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NORTH AMERICAN INSTRUMENTS INC.

PRELIMINARY WIND STUDIES FOR LOKI

By

Bernard Helfand

Design and Development of a Wind Correction Computer
For Use with M33 Director
in the Fire Control for LOKI Rockets

February 27, 1953

Quarterly Report for Second Quarter
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INTRODUCTION

The design of a computer system for LOKI which will automatically correct for the effect of wind during the boost phase of flight requires a knowledge of the function relating deviation at burnout with the wind distribution along the trajectory as well as a knowledge of the nature of the wind distribution at the time of flight. The function relating deviation at burnout with the distributed wind was determined in an earlier report on this project, Ref. 1, and was shown as a relation between influence coefficient (angular deviation of flight path direction at burnout from direction at launch per unit crosswind per unit distance increment along trajectory) and distance of rocket from launcher.

The purpose of this report is to examine the effects of arbitrary and observed wind distributions on LOKI, based on the foregoing influence function, with a view to establishing the basis for a practical field wind measuring technique to gather and transmit wind information to the correction computer.

From time series of wind profiles obtained experimentally, burnout deviations are computed and compared with concurrent winds at fixed levels for both instantaneous and time averaged winds to determine the feasibility of a correction method based on a linear relationship between burnout deviation and wind at one level. Although the available wind data were limited to about 150 cases and covered only the first 250 feet of trajectory accounting for 50% of the total correction, the high correlations found indicate a strong possibility of success for this method. Further work with more extensive observations will be necessary to substantiate these results and to explore other possibilities for wind specification such as block (space and time) averaging and to provide proportionality constants and limits of accuracy for working computer systems.

DISCUSSION

The total flight path angular deviation of LOKI due to wind during burning is given by:

$$\delta = \int_0^s \left[\Delta \gamma_F(s) \; W(s) \right] ds$$

where $\Delta \gamma_F(s)$ is the wind influence coefficient and $W(s)$ is the wind component perpendicular to the trajectory at a point on the trajectory distant s from the launcher. In the derivation of the $\Delta \gamma_F(s)$ function, Ref. 1, the wind component along the trajectory was assumed to be negligible in its effect on deviation at burnout, due to the high speed and forward acceleration of LOKI. A plot of $\Delta \gamma_F(s)$ is shown in Fig. 1.

The cumulative effect of a constant crosswind during burning is shown in Fig. 2 when δ is plotted against s for unit crosswind. Of the total deviation 0.8 mil, 50% is due to the first 250 feet of trajectory, while 94% is accounted for by the first 1000 feet.

An initial study of δ variation was made using a synthetic wind made up of a steady 1/7 power law component and a superimposed sinusoidal gust component, varying wave length and amplitude. The assumed wind is described by:

$$W(s) = W_0 \left(\frac{s}{s_0}\right)^{1/7} \left[1 + K \sin \frac{2\pi}{\lambda} s \right], \quad 0 < s < 1500 \text{ ft.}$$

$$W(s) = W_{1500}, \quad 1500 < s < 2000 \text{ ft.}$$

where $W(s)$ = wind velocity at height s

S_o = reference height, 50 ft. at which

λ = wave length of gust component, ft.

K = gust amplitude factor

Values of deviation were computed for

λ = 50, 100, 200 and 400 ft. with K = 0, 0.5 and 1.0

Results are summarized in the following table

Relative Deviation at Burnout

L \ K	0	0.5	1.0
50	1	1.014	1.029
100	1	1.027	1.043
200	1	1.004	1.010
400	1	1.042	1.084

Significant effects would undoubtedly be observed at values of λ greater than 400 feet and with the introduction of gust phase angle as a parameter. This investigation was not pursued further at this time, however, since the chief interest lies in the application to sampling requirements. It is evident from the small effect of the gust component on δ for $\lambda = 50$ and 100 feet, that for practical purposes the wind will be completely described by measurements at 25-foot intervals, the intervals that occur in the experimental data to be discussed.

From data published in Refs. 2 and 3, the vertical wind profiles shown in Figs. 3 to 6 were obtained. These show the time histories at one-second intervals, of the velocity distribution with height. The original measurements were made with pressure plate anemometers described in the foregoing references having an effective time constant of about 0.1 sec., located at 25-foot intervals on a 250-foot tower. Wind direction was not recorded, and the profiles do not exactly represent the crosswind in a fixed plane that would apply to a vertical trajectory. The assumption of constant direction leads to an exaggerated rather than smoothed profile. Four separate runs are included with velocities ranging from 14 to 54 mph, and all were obtained in winter storms in Michigan.

From the wind profiles, deviation sequences were calculated. The wind values at each measurement point were assumed to describe the wind in a layer extending 12 1/2 feet to either side (histogram distribution). Products of these values and the corresponding influence coefficient were summed to give the contribution of the wind in the first 250 feet of trajectory. This contribution is about 50% of the total that would be obtained if the integration were carried to burnout.

Time histories of deviation are plotted in Figs. 7A to 10A for the four runs along with concurrent winds at the 25, 50, 100, and 150-foot levels. These indicate a trend of wind velocity consistent with deviation. To better show the trend of a four-second average wind (arithmetic mean of the wind at time T, and the previous three observations) is plotted in Figs. 7B - 10B.

Deviation is plotted against wind velocity in Figs. 11A - 14A and against four-second average wind velocity in Figs. 11B - 14B . Regression lines are included determined by a least squares linear fit with Wind the independent variable. The limits within which 90% of the observations fall are also shown. These were determined assuming that the departure of δ from the regression line follows a normal Gaussian distribution. Histograms showing the distribution corresponding to Figs. 12A and 12B are shown in Figs. 15 and 16 . The following table summarizes the results:

Wind Measurement Level	Wind Deviation at Burnout			4-Second Average Wind Deviation at Burnout		
	Regression Line Slope mils/mph	Correlation Coefficient	Deviation Spread for 90% Obs. mils	Regression Line Slope mils/mph	Correlation Coefficient	Deviation Spread for 90% Obs. mils
25	.544	.802	± 4.9	.582	.823	± 4.4
50	.399	.805	± 4.7	.419	.836	± 3.9
100	.488	.901	± 3.3	.491	.896	± 3.2
150	.441	.939	± 2.6	.446	.945	± 2.3

CONCLUSIONS

It is apparent from the table that a correction based on the wind velocity at a fixed level and the corresponding regression line slope might be entirely reasonable in view of the small spread in wind deviation. The high correlations at 100 and 150 feet result from the secondary peak in the influence function near 150 feet and possibly from a tendency of the wind profile to "pivot" about this level.

Although the available wind data were obtained in one locality and covered only the first 250 feet of trajectory, accounting for 50% of the total effect, the high correlations do indicate a strong possibility of success for methods based on simple averages and limited sampling. Further work is being carried on first, to verify the influence function by comparison between experimental ballistic data and concurrent wind observations and second, to extend the statistical study. Large quantities of additional wind profile sequences, extending as far as 1000 feet, will be required for this purpose, and the use of correlation functions to describe the wind may be adopted to simplify the statistical analysis and to make the information generally useful.

REFERENCES

Reference (1) "LOKI Wind Response Analysis" by Donald L. Baker and Warren L. Phillips, January 15, 1953.

(2) "Variation of Wind Velocity and Gusts with Height" by R. H. Sherlock, M. ASCE, Proceedings of American Society of Civil Engineers, Vol. 78, April 1952.

(3) "Wind Structure in Winter Storms" by R. H. Sherlock and M. B. Stout, Journal of the Aeronautical Sciences, Vol. 5, 1937.

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FIGURE 1
LOKI CROSSWIND INFLUENCE FUNCTION

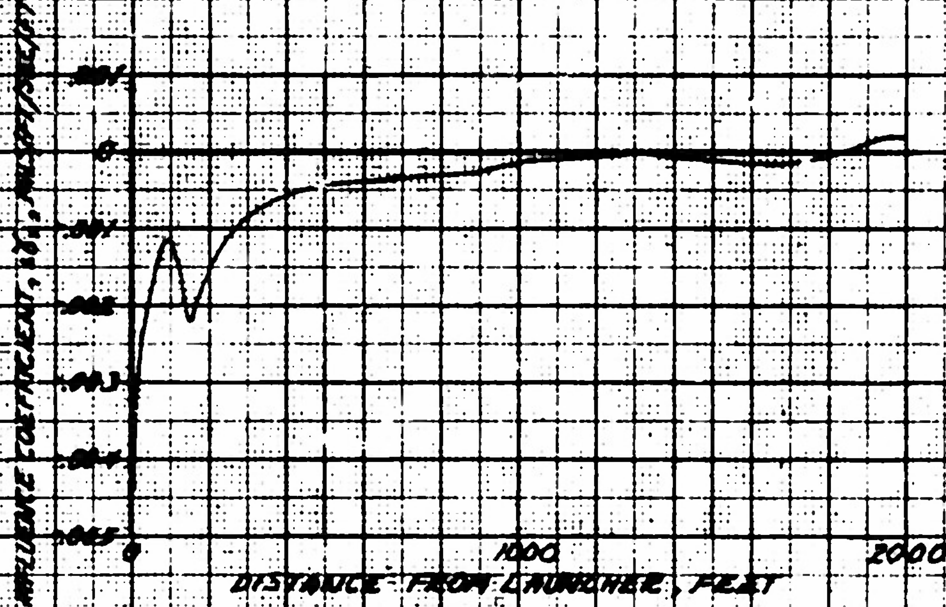

FIGURE 2
DEVIATION AT BURNOUT
DUE TO UNIT CROSSWIND

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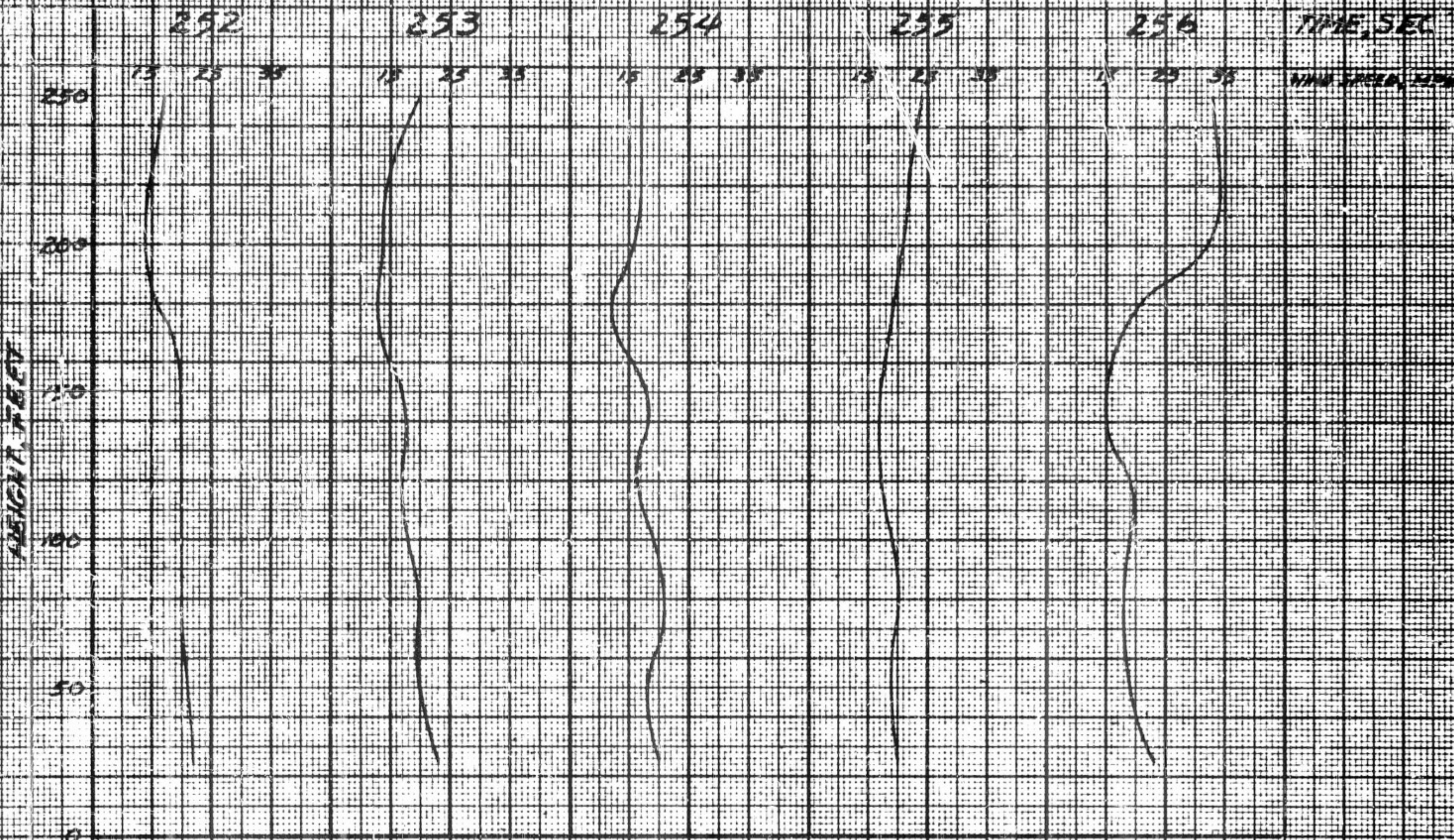

FIGURE 3A - WIND PROFILE SEQUENCE
RUN 025
REFERENCE (2)

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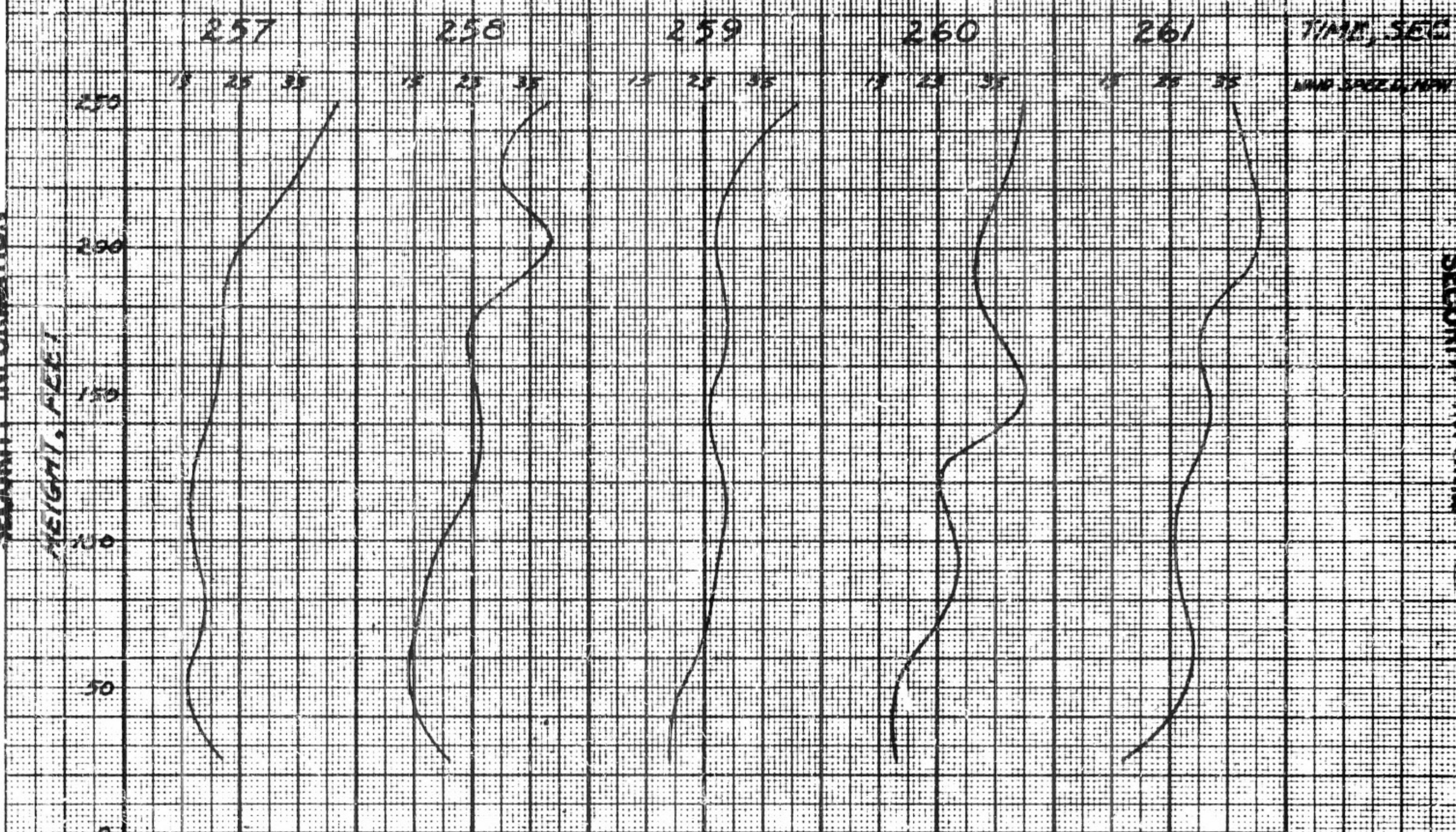

FIGURE 3B - WIND PROFILE SEQUENCE
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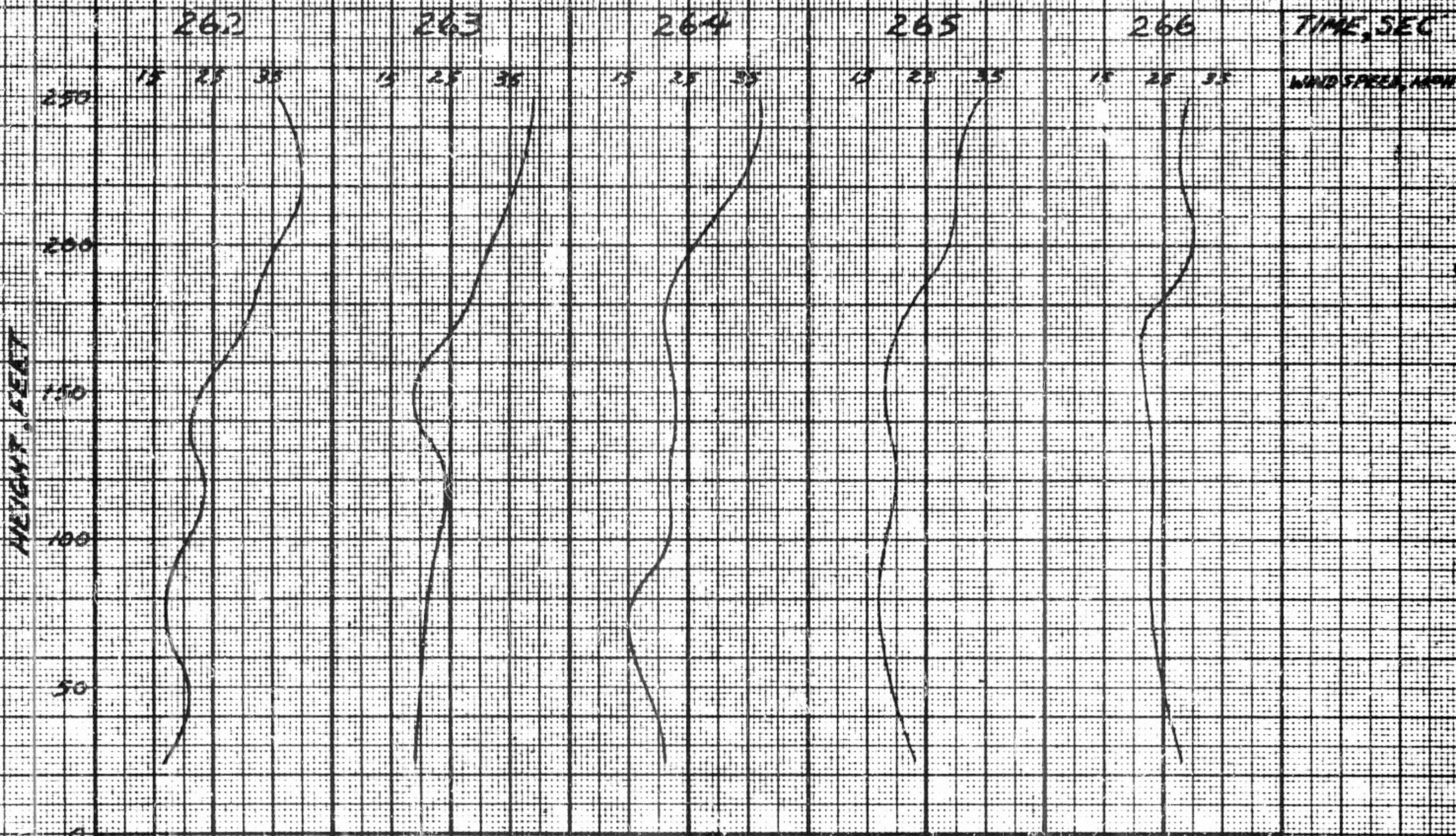

FIGURE 3c - WIND PROFILE SEQUENCE
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REFERENCE (2)

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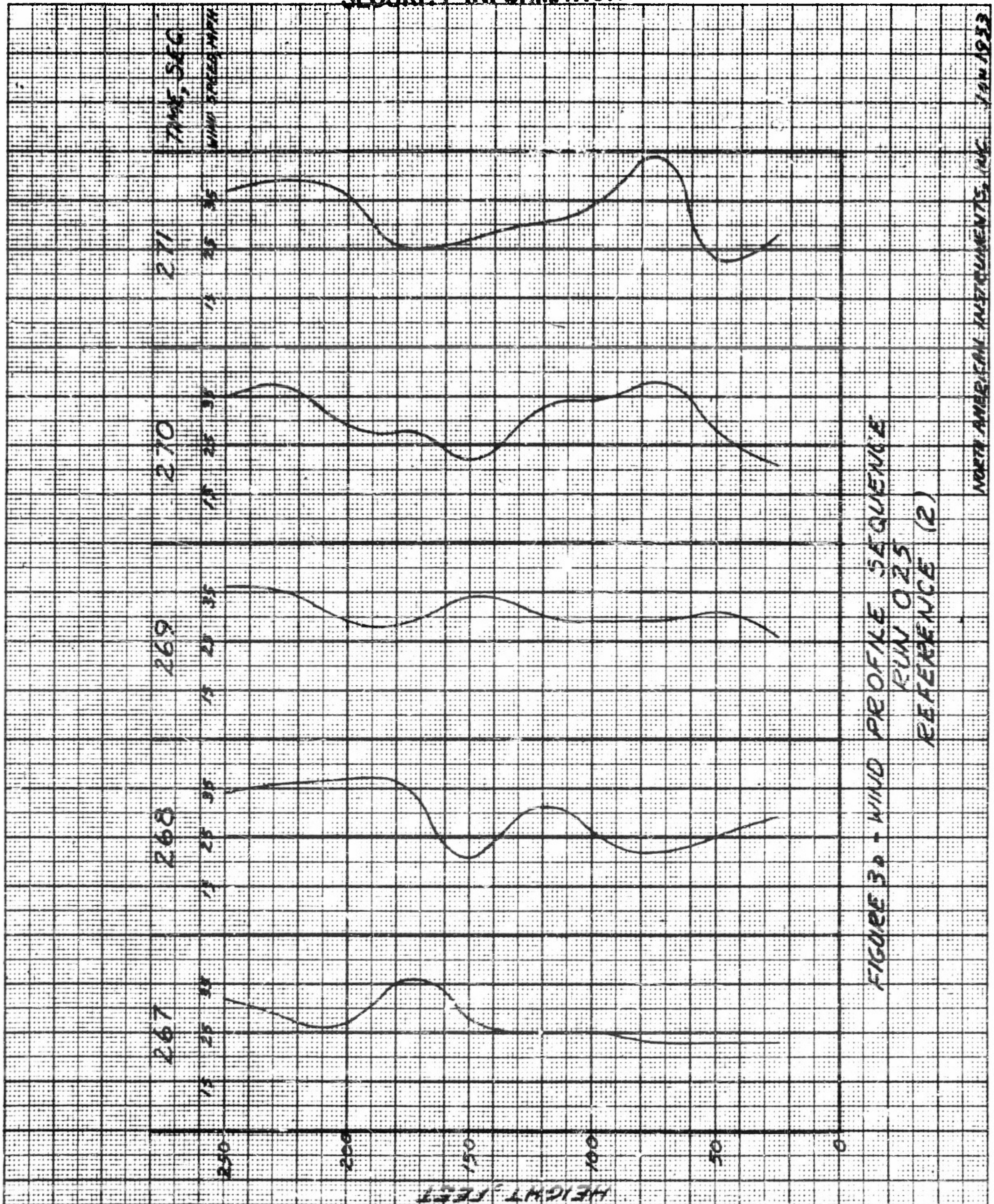

FIGURE 3p - WIND PROFILE SEQUENCE
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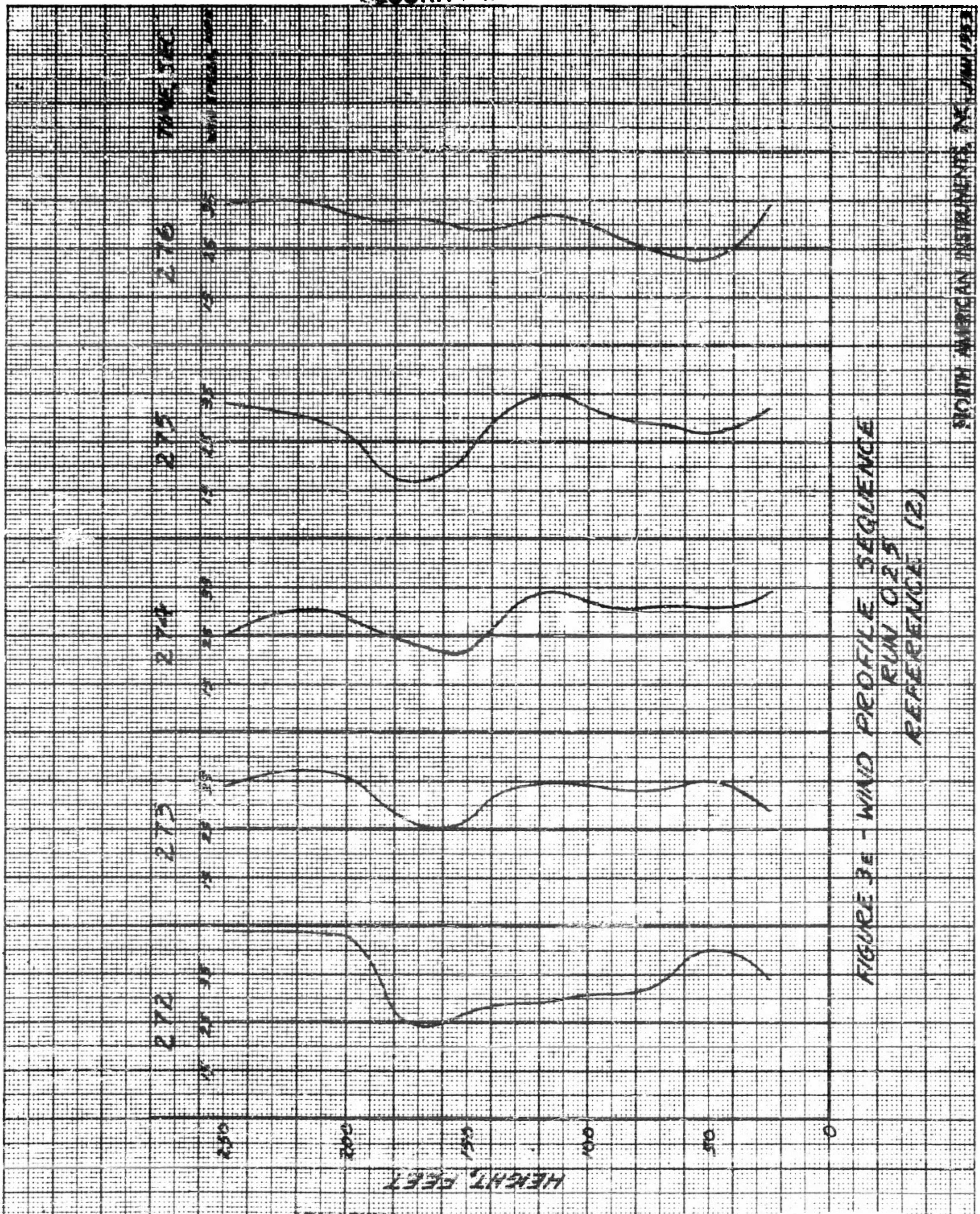

FIGURE 3e - WIND PROFILE SEQUENCE
RUN 0.25
REFERENCE (2)

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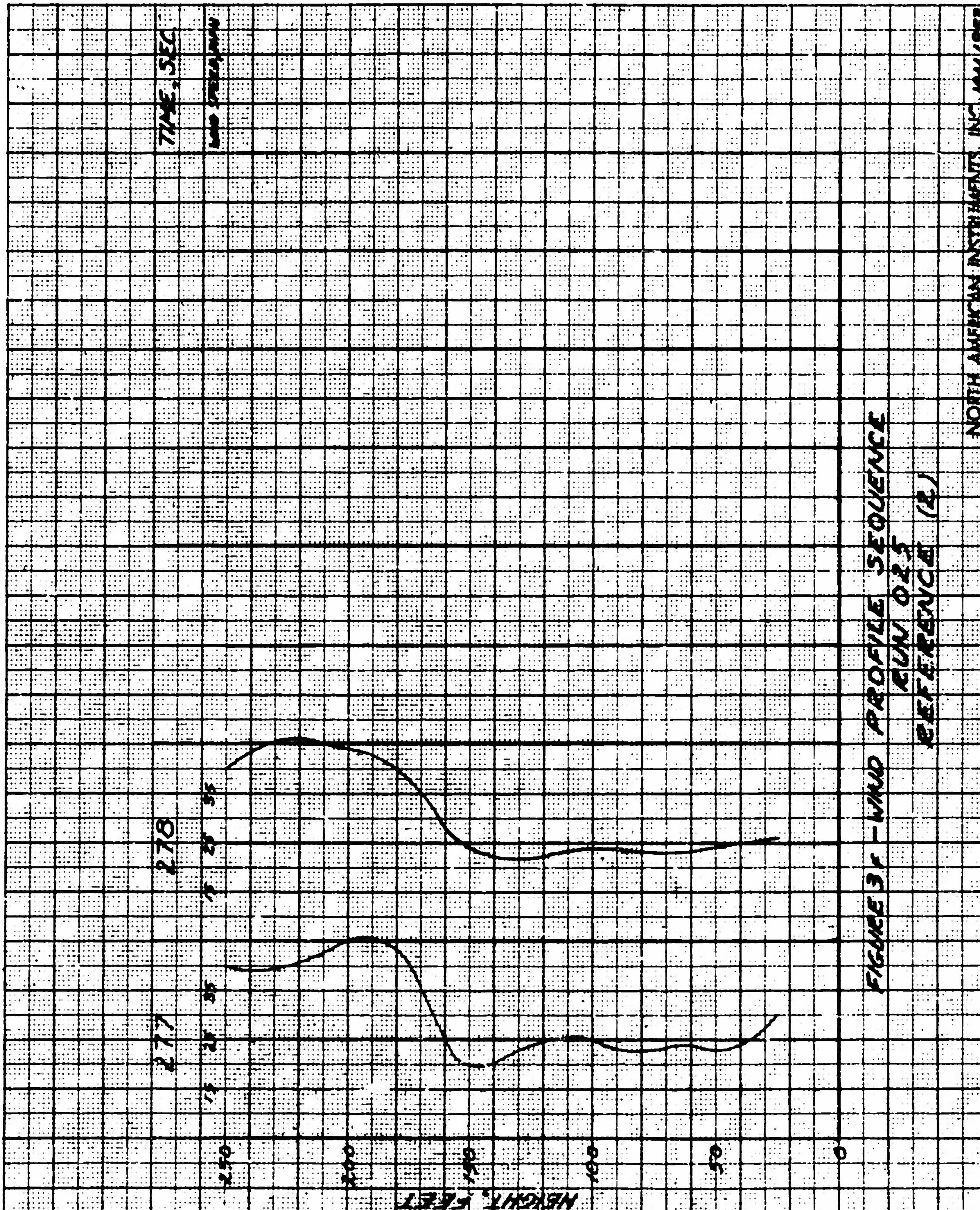

FIGURE 3F - WIND PROFILE SEQUENCE
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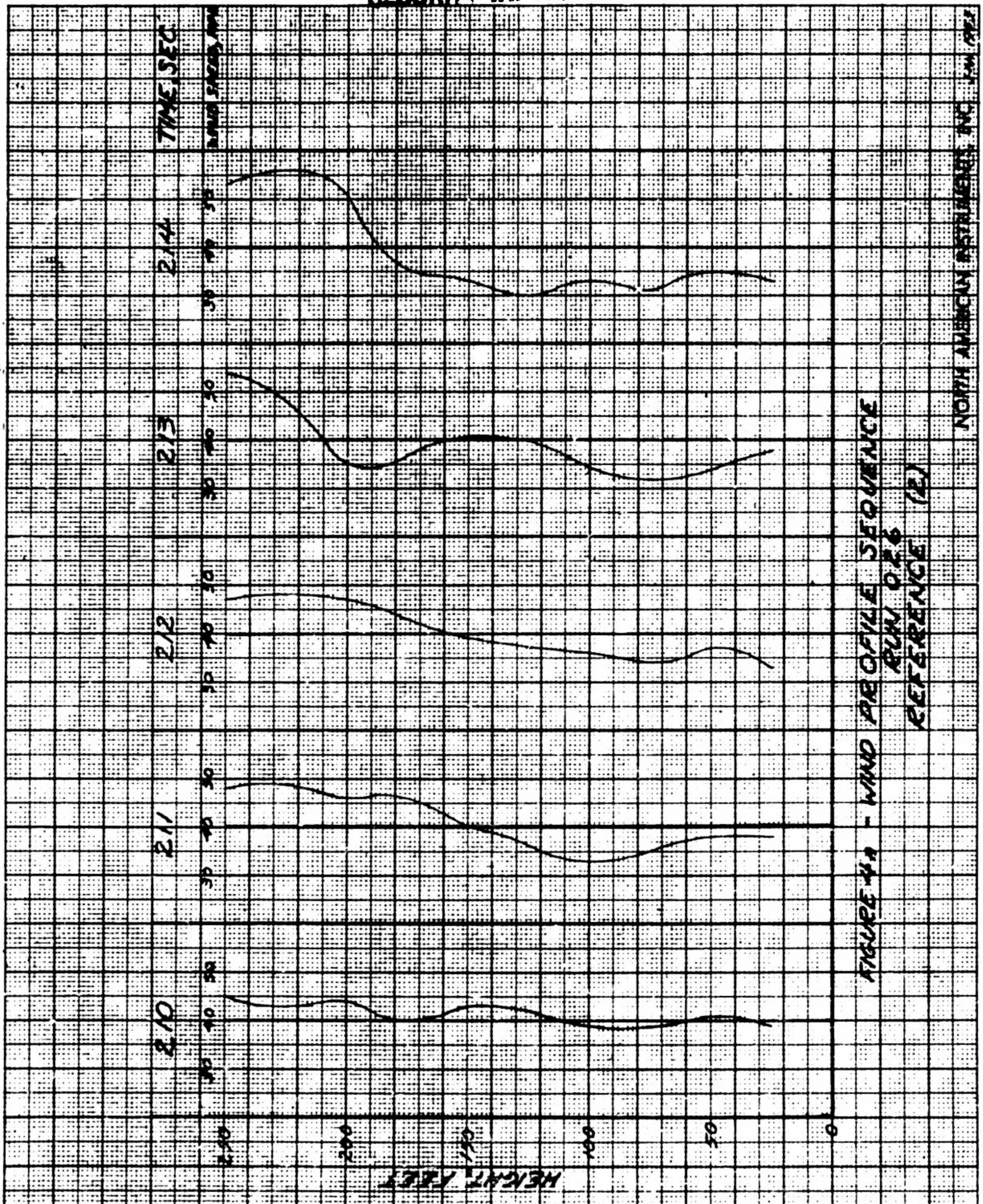

FIGURE 4a - WIND PROFILE SEQUENCE
RUN 026
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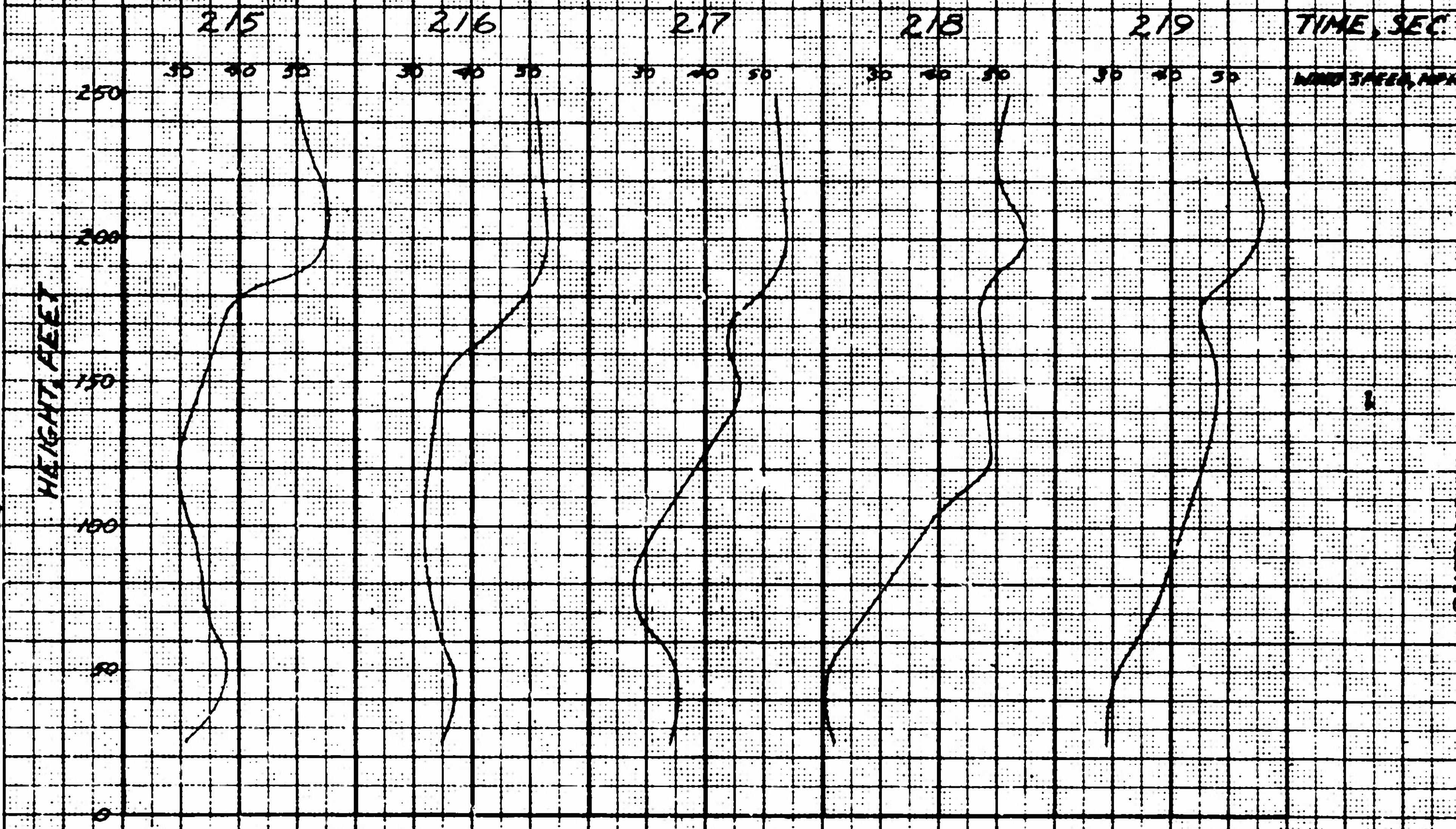

FIGURE 48 - WIND PROFILE SEQUENCE
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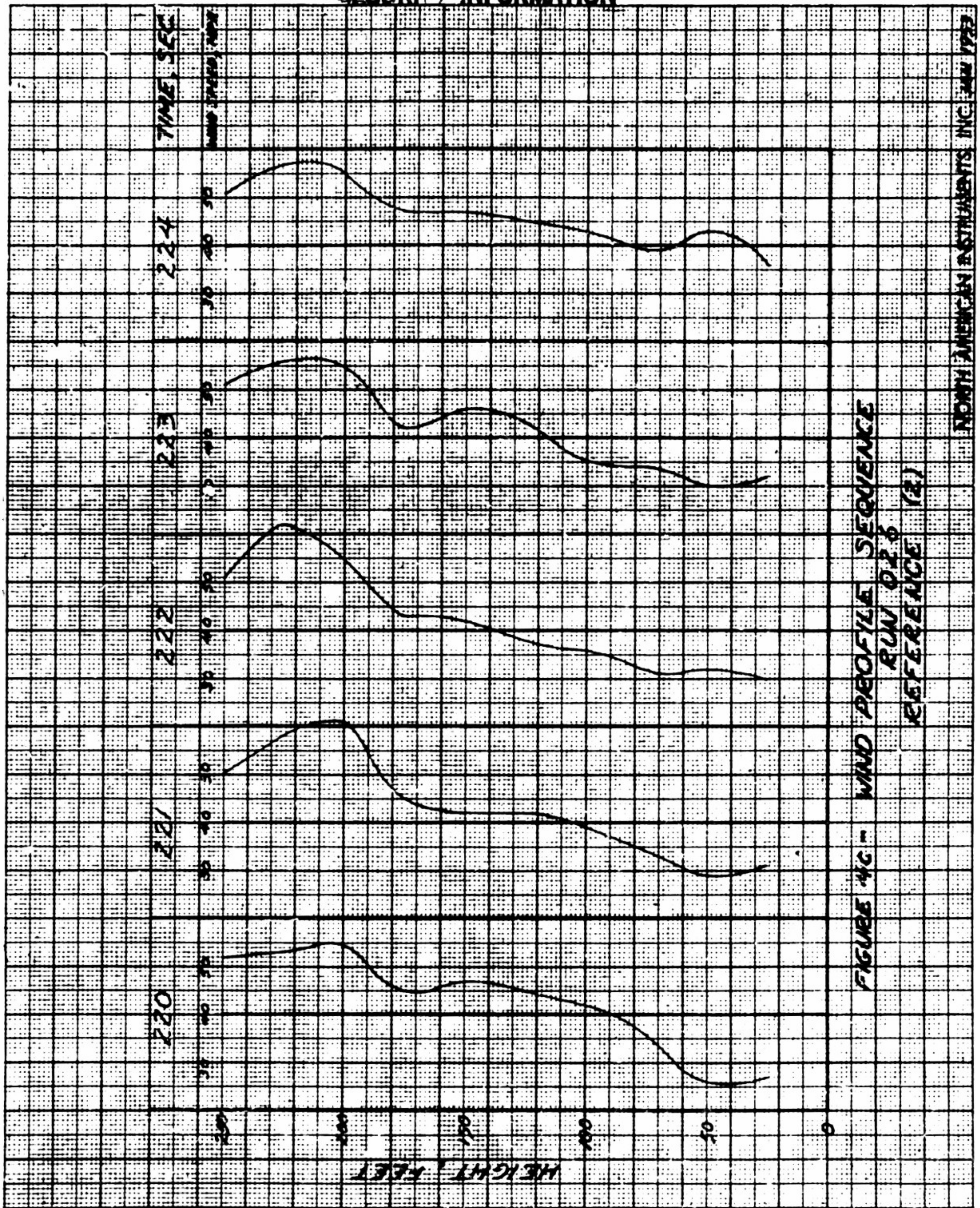

FIGURE 4C - WIND PROFILE SEQUENCE
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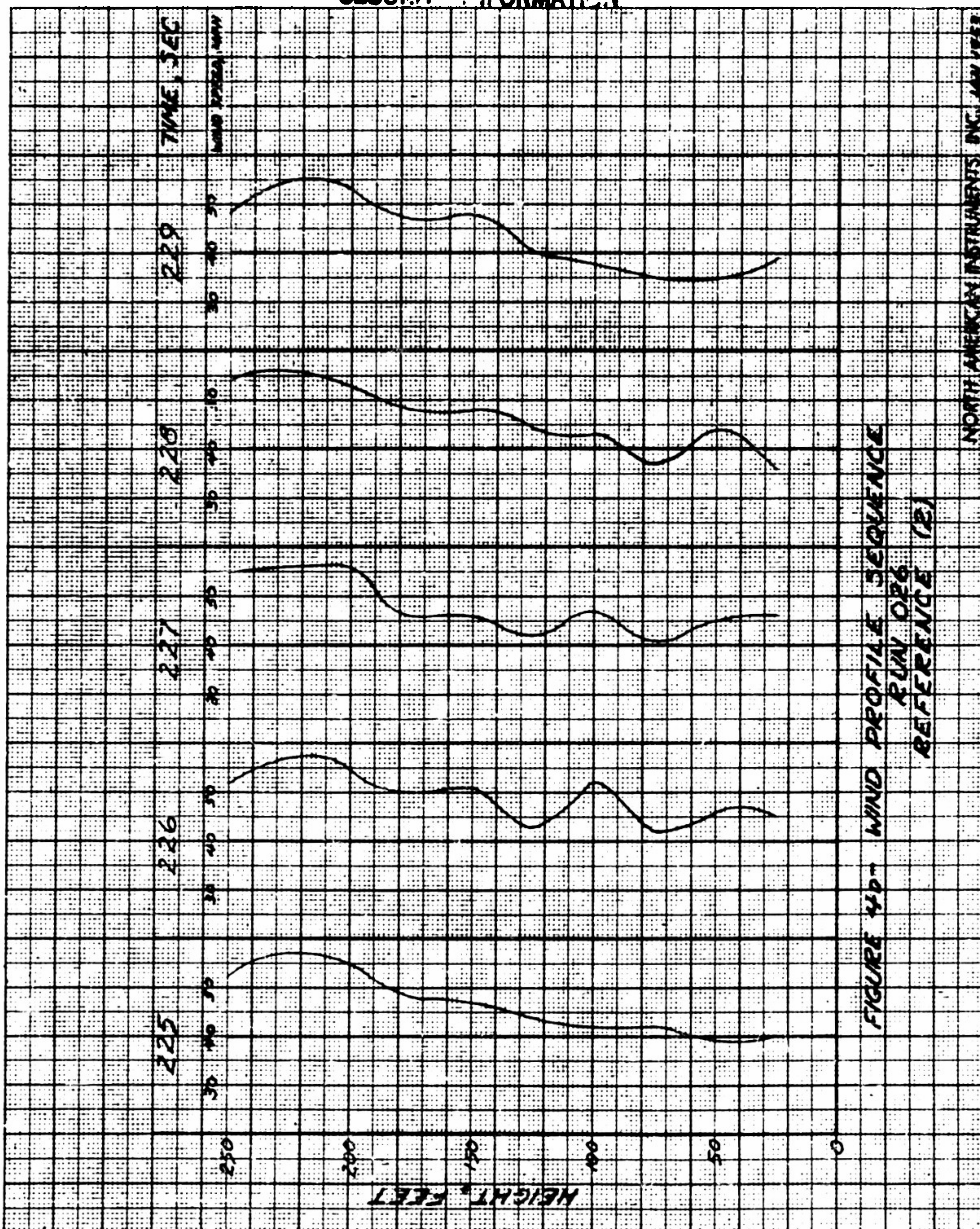

FIGURE 4D - WIND PROFILE SEQUENCE
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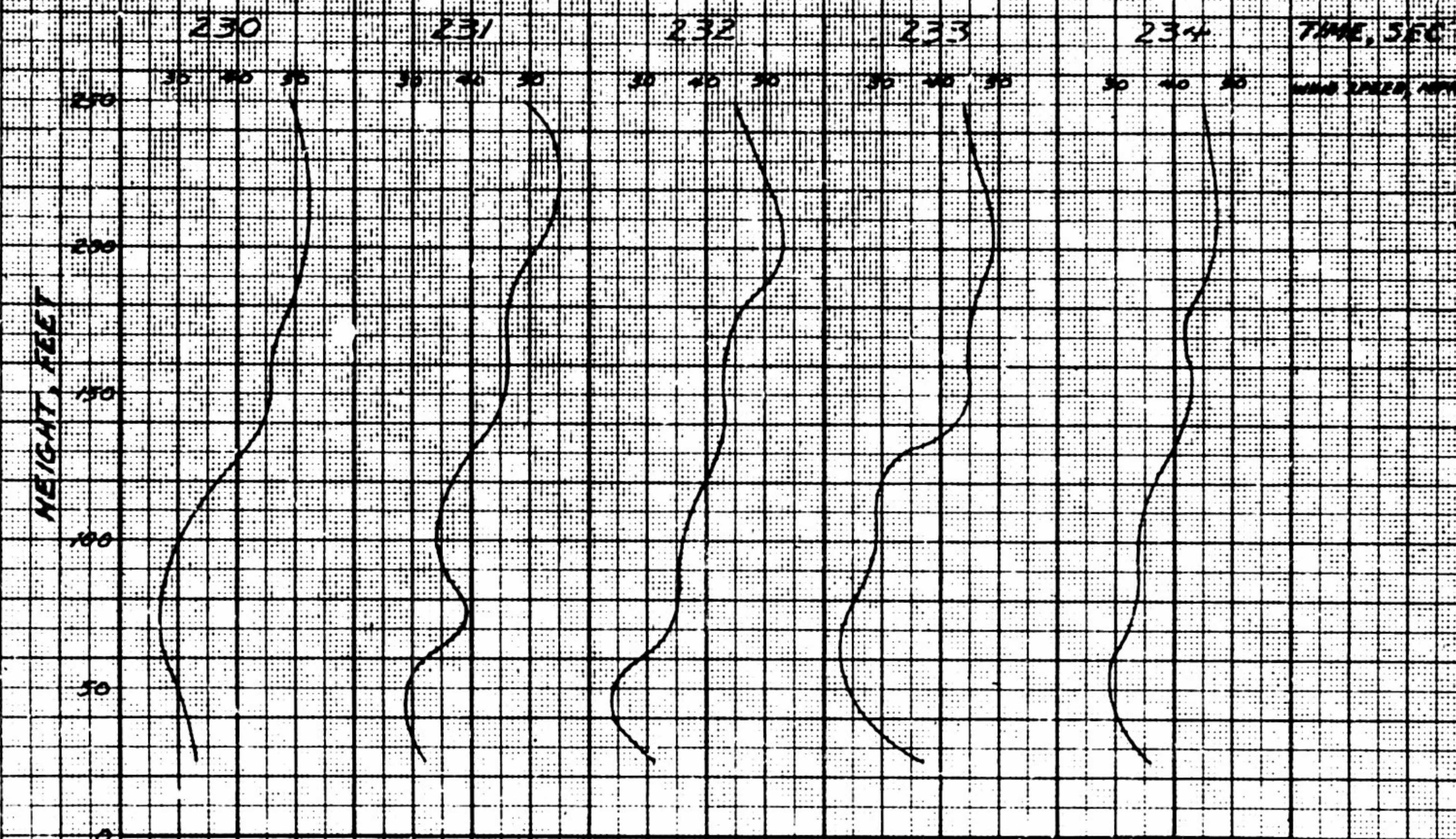

FIGURE 4E - WIND PROFILE SEQUENCE
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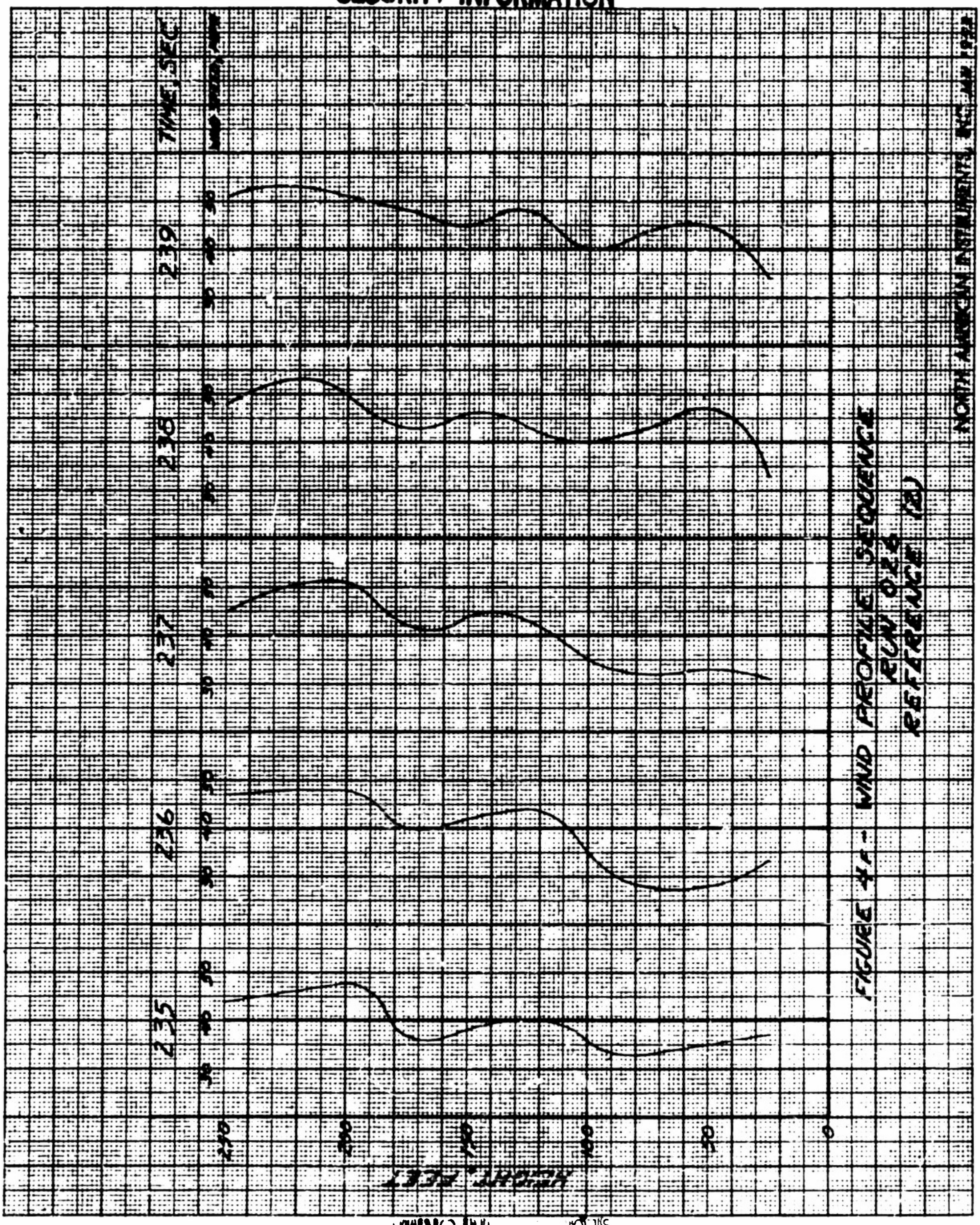

FIGURE 4F - WIND PROFILE SEQUENCE
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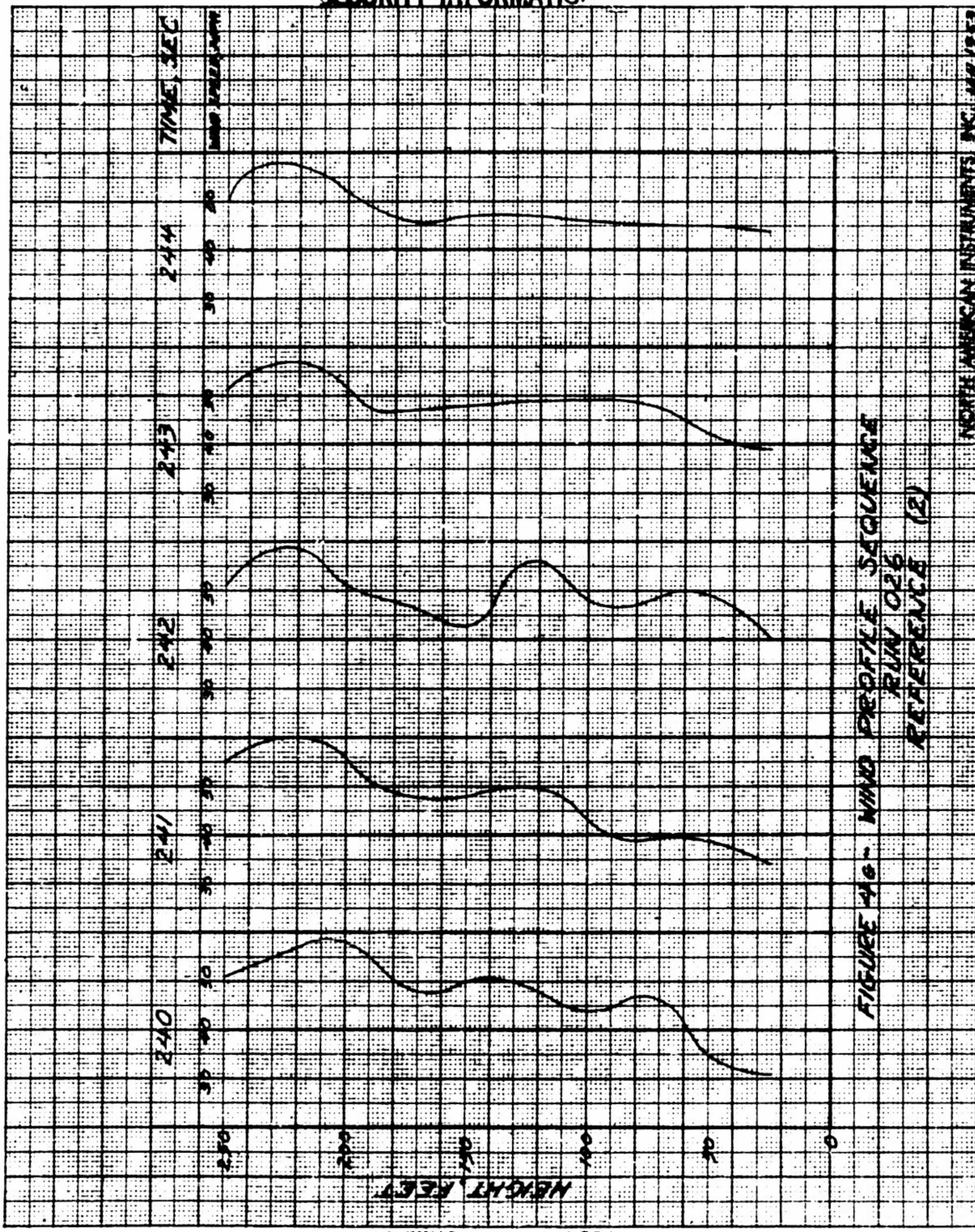

FIGURE 46 - WIND PROFILE SEQUENCE
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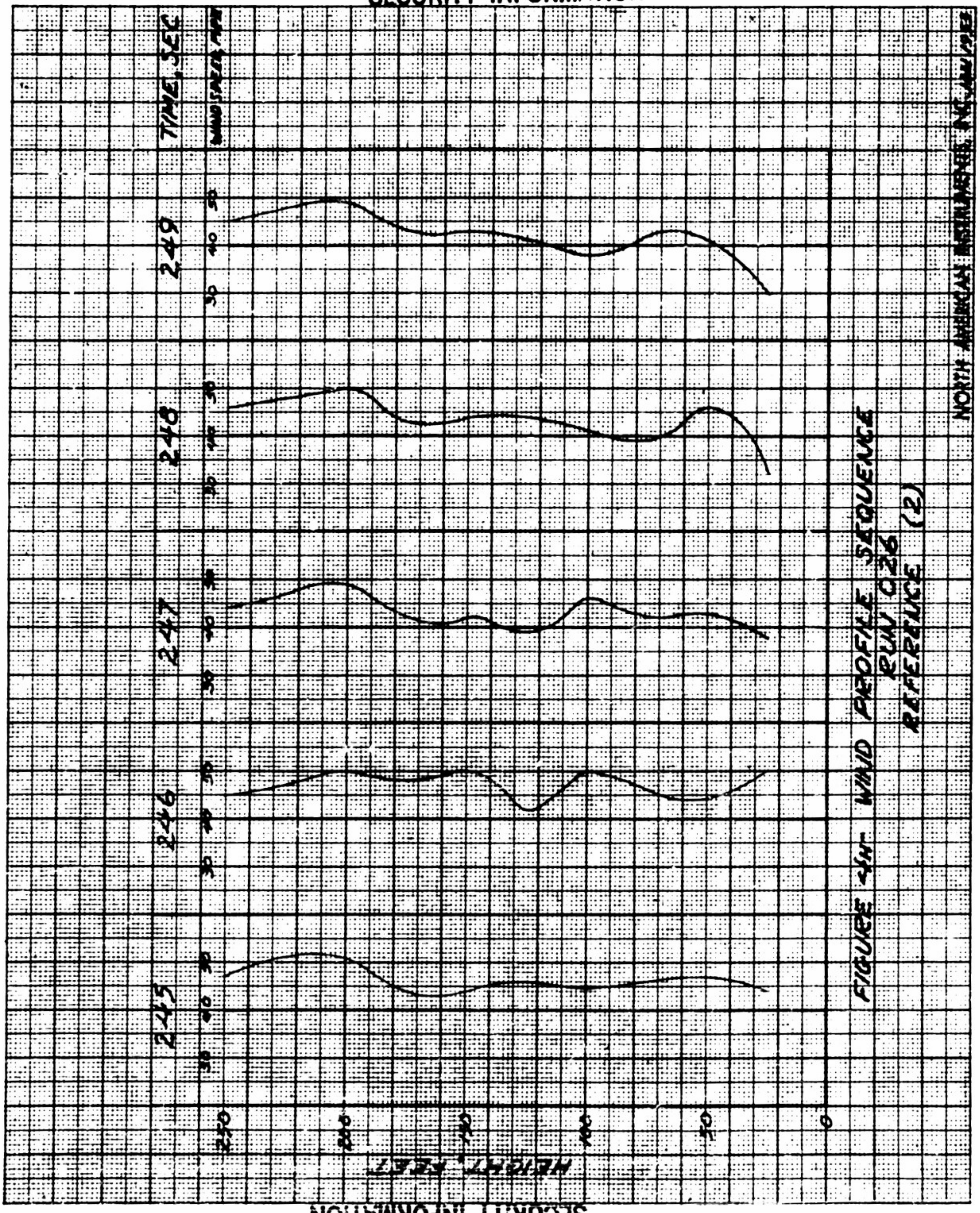

FIGURE 4H - WIND PROFILE SEQUENCE
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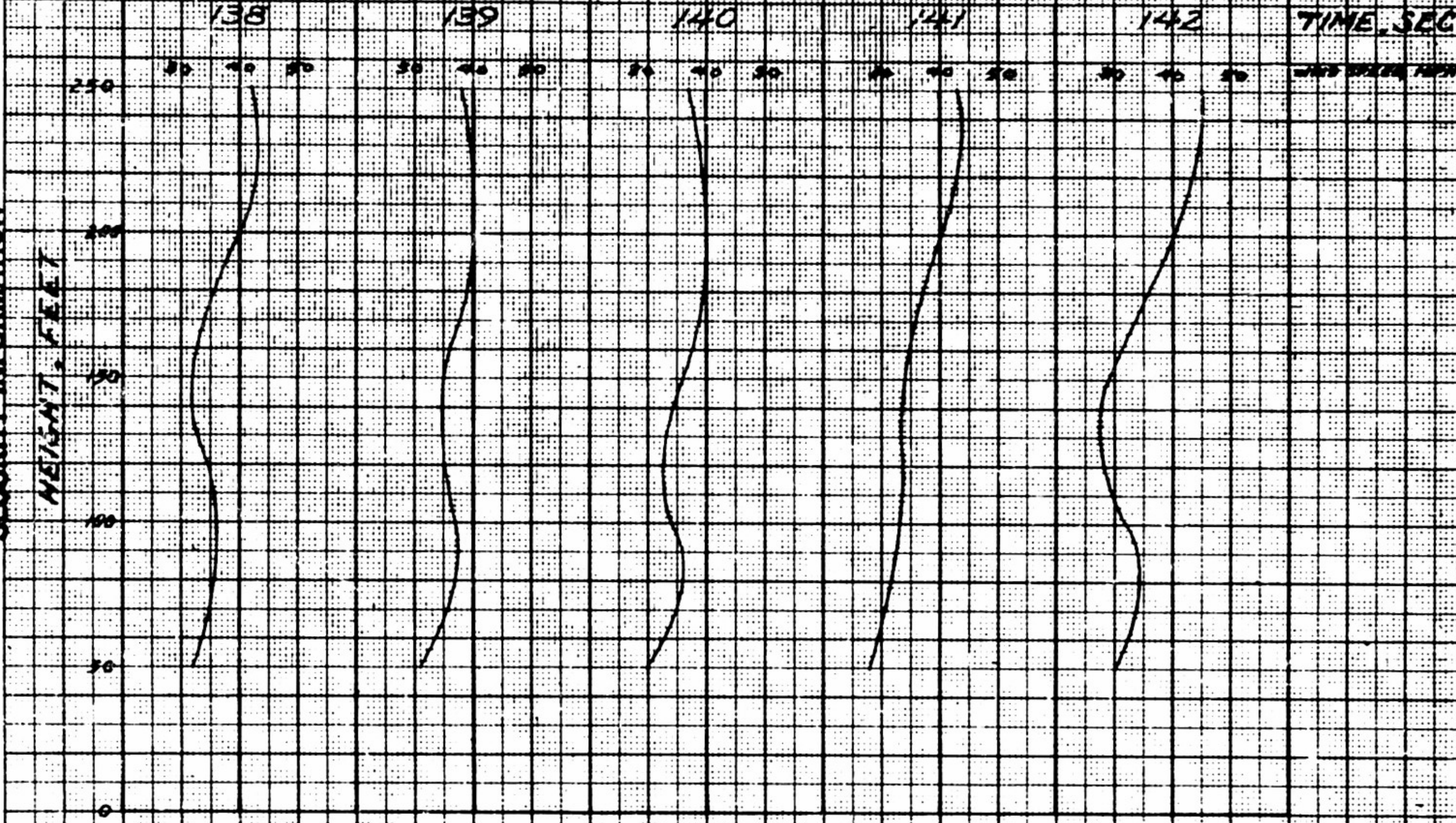

FIGURE 5a - WIND PROFILE SEQUENCE
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REFERENCE (3)

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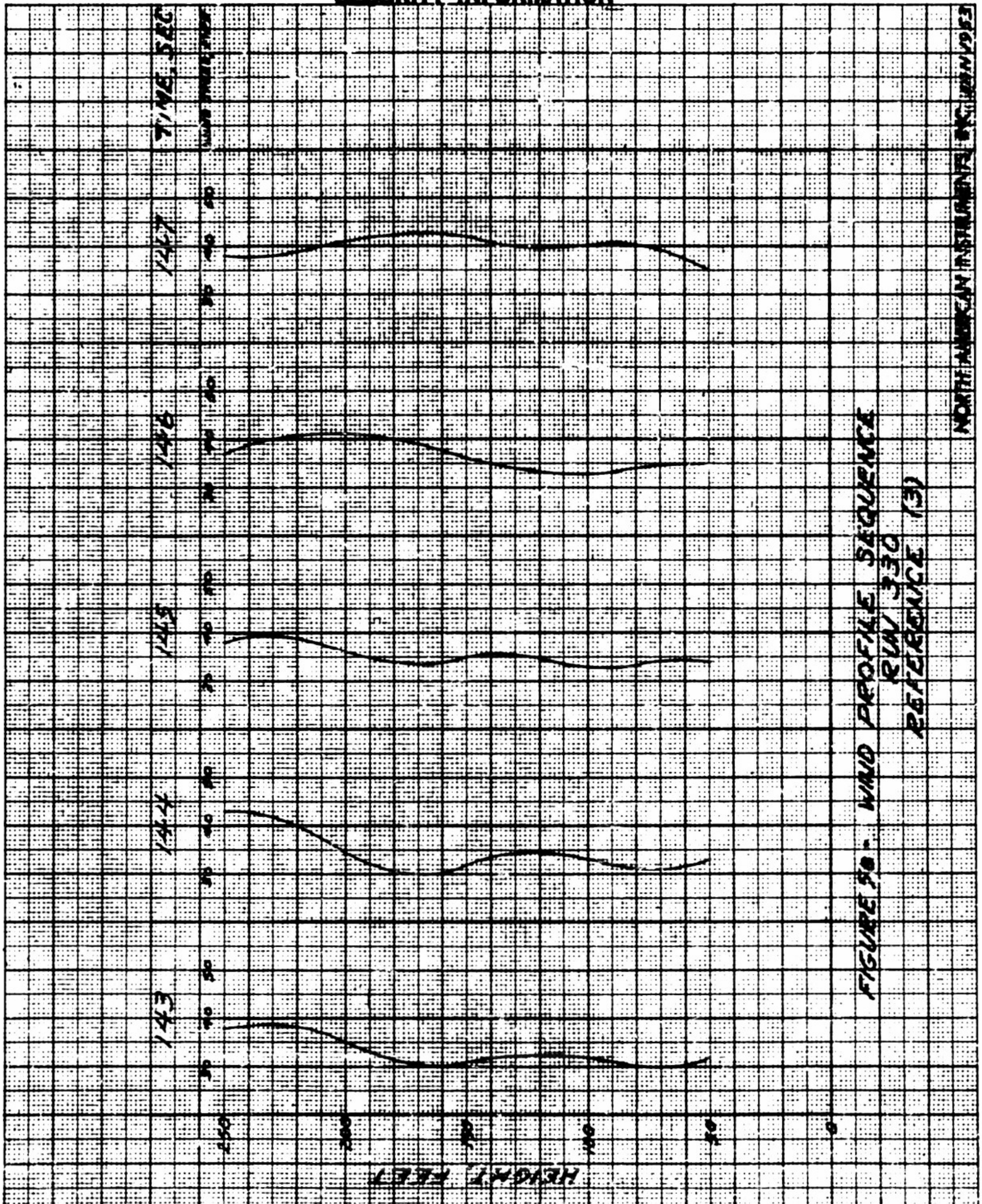

FIGURE 98 - WIND PROFILE SEQUENCE
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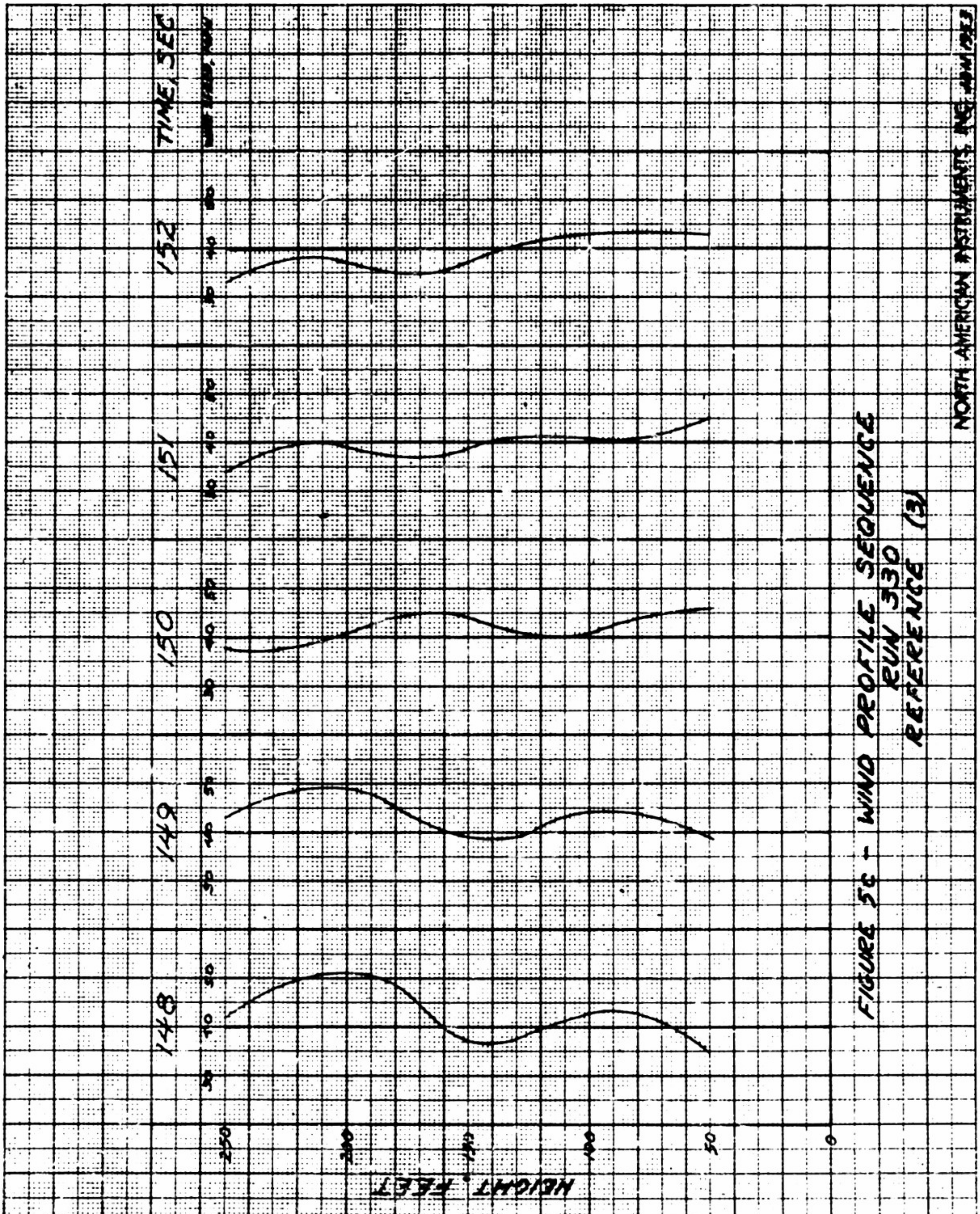

FIGURE 5c - WIND PROFILE SEQUENCE
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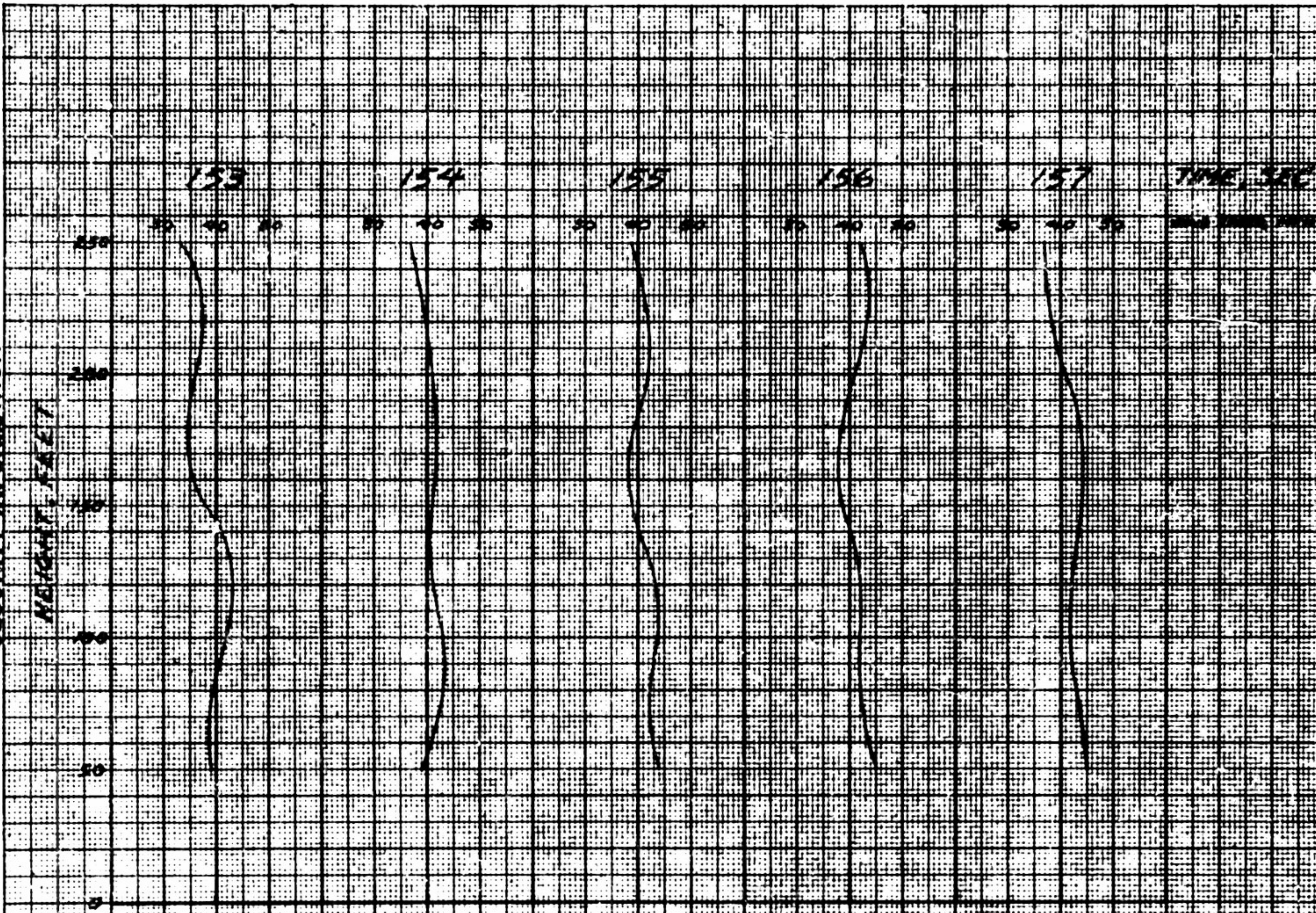

FIGURE 5b - WIND PROFILE SEQUENCE
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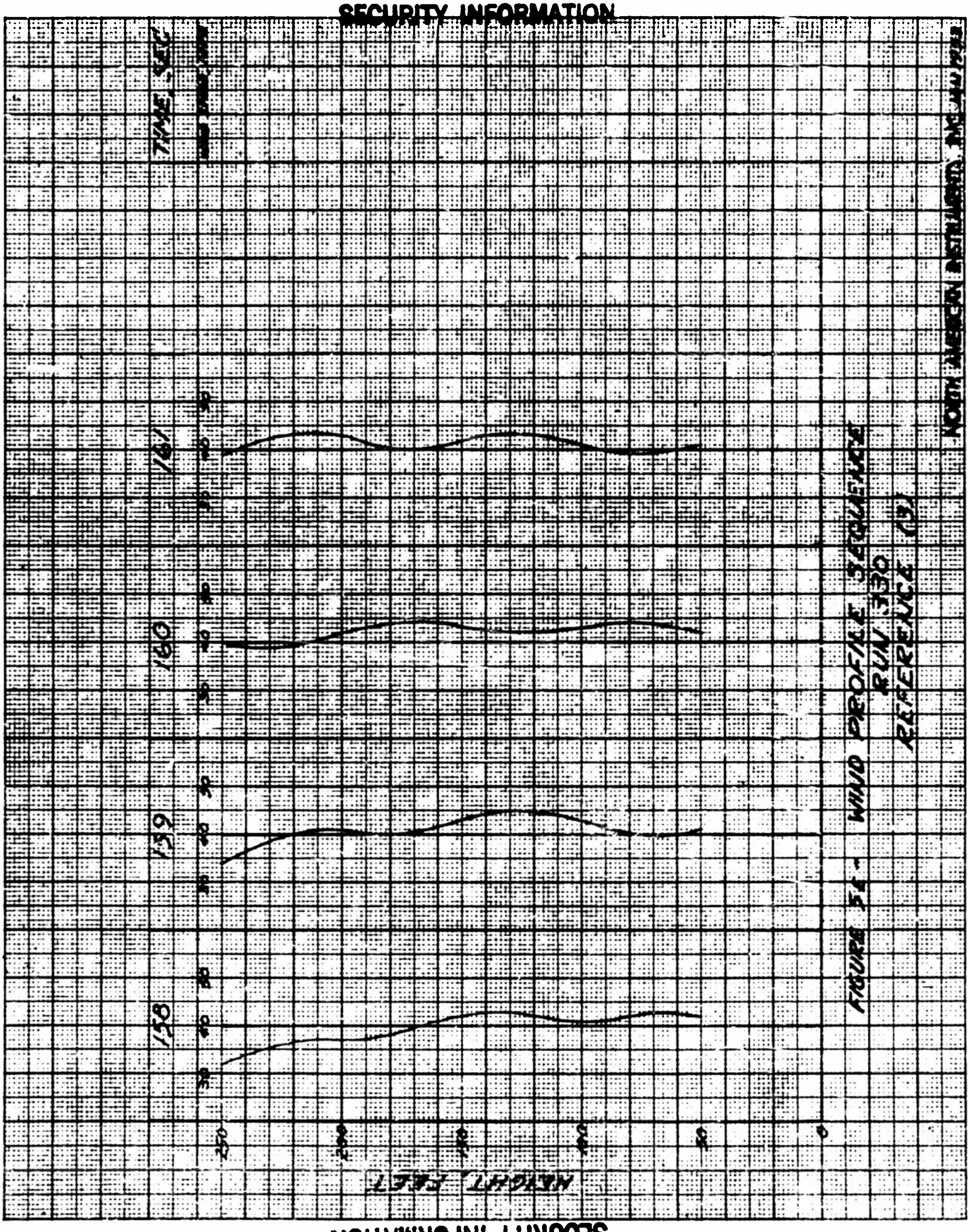

FIGURE 5E - WIND PROFILE SEQUENCE
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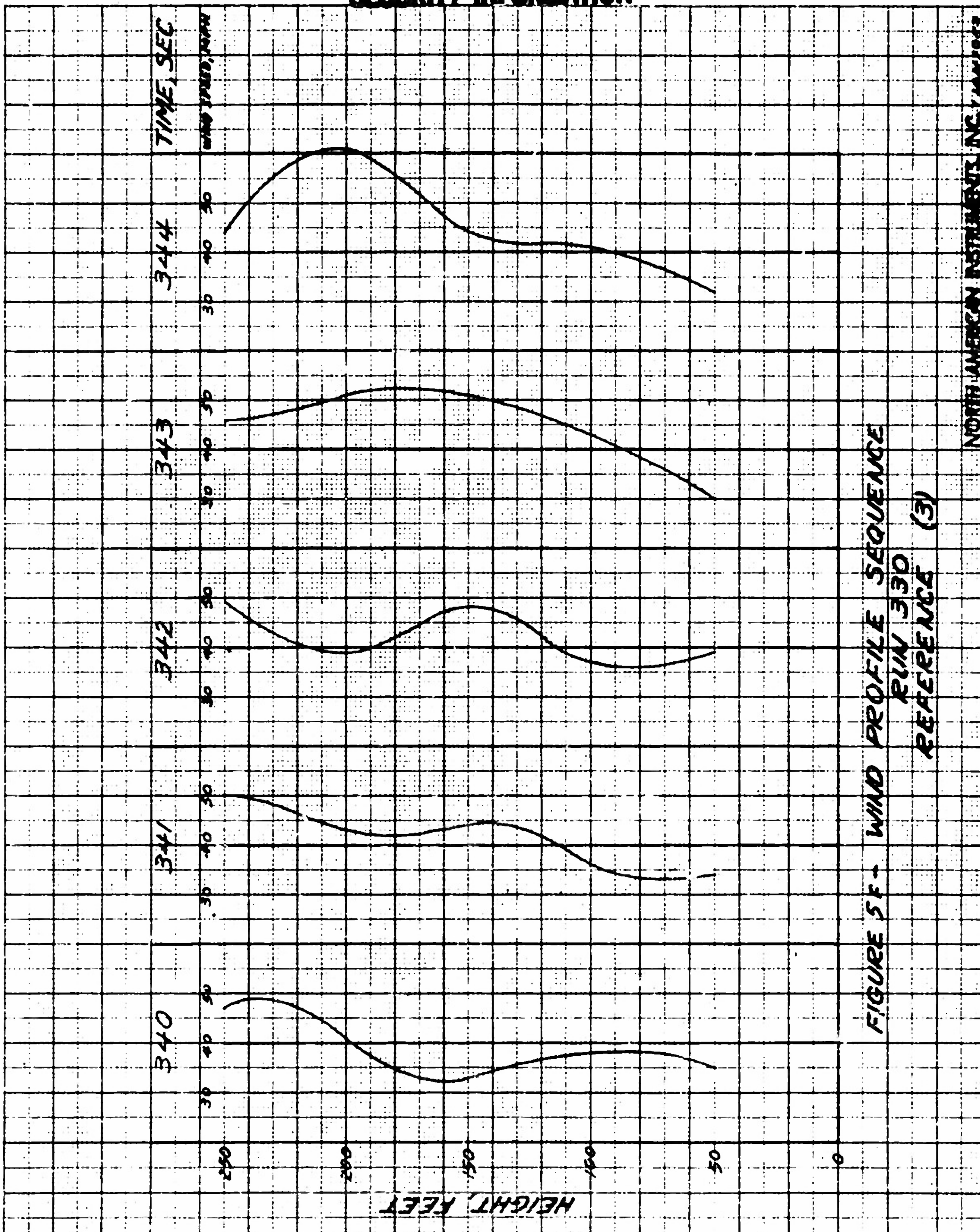

FIGURE 5F - WIND PROFILE SEQUENCE
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FIGURE 56 - WIND PROFILE SEQUENCE
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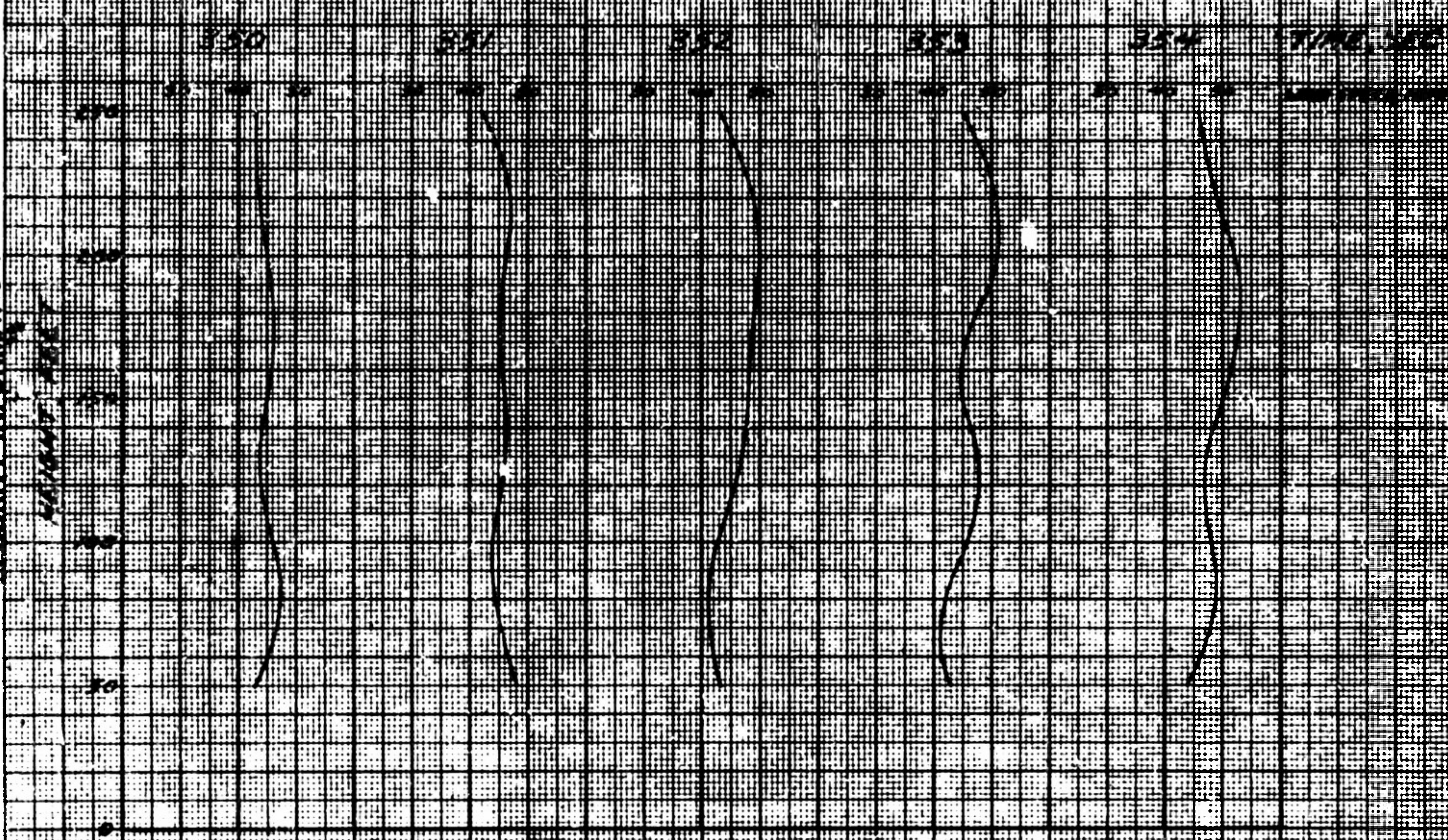

FIGURE 5a - WIND PROFILE SEQUENCE
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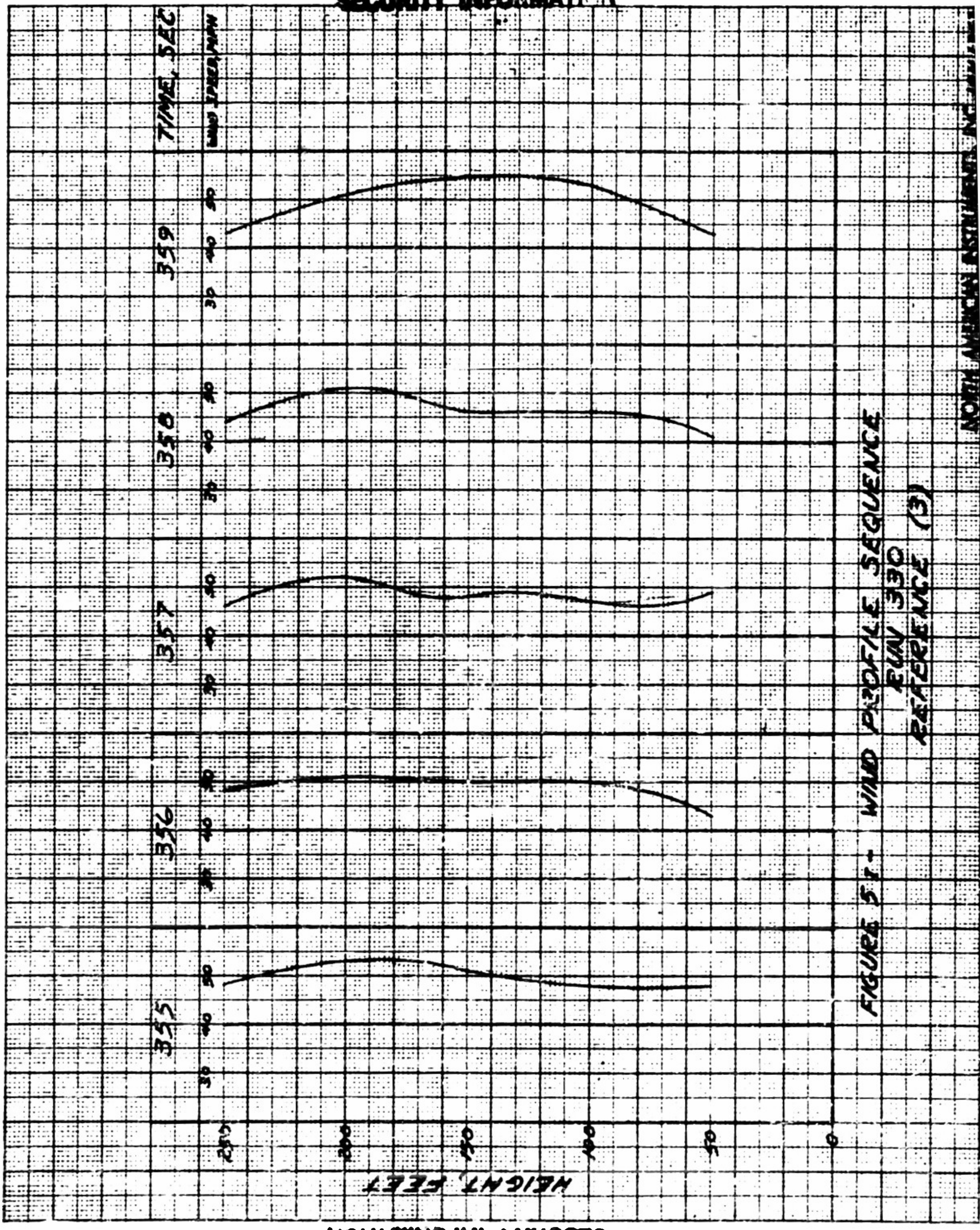

FIGURE 51 - WIND PROFILE SEQUENCE
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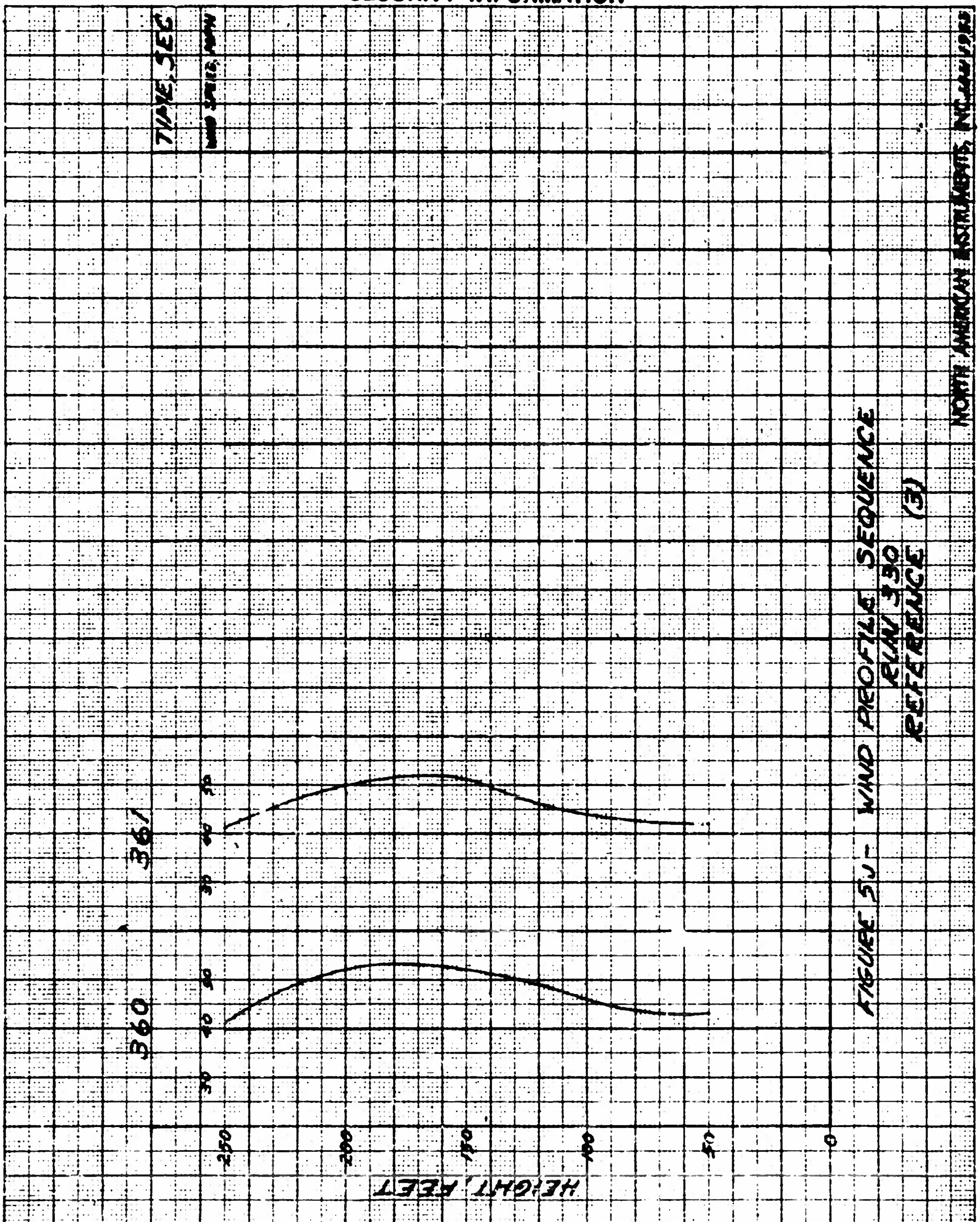

FIGURE 5U - WIND PROFILE SEQUENCE
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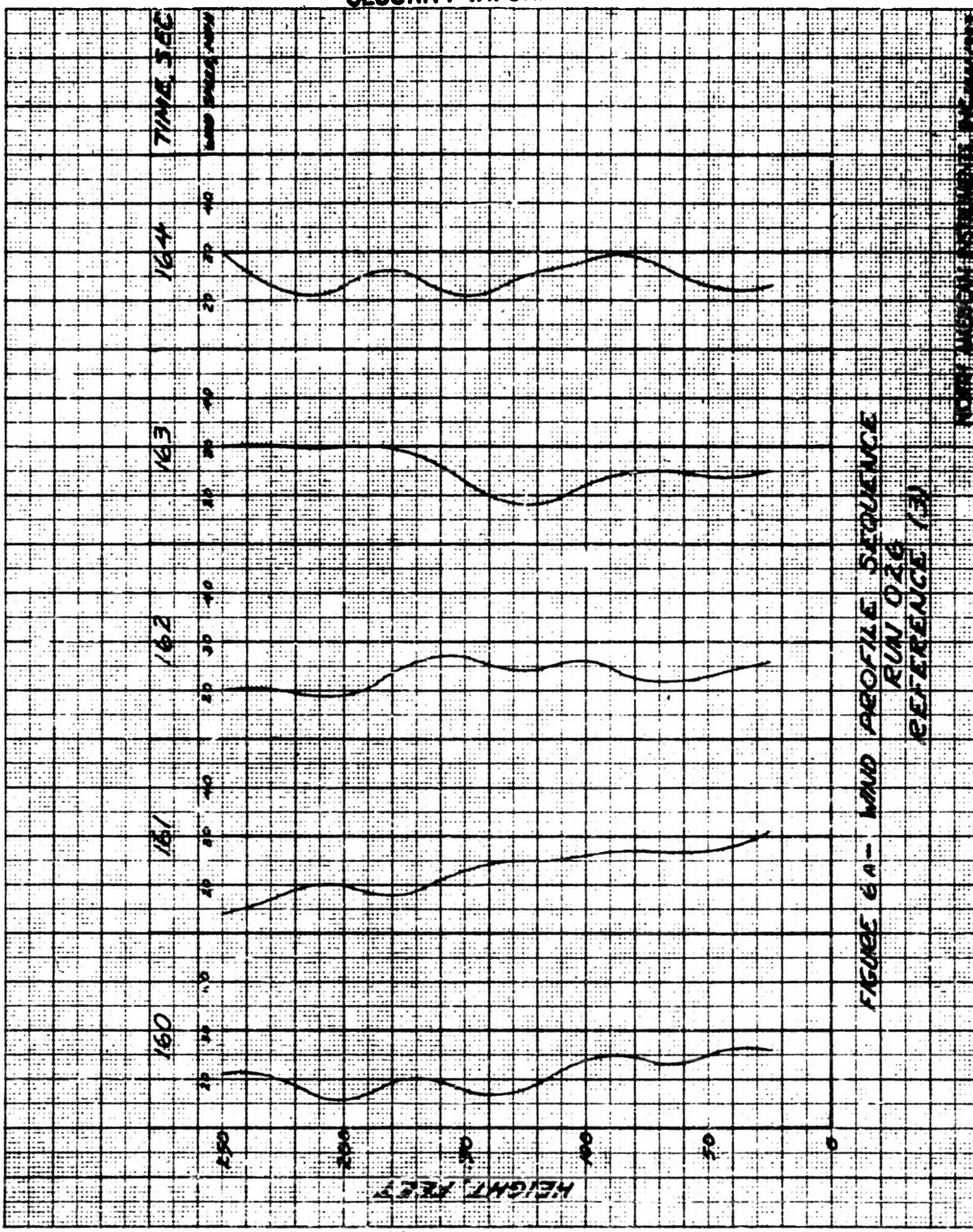

FIGURE 6A — WIND PROFILE SEQUENCE
RUN 026
REFERENCE (3)

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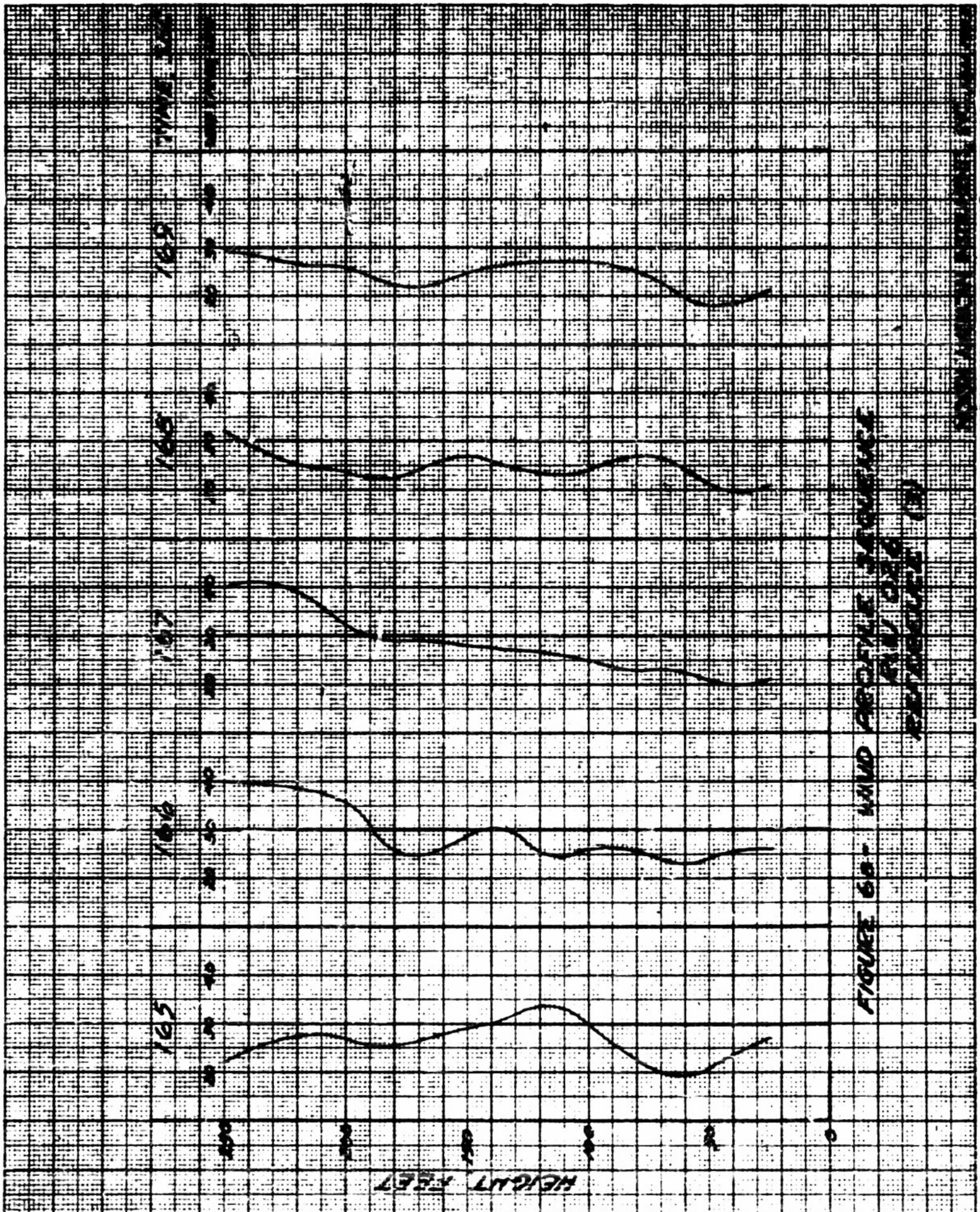

FIGURE 68 - WIND PROFILE SEQUENCE

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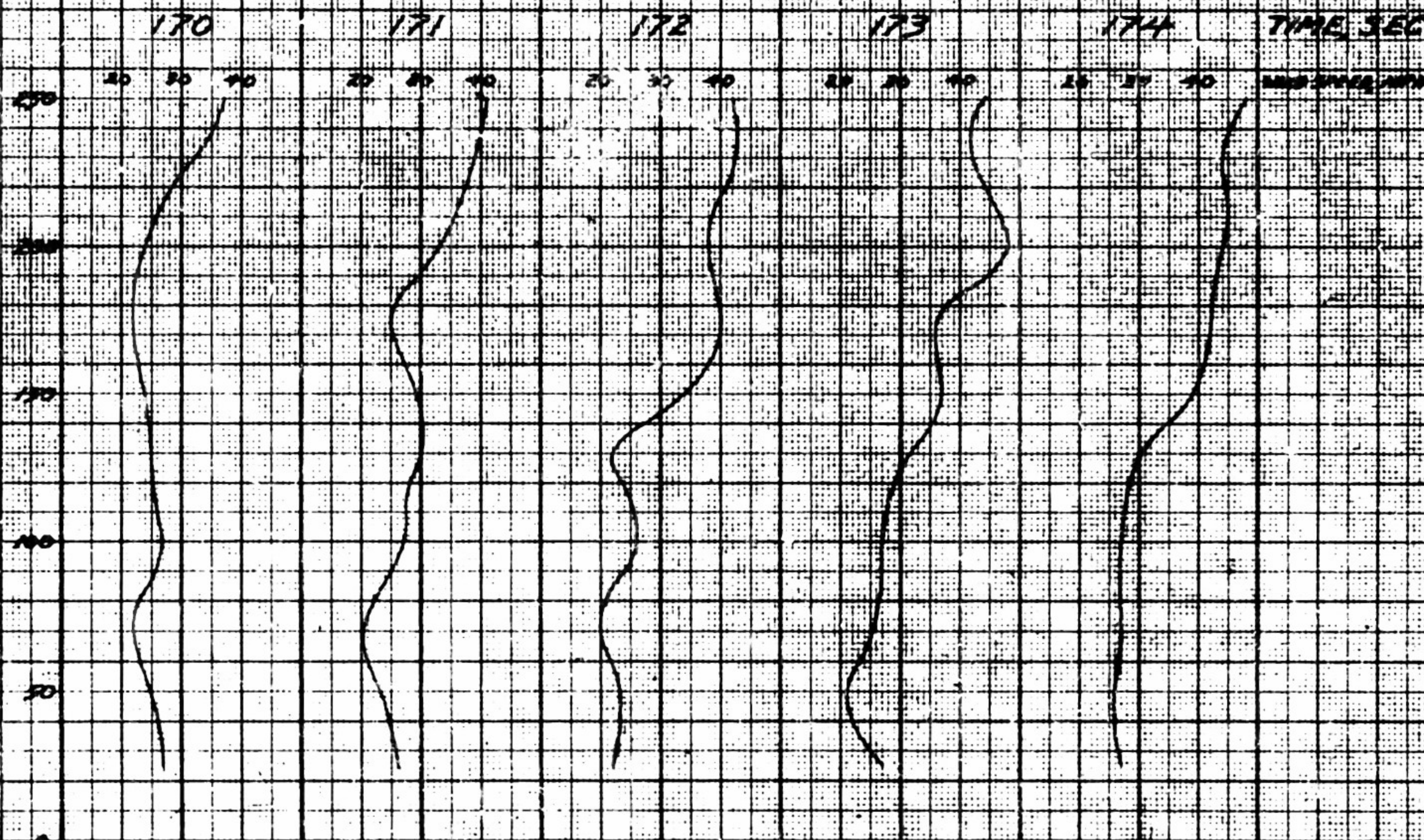

FIGURE 6c - WIND PROFILE SEQUENCE
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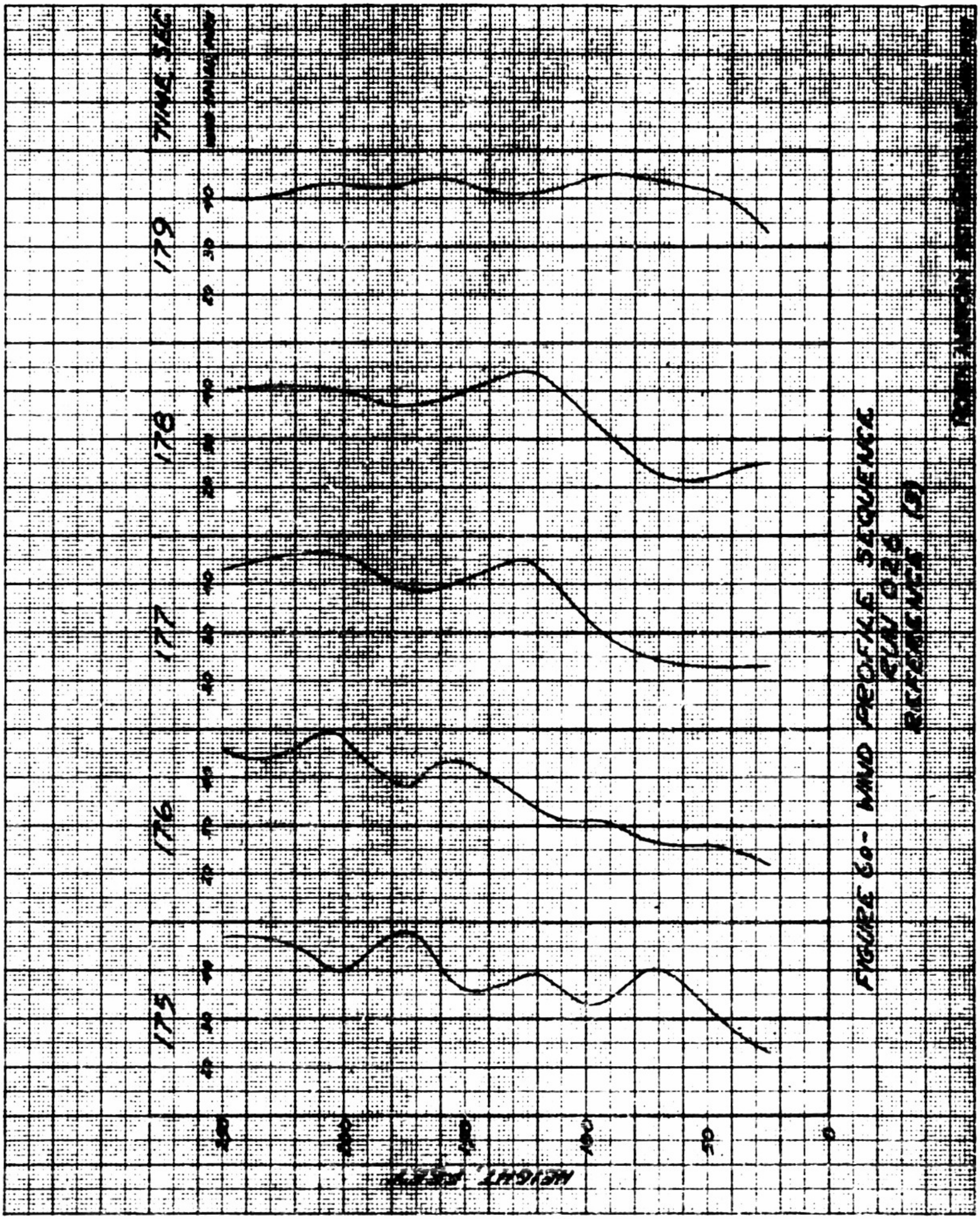

FIGURE 60- WIND PROFILE SEQUENCE
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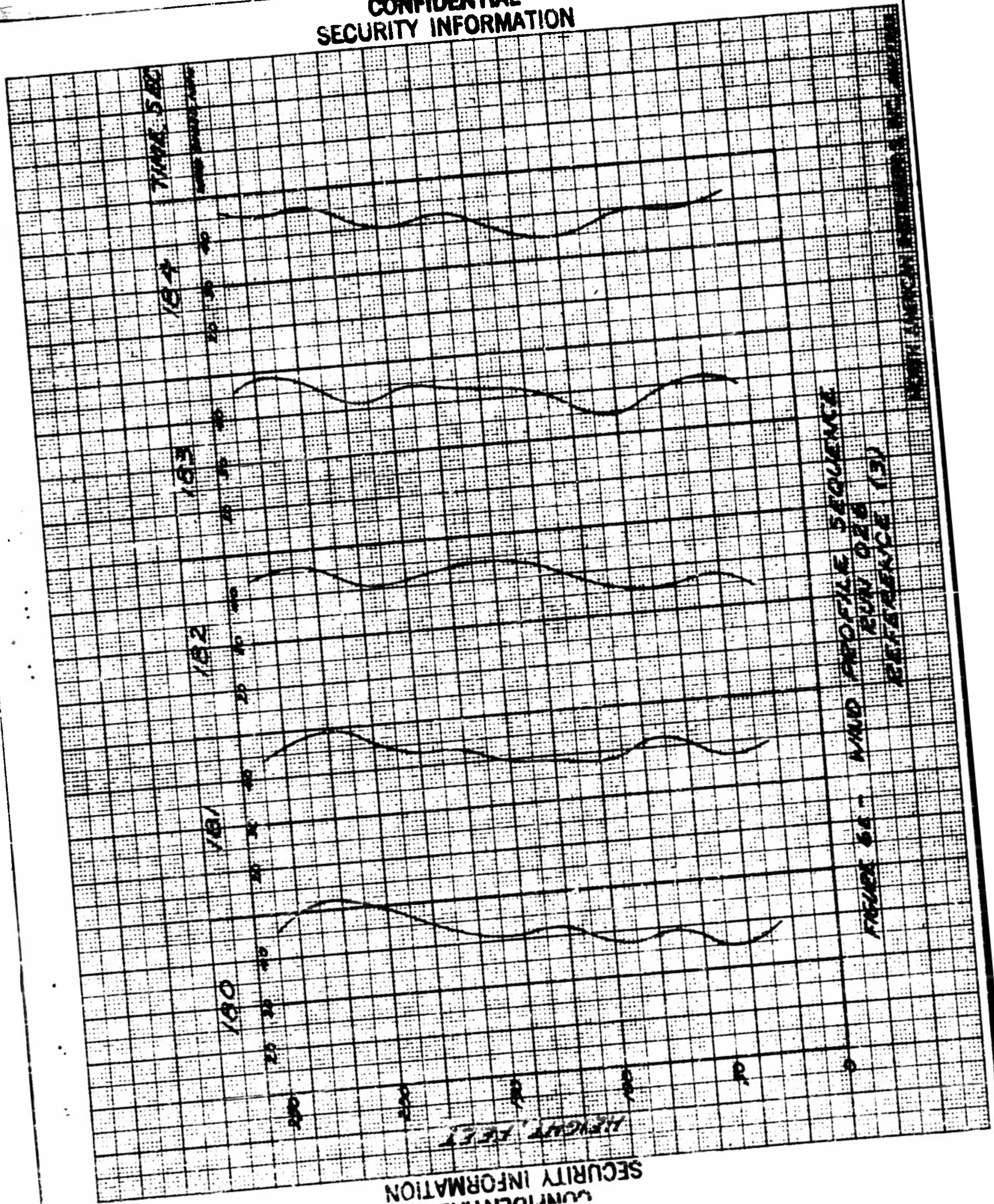

FIGURE 64 – WIND PROFILE SEQUENCE
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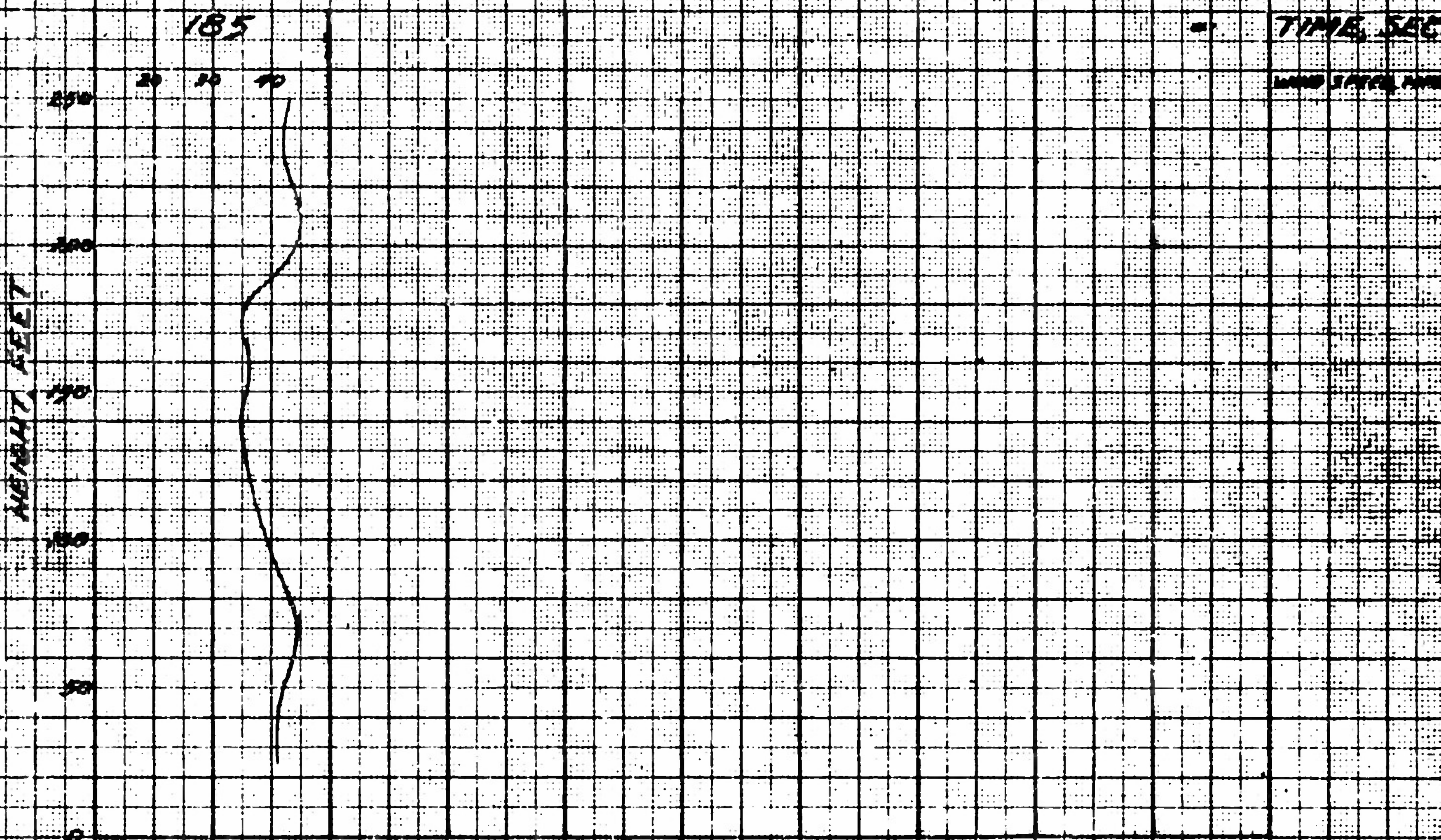

FIGURE 61 – WIND PROFILE SEQUENCE
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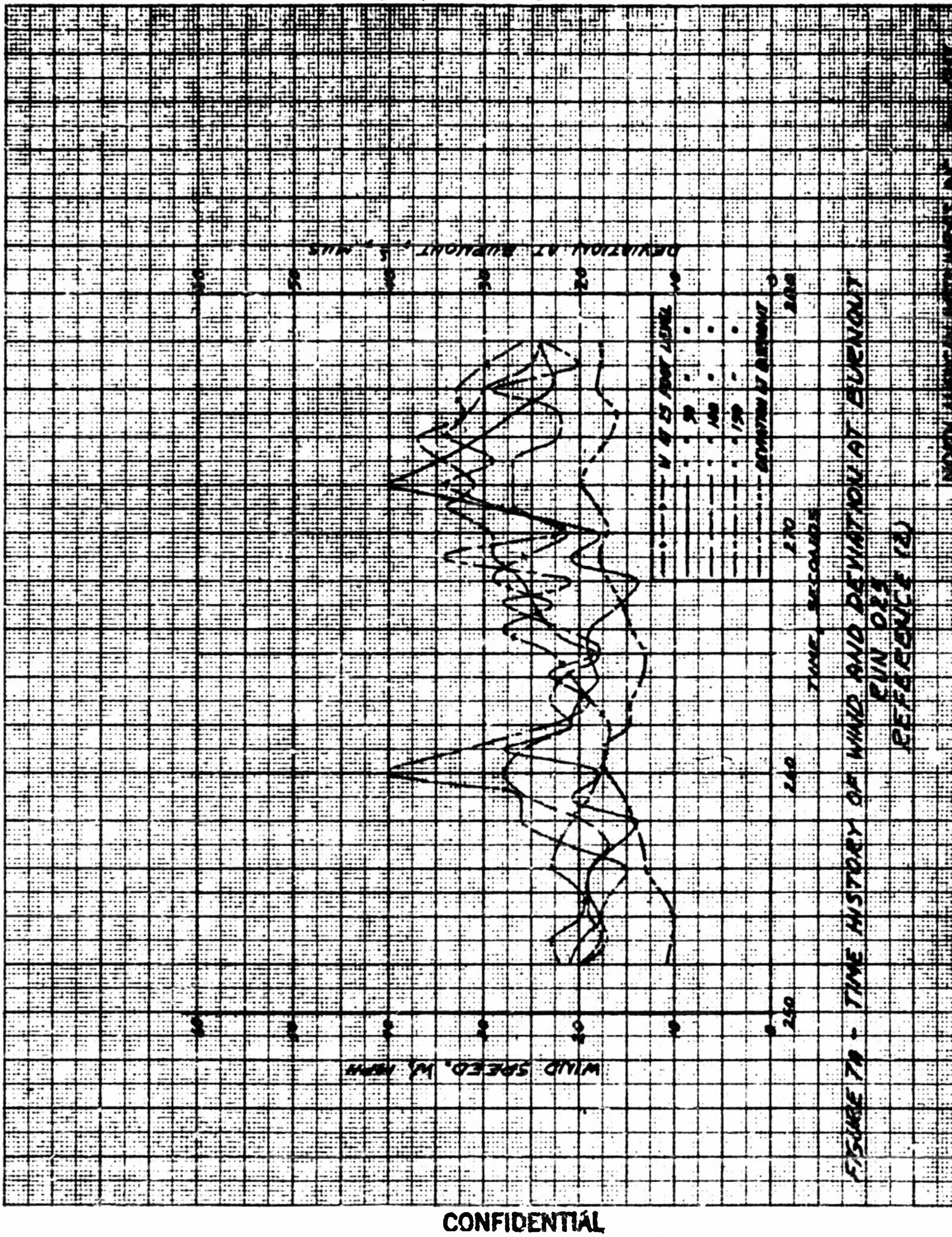

FIGURE 7[illegible] - TIME HISTORY OF WIND AND DEVIATION AT BURNOUT
RUN 0[illegible]
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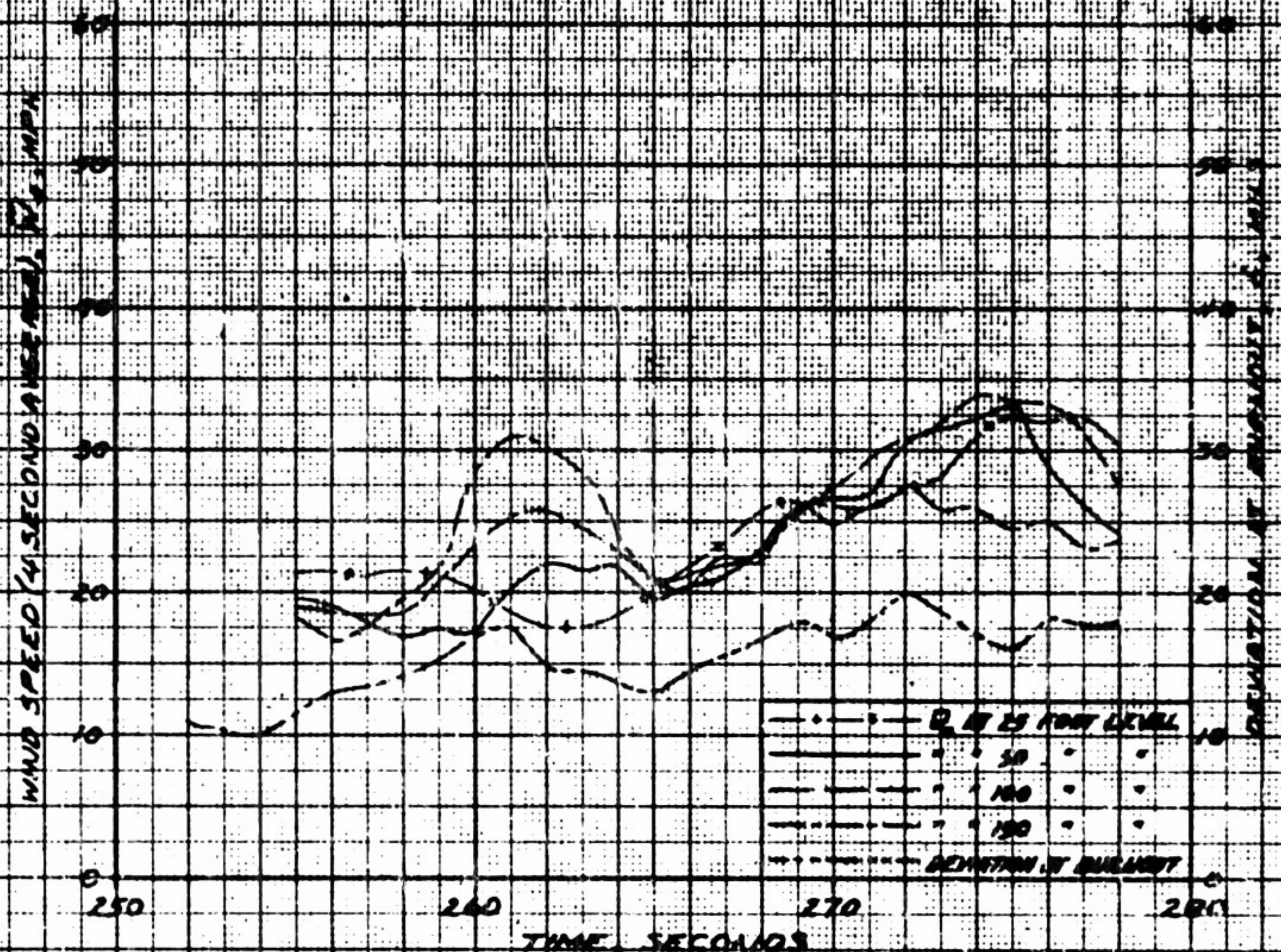

FIGURE 7B - TIME HISTORY OF SMOOTHED (4 SECOND AVERAGE) WIND AND DEVIATION AT BURNOUT
RUN 025
REFERENCE (2)

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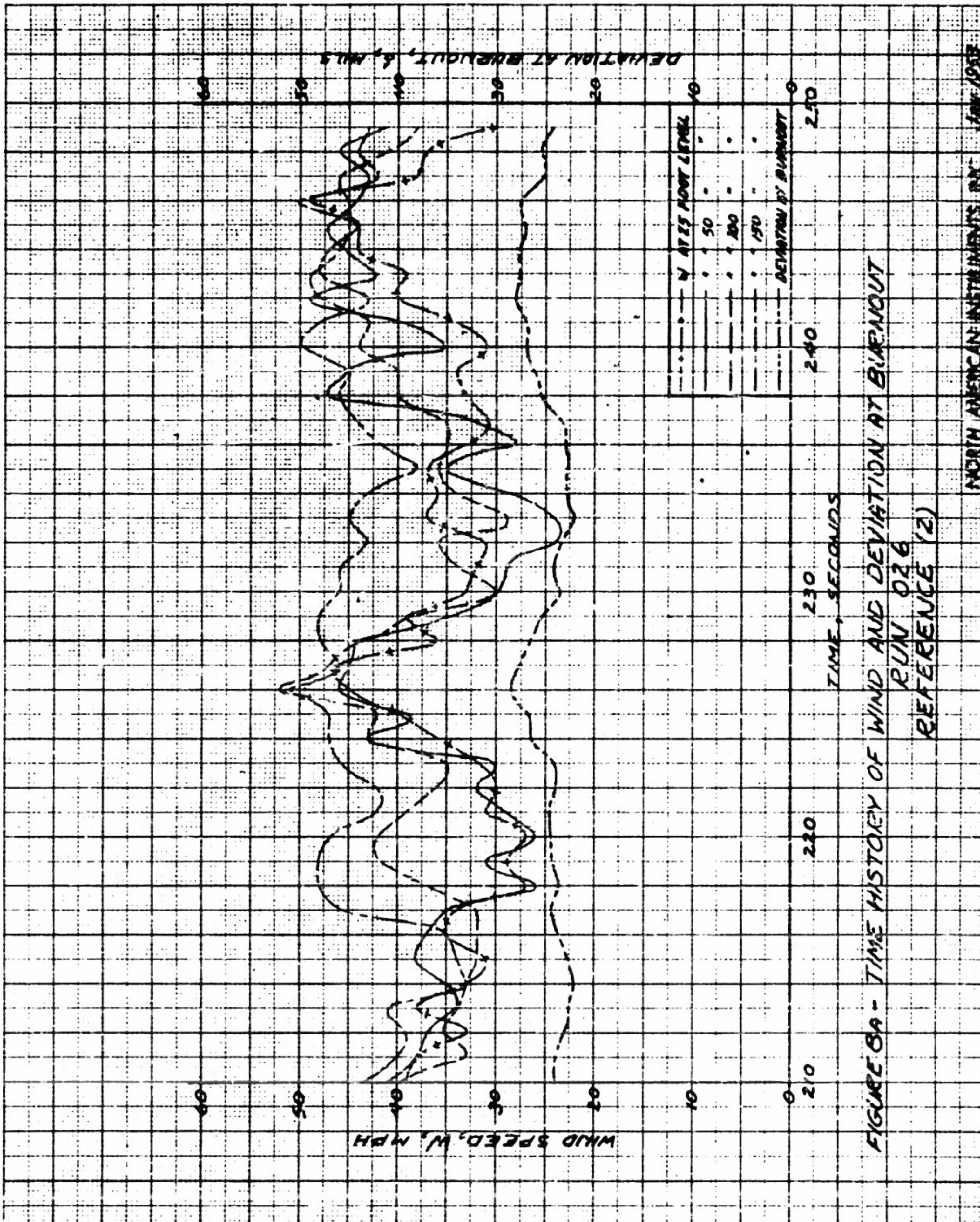

FIGURE 8A - TIME HISTORY OF WIND AND DEVIATION AT BURNOUT
RUN 026
REFERENCE (2)

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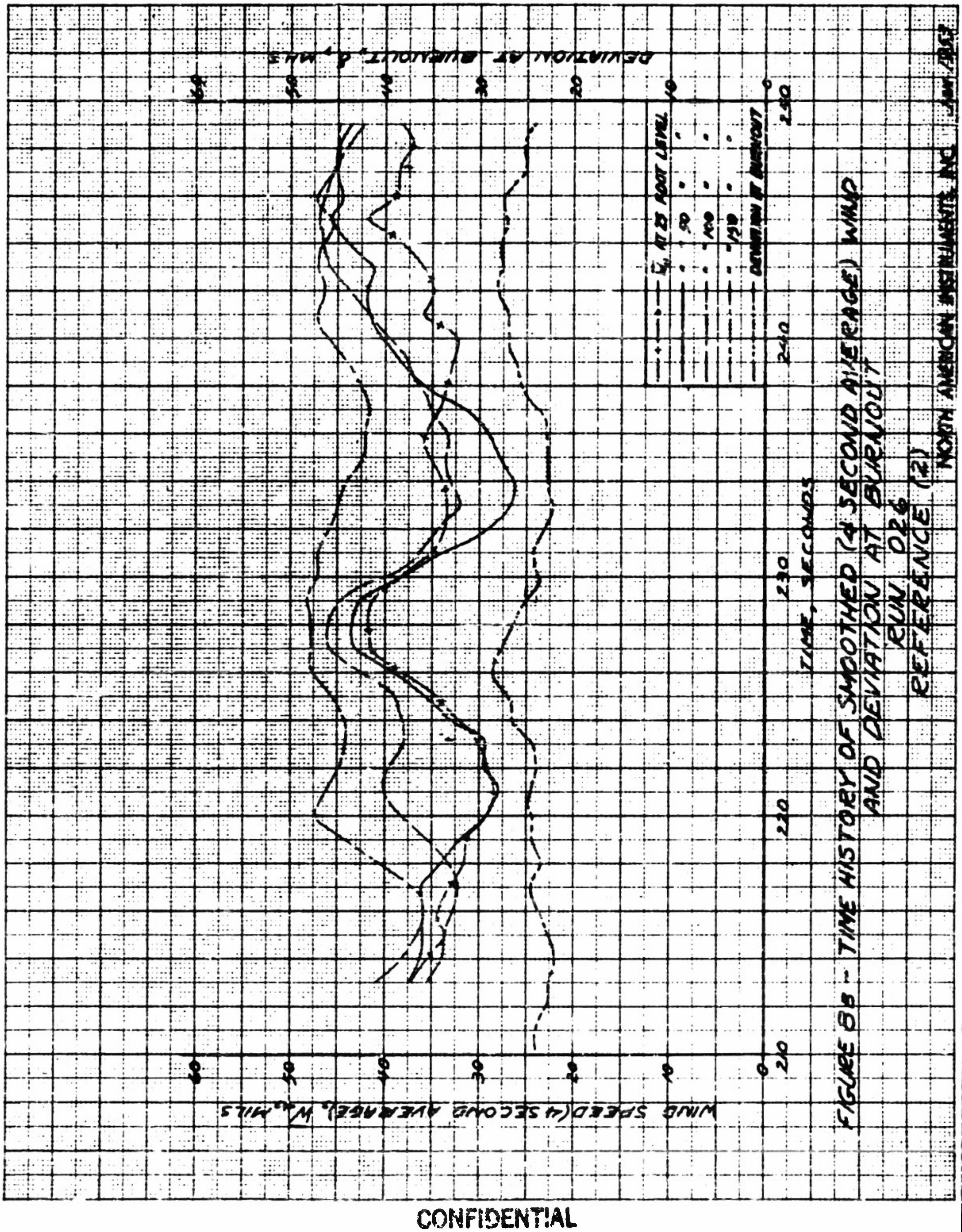

FIGURE 88 - TIME HISTORY OF SMOOTHED (4 SECOND AVERAGE) WIND AND DEVIATION AT BURNOUT
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REFERENCE (2)

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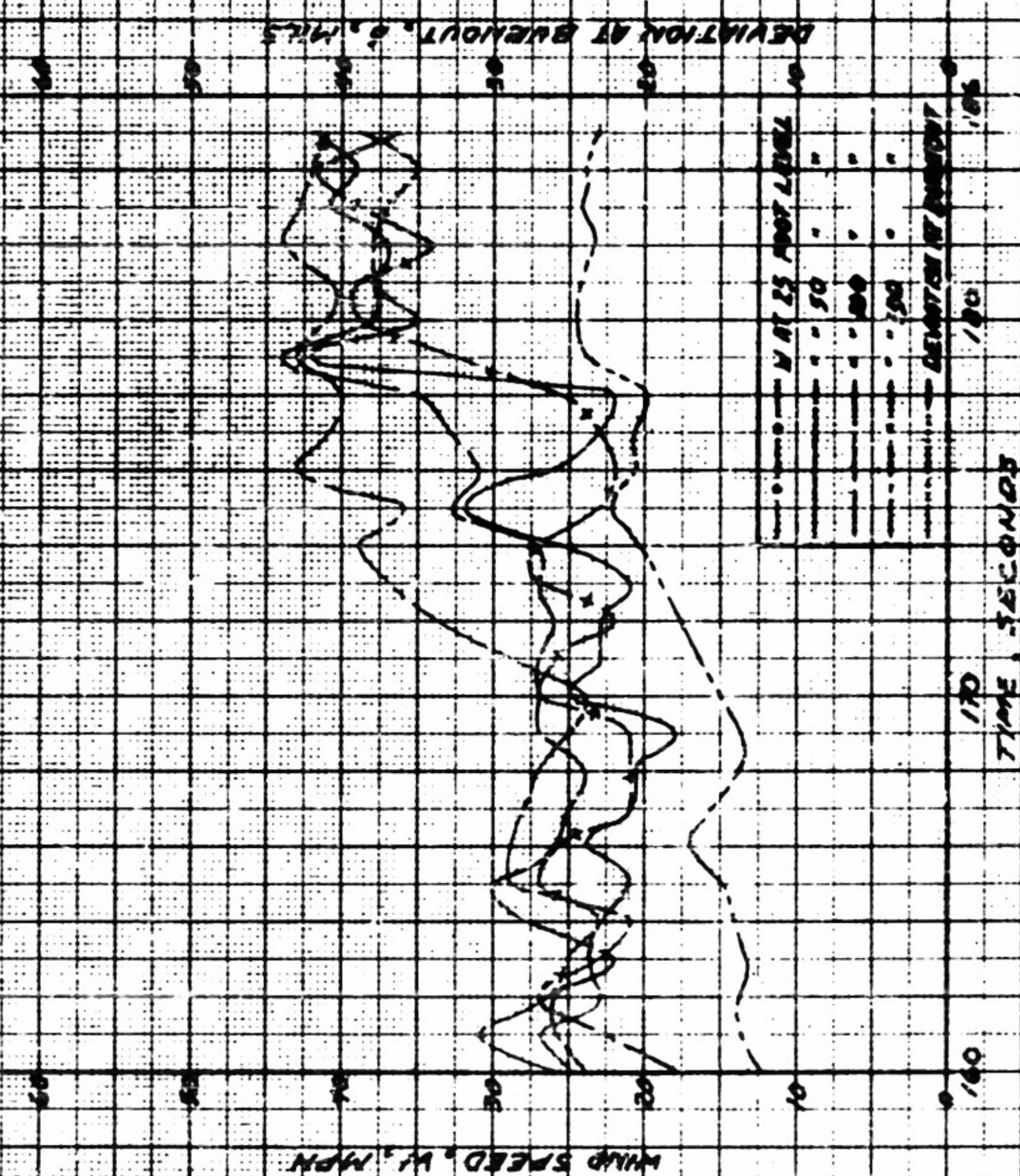

FIGURE 9A - TIME HISTORY OF WIND AND DEVIATION AT BURNOUT
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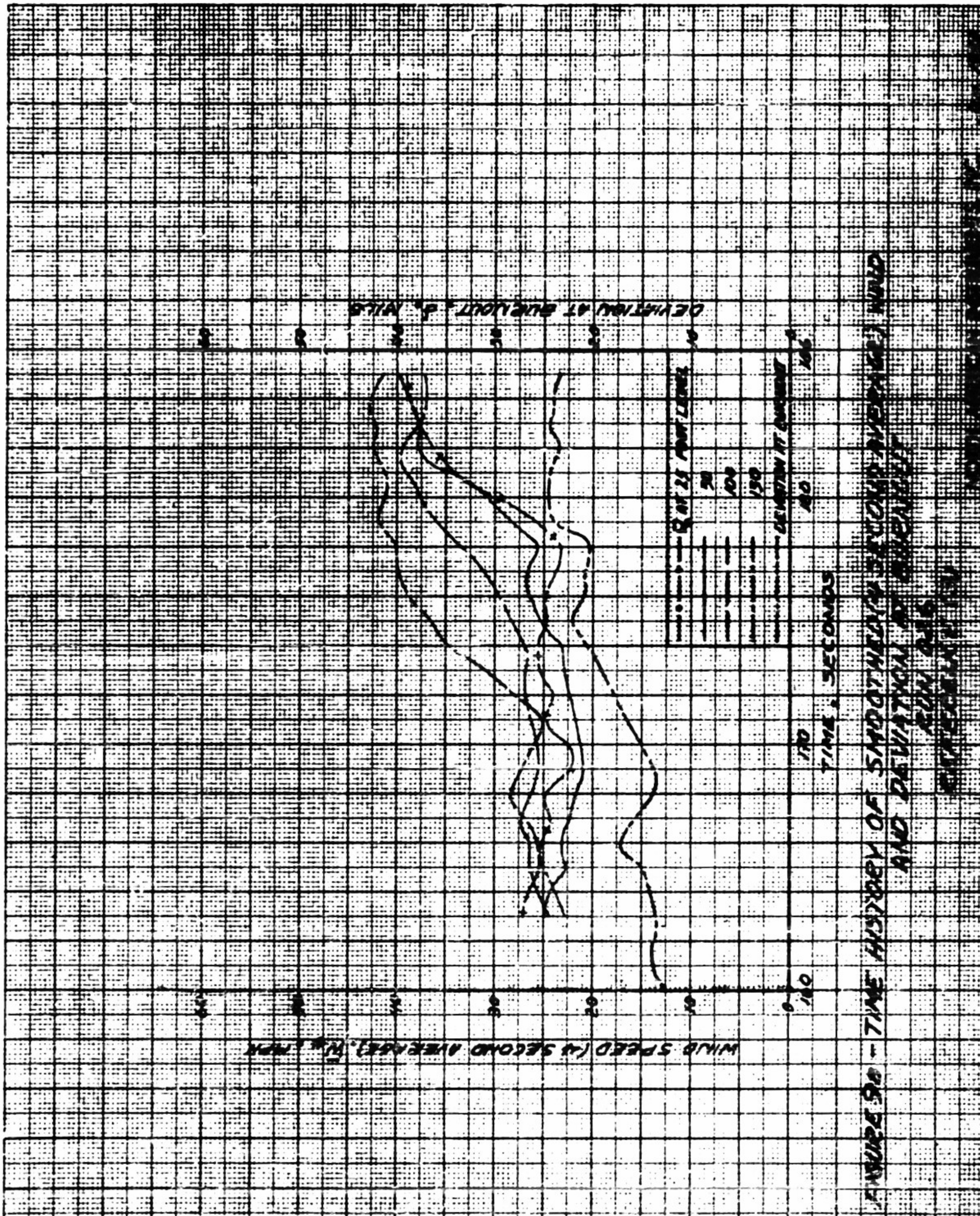

FIGURE 9a - TIME HISTORY OF SMOOTHED (4 SECOND AVERAGE) WIND AND DEVIATION AT BURNOUT
RUN 6-16

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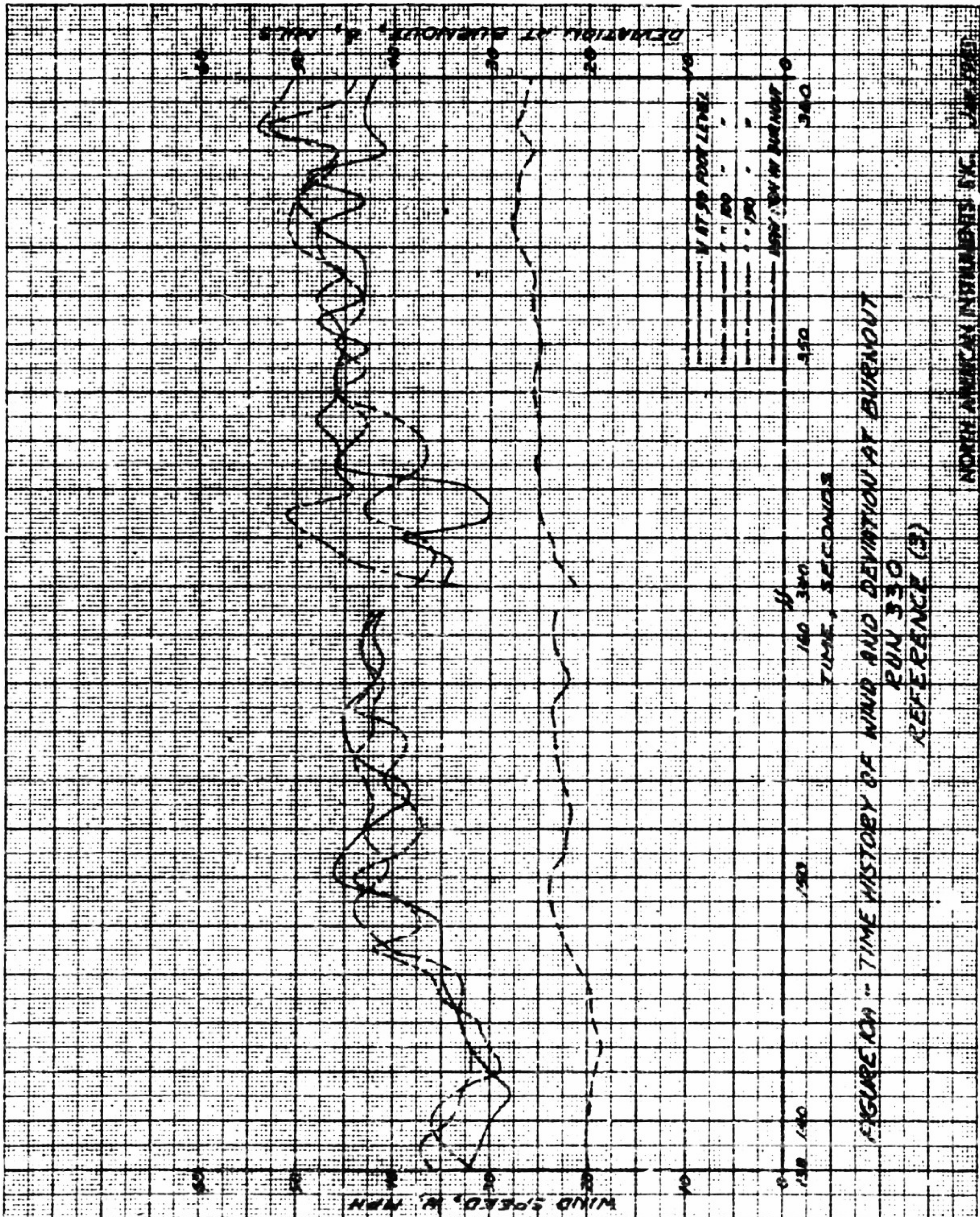

FIGURE 10A - TIME HISTORY OF WIND AND DEVIATION AT BURNOUT
RUN 330
REFERENCE (3)

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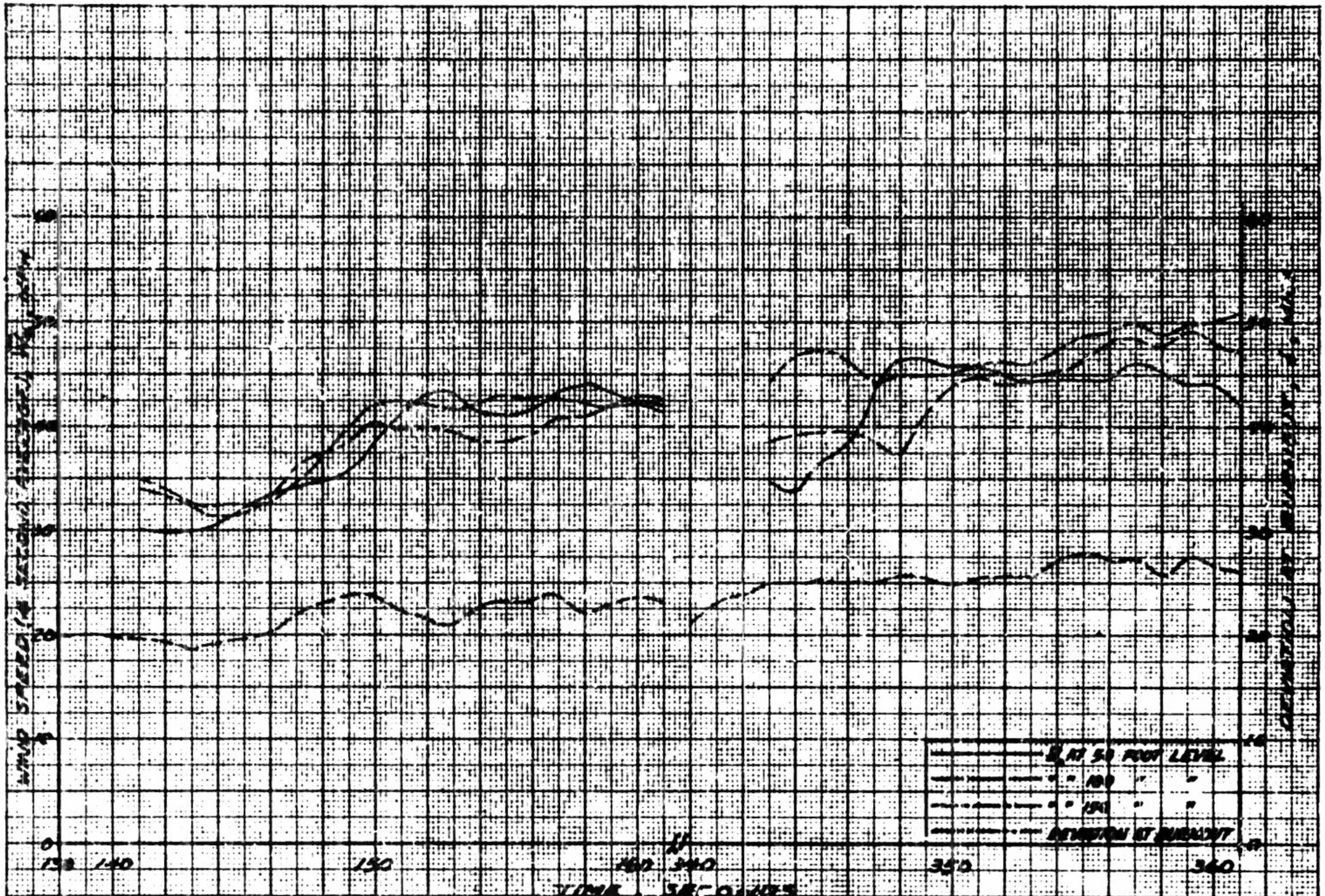

FIGURE [illegible] - TIME HISTORY OF SMOOTHED (4 SECOND AVERAGE) WIND
AND DEVIATION AT BURNOUT
RUN 330
REFERENCE (5)

SECURITY INFORMATION

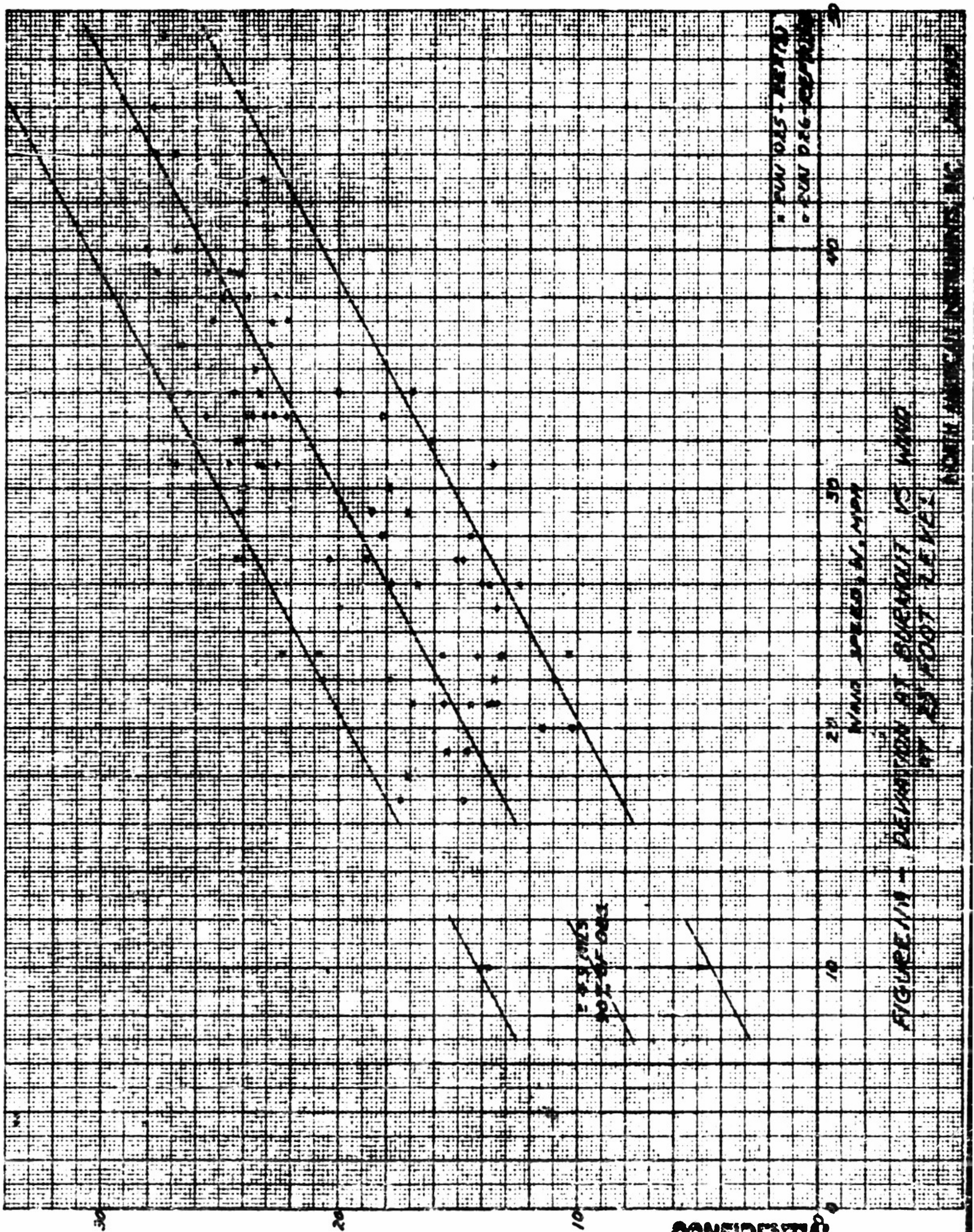

FIGURE I/II - DEVIATION AT BURNOUT VS WIND AT 25 FOOT LEVEL

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SECURITY INFORMATION

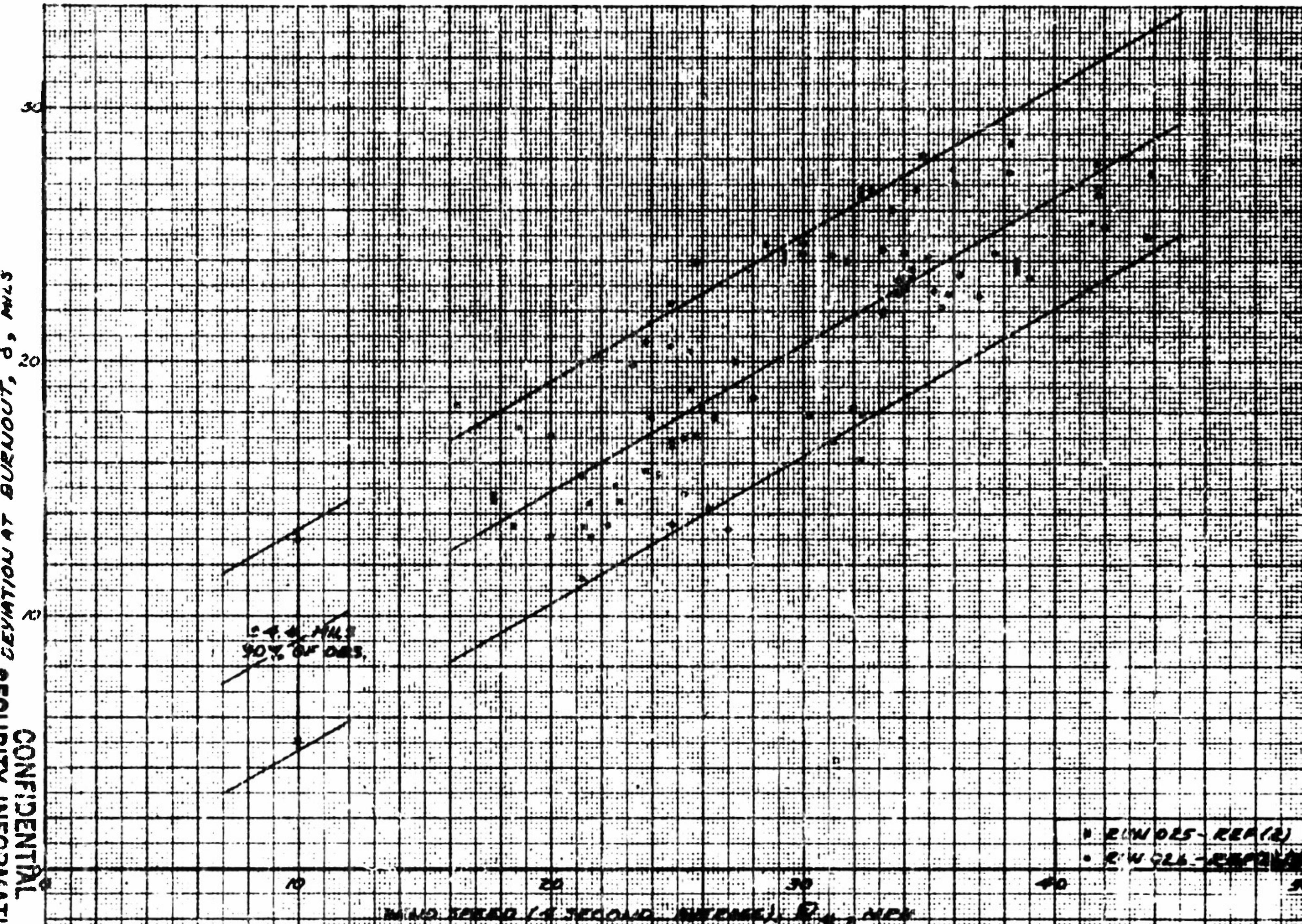

FIGURE 11B - DEVIATION AT BURNOUT VS 4 SECOND AVERAGE WIND AT 25 FOOT LEVEL

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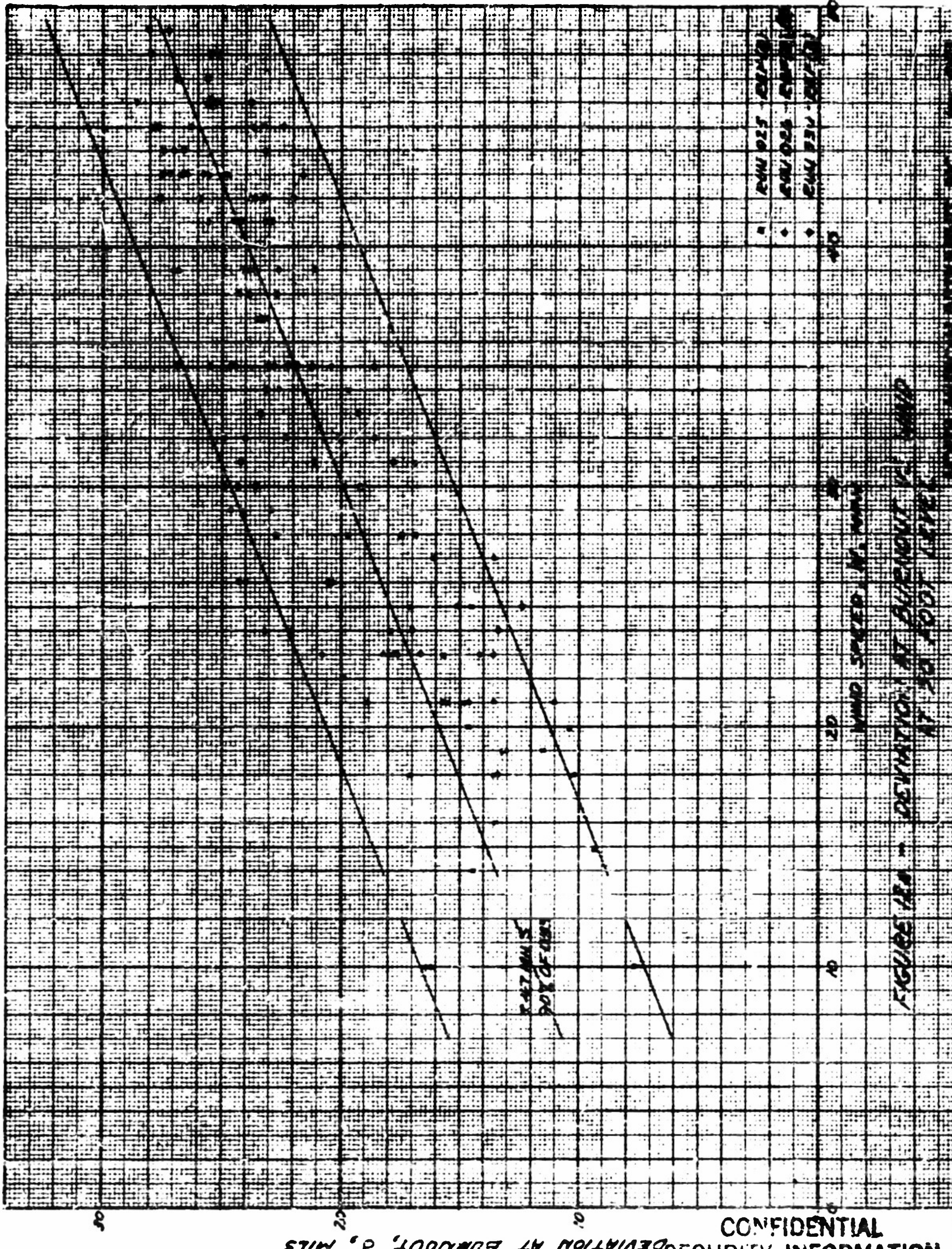

FIGURE 14A - DEVIATION AT BURNOUT VS WIND AT 90 FOOT LEVEL

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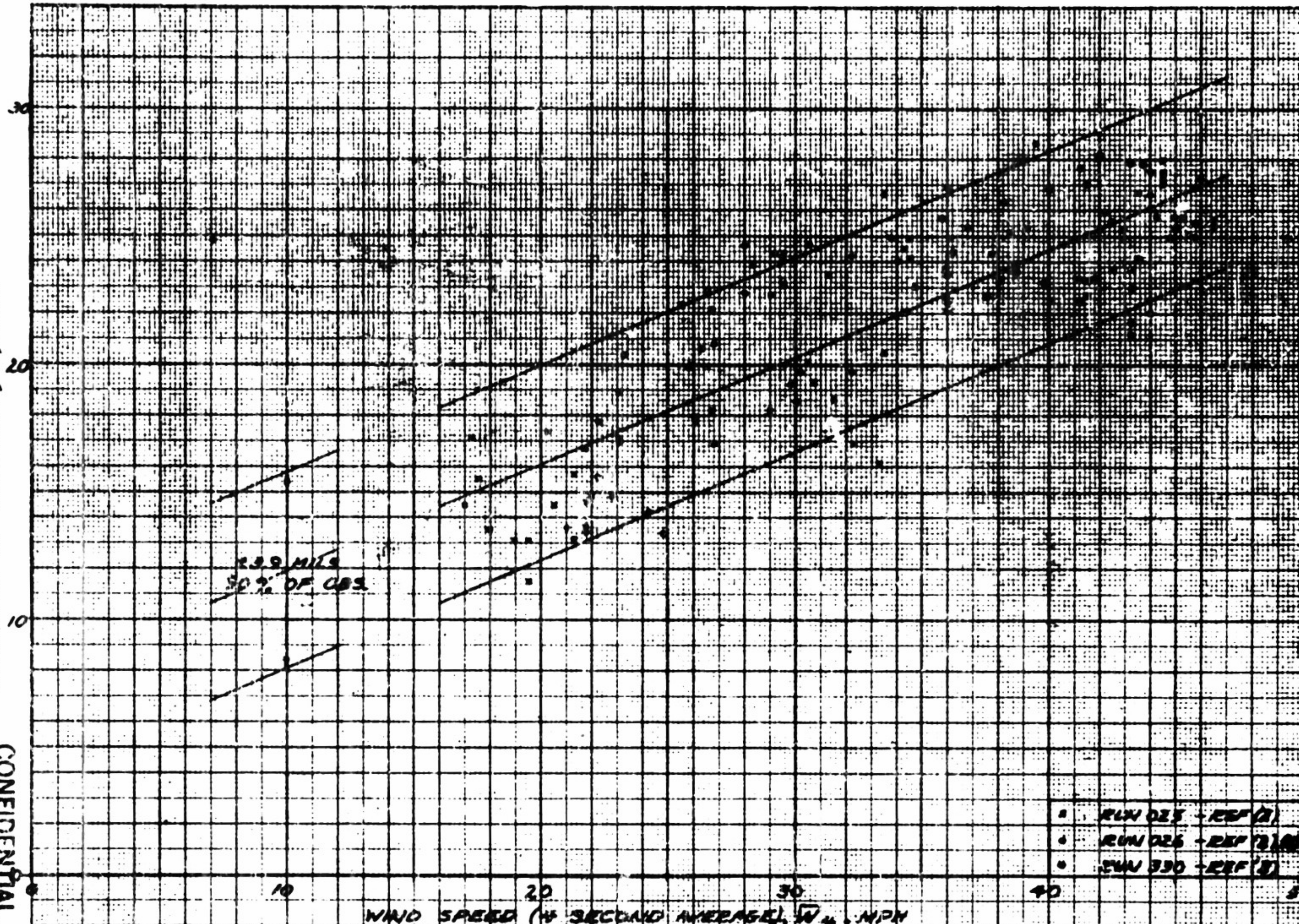

FIGURE 12B - DEVIATION AT BURNOUT VS 4 SECOND AVERAGE WIND AT 50 FOOT LEVEL

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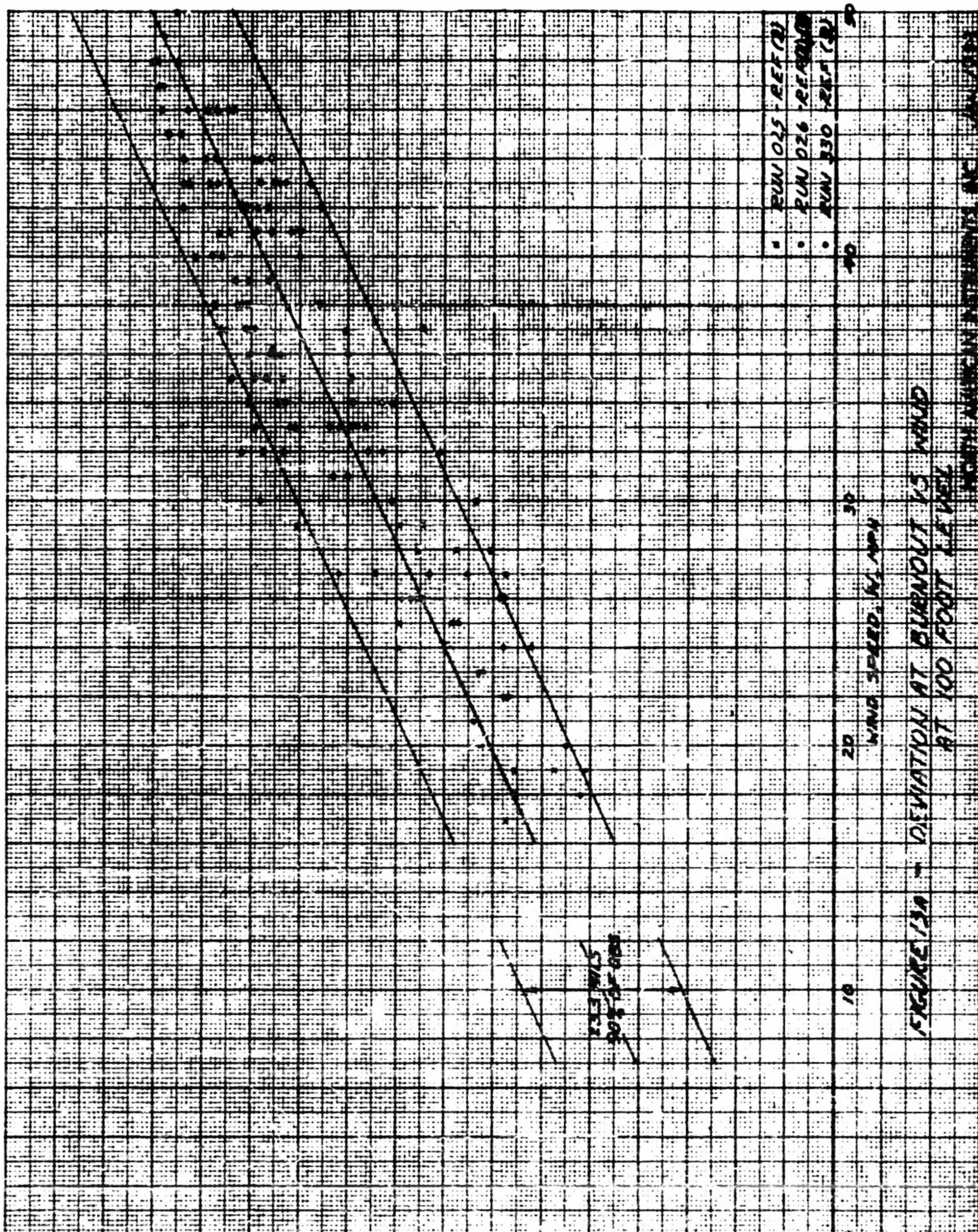

FIGURE 13A - DEVIATION AT BURNOUT VS WIND
AT 100 FOOT LEVEL

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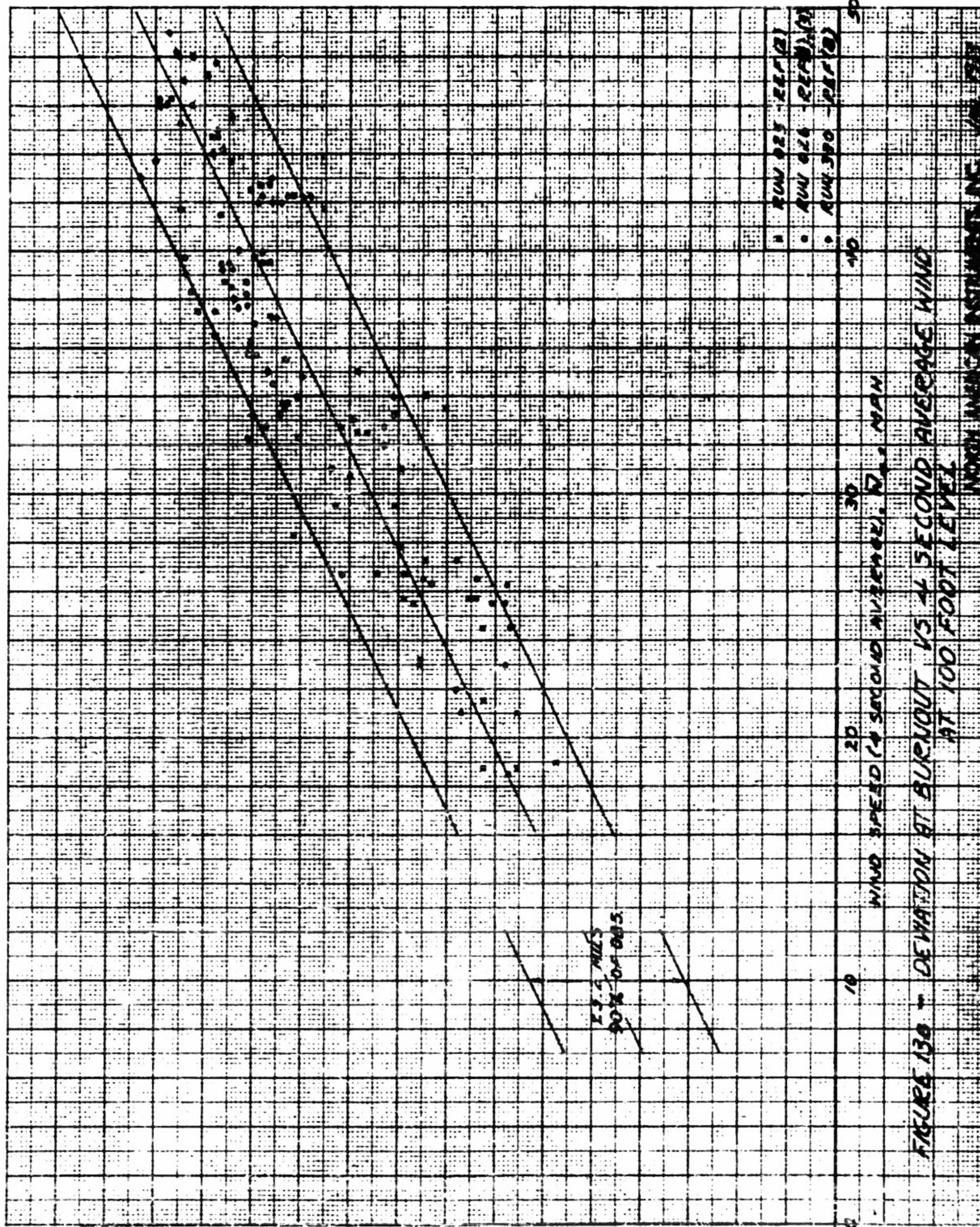

FIGURE 136 - DEVIATION AT BURNOUT VS 4 SECOND AVERAGE WIND AT 100 FOOT LEVEL

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SECURITY INFORMATION

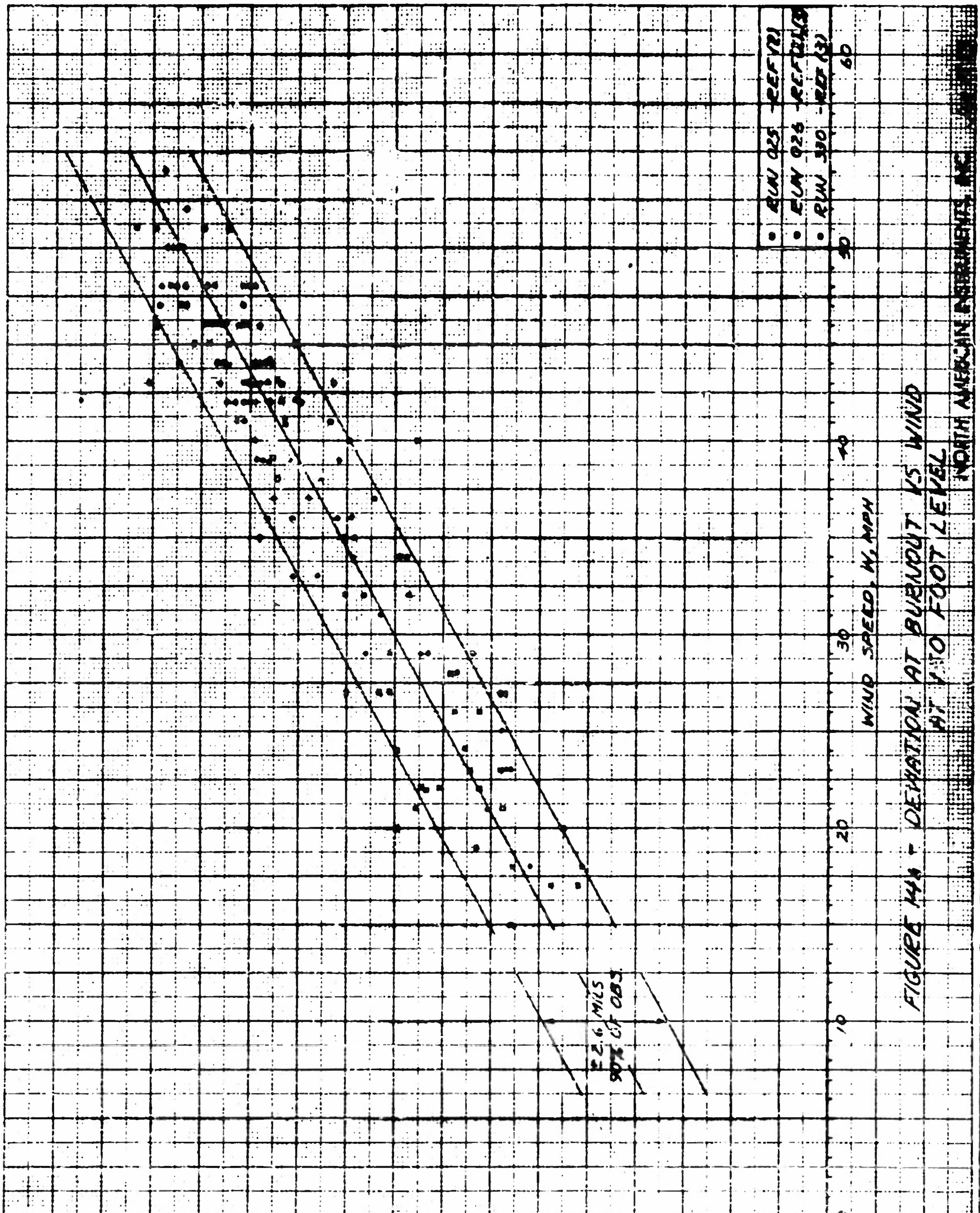

FIGURE 14 - DEVIATION AT BURNOUT VS WIND AT 150 FOOT LEVEL

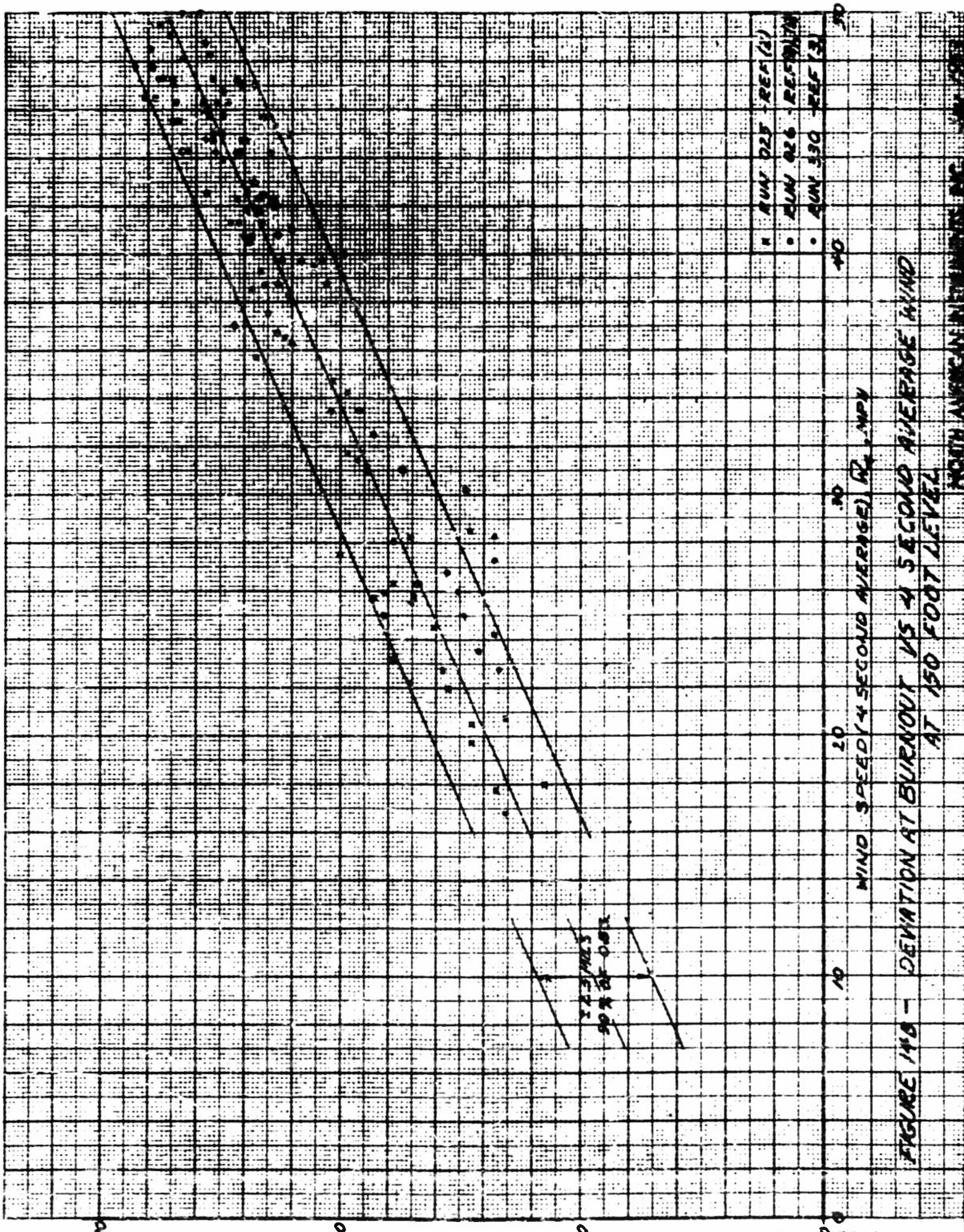

FIGURE 14B – DEVIATION AT BURNOUT VS 4 SECOND AVERAGE WIND AT 150 FOOT LEVEL

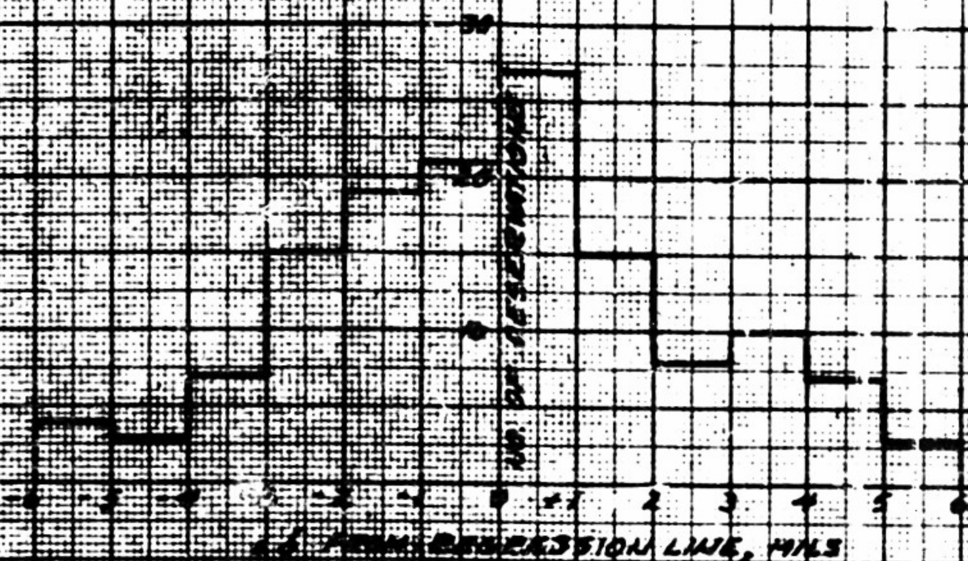

FIGURE 15
DEPARTURE FROM REGRESSION LINE
WIND AT 50 FOOT LEVEL

FIGURE 16
DEPARTURE FROM REGRESSION LINE
4 SECOND AVERAGE WIND AT 50 FOOT LEVEL