U. S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

Weather Bureau Technical Memorandum PR-5

A COMPUTER METHOD TO GENERATE AND PLOT STREAMLINES

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PACIFIC REGION
TECHNICAL MEMORANDUM PR-5

HONOLULU, HAWAII
February 1969

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ABSTRACT

A description of a method of generating and plotting streamlines of Tropical Pacific wind fields is presented. The program, using objectively analyzed wind fields provided by the Hawaii Cooperative Tropical NWP Group, computes wind directions at .1 inch intervals along lines which are selectively spaced. These short line segments are connected and represent streamlines of instantaneous wind flow. Actual lines are traced by an incremental plotter.

Cyclones and anticyclones in both hemispheres along with cols and other flow patterns showing confluence, diffluence, sources and sinks are well represented. Output is used to replace hand drawn streamlines, thus effecting a saving in manual effort. Program is written for use on a Control Data Corporation lower 3000 series computer.

A COMPUTER METHOD TO GENERATE AND PLOT STREAMLINES

1. Introduction.

The use of streamlines to graphically depict instantaneous wind flow, largely in tropical regions of the earth, has long been advocated by authors such as Riehl (3). Depiction of tropical wind flow through streamlines has become standard practice by meteorologists. In actual practice, however, streamlining by hand is often imprecise due to variable data density. Riehl (3) shows that representativeness of streamlines may be enhanced through a technique of analyzing the scalar field of wind directions, and producing contours of constant wind direction called isogons. By then indicating short wind arrows spaced at suitable intervals along isogons, one can "expand" the data to arrive at a more representative streamline pattern.

In recent years objective techniques of producing tropical wind fields using high speed computers have proved successful. Bedient and Vederman (1) describe the system for producing these analyses which is the basis for the present tropical analysis produced by the National Meteorological Center and by the Hawaii Cooperative Tropical NWP Group. Examples of the product can be seen in Fig. 7. Typically, these systems produce wind fields on an evenly spaced grid thus eliminating the variable spacing of data problem, as far as streamlining is concerned. With such a grid array of data available in digital form, it is easily seen that a computer may be used to direct a graphical plotter to trace streamlines to a degree of preciseness that is limited only by the resolution of the basic data themselves. Such a system is described below. In addition to streamlines, temperatures and wind barbs are plotted at grid points.

Pioneering in the field of streamlining was done by Belmont, Engberg, and Shen (2) on surface data in 1965 and on upper air data in 1966. It is believed that the wind barb plotting technique shown in this memorandum is largely unique with our group.

2. Initial Data Required.

The basic input data required are digital scalar data arranged sequentially on magnetic tape or in computer storage to represent an m x n Cartesian matrix. Our particular major grid is a 40x14 matrix. The grid is designed so that a one inch mesh length equals 300 nautical miles (5°) at the equator on a 1:20M Mercator projection true at 22.5° of latitude. The grid is displaced northward so that the top row, j=13, is at 37.1°N, the bottom row, j=0, is at 24.2°S latitude. The left hand bound, i=0, is at 75°E longitude; and the right bound, i=39, is at 90°W longitude.

These grids are produced by the Hawaii Cooperative Tropical Numerical Group using computer facilities operated by Fleet Weather Central, Pearl Harbor. A partial description of the history and activities of this group can be found in Pacific Region Technical Memorandum PR-4.

Data are available in u (west-east) and v (south-north) components of the wind plus temperature at each grid point in the matrix. Analyses are done for the 700, 500, 400, 300, 250, and 200 mb levels four times daily at six hourly intervals. A Southeast Asia 850 mb analysis is also available and a 600 mb level analysis is produced by vertical interpolation. In addition, the surface wind fields are produced experimentally and are expected to be produced routinely in the near future.

Physically, the data are written by the computer in identified records onto magnetic tape for storage. The wind component values are on tape in whole knots multiplied by 2^{12}. Temperatures are in whole degrees Celsius multiplied by 2^{12}.

3. Procedure.

The below listed procedures are followed to produce desired charts from digital records of wind and temperature data. There are five general steps. These are (1) formation of two submatrices within the 40x14 grid for plotter pen coordination, (2) generation of the locus of the streamline, (3) the spacing of streamlines, (4) wind barb generation and (5) actual plotting. We will now describe each of these steps in some detail.

a. Requirements for plotter pen coordinates.

The CalComp model 565 incremental plotter basically consists of a movable pen mounted on a cursor over a turnable drum. The drum can move forward or backward, the cursor moves left or right. All movements are in .01 inch steps, 300 per second. Such an arrangement permits the pen to move in eight possible directions. The possible steps are shown in Fig. 1.

All lines, characters, wind barbs, and other figures are generated as appropriately connected strings of these eight possible pen movements. In generating strings of pen movement commands, it is necessary to keep track of where we are at a given instant and where we have been. This requirement can be satisfied by setting up pen coordinates matrices within the larger 40x14 grid. Since grid points within the larger grid are spaced one inch apart, one can easily use a 100x100 submatrix for pen coordination. The u, v, and t values can be computed to sufficient accuracy at any point in the submatrix by linear interpolation. The relationship between the two grids is shown in Fig. 2.

b. Streamline generation.

As mentioned above, values of u, v wind components can be approximated at any point in the 100x100 pen position submatrix by linear interpolation. At a given point, the ratio of v to u provides the slope of the wind vector. If one drives the plotter along this line for a short distance, the segment approximates a streamline. The shorter the successive segments, the better the approximation. This provides the basis of our streamline

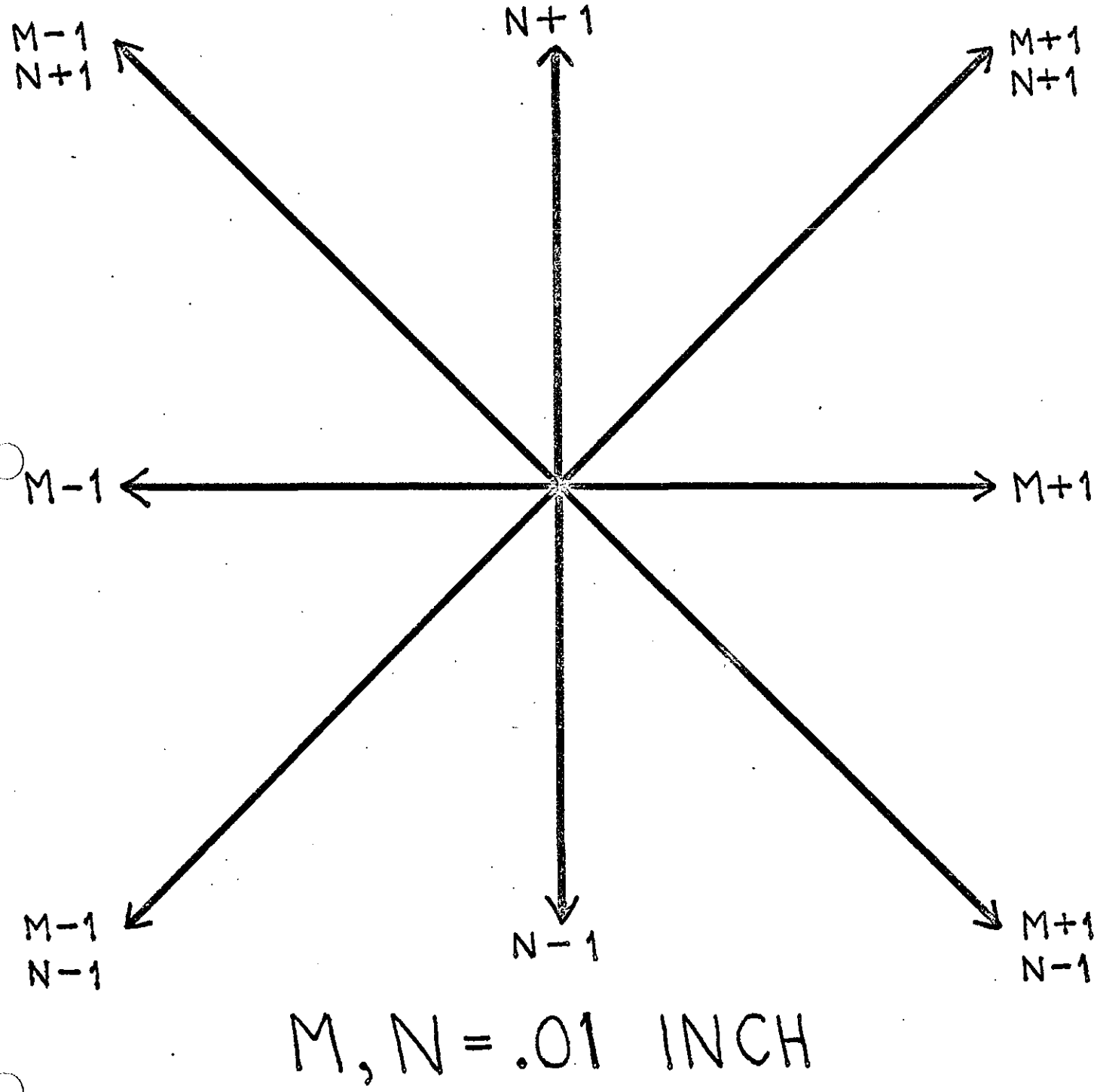


Fig. 1

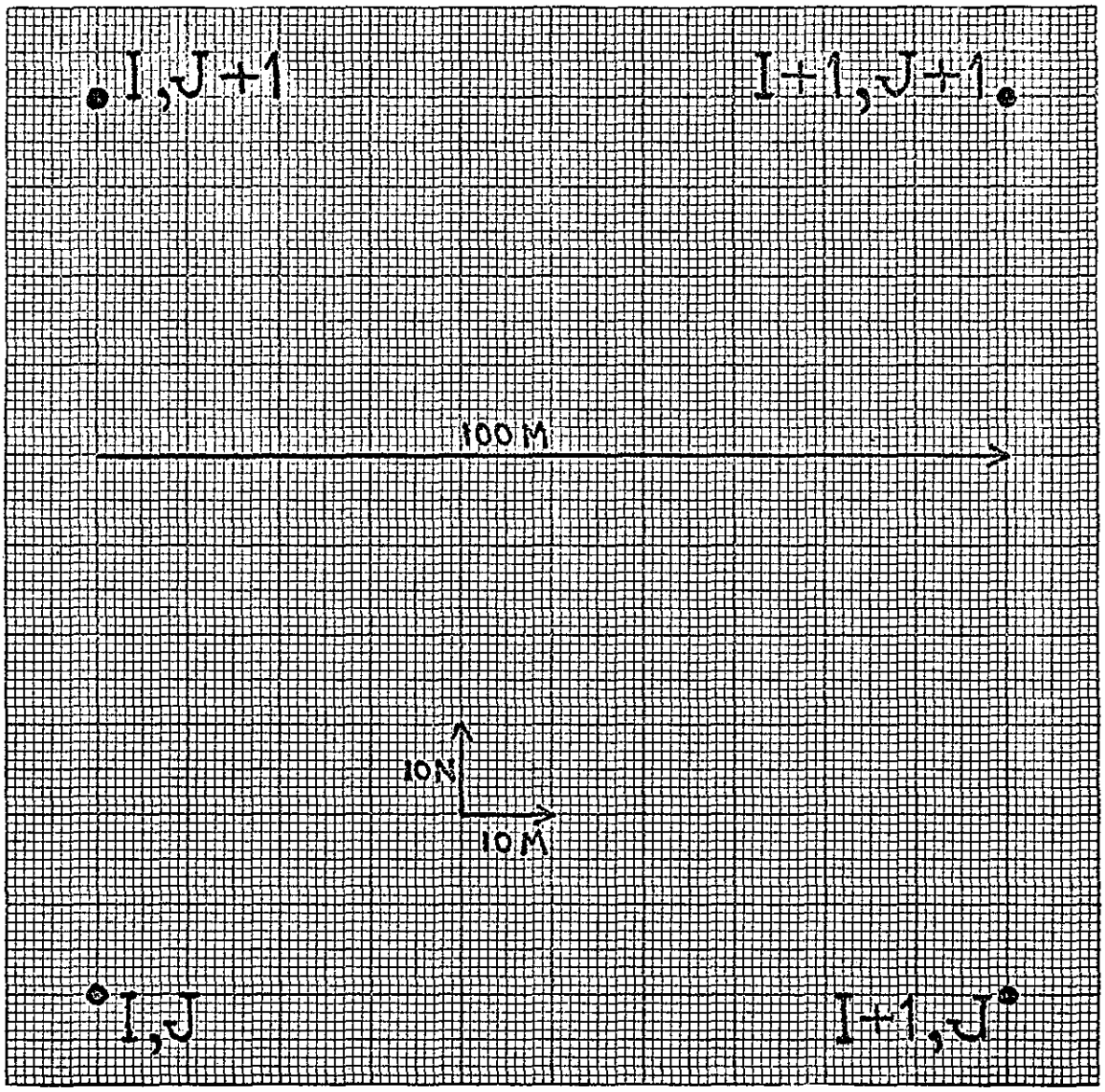


Fig. 2. Four points of the analysis grid superimposed onto the pen coordinate matrix.

generation technique.

In practice, the values of the interpolated u, v values are compared and the larger is set equal to 10 pen increments; the smaller proportionately less. Instructions are generated by the computer to drive the plotter along this vector to a terminal point. See Fig. 3.

This technique permits a simple and valuable method of "bookkeeping" to allow us to know where we have been so that we can prevent touching, excessive packing or crossing of previously generated streamlines. Since we always move the pen $\pm 10m$ or $\pm 10n$ increments along each vector, we can establish another system of reference sub grids within the larger grid having a mesh length of 1/10 inch. By use of this system, we can record the presence of any other streamline or arrowhead in any given 1/10 inch square. Thus, before each new interpolation, we can test if we have "been there before" and terminate a particular streamline if so. The streamline is continuous until the chart boundary or a previously "flagged" 1/10 square inch block indication is encountered.

c. Spacing between lines and sequencing.

Economy in plotting time is important. One desires the spacing between streamlines to be wide enough to minimize the number of lines, yet delineate flow patterns adequately. Further, lines should be generated in such a manner as to minimize pen travel between origins of streamlines.

Streamlining is begun at the left and right hand edges of the chart progressing from bottom to top along the edges. The 1/10 square inch reference grids are checked ahead vertically on the edge a certain arbitrary scan interval in the range of 1.2 to 1.6 inches (12 to 16 1/10 square inch mesh lengths) as shown in Fig. 4. If no previously plotted point has been found in that scan distance, the pen is positioned at a plotting interval (less than the scan interval) and the streamline is commenced. The most esthetically satisfying lines appear when the ratio of the spacing to the scan length is about 3/5.

If the wind speed drops below a certain arbitrary minimum values such as one knot, the streamline is terminated. Similarly, as mentioned before, termination occurs when the line reaches a boundary or a previously drawn line.

After the left and right edges are scanned, the side boundaries are moved inward one inch and scanned vertically. This enables streamlines to be originated, where needed, to fill out the interior of the field. Streamlines originating from interior side boundaries are always drawn toward the center of the chart. Progressive shrinking of the sides during scanning continues until the center is reached and the entire process of streamlining terminates.

At the beginning and at successive constant intervals along the streamline, wind direction arrow needs are plotted as seen in Fig. 5.

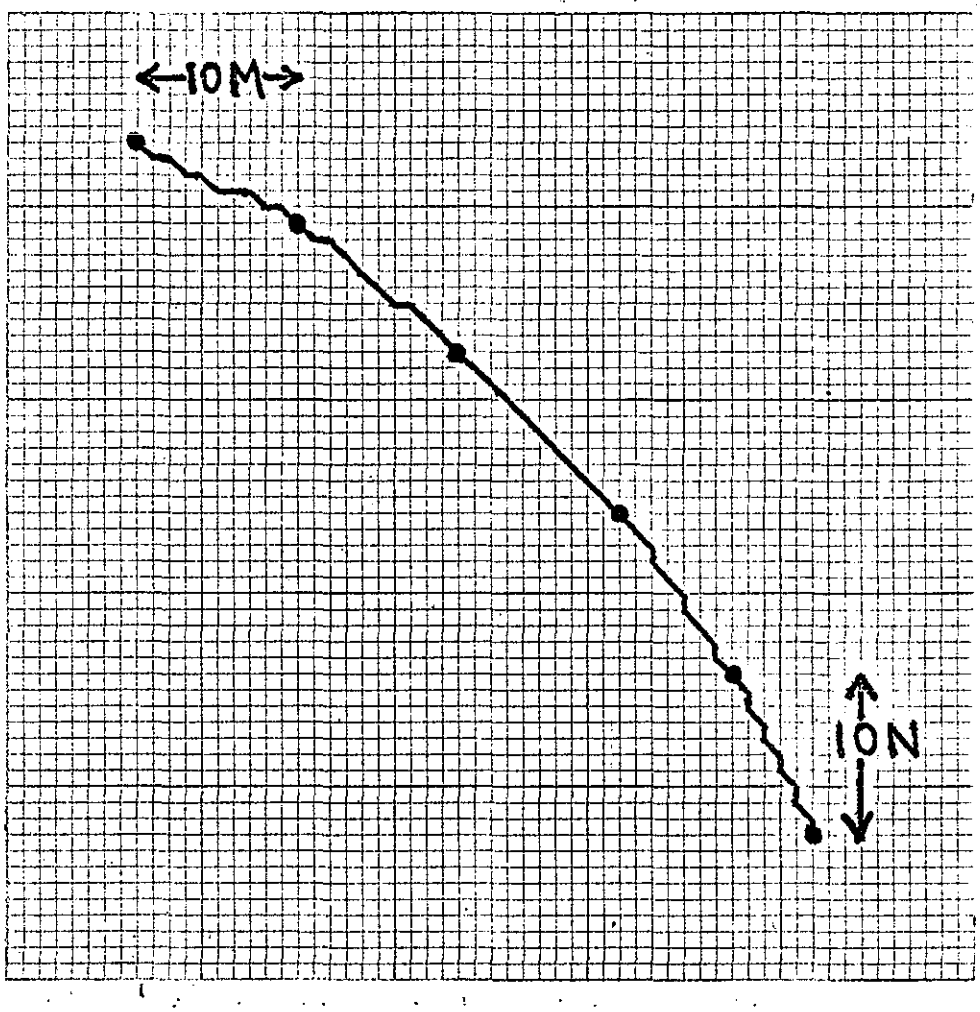


Fig. 3. Typical streamline plotter segments.

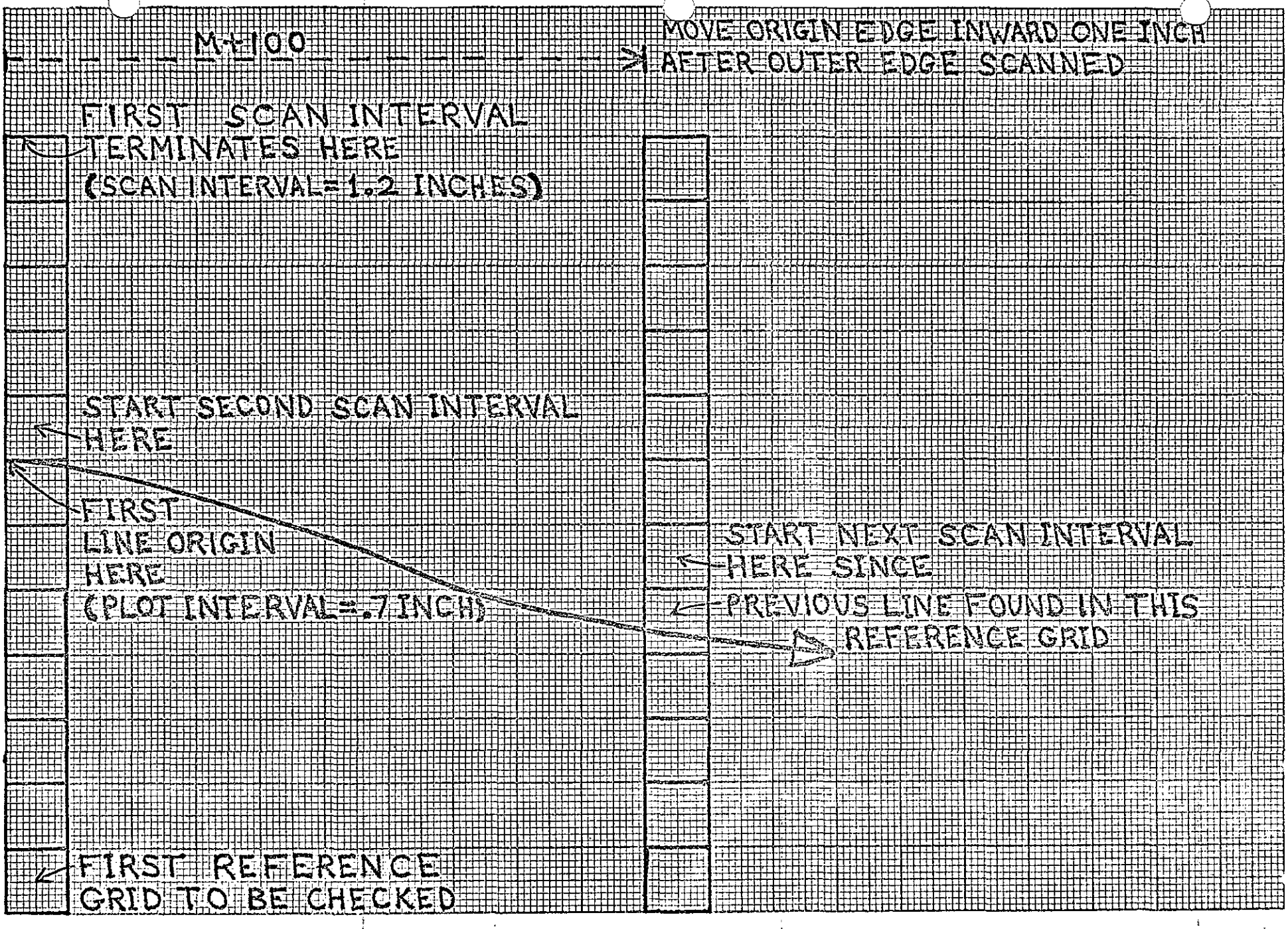


Fig. 4. Line sequencing scheme.

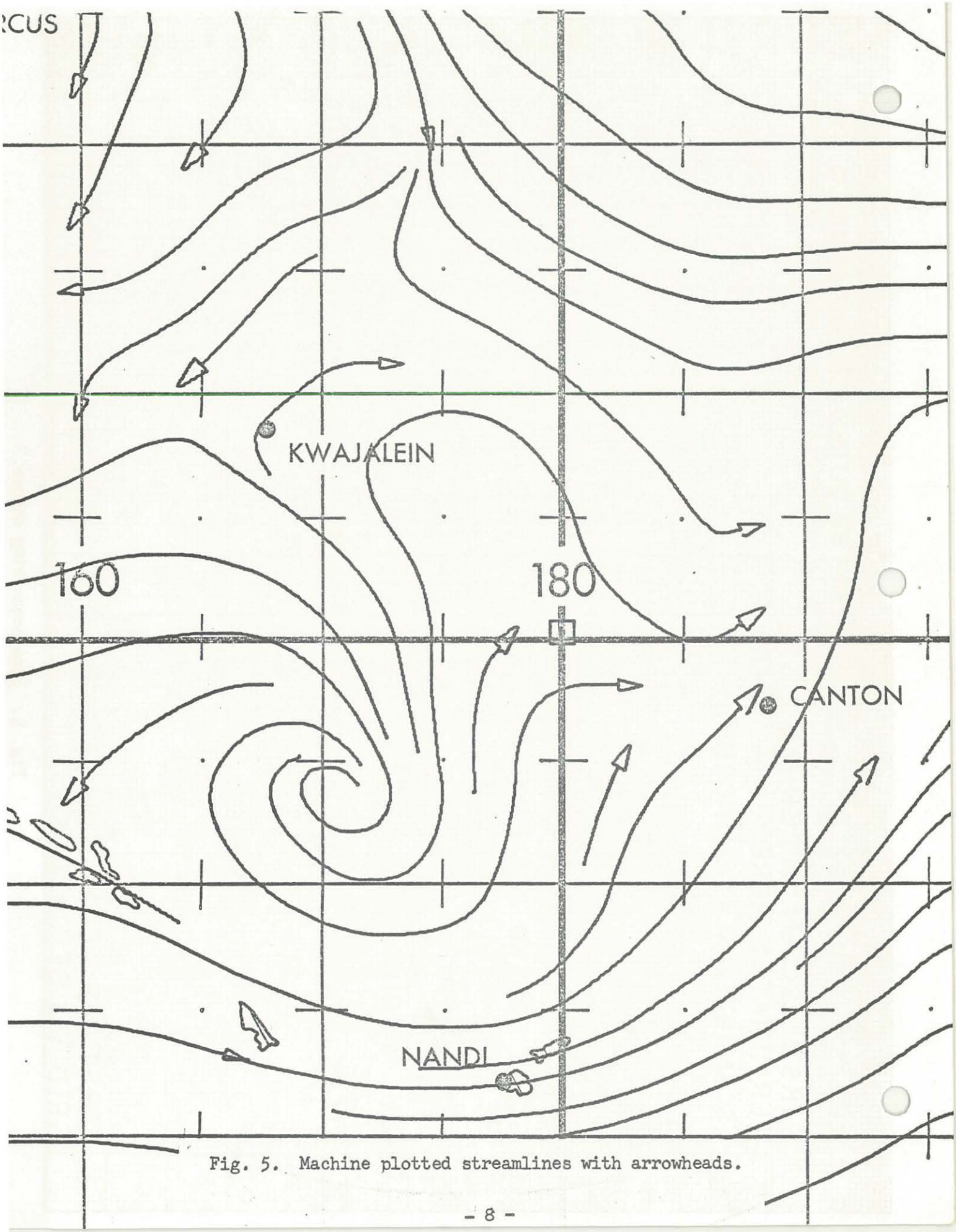


Fig. 5. Machine plotted streamlines with arrowheads.

At the time this is to be done, the usual interpolation is made but instead of plotting the next segment of streamline, the base of the arrow perpendicular to the interpolated segment is calculated. If the outer ends of the base are not in proximity with another line or not out of bounds, the arrow is completed with its point where the downwind end of a double length line segment would have been. Otherwise, the arrow is deleted and the line segment drawn instead.

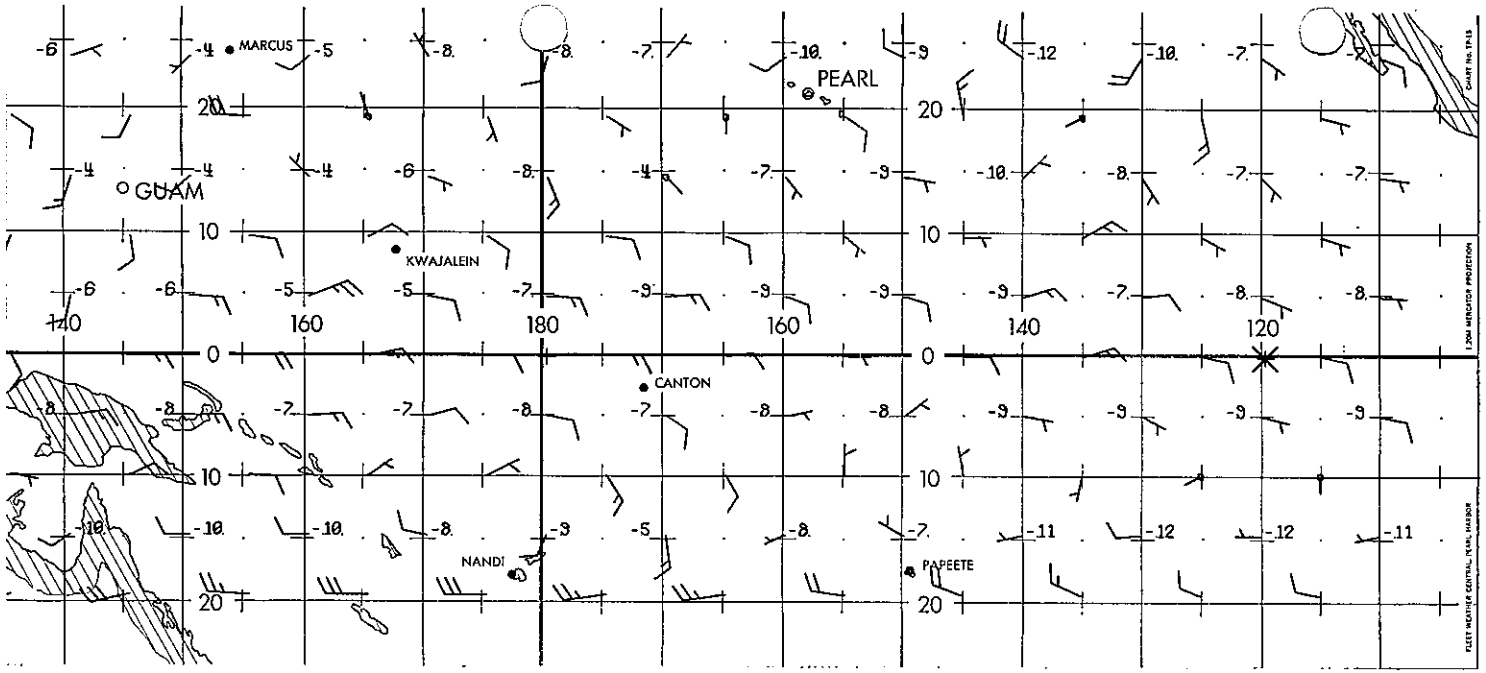
d. Wind direction and speed "barbs".

As can be seen from Fig. 6, other forms of graphics can be produced by an incremental plotter. One popular form is to present the winds at grid points in the familiar form of wind speed and direction "barbs". The directions depicted are accurate to the nearest 10 degrees and wind speeds are correct to the nearest 5 knots. A circle with no shaft indicates a speed of less than 2.5 knots. Similarly, temperatures are added to the chart at each grid point. The final product is shown in Fig. 7.

4. Versatility.

The program is designed to streamline any physical flow field reducible to two scalar components. The operational version of the program consists of a CDC 3100 COMPASS assembled pneumonic language subroutine with a control program also in COMPASS language. In actual practice, the subroutine is kept available as part of the callable subroutine library of the SCOPE monitor. The control program "calls" the basic program from the SCOPE library when needed. A FORTRAN language control program would be easily adaptable to any particular user's needs. It should contain 23 control parameters that specify matrix sizes, spacing, and other variables.

Installations having a lower CDC 3000 series machine and a CalComp incremental plotter should be able to use the program directly. Reprogramming of the basic program would be necessary with other machine installations.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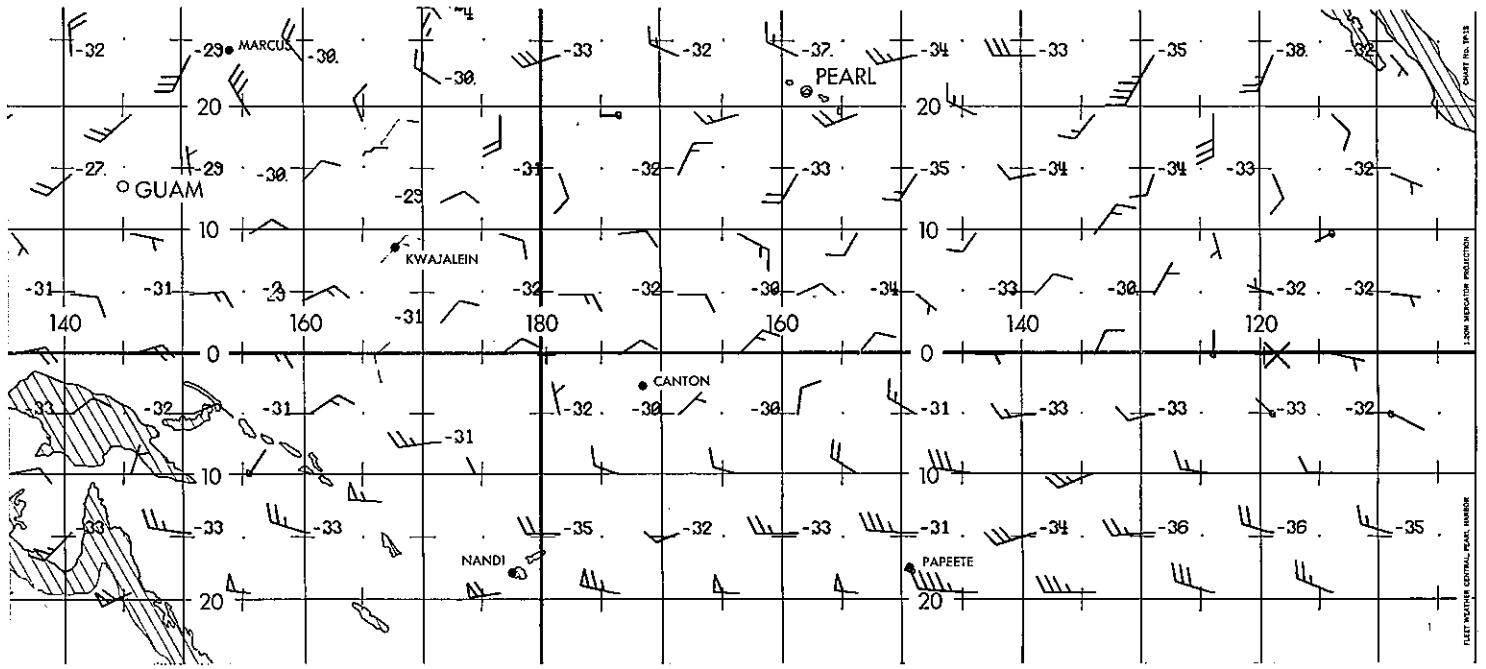
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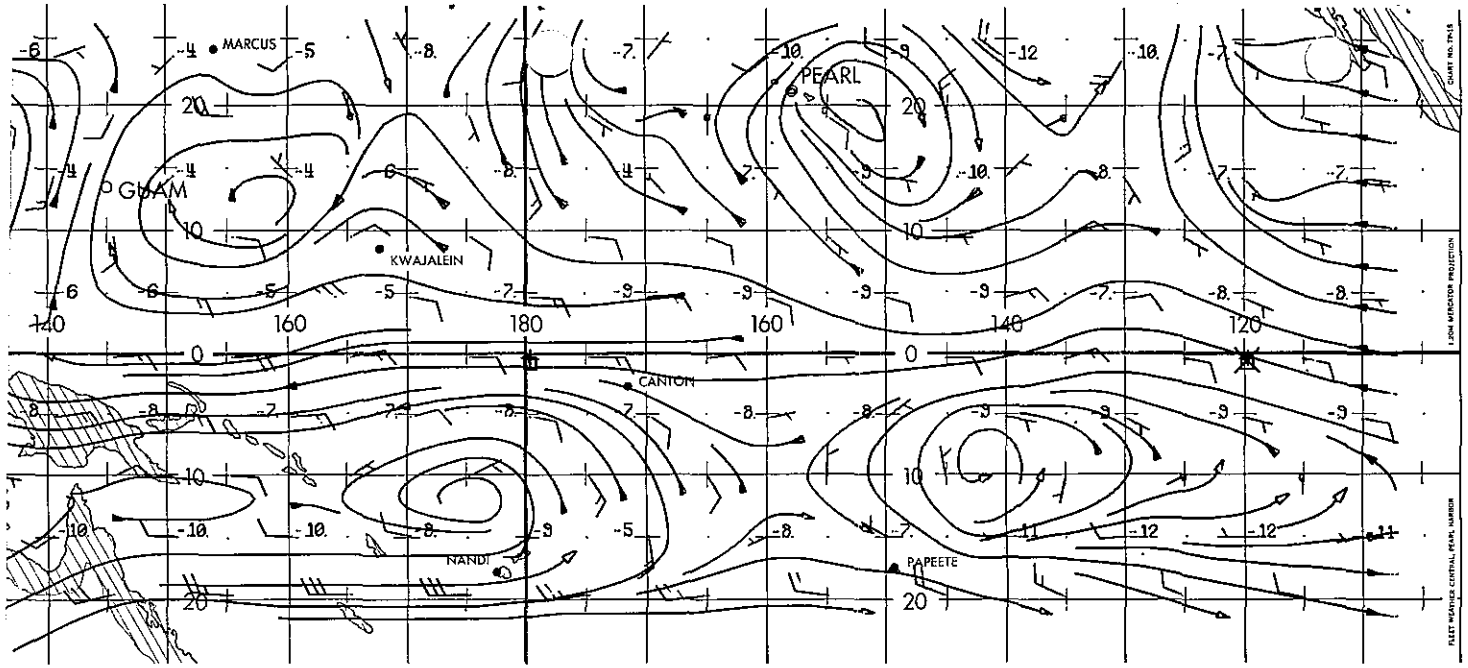
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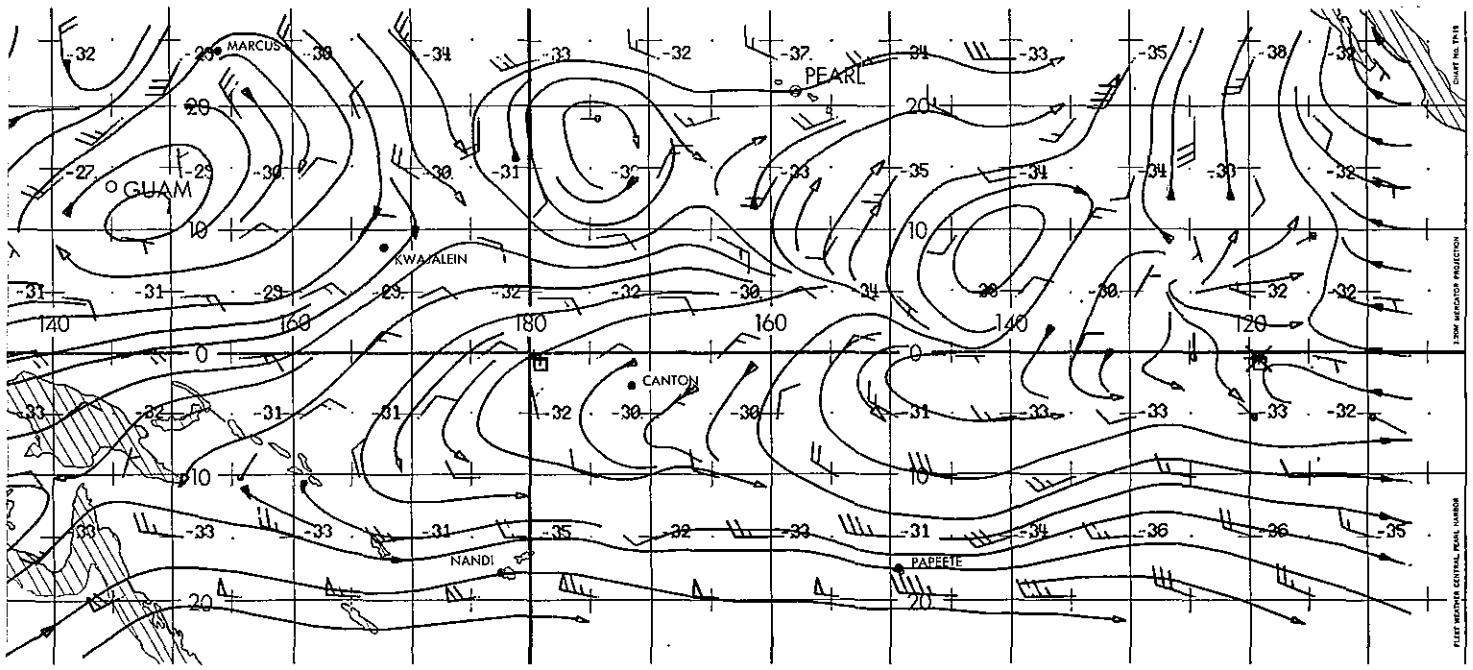
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