		
	o	kn	/s	°F	°C	gr/m^3	μ	Panel		
5.1.2	±0	200	102.9	20	-7.5	0.6	<15	4	215/6 min 216/9 min [illegible]/9.5 min 218/15 min	Deicing
7.1.0	+1	200	"	20	-7.2	0.6	<15	4	219/3 min [illegible]/8 min	partly deicing
7.1.1	+1	200	"	20	-7.5	0.6	<15	6	221/4 min	deicing /partly antiicing
7.1.2	+1	200	"	20-	-7.5	0.6	<15	8	222/[illegible]5 min	antiicing
7.2.0	+1	200	"	20	-7.5	1.4	20	4	223/6 min 224/6 min	no deicing
7.2.1	+1	200	"	20	-7.5	1.4	20	6	225/7.5 min 226/8 min	partly deicing
7.2.2	+1	200	"	20	-7.5	1.4	20	8	[illegible]7/7 min Polaroid 1	partly deicing
8.1.0	+2	200	"	20	-7.5	0.6	<15	4		de-icing after 1 min-delay (3-5 mi[illegible]
8.1.1	+2	200	"	20	-7.5	0.6	<15	4	228/4.5 min 229/6 min	de-icing after 3 min-delay (4-8 mi[illegible]
8.1.2	+2	200	"	20	-7.5	0.6	<15	4	230/1 min 231/2 min 232/3 min 233/4 min 234/5min 235/6min 236/10min	deicing after 6 min-delay (5-8.5m[illegible]
[illegible].0	+[illegible]	200	"	20	-7.5	1.4	25	4	241/6 min 242/7 min 243/7[illegible] min	de-icing after 1 min- delay (no deic[illegible]
8.3.0	+[illegible]	150	77.2	20	-7.5	0.8	<15	4	244/3.5 min	de-icing after 1 min- delay (3-4 mi[illegible]
8.3.1	+2	150	"	20	-7.5	0.8	<15	4	245/1 min 246/2 min 247/3 min	de-icing after 3 min- delay (5-10 [illegible]
8.3.2	+[illegible]	150	"	20	-7.5	0.8	<15	4	249/1 min 251/3 min 252/4 min 253/5 min 254/6 min 255/10 min	de-icing after 6 min- delay (12.5-15[illegible]
9.0.1	+2	200	102.9	20	-7.5	1.4	25	0	Bild 3 Polaroid, Pk 2364 a,	10 min ice accretion
9.0.2	+2	200	"	20	-7.5	1.4	25	0	Bild 4 Polaroid, Pk 2364 b 265/1 min 266/2 min 267/3; 268/4; 269/5	5 min ice accretion
9.0.3	±0	200	"	20	-7.5	1.4	25	0	Bild 5 Polaroid, Pk 2364 c 270/3; 271/5; 272/10 min	10 min ice accretion
9.0.4	±0	200	"	20	-7.5	1.4	25	0	Bild 6 Polaroid, Pk 2364 e	5 min ice accretion
9.0.5	+6	200	"	20	-7.5	1.4	25	0	Bild 7 Polaroid, Pk 2364 f 274/3; 275/5; 276/10; 277/12 min	5 min ice accretion
9.0.6	+10	200	"	20	-7.5	1.4	25	0	Bild 8 Polaroid, Pk 2364 h 279/3; 280/5; 281/10 min	10 min ice accretion
9.0.7	+10	200	"	20	-7.5	1.4	25	0	Bild 9 Polaroid, Pk 2364 i 282/5 min	5 min ice accretion
9.0.8	+6	200	"	20	-7.5	0.6	<15	0	Bild 10 Polaroid, Pk 2364 k 284/3; 285/5; 286/10 min	10 min ice accretion
9.0.9	+10	200	"	20	-7.5	1.4	25	0	Bild 2 Polaroid, Pk 2364	

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VIII Test Findings and Evaluation of the Validity of Test Results

In the following, the raw test results of the separate test program subjects 1-6 (Paragraph VII) are reproduced.

In Section 7 these individual test results are summarized in cross-plots of the individual influence parameters in diagram form, and these produce the basis for the parametric study of the optimum design for the fluid de-icing systems (Follow-on Report No.) [26].

The following special factors of the icing tunnel must be taken into consideration in evaluating these test results with respect to flight through natural icing conditions.

- Tunnel wall influence-	Since the ice buildup in the mid-portion of the control surface was recorded as representative and the model was turned between -2^o to $+10^o$, the tunnel wall influence up to about $\pm 7^o$ can be ignored (see Presentation Manuscript by Mr. Gray, FAA Icing Symposium 1969 AD 690-469) [27],[28]
- Turbulence	The tunnel turbulence amounts to 1-3%, thereby a limited cloud effect is generated [27]
- Structural vibration	Since the model is very strongly clamped, there are no structural vibrations and movements which promote ice dissolution, i.e. tougher conditions than in nature
- Location in the stream	The horizontal control surface stands vertically. The influence of gravity can be ignored from about 60 knots.

- Water supercooling	According to statements by Mr. Gray (NASA) there are no differences between the tunnel and natural conditions [22]. Nevertheless, during the 614 tests we operated at lower temperatures than in the FAR regulations in order to approach more closely the water supercooling effect. /34/
- Measurement equipment of the tunnel	Measurement accuracy ± 15% [27]

Altogether, the estimated measurement uncertainty with respect to natural icing amounts to ± 15%.

1. <u>Stagnation Point Migration</u> (Test Nos 1-16 Diagrams pp 41-44)*

The determination of stagnation point migration over the entire angle of attack range is one of the most important criteria for sizing of the distributor nozzles since the stagnation point migration range plus the fixed overlap increment gives the distributor nozzle depth. If too small a migration range is selected, in the case of the outside attack angles, insufficient wetting with de-icing fluid develops and ice buildup occurs on the corresponding side. If the migration range is too large, unncessary consumption of de-icing fluid is generated.

The location of the stagnation point was determined by means of pressure distribution measurments along three sections perpendicular to the leading edge. In the diagrams are plotted the pressure distributions for the three sections against the horizontal control surface nose configuration. The maximum of a curve like this shows the stagnation point location. The de-icing zone is included. In the diagrams the stagnation point migration with angle of attack is shown over the nondimensional wing chord x/1. The figures on pages 43-45 show the horizontal control surface nose with the deicing zone and the locations of the stagnation points.

*Translator's Note; Page (pp) references refer to the foreign text.

Result:

- The stagnation point location (% $\frac{x}{I}$) in the case of an identical angle of attack moves in the direction of the foil span, in connection with which a lower $\frac{x}{I}$ location occurs from the inside towards the outside.
- With increase in stream velocity a smaller $\frac{x}{I}$ situation is generated /35/
- The theoretical derivation of the stagnation point location agrees satisfactorily with the measured locations.

2. Measurement of the Icing Warning Sensor Sensitivity

Test No. 2.2-2.7

Diagram on page 46*

The switch-on time of the fluid de-icing system following the onset on icing was measured as a function of stream velocities from 80-150 knots and of liquid water content (LWC) values 0.8, 1.2, 1.5 and 1.9 gr/m^3.

Result:

- In general, the warning system activation time was shortened with higher LWC and higher velocity, i.e. higher water acquisition rate.
- The measured activation times are higher than those specified and exhibit discontinuities, i.e. the sensitivity is worse than specified.
- Functional deficiencies are set down in deficiency reports 6-9. [2]
- In summary, it can be said of the ice warning detector, the electronic unit and the automatic switching that the planned system functions. Due to the errors and/or disruptions that occurred in the subject components, appropriate improvements should be undertaken. If occasion arises, the applicability of another ice warning device should be investigated and an exchange undertaken.
- As further tests of the fluid de-icing system prove, a warning system which only indicates that icing is present is not sufficient, but the warning system must be able to indicate icing intensity (water /36/

*p.46 of translation.

acquisition rate), so that the fluid de-icing system can be appropriately regulated.

3. Calibration of the De-Icing Fluid for Anti-Icing and De-Icing and Checking the De-Icing Efficiency over the Range of Angles of Attack

Test Nos. 3.1.1 to 7.2.2
Diagrams on pp. 49-116

The de-icing efficiency was here divided into 5 quality classes:

a) Anti-icing: no ice buildup

b) Near anti-icing: thin ice layer builds up and melts immediately

c) De-icing: ice builds to a certain thickness and flies away at regular time intervals

d) Near de-icing: ice builds to a heavy thickness and flies away at irregular intervals or only incompletely

e) No de-icing Ice builds up and grows to unacceptable thicknesses

Using these quality classes, working diagrams have been generated. One can derive the de-icing boundaries from these figures as a function of various parameters. Thus, by means of cross-plotting, it is possible to derive the anti- and de-icing boundaries for the given angle of attack with the LWC as a parameter. Within certain limits, one can interpolate or extrapolate using these diagrams (see Paragraph 7).

In this program area, the test series have been so constituted that, in each case with the angle of attack held constant:

+ 2°	Test Nos. 3.1.1 to 3.6.3
$+10^{\circ}$	Test Nos. 4.1.0 to 4.4.1
$+6^{\circ}$	Test Nos. 5.1.1 to 5.8.1
0°	Test Nos 6.1.0 to 6.1.2
$+1^{\circ}$	Test Nos. 7.1.0 to 7.2.2,

the velocity for each of the subtest series also remained constant /37/
90,150, 200 knots, and , in further carrying out of the subdivision, the lower and upper liquid water contents that could be simulated in the tunnel were set in.

Following this, the de-cing fluid throughput was increased in stages for each individual test so that the de-icing and anti-icing conditions could be derived.

The results of these tests have been presented in the following diagrams and photos, and also in the Program Layout (Paragrpah VII).

Result:

- The working range of the test model lay between about $+2^{\circ}$ and $+9^{\circ}$ stream angle, that is, the overlap zone of the discharge surface must equal about 20mm above the stagnation points associated with $+2^{\circ}$ and $+9^{\circ}$ in order even to maintain satisfactory de-icing conditions in the case of greater rate of water acquisition.

- The consumption of de-icing fluid for de-icing or anti-icing conditions increases with an increase in free-stream velocity and with an increase in water acquisition rate (LWC, droplet Ø, decreasing profile radius).

- The decreasing of the temperature, given equal stream conditions and the same water acquisition rate, has a negligibly small influence on the de-icing efficiency. This shows a result comparable to tests 5.3.0 and 5.5.0 in which the temperature only was changed from -7.5° to -26°C and with the same de-icing fluid throughput similar de-icing conditions appeared.

Since the de-icing fluid remains capable of being pumped down to temperatures below -40°C, tests 5.5.0 to 5.8.1 at -26°C assured that the de-icing efficiency did not change down to the required temperature of -40°C.

- On the junction points and joints of the individual distributor /38/
nozzles, depending on their area, ice builds up to a certain thickness in order then to be loosened and then to rebuild again. For this reason, the junction points, that is,the points on which no de-icing fluid can emerge, should be kept as small as possible.

- The functional deficiencies are cited in the deficiency reports numbers 10-21. [2]

4. Determination of the Thawing Velocity after Occurrence of Ice Accretion

Test Nos. 8.1.0 to 8.3.2

Diagrams pages 117-126

This test series was deigned to determine the de-icing behaviour after late switch-on of the de-icing system (1.3 and 6 min).

Result:

- In general it was determined that, after a belated switch-on of the system, ice can be broken up, but after switch-on the ice does not immediately loosen, but that for a certain time it continues to build up. The later the switch-on time, the longer the build-up time (this applies up to an ice thickness at which the force of the stream breaks the ice loose).

- Due to lack of time we could not investigate the influence of an increase in de-icing fluid throughput on the break-up speed. However, it can be supposed that the break-up speed will be increased by this.

5. Development of the Icing Contour-Its Time Dependency /39/

Test Nos. 9.0.1 to 9.0.9

Photos pages 127-142

In this test series, the development of the icing contour was to be measured in order to determine whether the mathematical derivation [3] of the icing contour according to FAA Report ADS 4 [29], which served as the basis for setting the icing contour for the wind tunnel tests, actually corresponded to the icing tunnel findings.

Results:

- The icing contour derived for the wind tunnel tests agrees in the measurements sufficiently closely with the dimensions measured in the icing tunnel.

6. Recording of Measurement Values of the Johnson Liquid Water Content Indicator for Derivation of the Measurement Accuracy

Since a Johnson indicator is planned for measurement of LWC values in the flight testing, this type of a system was borrowed from BAC and switched on and observed during the tests.

Result:

Type 6506 gives values **consistent with those from the measurement systems of** the tunnel in the following working regime:

Velocity from V > 200 knots

Angle of attack $\alpha \leq \pm 1^{o}$

Temperature range to about $-15^{o}C$

7. Cross Plotting [31]

As mentioned at the beginning of Paragraph VIII, under point 7, the individual test results are plotted in summary form in the following diagrams. /40/

- required throughput of de-icing fluid (ccm/min/panel)

(These values are the observed uncorrected values and must be recalculated with the calibration diagram [16]) as a function of LWC.

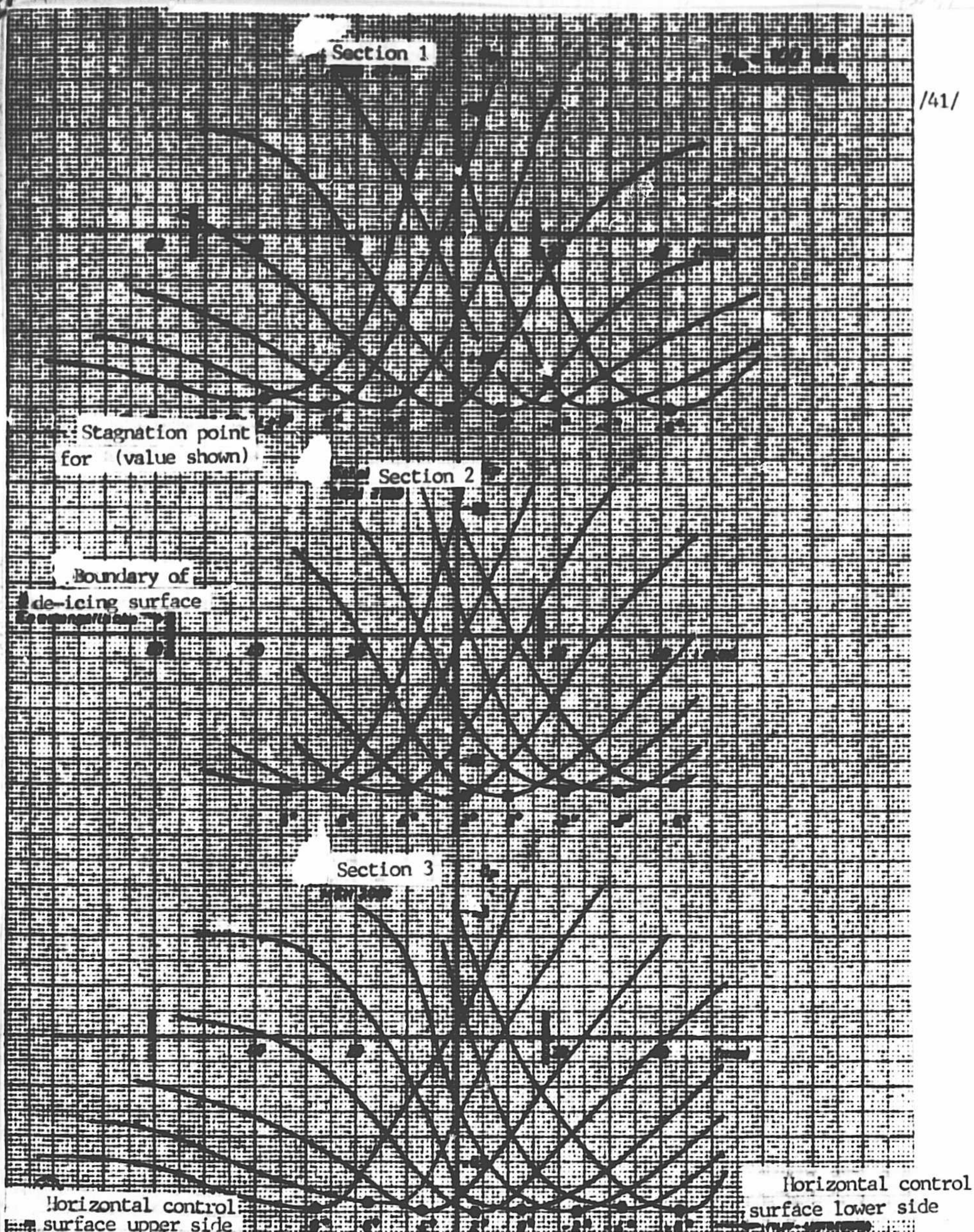
Parameter: Velocity and angle for de-icing and anti-icing

- required throughput of de-icing fluid (uncorrected values) [16] as a function of angle of attack for de-icing and anti-icing.

Parameter: LWC and Velocity

These diagrams form the basis for the required interpretations and extrapolations for sizing of the fluid de-icing system [26].

/41/



Pressure Distribution on the Horizontal Control Surface Nose Configuration for Determination of Stagnation Point

/42/

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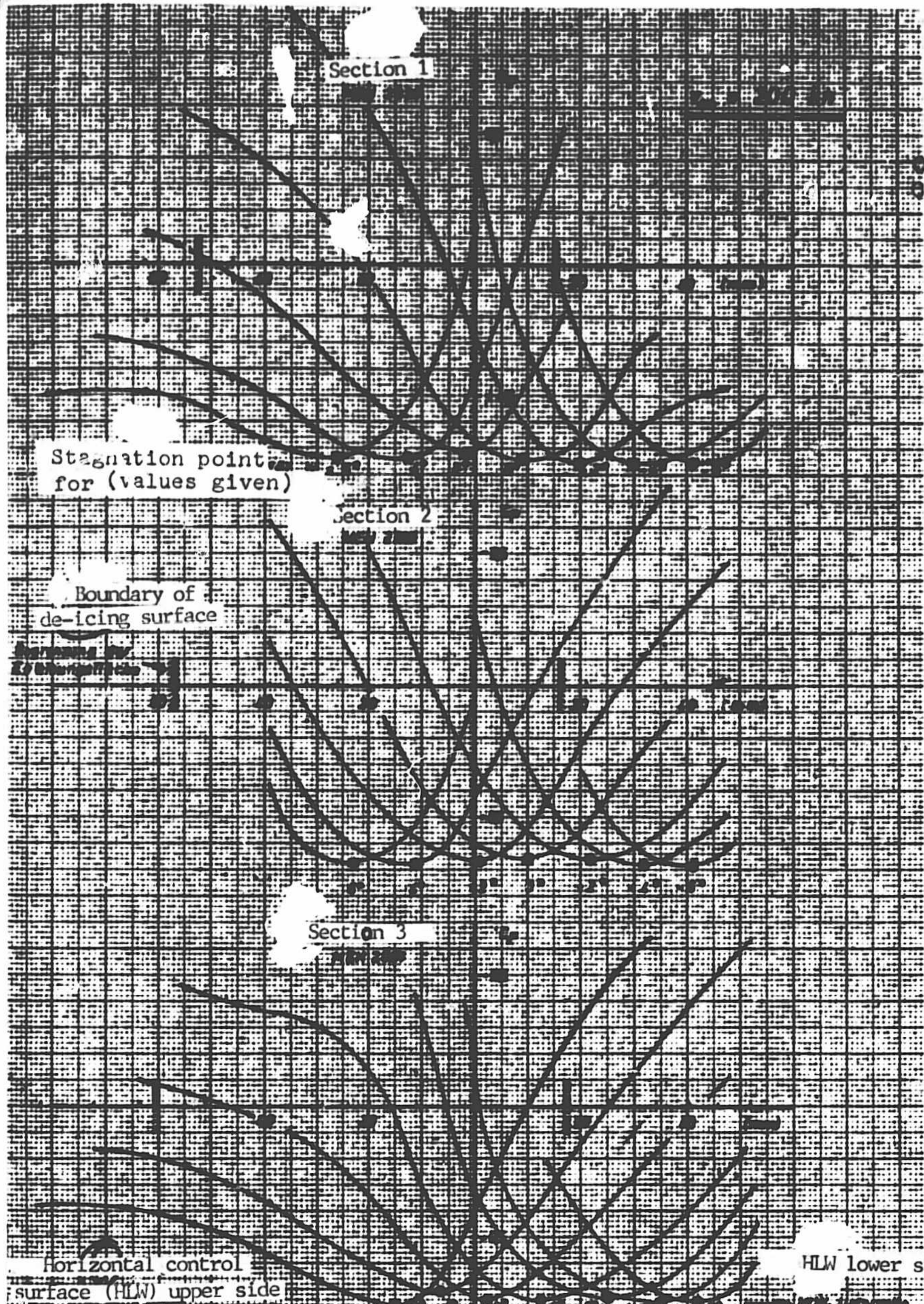
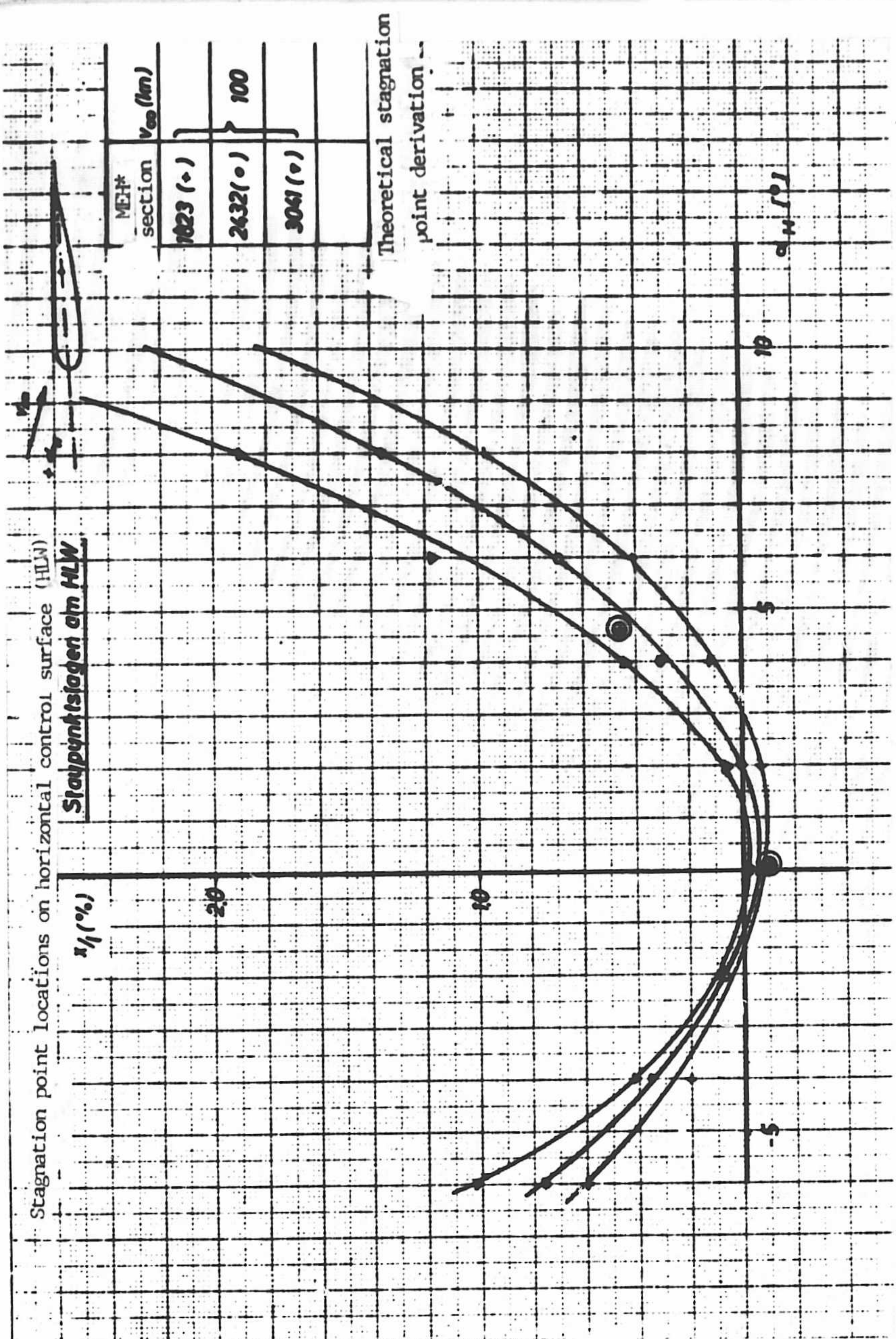


Pressure Distribution on the Horizontal Control Surface Nose Configuration for Determination of Stagnation Point

/43/



Stagnation point locations on horizontal control surface (HLW)

* MEH not defined in text- presumably refers to maximum de-icing level -transl.

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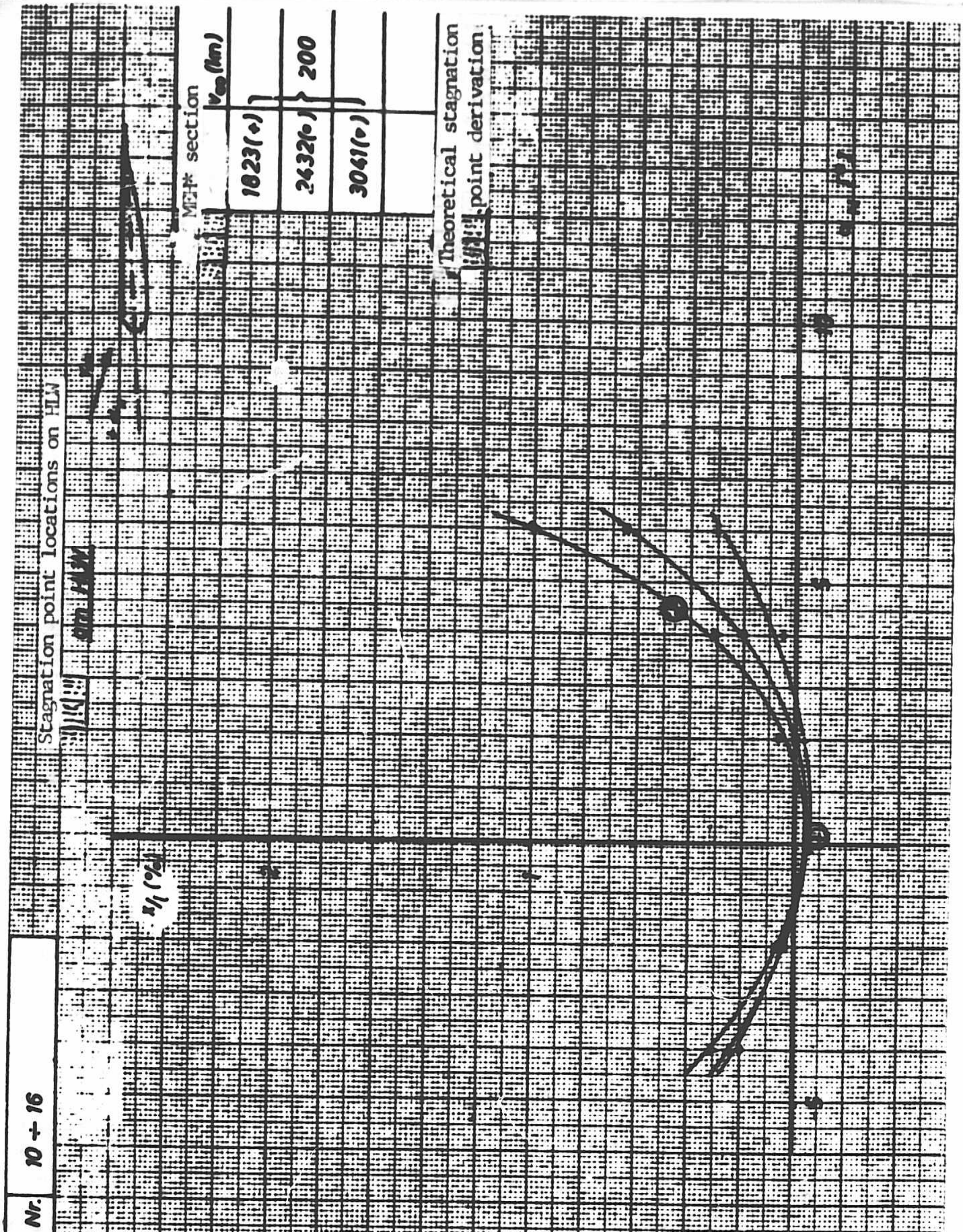
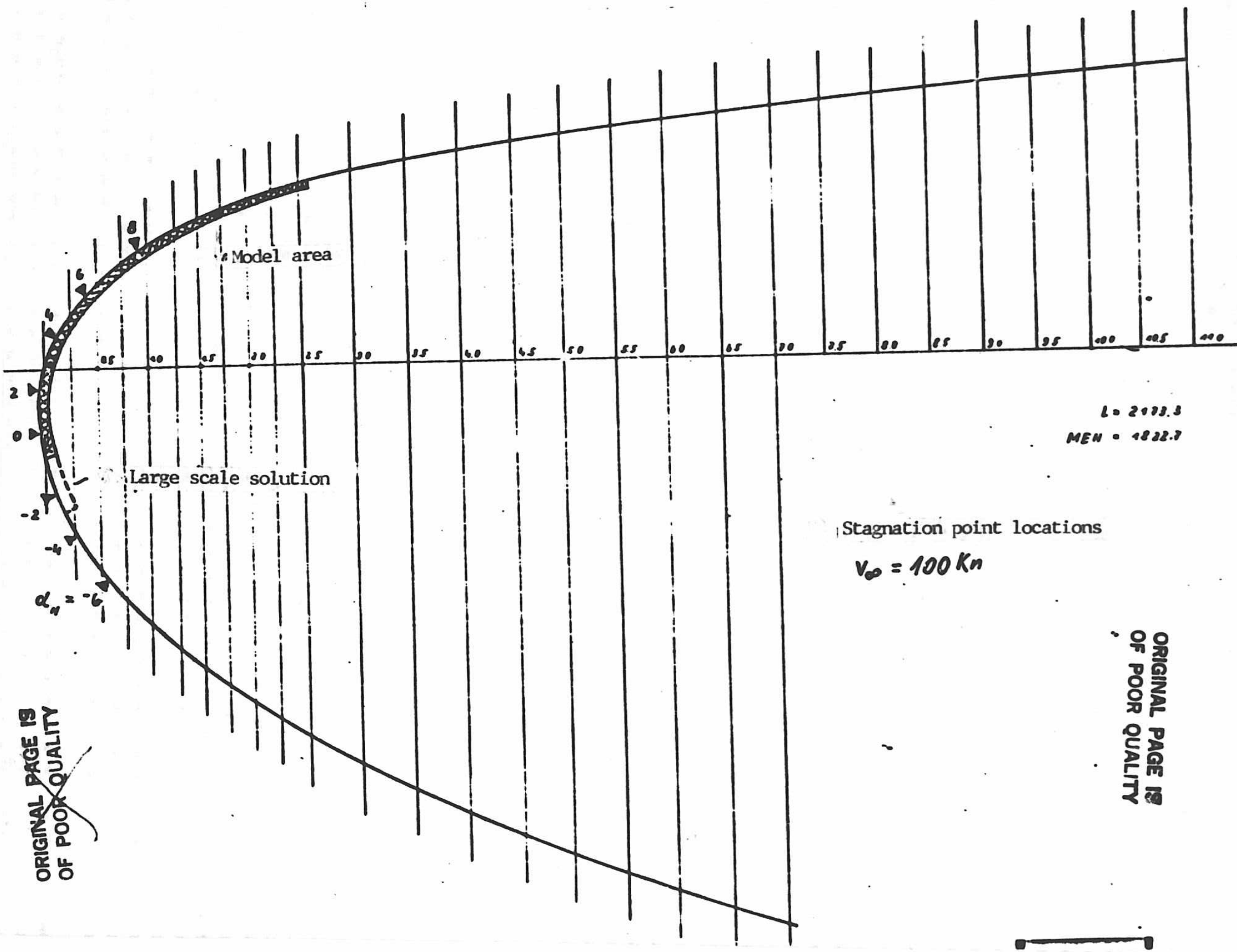


/44/

* Term MEH not defined in text-presumably refers tn max. de-icing level- transl.



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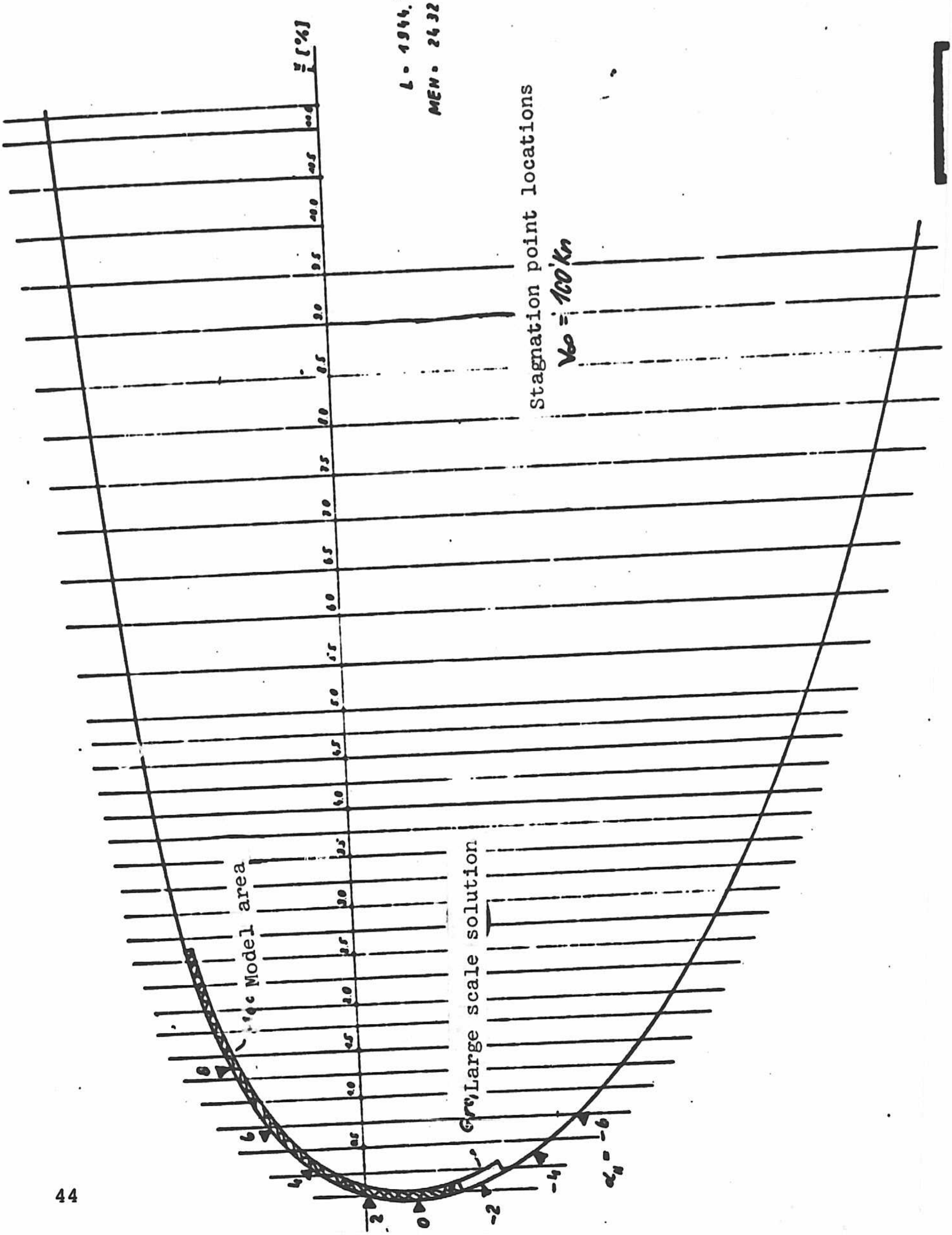
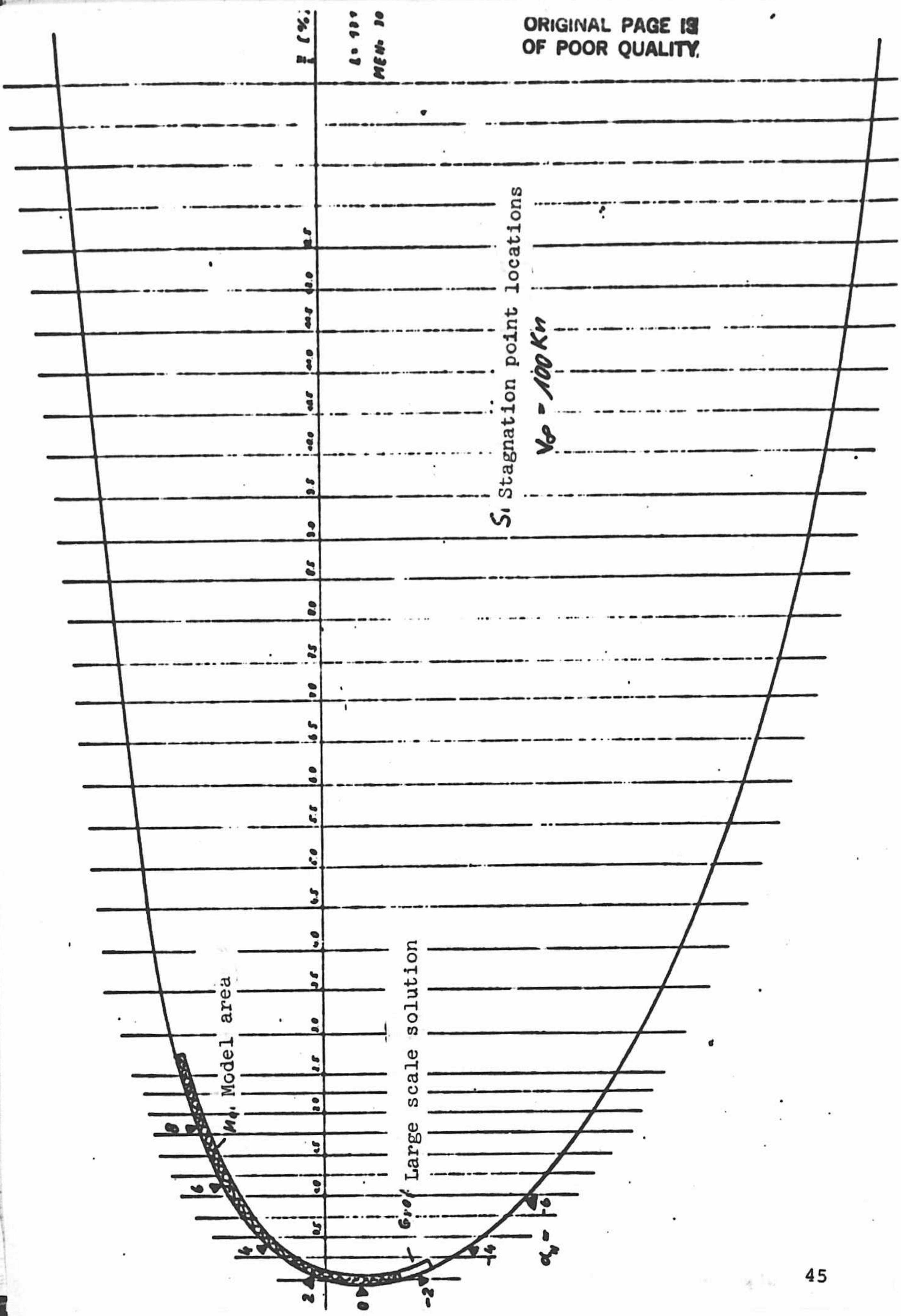
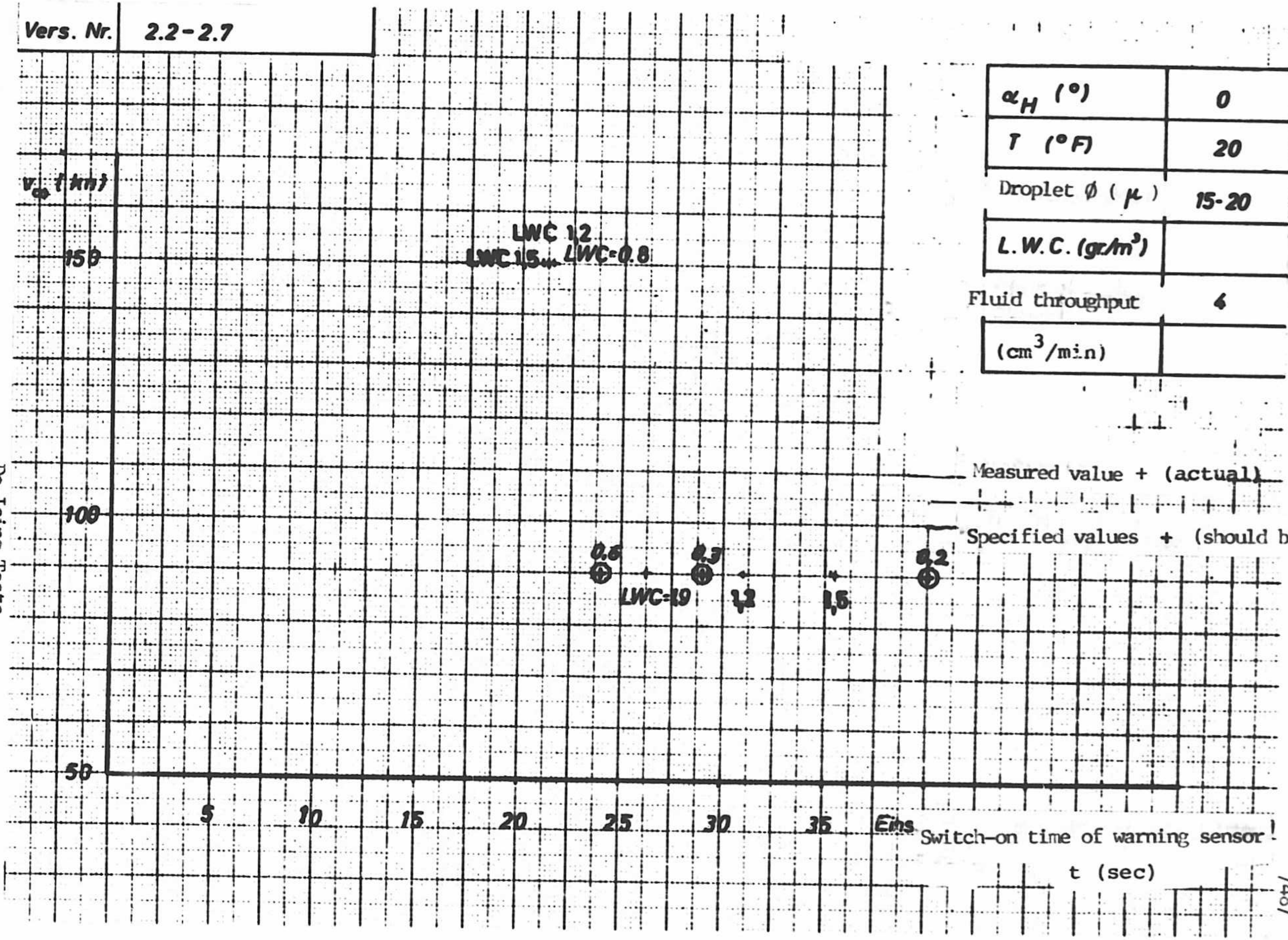

Stagnation point locations
$V_\infty = 100$ Km
Model area
Large scale solution
L = 1944.7
MEN. 2432
x [%]
2
0
-2
-4
-6
4
6
8


S1 Stagnation point locations
V∞ = 100 Kn
M1 Model area
Gro Large scale solution
8
6
4
2
0
-2
-4
-6
αg =

/48/

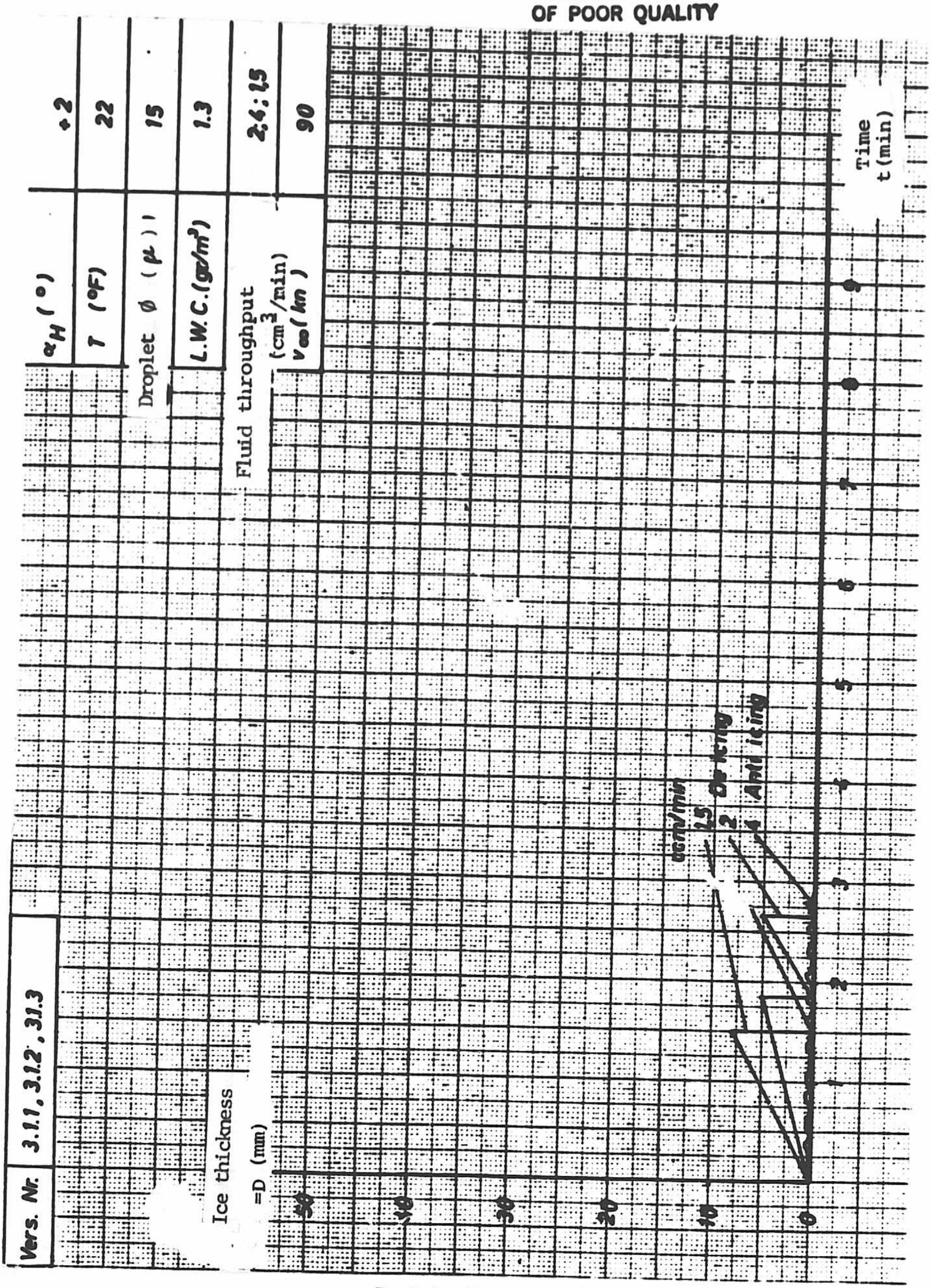
Vers. Nr.	2.2-2.7

α_H (°)	0
T (°F)	20
Droplet Ø (μ)	15-20
L.W.C. (gr/m³)	
Fluid throughput (cm³/min)	4



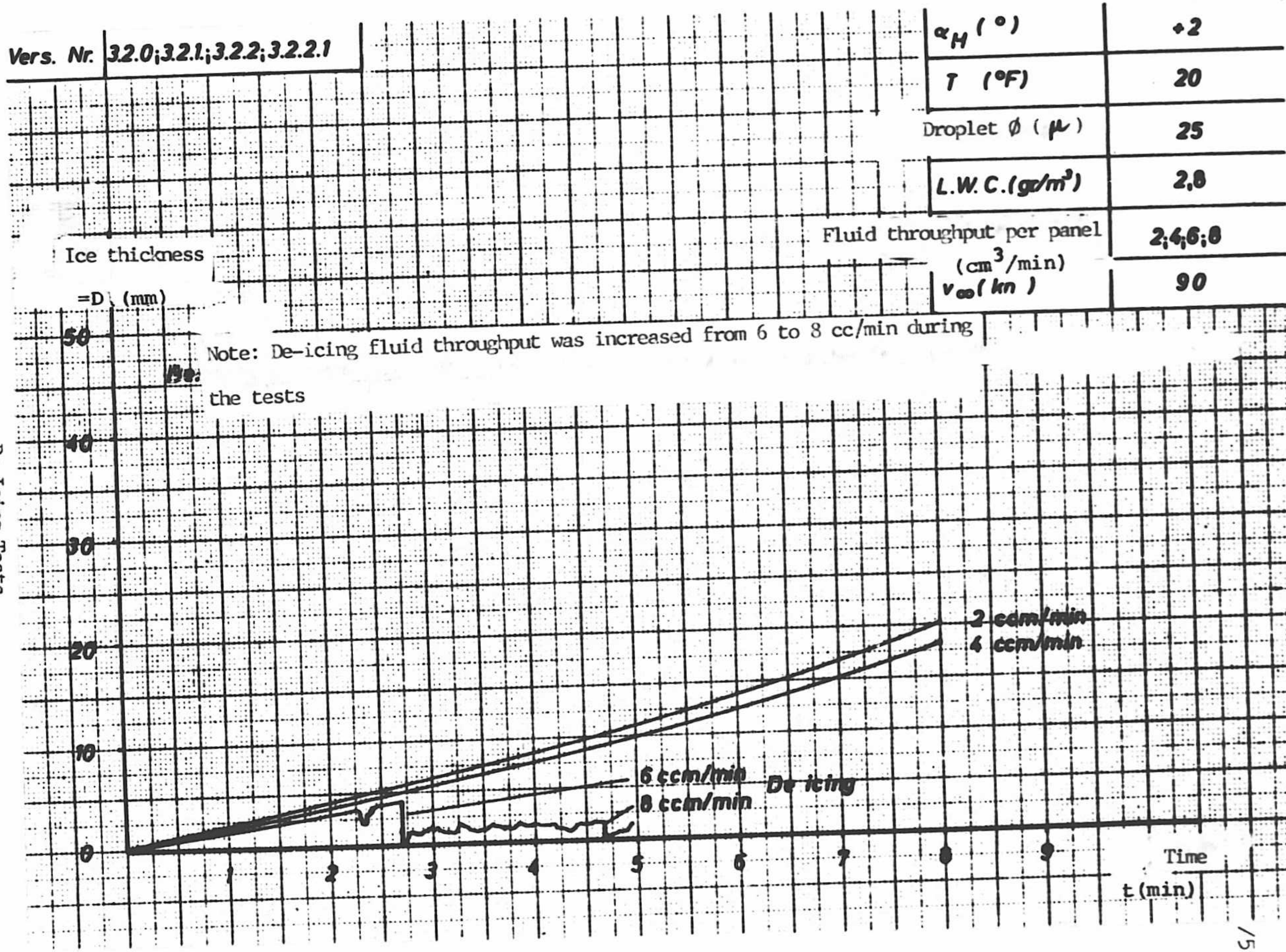
De-Icing Tests

/49/

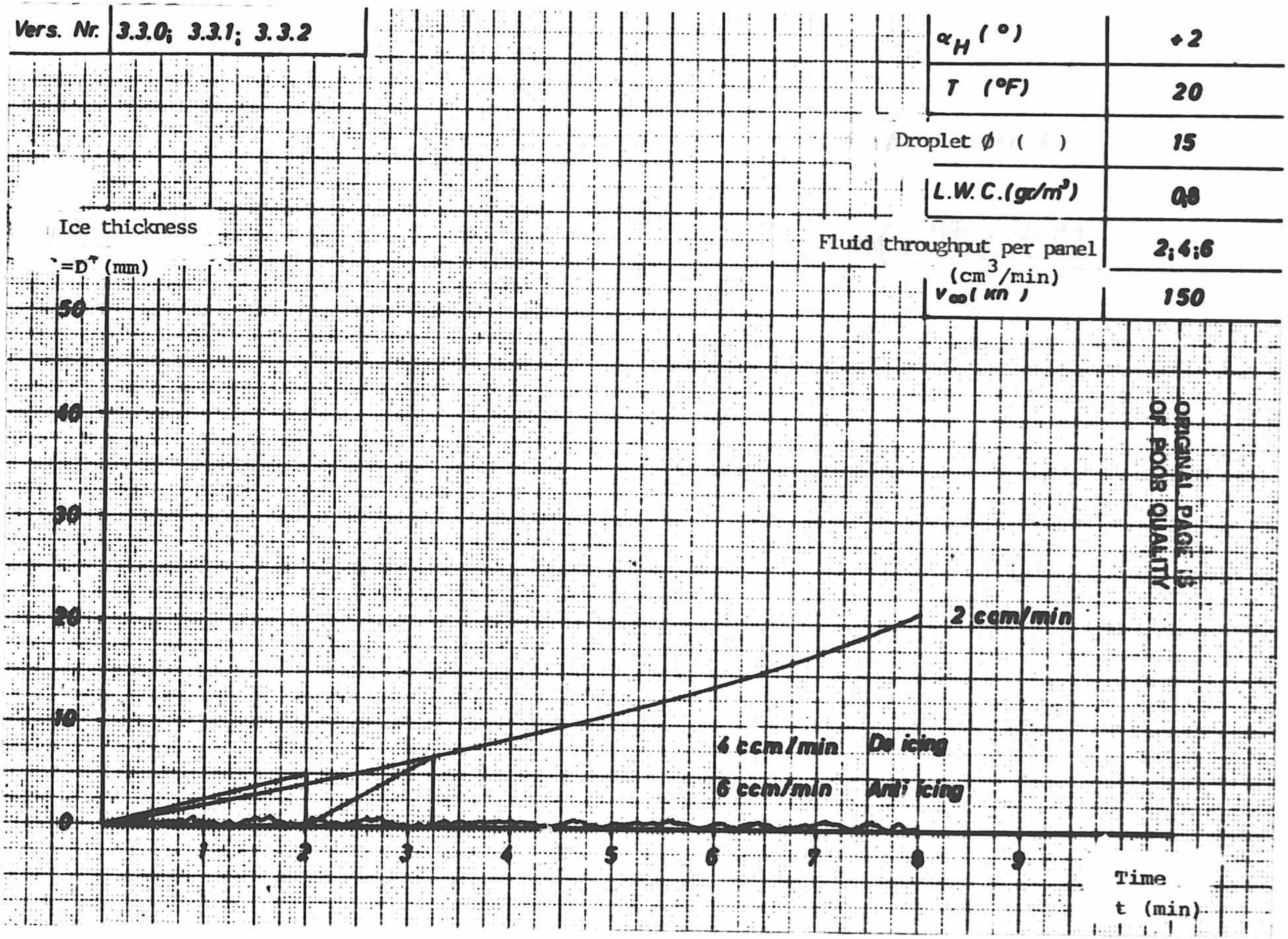


De-Icing Tests

/50/



De-Icing Tests



Vers. Nr. 3.3.0; 3.3.1; 3.3.2
α_H (°) +2
T (°F) 20
Droplet Ø ( ) 15
L.W.C. (gr/m³) 0,8
Fluid throughput per panel (cm³/min) 2; 4; 6
V_∞ (kn) 150
Ice thickness
=D* (mm)
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
Time
t (min)
2 ccm/min
4 ccm/min
De icing
6 ccm/min
Anti icing
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De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
3.3.0	+2	150	20	0.8	15	2

After 8 min.

After 10 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
3.3.1	+2	150	20	0.8	15	4

After 8 min.

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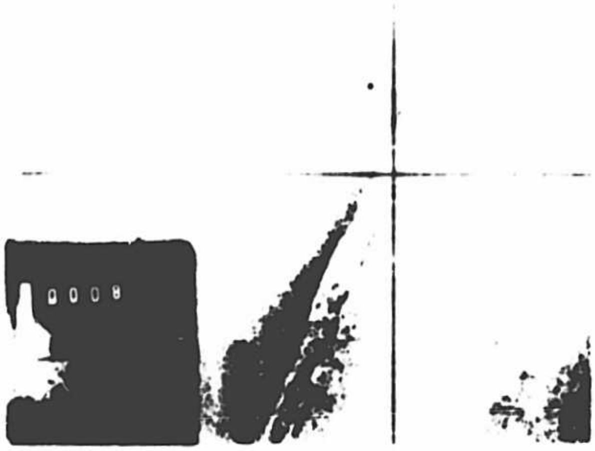
De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ⌀ [μ]	Fluid throughput [cm^3/min]
3.3.2	+2	150	20	0.8	15	6



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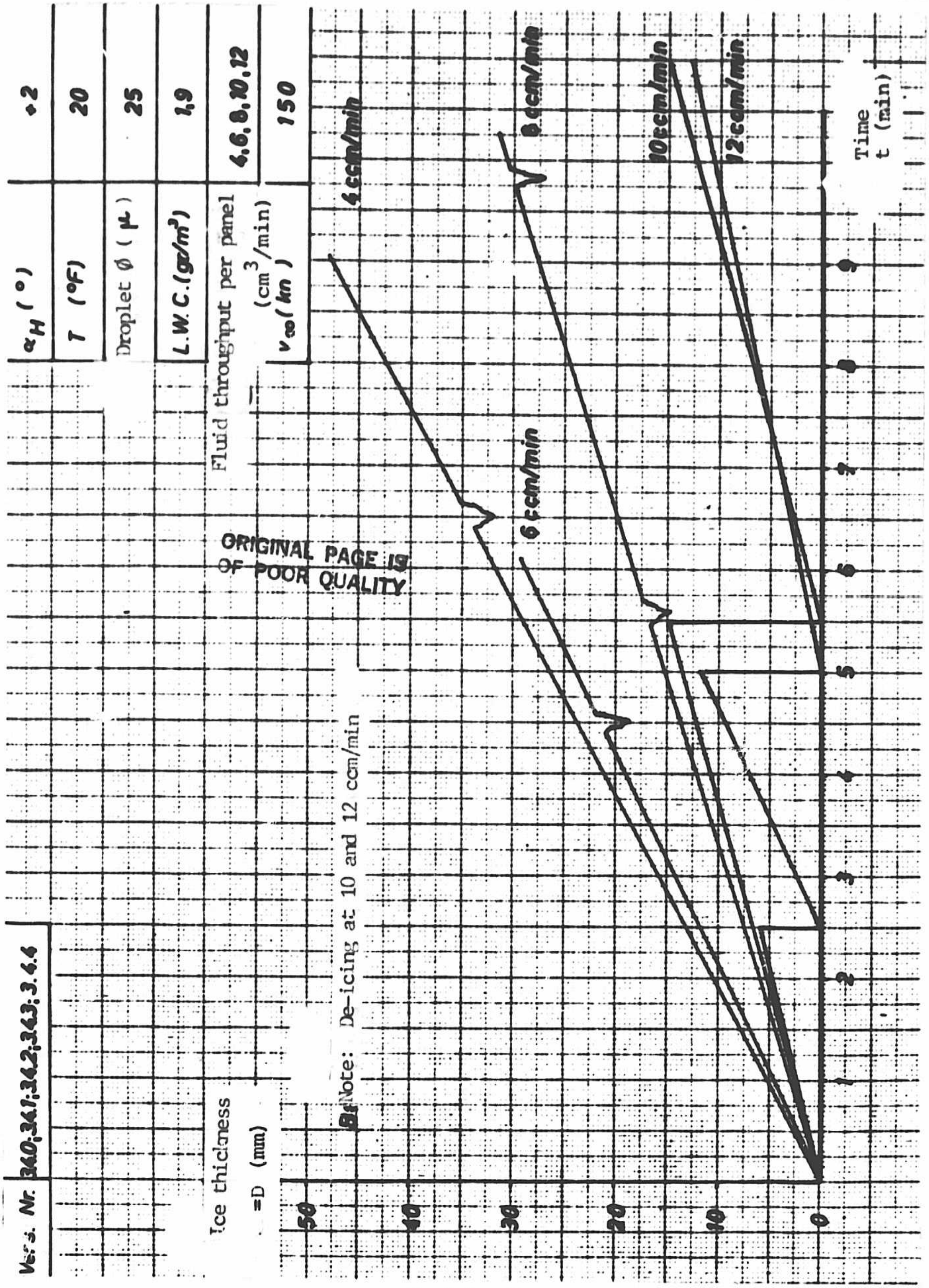
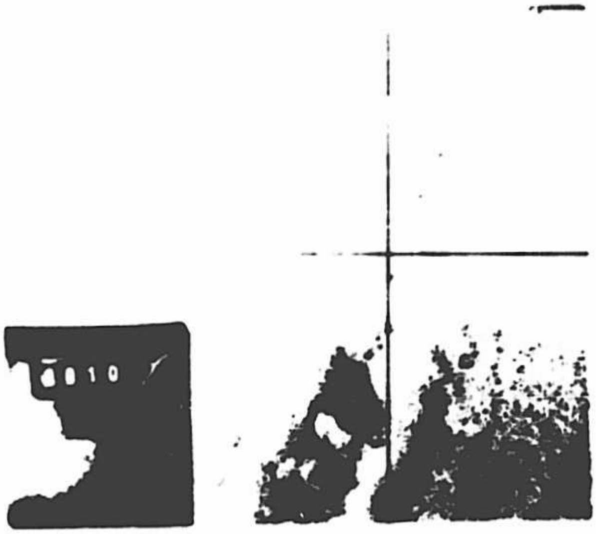
After 2 min.



De-Icing Tests

De-Icing Tests VFW 614

Test No.	Angle of attack α[°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
3.4.0	+2	150	20	1.9	25	4



After 9 min.

After 13 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α[°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
3.4.1	+2	150	20	1.9	25	6

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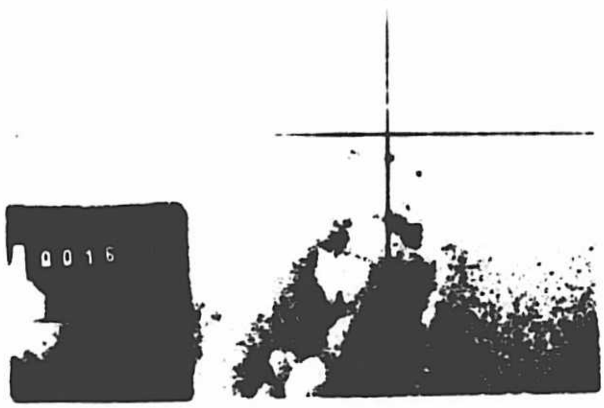
After 10.5 min.



After 15 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
3.4.2	+2	150	20	1.9	25	8

After 6 min.

After 12 min.
(without spray)

De-Icing Tests VFW 614

Test No.	Angle of attack α[°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
3.4.2	+2	150	20	1.9	25	10

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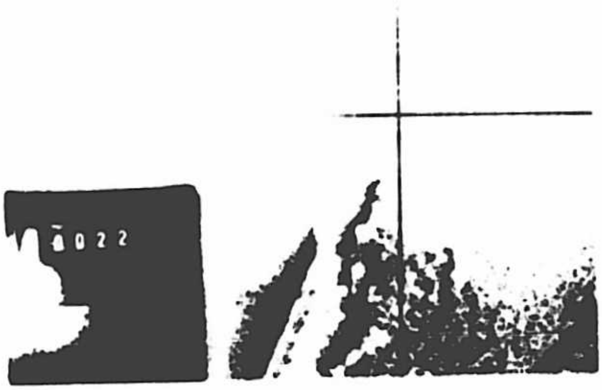
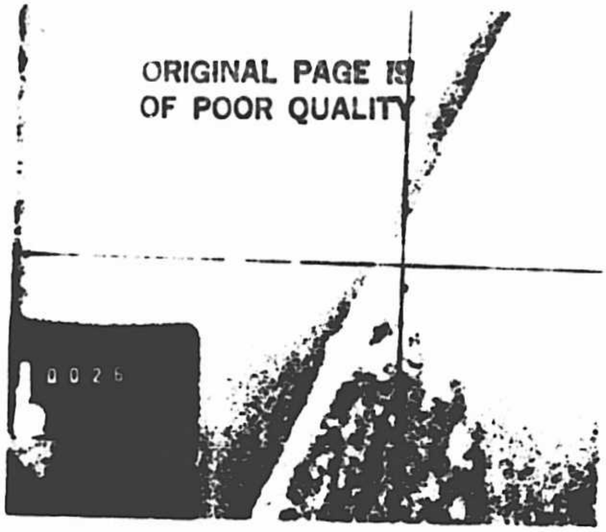


After 6 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
3.4.4	+2	150	20	1.9	25	12

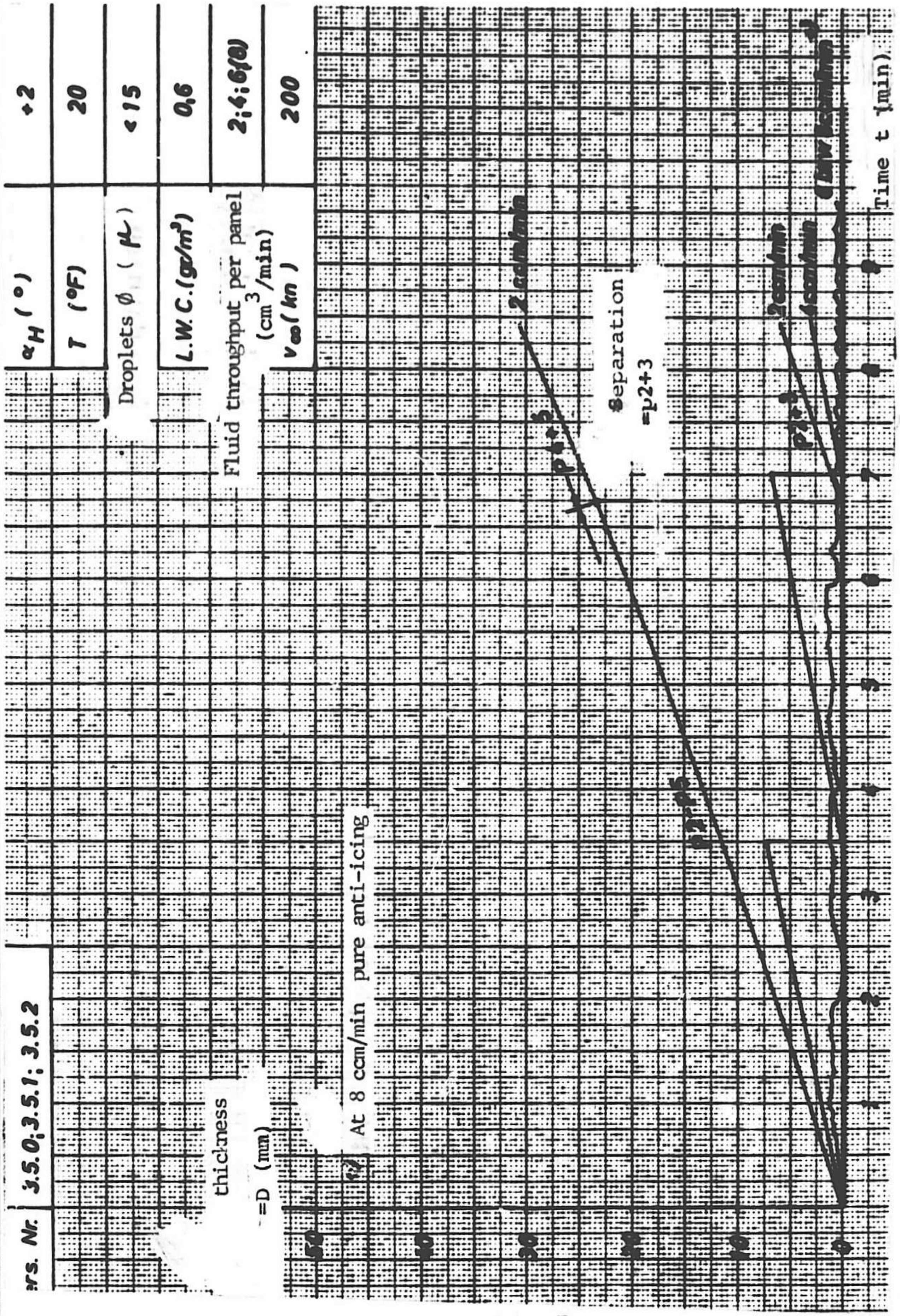
After 6 min.



After 14 min.

After 19 min.

/62/



De-Icing Tests

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De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
3.5.0	+2	200	20	0.6	15	2

After 6 min.

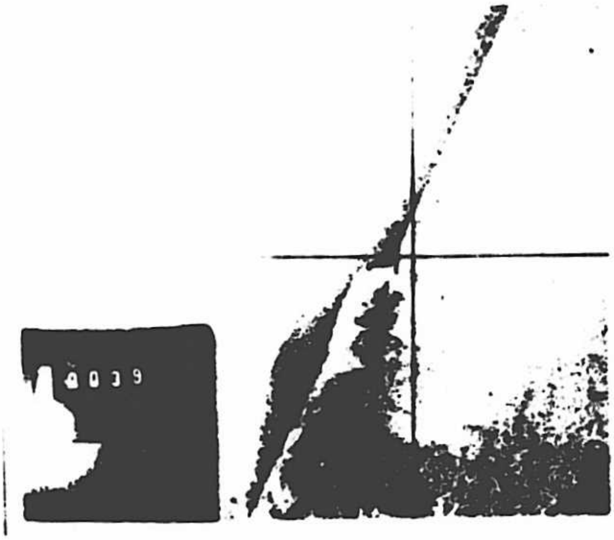
After 12 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
3.5.1	+2	200	20	0.6	15	4

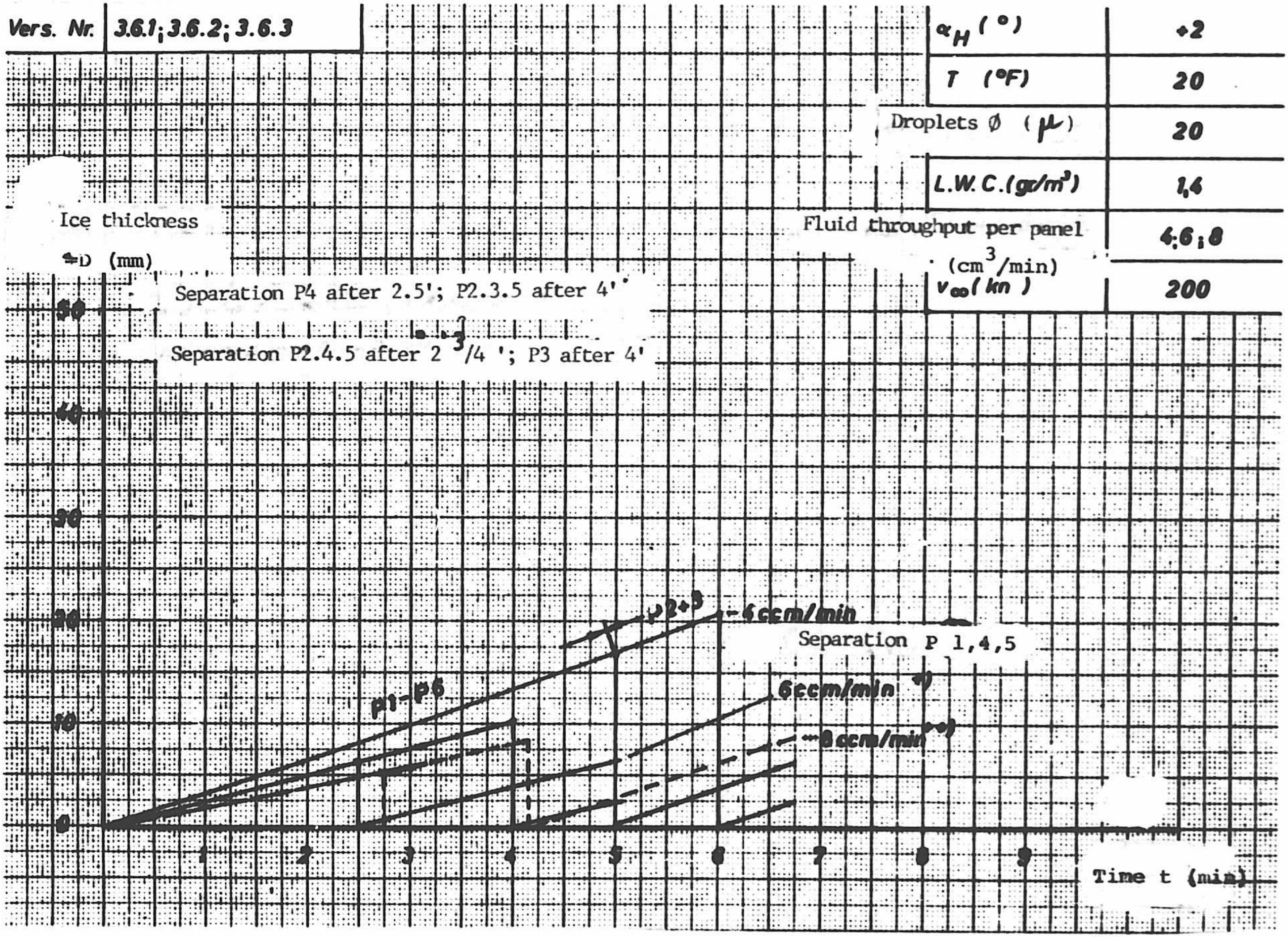
After 0 min.

After 4.5 min.



After 7.5 min.

/65/



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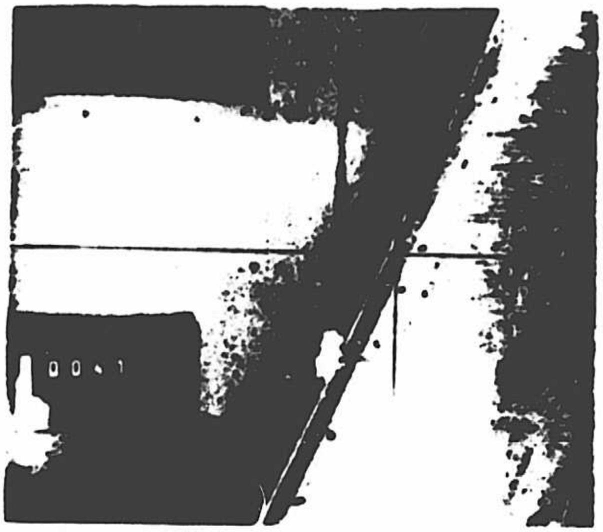
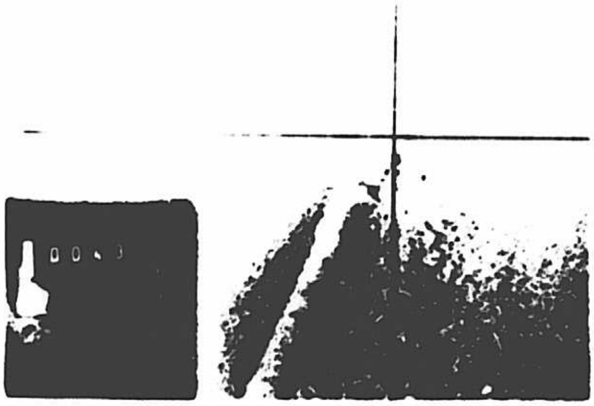
De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
3.6.1	+2	200	20	1.4	20	4



After 0.5 min.

After 6.5 min.



After 4 min.

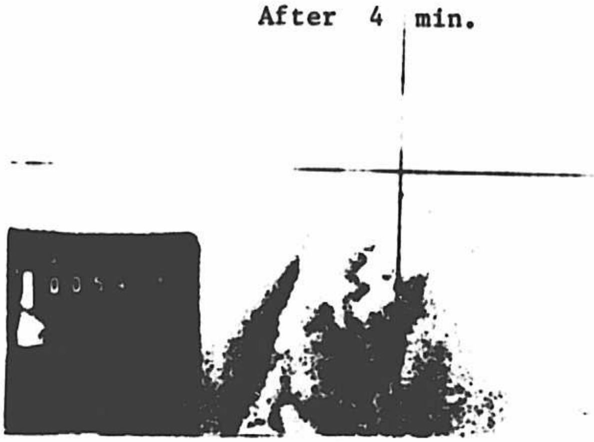
De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
3.6.2	+2	200	20	1.4	20	6

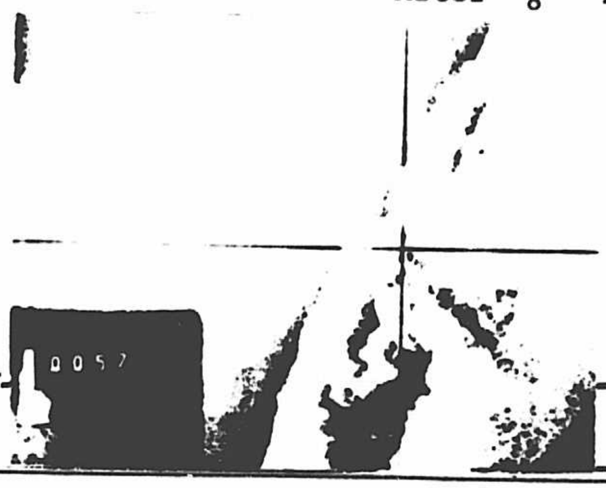
After 2 min.

After 4 min.

After 6 min.



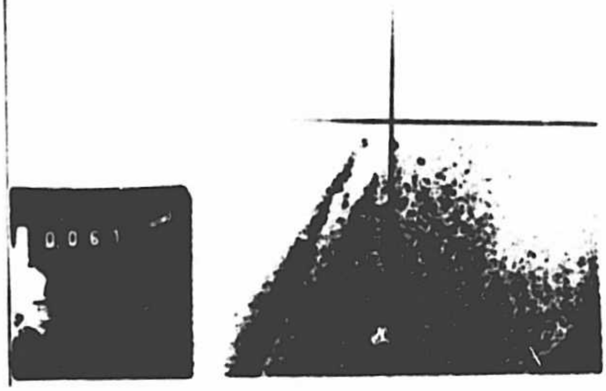
After 8 min.



After 8 min.
(without spray)

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
3.6.3	+2	200	20	1.4	20	8

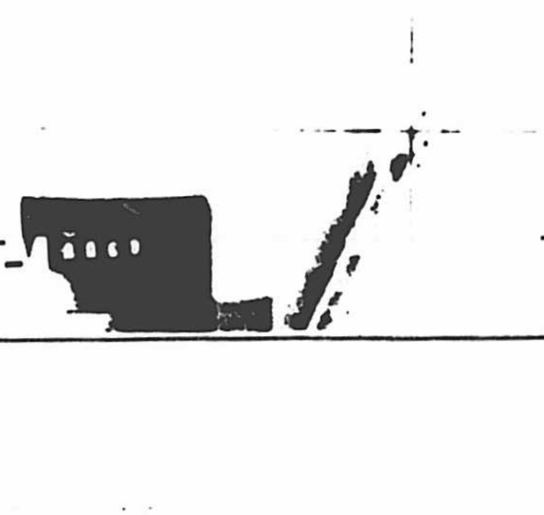


After 2 min.

After 4 min.

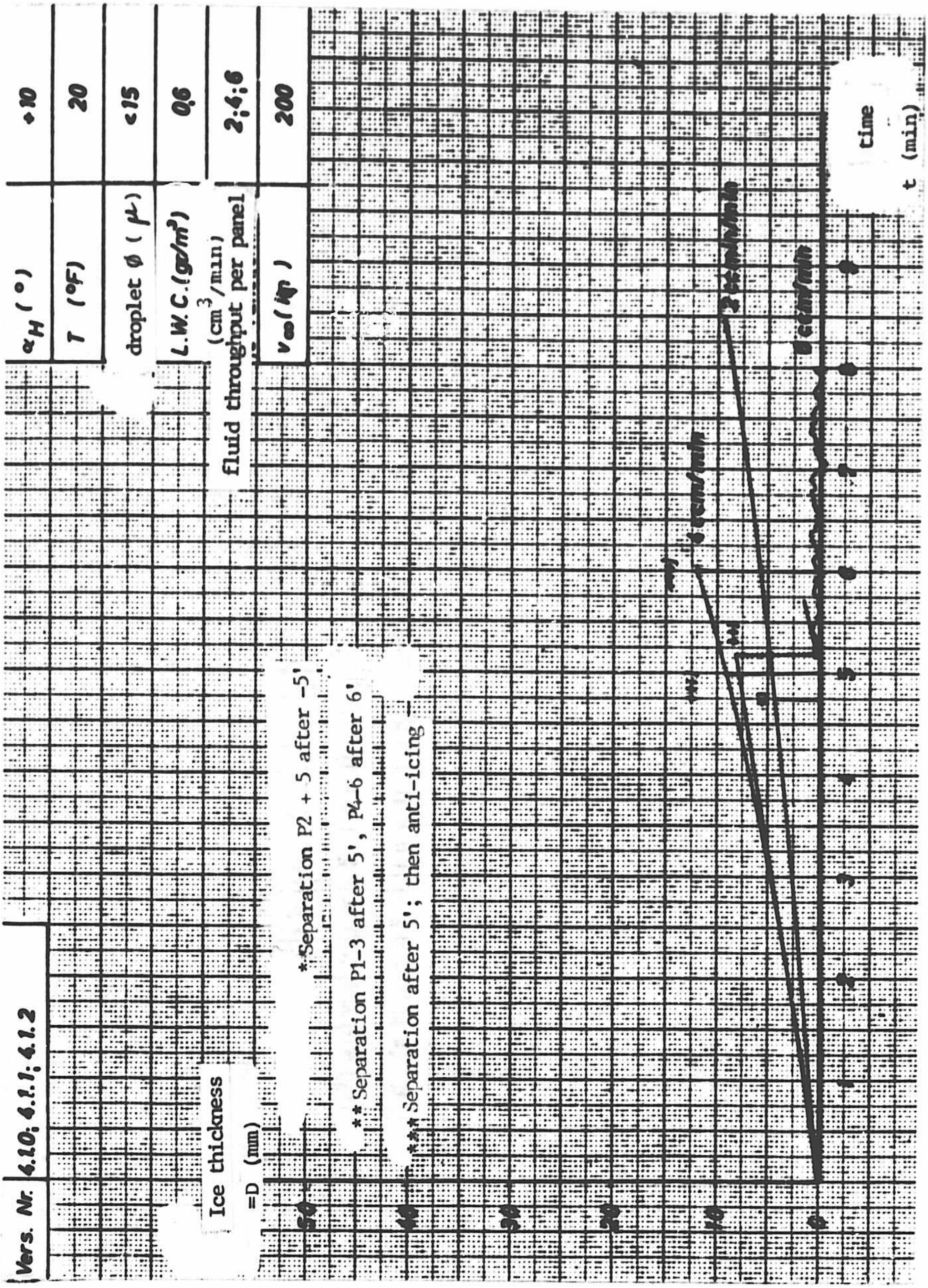
After 6 min.

After 6.5 min.
(without spray)



Deicing(partly)

/69/



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De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
4.1.0	+10	200	20	0.6	15	2

After 7 min.

After 9 min. deiced

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
4.1.1	+10	200	20	0.6	15	4

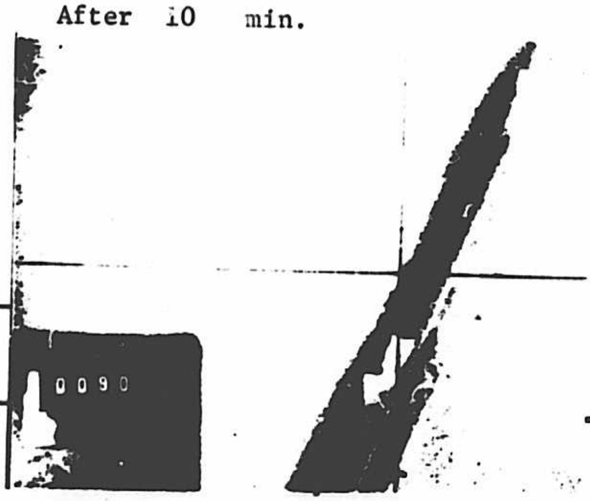
After 0 min.

After 2 min.

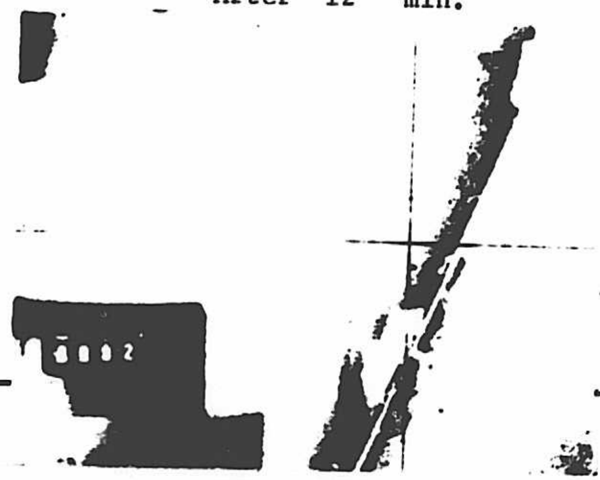
After 3.5 min.

After 4.5 min.

After 10 min.

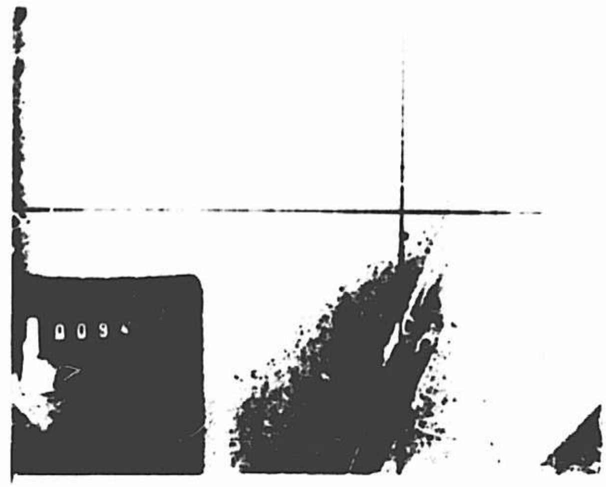


After 12 min.

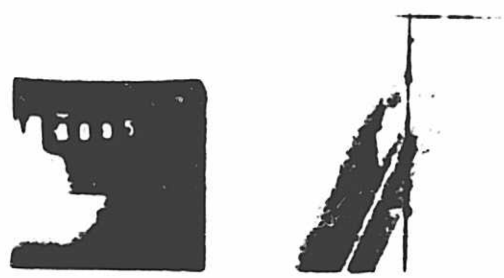


De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
4.1.2	10	200	20	0.6	15	6



After 2 min.

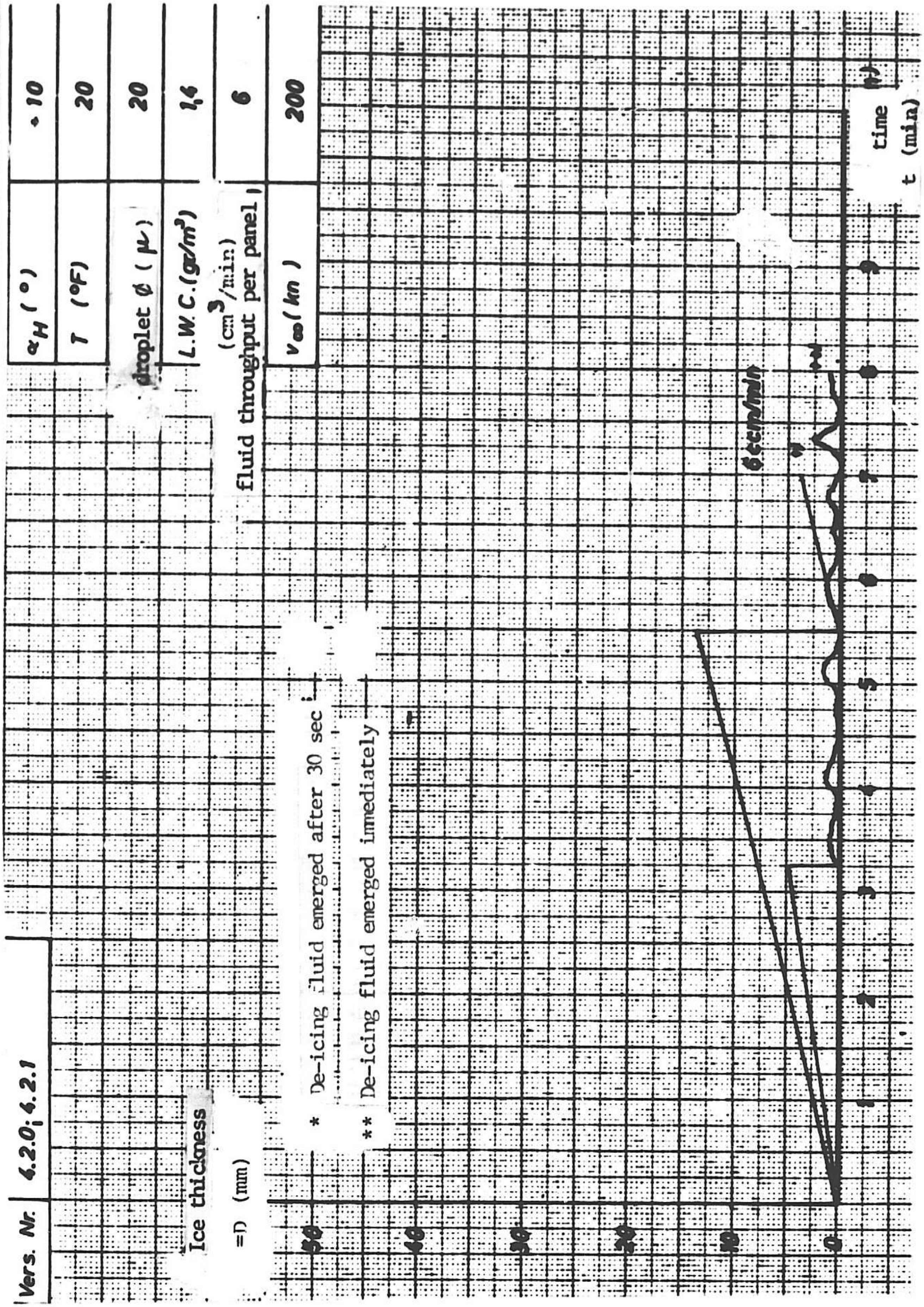


After 4 min.

After 6 min.

After 7.5 min.

/73/



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De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
4.2.0	10	200	20	1.4	20	6

After 2 min.

After 4 min.

After 6 min.

After 7 min

After 8 min.

De-Icing Tests VFW 614

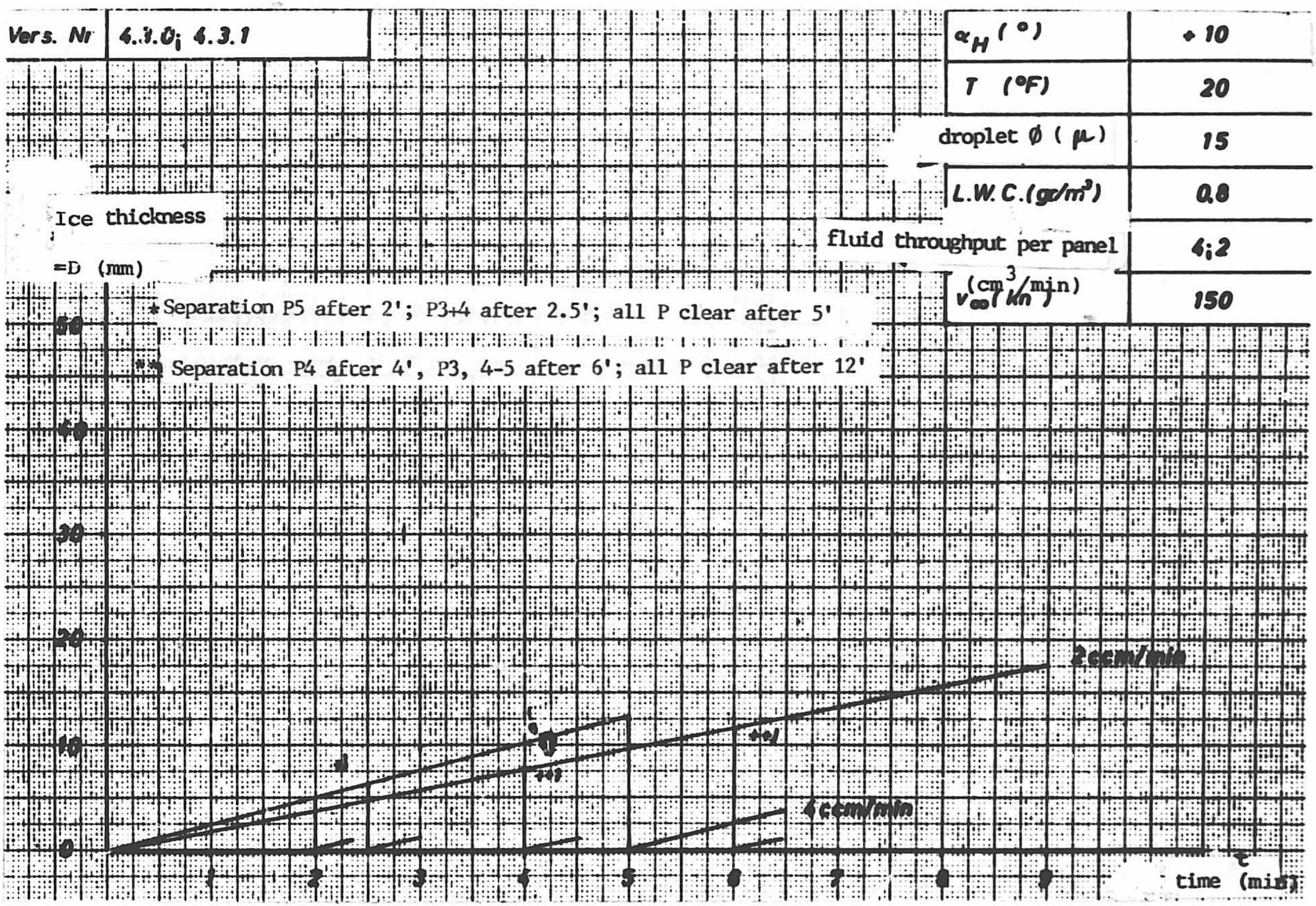
Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
4.2.1	10	200	20	1.4	20	6

After 2 min.

After 4 min.

After 6 min.

After 8 min.


Vers. Nr
4.3.0; 4.3.1
α_H (°)
+ 10
T (°F)
20
droplet Ø (µ)
15
L.W.C.(gr/m³)
0.8
fluid throughput per panel
4;2
v_∞ (cm³/min)
150
Ice thickness
=D (mm)
* Separation P5 after 2'; P3+4 after 2.5'; all P clear after 5'
** Separation P4 after 4', P3, 4-5 after 6'; all P clear after 12'
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
2 ccm/min
4 ccm/min
time (min)

/76/

De-Icing Tests VFW 614

Test No.	Angle of attack α[°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
4.3.0	10	150	20	0.8	15	4

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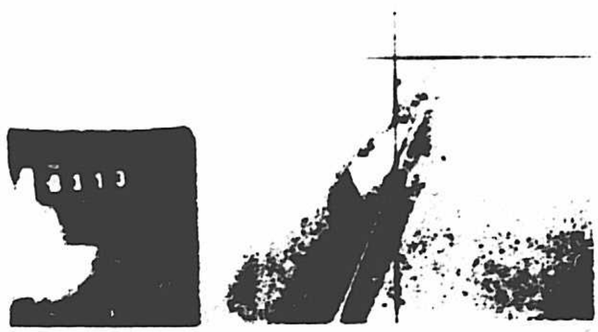
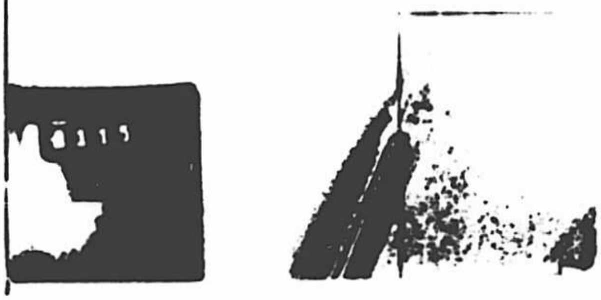
After 2 min.



After 8.5 min.

De-Icing Tests VFW 614

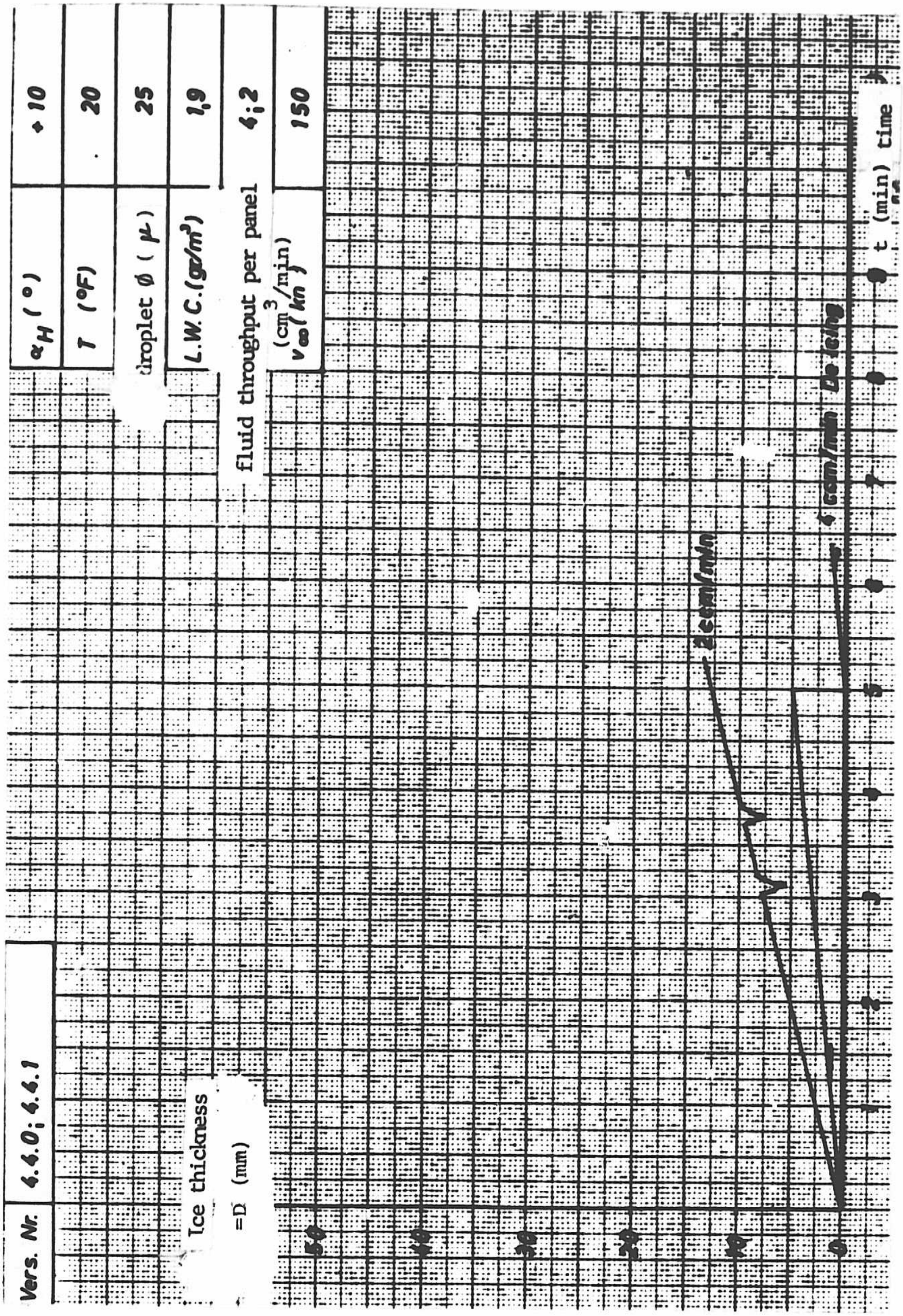
Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
4.3.1	10	150	20	0.8	15	2



After 2 min.

After 5 min.

/79/



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De-Icing Tests

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
4.4.0	10	150	20	1.9	25	4

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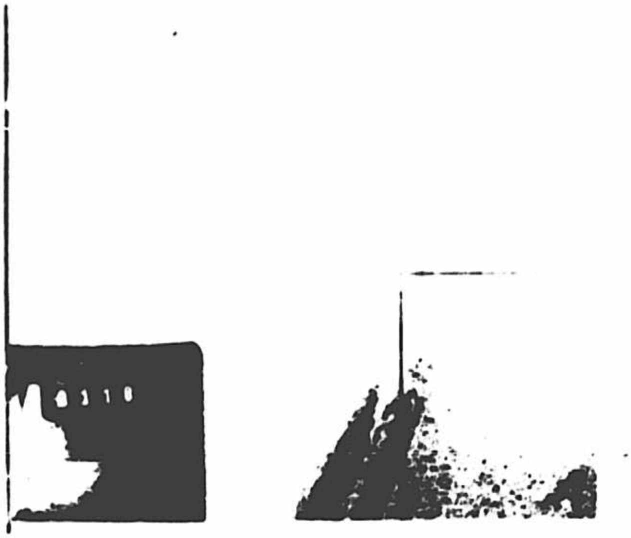


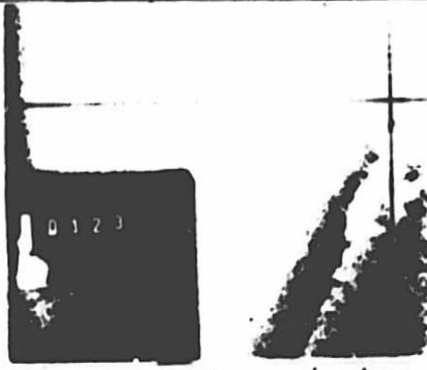
After 2 min.

After 6 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
4.4.1	10	150	20	1.9	25	2

After 2 min.

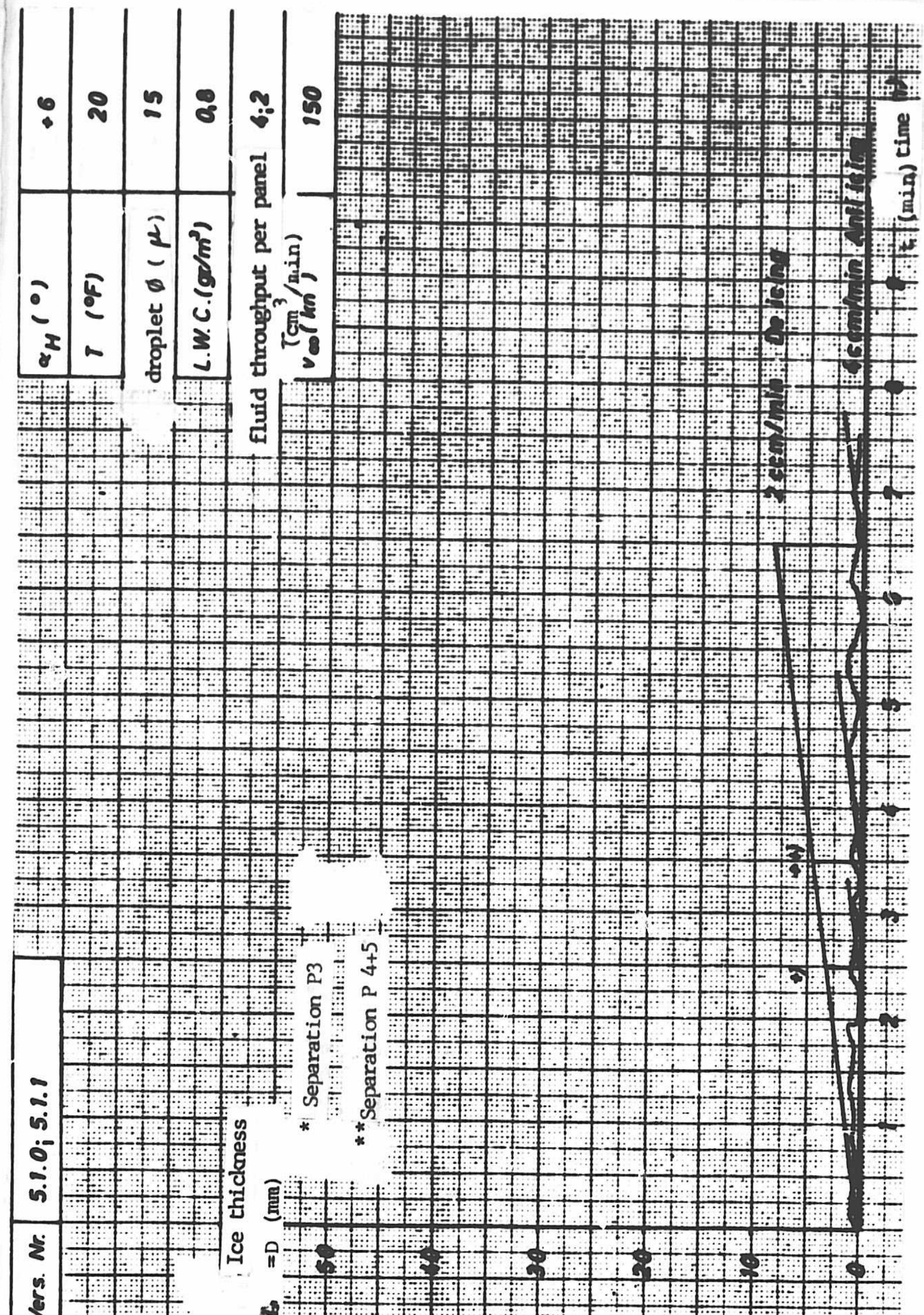


After 4 min.

After 6 min.

After 6 min.

After 6.5 min.



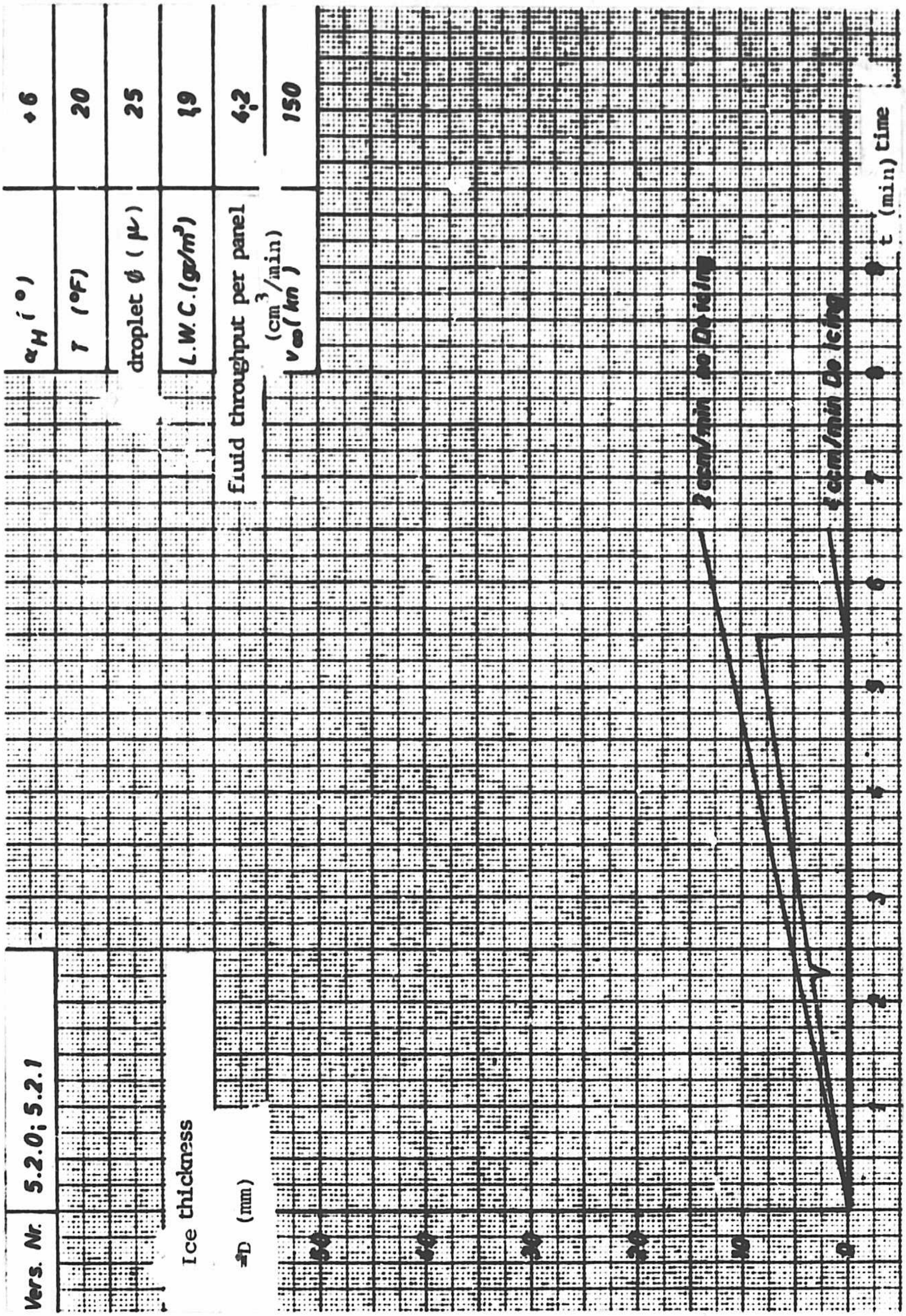
De-Icing Tests

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
5.1.1	6	150	20	0.8	15	2

After 2 min.

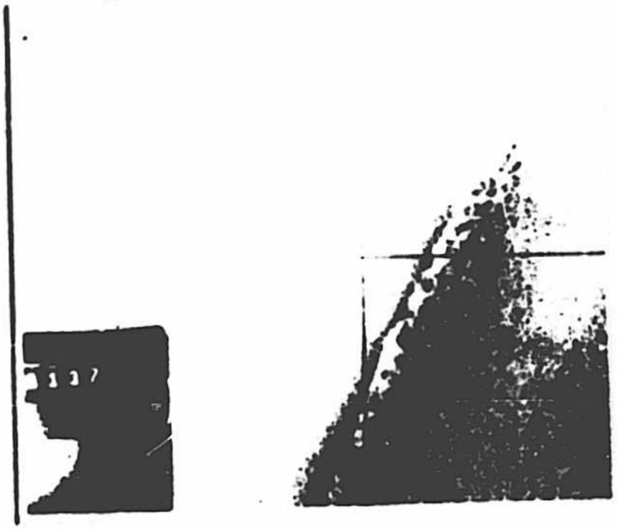
After 7 min.



De-Icing Tests

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
5.2.0	6	150	20	4.9	2.5	4

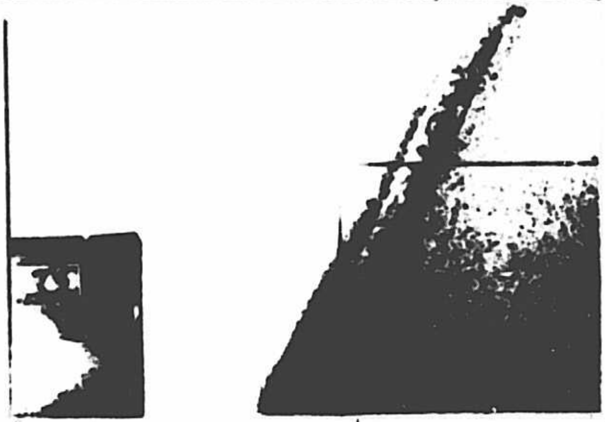


After 3 min.

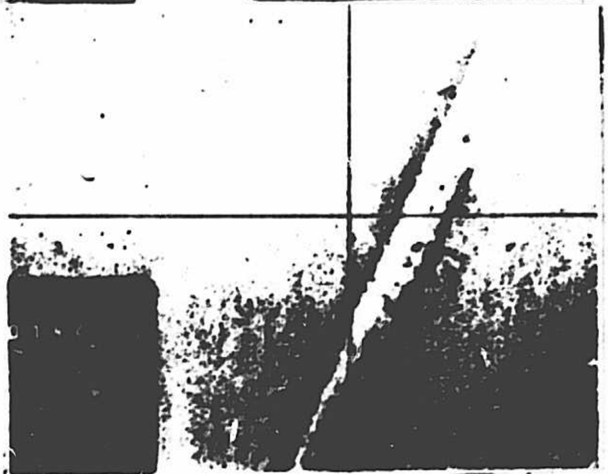
After 6 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α[°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
5.21	6	150	20	1.9	25	2



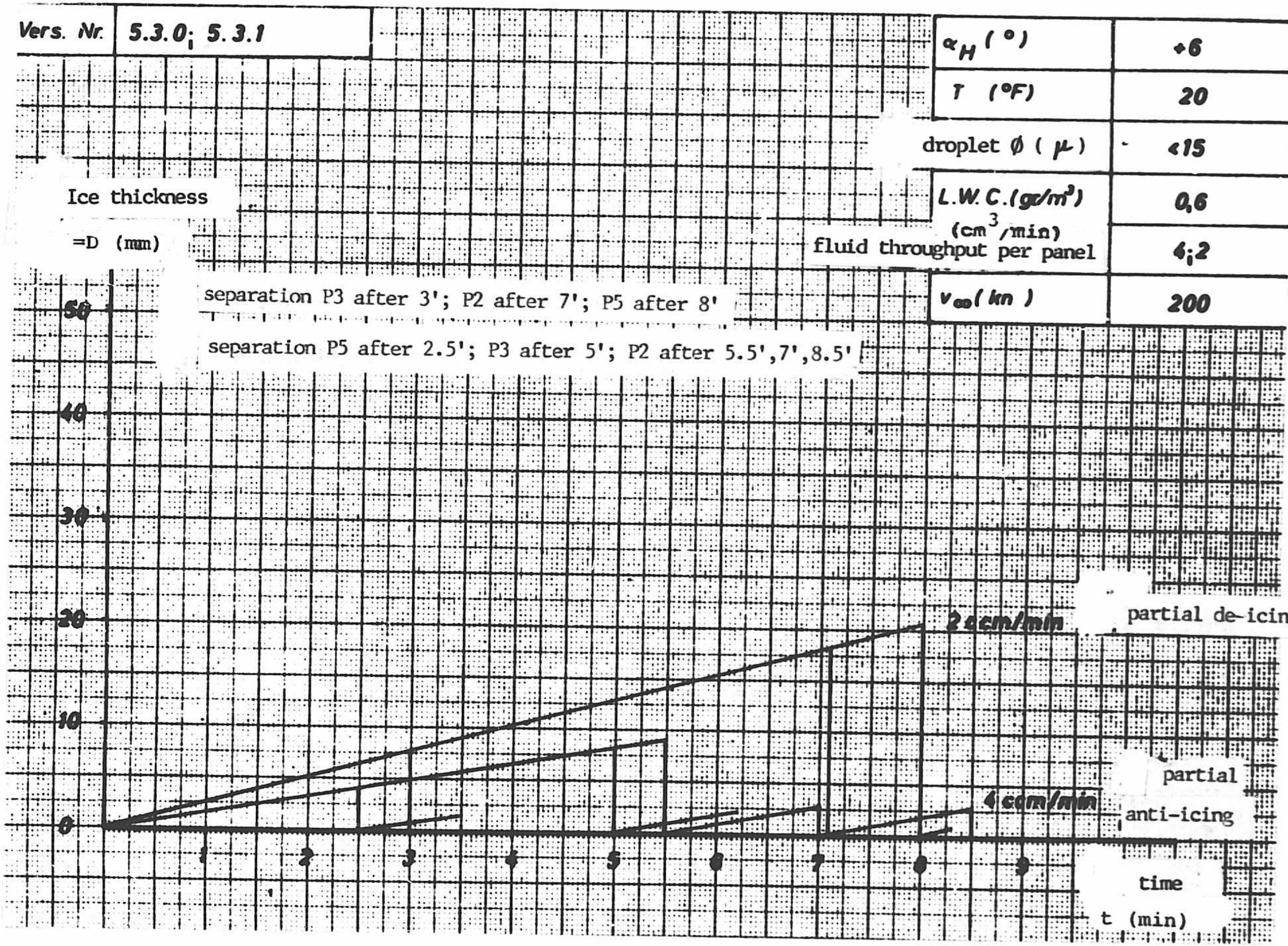
After 2 min.



After 4 min.

After 6 min.

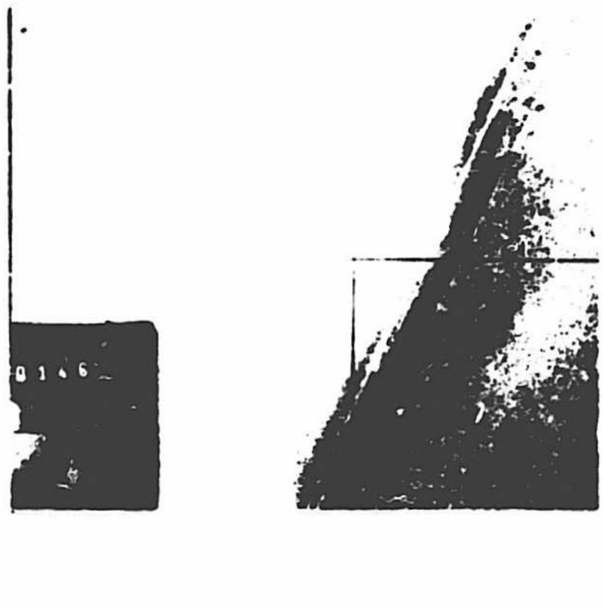
/87/


Vers. Nr. 5.3.0; 5.3.1
α_H (°) +6
T (°F) 20
droplet Ø (μ) <15
L.W.C.(gr/m³) 0,6
(cm³/min) fluid throughput per panel 4;2
v_∞(km) 200
Ice thickness
=D (mm)
separation P3 after 3'; P2 after 7'; P5 after 8'
separation P5 after 2.5'; P3 after 5'; P2 after 5.5',7',8.5'
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
2 ccm/min
partial de-icing
4 ccm/min
partial
anti-icing
time
t (min)

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet φ [μ]	Fluid throughput [cm³/min]
5.3.0	6	200	20	0.6	15	4

After 2 min.



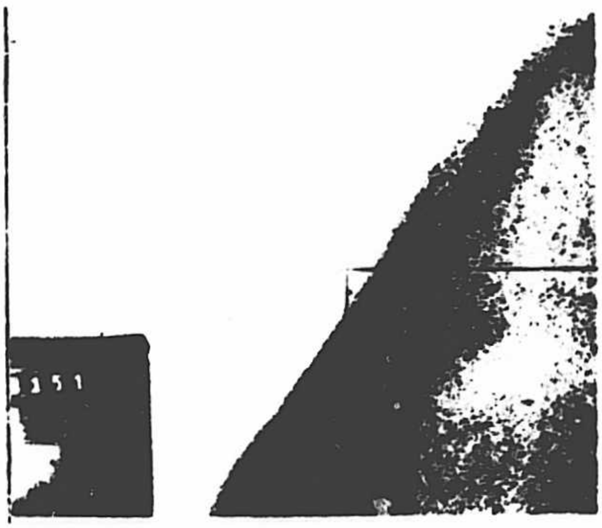
After 4 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α[°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
5.3.1	6	200	20	0.6	15	2

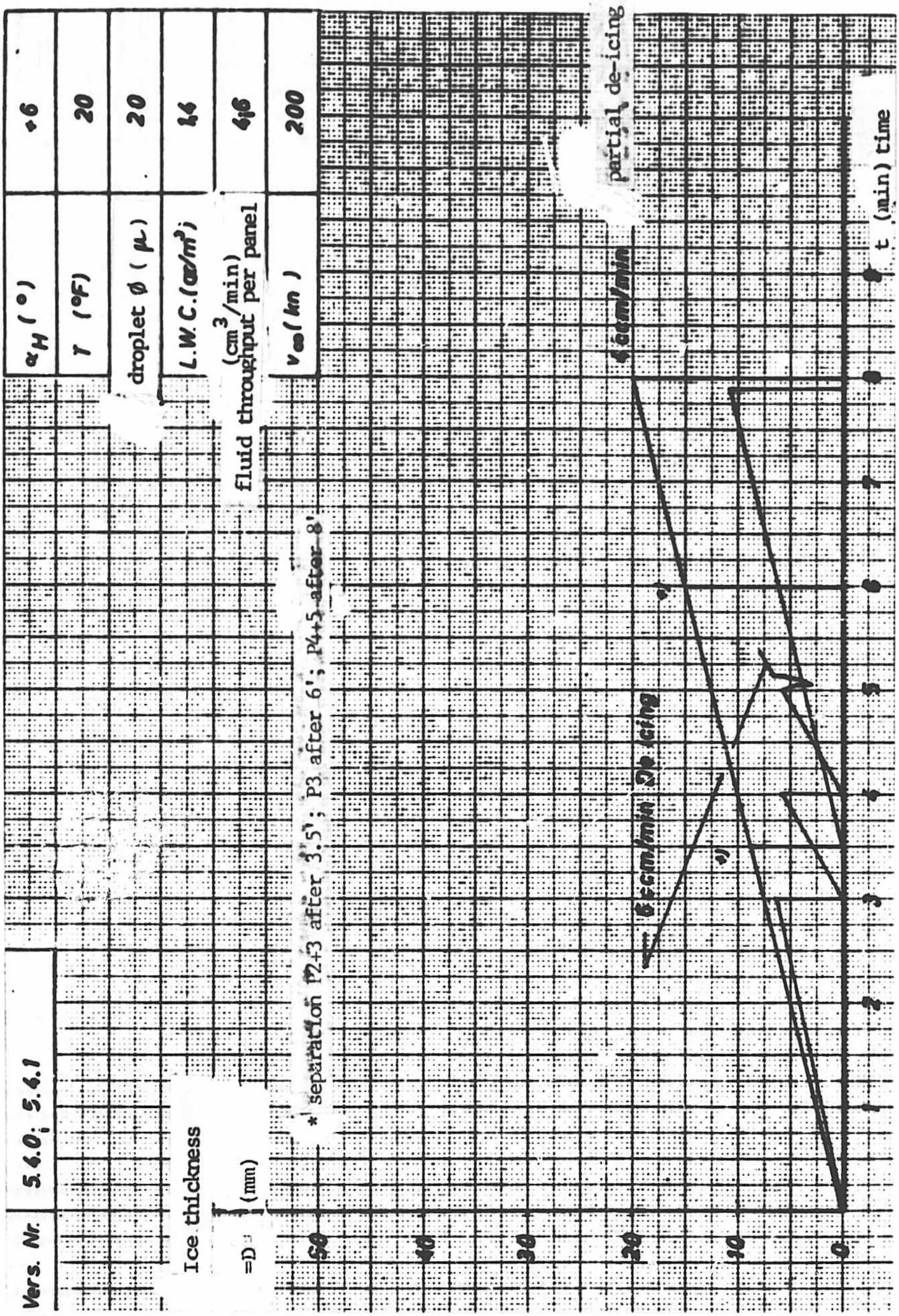
After 2 min.

After 6 min.



After 10 min.

After 12 min.



/90/

De-Icing Tests

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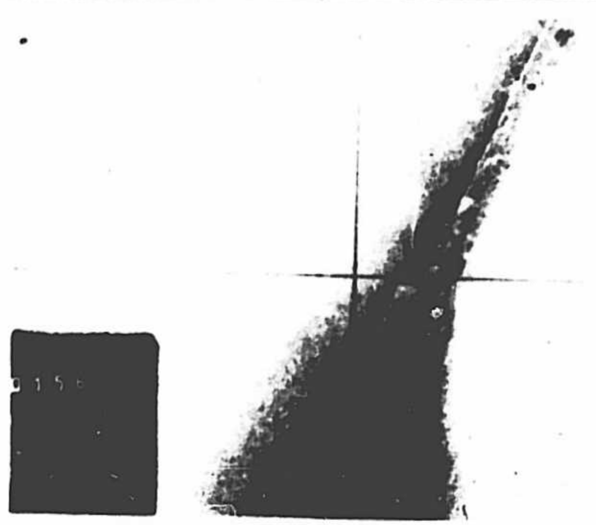
De-Icing Tests VFW 614

Test No.	Angle of attack α[°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
5.4.0	6	200	20	1.4	20	4

After 2 min.



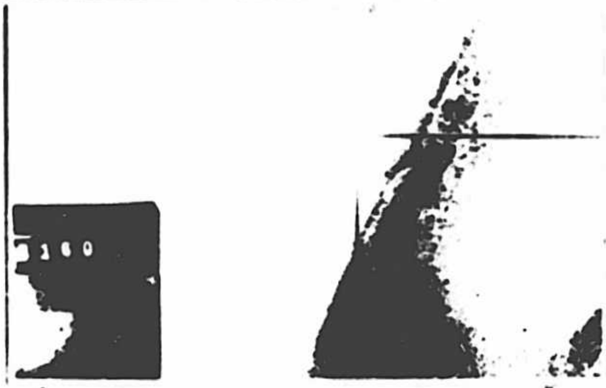
After 4 min

After 6 min.

After 8 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
5.4.1	6	200	20	1.4	20	6

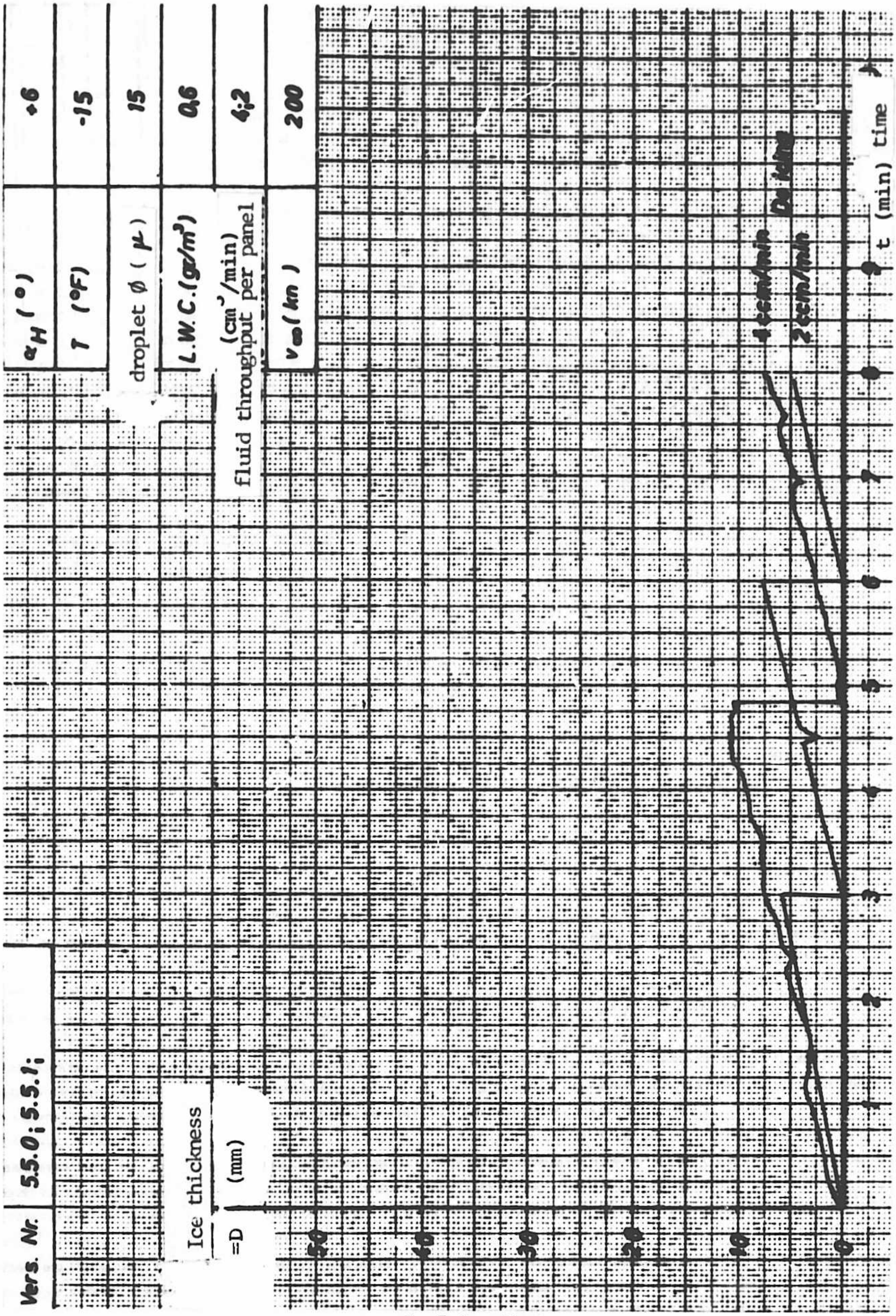


After 2.5 min.

After 4 min.

After 8 min.

/93/



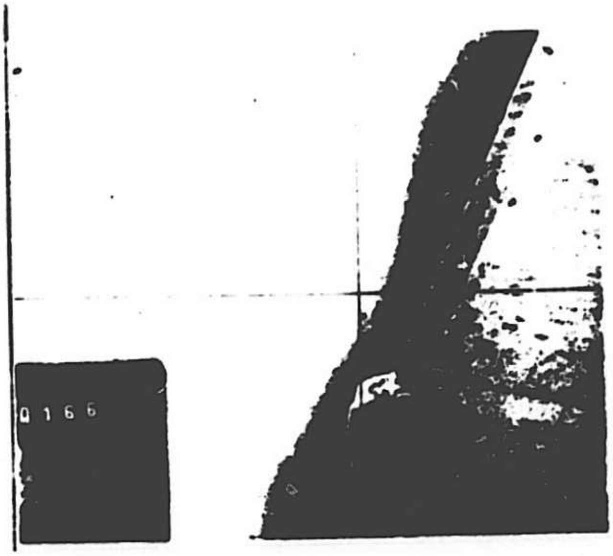
De-Icing Tests

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ⌀ [μ]	Fluid throughput [cm^3/min]
5.5.0	6	200	-15	0.6	15	4

After 1 min.

After 3 min.



After 8.5 min.

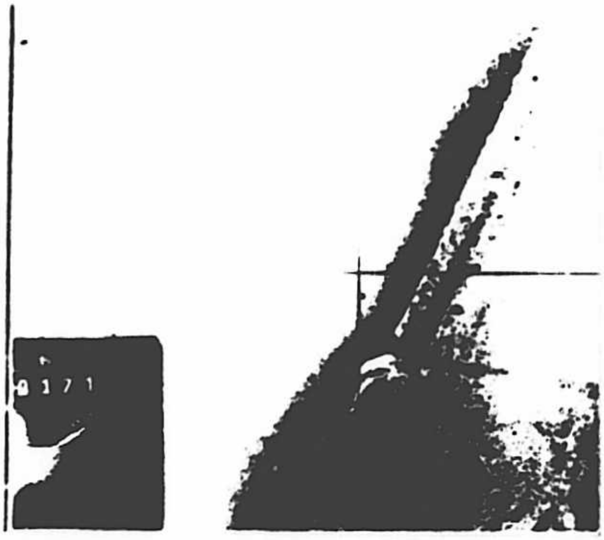
After 9 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α[°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
5.5.1	6	200	-15	0.6	15	2

After 2 min.

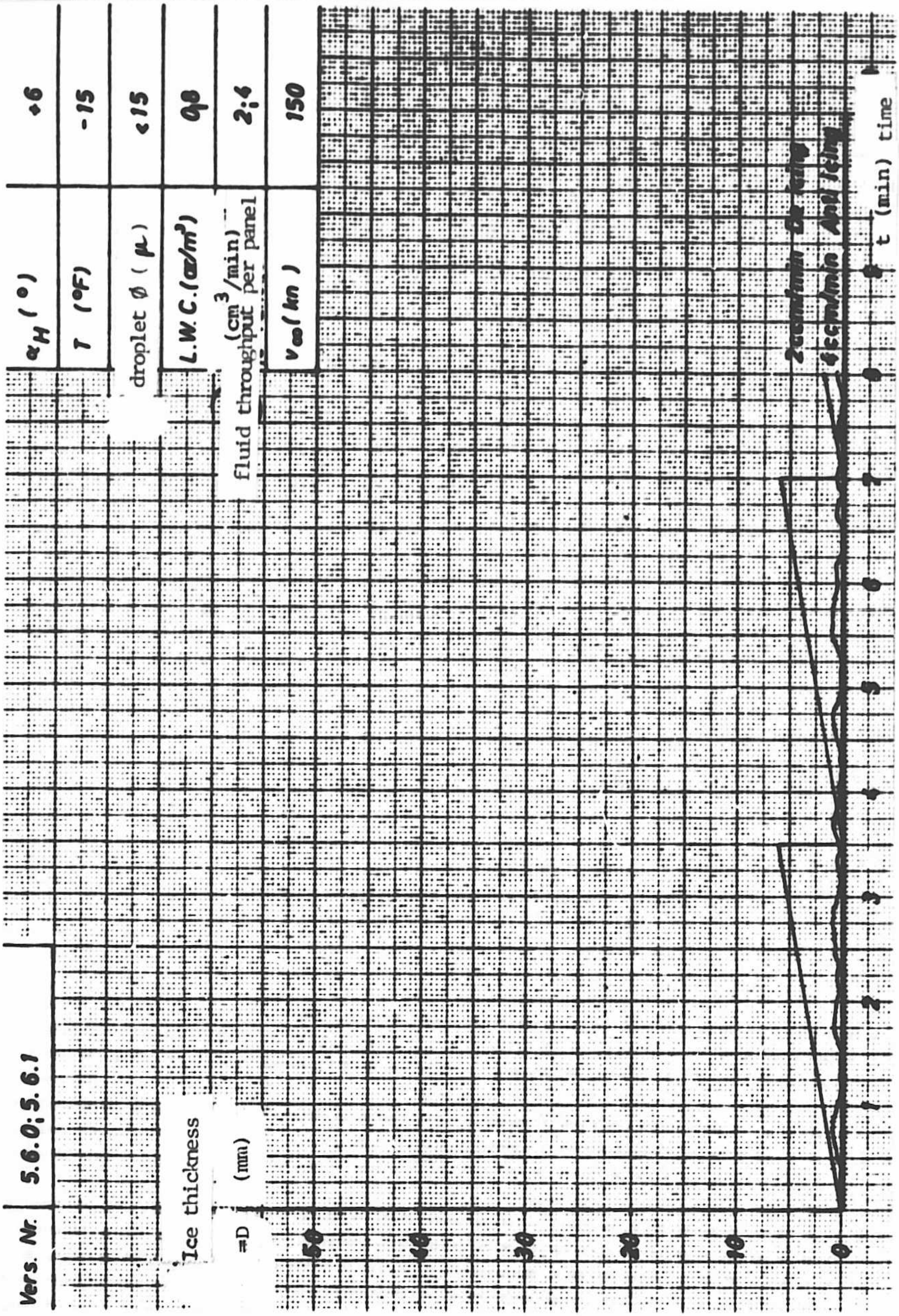
After 4 min.



After 7 min.

After 8.5 min.

/96



De-Icing Tests

De-Icing Tests VFW 614

Test No.	Angle of attack α[°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
5.6.0.	6	150	-15	0.8	15	2

After 2 min.

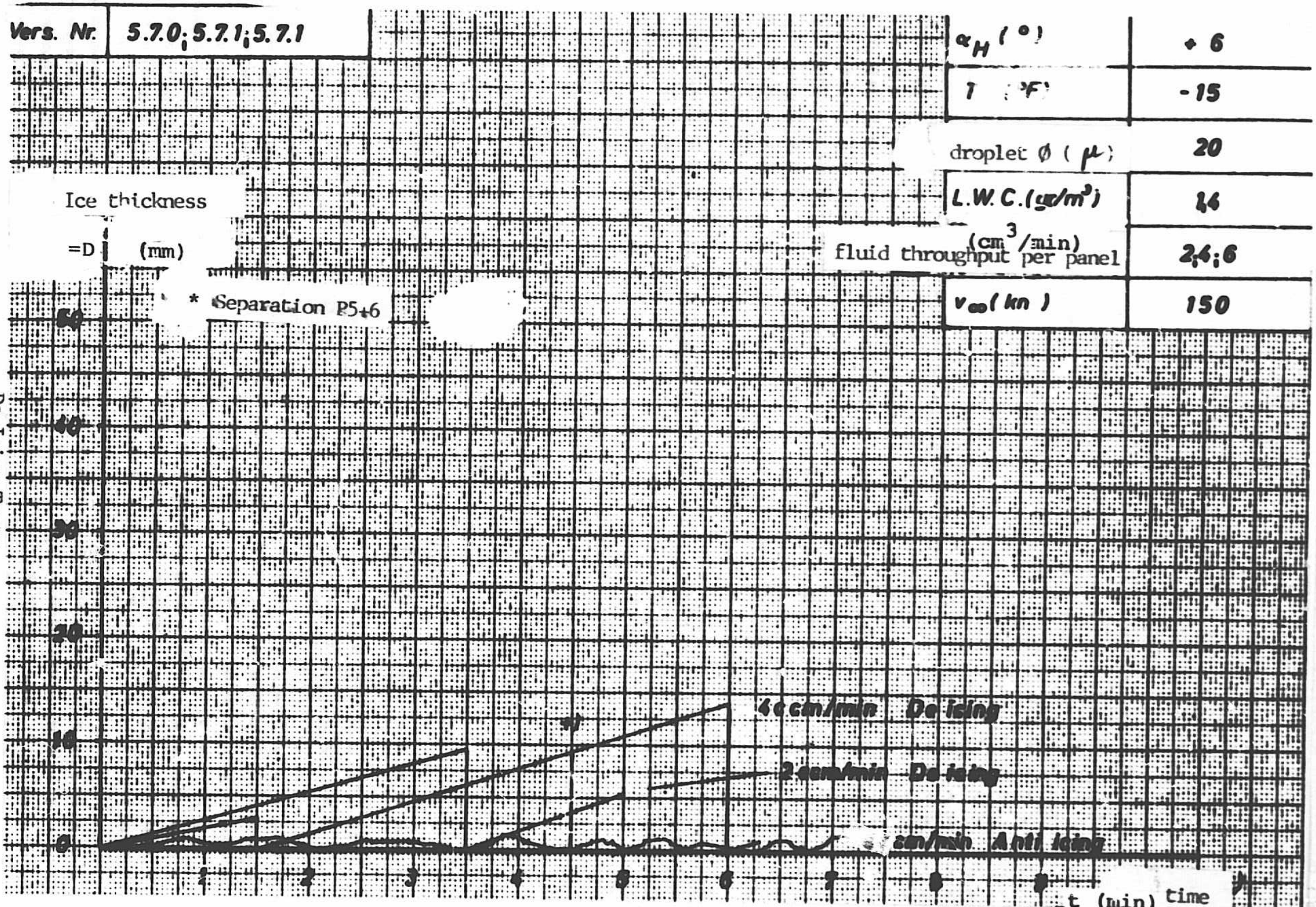
After 4 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
5.6.1.	6	150	-15	0.8	15	4

After 2 min.

After 4 min.



/99/

De-Icing Tests

C-2

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De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
5.7.0	6	150	-15	1.4	20	2

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After 4 min.

After 6 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [µ]	Fluid throughput [cm³/min]
5.7.1.	6	150	-15	1.4	20	4

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After 3 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
5.7.2.	6	150	-15	1.4	20	6

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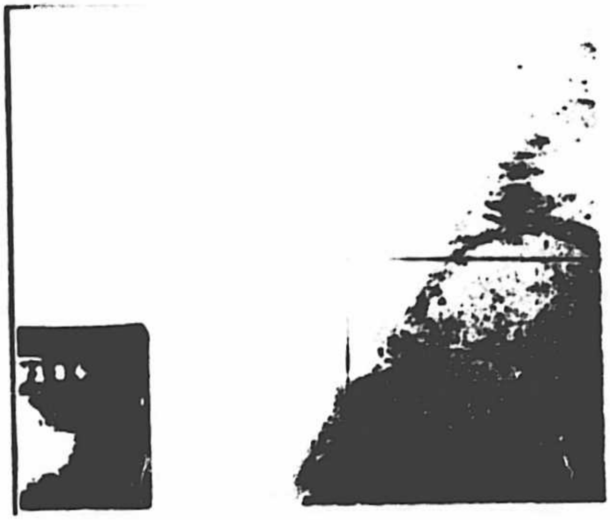
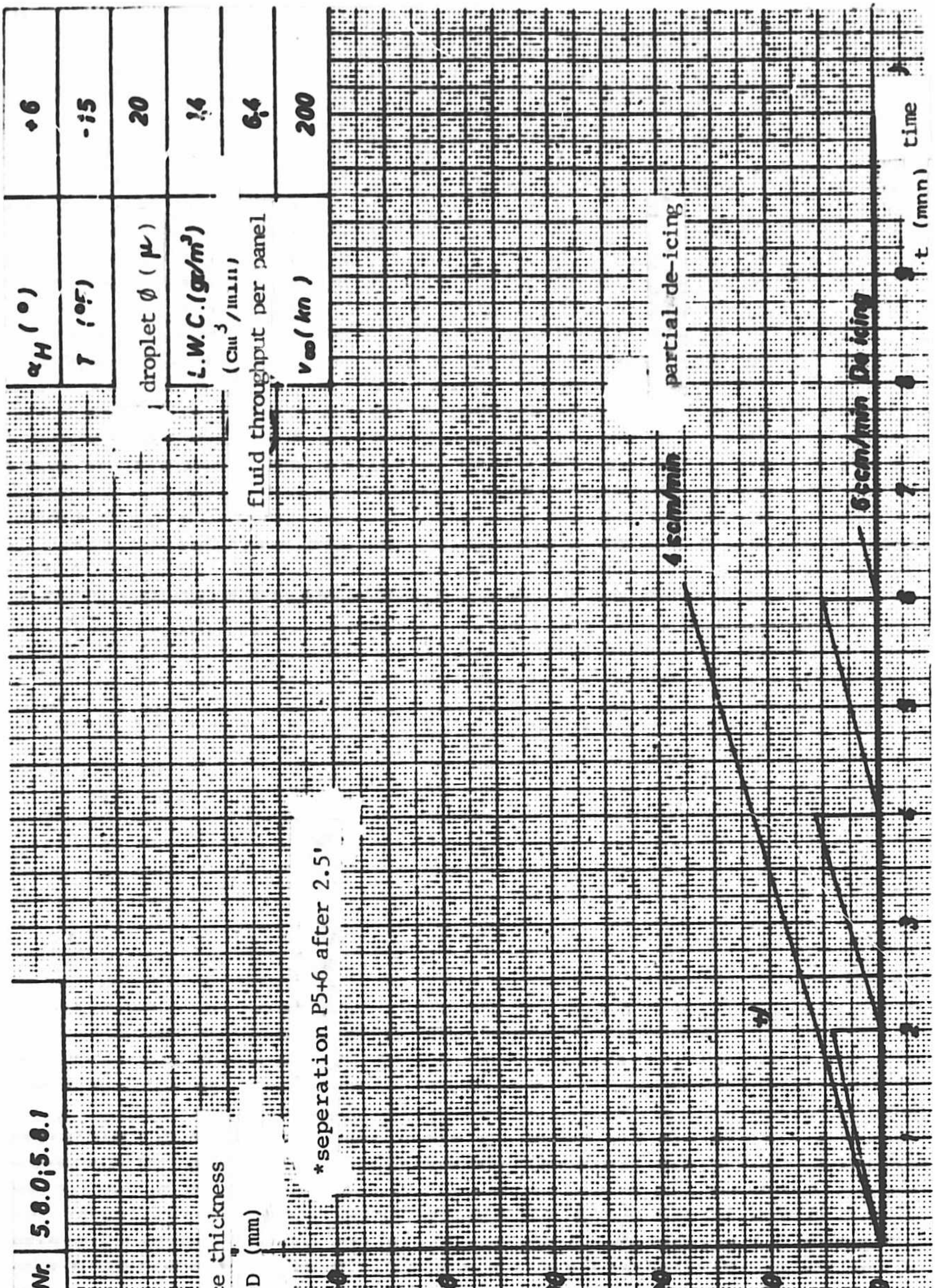


anti-icing



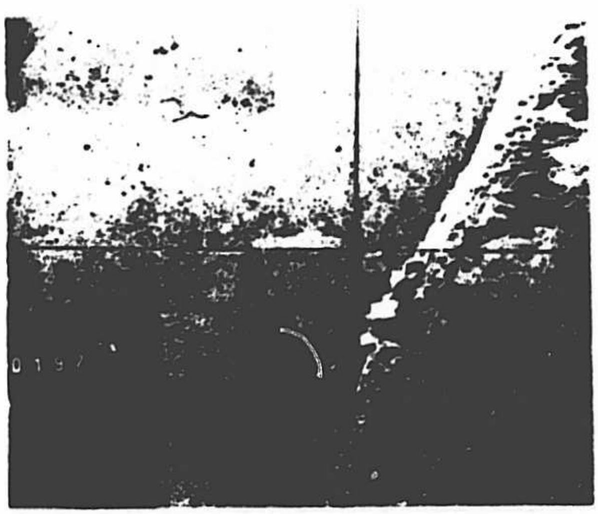
De-Icing Tests

De-Icing Tests VFW 614

Test No.	Angle of attack α[°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
5.8.0.	6	200	-15	1.4	20	6

After 2 min.

After 3 min.



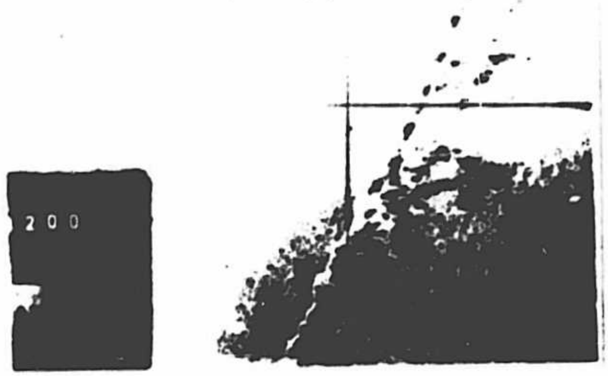
After 4 min.

After 6 min.

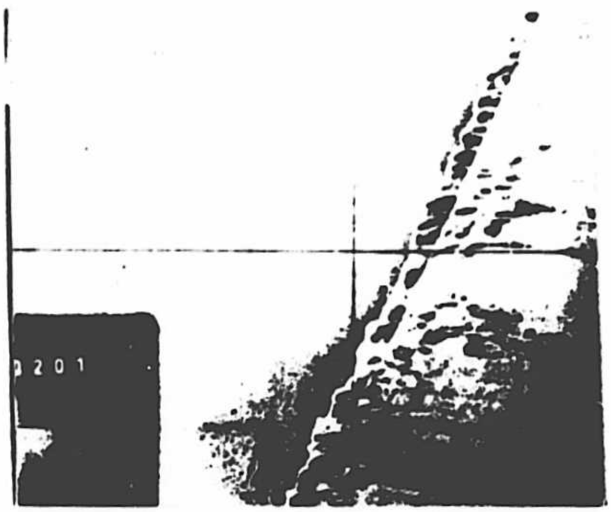
De-Icing Tests VFW 614

Test No.	Angle of attack α[°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
5.8.1.	6	200	-15	1.4	20	4

After 1 min.

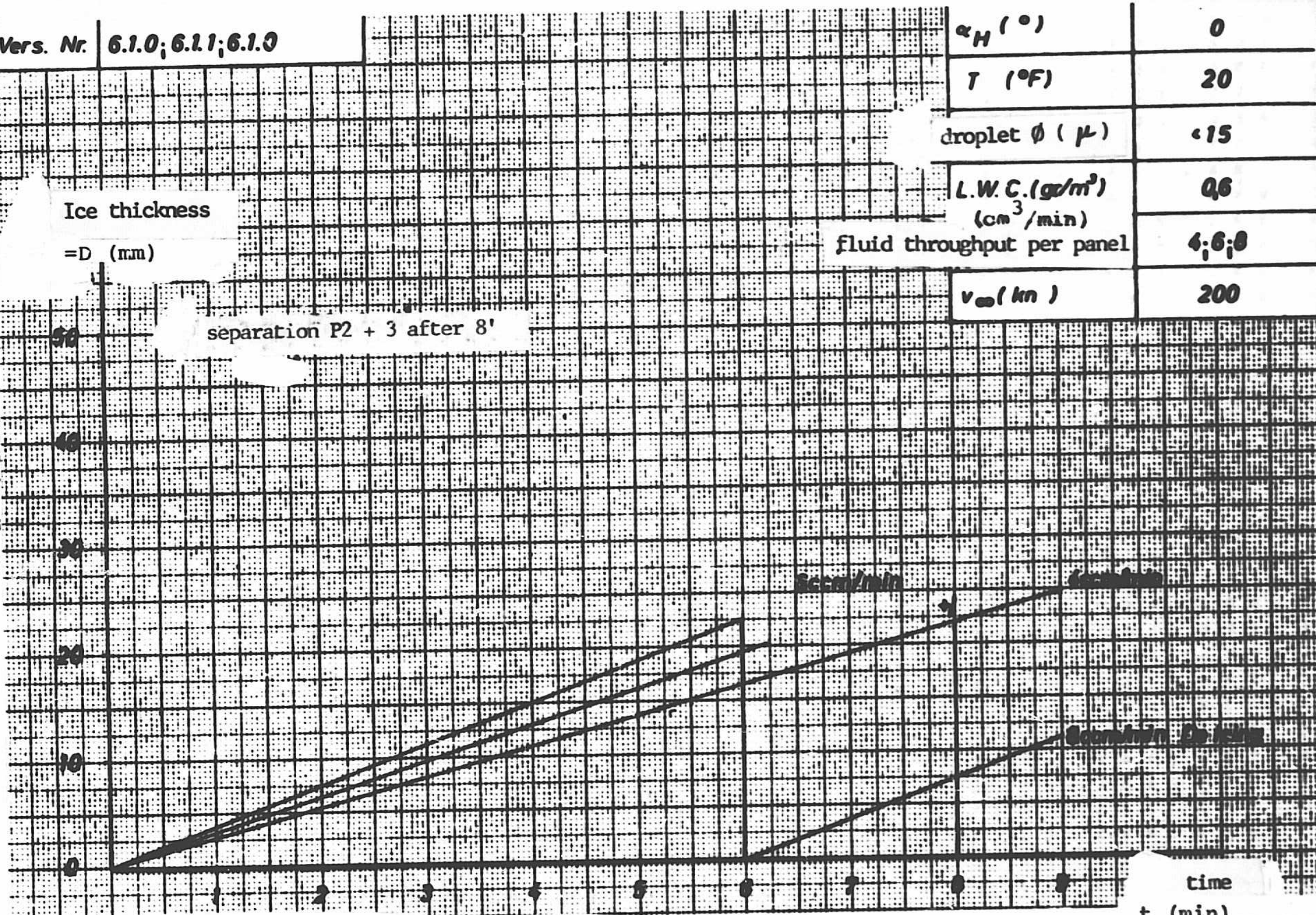


After 3 min.



After 4.5 min.

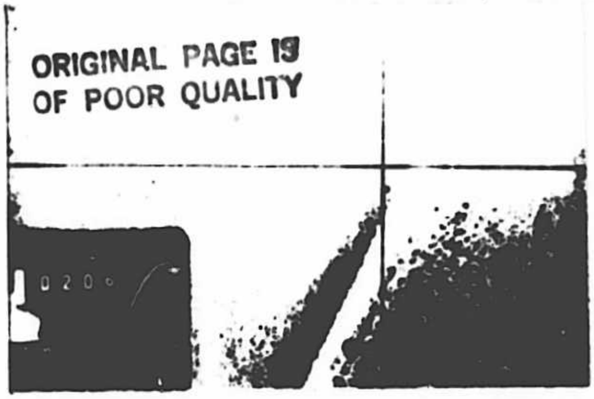
After 5 min.



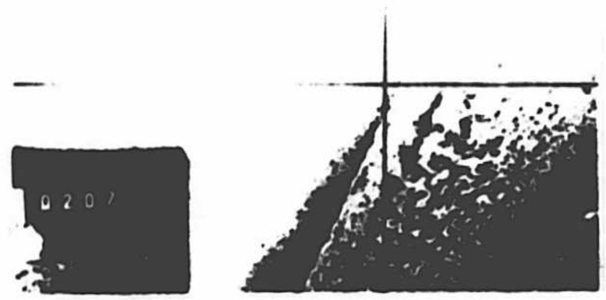
De-Icing Tests

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet φ [μ]	Fluid throughput [cm³/min]
6.1.0	0	200	20	0.6	15	4



After 2 min.



After 4 min.

After 6 min.

After 9 min.

After 9 min.

De-Icing Tests VFW 614

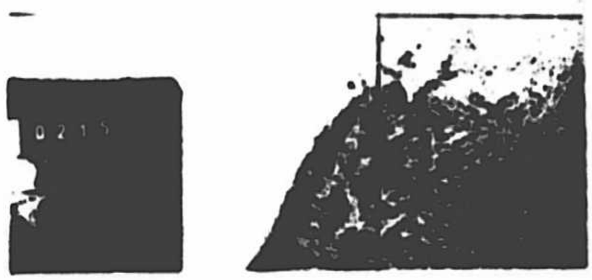
Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
6.1.1.	0	200	20	0.6	15	6

After 5 min.

After 5 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
6.1.2	0	200	20	0.6	15	8

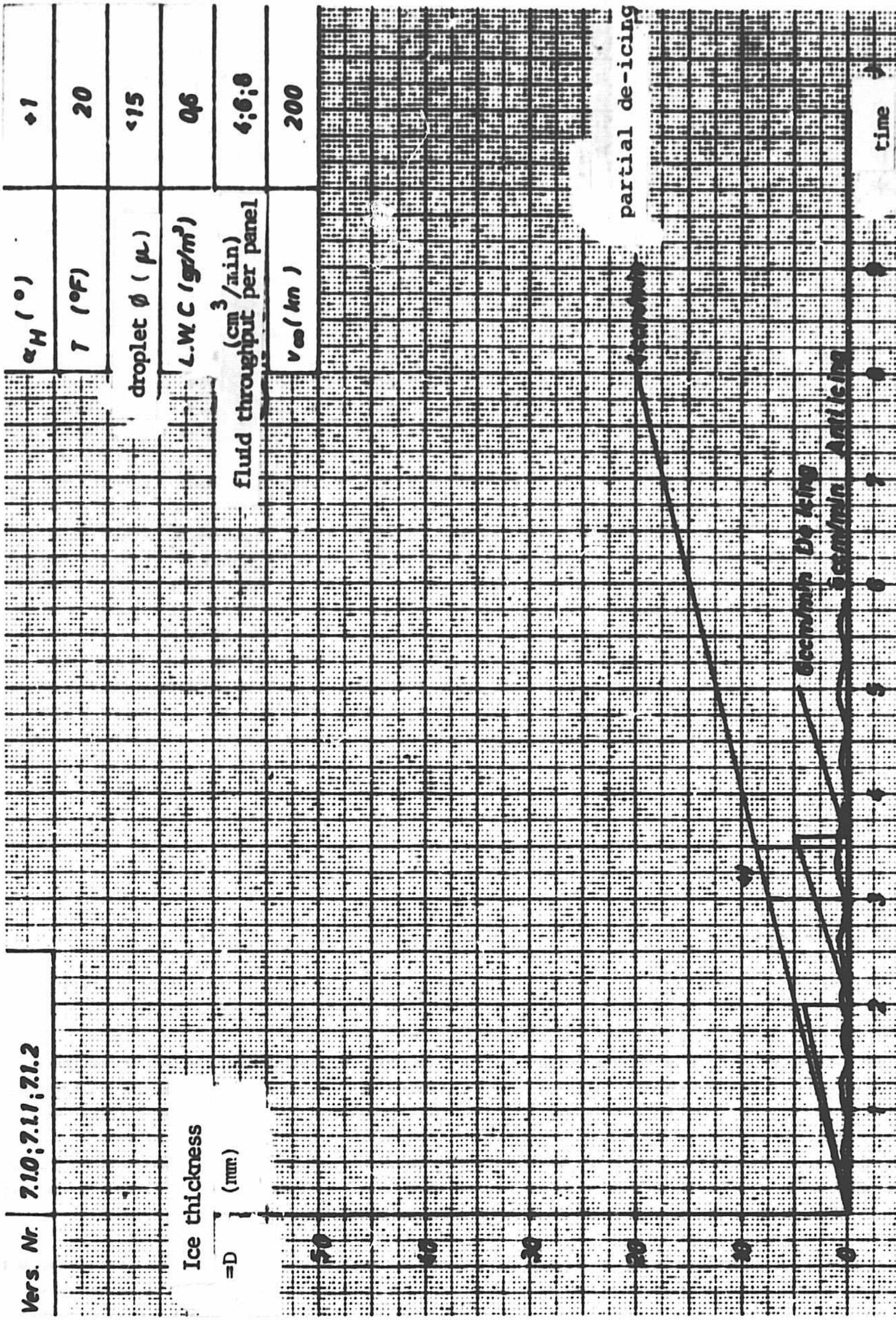


After 6 min.

After 9 min

After 9.5 min.

After 13 min.


Vers. Nr.
7.1.0; 7.1.1; 7.1.2
α_H (°)
+1
T (°F)
20
droplet Ø (μ)
15
L.W.C (gr/m³)
0.6
fluid throughput per panel (cm³/min)
4;6;8
v_∞ (kn)
200
Ice thickness
D (mm)
time
t (min)
partial de-icing
0
10
20
30
40
50

De-Icing Tests VFW 614

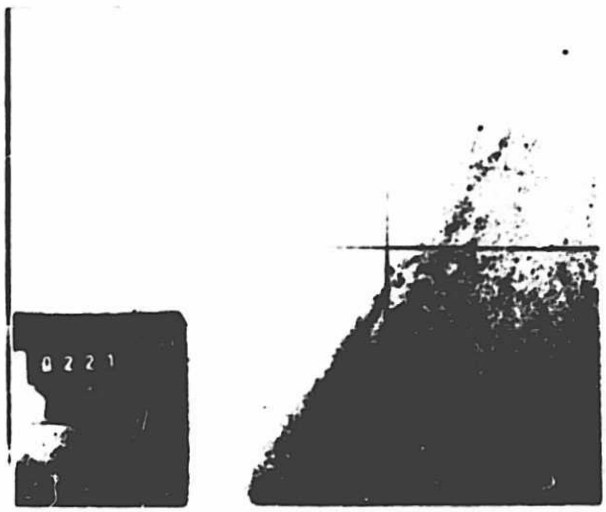
Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
7.1.0	+1	200	20	0.6	15	4

After 3 min.

After 8 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
7.1 1.	+1	200	20	0.6	15	6

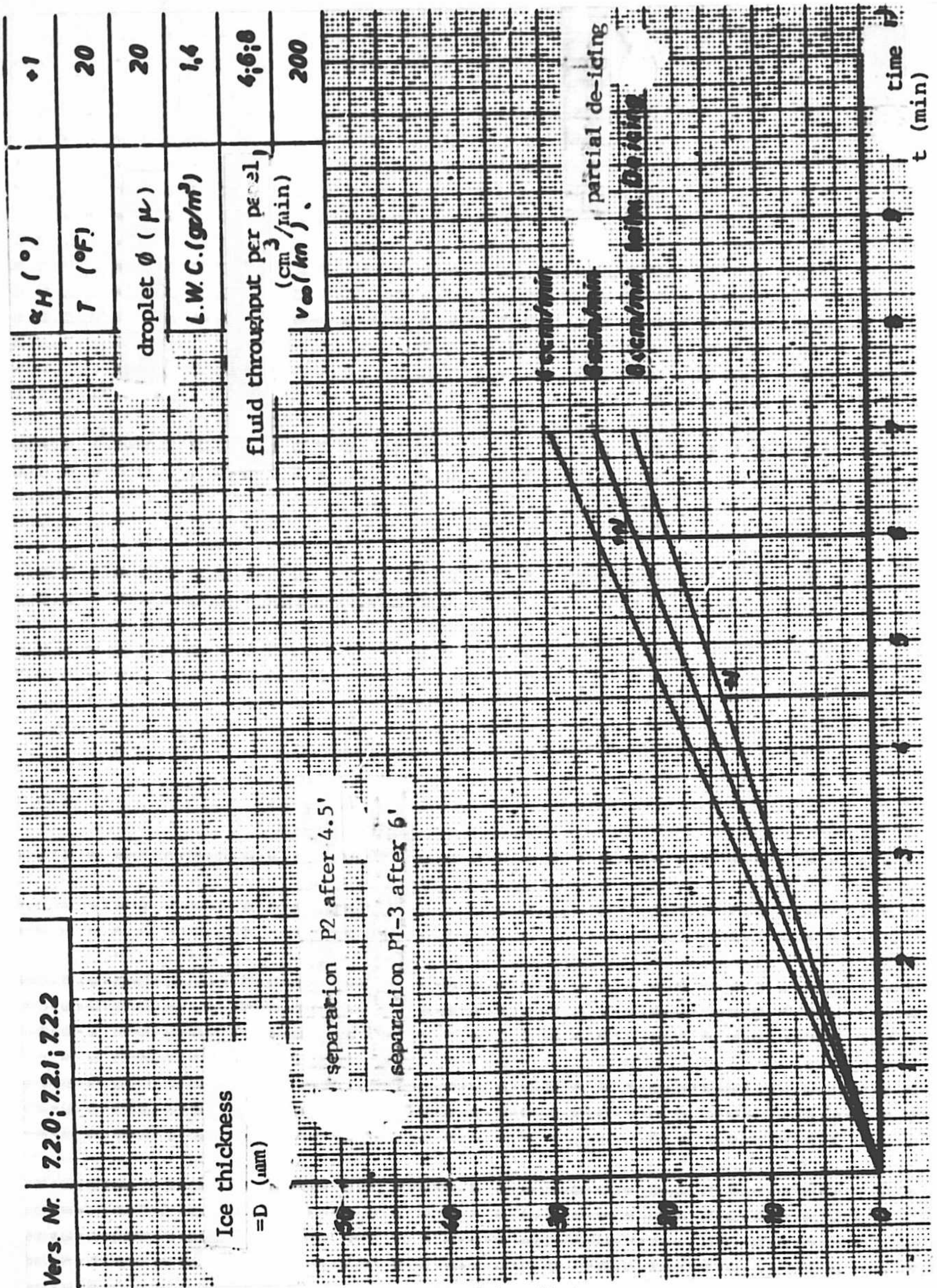


After 2.5 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet [μ]	Fluid throughput [cm^3/min]
7.1.2	+1	200	20	0.6	15	8

After 2.5 min.



De-Icing Tests

De-Icing Tests VFW 614

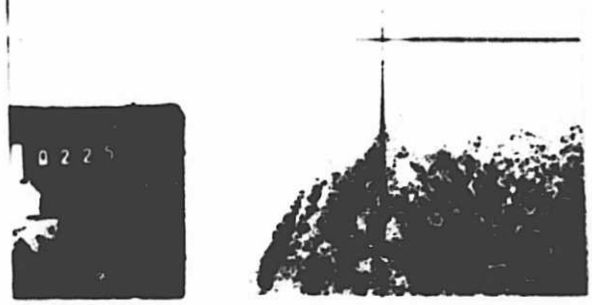
Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
7.2.0	+1	200	20	1.4	20	4

After 6 min.

After 6 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α[°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
7.2.1.	+1	200	20	1.4	20	6



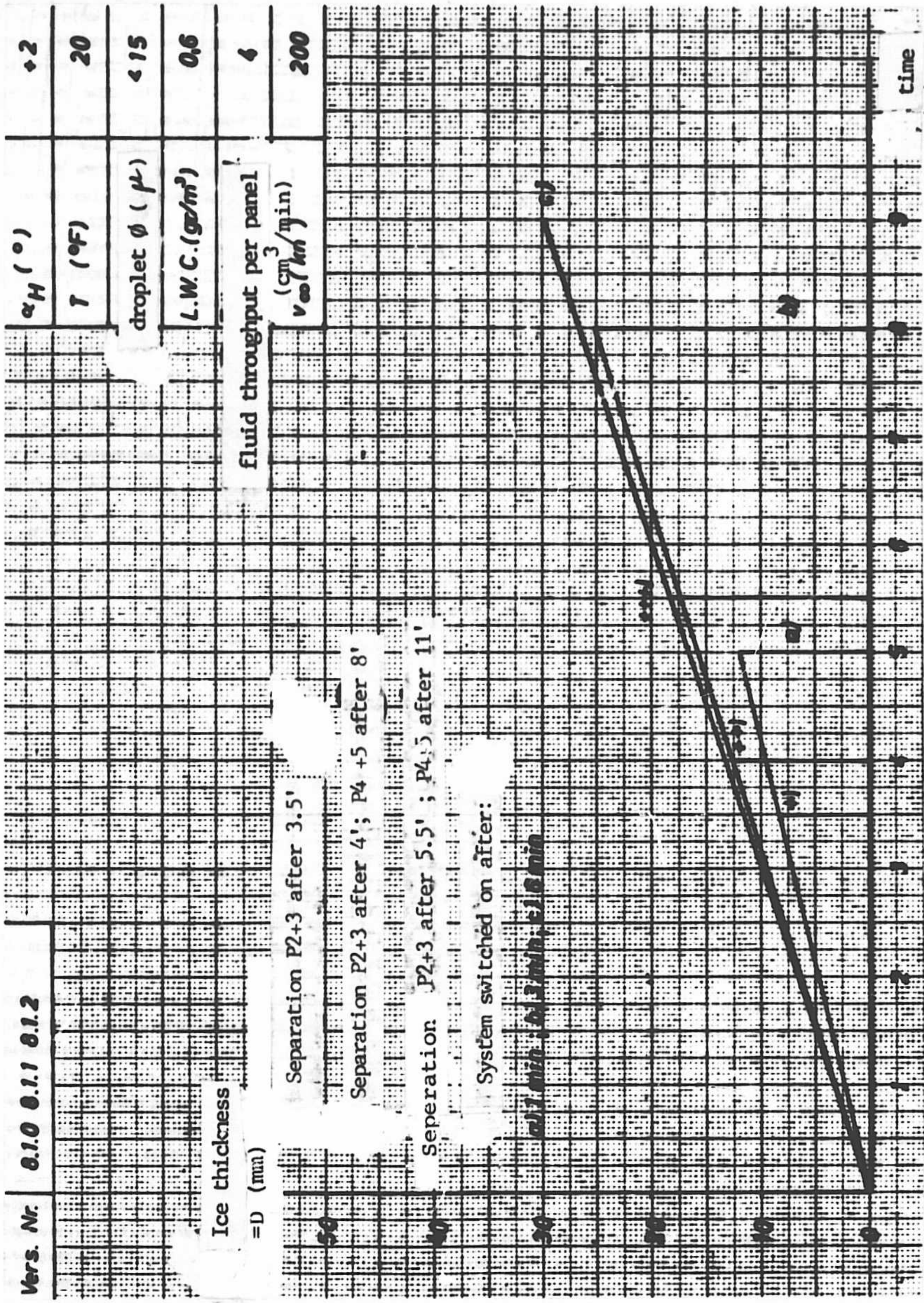
After 6.5 min.

After 8 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
7.2.2	+1	200	20	1.4	20	8

After 6.5 min.

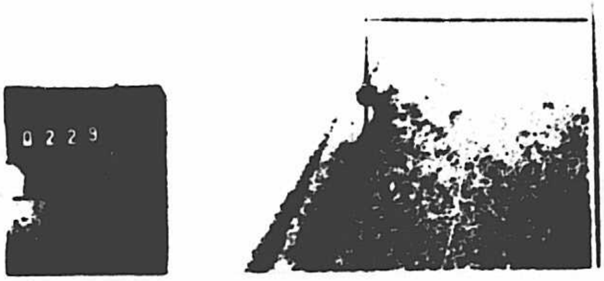


De-Icing Tests

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet φ [μ]	Fluid throughput [cm³/min]
8.1.1	+2	200	20	0.6	15	4

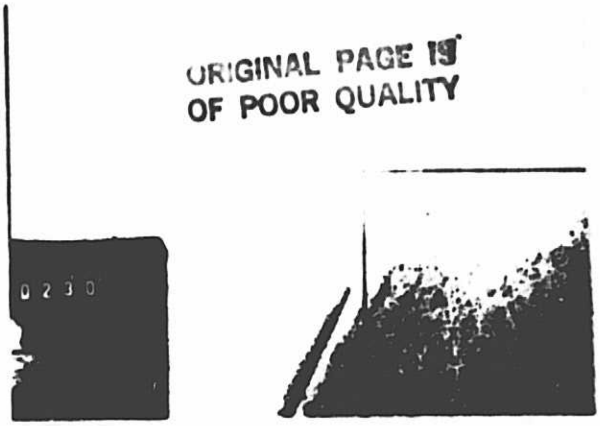
After 4.5 min.



After 6 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
8.1.2	+2	200	20	0.6	15	4

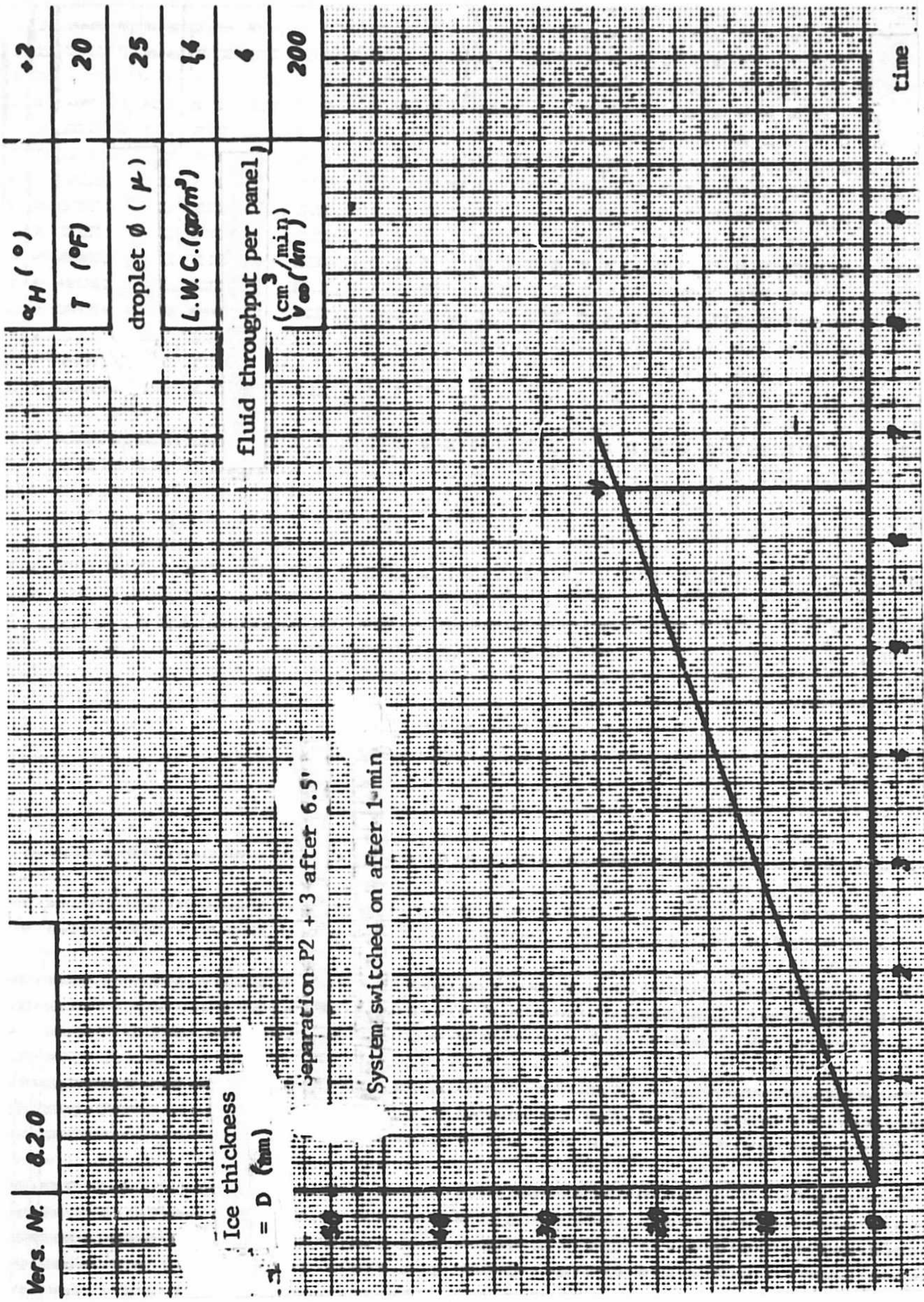


After 1 min.

After 2 min.

After 3 min.

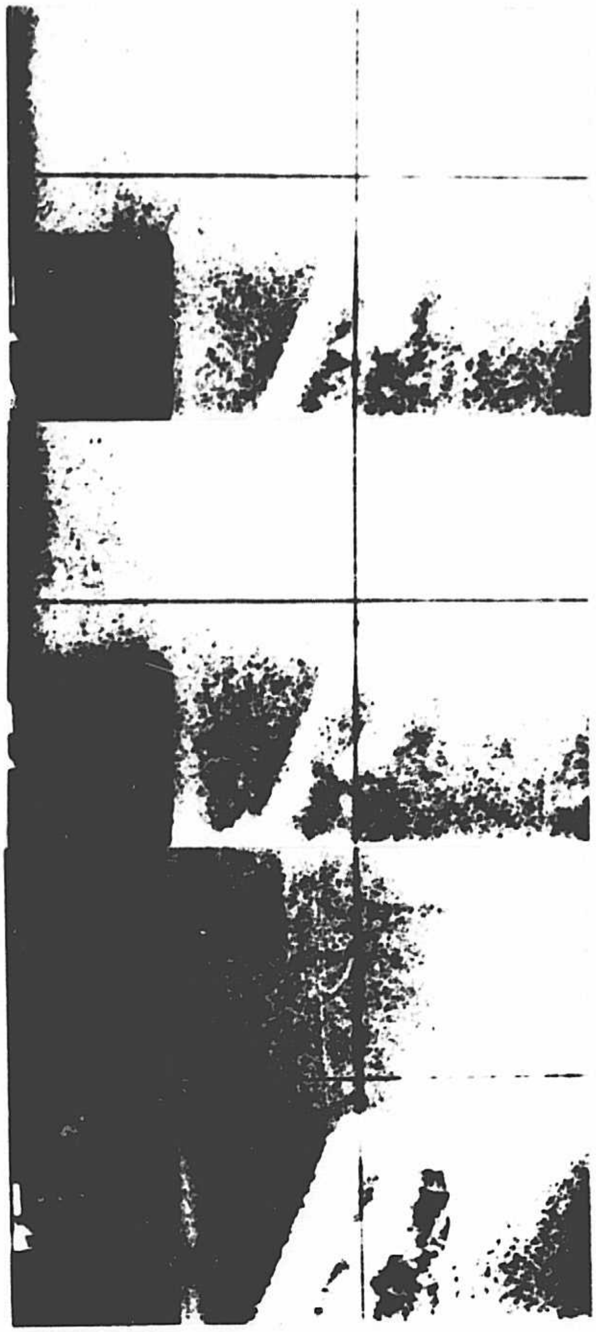
After 4 min.



De-Icing Tests VFW 614

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
8.20	+2	200	20	1.4	20	4



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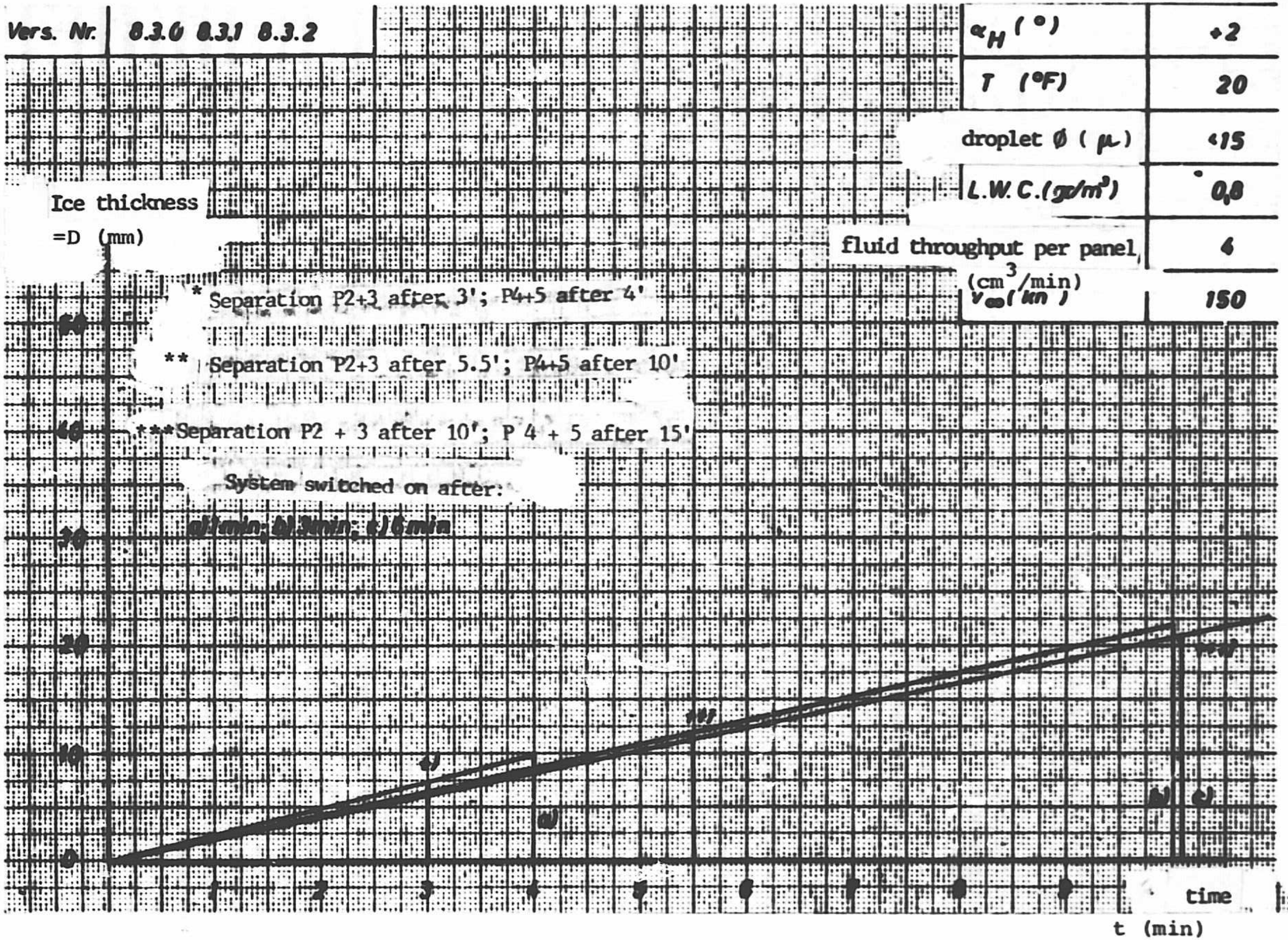
After 6 min.

After 7 min.

After 7.5 min.



De-Icing Tests

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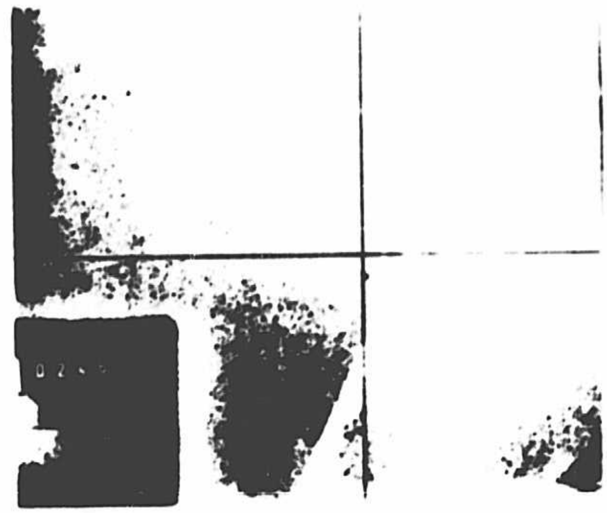
Test No.	Angle of attack α[°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
8.3.0	+2	150	20	0.8	15	4

After 3.5 min.

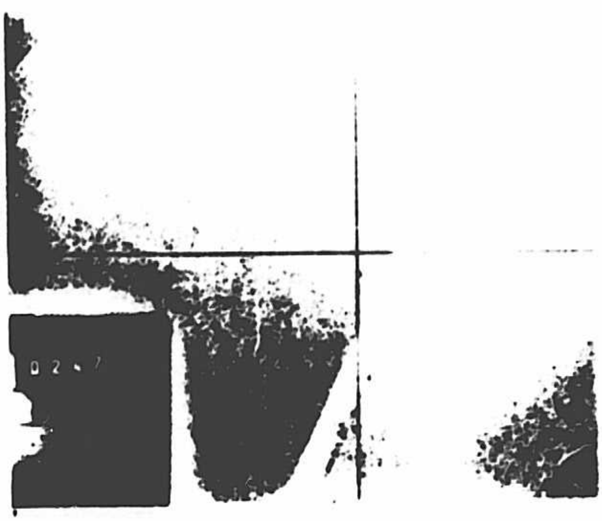
De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [µ]	Fluid throughput [cm^3/min]
8.3.1	+2	150	20	0.8	15	4

After 1 min.



After 2 min.



After 3 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
8.3.2	+2	150	20	0.8	15	4

After 1 min.

After 2 min.

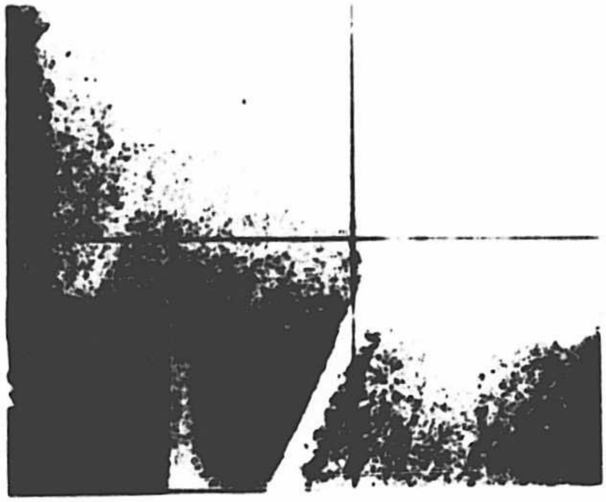
After 3 min.

After 4 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
8.3.2	+2	150	20	0.8	15	4

After 5 min.



After 6 min.

After 10 min.

After 15 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
9.0.1	+2	200	20	1.4	25	0

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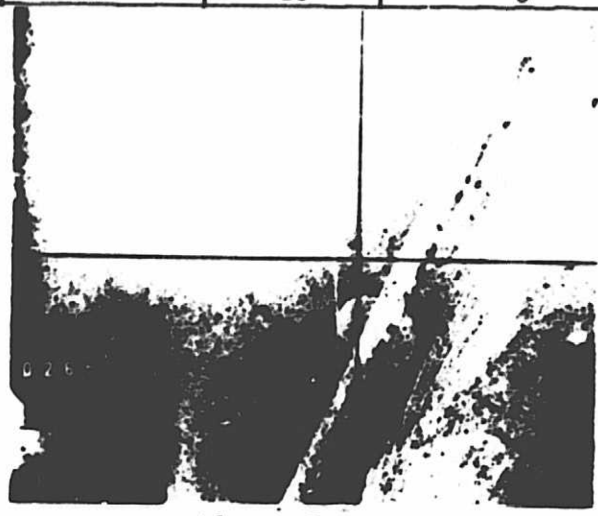
After 10 min.

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet φ [μ]	Fluid throughput [cm³/min]
9.0.2	+2	200	20	1.4	25	0

After 1 min.



After 2 min.

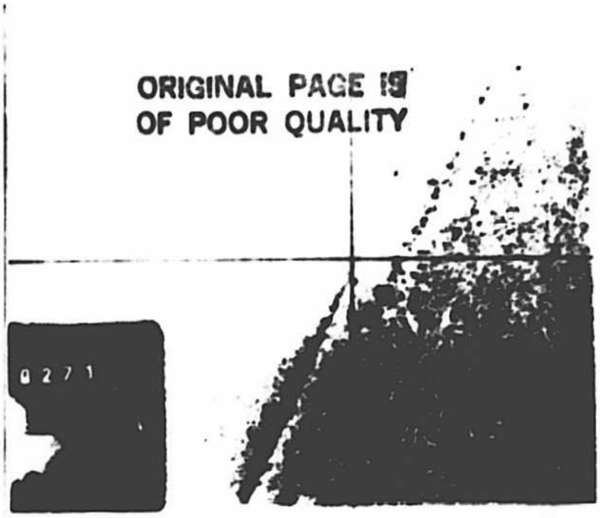
After 3 min.

After 4 min.

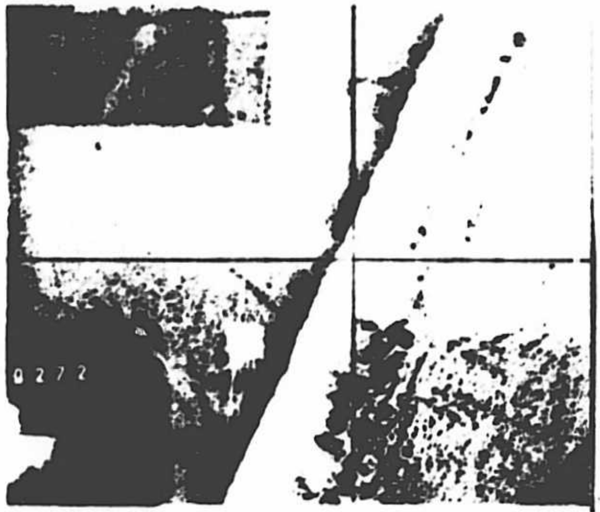
After 5 min.

De-Icing Tests VFW 614

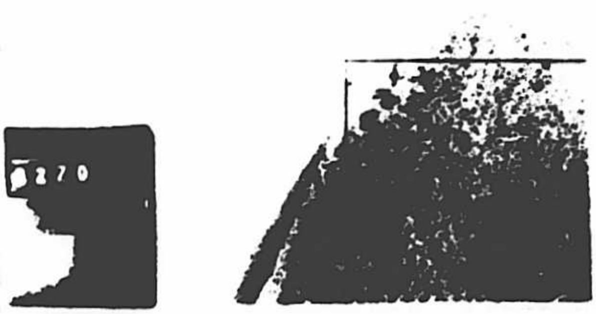
Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m^3]	Droplet ϕ [μ]	Fluid throughput [cm^3/min]
9.0.3	0	200	20	1.4	25	0



After 5 min.



After 10 min.



After 3 min.

Test 9.0.3

α	=	$0°$
V	=	200 kn
LWC	=	1.4 g/m^3
d	=	25 μ
T	=	20 °F
t	=	10 Min

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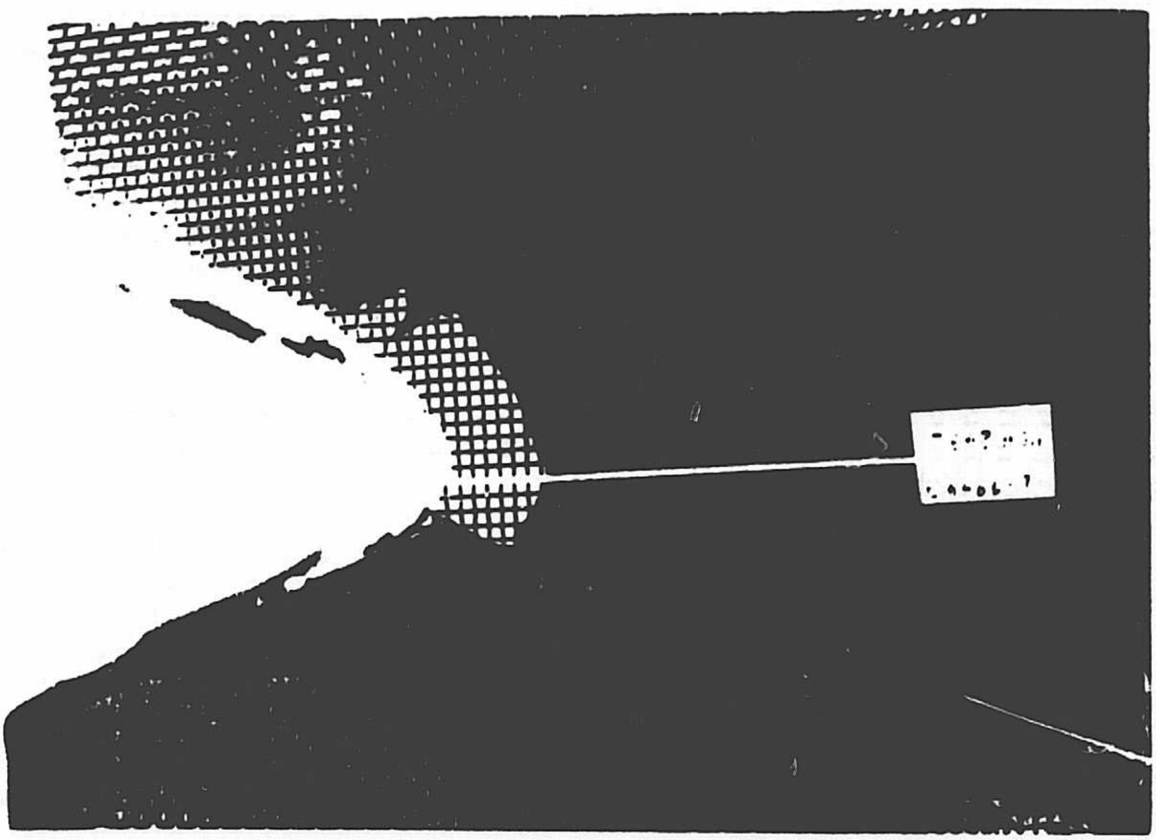
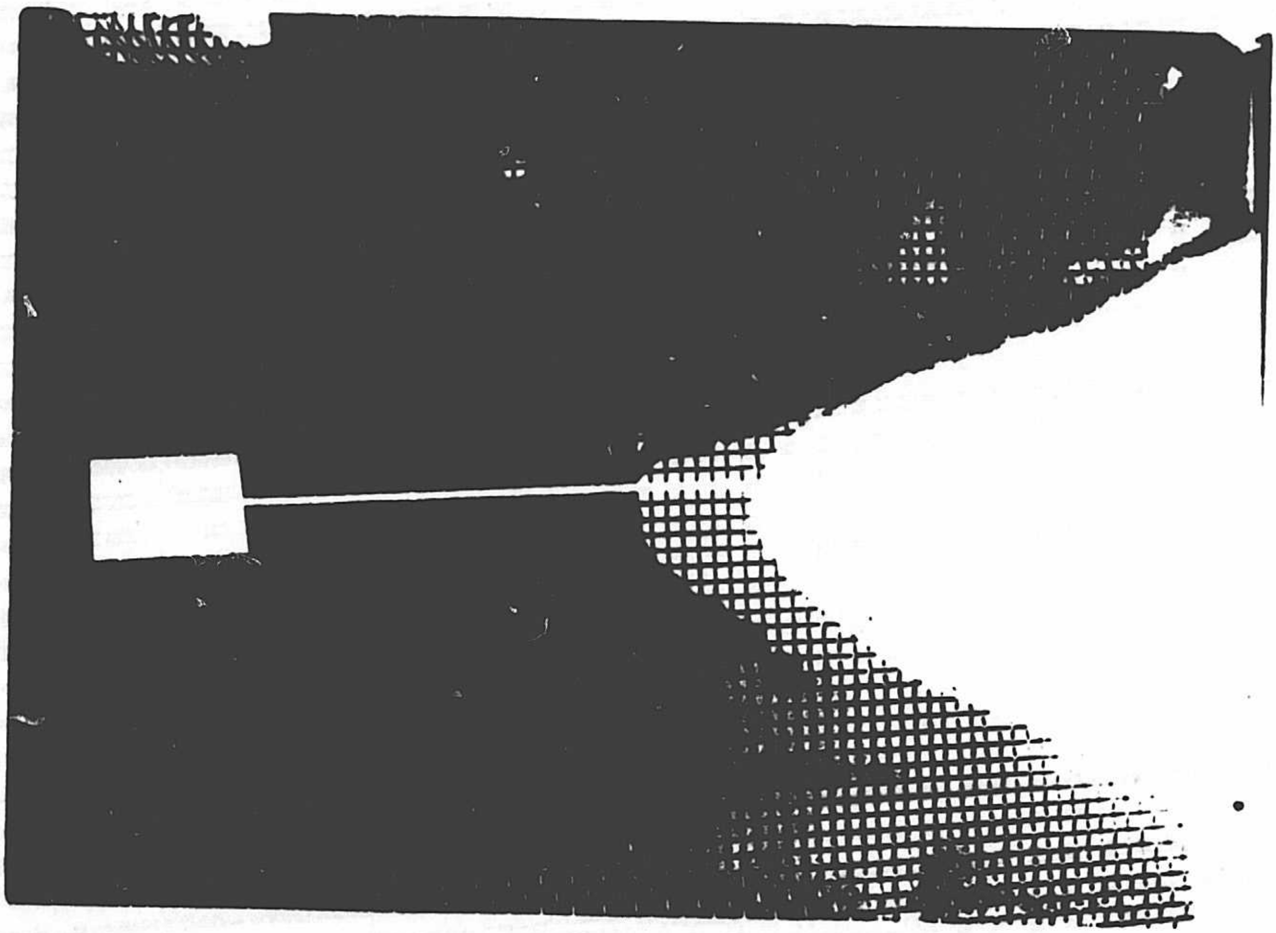


Test No. 9.0.3

Test No. 9.0.4

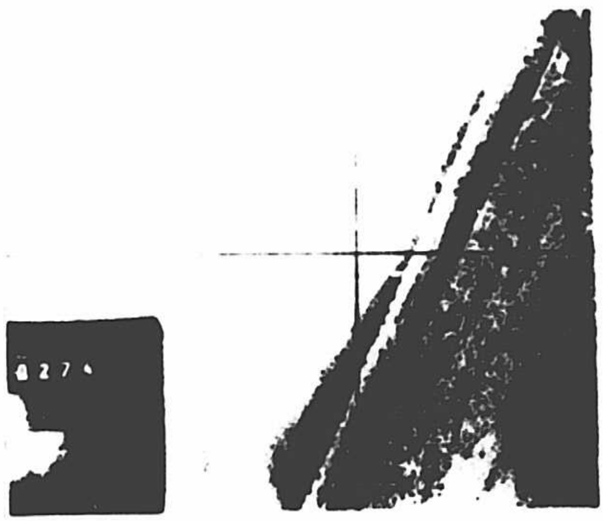
α	$= 0°$
v	$= 200$ Kn
LWC	$= 1.4$ g/m³
d	$= 25\ \mu$
T	$= 20$ °F
t	$= 5$ Min

Photo No: 2364 e



De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
9.0.5	6°	200	20	1.4	25	0



After 3 min.

After 5 min.

After 10 min.

After 10 min. (without spray)

Test No. 9.0.5

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α = 6°
V = 200 Kn
LWC = 1.4 g/m³
d = 25 μ
T = 20 °F
t = 5 Min

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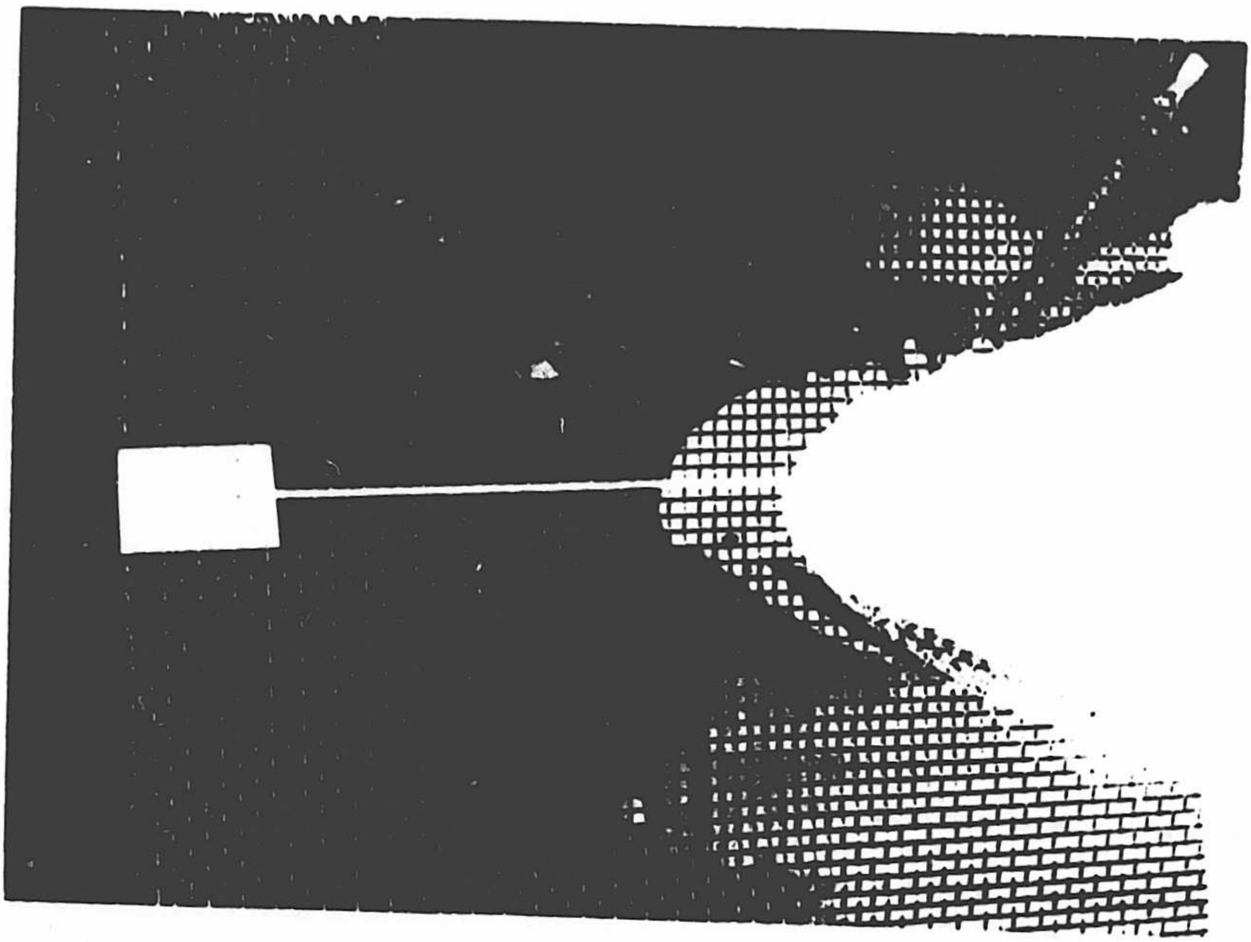


Test No. 9.0.5

De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m3]	Droplet ϕ [μ]	Fluid throughput [cm3/min]
9.0.6	10	200	20	1.4	25	0

After 3 min.

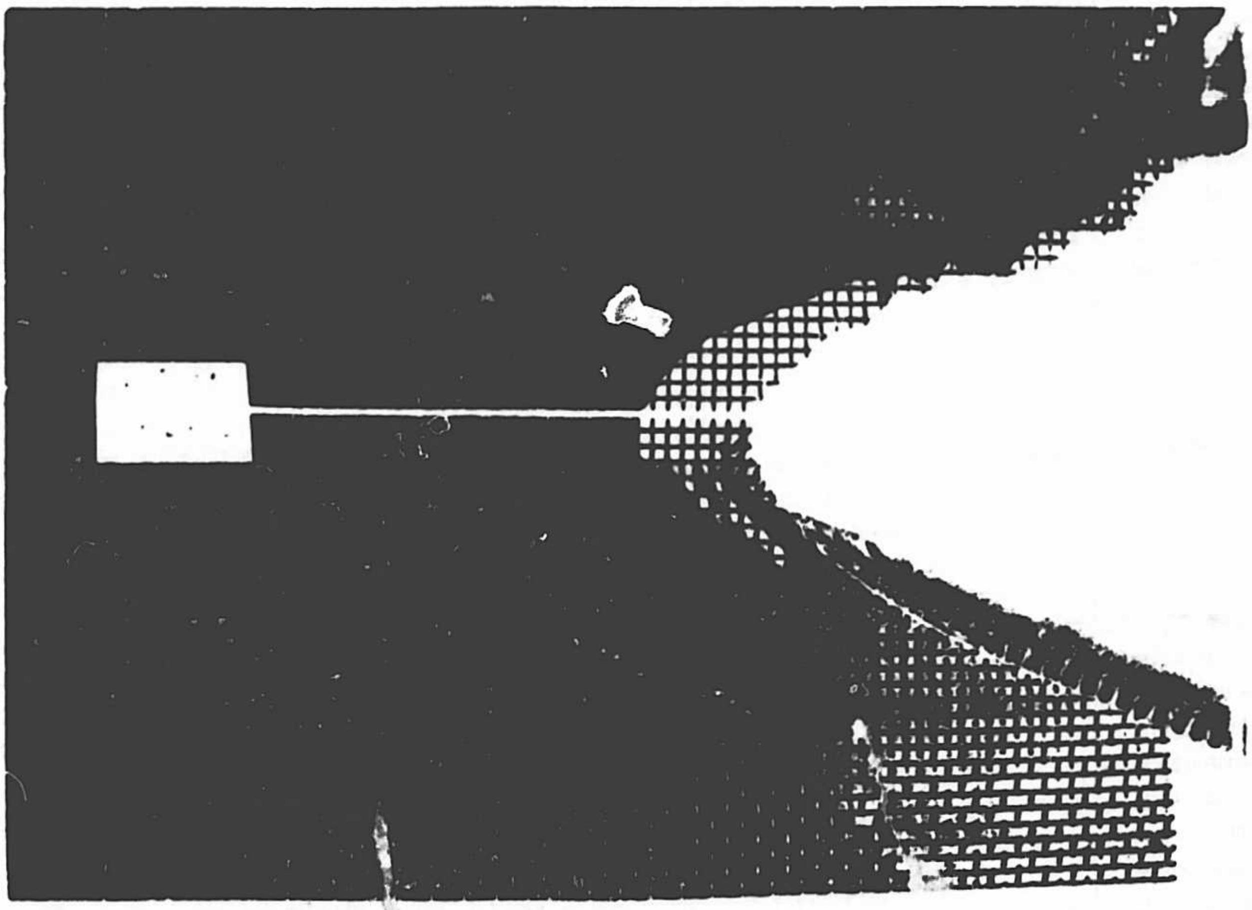
After 5 min.

After 10 min.

Test No. 9.0.6

α	=	10°
V	=	200 Kn
LWC	=	1.4 g/m³
d	=	25 μ
T	=	20 °F
t	=	10 Min

Photo No: 2364 h



De-Icing Tests VFW 614

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet φ [μ]	Fluid throughput [cm³/min]
9.0.7	10°	200	20	1.4	25	0

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After 5 min.

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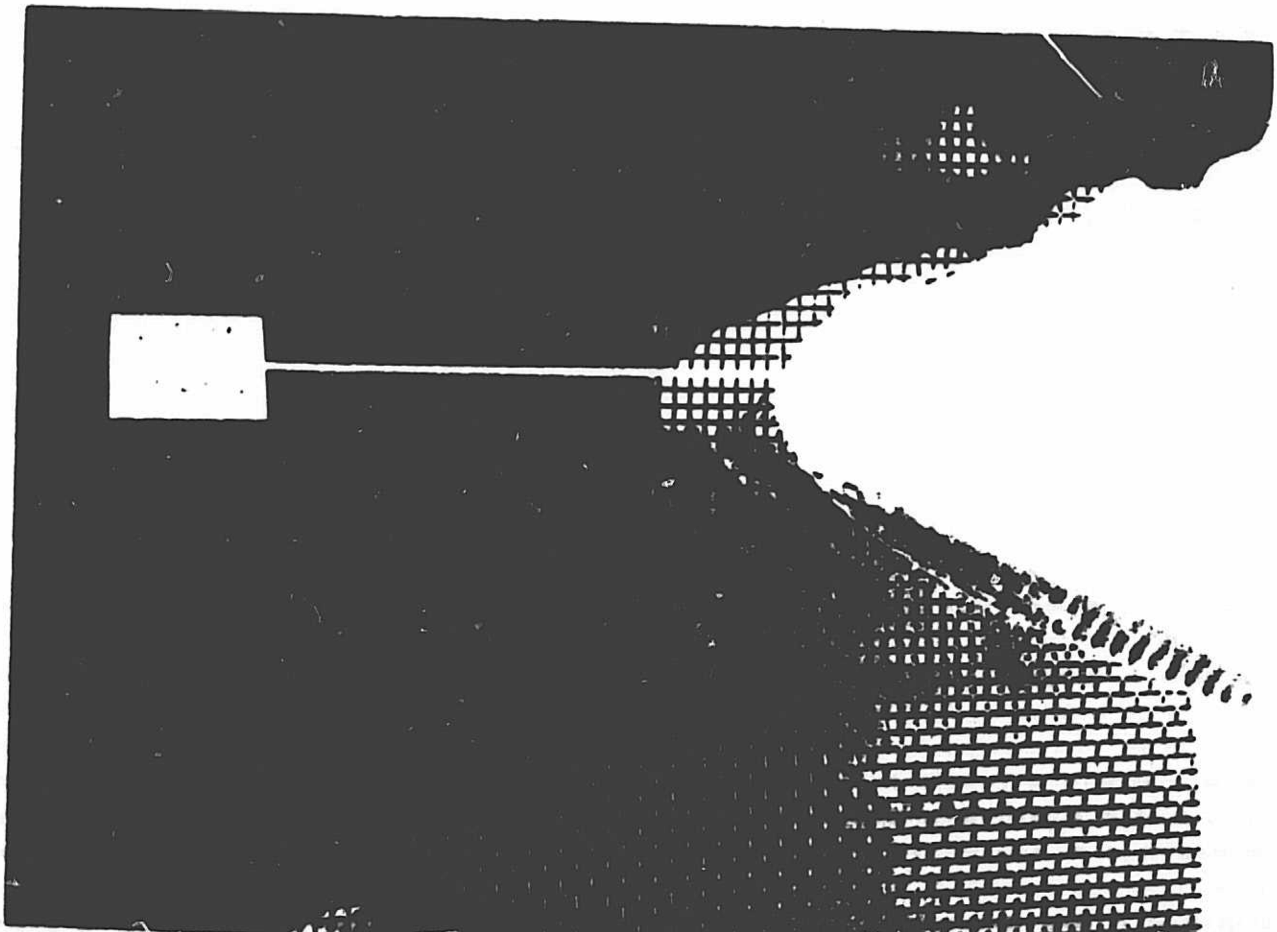
Test No. 9.0.7

α	=	10°
V	=	200 Kn
LWC	=	1.4 g/m³
$\bar{d}$	=	25 μ
T	=	20 °F
t	=	5 Min

Photo No: 2364i



<u>De-Icing Tests VFW 614</u>

Test No.	Angle of attack α [°]	Velocity [kts]	Temp [°F]	Liquid water content [gr/m³]	Droplet ϕ [μ]	Fluid throughput [cm³/min]
9.0.8	6°	200	20	0.6	15	0

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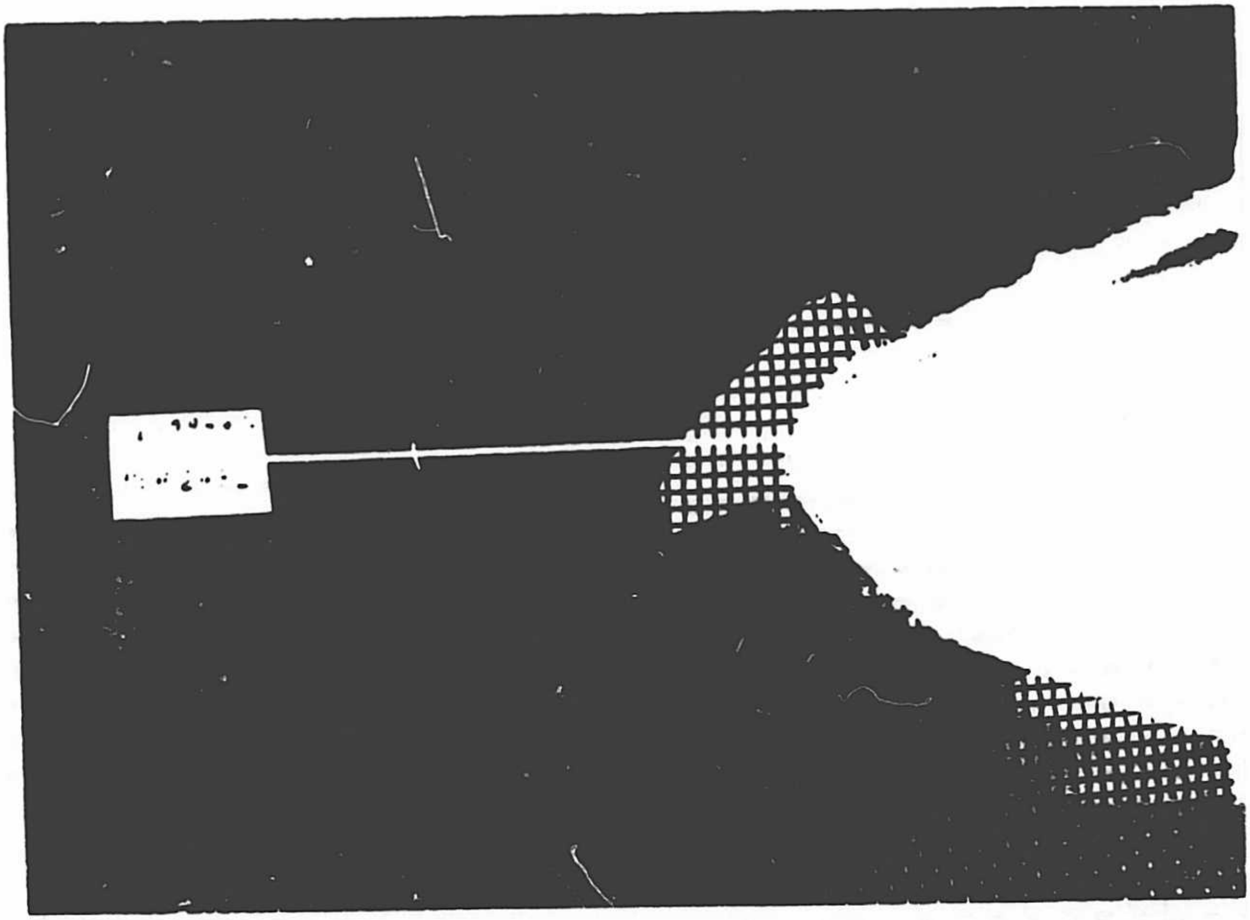
After 3 min.

After 5 min.

Test No: 9.0.8

α	= 6°
v	= 200 Kn
LWC	= 0,6 g/m³
d	= <15 μ
T	= 20°F
t	= 10 Min

Photo No: 2364k



(terms on page 206)

Test No: 9.0.9

α = 1°
V = 200 kn
LWC = 1.4 g/m³
d = 25 μ
T = 20 °F
t = 5 Min

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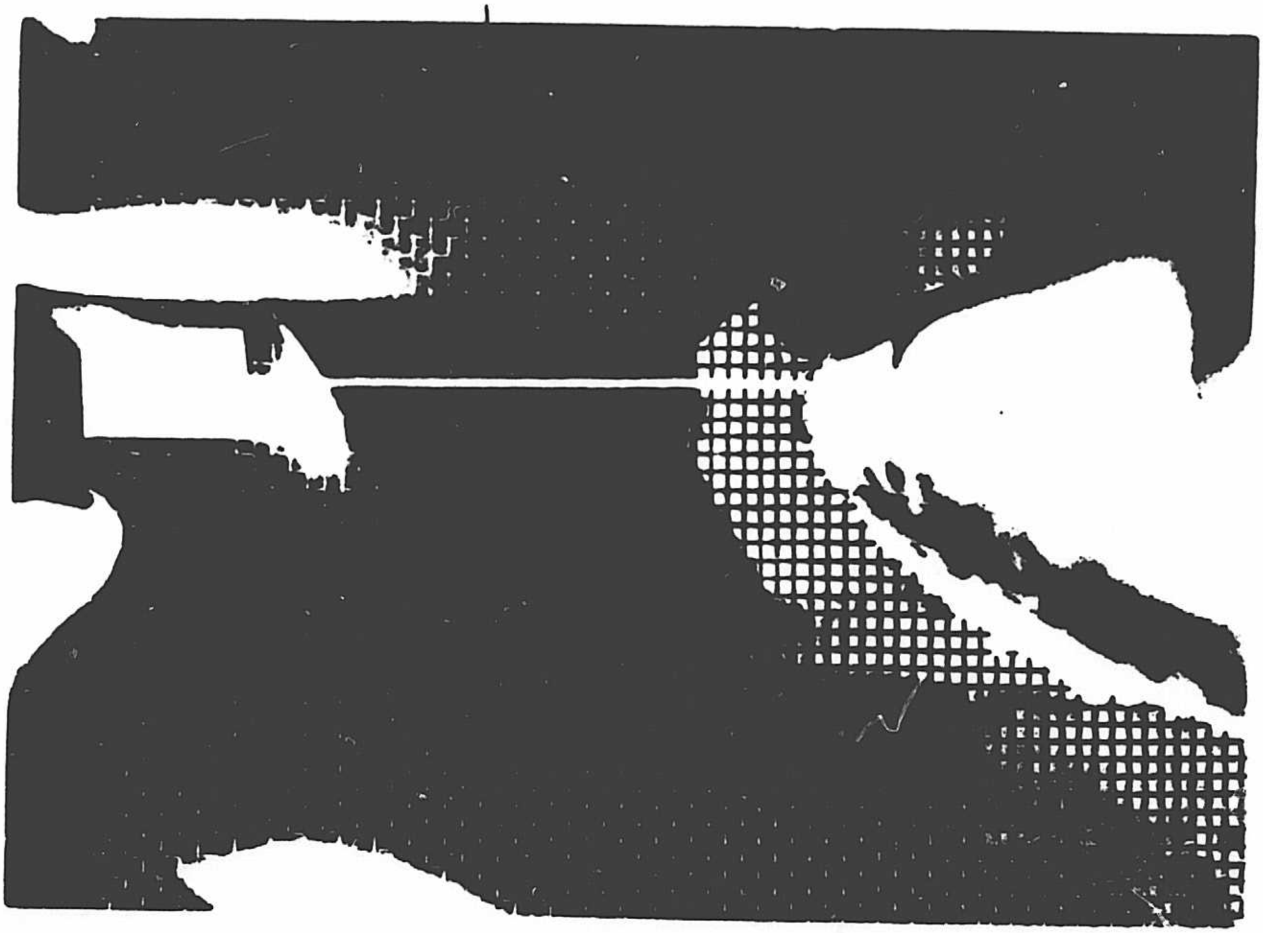


Figure No: F2/5a

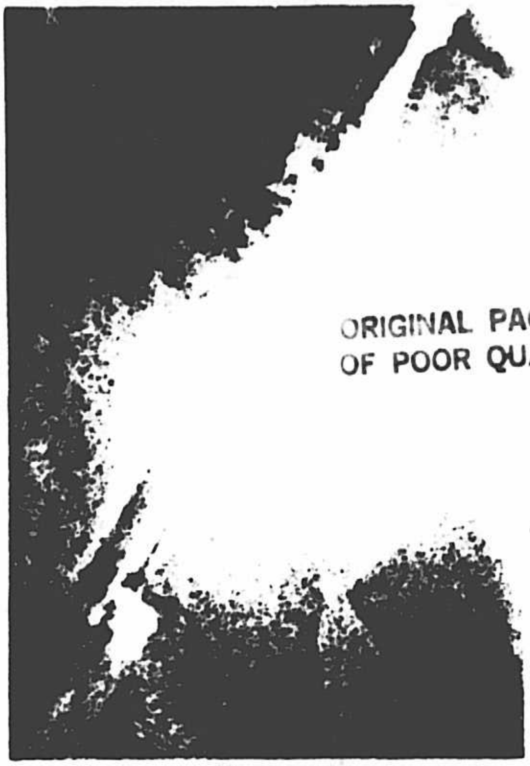


Figure No: F2/7

Figure No: F2/7a

Test No: 3.4

α	2°
v	150 Kn
LWC	1.9 g/m³
d	25 μ
T	

(terms on page 206)

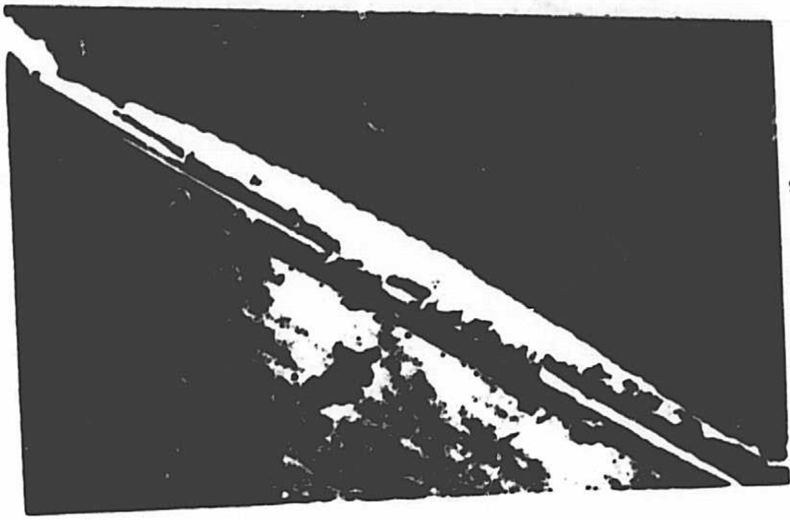


Figure No: F2/9

Figure No : F2/9a

Test No: 3.4

α = 2°
v = 150 Kn
LWC 1.9 g/m³
d 25 μ
T

Figure No: 3.4.1

α	2°
v	150 Kn
LWC	1.9 g/m³
d	25 µ
T	

Figure No: F2/13a

Test No: F2/15

Figure No: F2/31

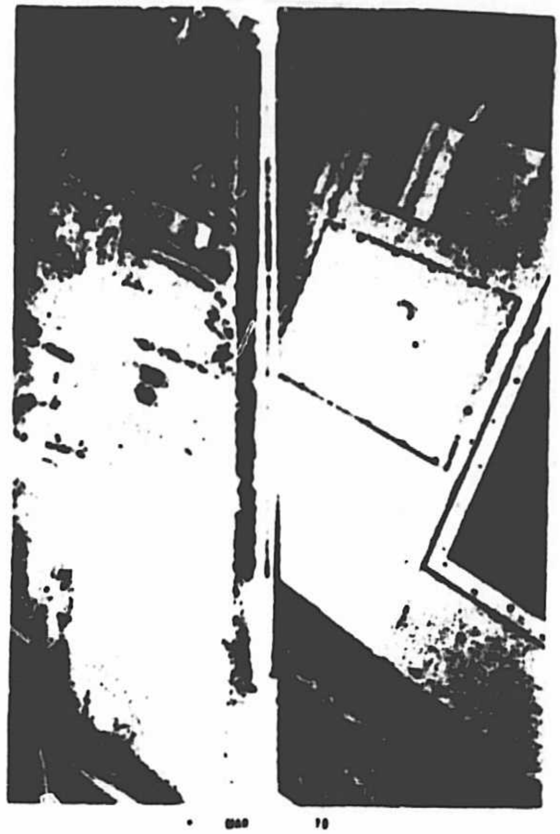


Figure No: F2/29

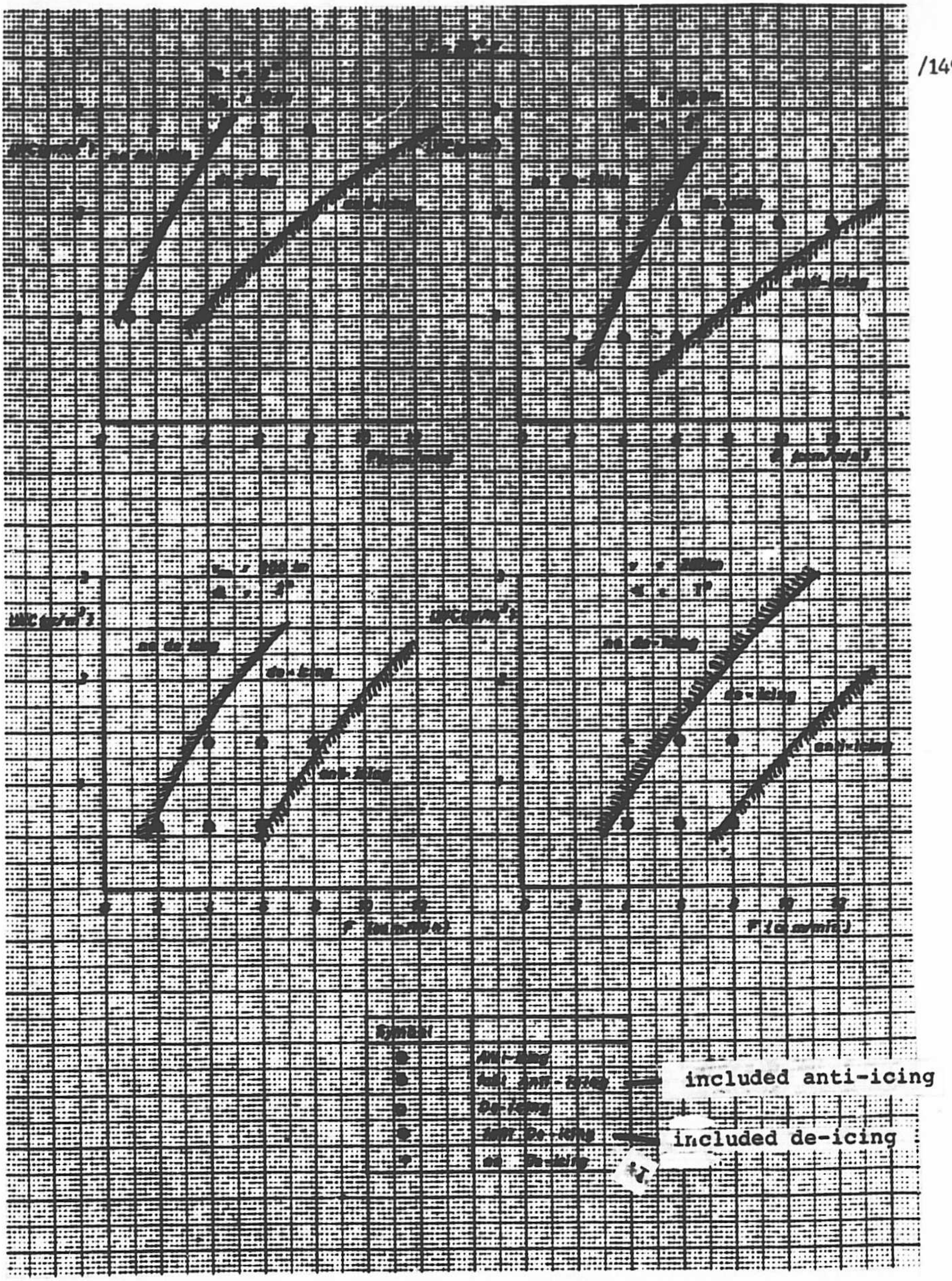
Figure No: F2/29a

/734

/735

/736

/737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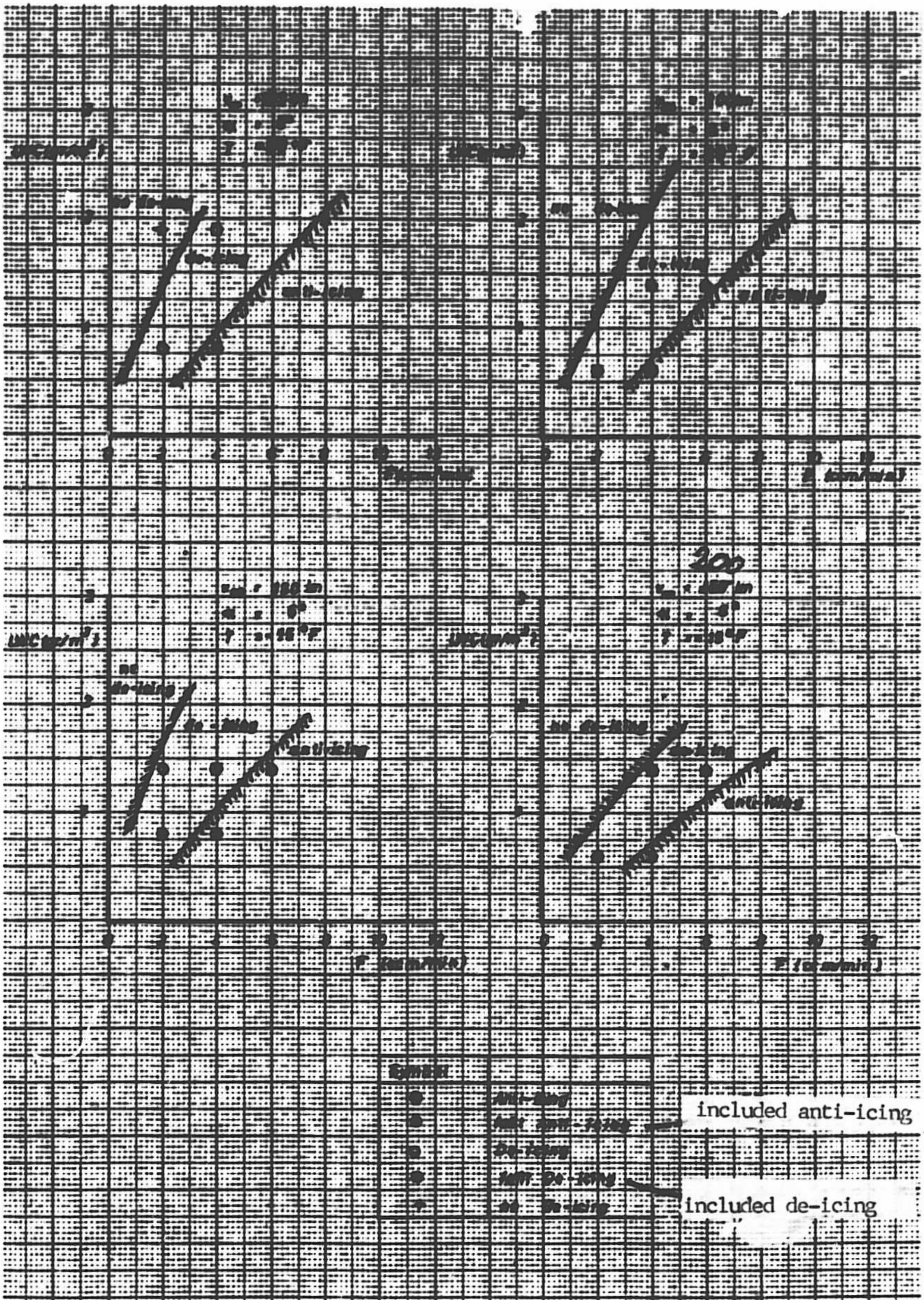
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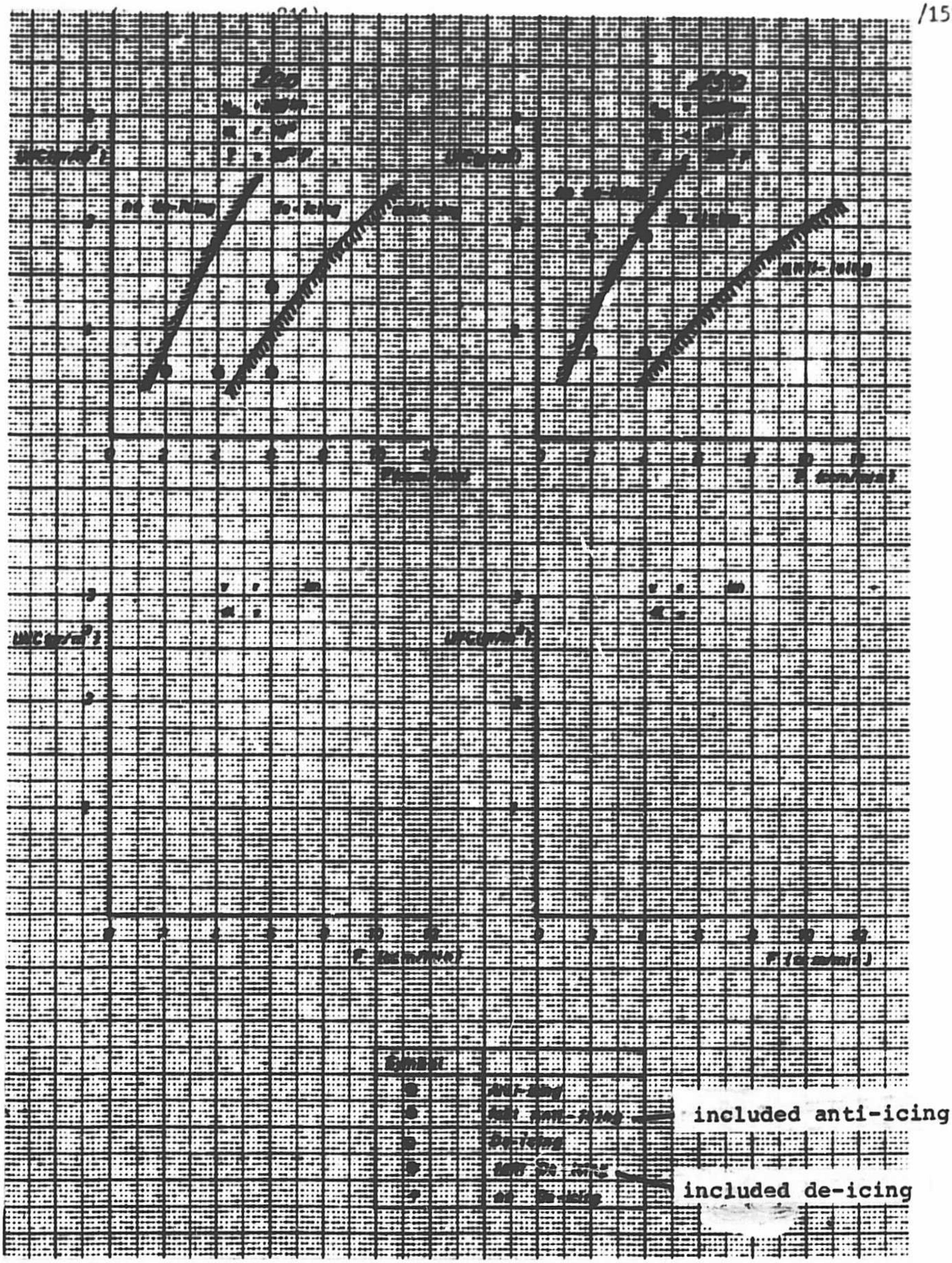
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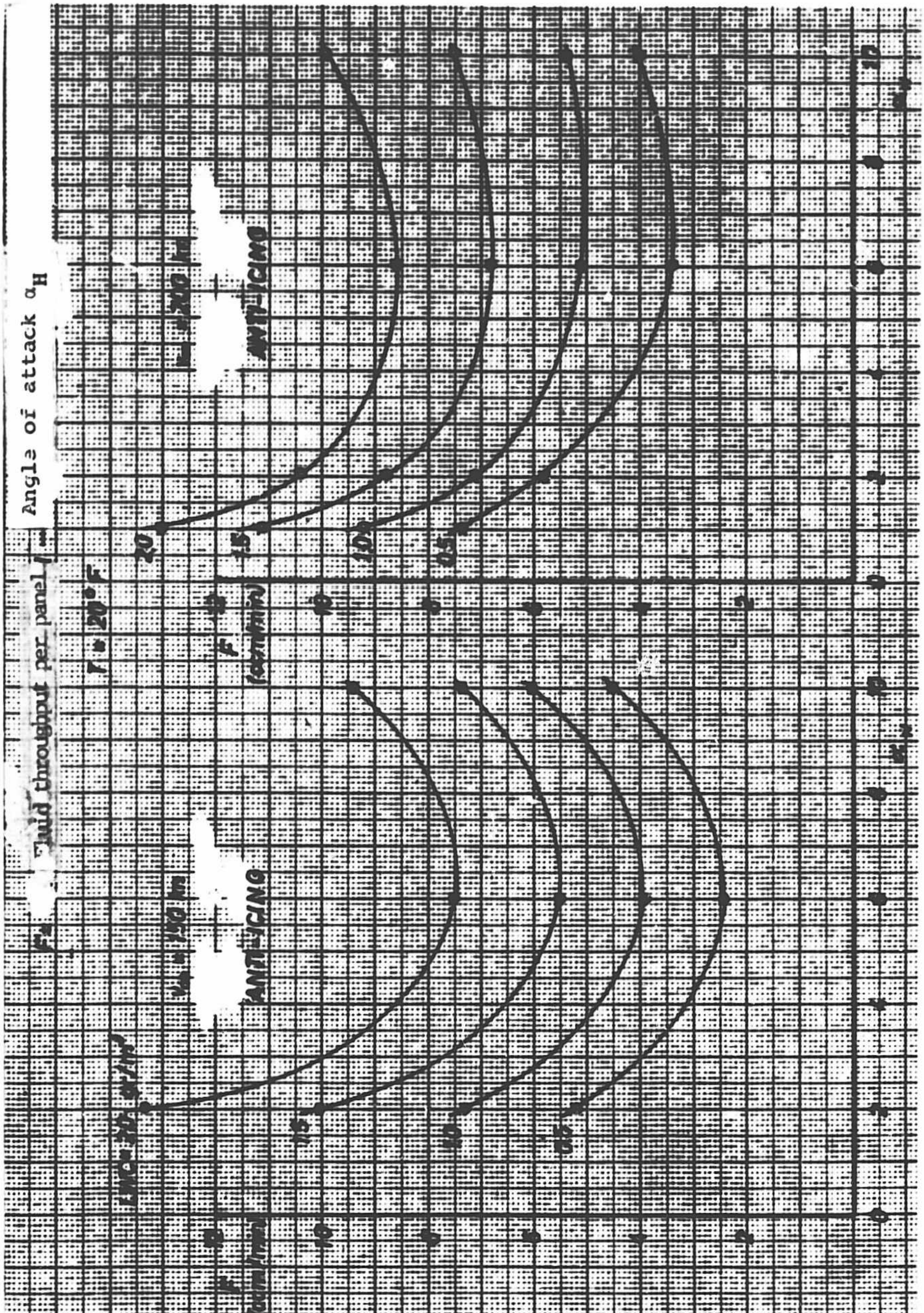
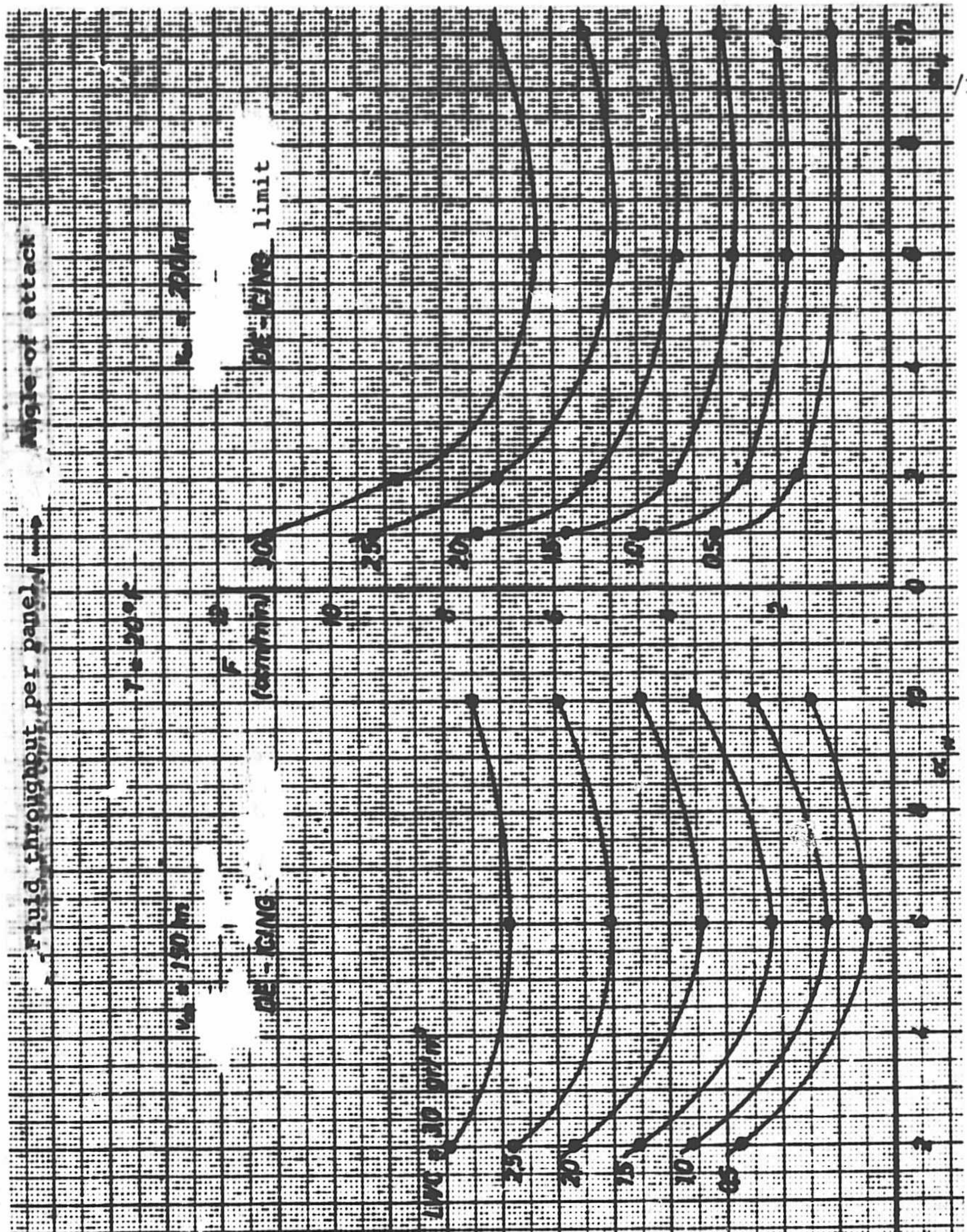


De-Icing Tests



De-icing Tests

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