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WIND FIELD ANALYSIS FOR CANTILEVER LOADS

Prepared under Contract No. NAS 8-21138 by
NORTH AMERICAN ROCKWELL CORPORATION

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NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

February 1968

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Aero-Astroynamics Laboratory

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NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

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<p>ABSTRACT</p> <p>TEST DATA CONSISTING OF ANEMOMETER STRIP CHART RECORDINGS TAKEN DURING THE 1966 SATURN V WIND LOADS TEST PROGRAM ARE ANALYZED TO DETERMINE INTERFERENCE EFFECTS FROM THE UMBILICAL TOWER AND VEHICLE.</p> <p>CONSIDERABLE FLOW INTERFERENCE IS SHOWN FOR THE MID-HEIGHT LEVELS, WHILE THE FLOW FIELD IS RELATIVELY UNIMPEDED AT THE ANEMOMETER POSITIONS USED AT GROUND AND EXTREME TOP LEVELS. NUMERICAL ANALYSES ARE PERFORMED IN ADDITION TO THE EXPERIMENTAL ANALYSIS TO GAIN FURTHER INSIGHT TO THE RELATIVELY LITTLE UNDERSTOOD INTERFERENCE EFFECTS IN THE LOCAL WIND FLOW ABOUT THE SATURN V - LAUNCHER UMBILICAL TOWER.</p>

FOREWORD

Interference effects in the local wind field about the Saturn V Vehicle and Launcher Umbilical Tower at Launch Complex 39A are analyzed herein. This study was conducted by the Space Division of North American Rockwell Corporation for the George C. Marshall Space Flight Center of National Aeronautics and Space Administration. R. F. Stevenson, supervisor of Methods and Criteria unit, was Project Manager. B. H. Ujihara was Principal Investigator. J. E. Davis developed the computer programs. H. D. McLaughlin analyzed anemometer data from the Saturn V 500 F Wind Loads Test Program and assisted in computer program development. C. D. Martin provided valuable technical advice during this study. At MSFC, the Project Manager was Mr. John Kaufman; alternate Project Monitor was Mr. C. Kelly Hill. Special appreciation is expressed for the many helpful comments and criticisms provided by the Project Monitors, by Mr. Jack Moore, R-P&VE, and by Messrs. Tom Reed and Bill Vaughn, R-AERO, in reviewing the final report rough draft.

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SUMMARY

The test data gathered during the 1966 Wind Loads Test Program at Launch Complex 39 included simultaneous wind recordings at various heights on the Umbilical Tower and near ground level. Analysis of these data (in paper strip chart form) was performed during this study, and pertinent conclusions were established regarding the nature of the interference flow field about the Saturn V/LUT on Launch Pad 39A. In addition, theoretical investigations were performed to augment these conclusions and gain further understanding of the interference flow field. The computer programs developed in this study employ a unique concept of separated flow analysis, which permits the efficient calculation of nonsteady separated flow fields.

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I. INTRODUCTION

The importance of ground winds in the structural design of vertically launched space vehicles has been recognized. Accordingly, considerable research has been expended in recent years toward a clearer definition of imposed ground wind environment and toward an accurate prediction of vehicle response to ground winds. Such research under NASA's direction reached a culmination in the design and operation of the Saturn vehicles. Wind tunnel tests of their dynamically scaled models indicated that large structural dynamic response would occur for certain wind direction and speed conditions.

Since these tests could not duplicate all the known significant environmental parameters, a Ground Wind Loads Test Program utilizing the full-scale Saturn V facilities vehicle (500 F) was conducted during the summer of 1966. Objectives of this test program were to provide full-scale data for evaluating and improving existing ground wind design criteria and methods of predicting ground wind vehicle response. Test instrumentation included wind measuring devices installed on the Launcher Umbilical Tower (LUT), and load measuring devices on the Saturn V vehicle.

The study reported herein has in part been directed towards evaluation of the wind data gathered during this Ground Wind Loads Test Program. This evaluation has revealed pertinent characteristics of the interference flow field derived from suitable reduction and correlation of simultaneously measured wind direction and speed data during the test program at Launch Complex 39.

Theoretical analyses of the flow fields have been made, in conjunction with these experimental results, to understand further the nature of mutual wind interference effects in the immediate region surrounding the Saturn V/ LUT positioned on Launch Pad 39A.

II. ANALYSIS OF EXPERIMENTAL DATA

GENERAL

Knowledge of the local wind field characteristics surrounding the Saturn V/LUT is important for several reasons:

- Their assessment will be helpful in correlating vehicle cantilever loads measured during the wind loads test program with those empirically predicted on the basis of wind tunnel data and analytical methods. This type of comparison is necessary to generate confidence in the validity of ground wind loads prediction methods.
- The existence of significant wind interference effects between the tower and vehicle has been amply demonstrated by wind tunnel test (Farmer and Jones, 1966). However, this mutual interference wind field has not been isolated to any significant degree. Hopefully, analysis of this wind field data will provide insight to the particular flow mechanics leading to interference-augmented vehicle cantilever loads.
- Study of the interference flow field should permit reasonable estimation of the degree of interference for analyzing wind data measured by anemometers mounted on the launcher umbilical tower, thus leading to recommendations regarding their placement to obtain more representative measurements of the local ambient free-stream flow.

Wind field analyses of interference, or wind shadow effects, have been made by several investigators to determine requirements for minimizing errors induced (i. e. , measured distorted flow) because of nearby and/or supporting structures. Moses and Daubek, 1961, are generally given credit for first quantifying the type and magnitude of errors in wind speed measurement caused by structures or other obstacles. Subsequent investigations, both in the wind tunnel and in full scale, have consistently confirmed their results (Meyer, et al. , 1965; Hsi, et al. , 1965; Gill, et al. , 1967). Induced variations in the wind velocity as measured in the lee of typical anemometer support structures have shown that the shape of the structural cross section and the solidity ratios are parameters of major importance (Gill, et al. , 1967). Studies have been made of the three dimensional flow in the lee of truss type structures. The results have shown that the structure seems to lose its influence rapidly on the mean transverse velocity with downwind distance. These results have been determined by comparing the transverse velocity

profiles across the wake at the same downwind distances but at different vertical points. Downstream distances as close as 1.5 tower widths have shown this similarity of profiles in wind tunnel tests by Meyers (1965). The results of studies have also shown that Reynolds number effects are not of primary importance, especially within practical wind velocity ranges. The relative unimportance of Reynolds number is understandable from the viewpoint that a truss type of tower cross section generally consists of structural members having sharply defined corners and lips. For such cross sections the flow separation points are well defined and stationary. This is the case for a flat plate normal to the free stream and, as is well known, the drag coefficient for such a plate is nearly independent of Reynolds number.

Two additional aspects of the flow field not considered in this study are the possible coupling effects that may occur between the vehicle oscillatory response and the nonsteady interference flow field; and possible coupling between normal atmospheric turbulence, and the turbulence induced by flow interference.

TEST CONDITIONS

Full-scale test data describing the local wind field about the Saturn V launcher umbilical tower were obtained during the 1966 Saturn V Ground Wind Loads Test Program at Launch Complex 39 at KSC, Florida. Although the Ground Wind Loads Test covered a period from late May, 1966, until about mid-October, 1966, only ground wind data obtained from 25 May through 25 June were used in this study. While four weeks of meteorological observation is not sufficient to permit general predictions of ground wind behavior, it has provided a significant basis for establishing the major characteristics of mutual interference effects between the Saturn V and the LUT upon the local flow field. A chart showing this data availability is given in Figure 1.

The LUT is an integral structure designed to help support the Saturn V space vehicle in its vertical launch attitude, and to provide access to the vehicle in this position. The LUT tower does not support the vehicle, as loads imposed by the umbilical arms are considered to be negligible. In the on-pad position the LUT vehicle plane of symmetry is in the north-south direction, with umbilical tower to the north. The launcher presents a rectangular solid configuration to the wind environment measuring 7.6 by 41 by 91 meters (25 by 135 by 160 ft), with the deck-zero level 14 meters above the launch pad. The umbilical tower is a truss-type structure having rectangular base dimensions 37 by 18 meters (113 by 60 ft). The rectangular cross section decreases linearly with height to minimum rectangular cross section of 12 by 12 meters (40 by 40 ft) at a height of 24 meters (80 ft) above deck zero. This cross section is maintained to the top of the truss structure 116 meters (380 ft) above deck zero. A 25-ton crane is mounted atop the

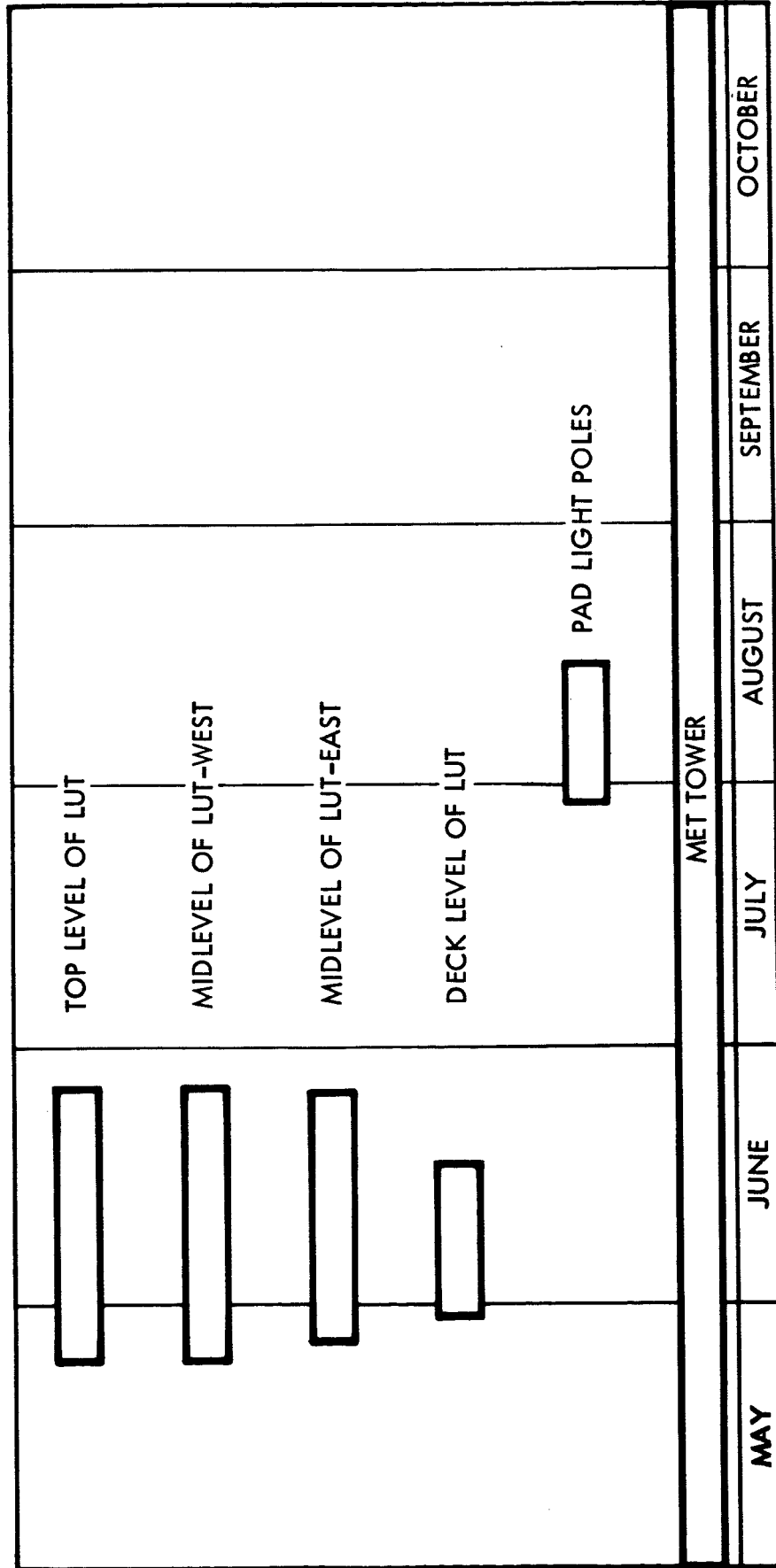


Figure 1. Available Ground Wind Data Observed at Launch Complex 39A and at NASA's Isometer Meteorological Tower

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tower, measuring approximately 39 meters in length (120 ft), 6 meters in maximum height (20 ft), and 6 meters in maximum width (20 ft). A side view is shown in Figure 2. In addition to the structural framework, personnel railings extend around the tower at each deck level. An elevator housing measuring 2.7 by 5.5 meters in cross section (9 x 18 ft) and a personnel staircase run the length of the tower in the north central portion of the tower (positioned on the launch pad). In addition, several conduits extend the length of the tower along the north side effectively blocking the air flow over approximately 50 percent of its breadth. The structural framework and railings alone account for about 10 percent solidity, and together with conduit, housing, and other paraphernalia, the net solidity is estimated to be 60 to 70 percent.

The east-west launch pad elevation is essentially a trapezoid of bases 152 and 91 meters (500 and 300 ft) and a height of 15 meters (50 ft). The north-south elevation is not so conveniently defined, being characterized by the gradually inclined crawler way from the south, and the service access ramp extending approximately 300 meters (1000 ft) to the northwest. Discounting these principal features, this elevation would also be trapezoidal with bases of about 122 and 214 meters (400 and 700 ft). A top view and east-west planform are indicated in Figure 3.

Although some wind data were gathered while the Saturn V LUT was in transit between the vertical assembly building (VAB) and Pad 39A, the preponderance of wind data were obtained with the Saturn V - LUT in the launch configuration atop Launch Pad 39A. The Mobile Service Structure (MSS) was placed in service in October; it did not influence the test data from the LUT-mounted anemometers. All the pads in Launch Complex 39 are oriented in the same direction, with the plane of vertical symmetry running north and south. Launch Pad 39A is the southernmost of the two existing pads in the launch complex. It is approximately one-half mile from the Atlantic coastline which runs generally northwest-southeast at this point. Banana Creek lies generally to the south and west of Launch Pad 39A. Surrounding terrain is generally flat and sandy with low lying (about one meter in height) scrub palmetto being fairly abundant. What appears to be a sand bar approximating a 3- or 4-meter levee closely parallels the coastline in both directions as far as can be seen by naked eye from Launch Pad 39A.

The nearest sizeable structure is the VAB situated about three and one-half miles west-southwest of Pad 39A. Somewhat smaller structures (vehicle integration buildings) exist farther south within the Titan III C Launch Complex.

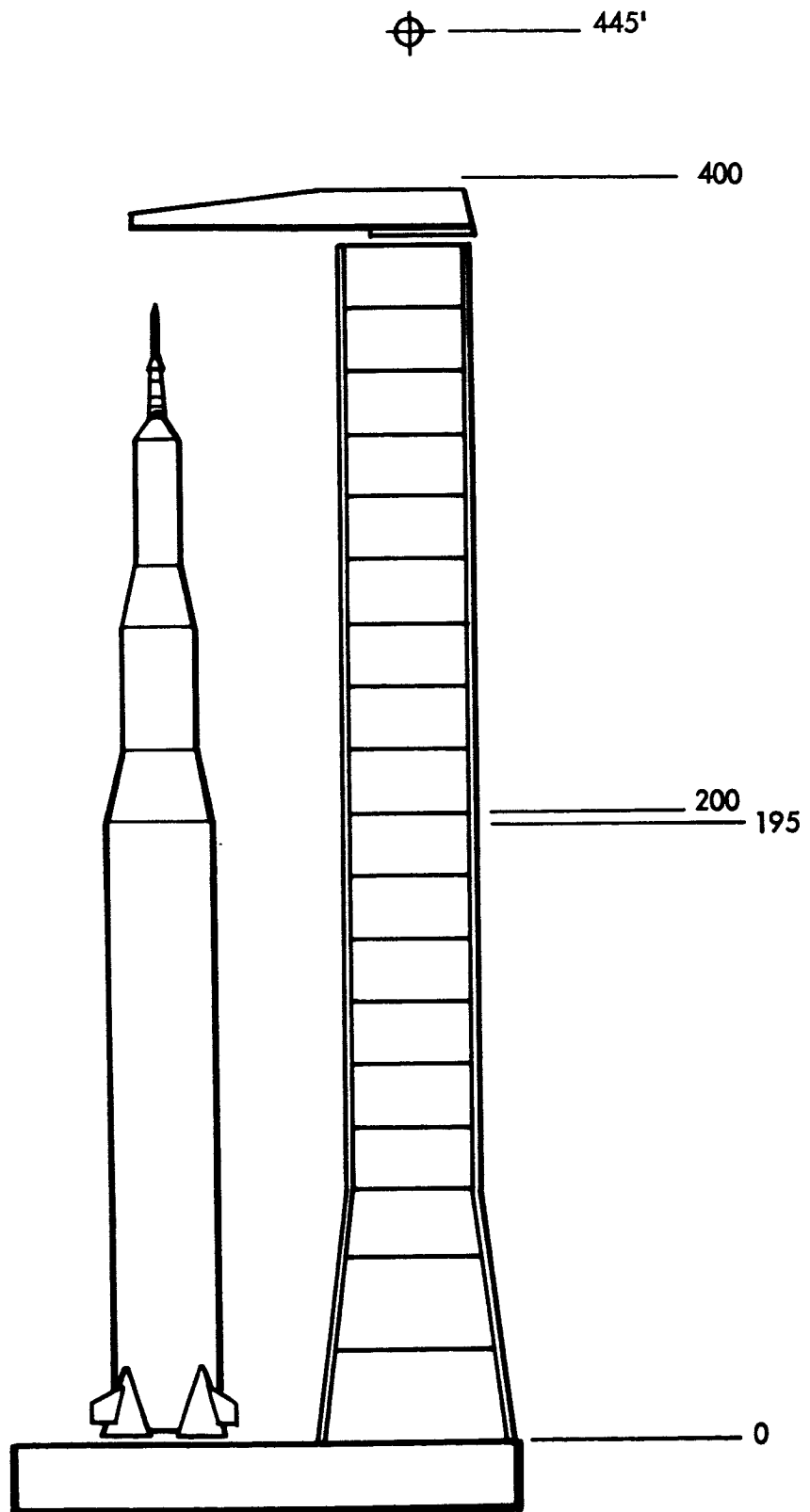


Figure 2. Saturn V Launcher Umbilical Tower

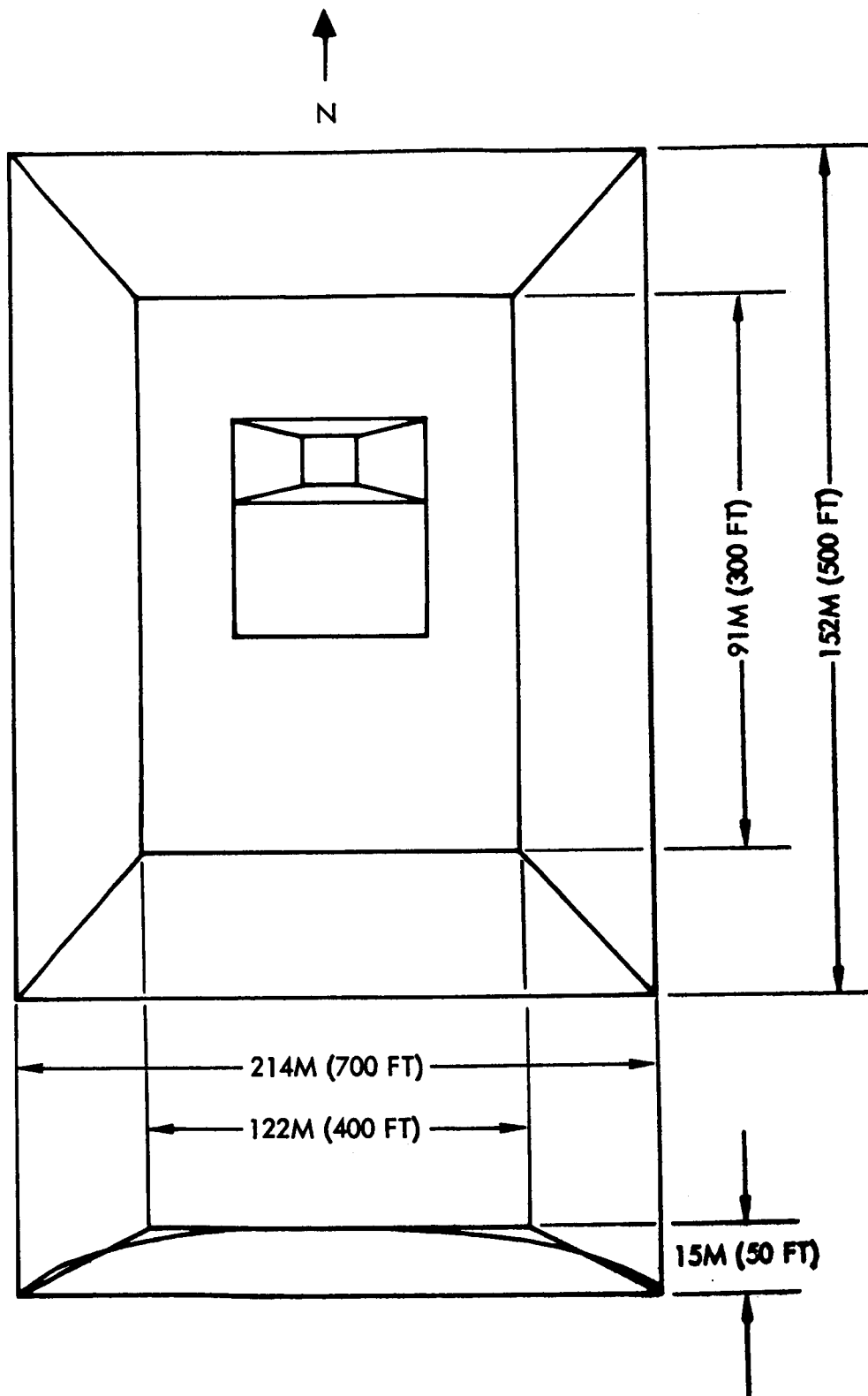


Figure 3. Basic Dimensions of Launch Pad 39A,
Vehicle and LUT Shown in Plan View

INSTRUMENTATION

During the test, four Model C1-14 Climet anemometers (Reference 1) were located on the LUT as shown in Figure 2. The highest (top level) was on a 12-meter (40-ft) mast surmounting the crane and on the centerline of the umbilical tower. This anemometer was 136 meters (445 ft) above deck level and 164 meters (537 ft) above natural grade.

Two anemometers were located on 25-foot booms extending horizontally outward from the tower, at the two corners farthest from the vehicle, and parallel to the side farthest from the vehicle. These anemometers were 59 meters (195 ft) above deck level and 87 meters (287 ft) above natural grade. The fourth anemometer was mounted on a 3.4-meter (11-ft) high mast on the deck of the launcher. This mast was located on the outer periphery of the southwest corner of the pad-positioned launcher attached to two bars of the personnel railing.

Additional wind speed and azimuth data were also obtained from two anemometers, identified as the PLP's, for pad light pole. These were mounted on individual light poles 18 meters (60 ft) above natural grade, and located 300 meters (1000 ft) northwest and southeast of the launch-positioned Saturn V body centerline. The PLP anemometers were also the C1-14 Climet type. Their data were recorded in a manner similar to those for the LUT-mounted anemometer. As shown in Figure 1, comparison of simultaneous PLP and LUT data was not possible.

For all of these anemometers, wind speed (mph), and direction were recorded continuously on a 24-hour basis by 2-channel Esterline-Angus paper strip chart recorders at a chart speed of .076 meters (3 inches) per hour. A sample of this chart data analyzed in this study is shown in Figure 4. Down time for maintenance and calibration adjustment caused some interruption of data. Wind azimuth was measured clockwise from true north to the approaching wind vector.

Perhaps the most serious interruption to the data was that caused by crane movement invalidating wind direction data from the top-level LUT wind vane. Thus, when the crane was not in its normal orientation (i. e., north-south with the boom tip over the vehicle) spurious directions were obtained. This deficiency was especially critical since the top-level wind direction data were the data expected to contain the least contamination from flow interference effects, and would therefore be expected to provide the best set of reference data for comparison with data from the remaining LUT anemometers.

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For further comparison, computer listings of climatological data from NASA's 150-meter meteorological tower at Cape Kennedy were utilized to obtain concurrent mean values of wind direction and speed at the 150-meter (500 ft) level. These data, also obtained from C1-14 Climet anemometers (Reference 1), consisted of 10-minute mean values around the hour (i. e. , from 5 minutes before until 5 minutes after the hour) and maximum values for the same time periods. This meteorological tower is located approximately three and one-half miles west-northwest of Launch Pad 39A. The form of data did not permit analysis of low periodicities near the range of vehicle bending frequencies. Such analyses would require the more detailed data recorded on magnetic tape, which were not considered a part of this study.

In evaluation of these ground wind data, as recorded on dual-channel paper strip charts, emphasis was placed upon the selection of time points characterized by relatively steady wind. Wherever possible high wind conditions were chosen. Winds from the north occurred the least often during the test period, with easterly and westerly winds predominating. The data points were read directly from the strip charts. Errors incurred in both time and ordinate values by reading, roundoff, and slide rule conversion were not evaluated. For wind direction readings, a separate graduated scale was placed at the selected point, first spotted in by pencil, since the given scale was difficult to interpolate.

EVALUATION AND ANALYSIS OF TEST DATA

The basic question to be answered by analysis of the test data is that of the nature and extent of the wind interference owing to the terrain and structures in the near vicinity of the PLP- and LUT-mounted anemometers.

Anemometer Above Crane

Of the four anemometer locations employed on the LUT during the ground wind loads test, the one located on the 12-meter mast atop the crane would be expected to provide the most accurate reading of local free stream. Certainly it is the one least obstructed in all azimuths.

The only available comparative data for that approximate height, which data may a priori be considered more reliable than the LUT data for exhibiting free-stream characteristics, are those gathered concurrently from NASA's 150-meter meteorological tower. One would not expect the instantaneous readings from the LUT and the meteorological tower to agree, considering their separation (3-1/2 miles). One would expect, however, that the long-duration averages would be in fair agreement, with the agreement

improving under stronger and steadier winds. A sample of this long-duration data is presented in Figures 5 through 7. Figure 5 shows ten-minute average directions at the LUT upper-level anemometer versus synchronized ten-minute average directions at the 150-meter level of the meteorological tower. As much as possible in all of this data analysis, the higher wind speeds were favored. Attempts were made to cover all azimuths; however, it is apparent that easterly and westerly winds predominated for the test period in question. Rather clearly this plot does not prove any appreciable average disagreement. The ten-minute average speed comparison between the LUT upper level and meteorological tower 150-meter level anemometers is shown in Figure 6.

The fitted line of Figure 6 was arrived at by sectioning the horizontal axis into one-meter-per-second intervals, for each interval taking a line of unit slope that divides the points in that interval into two equally large groups, marking where that line intersects the mid-abcissa of the interval, and hand-fitting a straight line through these marks. In addition to their ease of application, the main property of these "median methods" is their relative unresponsiveness to spurious extreme points when compared with "arithmetic mean methods" like least squares. Here one sees the improvement of correlation (reduction of scatter) at higher speeds. As it should, the fitted line of Figure 4 does pass through the centroid of data points with an approximate 45-degree slope. However, there is an apparent and distinct deviation of this line from the line of unit slope through the origin (shown dashed). This deviation ranges from about 3 percent at high wind speeds as measured at the meteorological tower to as much as 30 percent at the lower speeds. The actual wind speed difference ranges from about .4 meter/sec to 1 meter/sec respectively.

While the procedure used to determine the fitted line contains some arbitrariness, it is also clear by simple visual inspection that the unit slope line through the origin does not represent the data mean. Several possible explanations exist for some systematic bias in these data, none of which satisfactorily accounts for the type of deviation indicated.

1. The LUT upper level anemometer elevation is 12 meters higher than the 150-meter anemometer on the meteorological tower. Using the wind profile law

$$\frac{U_2}{U_1} = \left(\frac{z_2}{z_1} \right)^{.2} \quad (1)$$

the increase in speed at the LUT upper-level anemometer would be about 1.5 percent.

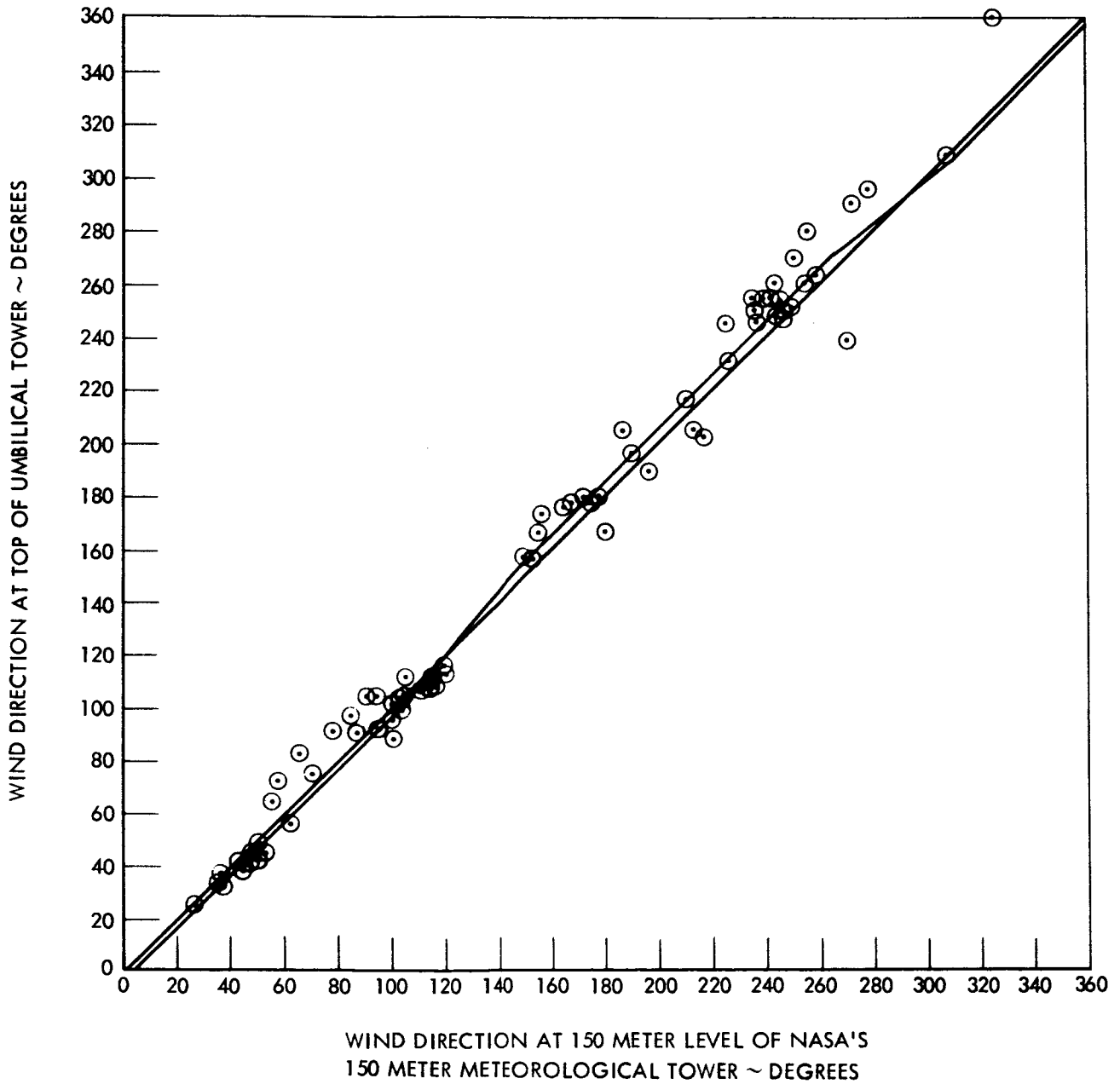


Figure 5. Comparison of Mean Wind Directions for the 150-Meter Level at NASA's 150-Meter Meteorological Tower Versus 445-Foot Level LUT Data, Ten-Minute Averages

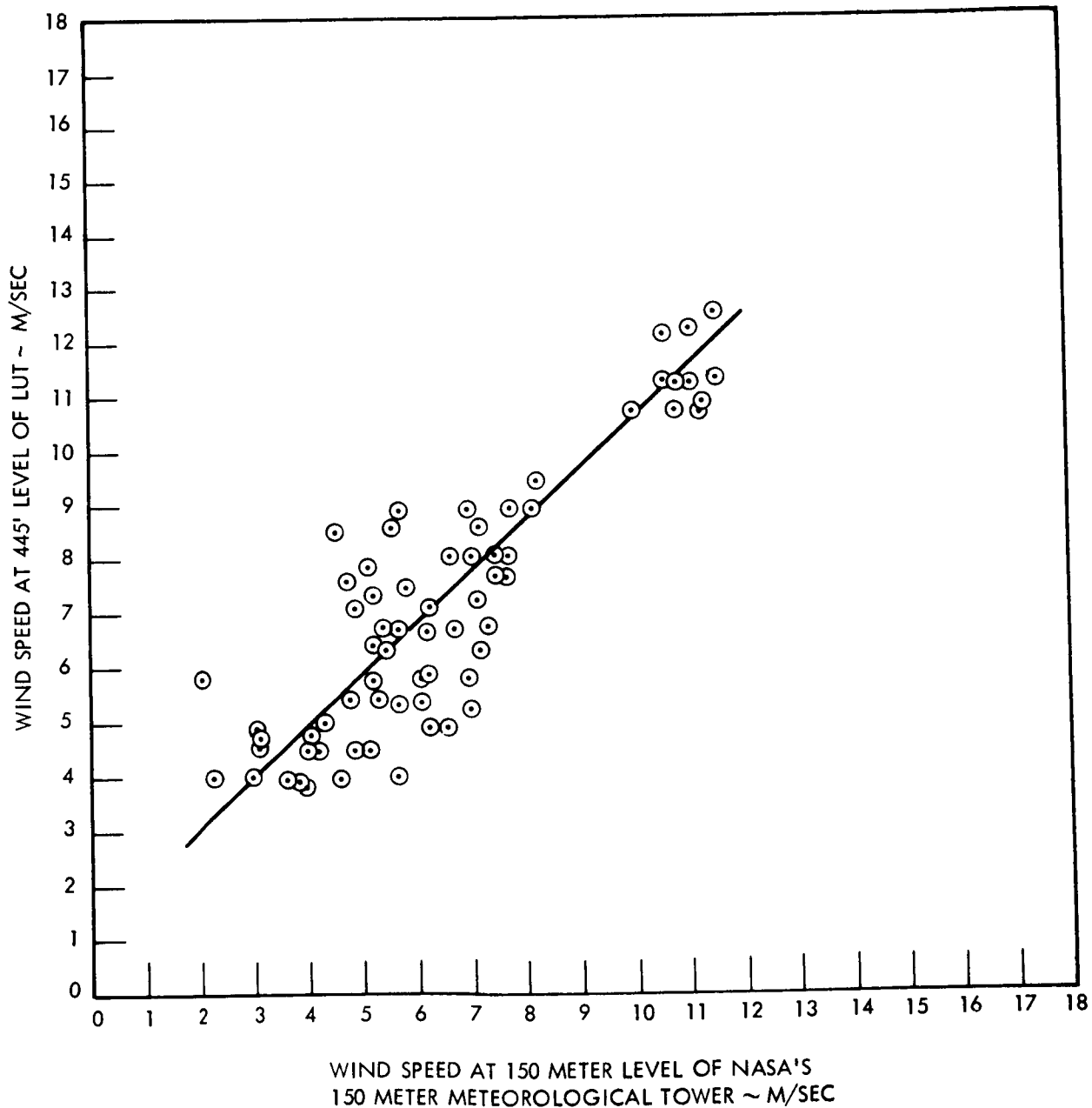


Figure 6. Comparison of Mean Wind Speeds for the 150-Meter Level at NASA's 150-Meter Meteorological Tower Versus 445-Foot Level LUT Data, Ten-Minute Averages

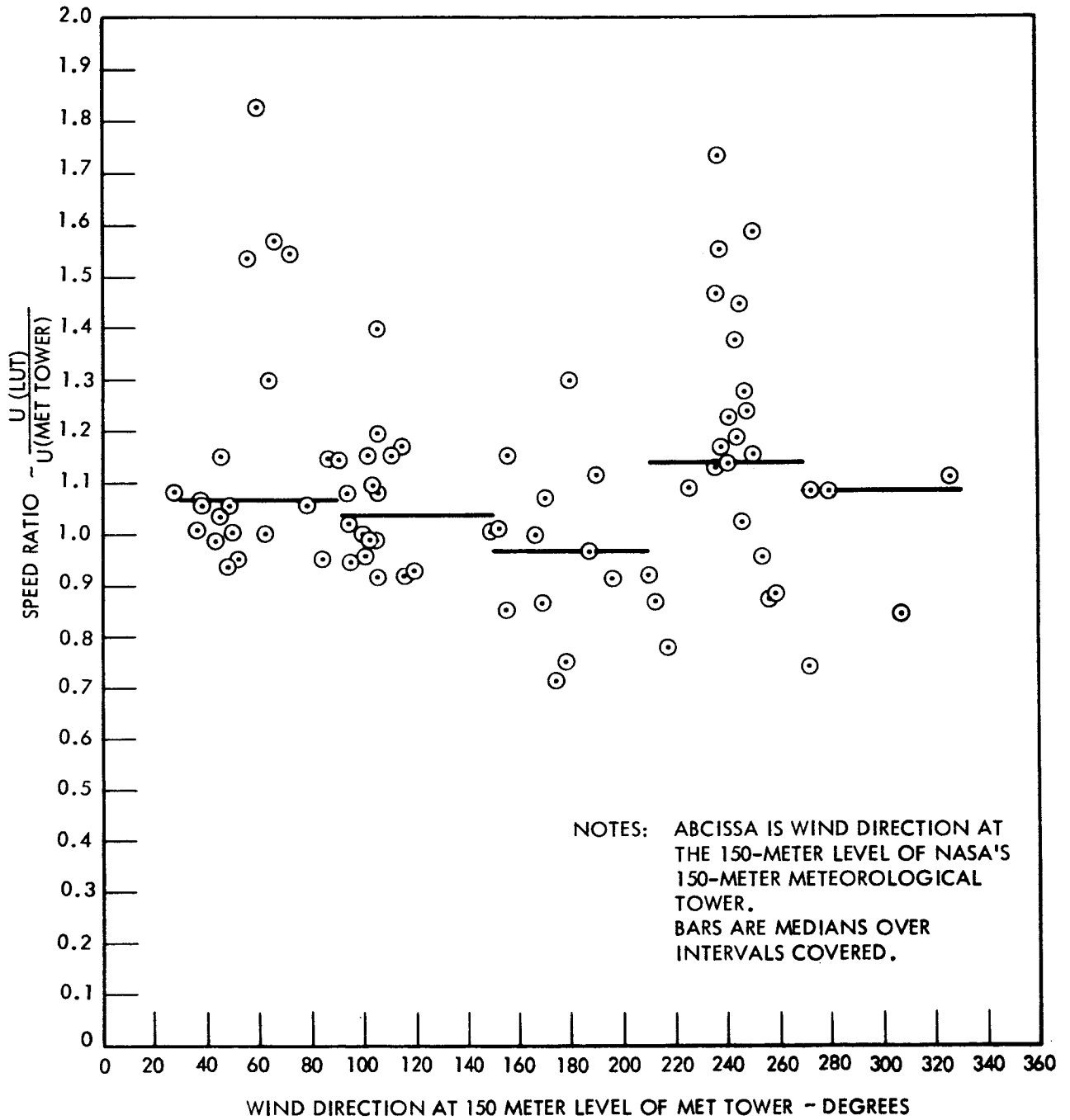


Figure 7. Speed at 445-Foot Level of LUT Divided by Speed at the 150-Meter Level of NASA's 150-Meter Meteorological Tower

2. East-west elevation profile of Launch Pad 39A presents a trapezoidal cross-section of 16 meters (50 ft) height. Using a conservative two-dimensional potential flow assumption, a speed up of about 2 percent as shown in Figure 8 is calculated at the LUT upper level for flow over an equivalent elliptical cross section. This idealized flow is analyzed in greater detail in a subsequent section.
3. A recommendation is made by Gill, et al., (1967) on the basis of observed experimental wind tunnel data for locating an anemometer atop a circular stack without effluent. It is stated herein that ". . . the accuracy of speed and direction measurements can be markedly improved by locating the top set of wind sensors 1/2 D [diameter] or higher above the stack." In the present case, the upper-level anemometer is located about 12 meters above the LUT. Cross section of the LUT is 13 meters square at all heights above the 26-meter level (from Deck Zero). Thus, this recommendation is apparently satisfied.
4. The 25-ton crane atop the LUT (see Figure 2) does represent an additional obstruction of sizeable dimensions. It is approximately 40 meters in length, with maximum cross section 6 meters square. Its maximum effect is estimated by assuming a 6-meter diameter circular cylinder in two-dimensional potential flow. In terms of this cylinder, the anemometer is located at a distance of 5 radii along the vertical centerline. The local velocity at this point is

$$\frac{U}{U_o} = 1 + \frac{1}{(y/R)^2} = 1.04$$

This effect would be felt most strongly for winds within the azimuth range of 90 degrees \pm 30 degrees, and 270 \pm 30 degrees. Approximately half the data points were found to represent wind conditions in this range.

5. Again considering winds primarily from the east or west, the basic breadth dimension may be greater than that of the tower. It is possible that the ratio of tower plus vehicle semi-breadths to their centerline spacing is sufficiently near unity that some blockage may occur, causing significant speed up in the flow up over the extremities. In this case, a pertinent dimension may be the tower-vehicle centerline spacing together with some porosity parameter such as the ratio mentioned above.

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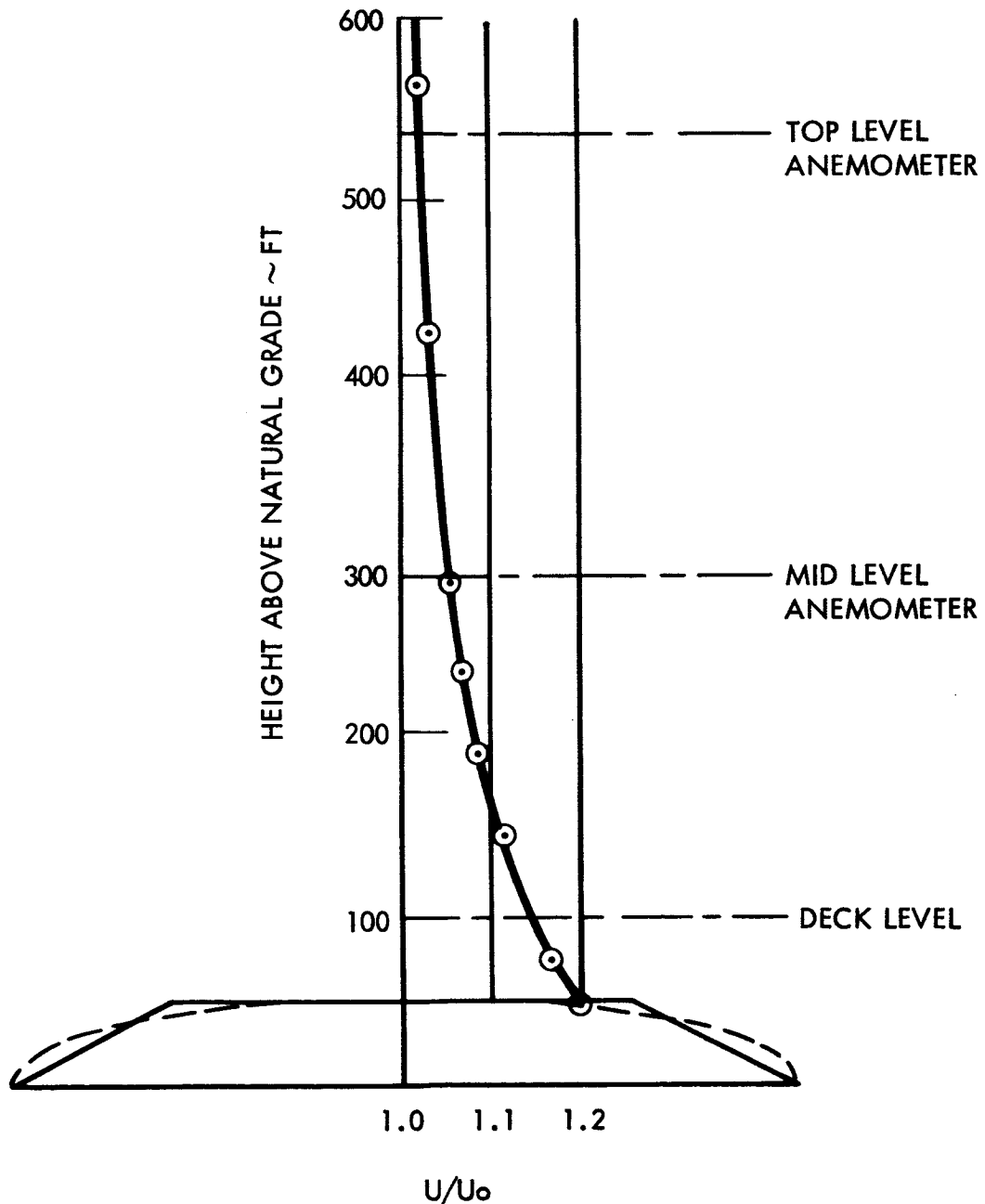


Figure 8. Wind Profile of Steady Two-Dimensional Potential Flow Over Pad Alone, East-West Section (Approximated by Equivalent Ellipse)

All of these possible explanations (1-5) would produce a deviation proportional to free stream velocity. Unfortunately this does not appear to be the type of deviation indicated in Figure 4. It is statistically possible, of course, that the data points selected (about 75 total) coincidentally exhibit the relationship obtained. In this event, it must be concluded that more data points are needed.

In a further attempt to correlate the concurrent data from LUT upper-level anemometers and the 150-meter meteorological tower data, the velocity ratios were plotted against the 150-meter meteorological tower azimuths. These are shown in Figure 7. Extremes in the scatter, as would be expected, occurred at low velocities (less than 6 meters/sec). Median values over 60-degree intervals were determined, and are shown as discontinuous bars over the interval spans. Again, a small but distinct speedup at the LUT upper level is indicated at all azimuth ranges except for the interval centered at 180 degrees azimuth. In view of the several contributing factors indicating some acceleration in the flow, it is concluded that a speedup on the order of 5 to 10 percent should be allowed.

Midlevel Anemometers

Analysis of the data for these locations aims to determine the mean shift in the free stream wind vector at this level. The only available estimate of the free stream vector in question is based on the strip chart data for the anemometer at the top of the LUT. It is felt that the raw readings from the top of the LUT will better estimate the midlevel free stream if they are scaled down to the midlevel of the LUT by means of the wind profile law (Equation 1) previously given.

Two types of plots were prepared: (1) ratio of speed at either of the midlevel anemometers to speed at the top anemometer (scaled or unscaled to midlevel) as a function of azimuth at the top anemometer, and (2) azimuth at either of the midlevel anemometers as a function of azimuth at the top anemometer.

Speed Ratio Plots

Figures 9a, 9b, 10a, and 10b are scattergrams of the speed ratio $UMID/UTOP$ with $UTOP$ uncorrected for height. Least-squared error curves, discussed in Appendix C, were determined for these scattergrams and are shown in Figures 9a and 10a. Each scattergram in Figures 9b and 10b is hand-fitted with a curve passing through the median ratios in 10-degree compass intervals. Figure 9 corresponds to the east midlevel anemometer, Figure 10 the west. Physical symmetry about the north-south centerline of the vehicle LUT assembly leads one to expect mirror behavior of the two midlevel anemometers. Figure 11 compares the west anemometer median curve

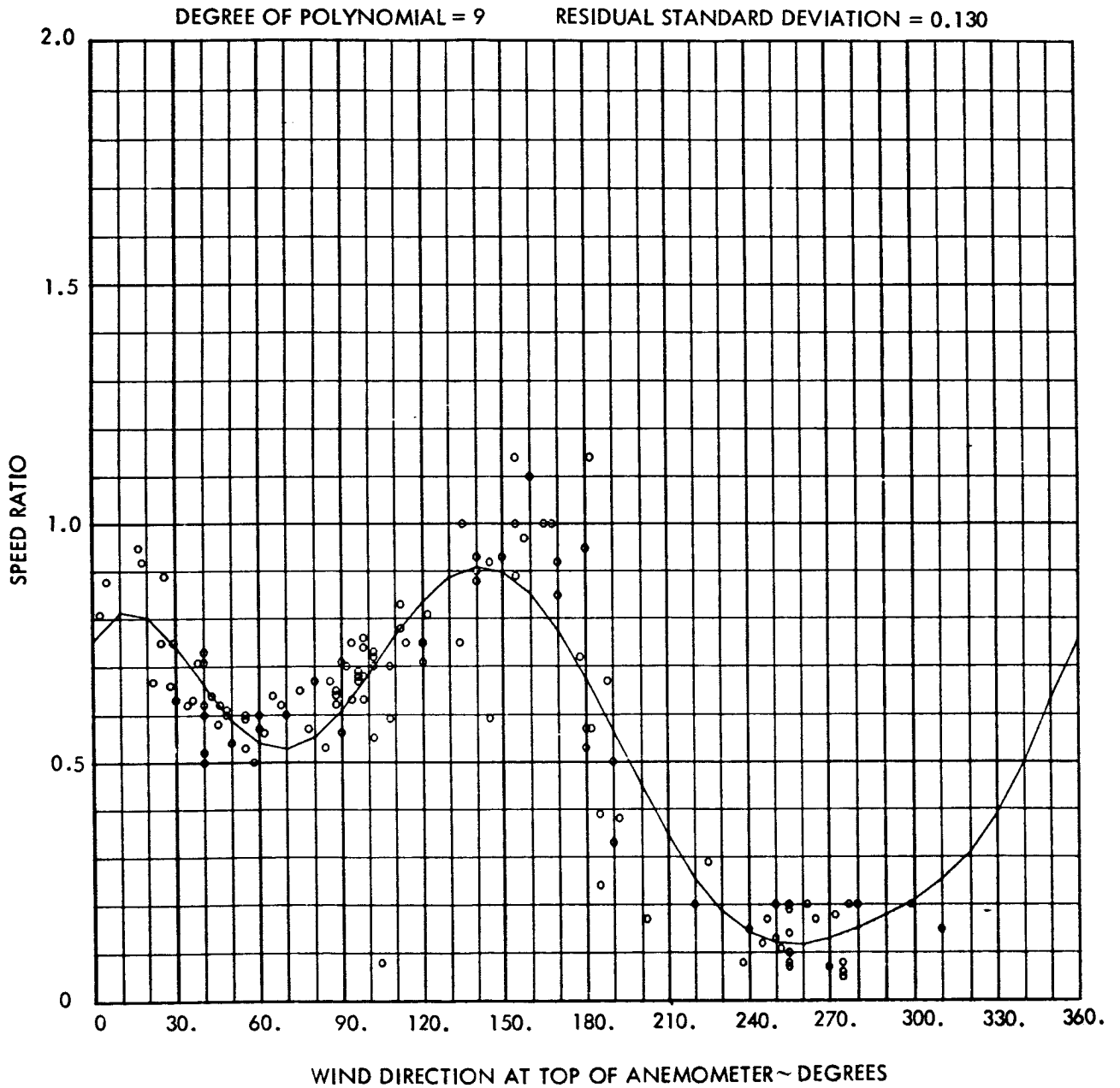


Figure 9a. Speed Ratio U_{MID}/U_{TOP} for East Anemometer

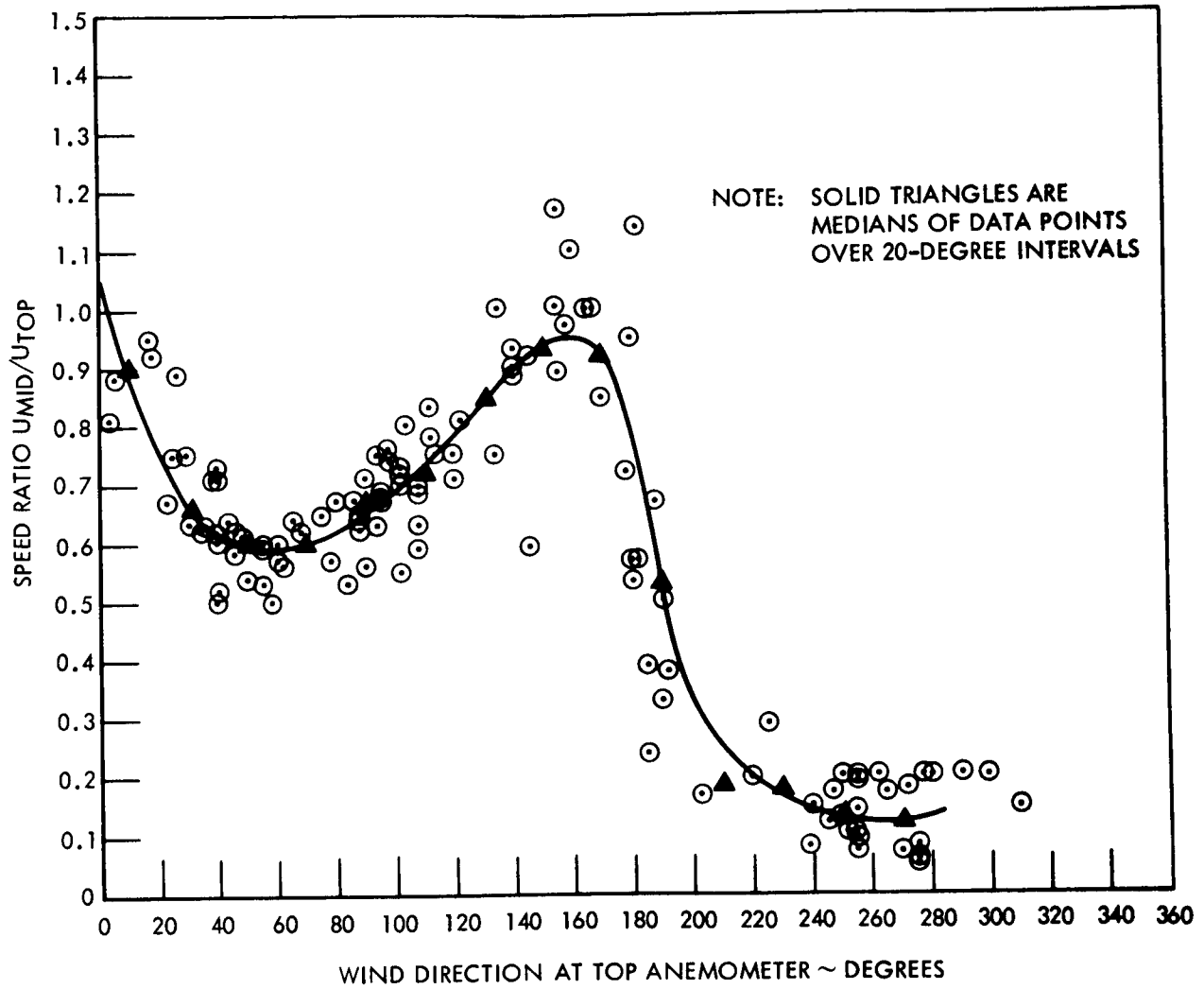


Figure 9b. Speed Ratio U_{MID}/U_{TOP} for East Anemometer

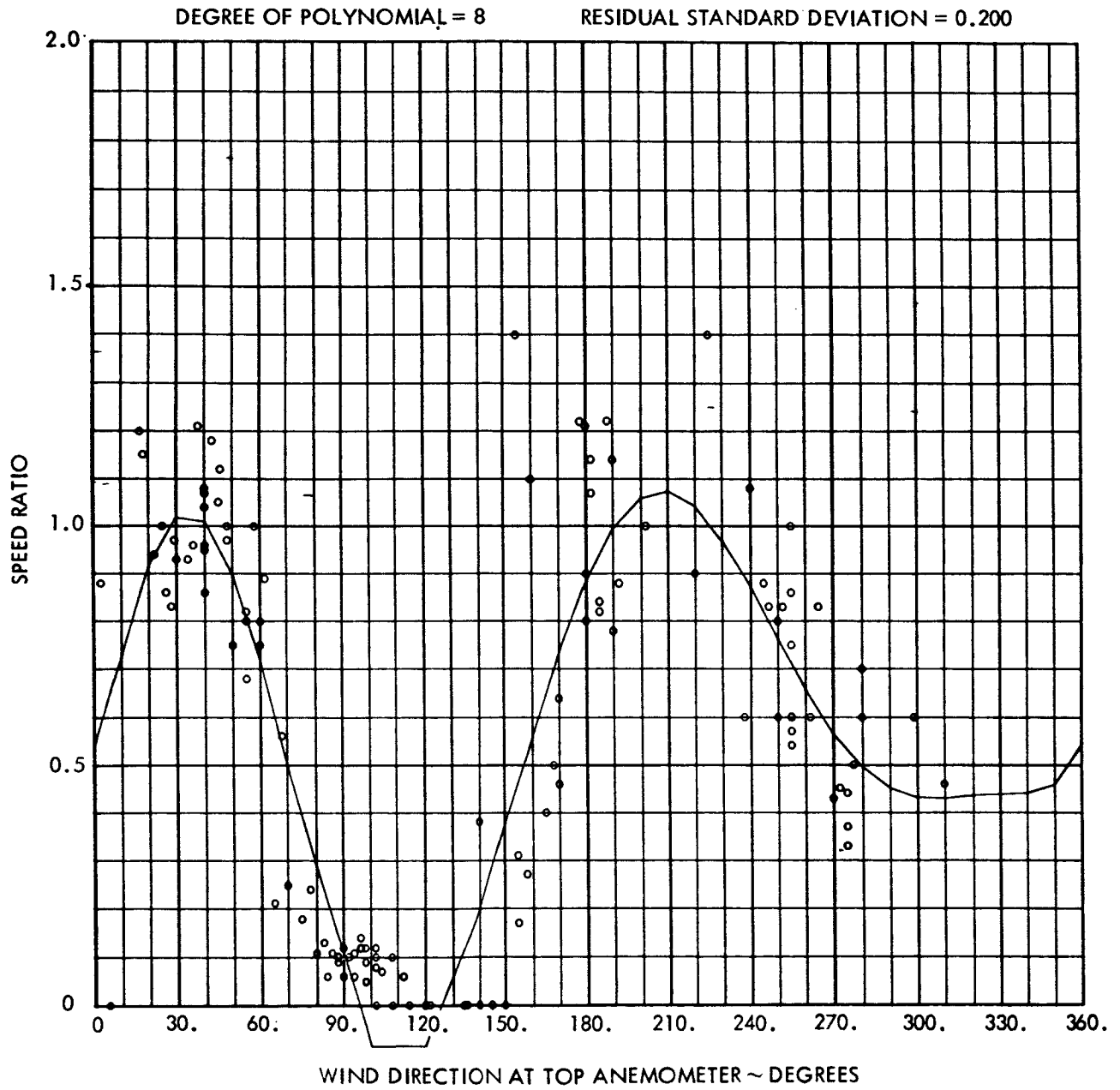


Figure 10a. Speed Ratio U_{MID} / U_{TOP} for West Anemometer

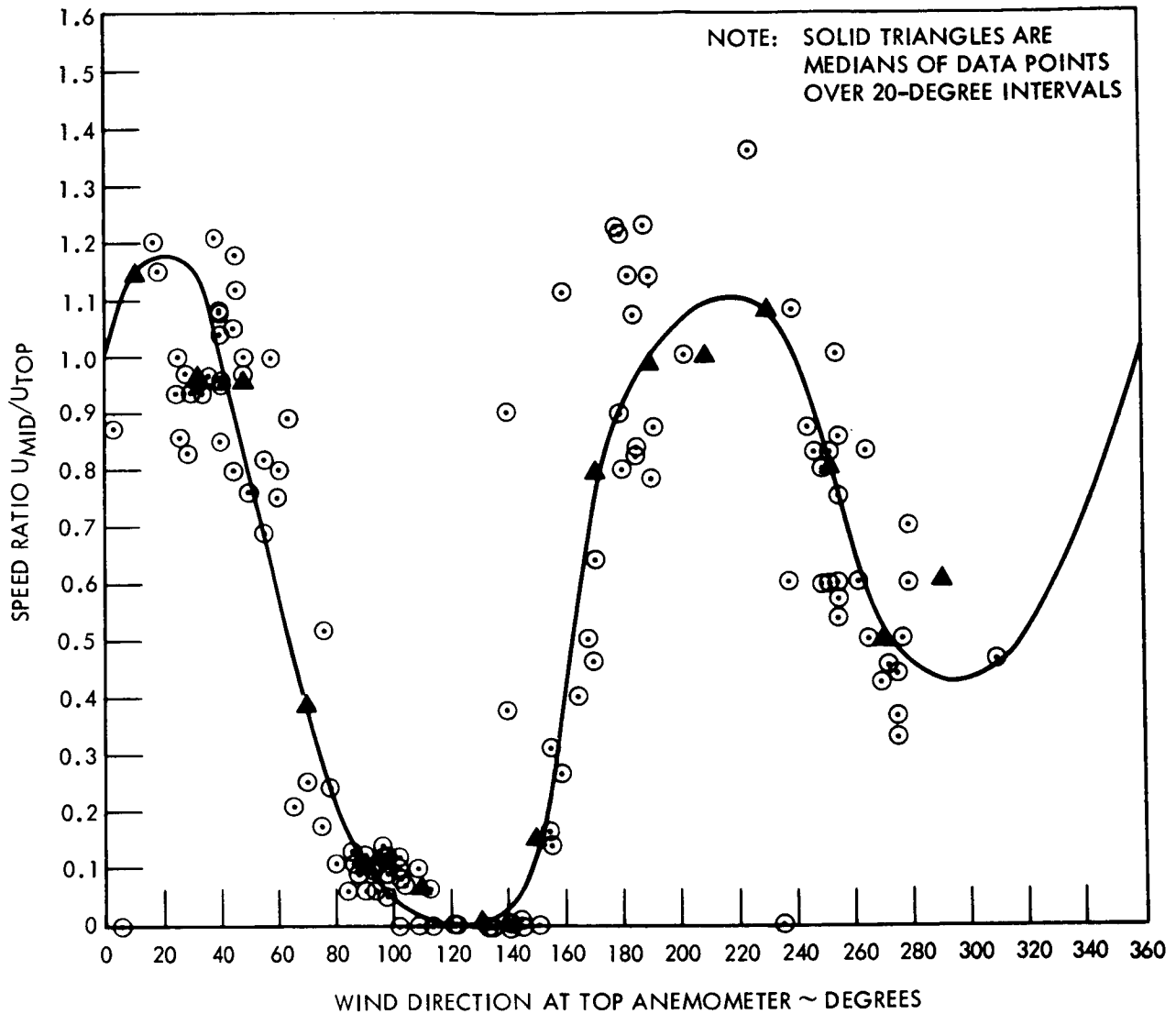


Figure 10b. Speed Ratio U_{MID}/U_{TOP} for West Anemometer

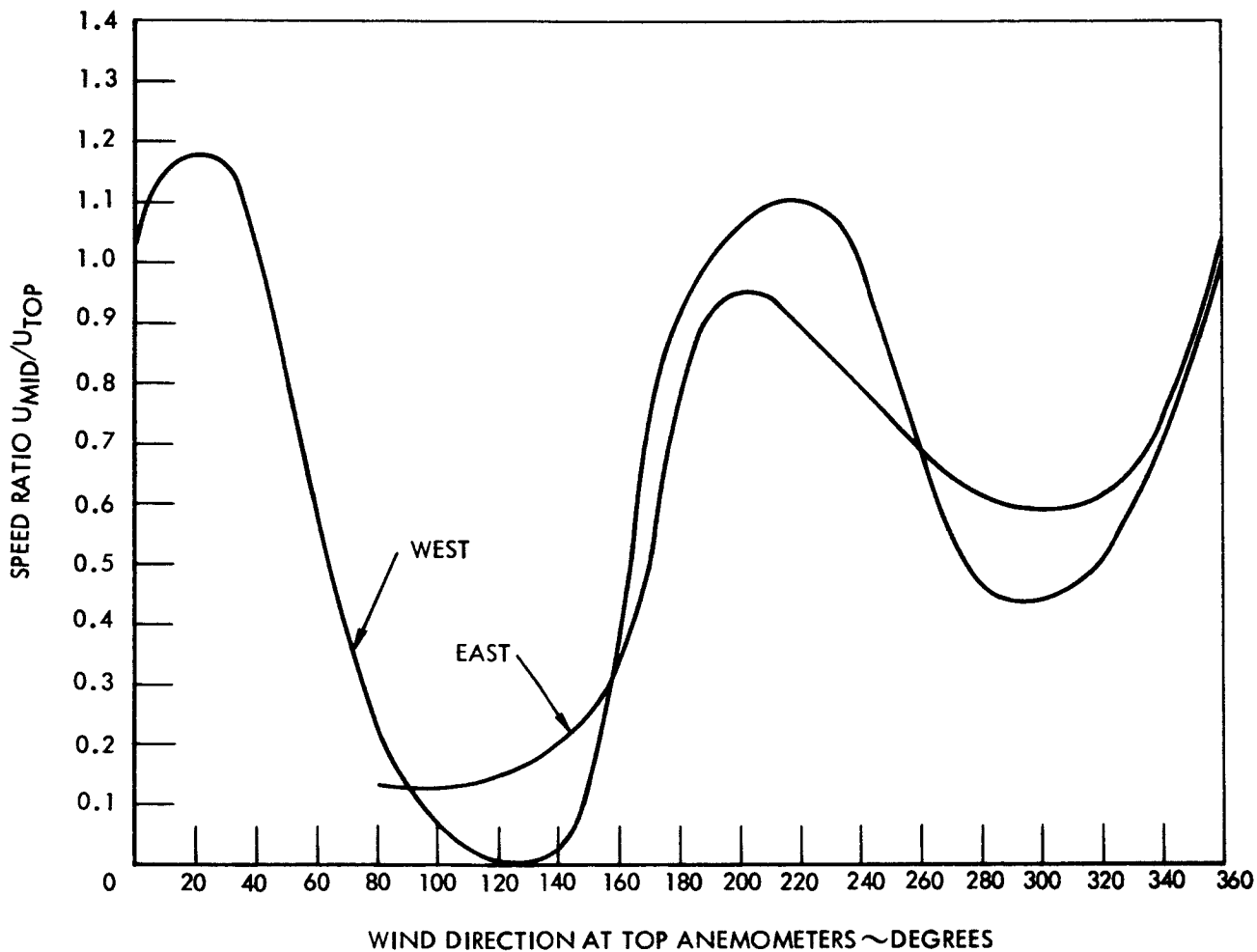


Figure 11. Comparison of Speed Ratio Curves for Midlevel Anemometers, Referred to West Anemometer

with the mirror image of the east anemometer median curve. Apparently the mirror assumption is valid. Hence, in Figures 12a and 12b, data from the two anemometers are pooled with reference to the east anemometer and a curve of the same description as in Figures 10 and 11 is generated.

A polar plot of this curve with the height correction applied to U_{TOP}

i. e. , $\frac{U_{MID}}{U_{TOP}} = \left(\frac{287}{537}\right)^2 = .882$, is shown in Figure 13. It has a nearly

symmetric cardiac shape and plainly shows:

1. Shadowing down to almost zero speed on the leeside of the LUT (azimuth around 250 degrees)
2. Partial stagnation down to .66 of free stream on the windward side of the LUT (azimuth around 60 degrees)
3. Increasing speed as the air flows around the LUT in such a manner that the anemometer boom is athwart the stream (azimuth around 160 degrees or 340 degrees)

Further correlation of this speed ratio plot is obtained from experimental data in the literature. Gill, et al. (1967), report upon wind tunnel tests of triangular and circular cross-sectional tower structures typical of those used for anemometer supports. For the triangular tower, speed ratio plots are presented for shadow densities (ratio of projected frontal area to total enclosed frontal area) of 26 percent and 100 percent. Their test results include those for anemometer arrangement corresponding to that employed for the LUT midlevel. In these tests, an anemometer was mounted on a boom extending outward in the plane of one face a distance of 1/2 tower breadth. In Figure 14 speed ratio plots obtained by Gill, et al., for these particular tests are superimposed upon the plot obtained for the LUT midlevel. In these plots, the curves of Gill, et al., have been rotated so that azimuth relationship to anemometer location are the same as those for the LUT data. As required, both stagnation and speedup are indicated in the same general ranges. The LUT data show a pronounced flatness compared to the triangular tower data.

A point of special interest is the value of speedup at zero azimuth. From separated flow observations, it is known that with the flow directly abutting one face, separation will be triggered at the edges of the face. Roshko (1954) in his application of free streamline theory has shown that flow streamlines are primarily determined by the body shape ahead of separation and the wake width. Hence for winds from zero azimuth, the

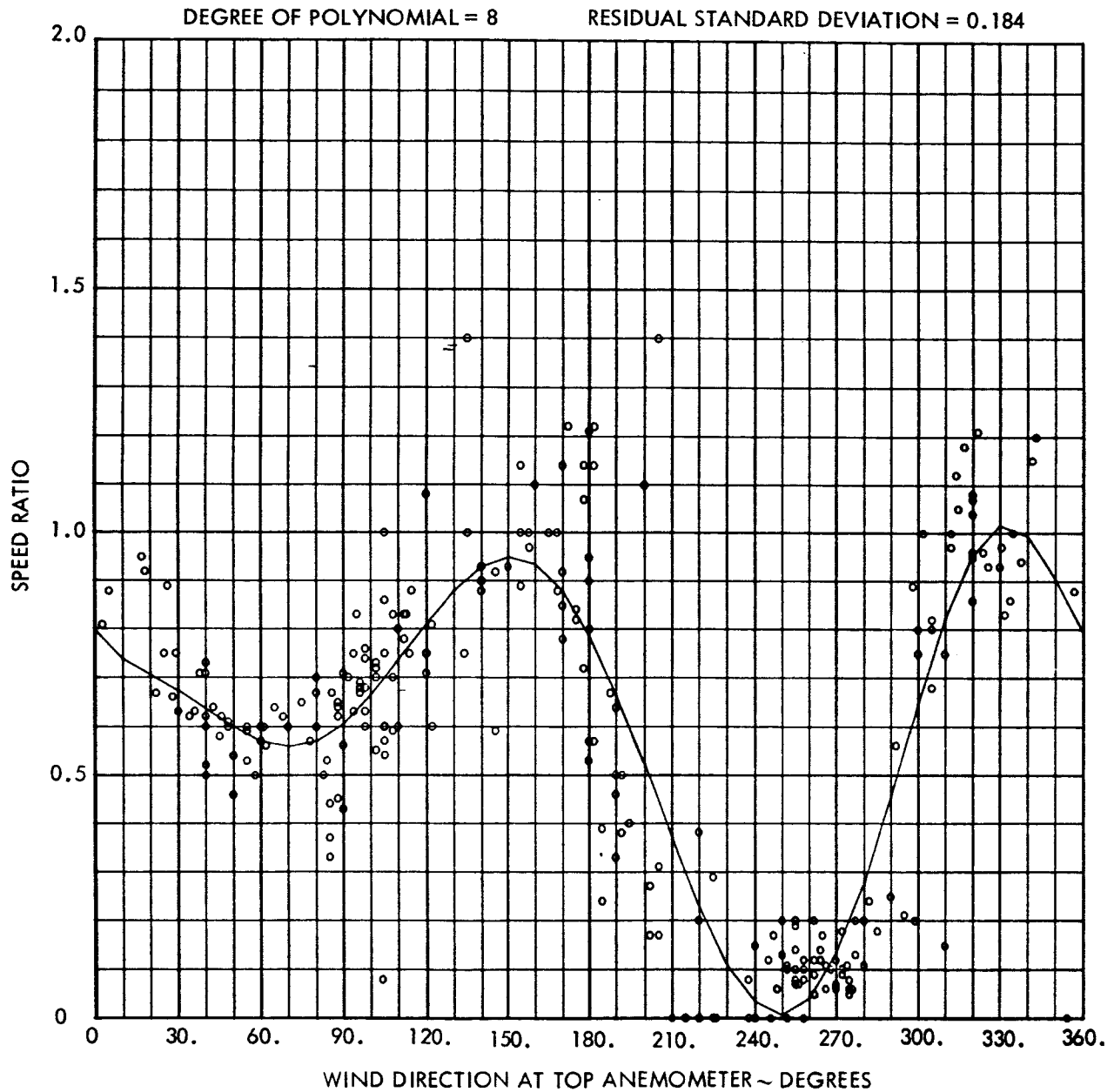


Figure 12a. Wind Speed at 195-Foot East Anemometer Divided by Wind Speed at 445 Feet, Composite of Data From East and West Anemometers, Fitted by Least Squared Error Curve

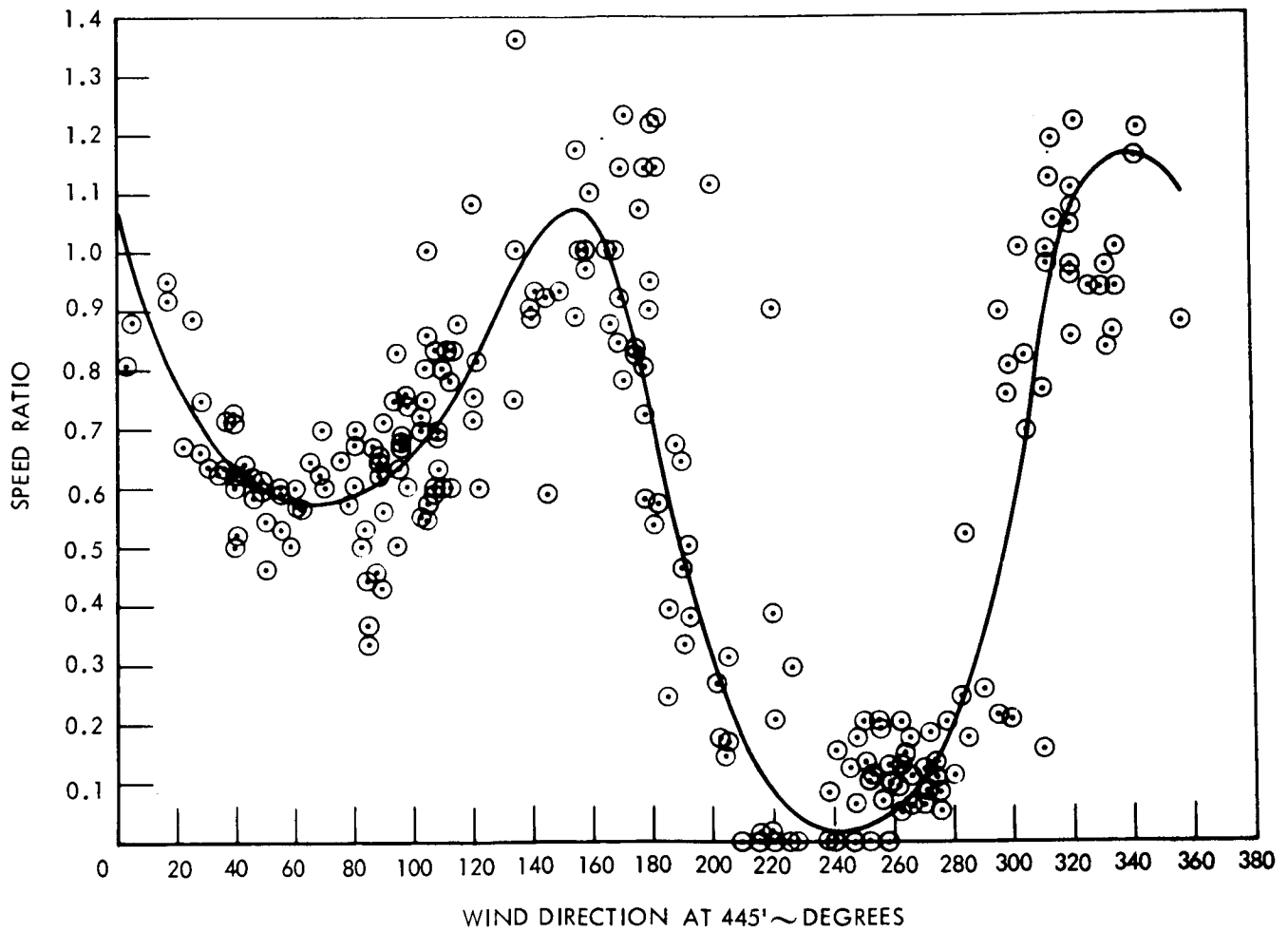


Figure 12b. Wind Speed at 195-Foot East Anemometer Divided by Wind Speed at 445 Feet, Composite of Data From East and West Anemometers, Fitted by Median Curve

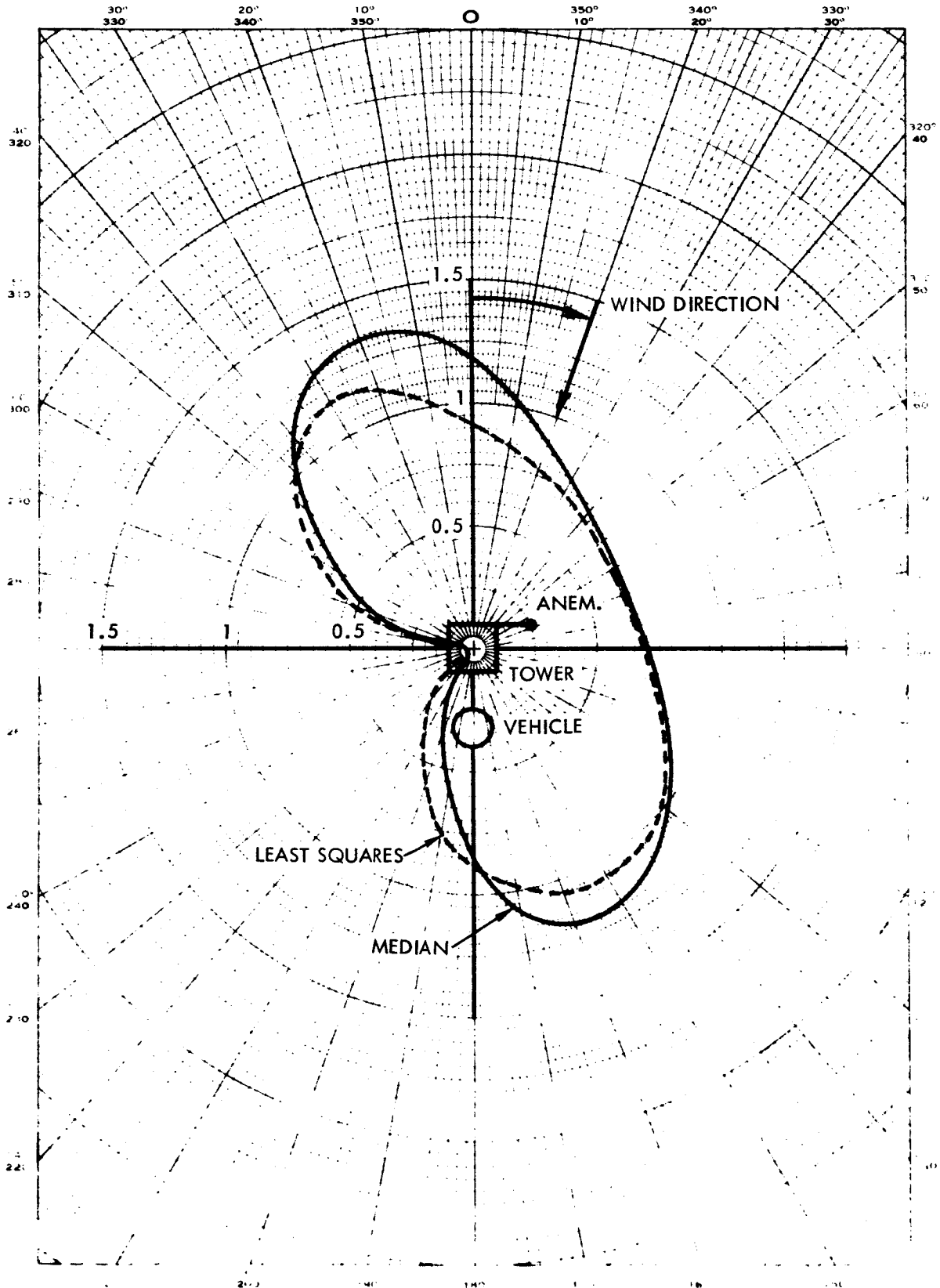


Figure 13. Polar Plot of Corrected Mean Speed Defect at 60-Meter (195-Foot) East Anemometer, Composite of Data From East and West Anemometers

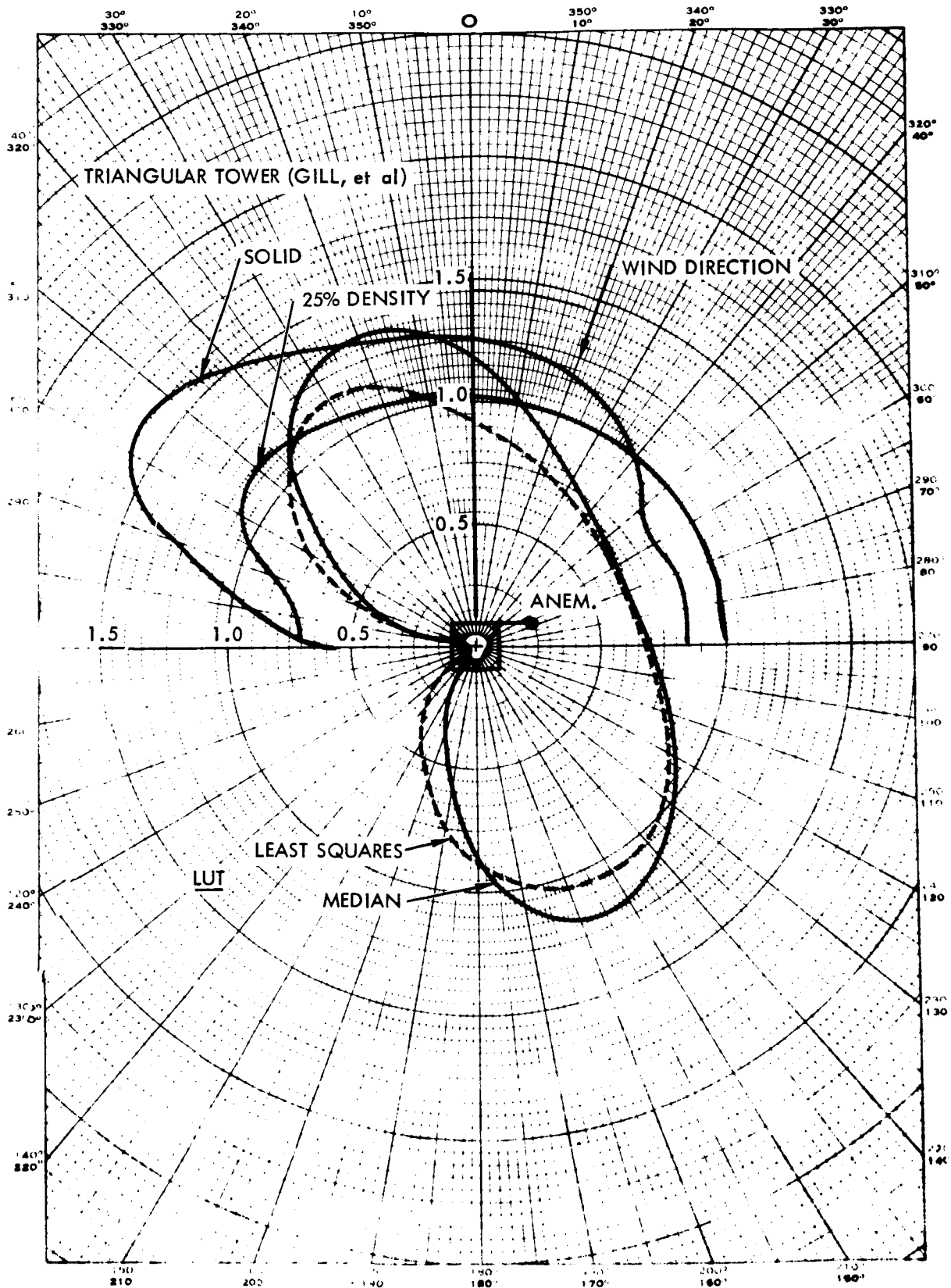


Figure 14. Speed Ratio Plots Superimposed on LUT Midlevel Plot

speedup encountered for the triangular tower should correspond to that encountered for the rectangular tower. Further substantiation of this statement is found in the fact that speedup for the circular stack from Gill, et al., at this same relative position, i. e., at 90-degree azimuth in Figure 15, is also about 1.25, coincident with the triangular tower data. On this premise, then, the LUT data at zero azimuth should fall between the 26 percent and 100 percent density speed ratio plots of Gill, et al. For the median curve, this is indeed the case, and its relative position confirms the estimated LUT shadow density of 60 to 70 percent previously estimated. To a certain extent this unusual agreement must be considered fortuitous, in view of the many ramifications involved. In this respect, the least squares curve does not fit the data nearly so well. The marked flatness of the LUT curves in Figure 14 are caused by at least two factors. One, of course, is the difference in tower cross sections. A second is the mutual interference between tower and vehicle. Considering the rather close similarity of speed ratio curves for solid triangle and circular stack over the azimuth range 0 to 90 degrees in Figure 14 and 90 to 180 degrees in Figure 15, it is tentatively concluded that effect of cross-sectional shape is not of prime importance to speed ratios in this azimuth range. Assuming this to be the case, the major contributor to flatness of the LUT speed ratio curve appears to be mutual interference effects between the umbilical tower and the vehicle.

As in any experimental test, the results and conclusions derived therefrom are never completely irrefutable. In the present case, the extent to which the data have been correlated with the completely independent data of Gill, et al., and the seemingly logical manner in which the LUT midlevel data fits into the overall picture of separated flows, seem to indicate the data and their reduction to be basically correct.

Based upon validity of results obtained, the relative unimportance of Reynolds number effects in establishing the mean characteristics of separated flows with interference has once more been verified. The tests by Gill, et al. (1967), were conducted at a tunnel speed of 12 ft/sec using tower breadths of 1.5 ft, giving a Reynolds number of about 100,000. The LUT data were obtained at speed ranges from 2 to 12 meters per second. Based upon tower breadth of 6.5 meters, the corresponding full scale Reynolds numbers ranged from 750,000 to 5 million.

Azimuth Versus Azimuth Plots

Figures 16a, 16b, 17a, and 17b are scattergrams of the azimuth at a midlevel anemometer as a function of the azimuth at the top-level anemometer. Least squared error curves as discussed in Appendix C were determined for these scattergrams, and are shown in Figures 16a, and 17a. Each scattergram in Figures 16b and 17b is hand fitted with a curve passing through the median ratios in 20-degree intervals. Figures 16a and 16b are for

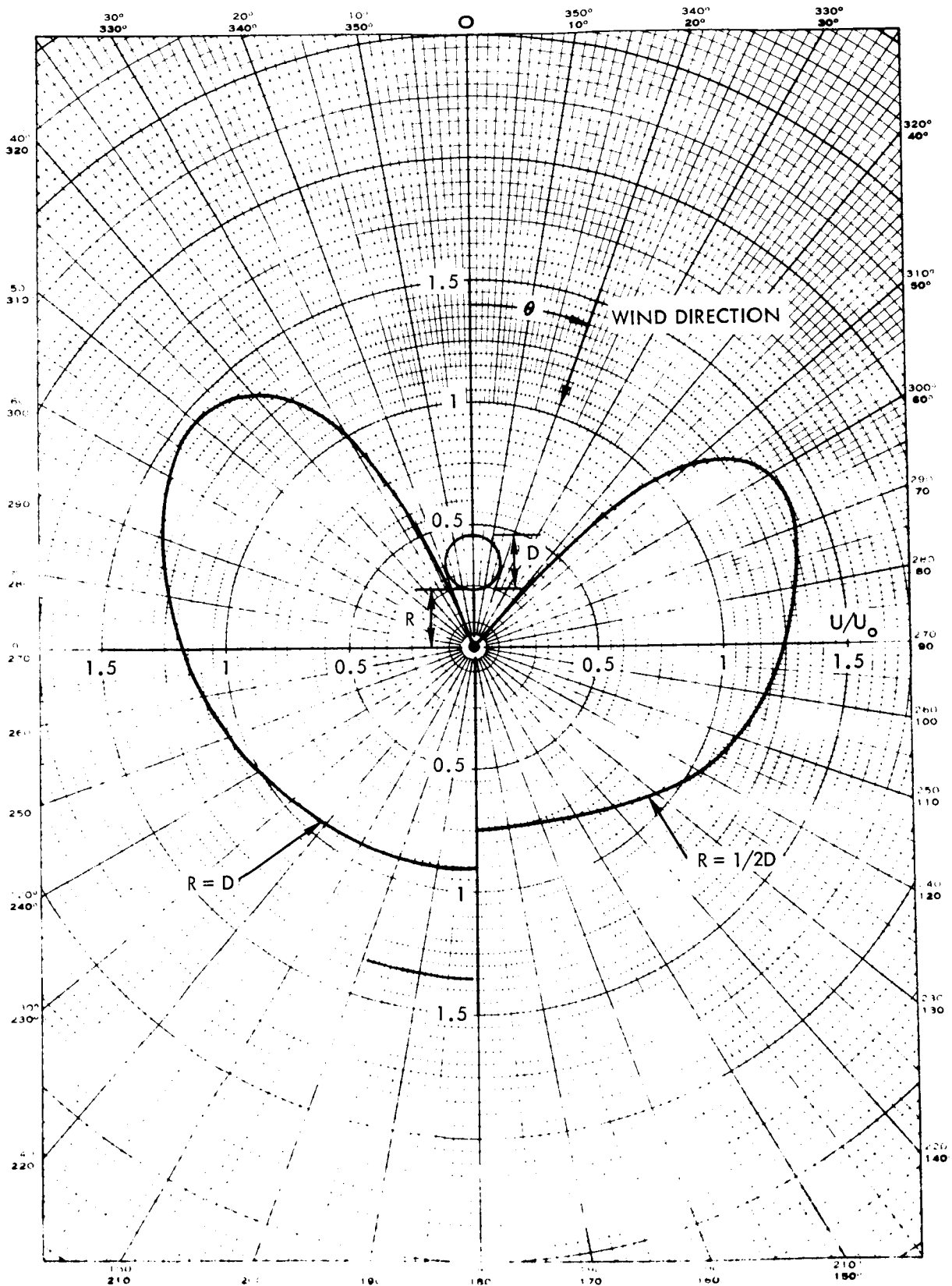


Figure 15. Polar Plot of Speed Ratio for a Circular Stack,
Wind Tunnel Data From Gill, et al.,
September 1967

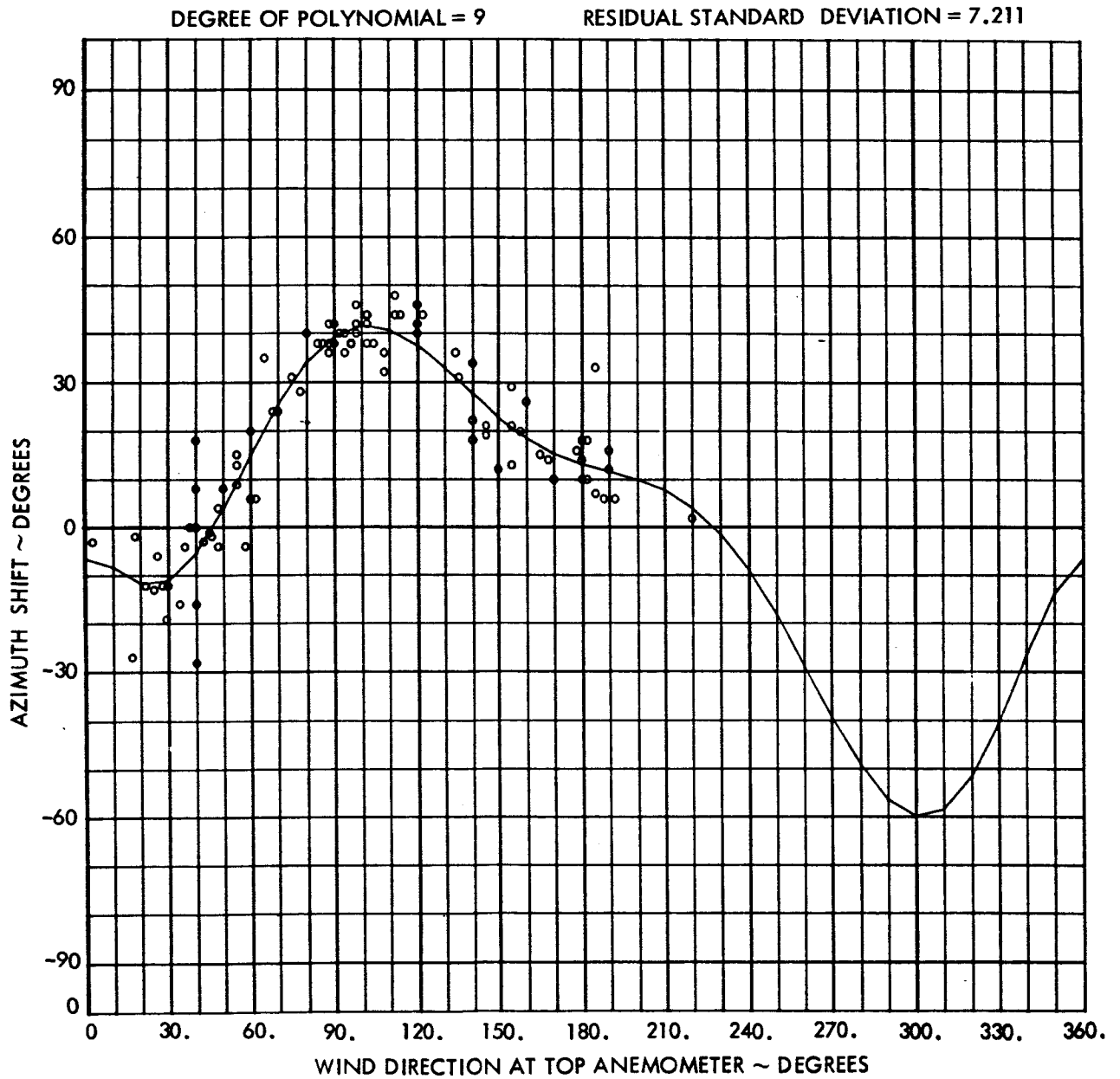


Figure 16a. Wind Direction at East Midlevel Anemometer as a Function of Wind Direction at Top Anemometer

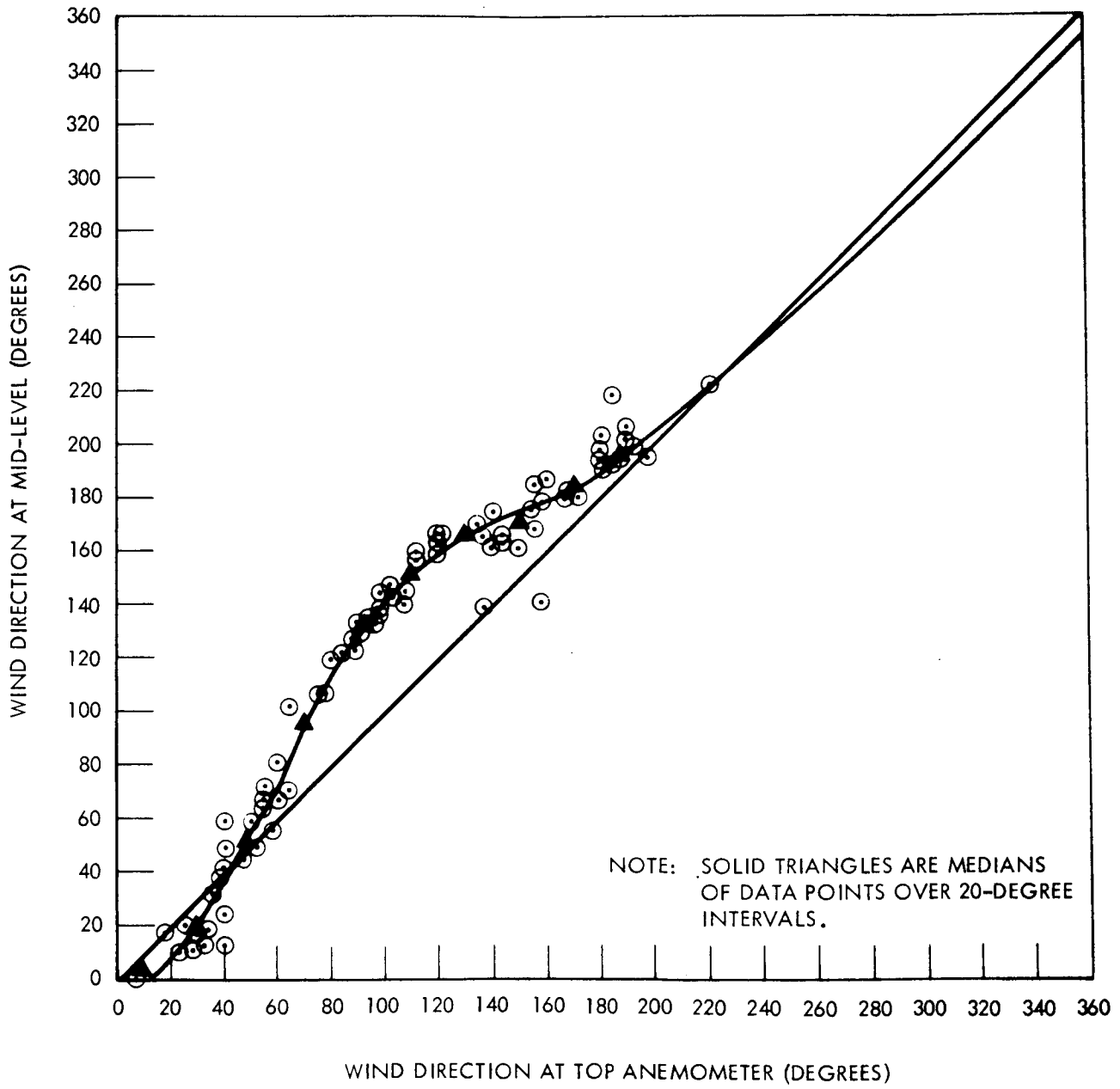


Figure 16b. Wind Direction at East Midlevel Anemometer as a Function of Wind Direction at Top Anemometer

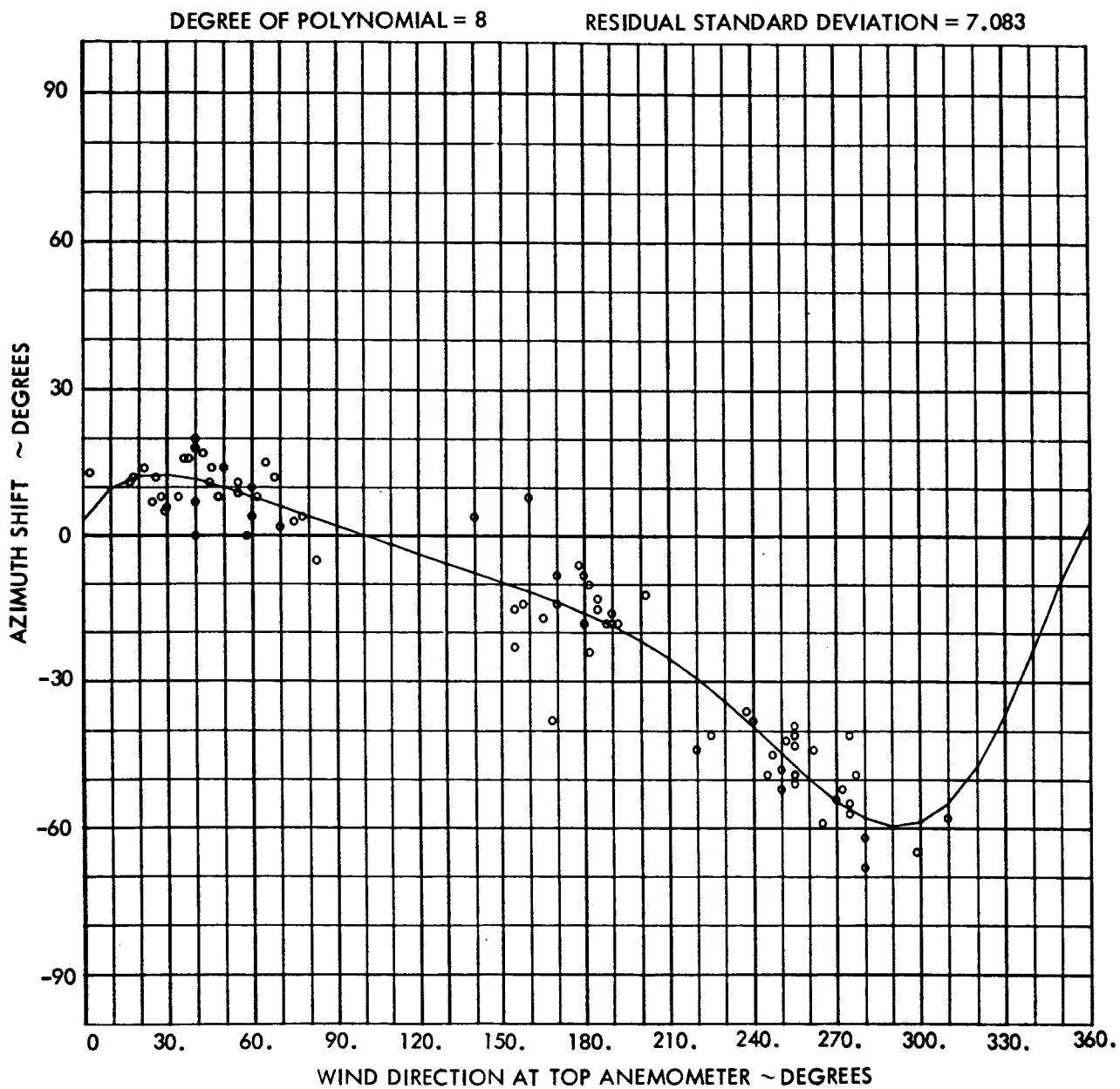


Figure 17a. Wind Direction at West Midlevel Anemometer as a Function of Wind Direction at Top Anemometer

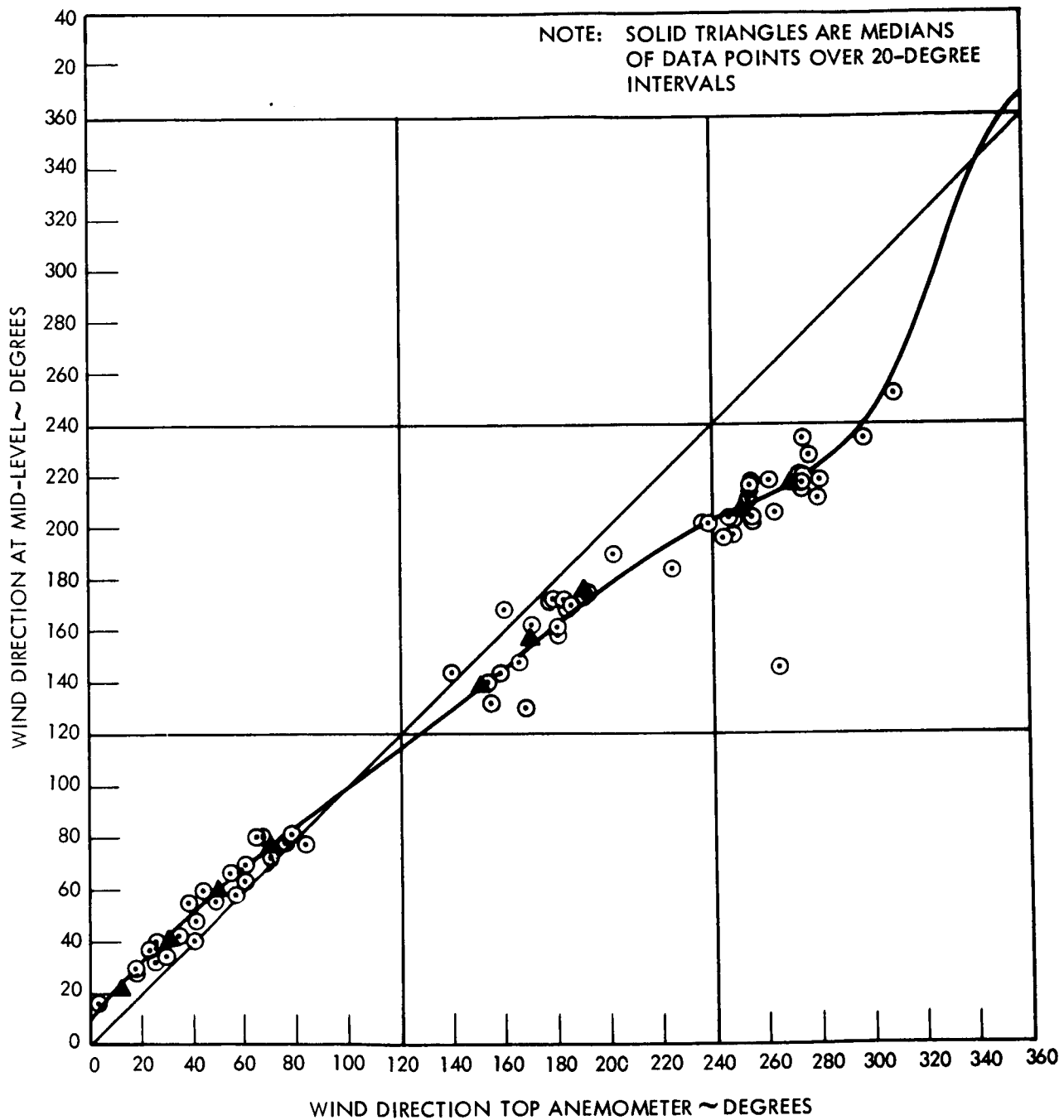


Figure 17b. Wind Direction at West Midlevel Anemometer as a Function of Wind Direction at Top Anemometer

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the east midlevel anemometer, and Figures 17a and 17b, for the west. The symmetry assumption is checked in Figure 18, and the pooled data given in Figures 19a and 19b are referred to the east anemometer. Figures 19a and 19b clearly reveal a wind shift to the south on the windward anemometer when the wind is from the east or west. The median shift is as much as 40 degrees, this for winds from 100 to 260 degrees.

Deck Level Anemometer

Strip chart data made available for this study for the deck-level anemometer covered the time period from May 30, 1966, through June 9, 1966. This anemometer was located at a height 3.4 meters (11.0 ft) above the deck-zero level and at an approximate azimuth and distance of 225 degrees southwest and 90 ft, respectively, from the vehicle centerline. Data points obtained were correspondingly sparse. Winds were predominantly from the east or west, and the azimuth range between 130 and 260 degrees could not be covered. Figure 20 shows a plot of speed ratio, normalized to simultaneous top-level speeds, versus the azimuth at the top level. Due to sparsity of data, no attempt was made to calculate median points, and the solid curve was simply faired in visually, taking into account the necessary conditions for continuity of slope and ordinate at the endpoints, and the fact that winds from approximately 150 to 160 degrees would be expected to exhibit maximum values. This curve was then renormalized to the local free stream velocity based upon the 0.2 power law, and is shown in polar form in Figure 21. The near circularity of this plot between 100 and 250 degrees indicates that this location may be of significant value for future wind loads tests in determining wind speeds. The near unity values of wind speed at 270 and 90 degrees is contrary to the notion that appreciable speedup occurs due to pad elevation. It is possible that boundary layer effects from the launcher and pad are decelerating the flow, and, if so, would require that the deck level anemometer be placed somewhat higher than the 11-ft elevation that was employed.

In the azimuth plot shown in Figure 22 a surprising lack of distortion is shown for easterly and westerly winds. For winds in the range from zero to 60 degrees, however, the anemometer is clearly immersed in nonsteady wake flow since the strip chart indicated almost 360 degrees variations, making impossible any estimate of mean values. Such points are indicated by small vertical markings along the abscissa.

Pad Light Pole (PLP) Anemometers

Since the PLP anemometer data were unfortunately not concurrent with the LUT data, no direct comparison could be made. Instead, the velocities of the individual PLP anemometers were compared with each other and are shown in Figure 23. The inference here is that good correlation would indicate negligible contamination from LUT, launch pad, and associated obstructions.

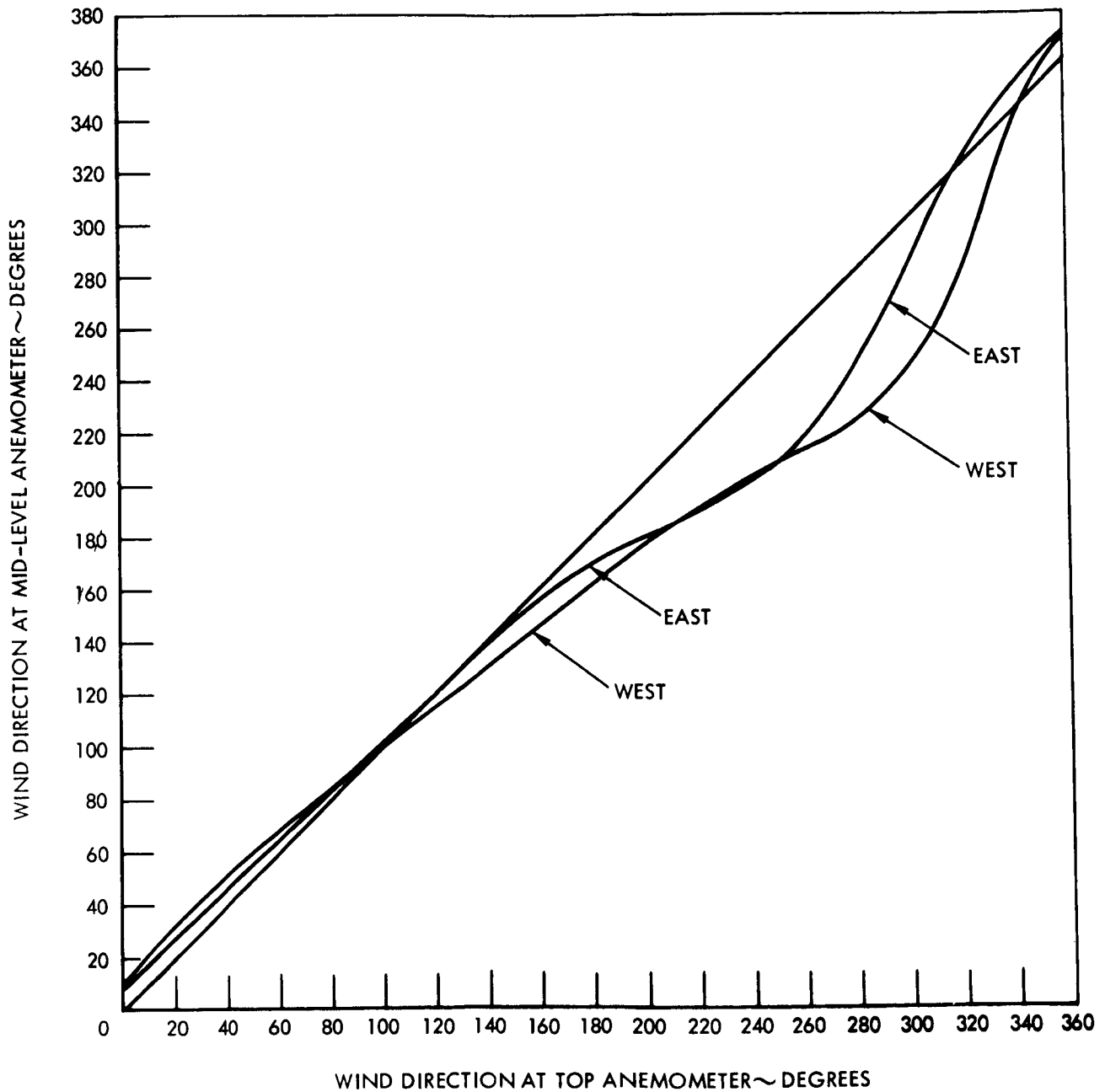


Figure 18. Comparison of Wind Direction Curves at Midlevel Anemometer as a Function of Wind Direction at Top Anemometer, Referred to West Anemometer

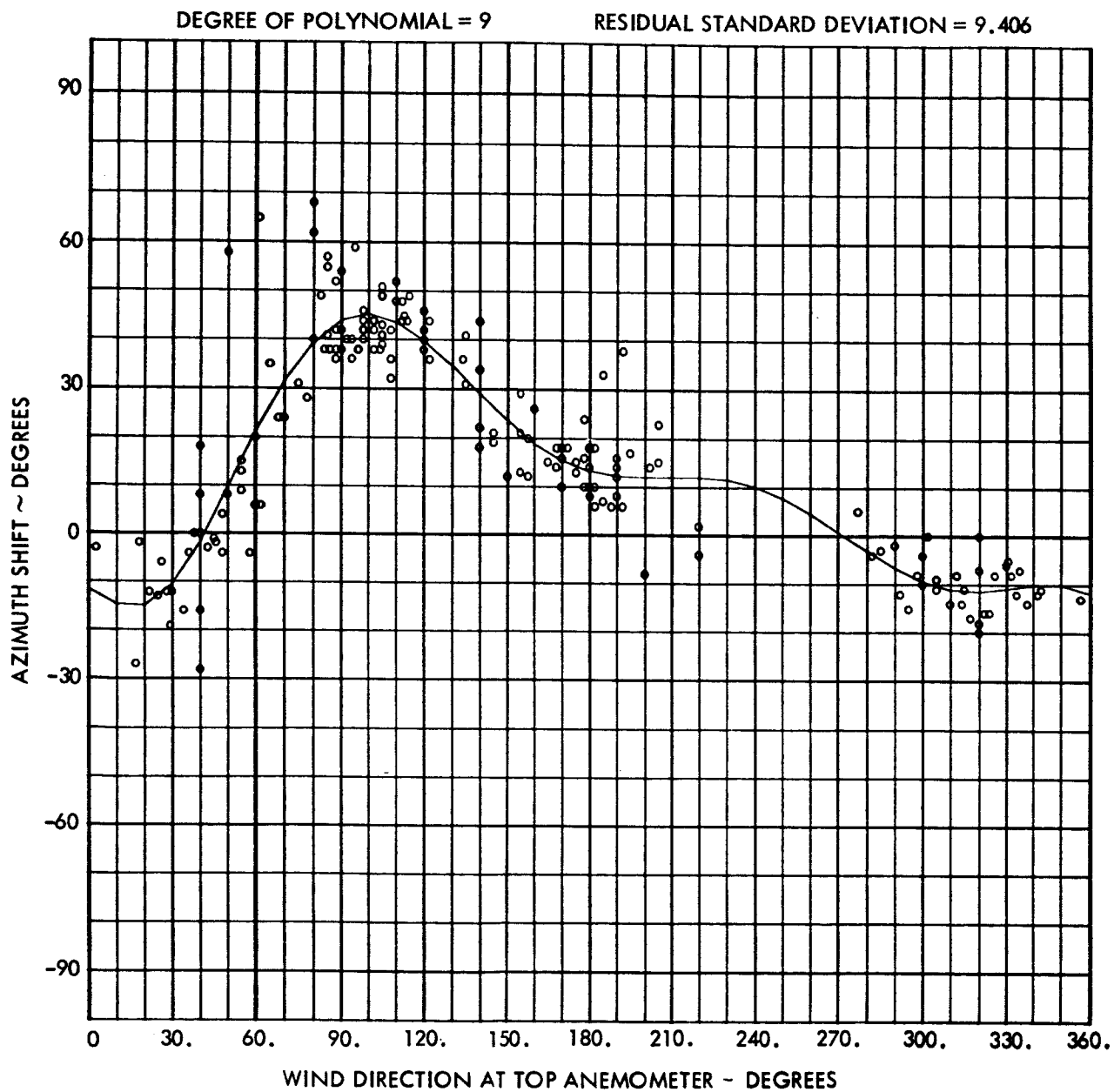


Figure 19a. Azimuth Shift at 195 Feet East Versus Wind Direction at 445 Feet, Composite of Data From East and West Anemometers

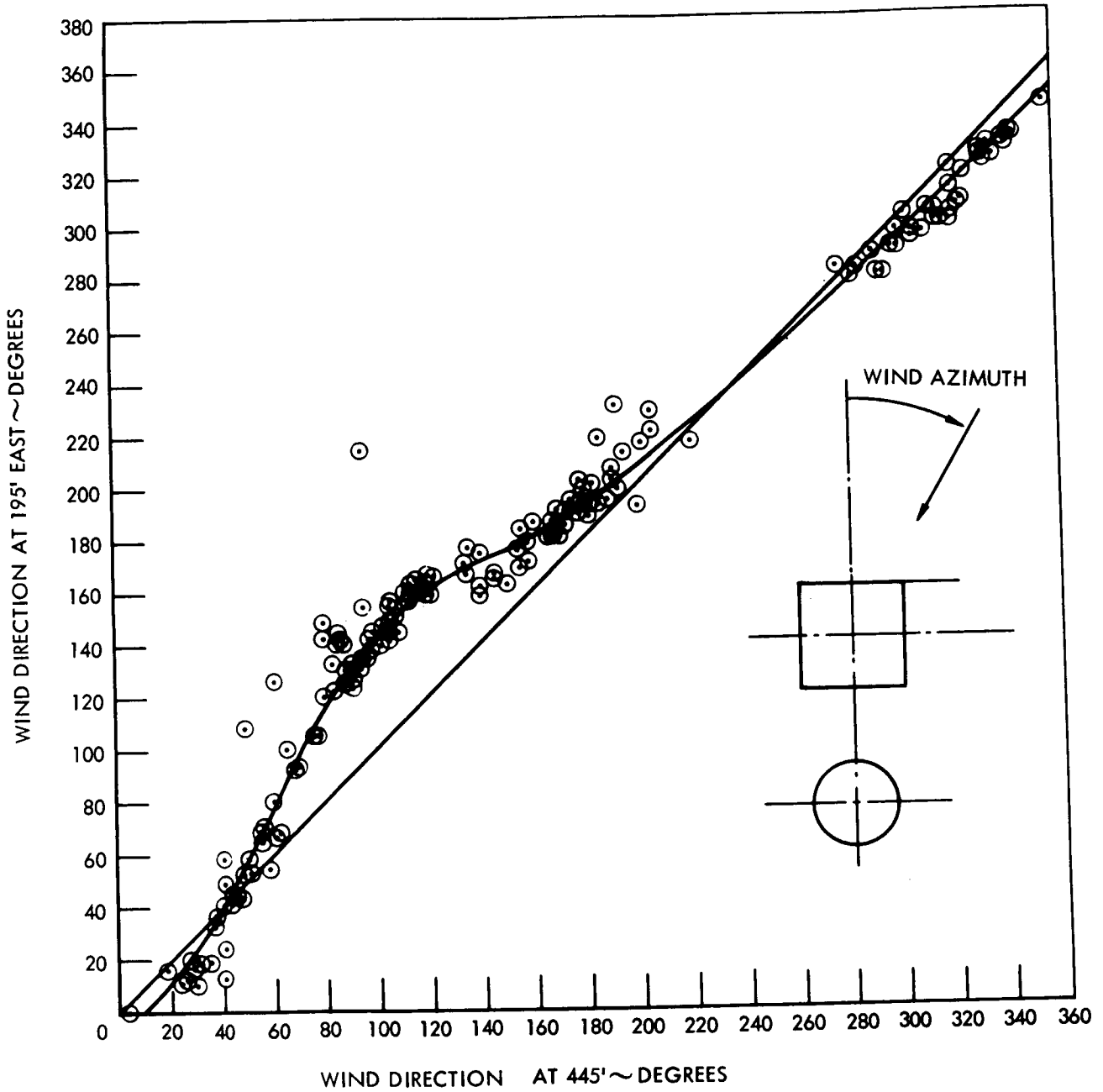


Figure 19b. Wind Direction at 195 Feet East Versus Wind Direction at 445 Feet, Composite of Data from East and West Anemometers

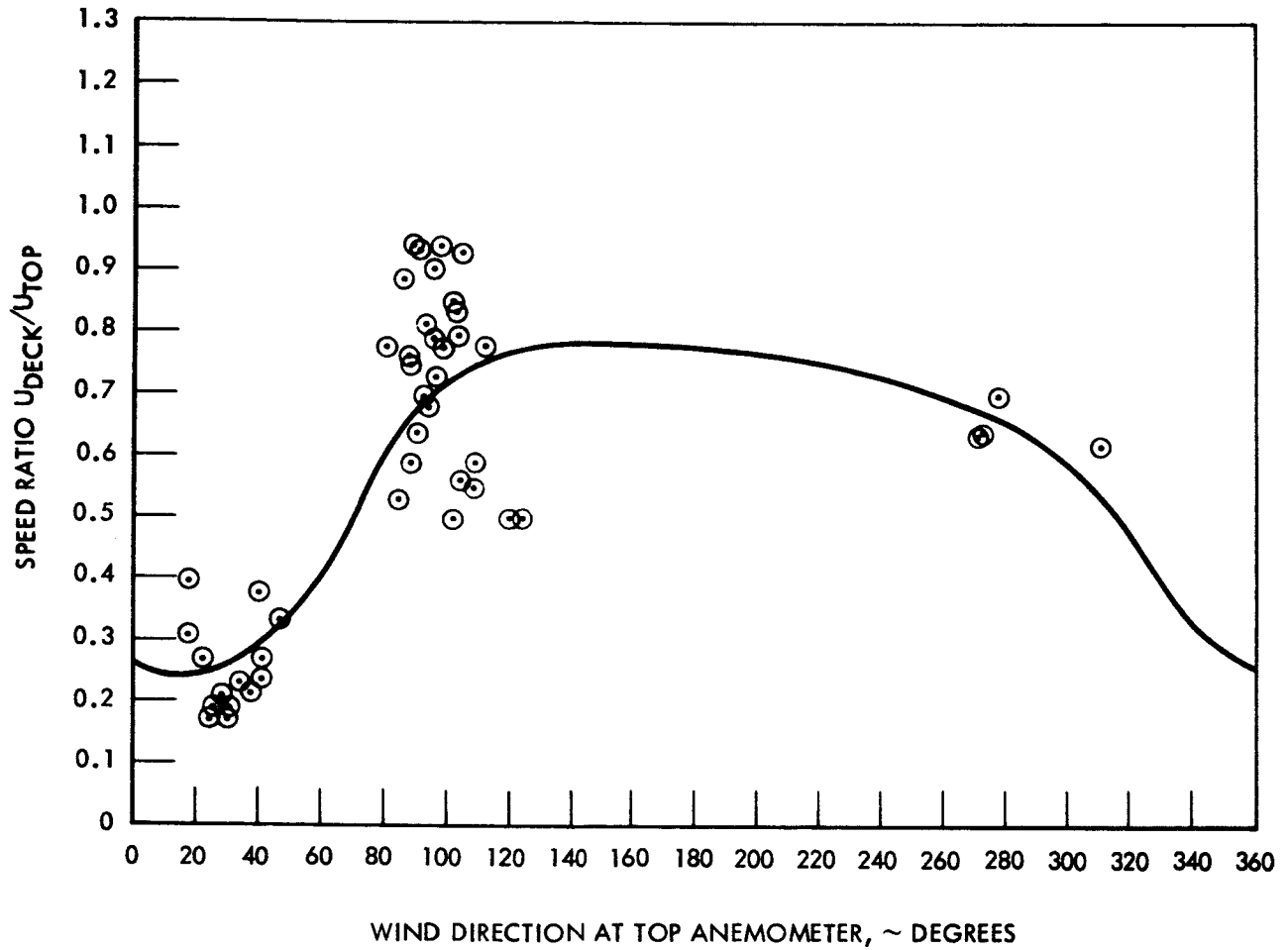


Figure 20. Wind Speed Ratio at Deck Level Versus Wind Direction at Top Anemometers

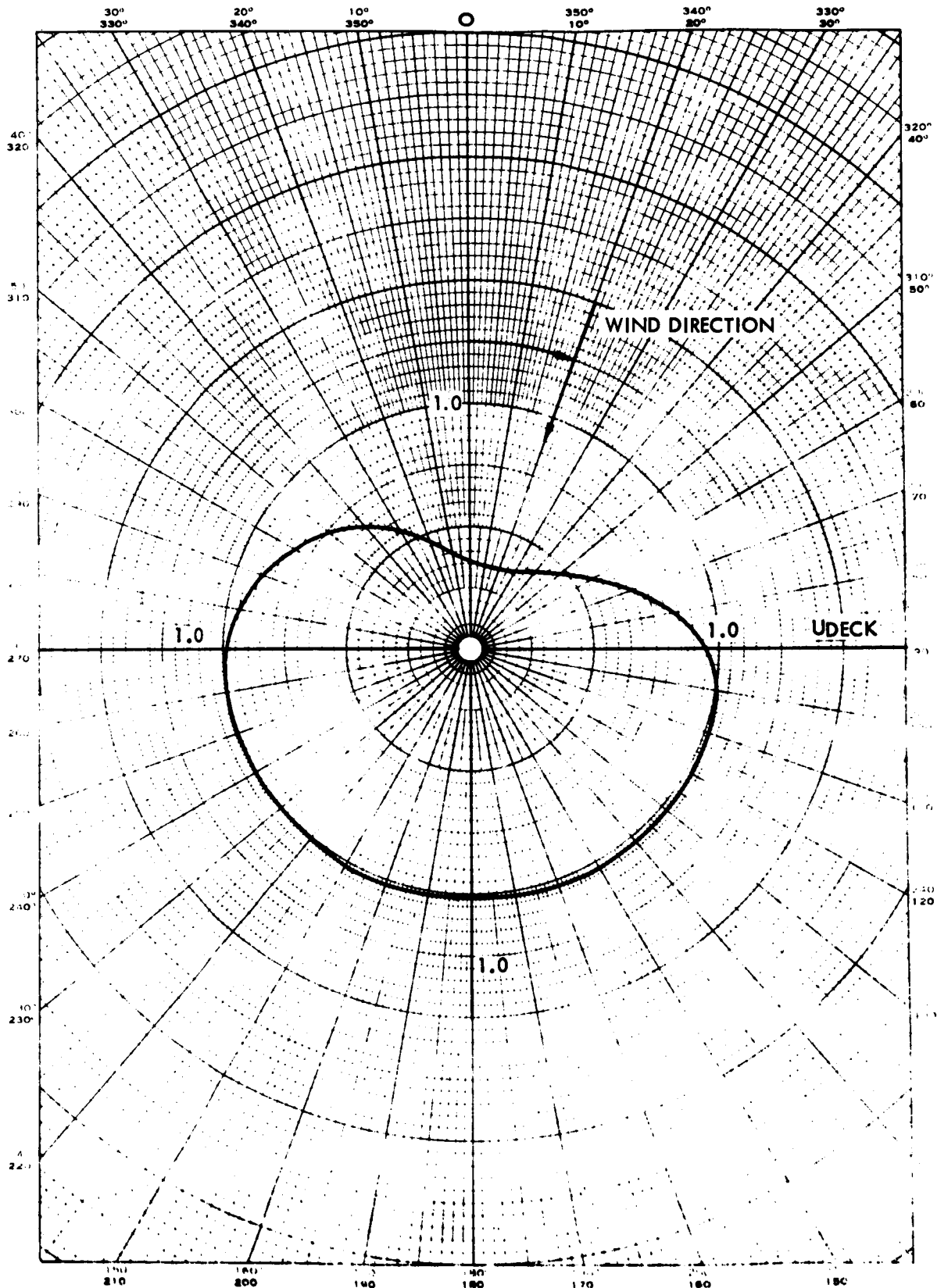


Figure 21. Polar Plot of Corrected Mean Velocity Defect at Deck-Level Anemometer

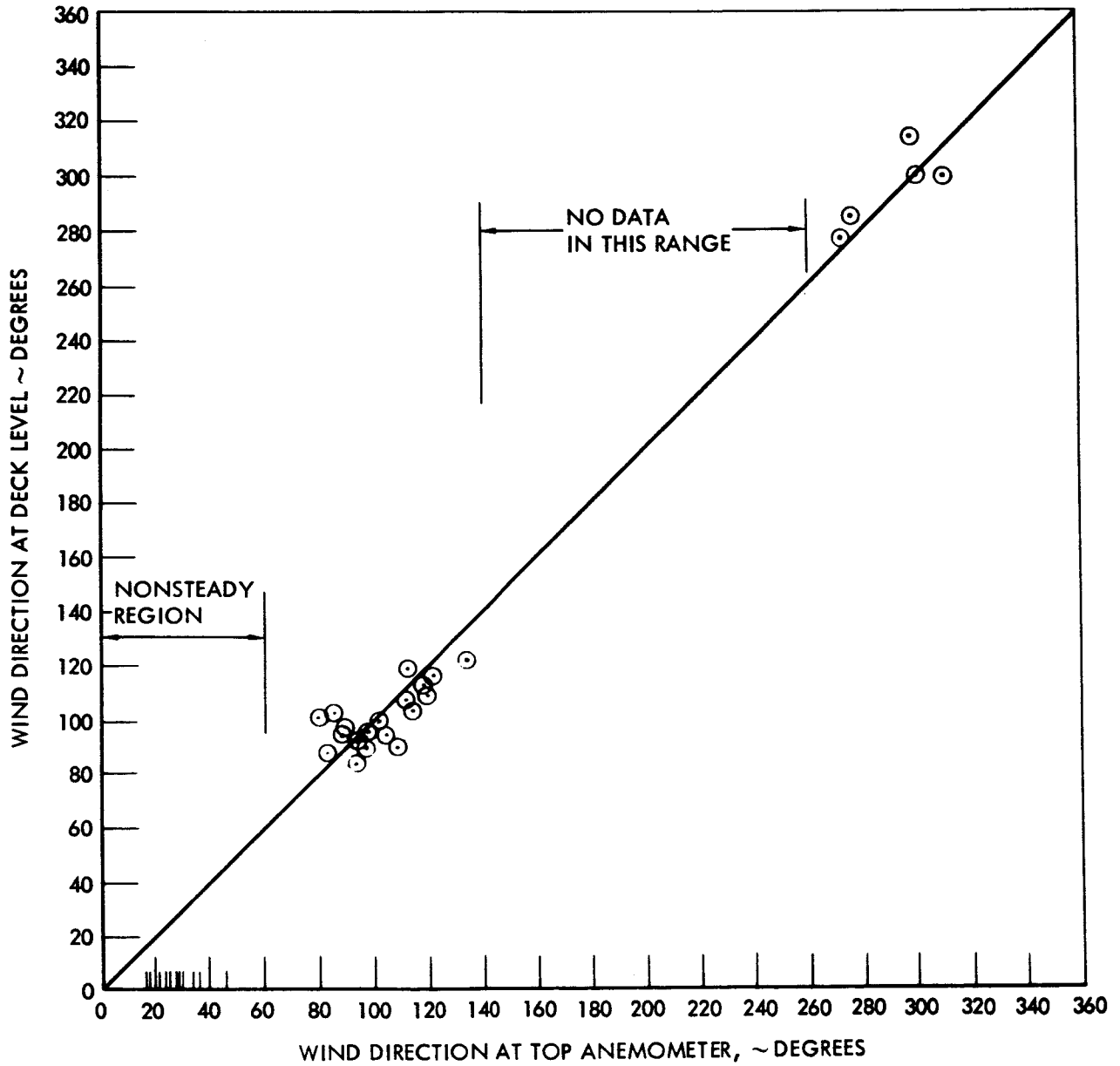


Figure 22. Wind Direction at Deck Level Versus Wind Direction at Top Anemometer

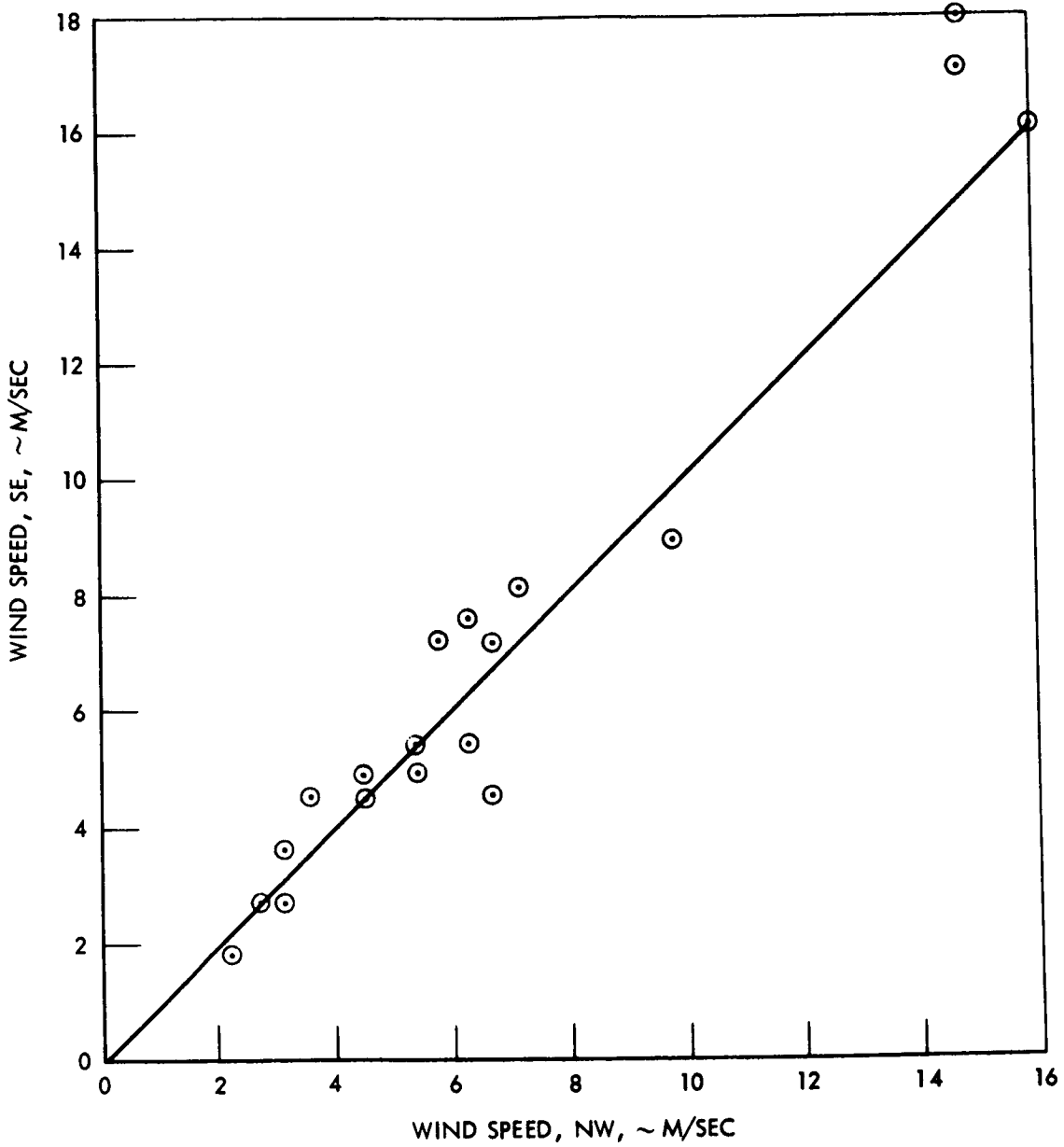


Figure 23. Comparison of Wind Speeds Indicated by PLP Anemometers

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The speeds obtained from the two PLP anemometers were analyzed as follows. Assume that at any instant there is a common mean free stream speed for the two locations and that the departures therefrom at a given time are random, statistically independent with the same RMS deviation, and independent from time to time. In that case, the speed difference $U_{NW} - U_{SE}$ has a variance (mean square) equal to twice that of either speed. Using this fact, the data yield, as an estimate of the RMS fluctuation, 0.85 meters/second (1.90 mph).

It was felt that, in order to demonstrate validity of the PLP anemometer readings, it would suffice for the readings from the two to agree to within reasonable limits. Figure 24 is a plot of the azimuth shift (AZ_{NW} minus AZ_{SE}) as a function of AZ_{NW} . The clear linear trend indicates that there was a scale factor difference on the two strip chart recorders. The NW anemometer showed readings over the entire range of azimuths while the simultaneous readings from the SE anemometer were all under 225 degrees. Had this linear deviation not existed, the two would have differed by approximately the amounts the points scatter around the hand-fitted line. The largest such deviation there is 13 degrees.

CONCLUSIONS BASED ON TEST DATA

An evaluation of paper strip chart anemometer data obtained during the 1966 Ground Wind Loads Test Program at Launch Complex 39A has resulted in the following assessment regarding the local Launch Pad 39A wind field and placement of anemometers. The anemometer at the 445-foot level is essentially exposed to the local free stream, with no systematic distortion of azimuth. The velocities show increase in local free stream of 5 to 10 percent in magnitude. However, this conclusion must be qualified to the extent that the number of data points does not appear to be quite sufficient. Evidently the 3-1/2 mile separation between Launch Complex 39A and the meteorological tower permits rather wide simultaneous differences in velocity at these points.

Analysis of the midlevel anemometers indicates a considerable interference in the local wind field, and their data would not be useful for establishing the free stream velocity at this level without considerable extensions of their support booms beyond the present 25 ft. Possibly 60- to 80-ft booms would be necessary to permit satisfactory free stream recordings over an appreciable azimuth range, centered about true north, assuming dual anemometers are employed. For complete azimuth coverage, the basic support structure dimension should be considered as the centerline to centerline distance between vehicle and tower. With such a dimension, it becomes evident that the most proficient means for measuring free stream at this level would be the extension of one of the current pad light poles to the necessary height.

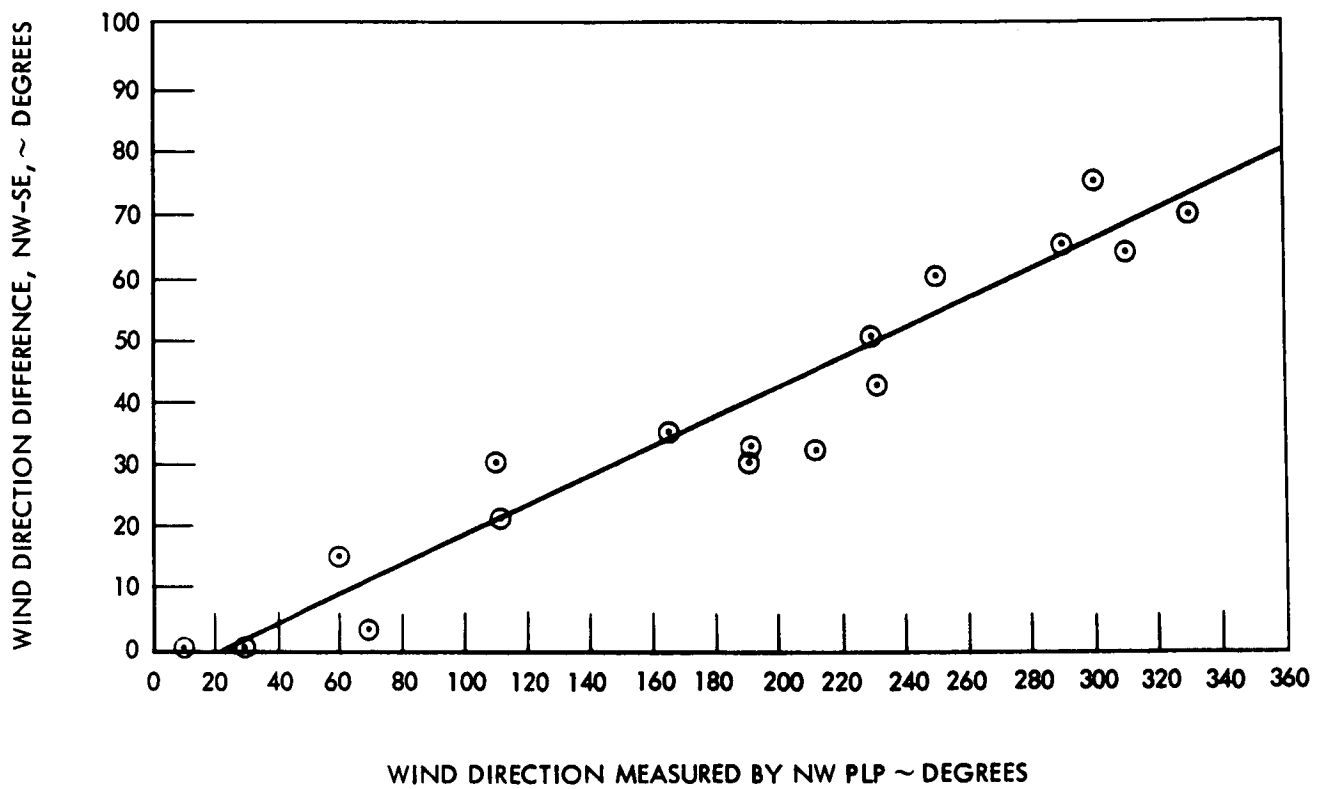


Figure 24. Comparison of Directions Indicated by PLP Anemometers

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The deck-level anemometers were represented by the least amount of data and conclusions regarding them are correspondingly qualified. Nevertheless, it does appear that a single deck-level anemometer at the present location, but higher, would provide valid data over the 90- to 270-degree azimuth range. Further tests are indicated in which the deck-level and PLP anemometers are simultaneously employed to ascertain possible wind speedup due to pad elevation. The objective here would be to improve the exponential constant in the speed power law that would account for pad elevation.

The two PLP anemometers, by mutual comparison, are found to exhibit essentially free stream characteristics in both speed and azimuth. The strip chart data themselves indicated a linear distortion of azimuth of the southeast anemometer versus true azimuth which was interpreted as calibration error. Assuming this to be the case, the present locations are considered to be satisfactory for establishing the local free stream.

III. THEORETICAL ANALYSIS

APPROACH

The local wind field about the Saturn V - LUT is three-dimensional. The tip and base regions probably exhibit the strongest three-dimensional characteristics. While some methods for their theoretical analysis appear feasible with present state of art in computer technology, such efforts are considered beyond the scope of this study. Nevertheless, meaningful two-dimensional studies can be made to improve knowledge of this complicated flow field. Two such investigations have been made in this study. In the first, the elevation profile of the launch pad (without the LUT) along its narrowest dimension is approximated by an ellipse. Potential and "separated" flow solutions over this ellipse are then obtained. Secondly, the horizontal tower-vehicle cross section at the midlevel (19 meters above elevation zero) are represented by a circular cylinder plus an arrangement of stationary point vortices to represent a rectangular tower cross section. Nonsteady separated flow solutions are then obtained for this configuration oriented at various wind directions.

The following background discussion precedes the detail discussion of these investigations. This background discussion is intended to serve as a descriptive basis for the numerical technique employed herein for the numerical solution of two-dimensional incompressible separated flows. The more rigorous theoretical developments are contained in Appendices.

Consider first the classical potential solution for steady lift on air foils. It is to be recalled that potential theory alone is insufficient to solve this problem. There is required, in addition, one empirically based criterion—that is the Kutta condition which states that the circulation strength at the trailing edge must be zero. This condition essentially accounts for the action of viscosity in the boundary layer in creating the physically observed lift inducing vorticity about the airfoil.

Viewing the separated flow problem in this same context, a necessary assumption is the inviscid nature of flow mechanics in the near wake, separated flow region. Next, a generalization of the Kutta condition is required which will permit the definition of nonsteady (instantaneous) transport of vorticity from the bluff body into the fluid stream. In previous NASA-funded studies (Ujihara, et al., 1965, 1966), such a generalized Kutta condition was developed, with reasonable success, for solution of separated flow about a circular cylinder. This generalized Kutta condition is expressed in the following way.

The transport of vorticity past any given point on a flow boundary is

$$\frac{d\gamma}{dt} = \frac{1}{2} U_s^2 \quad (2)$$

where U_s is the potentially calculated slip velocity at that point. The injection of free vorticity into the fluid stream occurs at points of velocity maxima. This free vorticity is expressed in terms of discrete vortices of strength

$$K = \frac{1}{2} \left(\frac{U_s^2 \Delta t}{2} \right) \quad (3)$$

where the solution is carried out in finite difference form, and Δt is the incremental time period over which the vortex strength is allowed to accumulate.

Successful application of this generalized Kutta condition represents the crux of this method. Basically then the solution of nonsteady separated flow about a bluff body requires the following steps:

1. Determine potential solution of flow about this body in a uniform free stream
2. Find the points of speed maxima on the boundary
3. Introduce free point vortices of proper strength
4. By finite differences compute the new flow field.
5. Return to step 2 and repeat.

This method enables the complete solution of nonsteady separated flows within the realm of potential theory. Flow rotationality in the wake is accounted for by the presence of discrete vortices convected downstream from their injection points. Separated flows about a circular cylinder are known to be strongly influenced by the Reynolds number. It is found upon closer analysis that the Reynolds number is only indirectly responsible for these observed variations. Stated more precisely, it is the attached shear layer thickness which is directly determined by the Reynolds number. The mechanics of vortex formation and shedding are found to be directly related to this shear layer thickness. A train of successive point vortices in potential flow possesses an equivalent shear layer thickness which depends only upon the vortex spacing. This may be related to known variations of attached shear layer thickness with Reynolds number to give a relationship between the finite difference time increment for vortex injection and the

flow Reynolds number being simulated. In these previous studies this relationship has been defined as

$$Re = \frac{25}{(\Delta t)^2} \quad (4)$$

where Re is the simulated Reynolds number. Further correlations with experimental data were shown in these previous studies at subcritical Reynolds number in which nonsteady lift, drag, and cylinder pressure distributions are in essential agreement. In particular, a distinct Strouhal frequency of 0.2 was obtained for vortex shedding. A calculated instability of the discrete vortices simulating the shear layer was also shown to correlate well with experimental data by defining (Sato, 1956, Roshko, 1967) the transition of a laminar free shear layer to turbulence.

TOWER VEHICLE CROSS SECTION AT MIDLEVEL

The midlevel anemometers are located in a region strongly influenced by the presence of tower and vehicle structures. This is clearly indicated from the noncircularity of the experimental wind rosettes of Figure 13. Further clarification of the wind field at this level is desirable; first, to permit more optimal placement of these anemometers with respect to measurement of free stream properties; second, an assessment of the velocity field particularly about the vehicle will hopefully bring insight to the nature of interference dependent flow mechanics which have been found to aggravate vehicle cantilever loads.

A theoretical approach was taken in this study to investigate this interference flow field. It is based upon the two-dimensional numerical method of separated flow analysis employing the previously described generalized Kutta condition. A computer program developed during previous NASA-funded studies was utilized for this study. This program was successfully used in these previous studies to numerically solve the nonsteady vortex shedding flow about a circular cylinder at subcritical Reynolds numbers. A major modification to this computer program consisted of the addition of a second bluff body representing the tower cross section. The method used to accomplish this addition is mathematically developed in Appendix A. A brief description is provided here for continuity of discussion and qualification of the necessary assumptions.

Discrete Vortex Simulation of Tower Cross Section

The flow field is assumed to be two-dimensional, with the vehicle circular cross section represented by a source sink cylinder in uniform flow. To this is added a configuration of closely arranged stationary vortices representing the second body to be added. This arrangement of

vortices may be of an arbitrary configuration, although for the tower representation it was taken to be rectangular. From assessment of the tower cross section, this second body should not entirely block the flow, since structural truss members, the elevator housing, conduits, and personnel railings making up the cross section do not present a completely closed surface. A detailed representation of this cross section would be possible, at the expense of a relatively large number of vortices. However, this represented an original attempt to apply this concept. Therefore, the number of vortices was held to a minimum, both for economy of computer time and in recognition of the exploratory aspects involved. Also a preconceived notion of high aerodynamic solidity was based upon informal remarks of personnel more familiar with wind conditions at the tower midlevel, that the tower seemed to effectively block any significant flow-through. At any rate, a gross representation of the tower cross section was employed in which the stationary vortices were placed in a rectangular arrangement, as shown in Figure 25 with closer spacing near the corners, since the velocity is known to be greater there.

Strengths of these vortices were then calculated instantaneously (in the finite difference scheme of numerical solution) by imposing the boundary condition of zero normal flow at each midpoint between consecutive vortices. Thus, a set of simultaneous equations in the unknown vortex strength is derived, the coefficients of which depend only upon the geometric arrangement of the stationary vortices. One additional equation is necessary to require that the total circulation about the body be equal to the cumulative negative sum of all free vortices generated by that body (condition of constant angular momentum). This residual circulation is satisfied by a stationary vortex at some point within the body, say the center. This complete matrix of coefficients is inverted only once, and instantaneous vortex strengths are subsequently determined by their matrix multiplication with the calculated normal boundary velocities imposed by the free stream, cylinder and free vortices at finite difference time points. The image method is used to satisfy cylinder boundary conditions for all vortices whether stationary or free.

Generalized Kutta Condition

It was recognized that a realistic solution of interference flow about the tower vehicle cross section would require simulation of vorticity transport from both bodies. Consequently, an empirical scheme was defined for applying the generalized Kutta condition to account for the major portion of vorticity shed from the two bodies.

Depending on the free stream azimuth, the tower wake could impinge upon the circular cylinder and vice versa. The circular cylinder, being

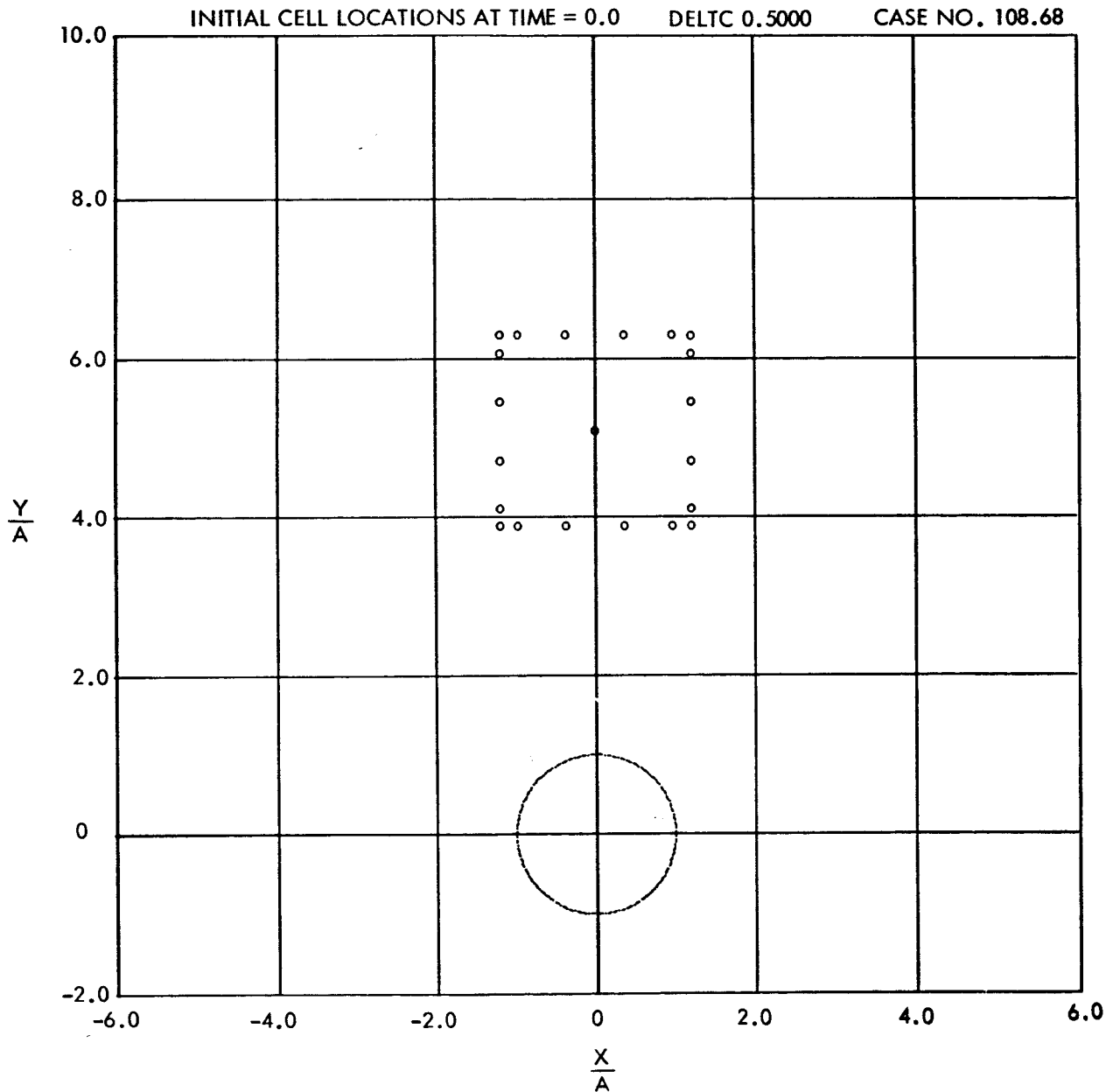


Figure 25. Typical Arrangement of Point Vortices to Represent Tower Cross Section

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smoothly curved, is known to exhibit greater sensitivity to flow conditions than sharp-cornered bodies. From previous studies it was also known that significant counter vorticity could sometimes be generated over the wake exposed surfaces. Again considering limitations of the computer program, a total of three possible vortex feeding points was allowed on the circular cylinder. These are internally determined by computing all the instantaneous speed maxima occurring on the cylinder surface, and selecting the three largest of these relative maxima for the incremental vortex feeding points. Thus, as many as three vortices could be introduced from the cylinder at each finite difference feeding time point. The radial distance from the surface at which these vortices are introduced was set equal to $0.28 u\Delta t$ which is the approximate center of the separating shear layer thickness.

Vorticity from the tower would be expected to shed primarily from the corners. It was also considered physically consistent to require that the primary vorticity be generated at the two corners presenting the broadest dimension to the free stream. It was desirable to keep the number of vortices to a minimum in order to limit the number of computations necessary to achieve a satisfactory solution. In the interest of simplicity in computer logic, the specification of the two corners selected as vortex feeding points was left variable as input data.

Since the characteristics of flow separation from sharp-cornered bodies are ordinarily not sensitive to changes in Reynolds number, the feeding point was located along the extension of the diagonals of the rectangle without regard to requirements for Reynolds number simulation. A distance of $1/10$ cylinder radius from the corner vortex was selected for the feeding point location. This value was predicated upon insuring sufficient distance from the corner vortex to preclude any numerical instability. Here again, a non-dimensional feeding period of 0.500 based on cylinder radius was primarily on the basis of computer economy. This corresponds to a cylinder Reynolds number of approximately 100 .

NUMERICAL SOLUTION

In the course of obtaining the numerical solutions shown in this section, a numerical singularity that nearly prevented achievement of satisfactory solutions was encountered. This singularity resulted from placement of a vortex at the center of the square vortex array simulating the tower cross section.

To the investigators of this study the singularity encountered was totally unexpected. Because of its apparently fundamental nature, a discussion of the difficulty is presented with the hope that it may prove useful in possible future applications of this technique.

As previously outlined, the finite element representation of a closed body with discrete vortices requires one vortex within the body to satisfy total circulation requirements. Furthermore, the precise location of this vortex within the body is immaterial, since the circulation about any closed path enclosing the vortex remains constant. For lack of a better choice, the internal vortex was simply placed at the center of the square cross-section. The generated matrix of coefficients was then inverted. A poor inversion was obvious from the product of the matrix multiplied by its inverse. Double precision was incorporated to increase the accuracy, but the inversion check showed no improvement.

Because the matrix of coefficients was suspected of being ill-conditioned, the coding for formation of the coefficients was thoroughly checked and rechecked to no avail. Simple finite element arrangements were then considered in any attempt to discern some physical explanation for the trouble. During this procedure, it was found that a square represented by a single vortex at each corner, with zero normal velocity at the midpoints, is indeed singular if the internal vortex is placed at the center. This system is represented by a matrix of coefficients as shown in the form on the left which may be reduced in two steps to the form on the right.

$$\begin{bmatrix} -a_1 & a_1 & a_2 & -a_2 & 0 \\ -a_2 & -a_1 & a_1 & a_2 & 0 \\ a_2 & -a_2 & -a_1 & a_1 & 0 \\ a_1 & +a_2 & -a_2 & -a_1 & 0 \\ 1 & 1 & 1 & 1 & 1 \end{bmatrix} \quad \begin{bmatrix} -a_1 & 0 & a_2 & 0 & 0 \\ -a_2 & -a_2 - a_1 & a_1 & 0 & 0 \\ a_2 & 0 & -a_1 & 0 & 0 \\ a_1 & a_1 + a_2 & -a_2 & 0 & 0 \\ 1 & 1 & 1 & 1 & 3 & 1 \end{bmatrix}$$

If, however, the internal vortex is placed off-center, the last column will not contain all off-diagonal terms as zeroes, and the singularity disappears. While it is difficult to generalize these results to matrices of higher order, this was considered sufficient reason to re-evaluate the manner in which vortex sheets are successfully employed in aerodynamic theory. It was observed, for example, that vortex sheets are employed invariably for zero-thickness configurations, (i. e., thin airfoils), to determine lift due to camber and angle of attack. In a previous study of this type, a finite-element vortex sheet representation was successfully employed to represent flow about a circular cylinder. In that solution, the "internal" vortex, by necessity, had to be located on the boundary because linearly varying vortex sheet elements were employed. Under this approach, the circular boundary was actually represented by a highly cambered "airfoil" having leading and trailing edges approaching within some arbitrarily small distance to one another.

This concept was pursued for the problem at hand, and the internal vortex was placed to within $b/20$ of the boundary, where b is the dimension of a side. The resulting matrix premultiplied by its inverse was accurate to six significant figures on the diagonal and was less than 10^{-7} on all off-diagonal terms using double precision. The difficulty was considered to have been surmounted.

The scope of numerical investigations of interference flow at midlevel was restricted in view of the effort expended in overcoming this numerical difficulty; consequently, a complete speed ratio plot for comparison with experimental results was not obtained.

Nonseparated, steady potential solutions were obtained for wind directions from 180 degrees and 270 degrees. Computer plots of flow streamlines are shown in Figures 26 and 27 for these two cases.

A single nonsteady separated flow solution was obtained for wind direction from 350 degrees. Steady nonseparated potential flow for this case is shown in Figure 28. A time history of the instantaneous separated flow configuration represented by point vortices is shown in Figures 29a through 29d. The same condition with corresponding streamlines superimposed is shown in Figures 30a through 30d.

For this separated flow solution, eight "anemometer" locations were specified at which wind speed and azimuth shifts were printed out. Six of these locations represent three pairs of symmetrically situated points in the plane of the tower north face. The closest pair (at $5/8$ tower breadth from the corner) represents the actual position used in the wind loads test. The remaining two pairs on the tower were situated at one and two tower breadths away from the corner. Finally, locations for one pair of "anemometers" were specified 1.5 radii directly east and west of the cylinder center.

Speed ratios and azimuth shifts calculated for these points at various nondimensional times are given in Table 1.

The streamline plots of Figures 30a through 30d show one streamline passing through the tower cross section, indicating some leakage. This flow, however, must be small since it appears to be near the stagnation streamline. After a nondimensional time of 6, it is noted that a wake cavity envelops the cylinder, and a large vortex is formed on one side of the cylinder. Shedding of the vortex does not occur within the period covered, but appears to be on the verge of doing so in Figure 29d. Also shown in Figure 29d are two incremental vortices that have passed through the cylinder boundary because of the roughness of numerical integration. This effect indicates that finer integration intervals should be used. The solution represented by Figure 29d was obtained with 10 minutes of computer time during which a total of 154 vortices were introduced.

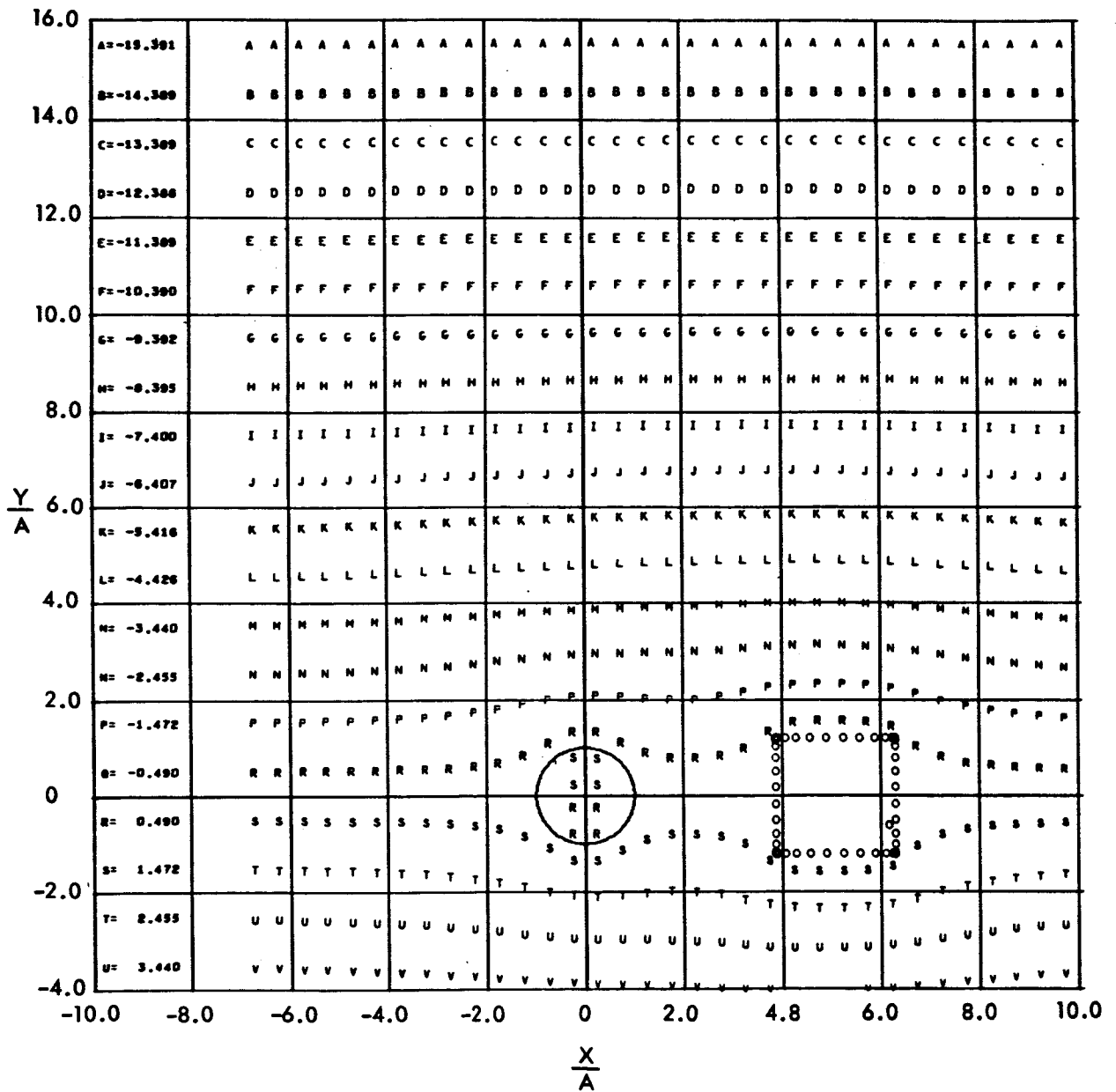


Figure 26. Steady Potential Flow Streamlines for Free Steam at 180 Degrees

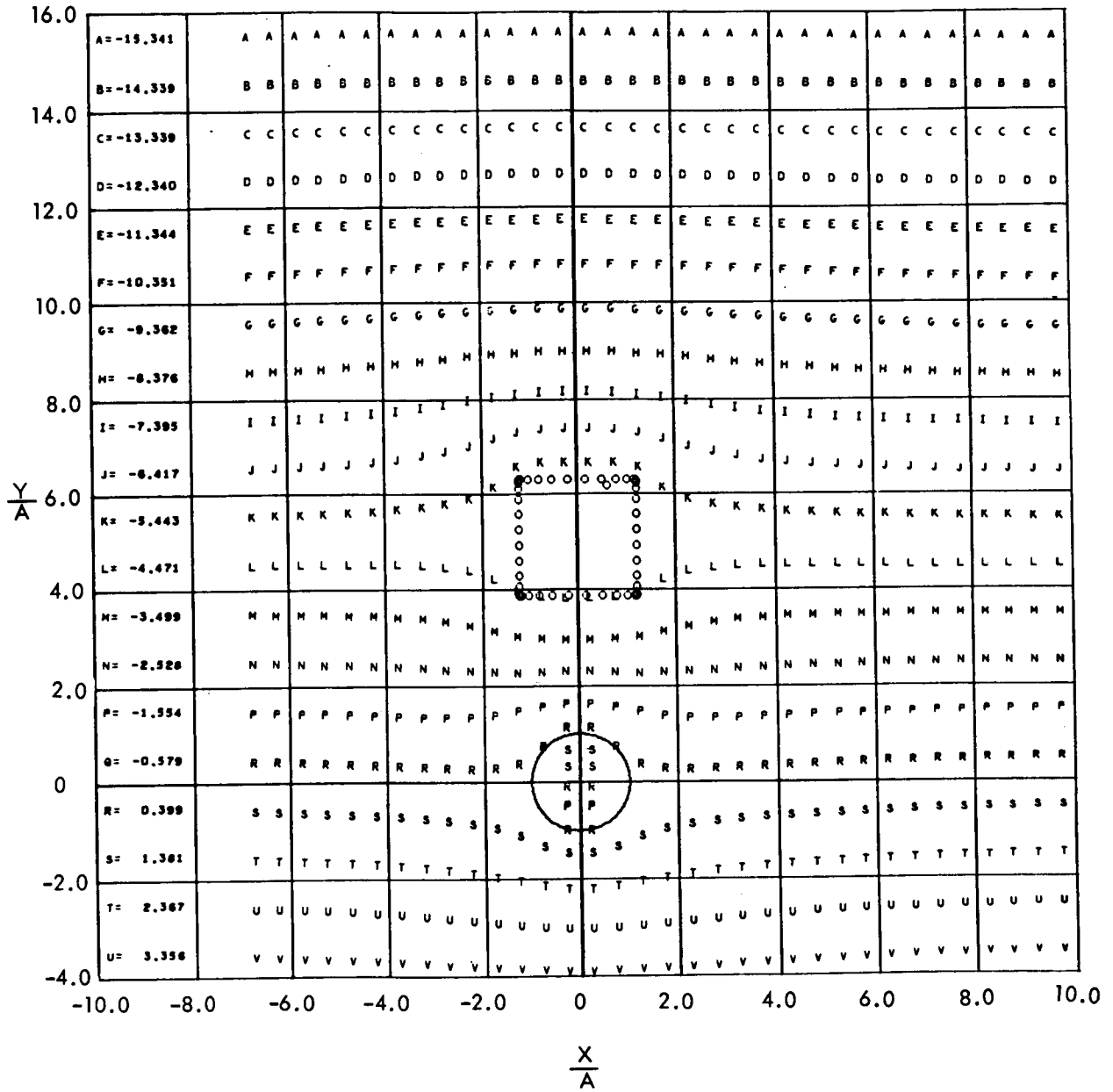


Figure 27. Steady Potential Flow Streamlines for Free Steam at 270 Degrees

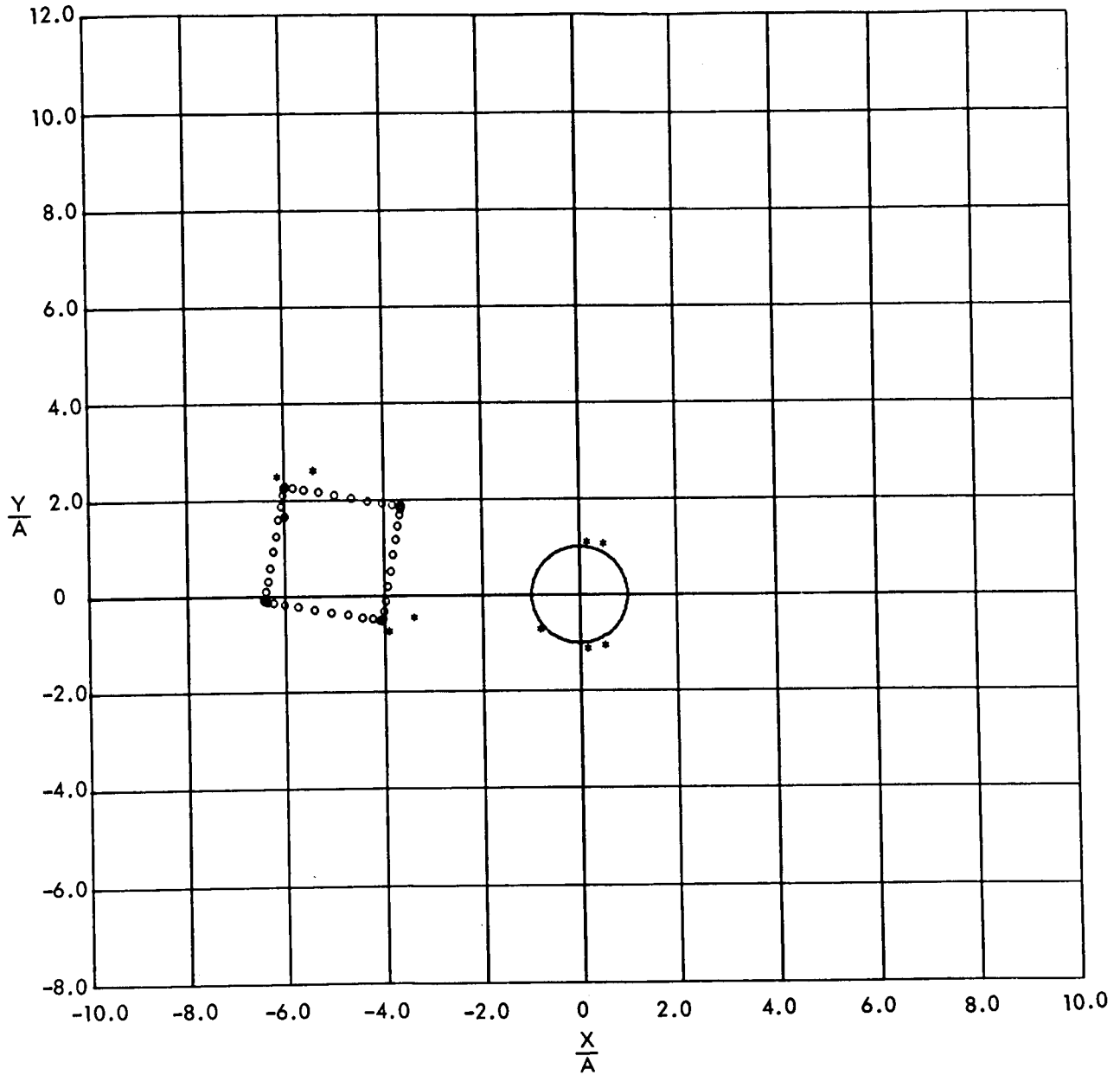


Figure 29a. Instantaneous Vortex Positions for Separated Flow at $T = 1 \frac{A}{U}$

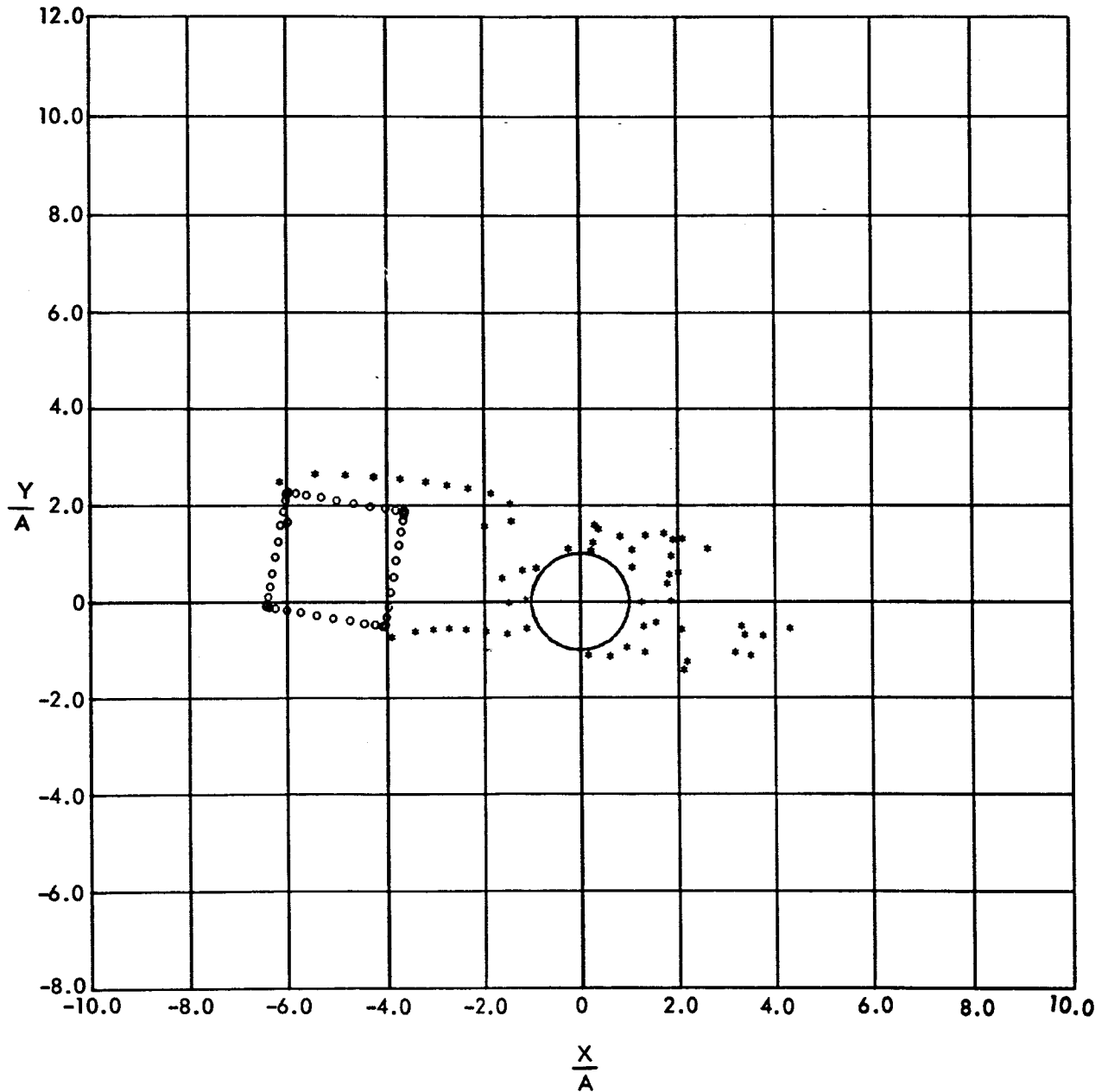


Figure 29b. Instantaneous Vortex Positions for Separated Flow at $T = 6\frac{A}{U}$

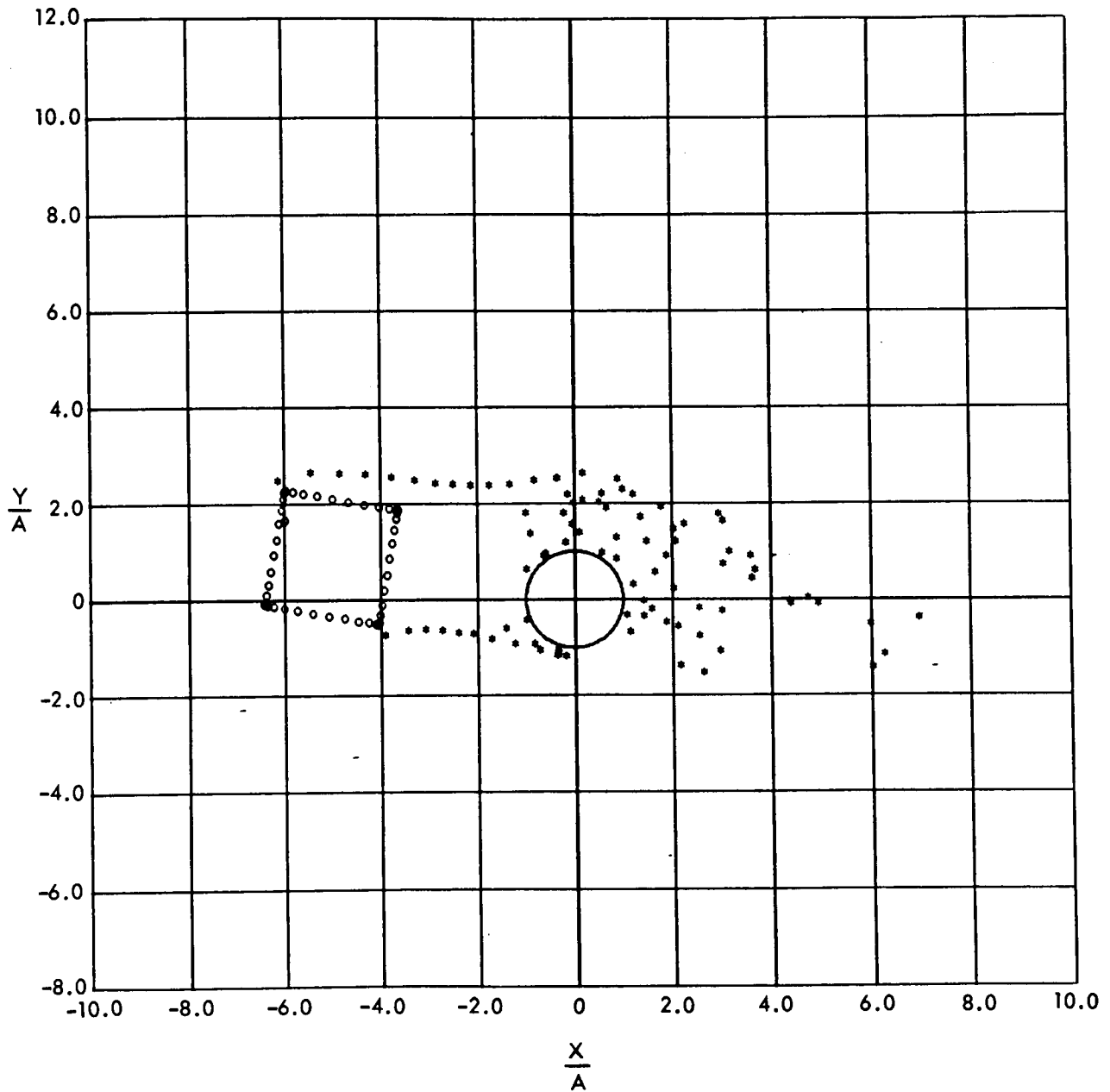


Figure 29c. Instantaneous Vortex Positions for Separated Flow at $T = 9 \frac{A}{U}$

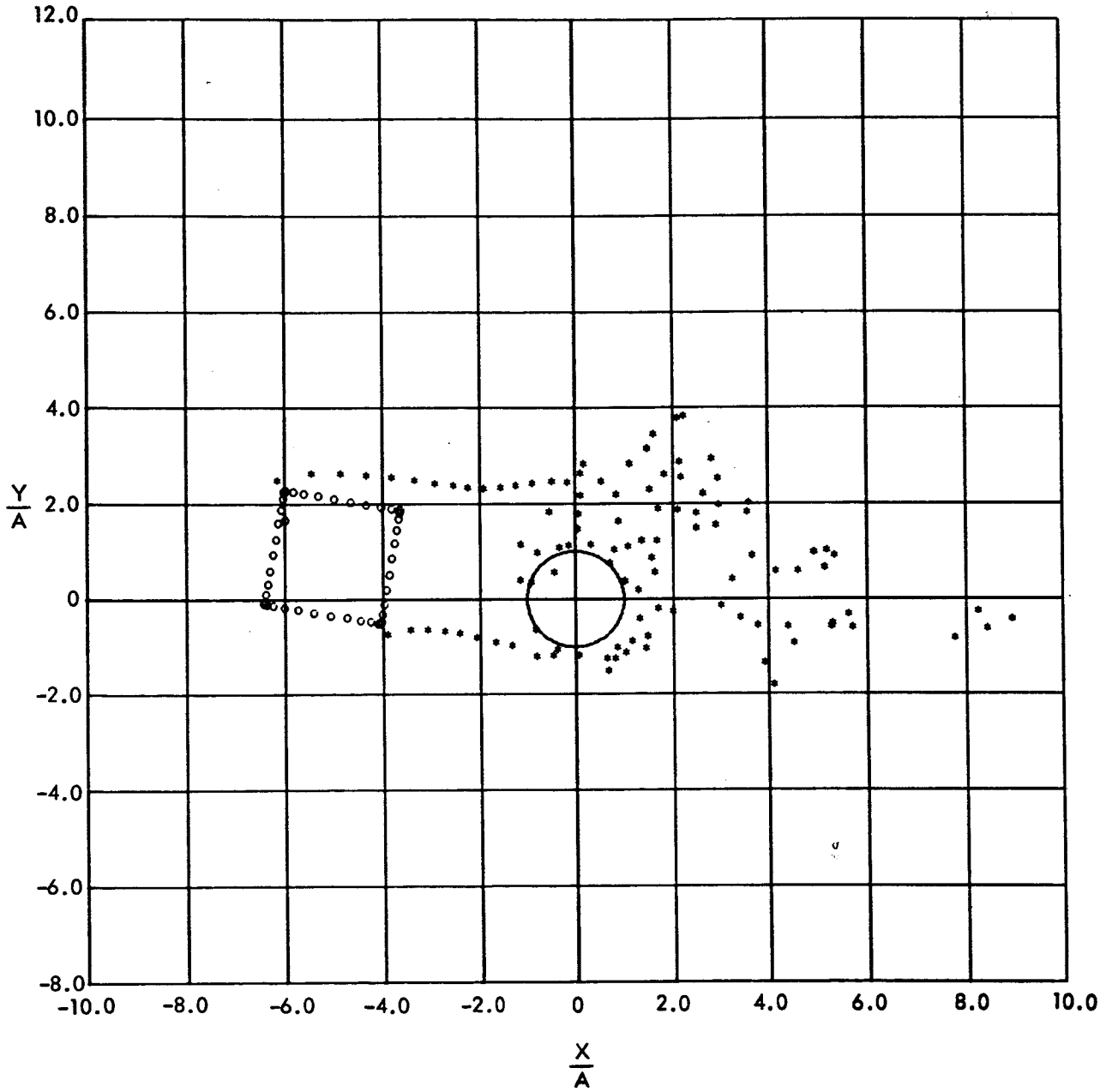


Figure 29d. Instantaneous Vortex Positions for Separated Flow at $T = 11 \frac{A}{U}$

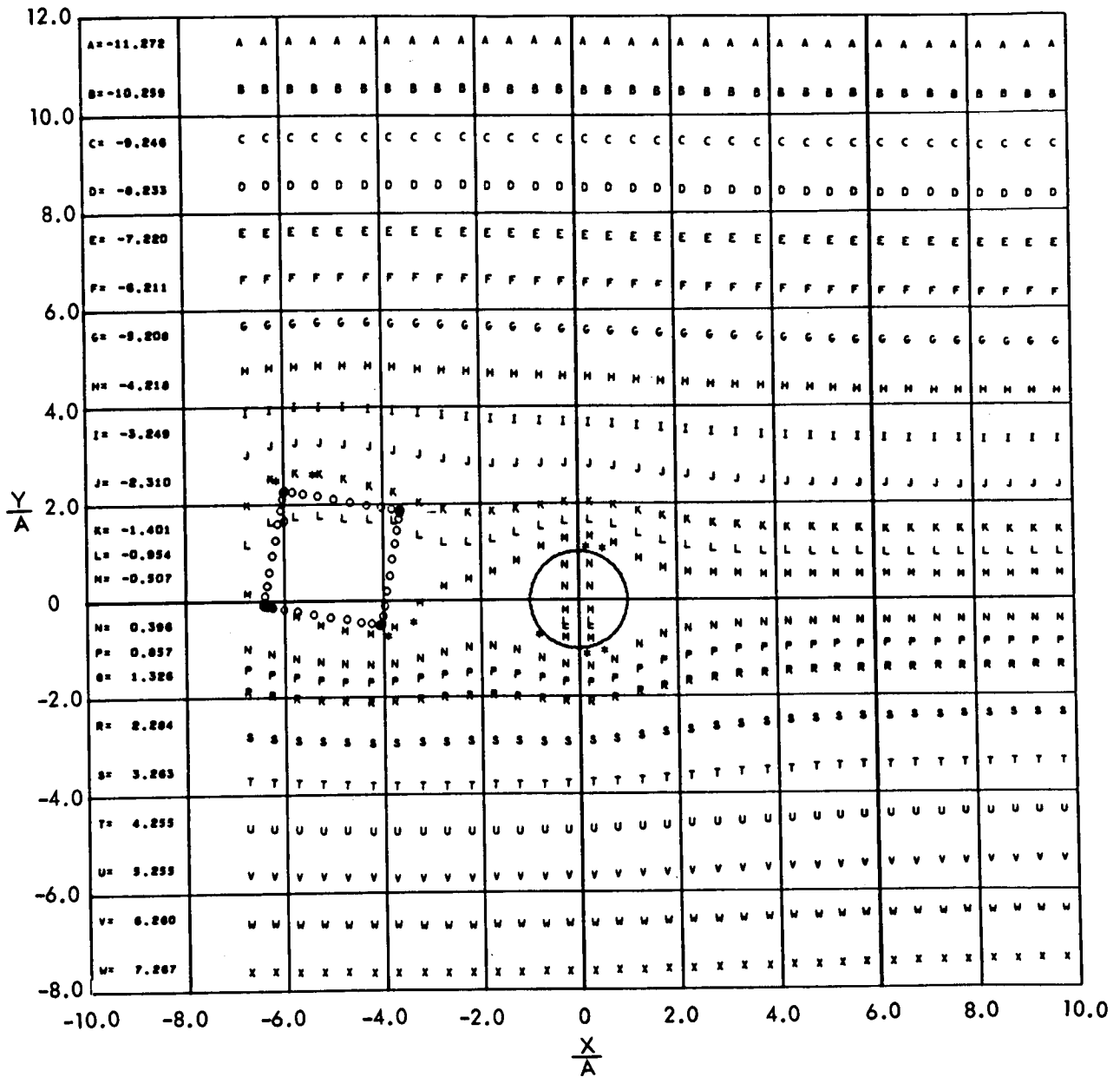


Figure 30a. Instantaneous Flow Streamlines for Vortex Positions of Figure 29a

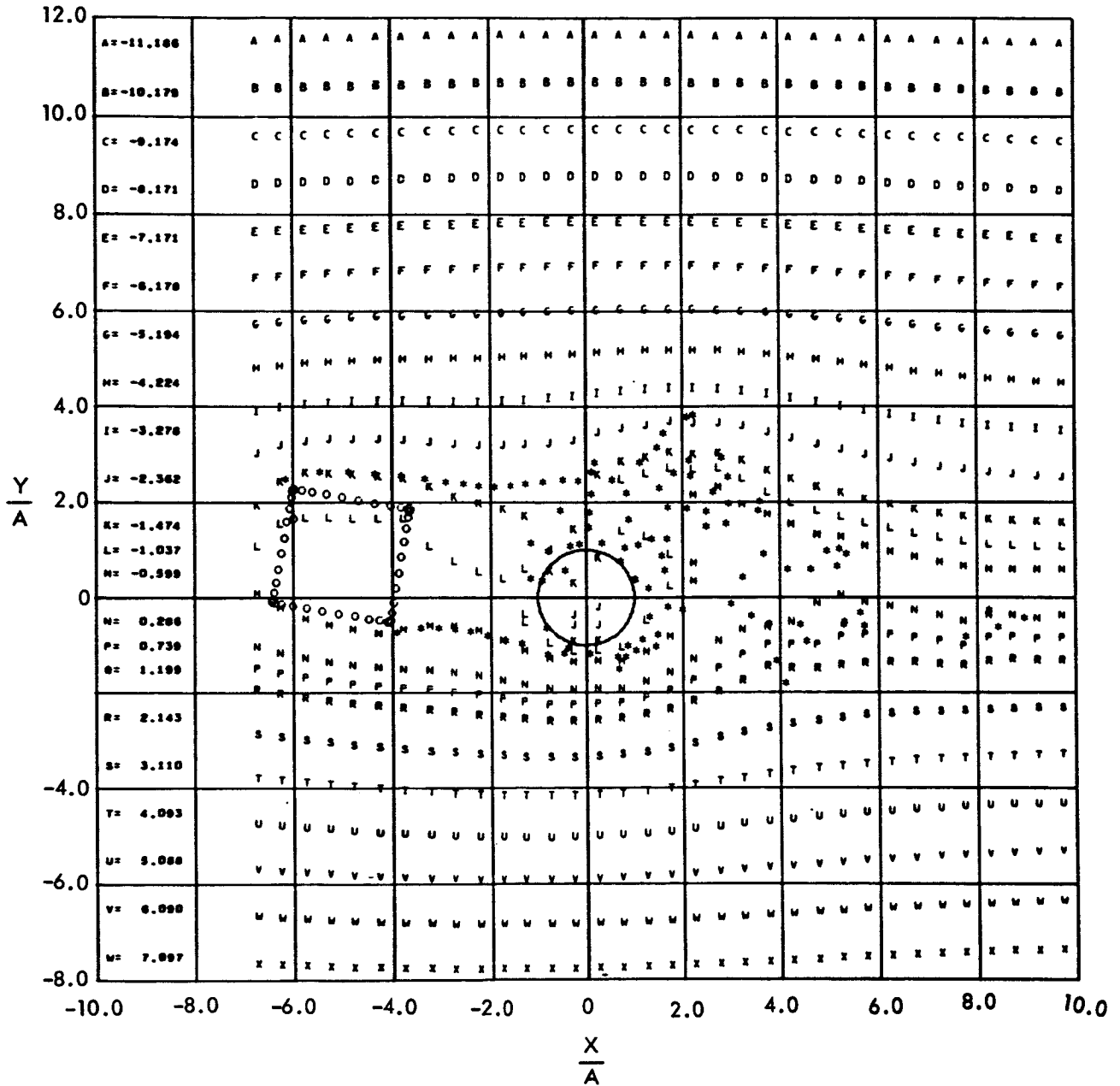


Figure 30d. Instantaneous Flow Streamlines for Vortex Positions of Figure 29d

Table 1. Anemometer Data for Azimuth of 350 Degrees

Anemometer Number	XAN	YAN	Speed	Azimuth	Shift
UT/A = 0					
1	-5.15	7.05	1.05	350.63	0.63
2	-5.57	4.67	1.13	352.10	2.10
3	-5.73	3.77	1.20	353.80	3.80
4	-6.68	-1.58	1.09	340.40	-9.60
5	-6.83	-2.48	1.06	343.95	-6.05
6	-7.25	-4.86	1.03	347.49	-2.51
7	0.26	1.48	1.33	343.08	-6.92
8	-0.26	-1.48	1.35	345.62	-4.38
UT/A = 3					
1	-5.15	7.05	1.07	350.84	0.84
2	-5.57	4.67	1.15	352.98	2.98
3	-5.73	3.77	1.23	355.44	5.44
4	-6.68	-1.58	1.06	339.59	-10.41
5	-6.83	-2.48	1.04	342.98	-7.02
6	-7.25	-4.86	1.03	346.70	-3.30
7	0.26	1.48	1.35	350.75	0.75
8	-0.26	-1.48	1.45	353.43	3.43
UT/A = 6					
1	-5.15	7.05	1.07	351.59	1.59
2	-5.57	4.67	1.14	353.91	3.91
3	-5.73	3.77	1.21	356.06	6.06
4	-6.68	-1.58	1.04	339.28	-10.72
5	-6.83	-2.48	1.03	342.54	-7.46
6	-7.25	-4.86	1.02	346.21	-3.79
7	0.26	1.48	1.73	393.80	43.80
8	-0.26	-1.48	1.32	339.03	-10.97
UT/A = 11					
1	-5.15	7.05	1.05	352.64	2.64
2	-5.57	4.67	1.10	354.44	4.44
3	-5.73	3.77	1.16	356.21	6.21
4	-6.68	-1.58	1.05	338.40	-11.60
5	-6.83	-2.48	1.04	341.67	-8.33
6	-7.25	-4.86	1.03	345.60	-4.40
7	0.26	1.48	1.05	407.78	57.78
8	-0.26	-1.48	1.60	356.75	6.75

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Referring to Figures 13, 19a, and 19b, the experimental values of speed ratio and azimuth shift for the east anemometer at a wind direction of 350 degrees are 1.3 and -10 degrees, respectively. These values correspond to 1.22 and 5.4, respectively, listed for anemometer 3 in Table 1. For the west anemometer, this wind direction corresponds to +10 degrees. Again, the experimental values at ten degrees are taken from Figures 13, 19a, and 19b to be 1.04 and 8 degrees, respectively. These values correspond to 1.04 and 10, respectively, listed for anemometer number 4. The general agreement of numerically calculated speed ratios and azimuth shifts with experimental values is fairly close. An interesting indication is that the experimental values based on median curves appear to be significantly better than those based on least-squared error.

DISCUSSION OF RESULTS

In view of numerical difficulties encountered, perhaps the single most significant result of this section is the demonstration of the fact that flow about arbitrary two-dimensional configurations can be obtained with the method employed. Practicality of the scheme is now substantiated, and the way is opened to further extensions and applications.

Observed differences between test data and numerical results are due in part to the assumed 100-percent solidity for the idealized tower cross-section. Also to be noted is the fact that numerically calculated results in Table 1 are instantaneous values. Average values over sufficiently long periods would be necessary for valid comparison. That instantaneous values are subject to appreciable variations is evident from the values recorded in Table 1 at different time points.

General similarity of numerically calculated speed ratios and azimuth shifts with those of the test data indicate the gross characteristics of the calculated flow to be correct. Further comparative studies could be made by obtaining numerical solutions for the entire range of wind directions, and obtaining the complete speed ratio and azimuth plots. Scope of funding for the present study was unfortunately insufficient for such an analysis. It is noted at this point that, in future studies of this type, lift and drag forces on the cylinder would also be obtainable within the framework of numerical solution obtained.

LAUNCH PAD

The launch pad dimensions are considerably larger in horizontal plan-form than those of the LUT. Thus, flow interference induced by the pad may significantly affect its local wind field. For a first estimate the east-west pad elevation was approximated by an equivalent ellipse of the same base-height ratio. Velocity profile was determined along the vertical centerline of this ellipse in symmetric, steady potential flow. This velocity profile is shown in Figure 8. While conservative, it does indicate that an appreciable acceleration of the flow may be expected due to pad elevation.

Based on this result, it was considered of sufficient further interest to determine the influence of a separated wake on the surrounding flow field. A computer program developed during a previous NASA-funded study was modified for this purpose. This computer program employs a Joukowski transformation to determine the two-dimensional symmetric separated flow about an elliptical configuration based upon the generalized Kutta conditions. Modification to this program consisted of fixing the vortex feeding point at a location on the ellipse corresponding to the forward top edge of the trapezoidal pad elevation. This point, 45 meters (150 ft) forward of the pad vertical centerline was calculated as 0.967 transformed circle radii forward of ellipse center. Slope discontinuity and orientation of this edge was considered sufficient to induce flow separation.

Due to numerical difficulties, a point vortex cannot be introduced exactly on the ellipse boundary. The nature of these difficulties stems primarily from the excessive velocity induced by image vortices. Furthermore, in the simulation of shear layer detachment from the boundary, the vortices should be introduced at a point corresponding to the center of the shear layer thickness; this thickness, in turn, is governed by the flow Reynolds number. Based upon a dimension of 100 ft (about twice the pad height), the Reynolds number is expressed by

$$Re = \frac{DV}{\mu} = \frac{100V}{.0016} \cong 6V \times 10^5$$

for a 20 mph wind, Re is 12×10^6 . Reynolds number of this magnitude cannot be simulated by the current computer program without prohibitive computer time and cost. Therefore, a greatly reduced simulated Reynolds number was employed. The vortex feeding period was .125 as nondimensionalized by the transformed circle radius, a , and the free stream velocity, U_0 .

Substitution into Equation 3 gives an approximate simulated Reynolds number of 1600. Equivalent shear layer thickness represented by a row of equally spaced vortices is $0.56 b$, where b is the spacing. Replacing b by $U_s \Delta t$, since U_s is approximately the convective velocity of the vortices at the feeding point, the equivalent nondimensional shear layer thickness is

$$\frac{\delta}{a} = 0.56 \frac{U_s}{U_0} \left(\frac{U_0 \Delta t}{a} \right) \quad (5)$$

where δ = shear layer thickness

a = radius of Joukowski cylinder

U_s = vortex convective velocity

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U_o = free stream velocity

Δt = vortex feeding period

Taking $\frac{U_s}{U_o} \cong 1.1$

$$\frac{U_1 \Delta t}{a} = .125$$

$$a = \frac{15.3 + 76.5}{2} = 45.9 \text{ meters (150 ft)}$$

The equivalent shear layer thickness is

$$\frac{\delta}{a} = 0.56 (1.1) (.125)$$

$$\cong .077$$

$$\delta = 45.9(.077) = 3.53 \text{ meters (11.5 ft)}$$

Using the center of this shear layer, the feeding point height was located at .035 units above the ellipse. Discrete vortices were then introduced at this feeding point according to the generalized Kutta condition already described. While additional velocity maxima occur at the aft edge of the top face, and at possibly additional points due to local influence of convecting vortices, these are considered to be of secondary importance on the overall velocity field.

The simulated Reynolds number is quite low; however, experimental data indicate that for configurations with a stationary separation point, as believed for this case, Reynolds number effects on wake width are not of primary importance. On this basis the gross effects exhibited by the velocity profiles are believed to be valid.

While for an ideal fluid, the assumption of symmetric flow also satisfies the conditions for flow over the half-plane, $y > 0$, this is not true in the case of physical flows. First, the condition of zero slip along the boundary requires that vorticity be generated not only on the ellipse, but also on the half-plane boundary considered. Also since only a finite extent of the half-plane can be considered, some assumption is necessary regarding vertical nonuniformity of the approaching flow.

These two effects could be incorporated by use of initial free vortices to impose a given free stream velocity profile, and calculation of vorticity generation along the plane surface (ground). Such solutions may be warranted

in further theoretical ground wind field studies. For the purposes of this study, however, these aspects were not incorporated on the assumption that for initial estimation purposes, the profiles obtained could be directly superimposed with any desired free stream wind profile.

To start the problem, the flow is initially assumed to be steady and without vortices. Horizontal velocity profiles associated with this steady potential flow are shown in nondimensional form in Figure 31. With a 5:1 ellipse representation of the pad, the equivalent Joukowski cylinder has a radius of 46 meters (150 ft), which may be regarded as the reference dimension for converting the vertical scale in Figure 31 to height above natural grade.

As previously discussed, a significant feature appears to be the substantial increase in velocity ratio exhibited by the profile along the vertical centerline.

Figures 32 and 33 are computer plots of vortex positions at nondimensional times of 10 and 12.5. Approximately 7 minutes of computer time was required to reach the solution shown in Figure 33. This solution, containing 100 discrete vortices, shows the wake has fully developed to a nondimensional downstream distance of about 4. Four vortices are shown to have penetrated the boundary due to coarseness of numerical integration. Their effects are considered to be minor, but do cause a peculiarity near the boundary in the velocity profile in Figure 34f for $x/a = 2.0$.

There is an evident periodicity with which vortices are being shed from the ellipse, and appear to be the type reported by Taneda at the IUTAM Symposium, 1964 (edited by Küchemann). For his experiments, periodic oscillation in the streamwise direction caused the formation of symmetrically arranged vortices.

Wake influence on the horizontal velocity profile along the vertical centerline is shown by comparing Figure 34d with the one shown in Figure 31. Except for obvious effects caused by the induced shear layer, the wake influence is seen to be negligible. This appears to be generally true for all the velocity profiles calculated. In other words, the profiles calculated on the basis of steady potential flow should be satisfactory in all regions except those directly in the wake. Within the wake region itself, appreciable velocity decrements are seen to occur; however, its applicability to the pad problem is uncertain, since three-dimensional effects should become more pronounced with downstream distance. Although the solution could have been carried out further to reach a more complete equilibrium condition, the solution obtained is considered to have answered the question in mind; namely, the wake influence on the velocity profile.

VELOCITY PROFILES AT VARIOUS VALUES OF $\frac{X}{a}$, AT TIME = $0.0 \frac{A}{U}$

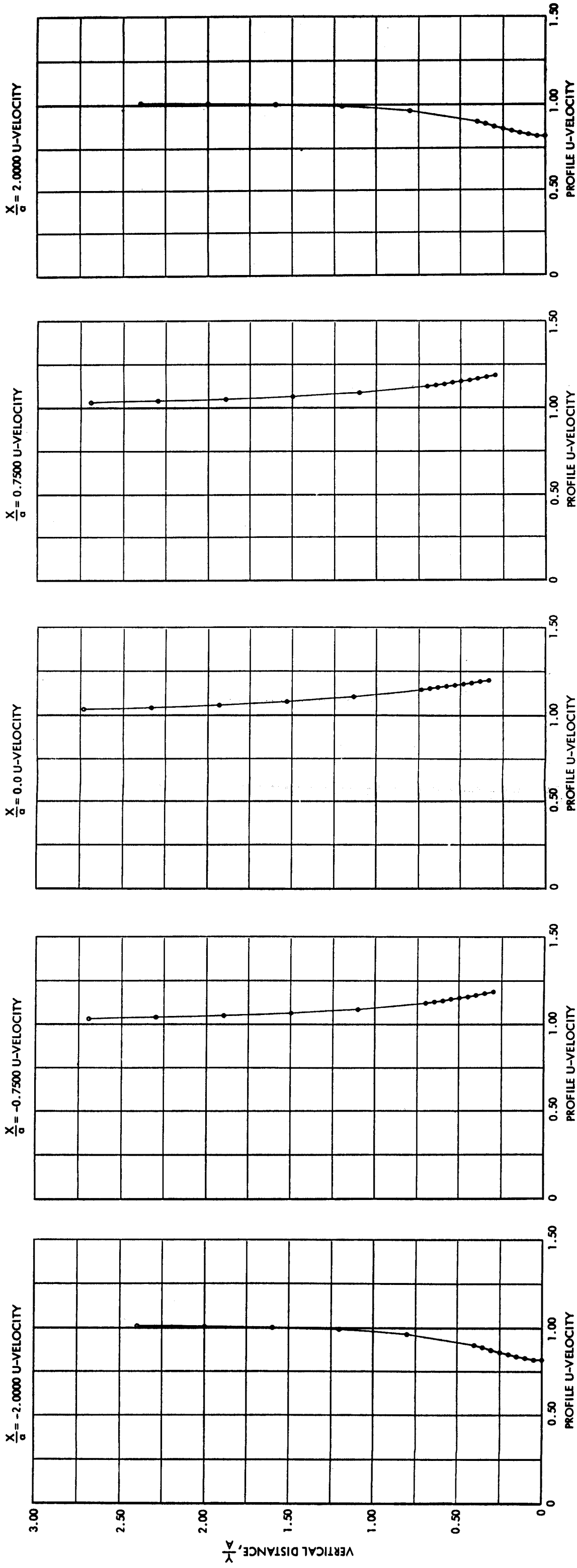


Figure 31. Wind Profile of Steady Potential Flow Over Ellipse

71

LOCATIONS OF 81 CELLS TIME = $10.0249 \frac{A}{U}$ SYM CASE NO. 112.68 DELTC = 0.125

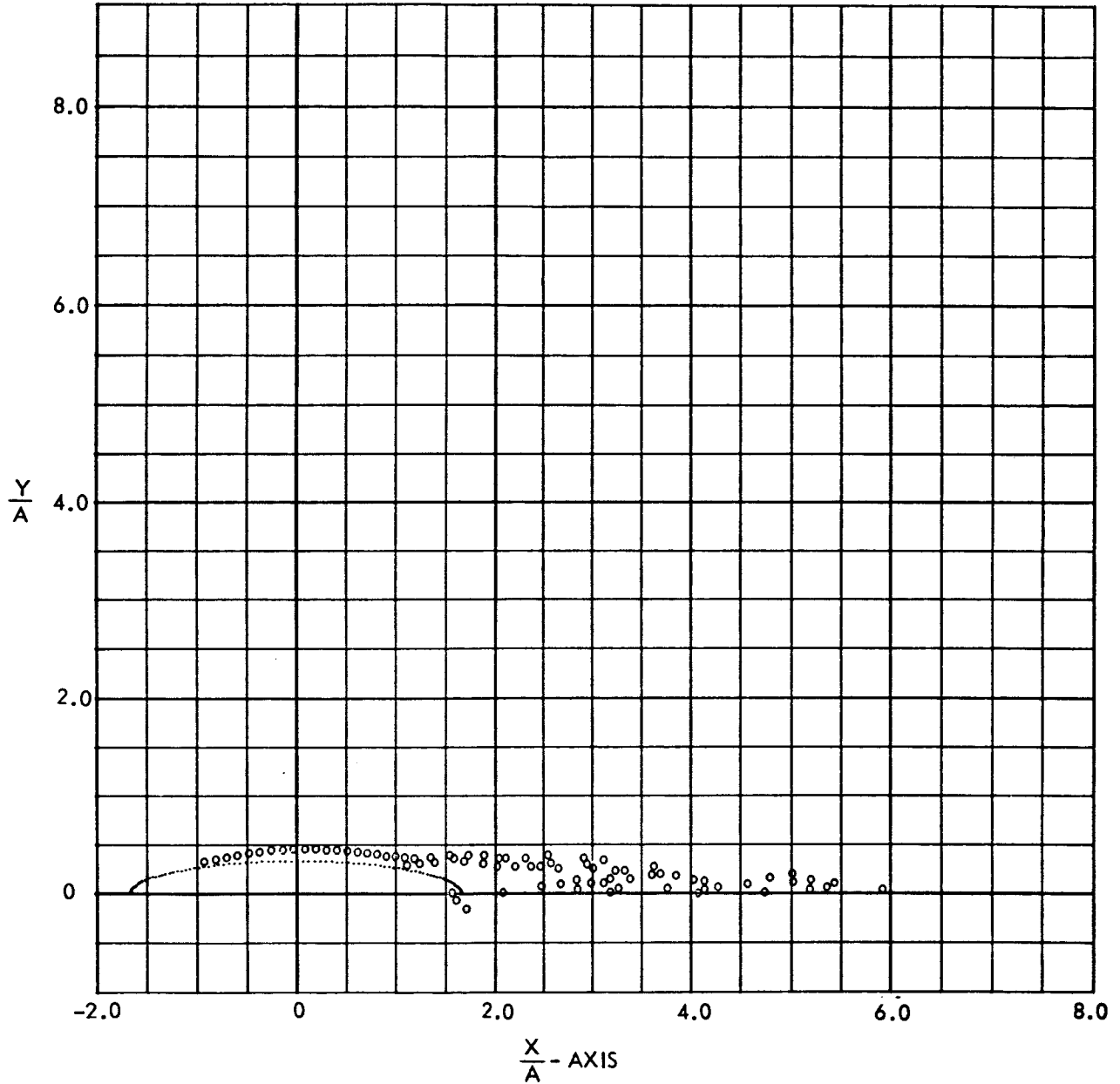


Figure 32. Instantaneous Vortex Positions at $t = 10.0249 \frac{A}{U}$

LOCATIONS OF 101 CELLS TIME = $12.4748 \frac{A}{U}$ SYM CASE NO. 112.68 DELTC = 0.125

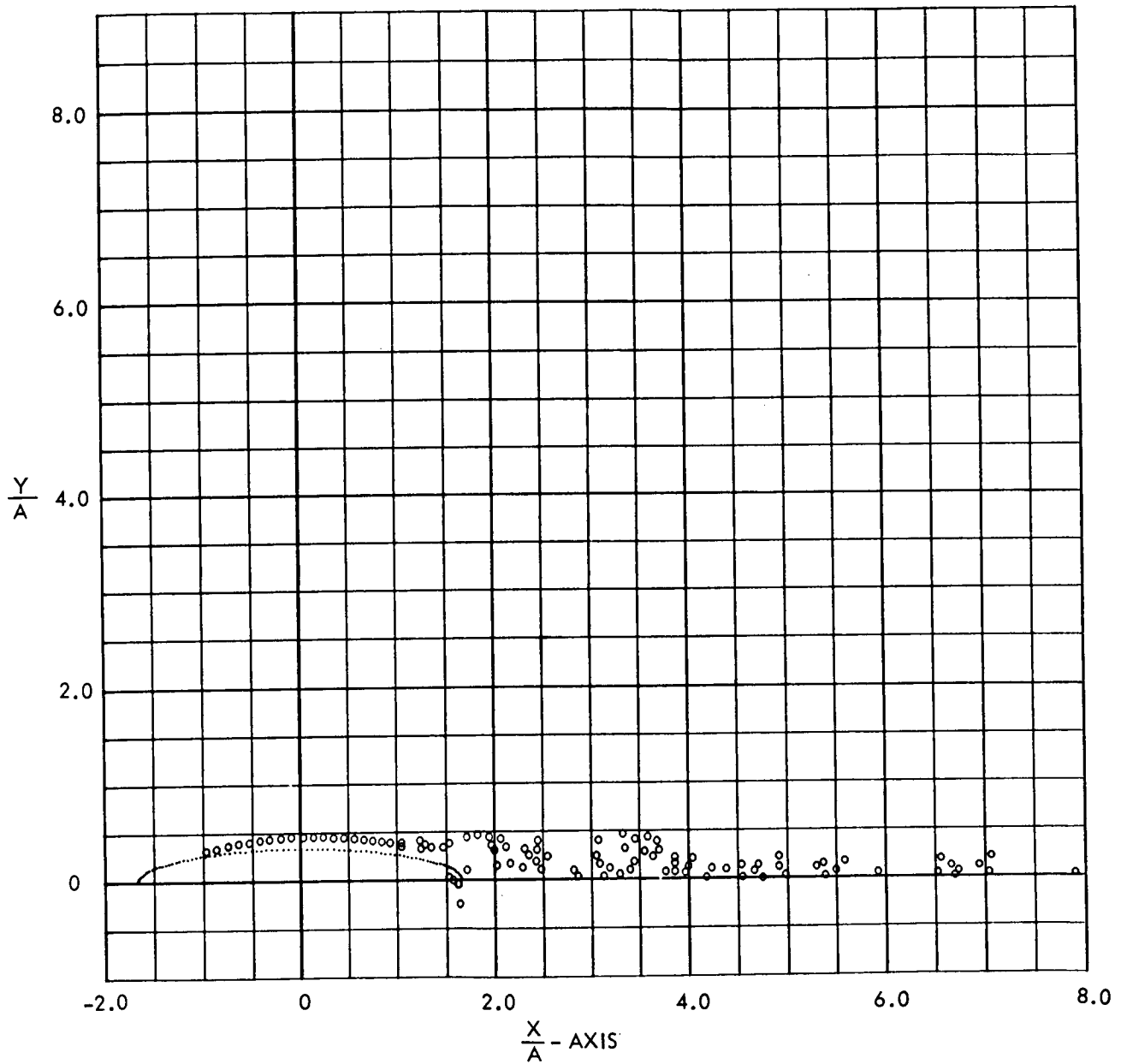


Figure 33. Instantaneous Vortex Positions at $t = 12.4748 \frac{A}{U}$

TIME = $12.4748 \frac{A}{U}$ $\frac{X}{A} = -2.0000$ U-VELOCITY $\frac{Y}{A}$

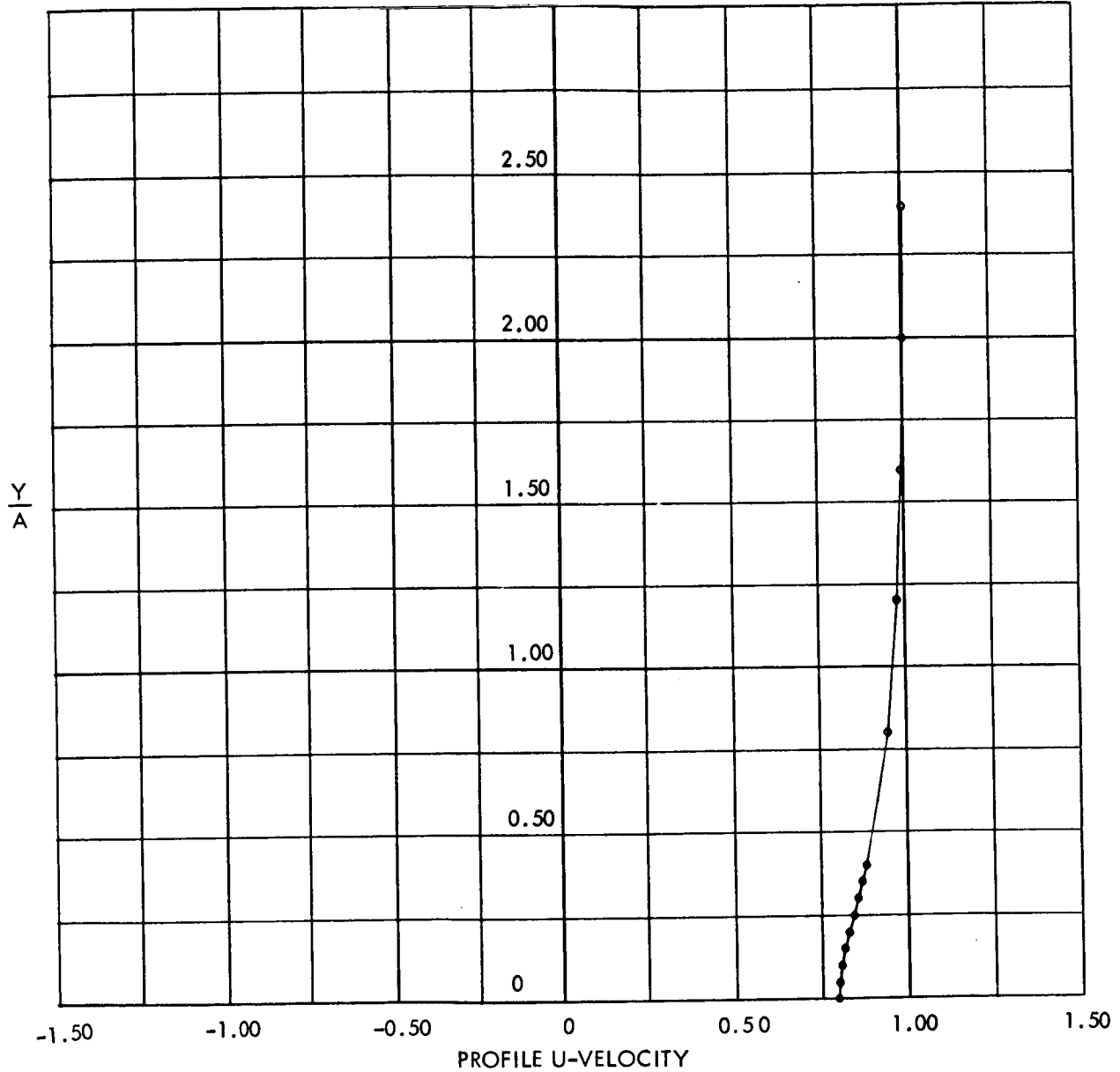


Figure 34b. Horizontal Velocity Profiles at $\frac{X}{A} = -2.00$

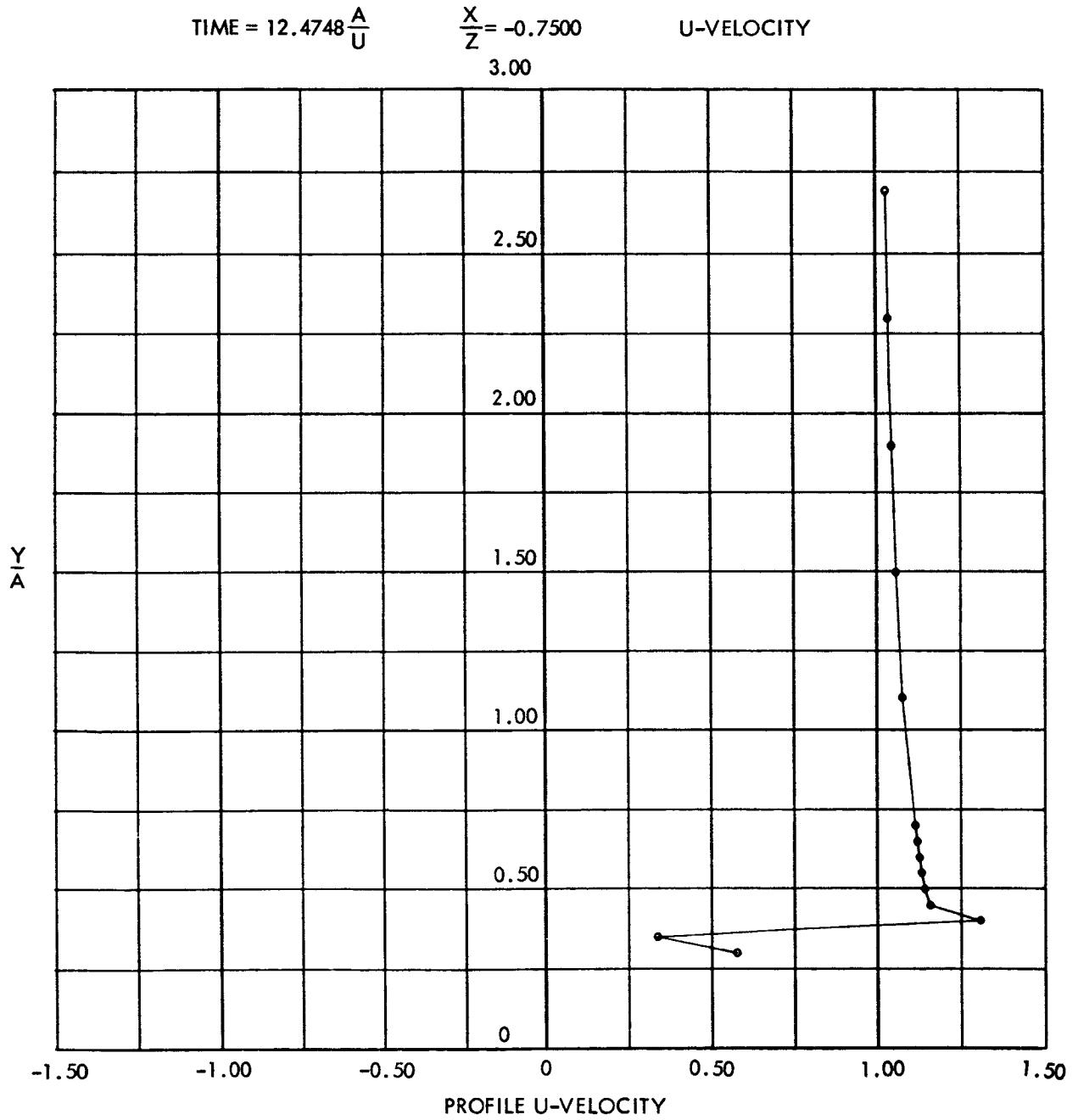


Figure 34c. Horizontal Velocity Profiles at $\frac{X}{A} = -0.75$

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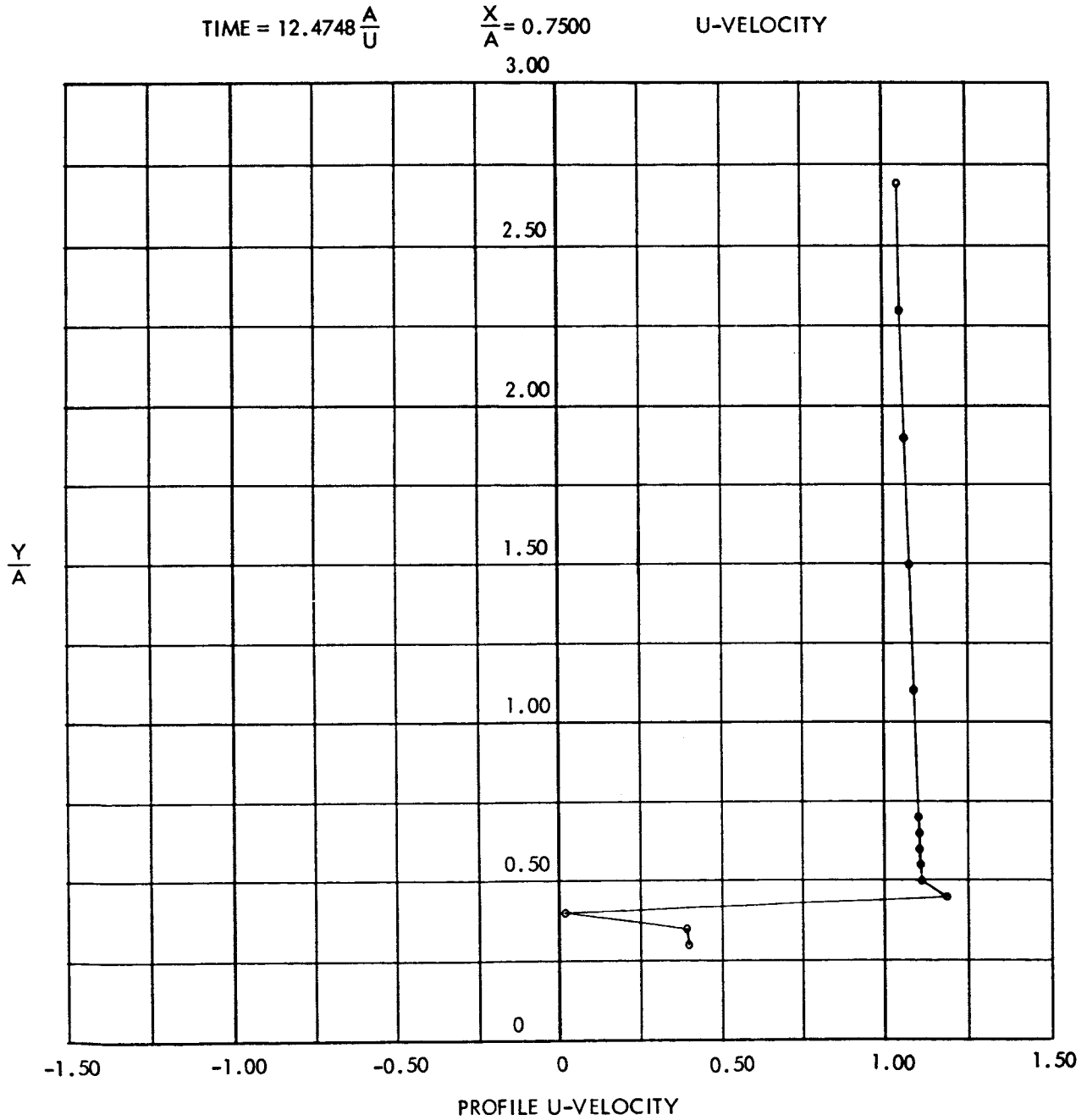


Figure 34e. Horizontal Velocity Profiles at $\frac{X}{A} = 0.75$

TIME = 12.4748 $\frac{A}{U}$

$\frac{X}{A} = 2.0000$
3.00

U-VELOCITY

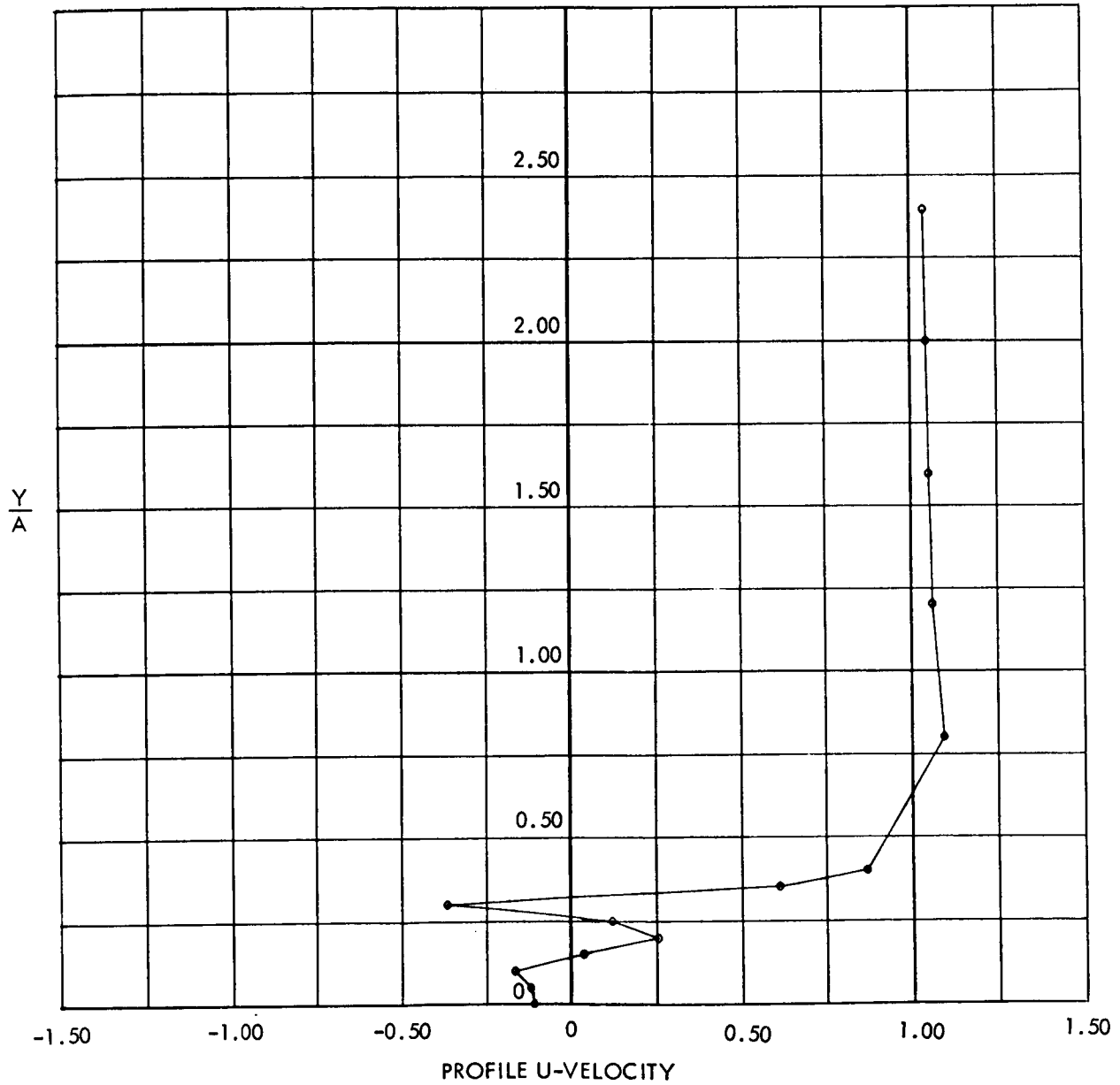


Figure 34f. Horizontal Velocity Profiles at $\frac{X}{A} = 2.00$

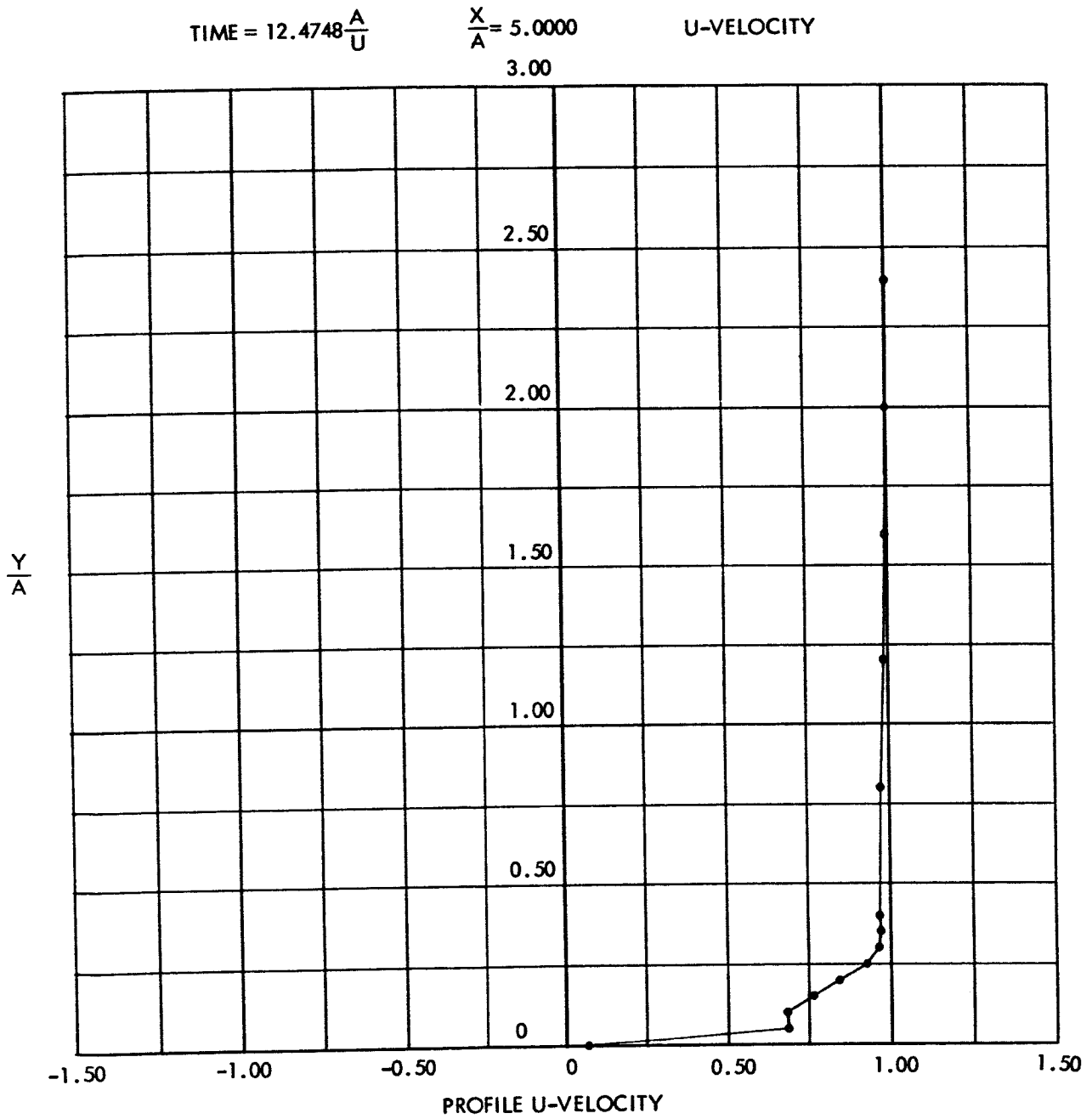


Figure 34g. Horizontal Velocity Profiles at $\frac{X}{A} = 5.00$

IV. CONCLUSIONS AND RECOMMENDATIONS

It was concluded from an analysis of test data that, for purposes of establishing existing wind conditions, the PLP and 445-ft-level anemometers would be most useful. The deck-zero anemometer should be useful for all wind directions, except those with a significant northerly component. The deck-zero anemometer over its range of usefulness will reflect local speed-up due to pad elevation and deflection by the launcher. For northerly winds, other methods of determining wind velocity are desirable since the anemometer will be exposed to the tower wake. The midlevel anemometers, at least near their present locations, provide data of most doubtful value for purposes of identifying local wind conditions for vehicle cantilever loads.

Previous studies have shown that for a cylinder alone, nonsteady effects of separated flow are of major importance to magnitude of transverse lift and drag loadings. Immersed in an interference flow field, this nonsteady effect would be expected to have even more significance. It is believed, therefore, that for purposes of cantilever load determination, the specification of average flow field characteristics will be insufficient. Computation of nonsteady lift and drag loadings versus wind direction would be much more useful. Using the PLP readings and the analytical method presented herein, one can predict the interference flow field about the vehicle and tower on the launch pad.

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APPENDIX A

TOWER-VEHICLE MIDHEIGHT CROSS SECTION (VSTV)

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APPENDIX A. TOWER-VEHICLE MIDHEIGHT CROSS SECTION
(VSTV)

AI. THEORETICAL DEVELOPMENT

In potential theory, the total flow is a superposition of all the individual flows. Boundary conditions for a circular cylinder may therefore be met by satisfying each flow contribution separately. The uniform flow component is met by a source-sink doublet and the normal flow at the surface induced by each vortex is nulled by an image vortex inside the cylinder according to the circle theorem.

The use of point vortices is especially convenient in nonsteady separated flow analyses since, as free vortices they may be utilized to represent rotationality in the flow, and considered as fixed vortices, they may be arranged to represent bodies of arbitrary shape. In either case the method of solving the resulting velocity field remains essentially unchanged within the framework of finite difference numerical solution.

In this appendix, the velocity field about a source-sink circular cylinder in a field of free vortices, some of which are growing, is developed with potential theory. It is part of a more complete theoretical treatment of the vortex shedding problem in a previous NASA-funded study (Ujihara, et al., 1965). A matrix technique is also developed for the use of stationary vortices to represent bodies of arbitrary configuration in two-dimensional potential flow.

AI. 1 Flow Field for a System of Vortices Outside a Circular Cylinder in Uniform Flow

For incompressible, inviscid, irrotational, two-dimensional flow, the flow field may be described by a potential function of the complex variable ($z = x + iy$). The complex potential, $w(z)$, of a system of vortices outside a circular cylinder of radius "a" in a uniform stream may be written as the sum of two potentials where

$$w(z) = w_1(z) + w_2(z)$$

$w_1(z)$ ~ uniform flow past a circular cylinder ($r = a$) at angle of attack

$w_2(z)$ ~ system of vortices outside a circular cylinder ($r = w$)

The velocity components are found from the relation

$$(u-iv) = - \frac{dw(z)}{dz} \quad (A-1)$$

From Reference 3, $w_1(z)$ and $w_2(z)$ are found to be

$$w_1(z) = - U_0 \left[ze^{-i\alpha} + \frac{a^2}{z} e^{-i\alpha} \right] \quad (A-2)$$

and for n vortices

$$\begin{aligned} w_2(z) &= -i \sum_{j=1}^n K_j \log(z-z_j) + i \sum_{j=1}^n K_j \log\left(z - \frac{a^2}{z_j}\right) \\ &= i \sum_{j=1}^n K_j \log z + i \sum_{j=1}^n K_j \log \bar{z}_j \end{aligned} \quad (A-3)$$

where K_j strength of the j^{th} vortex filament—positive rotation taken clockwise.

For a vortex outside the cylinder at $z = z_j$, the position of the image vortex inside the cylinder $\frac{a^2}{z_j}$, is denoted;

$$z_j^i = \frac{a^2}{z_j} = \frac{a^2(x_j + iy_j)}{x_j^2 + y_j^2} \quad (A-4)$$

Therefore

$$x_j^i = \frac{a^2 x_j}{x_j^2 + y_j^2}, \quad y_j^i = \frac{a^2 y_j}{x_j^2 + y_j^2} \quad (A-5)$$

The velocity of the m^{th} vortex filament outside the circular cylinder is given by

$$\begin{aligned} (u-iv)_m &= - \left\{ \frac{d}{dz} \left[w_2(z) - iK_m \log(z-z_m) \right] + \frac{dw_1(z)}{dz} \right\} \\ &= \sum_{j=1}^n \frac{K_j}{z_m - z_j} - i \sum_{j=1}^n \frac{K_j}{z_m - z_j^i} + i \sum_{j=1}^n \frac{K_j}{z_m} \end{aligned}$$

$$+ U_o \cos \alpha \left(1 - \frac{a^2}{z_m^2} \right) - i U_o \sin \alpha \left(1 + \frac{a^2}{z_m^2} \right) \quad (A-6)$$

At this point, it is of some importance to clarify physical significance of the last summation term, in Equation A-6.

This term,

$$i \sum_{j=1}^n \frac{K_j}{z_m}$$

included in Equation A-6 insures that total circulation within the fluid region, and around the circle in particular, remains unchanged, as long as rotationality within the external flow remains constant. In the present formulation, however, the concept of small discrete vortices is employed to represent a constantly generated vorticity from the separating boundary layer. In this framework, the addition of a discrete vortex to the external flow, regarded as being generated from the cylinder, requires that an opposite circulation be given to the cylinder in order to maintain the condition of zero total circulation about the entire fluid region. This is automatically accomplished by the image vortex required within the cylinder. On this basis, then, a third vortex at the center, represented by the term,

$$i \sum_{j=1}^n \frac{K_j}{z_m}$$

is not required. In the case of multiple bodies in the flow, say, for example, two separate cylinders, it would be necessary to identify from which body the particular vortex was generated. The center vortex would then be omitted from that body, but would be included on the other. If the vortex pre-existed, as an initial condition of the flow, then both bodies must contain the center vortex. In all cases, the condition of constant total circulation is preserved.

Separating Equation A-6 into real and imaginary parts gives the velocity components in non-dimensional form.

$$\left(\frac{U}{U_o} \right)_m = \sum_{\substack{j=1 \\ j \neq m}}^n \left(\frac{K_j}{U_o a} \right) \frac{y_m - y_j}{(x_m - x_j)^2 + (y_m - y_j)^2}$$

$$\begin{aligned}
 & - \sum_{j=1}^n \frac{K_j}{U_o a} \frac{y_m - y_j^i}{(x_m - x_j^i)^2 + (y_m - y_j^i)^2} \\
 & + 1 - \frac{x_m^2 - y_m^2}{(x_m^2 + y_m^2)^2} \cos \alpha - \frac{2 x_m y_m}{(x_m^2 + y_m^2)^2} \sin \alpha \quad (A-7)
 \end{aligned}$$

$$\begin{aligned}
 \left(\frac{V}{U_o}\right)_m &= - \sum_{\substack{j=1 \\ j \neq m}}^n \left(\frac{K_j}{U_o a}\right) \frac{x_m - x_j}{(x_m - x_j)^2 + (y_m - y_j^i)^2} \\
 & + \sum_{j=1}^n \frac{K_j}{U_o a} \frac{x_m - x_j^i}{(x_m - x_j^i)^2 + (y_m - y_j^i)^2} \\
 & - \frac{2x_m - y_m}{(x_m^2 + y_m^2)^2} \cos \alpha + 1 + \frac{x_m^2 + y_m^2}{(x_m^2 + y_m^2)^2} \sin \alpha \quad (A-8)
 \end{aligned}$$

Having an expression for the velocity field, the problem of nonsteady vortex shedding about a circular cylinder may be approximated by a finite difference technique. At a given time (t) the velocity of the mth vortex is given by Equation A-6. The new coordinates of the mth vortex are then found from the solution of the differential equations,

$$\begin{aligned}
 \frac{dx_m}{dt} &= u_m(x_1, x_2, \dots, x_n, y_1, y_2, \dots, y_n) \\
 \frac{dy_m}{dt} &= v_m(x_1, x_2, \dots, x_n, y_1, y_2, \dots, y_n)
 \end{aligned}$$

or written as difference equations

$$x_m(t + \Delta t) = x_m(t) + u_m(t) \Delta t \quad (A-9)$$

$$y_m(t + \Delta t) = y_m(t) + v_m(t) \Delta t \quad (A-10)$$

This procedure applied to all vortex filaments outside the circular cylinder results in a time history of their displacements. Once the velocity is known, the pressure distributions and resultant forces may be found for each time increment.

AI. 2. Finite Element Matrix Solution

The method of describing incompressible, inviscid fluid boundaries is in terms of a vortex sheet or source distribution. The finite element matrix methods is a numerical machination of this method in which the source or vortex sheet distribution is approximated by a finite element representation of their strengths. Various methods of representation can be used, the simplest being a lumped parameter approach wherein all the strength over an element is lumped at its midpoint. More sophisticated methods could employ linear or higher order strength distributions over the element.

The approach given herein uses lumped parameters.

The Cartesian velocity components induced at a point, m, by a system of vortices in uniform flow about a source-sink cylinder are given by Equations A-7 and A-8. If the system of vortices covered by index, j, are now required to represent a stationary body in this fluid, the Cartesian velocity components at all midpoints, m, induced by the stationary vortices, may be written in matrix form as

$$\begin{Bmatrix} U'_m \\ V'_m \end{Bmatrix} = \begin{bmatrix} a_{mj} \\ b_{mj} \end{bmatrix} \begin{Bmatrix} K'_j \end{Bmatrix} \tag{A-11}$$

$$\begin{Bmatrix} U'_m \\ V'_m \end{Bmatrix} = \begin{bmatrix} a_{mj} \\ b_{mj} \end{bmatrix} \begin{Bmatrix} K'_j \end{Bmatrix} \tag{A-12}$$

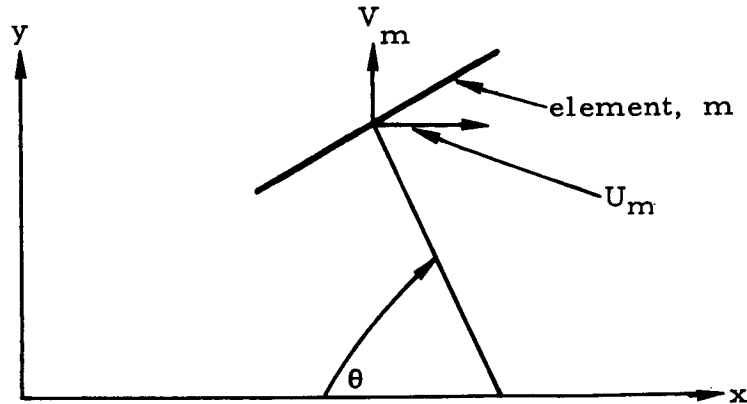
in which the primed quantities are nondimensional, and

$$a_{mj} = \frac{y_m - y_j}{(x_m - x_j)^2 + (y_m - y_j)^2} - \frac{y_m - y_j^i}{(x_m - x_j^i)^2 + (y_m - y_j^i)^2} \tag{A-13}$$

$$b_{mj} = \frac{-(x_m - x_j)}{(x_m - x_j)^2 + (y_m - y_j)^2} + \frac{x_m - x_j^i}{(x_m - x_j^i)^2 + (y_m - y_j^i)^2} \tag{A-14}$$

The normal velocities, VN , induced by the stationary vortices at points, m , according to the convention below are

$$(VN)_m = -U'_m \cos \theta_m + V'_m \sin \theta_m \quad (A-15)$$



In matrix form this becomes

$$\left\{ VN_m \right\} = \left[-a_{mj} \cos \theta_m + b_{mj} \sin \theta_m \right] \left\{ K'_j \right\} \quad (A-16)$$

Since the total normal velocity must be zero, $(VN)_m$ must be equal to the negative of the normal velocity induced by the free vortices and the source-sink cylinder. Denoting this quantity by VIN (velocity inward normal), Equation A-16 becomes

$$\left\{ VIN_m \right\} = \left[a_{mj} \cos \theta_m + b_{mj} \sin \theta_m \right] \left\{ K'_j \right\} \quad (A-17)$$

One additional equation is required to govern the total circulation represented by the stationary vortices (condition of constant circulation). This is accomplished by having an additional stationary vortex, K_c , within the body, say at the center. The magnitude of K_c is such that

$$K_c + K_j = -(KR) \quad (A-18)$$

where

the index, j , is summed over the stationary vortices (KR) is the sum of all free vortices generated by the finite element body.

Incorporating this equation into A-17 the last term of $\{VIN_m\}$ will now contain $(-KR)$, the last term in $\{K_j\}$ will contain K_c , and the matrix of coefficients in Equation A-17 will be expanded to include an additional row of unit values, including the diagonal term, and an additional column of coefficients for a vortex at center. Defining this final matrix of coefficients by $\{VON\}$, velocity outward normal, Equation A-17 becomes

$$\{VIN_m\} = \{VON_{mj}\} \{K'_j\} \quad (A-19)$$

Strengths of the stationary vortices are determined by the inverse of Equation A-19.

The matrix of coefficients, A_{mj} is seen to depend only upon the geometry of stationary vortices representing the body, hence needs to be determined and inverted only once for a given body. In the finite scheme of solution, the strengths of these stationary vortices are solved by matrix multiplication of $\{A_{mj}\}^{-1}$ with the instantaneous values of $\{VIN_m\}$.

AII. MAIN PROGRAM (VSTV)

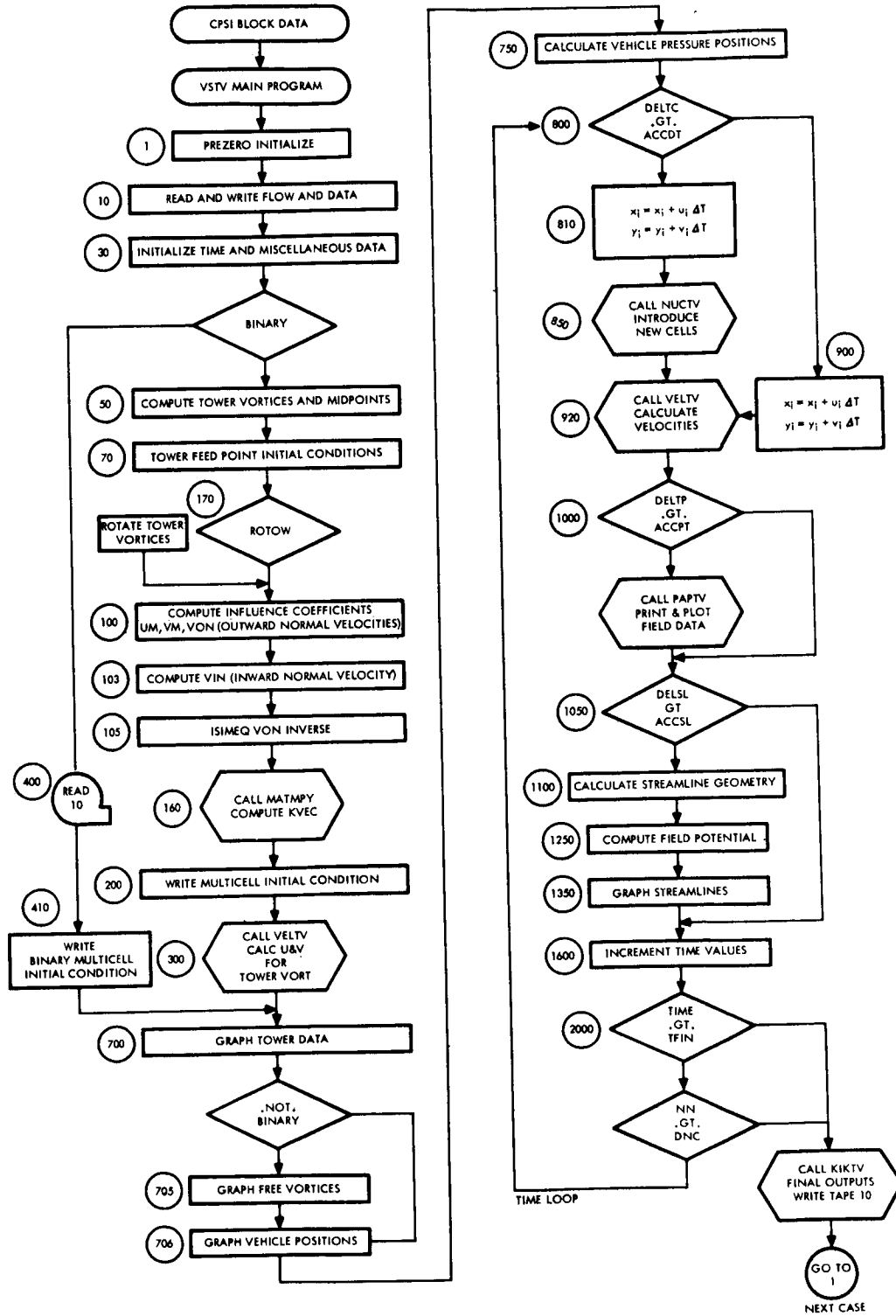
The VSTV program computes the vortex field around the vehicle and tower as assembled on the launch pad. This field is defined by x and y locations, u and v velocities and k, strengths, of the fixed and free vortices as the field grows in time. Within the time loop, the subroutines presented in Section AIII are called. The flow chart of the main program is presented in Section AII. 1.

VSTV is a Fortran G program for the channelled IBM 360-40 and IBM 360-65 computing system. A peripheral system, SC 4020 Optical Plotter, reads magnetic tape output and produces graphic data. The obvious application of this combination is the rapid production of tabulated data and labeled graphs which for this analysis is essential.

The input data allows control of the streamline computation and both printed and graphic output data. Machine run time is dependent upon the frequency of the requested output data relative to the growth of the field. The block data are items which change infrequently and are itemized in Section AII. 2. The input data are defined in Section AII. 3. 1 and a sample case set up in Section AII. 3. 2.

The program is terminated by either of two conditions controlled by input variables DNC, desired number of cells in field, or TFIN, final time. Both tests call subroutine KIKTV which writes terminating case data on

AII. 1 VSTV Functional Flow Chart



Fortran logical tape 10, calls PAPTIV for last computed output. The main program then returns to a read statement for next case input data which is the normal exit.

AII. 2 Block Data

The block data, CPSI, sets up the labels for the streamline graphs in BCD, the distribution of the y values for the field potential calculation as YSIP, and the SC 4020 character symbols for the streamline graphs, KSYM. The YSIP would vary if the graph margins are changed. The program is limited to 24 streamlines, the characters O and X being omitted.

AII. 3 Input Data

AII. 3.1 Data Definition

The input data consist of two standard Fortran G namelist arrays, FLOW and DATA. The FLOW data control the logical decisions throughout the program and consist of two items:

BINARY = F for the TIME = 0.0 case

= T for the restart case (Tape 10 data read)

ROTOW = F for the tower positioned upstream from the vehicle

= T for the tower rotated around vehicle center.

The program sets both values to false; hence, only true values need to be included in input data. However, the namelist cards FLOW and END must be in data set when both false.

The DATA namelist array is defined as follows:

TIME = 0.0 for BINARY = False case
Omit for BINARY = T case (TIME input from Tape 10)

DELTC Incremental time of new vortices

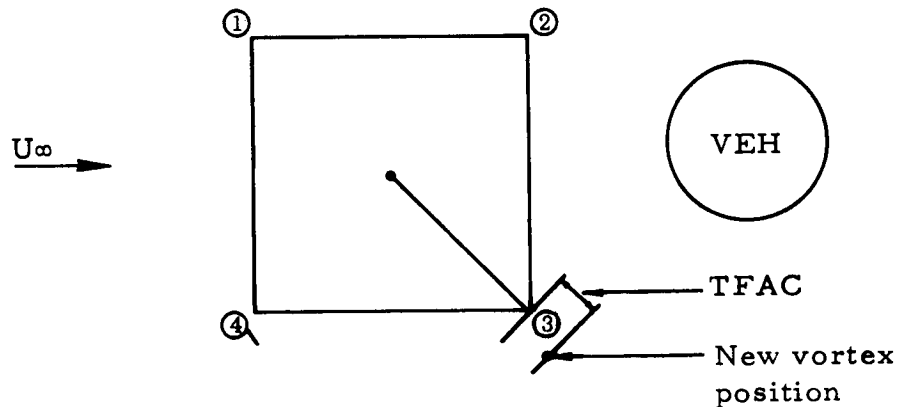
CONKC Constant to compute delta time (DELTA = CONKC * DELTC)

DELTP Time increment to print and graph data

TFIN Time to terminate run

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DELSL	Time increment to compute streamlines
DNC	Total number of vortices to be calculated (run terminates on either DNC or TFIN)
RØT	Angle of tower rotation (deg)
TFAC	Factor to generate tower feed points
TFP1	First tower feed point equal to position number (see sketch)
TFP2	Second tower feed point equal to position number (see sketch)



XUL	Tower position (x upper left)
YUL	Tower position (y upper left)
NXR	Number of tower points (x side)
NYR	Number of tower points (y side)
XREC	Length of tower x side
YREC	Length of y side (vehicle radius = unity)
NPHAF	Number of points on semi-cylinder
UTOP	Maximum velocity to pressure calculation test
CONST	Vehicle feed point height

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XXL	Graph left margin
XR	Graph right margin
YB	Graph bottom margin
YT	Graph top margin
CASENO	Case number in form XXXX.XX (date)
XINIT	Streamline initial X location
XINC	Streamline delta X
NXS	Streamline number of X values
NYS	Streamline number of Y values

AII. 3.2 Sample Case

The input data and namelist FLOW and DATA arrays for the simple case follow.

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AII. 4 VSTV Listing, Main Program, Memory Map

E-LEVEL LINKAGE EDITOR OPTIONS SPECIFIED MAP,LIST
 ****MEMBER DOES NOT EXIST BUT HAS BEEN ADDED TO DATA SET

MODULE MAP

CONTROL SECTION			ENTRY						
NAME	ORIGIN	LENGTH	NAME	LOCATION	NAME	LOCATION	NAME	LOCATION	NAME
VSTV#	00	3362	VSTV	00					
\$ELANKCOM	3368	3E5C							
CFLOW	68C8	E							
CINIT	68C0	AC							
CTIMES	6C80	3E							
CGFA	6C88	F7C							
CIF	7C38	2C							
CPSI	7C58	2B5E							
CTCW	A780	D33C							
CCYL	17AE0	1C5E							
CRCT	18B38	32C							
NUCTV#	18E58	15EE	NLCTV	18E58					
SCCUTV# *	1A3C0	2AE	SCOLTV	1A430	SCRTV	1A54C			
KIKTV#	1A668	32C	KIKTV	1A668					
MATMPY#	1A988	324	MATMPY	1A988					
VELTV#	1AC80	62E	VELTV	1AC80					
PAFTV#	1B2C8	5FC	PAPTV	1B2D8					
TLOOK1#	1B858	47C	TLOOK1	1B858					
H-CUR#	1BCC8	244	HOLR	1BCD8					
SMRCRT *	1BF20	CE							
SCBUFV	1BFEB	E4							
NHCAWAA *	1C070	E4D	FRAMEV	1C070	RESETV	1C088	CAMRAV	1C208	IDFRM# 1C2AA
CTAPEV *	1C8C0	4							
I-CFCOMM*	1C8C8	FFD	IBCOM#	1C8C8	FDICCS#	1C984			
INCTRCH *	1C8C8	27E							
I-CNAMEL*	1DB40	8A2	FRDNL#	1DB40	FWRNL#	1E0C8			
CCSD# *	1E3E8	26A	COSD	1E428	SIND	1E51C			
ATAND# *	1E658	17E	ATAND	1E668					
I-CIBER**	1E7C8	CE	IBERH#	1E7D8					
ISIMEQ# *	1E8A8	E44	ISIMEQ	1E928	IDETRM	1E884			
GRIC1V# *	1F0F0	8C2	GRID1V	1F1E0					
APRNTV# *	1FBFB	21C	APRNTV	1FC28					
N-CAWAP *	1FE08	EE	PRINTV	1FE08					
APLOTV# *	1FEF0	3F4	APLCTV	1FF40					
NXV# *	202E8	3B4	NXV	20328	IXV	20438	NYV	2040C	IYV 20558
LABELV# *	206A0	5AA	LABELV	20760					
I-CSSQRT*	20C50	AC							

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NAME	ORIGIN	LENGTH	NAME	LOCATION	NAME	LOCATION	NAME	LOCATION	NAME
IFCSLOC *	20D00	1CC	SORT	20C50					
IFCFMAXR*	20E10	CS	ALOGIC	20D00	ALCG	20E1C			
IFCAWCE *	20EE0	BC	MAXI	20E10	MINI	20E26	AMAX1	20E3C	AMINI 20E52
IFCAWEO *	20F90	4AE	CLOCK	20EE0					
IFCAWEP *	21438	14E	C4C2CV V4C2CV	20F90 211D4	T4020V	20FEB	P4020V	2107C	A4020V 21130
IFCAWEN *	21580	254	TRANSV	21438	TRANSC	21480			
IFCAWAC *	217C8	13C	X4C2CV	21580	ENDIOV	2163A			
IFCFCVTH*	21908	FF3	CLTRV	217D8	CUTIV	21844			
IFCAWER *	22900	35E	ADCON# FCVIO	21908 21E90	FCVZC FCVEC	21A54 22334	FCVAD FCVCO	21AFA 2252E	FCVLO 21B82
IFCUATBL*	22C58	2CE	FIOCS#	22900					
IFCUOPTN*	22E60	E							
IFCSSCN *	22F68	1C4	IHCLOPT	22E60					
IFCAWCC *	22F70	5C	COS	22E68	SIN	22E84			
IFCSATN2*	22FC0	16D	ARGO	22F70					
IFCFOVER*	23130	5C	ATAN2	22FC0	ATAN	22FCA			
IFCAWAO *	23180	CE	OVERFL	23130					
LINRV# *	23248	814	SCERRV	23180	SCERV	231A6	SERREV	231DC	SERSAV 23206
XSCALV# *	23A60	36C	LINRV	23320					
IFCAWAI *	23DC0	5C	XSCALV	23AA0	YSCALV	23BFF			
ACNLNV# *	23E50	5DC	STOPTV	23DC0					
ERRLV# *	24420	35E	NONLV	23F00					
ERRNLV# *	24788	32C	ERRLV	24490					
BRITV# *	24A88	162	ERRNLV	24810					
FLCTV# *	24C50	14E	BRITEV	24B08	FAINTV	24BE4			
IFCAWBN *	24D98	2E	PLOTV	24C68					
YMCDV# *	24DC8	FA	HOLLV	24D98					
XMCDV# *	24EC8	FA	YMODV	24DD0					
IFCAWFC *	24FC8	11E	XMODV	24ED0					
BNBCDV# *	250E0	372	INSERT	24FC8					
IFCFIOSM*	25458	CF2	BNBCDV	25150					
VXAXV# *	26150	254	FIOCS#	25458					
IFCFRXP1*	263E8	54	VXAXV	26180	VYAXV	262F0			
ERMVK# *	26480	124	FRXPT#	263E8					
			ERMVKV	264A0					

ENTRY ADDRESS CO
TOTAL LENGTH 265A4

AII.5 VSTV Listing, Main Program

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C MAIN PROGRAM - VORTEX STUDY TOWER AND VEHICLE VSTV0010
C NORTH AMERICAN ROCKWELL,SPACE DIV. 190-200 J.E.DAVIS X1230 VSTV0020
C VSTV0030
C VSTV0040
C PROGRAM EXITS ON READ FOR NEXT CASE VSTV0050
C VSTV0060
C FLOW DEFINITION VSTV0070
C BINARY TRUE FOR CASE TO READ BINARY INPUT VSTV0080
C FALSE FOR INITIALIZING NEW CASE VSTV0090
C VSTV0100
C ROTOW TRUE FOR TOWER ROTATION CASE VSTV0110
C FALSE FOR TOWER DOWNSTREAM OF VEHICLE VSTV0120
C VSTV0130
C DATA DEFINITION VSTV0140
C TIME TIME = 0.0 FOR NEW CASE VSTV0150
C DELTC INCREMENTAL TIME OF NEW VORTEX VSTV0160
C CONKC CONSTANT TO COMPUTE DELTA TIME VSTV0170
C (DELT = CONKC * DELTC) VSTV0180
C DELTP TIME INCREMENT TO GRAPH AND PRINT DATA VSTV0190
C TFIN TIME TO TERMINATE RUN VSTV0200
C DELSL TIME INCREMENT TO COMPUTE STREAMLINES VSTV0210
C DNC TOTAL NUMBER OF VORTICES TO BE CALCULATED VSTV0220
C (RUN TERMINATES ON EITHER DNC OR TFIN) VSTV0230
C ROT ANGLE(DEG) OF TOWER ROTATION VSTV0240
C TFAC FACTOR TO GENERATE TOWER FEED POINTS VSTV0250
C TFP1 TOWER FEED POINT (UPPER LEFT) VSTV0260
C TFP2 TOWER FEED POINT (UPPER RIGHT) VSTV0270
C NPHAF NUMBER OF POINTS ON SEMI CYLINDER VSTV0280
C UTOP MAXIMUM VELOCITY FOR TEST VSTV0290
C CONST VEHICLE FEED POINT HEIGHT VSTV0300
C XXL GRAPH LEFT MARGIN VSTV0310
C XR GRAPH RIGHT MARGIN VSTV0320
C YB GRAPH BOTTOM MARGIN VSTV0330
C YT GRAPH TOP MARGIN VSTV0340
C CASENO CASE NUMBER IN FORM XXXX.XX (DATE) VSTV0350
C XUL TOWER POSITION - X UPPER LEFT VSTV0360
C YUL TOWER POSITION - Y UPPER LEFT VSTV0370
C NXR NUMBER OF TOWER POINTS (X SIDE) VSTV0380
C NYR NUMBER OF TOWER POINTS (Y SIDE) VSTV0390
C XREC LENGHT OF TOWER X SIDE VSTV0400
C YREC LENGHT OF TOWER Y SIDE VSTV0410
C (VEHICLE RADIUS = UNITY) VSTV0420
C XINIT STREAMLINE INITIAL X LOCATION VSTV0430
C XINC STREAMLINE DELTA X VSTV0440
C NXS STREAMLINE NUMBER OF X VALUES VSTV0450
C NYS STREAMLINE NUMBER OF Y VALUES VSTV0460
C NAN NUMBER OF ANEMOMETER DATA POINTS VSTV0470
C XAN X ANEMOMETER LOCATION VSTV0480
C YAN Y ANEMOMETER LOCATION VSTV0490
C VSTV0500
C INTEGER *4 (A(50) VSTV0510
C INTEGER DNC,TFP1,TFP2 VSTV0520
C LOGICAL BINARY,ROTOW VSTV0530
C REAL KVEC,KSUM VSTV0540
C DOUBLE PRECISION VOND(50,50),DUNIT(50,50),DFSC(21),DET,SCALE VSTV0550
C * ,VIND(50) VSTV0560
C VSTV0570
C COMMON NN, NT,HEX, B(400,9) ,NEX1,NEX2,NBEG,PI4 VSTV0580
C COMMON /CFLOW/BINARY,ROTOW VSTV0590
C COMMON /CINIT/XTF(4),YTF(4), XC(10),YC(10),TFP1,TFP2 VSTV0600
C * ,XHAV,YHAV,GAM ,PHI(4),SINP(4),COSP(4) VSTV0610

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COMMON /CTIMES/TIME,DELT,DELTC,DELTP,ACCDT,ACCP,TFIN,DNC,CONKCVSTV0620
* ,TPO,TCO,TSO,ACCSL,DELSL VSTV0630
COMMON /CGRA/ DXGRA,DYGRA,NGRA,MGRA,LABX,LABY VSTV0640
* ,XXL,XR,YB,YT VSTV0650
* ,XL( 200 ),XU( 200 ),YL( 200 ),YU( 200 ) VSTV0660
* ,CX(45),CYU(45),CYL(45),CXN(45),CASEND VSTV0670
COMMON/CIP/ NXR,XREC, NYR,YREC ,NXS,NYS ,XUL,YUL VSTV0680
COMMON/CPSI/KSYM(24),BCD(24),XS(100),YS(26,100),YSIP(26) VSTV0690
C VSTV0700
COMMON/DBL/ VOND,DUNIT,DFSC,VIND VSTV0710
COMMON/CTOW/ VSTV0720
* XM( 50), YM( 50), PAR(2), YAR(2), KOUNT(26) VSTV0730
* ,PSI(26,100), YSII(100), XSII(100),NNARY(30) VSTV0740
* ,STH(100), CTH(100), VIN( 50),VINCK(50) VSTV0750
* ,UM( 50, 50), VM( 50, 50) VSTV0760
* ,VON( 50, 50), UNIT( 50, 50) VSTV0770
* ,IDUMA(21),TFPX(2),TFPY(2),TFRAD1,TFRAD2 VSTV0780
* ,KVEC(50), XV(50), YV(50) ,THSIDE(50) VSTV0790
C VSTV0800
COMMON/CCYL/ XCPRES(105),YCPRES(105),NPCIR,UTOP,CONST VSTV0810
* ,UCYL(105),VCYL(105),SINCYL(105),TANVEL(105) VSTV0820
* ,UABS(105),INDX(105), INDXFP(3) VSTV0830
* ,UFP(50),VFP(50), UNORM(50),VNORM(50) VSTV0840
COMMON/CROT/ RXV(50), RYV(50), RXM(50), RYM(50) VSTV0850
COMMON/ANEM/NAN,ROT,XAN(10),YAN(10),RXAN(10),RYAN(10), VSTV0860
* ANRAD(10),AZAN(10),UAN(10),VAN(10),SPEED(10),AZSH(10) VSTV0870
DIMENSION ITH(400,1), X(400,1), VSTV0880
* Y(400,1), U(400,1), VSTV0890
* V(400,1), AUK(400,1), VSTV0900
* ARAD(400,1) VSTV0910
C VSTV0920
EQUIVALENCE(B(1,1),ITH(1,1)), (B(1,2),X(1,1)), VSTV0930
* (B(1,3),Y(1,1)), (B(1,4),U(1,1)), VSTV0940
* (B(1,5),V(1,1)), (B(1,6),AUK(1,1)), VSTV0950
* (B(1,7),ARAD(1,1)) VSTV0960
C VSTV0970
NAMELIST /FLOW/BINARY,ROTOW VSTV0980
C VSTV0990
NAMELIST/DATA/ TIME,DELTC,CONKC,DELTP,TFIN,DELSL,DNC VSTV1000
* ,ROT, TFAC,TFP1,TFP2, NPHAF,UTOP,CONST VSTV1010
* ,XXL,XR,YB,YT,CASEND VSTV1020
* ,NXR,XREC, NYR,YREC, XUL,YUL VSTV1030
* ,XINIT,XINC, NXS,NYS VSTV1040
* ,NAN,XAN,YAN VSTV1050
C VSTV1060
C VSTV1070
CALL SCOUTV VSTV1080
CALL CAMRAV(9) VSTV1090
C VSTV1100
TPO = .000001 VSTV1110
TCO = .000001 VSTV1120
TSO = .000001 VSTV1130
PI4 = 4. * 3.14159 VSTV1140
C VSTV1150
DXGRA = 2.0 VSTV1160
DYGRA = 2.0 VSTV1170
NGRA = -1 VSTV1180
MGRA = -1 VSTV1190
LABX = -1 VSTV1200
LABY = -1 VSTV1210
C VSTV1220
I DO 2 I= 1,50 VSTV1230
XM(I) = 0.0 VSTV1240
YM(I) = 0.0 VSTV1250

```

	XV(I) = 0.0	VSTV1260
	YV(I) = 0.0	VSTV1270
	RXV(I) = 0.0	VSTV1280
	RYV(I) = 0.0	VSTV1290
	RXM(I) = 0.0	VSTV1300
	RYM(I) = 0.0	VSTV1310
	KVEC(I) = 0.0	VSTV1320
	VIN(I) = 0.0	VSTV1330
	VIND(I) = 0.0 DO	VSTV1340
	UFP(I) = 0.0	VSTV1350
	VFP(I) = 0.0	VSTV1360
	UNORM(I) = 0.0	VSTV1370
	VNORM(I) = 0.0	VSTV1380
	IA(I) = 0	VSTV1390
C		VSTV1400
	DO 2 J = 1,50	VSTV1410
	UM(I,J)=0.0	VSTV1420
	VM(I,J)=0.0	VSTV1430
	VON(I,J)=0.0	VSTV1440
	VOND(I,J) = 0.0 DO	VSTV1450
	2 CONTINUE	VSTV1460
C		VSTV1470
	DO 3 I = 1,105	VSTV1480
	XCPRES(I) = 0.0	VSTV1490
	YCPRES(I) = 0.0	VSTV1500
	UCYL(I) = 0.0	VSTV1510
	VCYL(I) = 0.0	VSTV1520
	SINCYL(I) = 0.0	VSTV1530
	TANVEL(I) = 0.0	VSTV1540
	UARS(I) = 0.0	VSTV1550
	INDX(I) = 0.0	VSTV1560
	3 CONTINUE	VSTV1570
C		VSTV1580
	DO 4 I=1,100	VSTV1590
	ITH(I,1)=0.0	VSTV1600
	XS(I) = 0.0	VSTV1610
	YSII(I) = 0.0	VSTV1620
	XSII(I) = 0.0	VSTV1630
	STH(I) = 0.0	VSTV1640
	CTH(I) = 0.0	VSTV1650
	DO 4 J=1,26	VSTV1660
	PSI(J,I) = 0.0	VSTV1670
	YS(J,I) = 0.0	VSTV1680
	4 CONTINUE	VSTV1690
	DO 6 J=1,9	VSTV1700
	DO 6 I=1,400	VSTV1710
	6 B(I,J) = 0.0	VSTV1720
C		VSTV1730
	BINARY = .FALSE.	VSTV1740
	ROTOW = .FALSE.	VSTV1750
	ROT = 0.0	VSTV1760
C		VSTV1770
		VSTV1780
10	READ(5, FLOW)	VSTV1790
	READ(5, DATA)	VSTV1800
	WRITE(6,11)CASENO	VSTV1810
11	FORMAT (1H1,42X 26HVEHICLE - TOWER ANALYSIS/1H ,43X,	VSTV1820
	* 23HVIRTEX SHEDDING MODEL 6/1H ,45X9HCASE ,F10.2)	VSTV1830
	WRITE (6,12) BINARY,ROTOW	VSTV1840
12	FORMAT (1H0, 24X, 'BINARY' L5, 34X, 'ROTOW' L5 ,/)	VSTV1850
	WRITE (6,20) TIME,DELTC,CONKC,DELTP,TFIN,DELSL,DNC,	VSTV1860
	* ROT,TFAC,TFP1,TFP2,XUL,YUL,NXR,XREC,NYR,YREC,	VSTV1870
	* NPHAF,UTOP,CONST,	VSTV1880
	* CASENO, XXL,XR,YB,YT	VSTV1890
	WRITE(6,21) XINIT,XINC,NXS,NYS	VSTV1900
	WRITE (6,22) NAN,(XAN(I),YAN(I), I = 1,NAN)	

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```

C
20 FORMAT (1H , 24X, 'TIME DATA' /
* 35X, 'TIME ' F10.3, 20X, 'DELTC' F10.3 /
* 35X, 'CONKC' F10.3, 20X, 'DELTP' F10.3 /
* 35X, 'TFIN ' F10.3, 20X, 'DELSL' F10.3 /
* 35X, 'DNC ' 110 /
* 25X, 'TOWER DATA' /
* 35X, 'ROT ' F10.3, 20X, 'TFAC ' F10.3 /
* 35X, 'TFP1 ' 110 , 20X, 'TFP2 ' 110 /
* 35X, 'XUL ' F10.3, 20X, 'YUL ' F10.3 /
* 35X, 'NXR ' 110 , 20X, 'XREC ' F10.3 /
* 35X, 'NYR ' 110 , 20X, 'YREC ' F10.3 /
* 25X, 'VEHICLE DATA' /
* 35X, 'NPHAF' 110 , 20X, 'UTOP ' F10.3 /
* 35X, 'CONST' F10.3 /
* 25X, 'GRAPH DATA' /
* 35X, 'CASENO' F 9.3, 20X /
* 35X, 'XXL ' F10.3, 20X, 'XR ' F10.3 /
* 35X, 'YB ' F10.3, 20X, 'YT ' F10.3 )
21 FORMAT(1H , 24X, 'STREAMLINE DATA' /
* 35X, 'XINIT' F10.3, 20X, 'XINC ' F10.3 /
* 35X, 'NKS ' 110 , 20X, 'NYS ' 110)
22 FORMAT (1H , 24X, 'ANEMOMETER DATA' /
* 35X, 'NAN ' 110 /
* 35X, 'XAN ' 15X, 'YAN' / (30X, F10.2, 10X, F10.2))
WRITE (6,51)
51 FORMAT (1H1)
C
C INITIALIZE
30 DELT= CONKC*DELTC
ACCDT=TCU + DELT
ACCPY=TPO +DELTC
ACCSL = TSO + DELT
NT= 2*NXR +2*NYR
NEX = NT+1
NREG = NT + 2
NEX1 = NEX +1
NEX2 = NEX +2
NN = NT + 1
C
C
DO 40 I = 1, NXR
THSIDE(I) = 90.
THSIDE(NXR + I) = 180.
THSIDE(NXR + NYR + I) = 270.
THSIDE(2*NXR + NYR + I) = 0.
40 CONTINUE
C
C STREAMLINE GEOMETRY
XS(1)= XINIT
DO 42 I = 2, NXS
42 XS(I)= XS(I-1)+XINC
C
C
DO 44 J=1, NXS
DO 44 I=1, NYS
44 YS(I,J)= YSIP(I)
C
C
IF(BINARY)GO TO 400
C
C VORTICES ON TOWER
50 XV(1)= XUL
YV(1)= YUL
NXRP = NXR+1
DO 52 I= 2, NXRP

```

VSTV1910
VSTV1920
VSTV1930
VSTV1940
VSTV1950
VSTV1960
VSTV1970
VSTV1980
VSTV1990
VSTV2000
VSTV2010
VSTV2020
VSTV2030
VSTV2040
VSTV2050
VSTV2060
VSTV2070
VSTV2080
VSTV2090
VSTV2100
VSTV2110
VSTV2120
VSTV2130
VSTV2140
VSTV2150
VSTV2160
VSTV2170
VSTV2180
VSTV2190
VSTV2200
VSTV2210
VSTV2220
VSTV2230
VSTV2240
VSTV2250
VSTV2260
VSTV2270
VSTV2280
VSTV2290
VSTV2300
VSTV2310
VSTV2320
VSTV2330
VSTV2340
VSTV2350
VSTV2360
VSTV2370
VSTV2380
VSTV2390
VSTV2400
VSTV2410
VSTV2420
VSTV2430
VSTV2440
VSTV2450
VSTV2460
VSTV2470
VSTV2480
VSTV2490
VSTV2500
VSTV2510
VSTV2520
VSTV2530

```

XV(I) = XV(I) + XREC * SINU( 90. * (I-1) /NXR) **2
52 YV(I)= YUL
C
NYRP = NYR +1
DO 54 I= 2,NYRP
N= NXR+I
XV(N)= XUL + XREC
54 YV(N) = YUL - YREC * SINU(90. * (I-1) /NYR) **2
C
DO 56 I=1,NXR
M= NXR +NYR+I
XV(M) = XV(NXR+2-I)
56 YV(M) = YUL-YREC
C
DO 58 I=1,NYR
J= NXR*2 +NYR+I
XV(J)= XUL
58 YV(J)= YV(NXR+2+NYR-I)
C
XV(NT+1)=XV(1)
YV(NT+1)=YV(1)
DO 64 I=1,NT
XM(I)=(XV(I)+ XV(I+1))/2.
64 YM(I)=(YV(I)+ YV(I+1))/2.
C
VORTICES AT TOWER CENTER
XV(NEX) = XUL + XREC/20.
YV(NEX) = YUL - YREC/4.
IF(YV(NEX) .LT. .0001 .AND. YV(NEX) .GT. -.0001) YV(NEX) = 0.0
C
IYMID = 1 + NYR/2
IYM2 = NXR + IYMID
IYM4 = 2*NXR + NYR +IYMID
YM(IYM2) = 0.0
YM(IYM4) = 0.0
C
TOWER FEED POINT INITIAL CELLS
70 XHAV = XREC/2.
YHAV = YREC/2.
TXHAV = TFAC * XHAV
TYHAV = TFAC * YHAV
CENX = XUL + XHAV
CENY = YUL - YHAV
XTF(1) = CENX - TXHAV
YTF(1) = CENY + TYHAV
XTF(2) = CENX + TXHAV
YTF(2) = CENY + TYHAV
XTF(3) = CENX + TXHAV
YTF(3) = CENY - TYHAV
XTF(4) = CENX - TXHAV
YTF(4) = CENY - TYHAV
C
XV(NEX1) =XTF(TFP1)
YV(NEX1) =YTF(TFP1)
XV(NEX2) =XTF(TFP2)
YV(NEX2) =YTF(TFP2)
C
GAM = ATAND(YHAV,XHAV)
PHI(1) = ROT + GAM
PHI(2) = ROT - GAM + 180.
PHI(3) = ROT + GAM + 180.
PHI(4) = ROT - GAM
VSTV2540
VSTV2550
VSTV2560
VSTV2570
VSTV2580
VSTV2590
VSTV2600
VSTV2610
VSTV2620
VSTV2630
VSTV2640
VSTV2650
VSTV2660
VSTV2670
VSTV2680
VSTV2690
VSTV2700
VSTV2710
VSTV2720
VSTV2730
VSTV2740
VSTV2750
VSTV2760
VSTV2770
VSTV2780
VSTV2790
VSTV2800
VSTV2810
VSTV2820
VSTV2830
VSTV2840
VSTV2850
VSTV2860
VSTV2870
VSTV2880
VSTV2890
VSTV2900
VSTV2910
VSTV2920
VSTV2930
VSTV2940
VSTV2950
VSTV2960
VSTV2970
VSTV2980
VSTV2990
VSTV3000
VSTV3010
VSTV3020
VSTV3030
VSTV3040
VSTV3050
VSTV3060
VSTV3070
VSTV3080
VSTV3090
VSTV3100
VSTV3110
VSTV3120
VSTV3130
VSTV3140
VSTV3150

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C	DO 72 I = 1,4	VSTV3160
	SINP(I) = SIND(PHI(I))	VSTV3170
	72 COSP(I) = COSD(PHI(I))	VSTV3180
C		VSTV3190
	IF (.NOT. ROTOW) GO TO 80	VSTV3200
C		VSTV3210
	ROTATION OF TOWER VORTICES (INCLUDING CENTER AND I.C.)	VSTV3220
C		VSTV3230
	74 NN2 = NM + 2	VSTV3240
	SI = SIND(ROT)	VSTV3250
	CS = COSD(ROT)	VSTV3260
	DO 75 I = 1,NN2	VSTV3270
	RXV(I) = XV(I) * CS + YV(I) * SI	VSTV3280
	RYV(I) = -XV(I) * SI + YV(I) * CS	VSTV3290
	RXM(I) = XM(I) * CS + YM(I) * SI	VSTV3300
	RYM(I) = -XM(I) * SI + YM(I) * CS	VSTV3310
	XM(I) = RXM(I)	VSTV3320
	YM(I) = RYM(I)	VSTV3330
	X(I,1) = RXV(I)	VSTV3340
	Y(I,1) = RYV(I)	VSTV3350
	75 CONTINUE	VSTV3360
	DO 78 I = 1,NAN	VSTV3370
	RXAN(I) = XAN(I) * CS + YAN(I) * SI	VSTV3380
	RYAN(I) = -XAN(I) * SI + YAN(I) * CS	VSTV3390
	XAN(I) = RXAN(I)	VSTV3400
	YAN(I) = RYAN(I)	VSTV3410
	78 CONTINUE	VSTV3420
C		VSTV3430
	GO TO 86	VSTV3440
C		VSTV3450
	80 CONTINUE	VSTV3460
	DO 82 I = 1,NM	VSTV3470
	X(I,1) = XV(I)	VSTV3480
	82 Y(I,1) = YV(I)	VSTV3490
C		VSTV3500
	86 TFPX(1) = X(NEX1,1)	VSTV3510
	TFPY(1) = Y(NEX1,1)	VSTV3520
	TFPX(2) = X(NEX2,1)	VSTV3530
	TFPY(2) = Y(NEX2,1)	VSTV3540
	TFRAD1 = TFPX(1)**2 + TFPY(1)**2	VSTV3550
	TFRAD2 = TFPX(2)**2 + TFPY(2)**2	VSTV3560
C		VSTV3570
	NTM = NT - 1	VSTV3580
	DO 90 I = 1, NTM	VSTV3590
	DENOM = SQRT((X(I+1,1)-X(I,1))**2 + (Y(I+1,1)-Y(I,1))**2)	VSTV3600
	CTH(I) = (Y(I+1,1) - Y(I,1)) / DENOM	VSTV3610
	90 STH(I) = (X(I+1,1)-X(I,1))/ DENOM	VSTV3620
	DENO = SQRT ((X(1,1) - X(NT,1))**2 + (Y(1,1) - Y(NT,1))**2)	VSTV3630
	CTH(NT) = (Y(1,1) - Y(NT,1)) / DENO	VSTV3640
	STH(NT) = (X(1,1) - X(NT,1))/ DENO	VSTV3650
C		VSTV3660
	DO 100 I=1,NT	VSTV3670
	DO 100 J=1,NEX	VSTV3680
	DENOM = (X(J,1) - XM(I))**2 + (Y(J,1) - YM(I))**2	VSTV3690
	DEN = X(J,1)**2 + Y(J,1)**2	VSTV3700
	XIM = X(J,1) /DEN	VSTV3710
	YIM = Y(J,1) /DEN	VSTV3720
	DENO = (XIM - XM(I))**2 + (YIM - YM(I))**2	VSTV3730
	UM(I,J) = -(Y(J,1) - YM(I)) /DENOM + (YIM - YM(I))/DENO	VSTV3740
	VM(I,J) = (X(J,1) - XM(I)) /DENOM - (XIM - XM(I))/DENO	VSTV3750
	VON(I,J) = -UM(I,J)*CTH(I) + VM(I,J)*STH(I)	VSTV3760
	100 CONTINUE	VSTV3770
	DO 102 J = 1,NEX	VSTV3780
	102 VON(NEX,J) = 1.0	VSTV3790

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```

410 FORMAT (1H1,25X,40H BINARY MULTICELL INITIAL CONDITION (CASE F10.4,VSTV4430
* 4H) ,13,2X,8HVORTICES) VSTV4440
450 WRITE (6,5020) VSTV4450
WRITE (6,5030)((B(I,J),J=1,6), I=1,NN) VSTV4460
C VSTV4470
500 CONTINUE VSTV4480
C CALCULATE CYLINDER VSTV4490
DDEG = 0. VSTV4500
DO 510 I = 1,45 VSTV4510
DDEG = DDEG + 2. VSTV4520
CX(I) = SIND(DDEG ) VSTV4530
CXN (I) = -CX(I) VSTV4540
CYU(I) = COSD(DDEG) VSTV4550
510 CYL (I) = -CYU(I) VSTV4560
C VSTV4570
700 CONTINUE VSTV4580
DO 702 I = 1,NEX VSTV4590
XL(I) = X(I,1) VSTV4600
702 YL(I) = Y(I,1) VSTV4610
C VSTV4620
CALL GRIDIV (-3, XXL,XR,YH,YT,DXGRA,DYGRA,NGRA,MGRA
* ,LABX,LABY,6,6) VSTV4630
CALL APRNTV (0, -13, 3,'Y/A', 4,500) VSTV4640
CALL PRINTV (3, 'X/A', 450,4) VSTV4650
CALL APLOTV( NEX, XL, YL, 1,1,1, 38,IERR) VSTV4660
C VSTV4670
TIME = DELT VSTV4680
701 IF( .NOT. BINARY) GO TO 706 VSTV4690
703 NIC = NN - NEX VSTV4700
C VSTV4710
DO 705 I=1,NIC VSTV4720
NTPI = NT + 1 + I VSTV4730
XL(I) = X(NTPI,1) VSTV4740
705 YL(I) = Y(NTPI,1) VSTV4750
CALL APLOTV( NIC, XL,YL, 1,1,1, 44,IERR) VSTV4760
C VSTV4770
706 CALL APLOTV( 45, CX , CYU, 1,1,1, 47, IERR) VSTV4780
CALL APLOTV( 45, CX , CYL, 1,1,1, 42, IERR) VSTV4790
CALL APLOTV( 45, CXN, CYU, 1,1,1, 42, IERR) VSTV4800
CALL APLOTV( 45, CXN, CYL, 1,1,1, 42, IERR) VSTV4810
WRITE (16 ,710 ) TIME , DELTC,CASENO VSTV4820
710 FORMAT (1H+,5X 'INITIAL VORTEX LOCATIONS AT TIME ='1F9.4,6X,15X6H VSTV4830
*ELTC=,1F9.4,9X,8H CASE NO.,2XF10.2) VSTV4840
C VSTV4850
CALL STREAM VSTV4860
C VSTV4870
NPCIR = NPHAF * 2 VSTV4880
FNPC = NPCIR VSTV4890
DEGI = 360./FNPC VSTV4900
C VSTV4910
DO 750 I= 1,NPCIR VSTV4920
DEG= (I-.5)* DEGI VSTV4930
XCPRES(I) = -COSD(DEG) VSTV4940
YCPRES(I) = SIND(DEG) VSTV4950
750 CONTINUE VSTV4960
C VSTV4970
800 IF(DELTC.GT.ACDDT)GO TO 900 VSTV4980
C VSTV4990
DO 810 I = NBEG,NN VSTV5000
X(I,1)= X(I,1) +U(I,1) *DELT VSTV5010
810 Y(I,1)= Y(I,1) +V(I,1) *DFLT VSTV5020
C VSTV5030
NEXT = NN+1 VSTV5040
VSTV5050

```

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```

NEX2 = NN+2
ACCDT = TCO
C
850 CALL NUCTV
GO TO 920
900 DO 910 I=NBEG,NN
X(I,1)= X(I,1) +U(I,1) *DELT
910 Y(I,1)= Y(I,1) +V(I,1) *DELT
920 CALL VELTV
C
1000 IF(DELT.P.GT.ACCPT)GO TO 1050
C
CALL PAPT
CALL HOUR
ACCPT =TPO
C
1050 IF(DELSL .GT. ACCSL) GO TO 1600
C
ACCSL = TSO
1100 CALL STREAM
C
1600 TIME= TIME + DELT
ACCDT= ACCDT + DELT
ACCPT= ACCPT + DELT
ACCSL = ACCSL + DELT
C
2000 IF(TIME.GT.TFIN) GO TO 4000
3000 IF(NN.GT.DNC)GO TO 4000
GO TO 800
C
4000 CONTINUE
CALL KIKTV
CALL STREAM
C
GO TO 1
C
5000 FORMAT (1H-,5X,8HVORTICES,12X,3HX/A,17X,3HY/A,17X,1HK ,//)
5010 FORMAT (1H ,8X,14,1P3E20.7)
5020 FORMAT (1H-,4X8HVORTICES,3X,3HX/A,15X,3HY/A,15X,7HU/U INF,11X,
* 7HV/U INF,11X,7HK/U*A ,//)
5030 FORMAT (1H ,6X,14,2X,1P5E18.7)
END
/*
/*
/*
VSTV5060
VSTV5070
VSTV5080
VSTV5090
VSTV5100
VSTV5110
VSTV5120
VSTV5130
VSTV5140
VSTV5150
VSTV5160
VSTV5170
VSTV5180
VSTV5190
VSTV5200
VSTV5210
VSTV5220
VSTV5230
VSTV5240
VSTV5250
VSTV5260
VSTV5270
VSTV5280
VSTV5290
VSTV5300
VSTV5310
VSTV5320
VSTV5330
VSTV5340
VSTV5350
VSTV5360
VSTV5370
VSTV5380
VSTV5390
VSTV5400
VSTV5410
VSTV5420
VSTV5430
VSTV5440
VSTV5450
VSTV5460
VSTV5470

```


AIII. SUBROUTINES

All subroutines are Fortran G subroutines called without arguments. The communication between the main program, VSTV, and the subroutines is controlled by blank and several labeled commons. Use of the subroutines is shown in the main program flow chart, Section AII. 1.

AIII. 1 NUCTV (New Cell) Subroutine

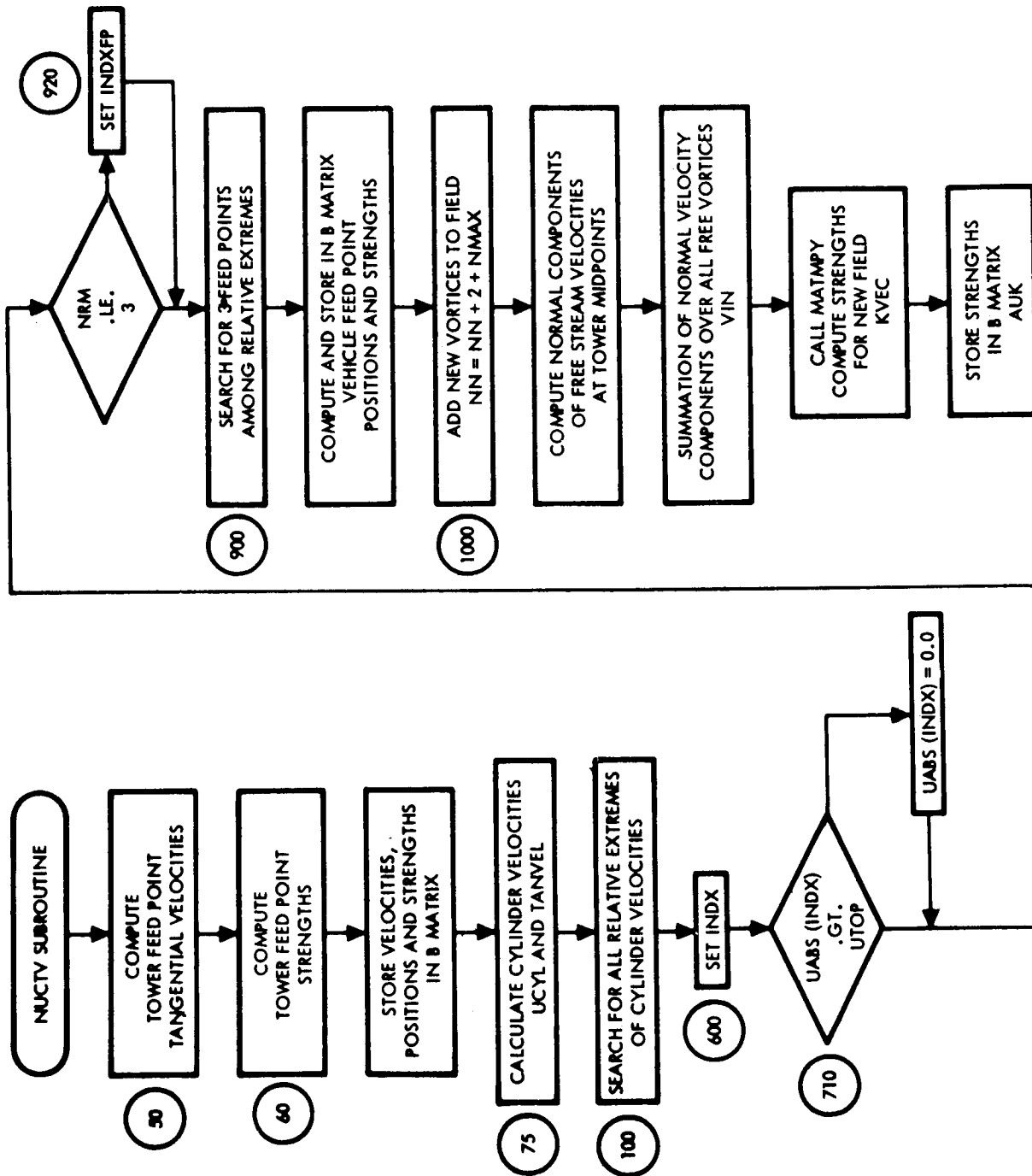
The NUCTV subroutines introduced the new vortices into the field when the ACCDT which is incremented by DELT exceeds the input DELTC, incremental time of new vortices.

Two tower vortices are introduced at the selected input tower feed points, TFP1 and TFP2 as described in data definition, Section AII. 3. 1. TFAC is percentage increment of the line intersecting tower center and corner to calculate the positions of new vortex introduction. The subroutine calculates the tower feed point velocities and positions and the inward normal velocity vector, VIN which, when multiplied by the VON, outward normal velocity influence coefficient matrix, yields the strength, AUK, of the tower vortices.

One to three new vortices are introduced on the vehicle per feed time depending upon the relative extremes of vehicle tangential velocities. The input value UTØP is a limiting value for the tangential velocities to avoid local extreme values. The input value of NPHAF determines the number of points where velocities are calculated.

The flow chart and listing of NUCTV follow.

III. 1. 1 Flow Chart of NUCTV



AHL 1.2 Listing of NUCTV

```

FORTRAN IV G LEVEL 0, MOD 0          NUCTV          DATE = 68040          00/59/27

0001      SUBROUTINE NUCTV
0002      REAL KVFC,KSUM
0003      INTEGER DNC,TFP1,TFP2
0004      COMMON      NN, NT,NEX,  B(400,9) ,NEX1,NEX2,NBEG,PI4
0005      COMMON      /CFLOW/BINARY,ROTOR
0006      COMMON      /CINIT/XTF(4),YTF(4),  XC(10),YC(10),TFP1,TFP2
*          ,XHAV,YHAV,GAM  ,PHI(4),SINP(4),COSP(4)
0007      COMMON      /CTIME/TIME,DELT,DELTC,DELTG,ACCDT,ACCPY,TFIN,DNC,CONKCKT2M1070
*          ,TPO,TCO,TSO,ACCSL,DELSL
0008      COMMON/CROW/
*          XM( 50),  YM( 50),  PAR(2),  YAR(2),  KOUNT(26)
*          ,PSI(26,100),  YSII (100),  XSII(100),NNARY(30)
*          ,STH(100),  CTH(100),  VIN( 50),VINCK(50)
*          ,UM( 50, 50),  VM( 50, 50)
*          ,VONI 50, 50),  UNIT( 50, 50)          00000350
*          ,IDJMA( 21),TFPX(2),TFPY(2),TFRAD1,TFRAD2
*          ,KVEC(50),  XV(50),  YV(50),  THSIDE(50)
0009      COMMON/CCYL/ XCPRES(105),YCPRES(105),NPCIR,ITOP,CONST
*          ,KCYL(105),VCYL(105),SINCYL(105),TANVEL(105)
*          ,UABS(105),INDX(105),  INDXFP(3)
*          ,UFP(50),VFP(50),  UNORM(50),VNORM(50)

C
0010      DIMENSION ITH(400,1),  X(400,1),
*          Y(400,1),  U(400,1),
*          V(400,1),  AUK(400,1),
*          ARAD(400,1)

C
0011      EQUIVALENCE(B(1,1),ITH(1,1)),  (B(1,2),X(1,1)),
*          (B(1,3),Y(1,1)),  (B(1,4),U(1,1)),
*          (B(1,5),V(1,1)),  (B(1,6),AUK(1,1)),
*          (B(1,7),ARAD(1,1))

C
C
C          TOWER F.P. VELOCITIES
0012      DO 50 J = NEX1,NEX2
0013      M = J - NN
C          FREE STREAM
0014      XVSQ = TFPX( M)**2
0015      YVSQ = TFPY( M)**2
0016      ADEN = (XVSQ + YVSQ) **2

0017      UFP(M) = 1. -(XVSQ - YVSQ)/ADEN
0018      VFP(M) =-2.*TFPX( M) * TFPY( M) /ADEN

C
0019      DO 50 I = 1,NN
0020      DEN = X(I,1)**2 + Y(I,1)**2
0021      XIM = X(I,1)/DEN
0022      YIM = Y(I,1)/DEN
0023      DX = X(I,1) - TFPX(M)
0024      DY = Y(I,1) - TFPY(M)
0025      DXI = XIM - TFPX(M)
0026      DYI = YIM - TFPY(M)
0027      DENOM = DX**2 + DY**2
0028      DENO = DXI**2 + DYI**2
0029      UFP(M) =UFP(M) +(-DY/DENOM + DYI/DENO) * AUK(I,1)
0030      VFP(M) =VFP(M) +(DX/DENOM - DXI/DENO) * AUK(I,1)
0031      UTANI = UFP( M) *COSP(TFP1) + VFP( M) *SINP(TFP1)

```

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```

FORTRAN IV G LEVEL 0, MOD 0          NUCTV          DATE = 68040          00/59/27
0032      UTAN2 = UFP (M) *COSP(TFP2)+ VFP (M) *SINP(1+P2)
0033      AUK(NN+1,1) = UTAN1 * ABS(UTAN1) * DELTC/ PI4
0034      AUK(NN+2,1) = UTAN2 * ABS(UTAN2) * DELTC/ PI4
0035      VIN(NEX) = VIN(NEX) -AUK(NN+1,1) - AUK(NN+2,1)
0036      X(NN+1,1) = TFPX(1)
0037      Y(NN+1,1) = TFPY(1)
0038      ARAD(NN+1,1) = TFRAD1
0039      X(NN+2,1) = TFPX(2)
0040      Y(NN+2,1) = TFPY(2)
0041      APAD(NN+2,1) = TFRAD2
C          CALCULATE CYLINDER VELOCITIES
0042      DO 75 I=1,NPCIR
C          FREE STREAM
0043      XCSQ = XCPRES(J)**2
0044      YCSQ = YCPRES(J)**2
0045      ADEN = (XCSQ + YCSQ) **2
0046      UCYL(J) = 1. - (XCSQ - YCSQ)/ADEN
0047      VCYL(J) = -2. * XCPRES(J) * YCPRES(J) /ADEN
C
0048      DO 70 I = 1,NN
C          VORTICES
0049      DEN = Y(I,1)**2 + X(I,1)**2
0050      XIM = X(I,1)/DEN
0051      YIM = Y(I,1)/DEN
C
0052      DX = X(I,1) -XCPRES(J)
0053      DY = Y(I,1) - YCPRES(J)
0054      DXI = XIM - XCPRES(J)
0055      DYI = YIM - YCPRES(J)
0056      DENOM = DX**2 + DY**2
0057      DENI = DXI**2 + DYI**2
0058      70 UCYL(J) = UCYL(I) + (-DY/DENOM +DYI/DENI) * AUK(I,1)
0059      75 TANVEL(J) = UCYL(J)/YCPRES(J)
C
C          SEARCH FOR ALL RELATIVE EXTREMES OF CYLINDER VELOCITIES
0060      DO 100 I= 1,NPCIR
0061      100 UABS (I) = ABS ( TANVEL(I) )
0062      NPM = 0
0063      IF(UABS(1) .GT. UABS(2) .AND. UABS(1) .GT. UABS(NPCIR))
C          *          GO TO 200
0064      GO TO 300
0065      200 NPM = 1
0066      INDX(NPM) = I
0067      300 IF(UABS(NPCIR) .GT. UABS(1) .AND. UABS(NPCIR) .GT. UABS(NPCIR-1))
C          *          GO TO 400
0068      GO TO 500
0069      400 NPM = NPM + 1
0070      INDX(NPM) = NPCIR
0071      500 CONTINUE
0072      NCM = NPCIR - 1
0073      DO 700 I= 2,NCM
0074      IF(UABS(I) .GT. UABS(I-1) .AND. UABS(I) .GT. UABS(I+1))
C          *          GO TO 600
0075      GO TO 700
0076      600 NPM = NPM + 1
0077      INDX(NPM) = I
0078      700 CONTINUE
C
C          SEARCH FOR 3 FEEDING POINTS AMONG THE REL EXTREMES
0079      IDVER = 0
0080      DO 710 I = 1,NPM
0081      IF(UABS(INDX(I)) .GT. UTOP) GO TO 705

```

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```

FORTRAN IV G LEVEL 2, MOD 0          NUCTV          DATE = 68040          00/59/27
0092          GO TO 710
0093          705 UARS(INDX(I)) = 0.0
0094          IOVER = IOVER + 1

0095          710 CONTINUE
0096          NRM = NRM - IOVER
0097          IF (NRM .EQ. 0) GO TO 760
0098          GO TO 750

C
0099          760 WRITE (6,761) NRM,(TANVEL(I), I=1,NPCIR)
0100          761 FORMAT (1H), 4X 'NRM IS ' 14, //
*           5X 'TANGENTIAL VELOCITIES ' // (5X, 5F20.4) )
0101          STOP

C
0102          750 NMAX = NRM
0103          NPM = NRM - 1
0104          IF (NRM .LE. 3) GO TO 920
0105          DO 900 I = 1,3

C
C           UTOP IS MAX VELOCITY LIMIT
0106          MAX = INDX (I)
0107          UABSJ = UARS (MAX)

C
0108          DO 805 J = 1, NRMM
0109          IF ( UARS ( INDX (J+1)) .GT. UABSJ ) GO TO 800
0110          GO TO 805
0111          800 MAX = INDX (J+1)
0112          UABSJ = UARS (MAX)
0113          805 CONTINUE

C
0114          INDXP(I) = MAX
0115          UARS(MAX) = 0.
0116          900 CONTINUE
0117          NMAX = 3
0118          GO TO 950

C
0119          920 KNT = 0
0120          NRMPI = NRM + IOVER
0121          DO 930 I = 1,NRMPI
0122          IF( UABS(INDX(I)) .EQ. 0.0) GO TO 930
0123          KNT = KNT + 1
0124          INDXP(KNT) = INDX(I)
0125          930 CONTINUE

C
0126          950 CONTINUE
0127          U1 = TANVEL(INDXP(1))
0128          DELR = CONST * ABS(U1) * DELTC
0129          NARG = INDXP(1)
0130          X(NN+3,1) = -(1. + DELR) * XCPRES(NARG)
0131          Y(NN+3,1) = (1.+DEL R) * YCPRES(NARG)
0132          AUK(NN+3,1) = U1 * ABS(U1) * DELTC / PI4
0133          ARAD(NN+3,1) = X(NN+3,1)**2 + Y(NN+3,1)**2
0134          IF(NMAX .LT. 2) GO TO 1000

C
0135          U2 = TANVEL(INDXP(2))
0136          DELR = CONST * ABS(U2) * DELTC
0137          NARG = INDXP(2)
0138          X(NN+4,1) = -(1. + DELR) * XCPRES(NARG)
0139          Y(NN+4,1) = (1. + DELR) * YCPRES(NARG)
0140          AUK (NN+4,1) = U2 * ABS(U2) * DELTC / PI4
0141          ARAD(NN+4,1) = X(NN+4,1)**2 + Y(NN+4,1)**2
0142          IF(NMAX .LT. 3) GO TO 1000

```

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FORTRAN IV G LEVEL 0, MOD 0

NUCTV

DATE = 68040

00/59/27

```

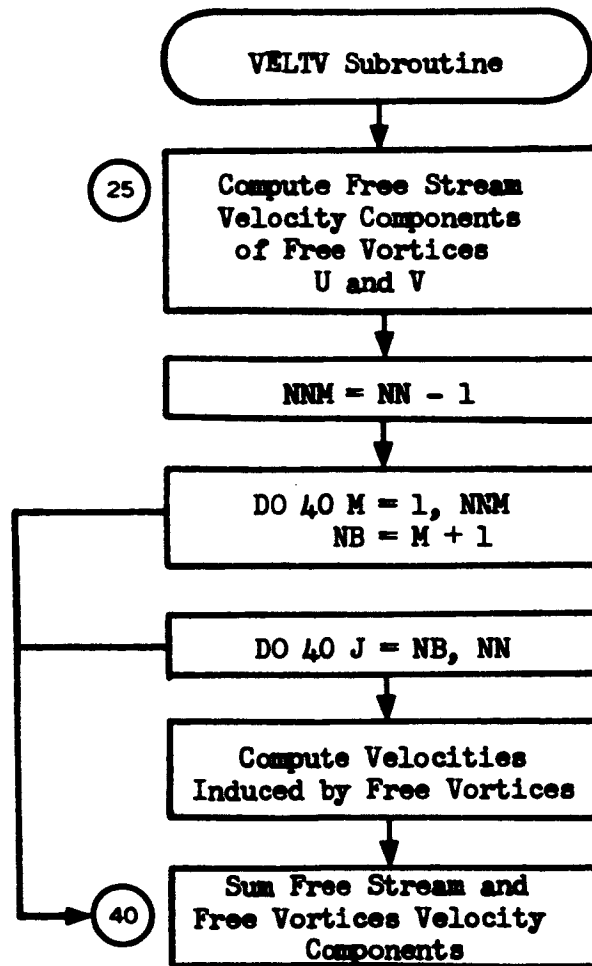
C
0133      U3 = TANVEL(INDXFP(3))
0134      DELR = CONST * ABS(U3) * DELTC
0135      NARG = INDXFP(3)
0136      X(NN+5,1) = -(1. + DELR) * XCPRES(NARG)
0137      Y(NN+5,1) = (1. + DELR) * YCPRES(NARG)
0138      AUK(NN+5,1) = U3 * ABS(U3) * DELTC / PI4
0139      APAD(NN+5,1) = X(NN+5,1)**2 + Y(NN+5,1)**2
0140      1000 NP1 = NN + 2 + NMAX
C
C      COMPUTE NORMAL COMPONENT OF VELOCITY AT EACH MIDPOINT
0141      DO 1030 J = 1,NT
C      INITIALIZE WITH FREE STREAM VALUES
0142      RESULT = XM(J)**2 + YM(J)**2
0143      ADEN = RESULT**2
0144      UNORM(J) = 1. - (XM(J)**2 - YM(J)**2) / ADEN
0145      VNORM(J) = -2. * XM(J) * YM(J) / ADEN
C      SUMMATION OVER ALL FREE VORTICES
0146      DO 1025 I = NREG,NN
0147      DEN = X(I,1)**2 + Y(I,1)**2
0148      XIM = X(I,1)/DEN
0149      YIM = Y(I,1)/DEN
0150      DX = Y(I,1) - YM(J)
0151      DY = X(I,1) - XM(J)
0152      DXI = XIM - XM(J)
0153      DYI = YIM - YM(J)
0154      DENIM = DX**2 + DY**2
0155      DENI = DXI**2 + DYI**2
0156      UNORM(J) = UNORM(J) + (-DY/DENIM + DYI/DENI) * AUK(I,1)
0157      VNORM(J) = VNORM(J) + (DX/DENIM - DXI/DENI) * AUK(I,1)
0158      1025 VIN(J) = UNORM(J)*CTH(J) - VNORM(J) * STH(J)
C
0159      CALL MATMPY(VCN,VIN,KVEC,NFX,NEX,1,50,50,1)
0160      KSUM = 0.0
0161      DO 1032 I = 1,NFX
0162      1032 KSUM = KSUM + KVEC(I)
C
C      PUT KVEC INTO A
0163      DO 1035 I = 1,NFX
0164      1035 AUK(I,1) = KVEC(I)
0165      RETURN
0166      END

```

AIII.2 VELTV (Velocities) Subroutine

The VELTV subroutine is called by the main program, VSTV, in the time-loop to compute free stream velocity components for all free vortices in the field and the velocities induced by the free vortices. The tower velocities are unnecessarily computed to take advantage of the symmetrical calculation.

AIII.2.1 Flow Chart of VELTV



AHL. 2.2 Listing of VELTV

FORTRAN IV G LEVEL 0, MOD 0 VELTV DATE = 68040 00/59/77

```

0001 SUBROUTINE VELTV
      C
      C      VELOCITY COMPUTATION IN TIME CYCLE      VSTV PROGRAM
0002 COMMON NN, NT, NEX, R(400,9), NEX1, NEX2, NBEF, PI4
0003 REAL NUJU, NUJV, NUMU, NUMV
      C
0004 DIMENSION X(400,1), Y(400,1), U(400,1), V(400,1), AUK(400,1)
      * , ARAD(400,1)
      C
0005 EQUIVALENCE(R(1,2), X(1,1)), (R(1,3), Y(1,1)),
      * (R(1,4), U(1,1)), (R(1,5), V(1,1)),
      * (R(1,6), AUK(1,1)), (R(1,7), ARAD(1,1))
      C
      C
      C      VELOCITY COMPUTATION FOR FREE VORTICES
0006 DO 25 I= NBEF, NN
0007 APAD(I,1) = X(I,1)**2 + Y(I,1)**2
0008 ADEN = APAD(I,1)**2
0009 BDEN = 1. - ARAD(I,1)
0010 U(I,1) = 1. - ((X(I,1)**2 - Y(I,1)**2) / ADEN) + AUK(I,1) * Y(I,1) / BDEN
0011 25 V(I,1) = -(2. * X(I,1) * Y(I,1) / ADEN) - AUK(I,1) * X(I,1) / BDEN
      C
      C
      C      VELOCITIES CALCULATED FOR TOWER VORTICES TO TAKE
      C      ADVANTAGE OF SYM. CALC.
0012 NNM = NN - 1
0013 DO 40 M = 1, NNM
0014 NR = M+1
0015 DO 40 J= NR, NN
0016 ARAD(M,1) = X(M,1)**2 + Y(M,1)**2
0017 DENOM = 1. - 2. * (X(J,1) * X(M,1) + Y(J,1) * Y(M,1))
      * + ARAD(J,1) * ARAD(M,1)
0018 ANY = Y(J,1) - Y(M,1)
0019 ANX = X(J,1) - X(M,1)
0020 FDN = ANX **2 + ANY ** 2
0021 NUJU = Y(M,1) - Y(J,1) * ARAD(M,1)
0022 NUJV = X(M,1) - X(J,1) * ARAD(M,1)
0023 NUMU = Y(J,1) - Y(M,1) * ARAD(J,1)
0024 NUMV = X(J,1) - X(M,1) * ARAD(J,1)
0025 U(J,1) = U(J,1) + AUK(M,1) * (NUJU / DENOM + ANY / FDN)
0026 V(J,1) = V(J,1) - AUK(M,1) * (NUJV / DENOM + ANX / FDN)
0027 U(M,1) = U(M,1) + AUK(J,1) * (NUMU / DENOM - ANY / FDN)
0028 40 V(M,1) = V(M,1) - AUK(J,1) * (NUMV / DENOM - ANX / FDN)
      C
0029 RETURN
0030 END
    
```

FORTRAN IV G LEVEL 0, MOD 0 VELTV DATE = 68040 00/59/77 PAGE 000

COMMON BLOCK /		/ MAP SIZE 3950							
SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LO
NN	0	NT	4	NEX	8	R	C	X	
Y	09C	U	120C	V	190C	AUK	1F4C	ARAD	
NEX1	394C	NEX2	3950	NBEF	3854	PI4	3858		
SCALAR MAP									
SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LO
I	AC	ADEN	80	BDEN	84	NNM	88	M	
NR	0C	J	04	DENOM	08	ANY	0C	ANX	
FDN	04	NUJU	08	NUJV	0C	NUMU	00	NUMV	

TOTAL MEMORY REQUIREMENTS 000442 BYTES

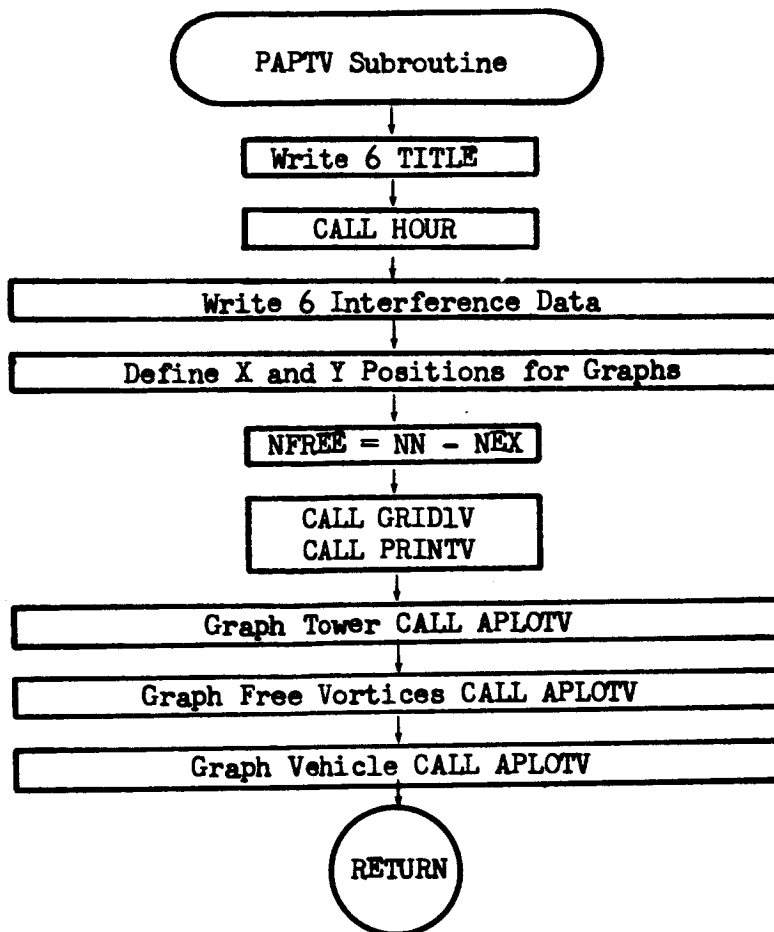
AIII. 3 PAPTIV (Print and Plot) Subroutine

The PAPTIV subroutine produces the vehicle and tower interference printed and graphic output when the ACCPT, which is incremented by DELT, exceeds the input DELTP.

The HOUR subroutine is called in PAPTIV and extracts the IBM machine time and prints both IBM and problem times. The CRT output shows the positions of vehicle, tower which may be in rotated position, and the free vortices. A good graph reproduces this data with the streamlines which are calculated in the main program. The input DELSL, incremental time to calculate streamlines, must be equal to or a multiple of DELTP.

The subroutines CRIDIV, APRNTV, PRINTV, and APLOTV are Fortran G, SC 4020 standard routines.

AIII. 3.1 Flow Chart



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FORTRAN IV G LEVEL 0, MOD 0

PARTV

DATE = 69014

01/52/33

		COMMON BLOCK /CTIMS / MAP SIZE 38							
SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	
TIME	C	DELT	4	DELTC	R	DELTP	C	ACCDT	10
ACCPY	14	TFTN	1R	DNC	1C	CONKC	20	TPN	24
TCN	2R	TSC	2C	ACCSL	3C	DELSI	34		
		COMMON BLOCK /CGRA / MAP SIZE F7C							
SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	
DXGRA	C	DXGRA	4	AGRA	B	MGRA	C	LARK	10
LARY	14	XXI	1R	XR	1C	YR	20	YT	24
XL	2R	XU	34R	YL	66R	YU	98B	CX	CAB
CYU	D5C	CYL	E1C	CXA	EC4	CASEND	F7B		
		SCALAR MAP							
SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	
I	B4	J	B9	KRFF	BC	IERR	C0	IER	C4
		SUBPROGRAMS CALLED							
SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	
IBCON#	CR	HOUR	CC	GRIDIV	DD	APRNTV	D4	PRINTV	DB
APLDTV	DC								
		FORMAT STATEMENT MAP							
SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	
IC	202	4C	231	5D	274	60	286		

TOTAL MEMORY REQUIREMENTS 000580 BYTES

APPENDIX B

LAUNCH PAD WIND PROFILE ANALYSIS

Index

BI. THEORETICAL DEVELOPMENT

1. Flow Field for a System of Vortices Outside an Elliptical Cylinder in Uniform Flow

BII. MAIN PROGRAM (PADPR ϕ)

1. Functional Flow Chart and Module Map
2. Input Data
 1. Data Definition
3. Program Listing

BIII. SUBROUTINES

1. Listings

APPENDIX B. LAUNCH PAD WIND PROFILE ANALYSIS

BI. THEORETICAL DEVELOPMENT

BI.1 Flow Field for a System of Vortices Outside an Elliptical Cylinder in Uniform Flow

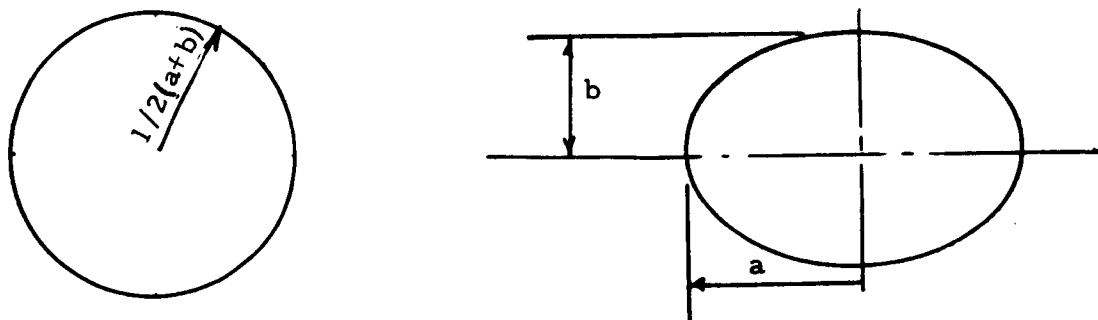
The following development was originally presented in Reference 3 as part of a more complete theoretical treatment of a nonsteady potential flow field containing a stationary cylinder and free vortices in uniform flow.

The analysis for the circular cylinder (Appendix A) may be extended to the case of an elliptical cylinder by a conformal transformation. The circular cylinder is mapped into an elliptical cylinder by the well-known Joukowski transformation.

In the plane of the circular cylinder, say the z_1 -plane, the circle of radius $r_0 = (a+b)/2$ is mapped by the transformation

$$z = z_1 + \frac{C^2}{4z_1} \quad \text{where } C^2 = a^2 - b^2 \quad (\text{B-1})$$

into an ellipse in the z -plane with major axis, $2a$, and minor axis, $2b$.



When $b \rightarrow 0$ we have the degenerate case of a flat plate of length $2a$ in the z -plane.

The velocity field in the z -plane is completely determined from the z_1 -plane and the mapping transformation. For a general system of vortices in the z -plane (plane of ellipse), the velocity of the m^{th} vortex is

$$(u - iv)_m = \frac{dF(z)}{dz} \quad (B-2)$$

where

$$F(z) = -w(z_1) + iK_m \log(z - z_m) \quad (B-3)$$

and from Equations A-2 and A-3;

$$w(z_1) = i \sum_{j=1}^n K_j \left[\log(z_1 - z_{1j}) - \log\left(z_1 - \frac{1}{z_{1j}}\right) + \log z_1 - \log \bar{z}_{1j} \right] - U_o \left[z_1 e^{-i\alpha} + \frac{1}{z_1} e^{i\alpha} \right] \quad (B-4)$$

where the circle in the z_1 -plane is chosen to have unit radius.

Therefore

$$z = \left(\frac{a+b}{2}\right) z_1 + \left(\frac{a-b}{2}\right) \frac{1}{z_1}$$

The derivative, $\frac{dF(z)}{dz}$, may be written

$$\frac{dF(z)}{dz} = \frac{dF(z)}{dz_1} \frac{dz_1}{dz} \quad (B-5)$$

where the mapping function is

$$z = f(z_1)$$

and

$$\frac{dz}{dz_1} = \frac{df(z_1)}{dz_1} = f'(z_1) \quad (B-6)$$

From Equations B-3 and B-4

$$\frac{dF(z)}{dz_1} = i \sum_{j=1}^n K_j \left[\frac{1}{z_1 - z_{1j}} - \frac{z_{1j}}{z_1 z_{1j}} - 1 + \frac{1}{z_1} \right] + U_o \cos \alpha \left(1 - \frac{1}{z_1} \right)$$

$$-i U_0 \sin \alpha \left(1 + \frac{1}{z_1} \right) - \frac{i K_m f'(z_1)}{f(z_1) - f(z_{1m})} \quad (\text{B-7})$$

Thus,

$$\begin{aligned} \frac{dF(z)}{dz} \Big|_{z=z_m} &= \left[i \sum_{j=1}^n K_j \left(\frac{1}{z_1 - z_{1j}} - \frac{z_{1j}}{z_1 z_{1j} - 1} + \frac{1}{z_1} \right) \right. \\ &\quad + U_0 \cos \alpha \left(1 - \frac{1}{z_1} \right) - U_0 \sin \alpha \left(1 + \frac{1}{z_1} \right) \\ &\quad \left. - \frac{i K_m f'(z_1)}{f(z_1) - f(z_{1m})} \right]_{z_1=z_{1m}} \times \left(\frac{1}{f'(z_1)} \right)_{z_1=z_{1m}} \quad (\text{B-8}) \end{aligned}$$

The first and last terms in the brackets have singularities when $z_1 = z_{1m}$, but the other terms are regular if $|z_1| > 1$. Rewriting Equation B-8

$$\begin{aligned} \frac{dF(z)}{dz} \Big|_{z=z_m} &= F'(z_m) \\ &= \frac{1}{f'(z_{1m})} \left\{ i \left[\sum_{\substack{j=1 \\ j \neq m}}^n \frac{K_j}{z_{1m} - z_{1j}} - i \sum_{j=1}^n \frac{K_j}{z_{1j} (z_{1m} z_{1j} - 1)} \right] \right. \\ &\quad + U_0 \cos \alpha \left(1 - \frac{1}{z_1} \right) - i U_0 \sin \alpha \left(1 - \frac{1}{z_1} \right) \\ &\quad \left. + i K_m \left[\frac{1}{z_1 - z_{1m}} - \frac{f'(z_1)}{f(z_1) - f(z_{1m})} \right]_{z_1=z_{1m}} \right\} \quad (\text{B-9}) \end{aligned}$$

Expanding $f(z_1)$ in a Taylor's series about the point $z_1 = z_{1m}$ results in

$$\left[\frac{1}{z_1 - z_{1m}} - \frac{f'(z_1)}{f(z_1) - f(z_{1m})} \right]_{z_1=z_{1m}} = \frac{1}{2} \frac{f''(z_{1m})}{f'(z_{1m})} \quad (\text{B-10})$$

Finally

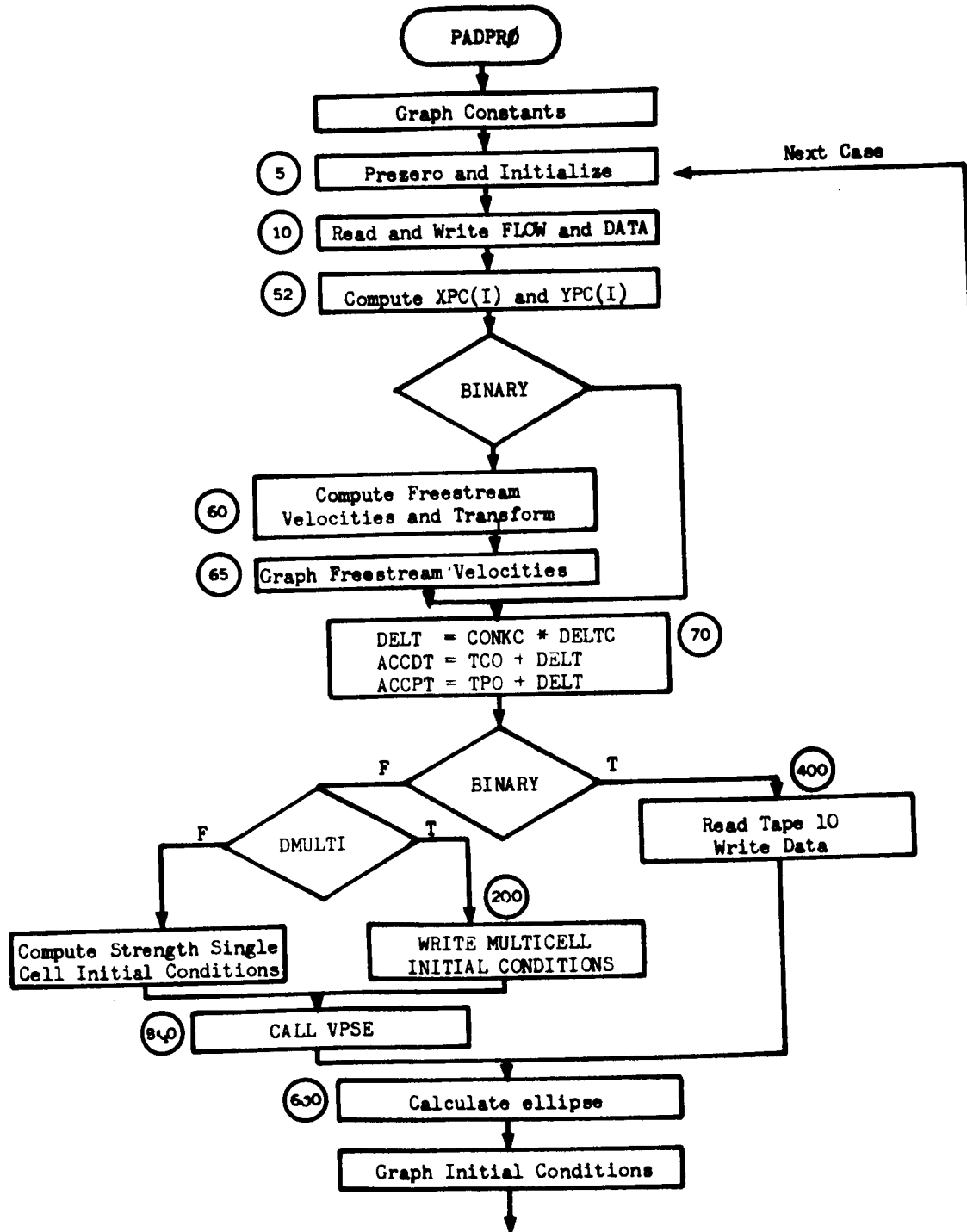
$$\begin{aligned}
 (u-iv)_m &= f'(z_m) \\
 &= \frac{1}{f'(z_m)} \left[i \left[\sum_{\substack{j \neq m \\ j \neq 1}}^n \frac{K_j}{z_{1m} - z_{1j}} - i \sum_{j=1}^n z_{1j} \frac{K_j}{(z_{1m} z_{1j} - 1)} \right. \right. \\
 &\quad \left. \left. + U_0 \cos \alpha \left(1 - \frac{1}{z_1} \right) - i U_0 \sin \alpha \left(1 + \frac{1}{z_1} \right) \right. \right. \\
 &\quad \left. \left. + \frac{iK_m}{2} \frac{f''(z_{1m})}{f'(z_{1m})} \right] \right] \quad (B-11)
 \end{aligned}$$

As discussed in Appendix A, the last term of Equation B-11 represents the contribution of a center vortex, which within the framework of this study is to be omitted as long as the vortices are generated by the ellipse, and no other body is present in the flow.

This being the case, the expression within brackets is identical to the flow field equation for a circular cylinder, and must be multiplied by the transformation expression, $\frac{1}{f'(z_m)}$. For symmetrical flow further obvious simplification can be made.

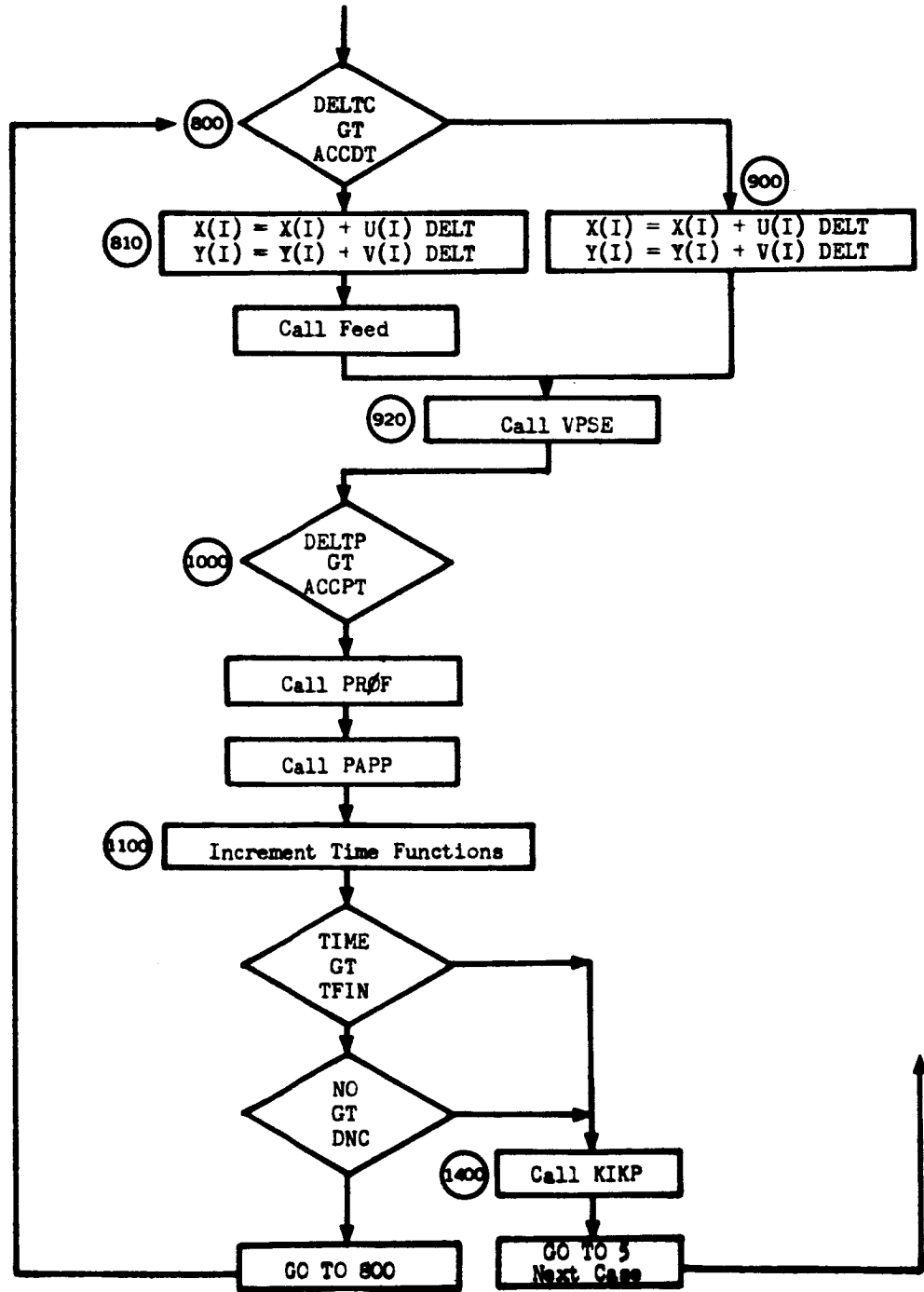
BII. MAIN PROGRAM (PADPRØ)

BII.1 Functional Flow Chart



#

BII.1 Functional Flow Chart (Cont)



BII. 2. Input Data

BII. 2. 1. Data Definition

The input data read are in two namelist arrays, FLOW and DATA.

FLOW has two logical items:

BINARY = F for initial case
 = T for restart case
 DMULTI = F for single cell case
 = T for multicell case

The DATA array is defined:

TIME Start time (= 0 for initial)
 TFIN Final time
 DNC Number of cells to terminate
 CONKC Factor to compute integration increment
 DELTC Time increment to introduce new vortex
 DELTP Time increment to output data
 NØ Initial number of vortices
 XØU X-Location of feeding point
 YØU Y-Location of feeding point
 BETA Ellipse defined by —
 A = 1 + BETA
 B = 1 - BETA
 NP Number of YIP points
 YIP Y-location of profiles (Max NP)
 NPRO Number of profiles
 XIP X-locations of profiles (Max NPRØ)
 CASENØ Case number (Mo Da Yr)

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BII. 3 Program Listing

```

C      MAIN PROGRAM - LAUNCH PAD INTERFERENCE STUDY -
C                          VORTEX SHEDDING MODEL 6
C                          SYMMETRICAL FLOW
C
C      PROGRAM EXITS ON READ FOR NEXT CASE
C
C      LOGICAL      BINARY,DMULTI
C      INTEGER      DNC
C
C      COMMON NO,R(400,7),XDU,YDU,BETA,ALFAS
C      COMMON      /CFLOW/BINARY,DMULTI
C      COMMON      /CTIMES/TIME,DELT,DELTC,DELTP,ACCDT,ACCPY,TFIN,DNC,CONKC
C      *           ,TPO,TCO
C      COMMON      /CGRAF/XXL,XR,YB,YT,DXGRA,DYGRA,NGRA,MGRA,LABX,LABY
C      *           ,CX(45),CYU(45),CYL(45),CXN(45),CASEND
C      COMMON /CPAD/XP(20,50),YP(20,50),NP, XPC(20,50),YPC(20,50)
C      *           ,UCYL,VCYL,XFP,YFP,CC,DD,UP(20,50),VP(20,50),NPRO
C
C      DIMENSION  ITH(400,1),           X(400,1),
C      *           Y(400,1),           U(400,1),
C      *           V(400,1),           AUK(400,1),
C      *                                   ARAD(400,1),
C      *           XU(200),           XL(200),
C      *           YU(200),           YL(200),
C      *           XE(400,20),        YE(400,20),
C      *           H(50),           XIP(50),        YIP(20)
C
C      EQUIVALENCE(H(1,1),ITH(1,1)),    (H(1,2),X(1,1)),
C      *           (B(1,3),Y(1,1)),    (B(1,4),U(1,1)),
C      *           (B(1,5),V(1,1)),    (B(1,6),AUK(1,1)),
C      *           (B(1,7),ARAD(1,1))
C
C      NAMELIST /FLOW/ BINARY,DMULTI
C      NAMELIST /DATA/ TIME,TFIN,DNC,CONKC,DELTC,DELTP,NO,XDU,YDU,BETA
C      *           ,NP,YIP,NPRO,XIP,CASEND
C
C      REWIND 10
C      CALL SCOUTV
C      CALL CAMRAV(9)
C      XXL = -2.0
C      XR = 8.0
C      YB = -1.0
C      YT = 9.0
C      DXGRA = .5
C      DYGRA = .5
C      NGRA = -4
C      MGRA = -4
C      LABX = -4
C      LABY = -4
C
C      TPO = .00001
C      TCO = .00001
    
```

```

C
5 DO 6 J=1,7
  DO 6 I=1,400
6 B(I,J) = 0.0
  DO 7 J = 1,50
    H(J) = 0.0
  DO 7 I = 1,20
    XP(I,J) = 0.0
    YP(I,J) = 0.0
    UP(I,J) = 0.0
    VP(I,J) = 0.0
    XPC(I,J) = 0.0
    YPC(I,J) = 0.0
7 CONTINUE

C
  DMULTI = .FALSE.
  BINARY = .FALSE.

C
  READ(5,FLOW)
  READ(5,DATA)

C
  WRITE (6,10) CASENO
10 FORMAT (1H1, 39X, 'LAUNCH PAD INTERFERENCE STUDY' /
*          43X, 'VORTEX SHEDDING MODEL 6' /
*          43X, 'NORTH AMERICAN ROCKWELL' /
*          45X, 'DEPARTMENT 190/200' //
*          40X, 'INPUT DATA FOR CASE NO.' ,F8.2 ,//)
  WRITE (6,FLOW)

C
  WRITE (6,12) TIME,TFIN,DNC,CONKC,DELTC,DELTP,NO,XOU,YOU,BETA
*           ,XAUK,YAUK
*           ,CASENO
*           ,NP, (YIP(I), I=1,NP)
  WRITE (6,13) NP, (XIP(I), I=1,NPRO)

C
12 FORMAT (1H-, 9X, 'TIME 'F10.3,20X'TFIN 'F10.3,20X'DNC 'I10 ///
*           10X 'CONKC'F10.3,20X'DELTC'F10.3,20X'DELTP'F10.3///
*           10X 'NO 'I10 ,20X'XOU 'F10.3,20X'YOU 'F10.3///
*           10X 'BETA 'F10.3,20X'XAUK 'F10.3,20X'YAUK 'F10.3///
*           10X 'CASENO' F9.2 ///
*           10X 'NP 'I10 ,20X'YIP '/ (51X,5F10.3 ))

C
13 FORMAT(1H0,9X 'NPRO 'I10 ,20X'XIP '/ (51X,5F10.3 ))

C
C
  OPB = 1. + BETA
  OPBSQ = OPB * OPB
  OMB = 1. - BETA
  DIF = OMB/OPB
  DO 30 J=1,NPRO
  DO 30 I=1,NP
    XP(I,J) = XIP(J)
    YP(I,J) = YIP(I)
    IF(XIP(J) .GE. -OPB .AND. XIP(J) .LE. OPB) GO TO 20
  GO TO 30

C
20 H(J) = DIF * SQRT (OPBSQ - XIP(J)**2)
  YP(I,J) = H(J) + YIP(I)
30 CONTINUE
C

```

```

C                               INITIALIZE
NPP = NP+ 1
XP(NPP,1)=XOU
YP(NPP,1)=YOU
C
DO 59 J=1,NPRO
DO 59 I= 1,NPP
XE(I,J) = XP(I,J)
YE(I,J) = YP(I,J)
ARG1=2.*XE(I,J)*YE(I,J)
ARG2 =(XE(I,J)**2) - (YE(I,J)**2) -4.*BETA
ROT = (ARG1**2) + (ARG2**2)
RO=SQRT(ROT)
RO=SQRT(RO)
TH=ATAN2(ARG1,ARG2)
IF(TH) 50,51,51
50 TH=2.*3.1415926+ TH
51 TH= TH/2.
A=RO*COS(TH)
C=RO*SIN(TH)
XPC(I,J)=(XE(I,J) + A) /2.
YPC(I,J)=(YE(I,J) +C) /2.
ARAT = XPC(I,J)**2+YPC(I,J)**2
IF(ARAT - .99999) 52,52,59
52 XPC(I,J)=(XE(I,J) -A) /2.
YPC(I,J) = (YE(I,J) -C) /2.
59 CONTINUE
C
XFP = XPC(NPP,1)
YFP = YPC(NPP,1)
C
IF(BINARY) GO TO 70
C
DO 60 JJ= 1,NPRO
DO 60 J=1,NP
DENO = (XPC(J,JJ)**2 + YPC(J,JJ)**2)**2
UPRO = 1. - (XPC(J,JJ)**2 - YPC(J,JJ)**2)/DENO
VPRO = -2. * XPC(J,JJ) * YPC(J,JJ) /DENO
C
C                               TRANSFORMATION OF VELOCITY
C
AA = XPC(J,JJ)**2 - YPC(J,JJ)**2
BB = 2. * XPC(J,JJ) * YPC(J,JJ)
DENOM = (AA - BETA)**2 + BB**2
CM = 1. + BETA * (AA - BETA) /DENOM
DM = BB * BETA/DENOM
UPI(J,JJ)=CM*UPRO- DM * VPRO
VPI(J,JJ)=CM*VPRO+ DM * UPRO
60 CONTINUE
C
WRITE (6,65)
65 FORMAT (1H1, 42X, 'FREESTREAM PROFILES')
CALL PLOTPR
C
70 DELT= CONKC*DELTC
ACCDT=TCO + DELT
ACCPT=TPU +DELT
C
DO 80 I=1,45
CX(I) = 0.0
CXN(I) = 0.0
CYU(I) = 0.0
80 CYL(I) = 0.0

```

```

C      IF(BINARY)GO TO 400
      IF(DMULTI)GO TO 200
      WRITE(6,100)
100  FORMAT(1H1,40X,38HSINGLE CELL ***** INITIAL CONDITION )
C
      CALL HOUR
C
      X(1,1)=XOU
      Y(1,1)=YOU
      ITH(1,1) = 1
C
      SQFUN = SQRT(XFP**2 + YFP**2)
      XCYL = XFP/SQFUN
      YCYL = YFP/SQFUN
      UCYL = 2. * YCYL**2
      VCYL = -2. * XCYL * YCYL
      AA = XCYL**2 - YCYL**2
      BB = -VCYL
      DENOM = (AA-BETA)**2 + BB**2
      CC = 1. + BETA *(AA-BETA)/DENOM
      DD = BB*BETA/DENOM
      UFP = CC *UCYL - DD *VCYL
      VFP = CC *VCYL + DD *UCYL
      ALFAS = (UFP**2 + VFP**2)
C
      AUK(1,1)=DELTC * ALFAS / (4.0 * 3.14159)
      WRITE (6,5000)
      WRITE(6,5010)(ITH(I,1),X(I,1),Y(I,1),AUK(I,1),I=1,NO)
      GO TO 300
C
200  WRITE(6,210)TIME,NO
210  FORMAT (1H1, 10X, 6HTIME = , F10.6, 14X
      *      27HMULTICELL INITIAL CONDITION(3,2X, 5HPAIRS)
      DO 215 I=1,NO
215  READ (5,220)      ITH(I,1),X(I,1),Y(I,1),AUK(I,1)
      WRITE(6,5000)
      WRITE (6,5010) (ITH(I,1),X(I,1),Y(I,1),AUK(I,1), I=1,NO)
220  FORMAT (112,3E12.0)
C
300  CALL VPSE
      GO TO 600
C
400  READ (10,ERR=9999) NO,((B(I,J),I=1,NO),J=1,7),CSNO,TIME
      WRITE(6,410)CSNO,NO
410  FORMAT (1H1,25X,40HBINARY MULTICELL INITIAL CONDITION (CASE F10.4,
      *      4H)      ,13,2X5HPAIRS)
450  WRITE (6,5020)
      WRITE(6,5030)((B(I,J),J=1,6),I=1,NO)
C
C
600  CONTINUE
C      CALCULATE ELLIPSE
      DDEG=0.0
      DO 610 I=1,45
      DDEG=DDEG+2.0
      CX(I)=(1.+BETA)*CNSD(DDEG)
      CXN(I)=-CX(I)
610  CYU(I)=(1.-BETA)*SIND(DDEG)
C

```

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```

700 CONTINUE
  CALL GRIDIV( -3, XXL, XR, YB, YT, DXGRA,DYGRA, NGRA,MGRA,
  *           LABX,LABY, 3,3)
  CALL PRINTV(11, 'X/A - AXIS ', 472,4)
C
  IF(DMULTI) GO TO 705
  CALL APLQTV( NO, XOU,YOU, 1,1,1,38,IERR)
  GO TO 725
C
705 DO 720 I=1,NO
  XU(I) = X(I,1)
720 YU(I) = Y(I,1)
C
  CALL APLQTV( NO, XU,YU, 1,1,1,38,IERR)
C
725 CALL APLQTV( 45, CX, CYU, 1,1,1, 42,IERR)
  CALL APLQTV( 45, CXN,CYU, 1,1,1, 42,IERR)
  WRITE (16,750) TIME,CASENO,DELTC
750 FORMAT (1H+,5X34H INITIAL CELL LOCATIONS AT TIME = 1F9.4,2X,3HA/U,
  *           20X,8HCASE NO.,2X,FB.2, 8X, 'DELTC = ' F5.3)
C
800 IF(DELTC.GT.ACCDT)GO TO 900
C
  DO 810 I=1,NO
  X(I,1)= X(I,1) +U(I,1) *DELT
810 Y(I,1)= Y(I,1) +V(I,1) *DELT
C
  INTRODUCE NEW CELLS
C
  CALL FEED
C
  NO=NO+1
  X(NO,1)= XOU
  Y(NO,1)= YOU
  AUK(NO,1)= DELTC*ALFAS / (4.*3.14159)
  ITH(NO,1)= NO
  ACCDT=TCO
C
  END OF INTRODUCTION OF NEW CELL
C
  GO TO 920
900 DO 910 I=1,NO
  X(I,1)= X(I,1) +U(I,1) *DELT
910 Y(I,1)= Y(I,1) +V(I,1) *DELT
920 CALL VPSE
C
1000 IF(DELTP.GT.ACCEPT)GO TO 1100
C
  CALL PROF
C
  CALL PAPP
C
1100 TIME= TIME + DELT
  ACCDT= ACCDT + DELT
  ACCEPT= ACCEPT + DELT
C
1200 IF(TIME.GT.TFIN) GO TO 1400
1300 IF(NO.GT.DNC) GO TO 1400
  GO TO 800
C
1400 CALL KIKP

```


C

```
GO TO 5
9999 I=16000000
      HHHHHH=H(I)
      STOP
```

C

C

```
5000 FORMAT (1H-,5X,8HITH CELL,12X,3HX/A,17X,3HY/A,17X,1HK ,//)
5010 FORMAT (1H ,8X,14,1P3E20.7)
5020 FORMAT (1H-,4X8HCELL NO.,3X,3HX/A,15X,3HY/A,15X,7HU/U INF,11X,
*       7HV/U INF,11X,7HK/U*A ,//)
5030 FORMAT (1H ,6X,14,2X,1P5E18.7)
      END
```

/*

BIII. SUBROUTINES

Subroutines for the PADPRØ Program have functions that are similar to those of the subroutines for the VSTV Program (Appendix A, AIII). No flow charts will be presented; listings are in Section BIII. 1. The VPSE (velocity) subroutine parallels the VELTV (AIII. 2.); the FEED (feeding-point) subroutine parallels NUCTV (AIII. 1.), the PAPP (print-and-plot) subroutine parallels PAPTIV, the KIKP subroutine parallels the KIKTV (AIII. 4.). The new subroutine PROF (profile) computes (NPRO, input) velocity profiles at the XIP (input), X locations over the NP (number of points) on the YIP (input), and Y locations. The HOUR subroutine calculates the IBM machine time and prints on header of profile output data. All subroutine listings are in Section BIII. 1.

BIII.1 Listings

```

SUBROUTINE VPSE
C   ELLIPTICAL VELOCITY COMPUTATION ,SYMMETRICAL
C   PAD PROFILE
C
C   COMMON NO,B(400,7),XOU,YOU,BETA,ALFAS
C
C   DIMENSION X(400,1),Y(400,1),U(400,1),V(400,1),AUK(400,1),ARAD(400
*   ,1)
C   DIMENSION XE(400,1),YE(400,1),
*   XSQ(400,1),YSQ(400,1)
C
C   EQUIVALENCE(B(1,2),X(1,1)),           (B(1,3),Y(1,1)),
*   (B(1,4),U(1,1)),           (B(1,5),V(1,1)),
*   (B(1,6),AUK(1,1)),          (B(1,7),ARAD(1,1))
C
C   DO 10 I=1,NO
C   XE(I,1)= X(I,1)
10  YE(I,1)= Y(I,1)
C
C   DO 300 I=1,NO
C   ARG1=2.*XE(I,1)*YE(I,1)
C   ARG2 =(XF(I,1)**2) - (YF(I,1)**2) -4.*BETA
C   ROT = (ARG1**2) + (ARG2**2)
C   RO=SQRT(ROT)
C   RO=SQRT(RO)
C   TH=ATAN2(ARG1,ARG2)
C
C   IF(TH) 50,51,51
50  TH=2.*3.1415926+ TH
51  TH= TH/2.
C   A=RO*COS(TH)
C   C=RO*SIN(TH)
C   X(I,1)=(XE(I,1)+A)/2.
C   Y(I,1)=(YE(I,1)+C)/2.
C   XSQ(I,1) = X(I,1)**2
C   YSQ(I,1)=Y(I,1) **2
C   ARAD(I,1) = XSQ(I,1)+ YSQ(I,1)
C
C   IF(ARAD(I,1)-.99999) 11,11,12
11  X(I,1)=(XE(I,1)-A)/2.
C   Y(I,1)=(YE(I,1)-C)/2.
12  XSQ(I,1)=X(I,1)**2
C   YSQ(I,1)=Y(I,1) **2
C   ARAD(I,1) = XSQ(I,1)+ YSQ(I,1)
C   RSQ=ARAD(I,1)**2
C   DEN2=(1.-2.*ARAD(I,1)+RSQ)*(1.-2.*(X(I,1)**2-Y(I,1)**2)+RSQ)
C   AB=4.*(Y(I,1)**2)/DEN2
C   D=2.*(1.-2.*X(I,1)**2+RSQ)/DEN2
C   ALPHA=0.0
C   SAL=SIN(ALPHA)
C   CAL=COS(ALPHA)
C   XX=1.-(X(I,1)**2-Y(I,1)**2)/RSQ
C   YY= 2.*X(I,1)*Y(I,1)/RSQ
C   U(I,1)=-AUK(I,1)*Y(I,1)*(ARAD(I,1)*AR-D)+XX*CAL-YY*SAL
*   -AUK(I,1)/(2.*Y(I,1))
300 V(I,1)=AUK(I,1)*X(I,1)*AR*(ARAD(I,1)-1.)-YY*CAL-XX*SAL
C

```

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```

NNM=NO-1
IF(NNM) 101,105,101
101 CONTINUE
DO 301 M=1,NNM
MP= M+1
C
DO 301 J=MP,NO
DX=(X(M,1)-X(J,1))**2+(Y(M,1)-Y(J,1))**2
DY=1.-2.*(X(J,1)*X(M,1)+Y(J,1)*Y(M,1))+ARAD(J,1)*ARAD(M,1)
YYY=Y(J,1)*Y(M,1)
DEN1=DX*(DX+4.*YYY)
DEN2=DY*(DY+4.*YYY)
A=4.*YYY/DEN1
AB=4.*YYY/DEN2
C= 2.*(DX+2.*YYY)/DEN1
D =2.*(DY+2.*YYY)/DEN2
E=A-AB
F=C-D
G=A-ARAD(J,1)*AB
H=A-ARAD(M,1)*AB
USUMM=Y(M,1)*G-Y(J,1)*F
USUMJ=Y(J,1)*H-Y(M,1)*F
VSUMM=X(M,1)*G-X(J,1)*E
VSUMJ=X(J,1)*H-X(M,1)*E
U(M,1)=U(M,1)+AUK(J,1)*USUMM
U(J,1)=U(J,1)+AUK(M,1)*USUMJ
V(M,1)=V(M,1)-AUK(J,1)*VSUMM
301 V(J,1)=V(J,1)-AUK(M,1)*VSUMJ
C
105 DO 110 I=1,NO
A=XSQ(I,1)-YSQ(I,1)
P=A-BETA
C=2.*X(I,1)*Y(I,1)
DEN1=P**2+C**2
D=3.*XSQ(I,1)-YSQ(I,1)-BETA
E=XSQ(I,1)-3.*YSQ(I,1)-BETA
DEN2=XSQ(I,1)*(E**2)+YSQ(I,1)*(D**2)
F=A*P+C**2
G=C*BETA
U(I,1)=(U(I,1)*F-V(I,1)*G)/DEN1+(Y(I,1)*BETA+AUK(I,1)*D)/DEN2
110 V(I,1)=(V(I,1)*F+U(I,1)*G)/DEN1-(X(I,1)*BETA+AUK(I,1)*E)/DEN2
C
DO 22 I=1,NO
X(I,1)= XE(I,1)
22 Y(I,1)= YE(I,1)
RETURN
END
/*
SUBROUTINE FEED
C FEED POINT VELOCITY COMPUTATION
C
C
C
COMMON NO,B(400,7),XOU,YOU,BETA,ALFAS
COMMON /CPAD/XP(20,50),YP(20,50),VP, XPC(20,50),YPC(20,50)
* ,UCYL,VCYL,XFP,YFP,CC,DD,UP(20,50),VP(20,50),NPRU
C
C
C DIMENSION X(400,1),Y(400,1),U(400,1),V(400,1),AUK(400,1),ARAD(400
* ,1)
C DIMENSION XE(400,20), YE(400,20),
C *XSQ(400,1),YSQ(400,1)

```

```

X(I,1)= XE(I,1)
22 Y(I,1)= YE(I,1)
RETURN
END

/*
SUBROUTINE PROF
C
C CALCULATE THE UPSTREAM VELOCITY PROFILES
C
C
COMMON NO,B(400,7),XDU,YDU,BETA,ALFAS
COMMON /CPAD/XP(20,50),YP(20,50),NP, XPC(20,50),YPC(20,50)
* ,UCYL,VCYL,XFP,YFP,CC,DD,UP(20,50),VP(20,50),NPRO

C
C DIMENSION X(400,1),Y(400,1),U(400,1),V(400,1),AUK(400,1),ARAD(400
* ,1)
DIMENSION XF(400,1),YE(400,1),
*XSQ(400,1),YSQ(400,1)

C
C EQUIVALENCE(B(1,2),X(1,1)), (B(1,3),Y(1,1)),
* (B(1,4),U(1,1)), (B(1,5),V(1,1)),
* (B(1,6),AUK(1,1)), (B(1,7),ARAD(1,1))

C
C TRANSFORMATION OF POINTS TO CIRCULAR PLANE
C
DO 10 I=1,NO
XE(I,1)= X(I,1)
10 YE(I,1)= Y(I,1)

C
DO 300 I=1,NO
ARG1=2.*XE(I,1)*YE(I,1)
ARG2 =(XE(I,1)**2) - (YE(I,1)**2) -4.*BETA
ROT = (ARG1**2) + (ARG2**2)
RD=SQRT(ROT)
RO=SQRT(RD)
TH=ATAN2(ARG1,ARG2)

C
IF(TH) 50,51,51
50 TH=2.*3.1415926+ TH
51 TH= TH/2.
A=RU*COS(TH)
C=RO*SIN(TH)
X(I,1)=(XE(I,1)+A)/2.
Y(I,1)=(YE(I,1)+C)/2.
XSQ(I,1) = X(I,1)**2
YSQ(I,1)=Y(I,1) **2
ARAD(I,1) = XSQ(I,1)+ YSQ(I,1)

C
IF(ARAD(I,1)-.99999) 11,11,300
11 X(I,1)=(XE(I,1)-A)/2.
Y(I,1)=(YE(I,1)-C)/2.
ARAD(I,1) = X(I,1)**2 + Y(I,1)**2
300 CONTINUE

C
C COMPUTATION OF VELOCITY IN CIRCULAR PLANE
C
DO 500 JJ= 1,NPRO
DO 500 J=1,NP
DENO = (XPC(J,JJ)**2 + YPC(J,JJ)**2)**2
UPRO = 1. - (XPC(J,JJ)**2 - YPC(J,JJ)**2)/DENO
VPRO = -2. * XPC(J,JJ) * YPC(J,JJ) /DENO

```

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```

EQUIVALENCE(B(1,2),X(1,1)),          (B(1,3),Y(1,1)),
*           (B(1,4),U(1,1)),          (B(1,5),V(1,1)),
*           (B(1,6),AUK(1,1)),        (B(1,7),ARAD(1,1))

```

C
C
C
C

TRANSFORMATION OF POINTS TO CIRCULAR PLANE

```

DO 10 I=1,NO
XE(I,1)= X(I,1)
10 YE(I,1)= Y(I,1)
C
DO 300 I=1,NO
ARG1=2.*XE(I,1)*YE(I,1)
ARG2 =(XE(I,1)**2) - (YE(I,1)**2) -4.*BETA
ROT = (ARG1**2) + (ARG2**2)
RO=SQRT(ROT)
RO=SQRT(RO)
TH=ATAN2(ARG1,ARG2)
IF(TH) 50,51,51
50 TH=2.*3.1415926+ TH
51 TH= TH/2.
A=RO*COS(TH)
C=RO*SIN(TH)
X(I,1)=(XE(I,1)+A)/2.
Y(I,1)=(YE(I,1)+C)/2.
XSQ(I,1) = X(I,1)**2
YSQ(I,1)=Y(I,1) **2
ARAD(I,1) = XSQ(I,1)+ YSQ(I,1)
IF(ARAD(I,1)-.99999) 11,11,300
11 X(I,1)=(XE(I,1)-A)/2.
Y(I,1)=(YE(I,1)-C)/2.
ARAD(I,1) = X(I,1)**2 + Y(I,1)**2
300 CONTINUE

```

C
C
C

COMPUTATION OF VELOCITY ON CYLINDER IN CIRCULAR PLANE
FOR FEEDING POINT

```

UCFP = UCYL
VCFP = VCYL
C
DO 400 I = 1,NO
XI = X(I,1) /ARAD(I,1)
YI = Y(I,1) /ARAD(I,1)
DX = XFP - X(I,1)
DY = YFP - Y(I,1)
DYL = YFP + Y(I,1)
DXI = XFP - XI
DYUI = YFP - YI
DYLI = YFP + YI
DSU = DX**2 + DY**2
DSL = DX**2 + DYL**2
DSUI = DXI**2 + DYUI**2
DSL I = DXI**2 + DYLI**2
UCFP = UCFP + AUK(I,1) * (DY/DSU -DYUI/DSUI -DYL/DSL +DYLI/DSL I)
VCFP = VCFP - AUK(I,1) * (DX/DSU -DXI/DSUI -DX/DSL + DXI/DSL I)
400 CONTINUE

```

C
C

TRANSFORMATION OF VELOCITY FOR FEED POINT

```

UFP = CC * UCFP - DD * VCFP
VFP = CC * VCFP + DD * UCFP
ALFAS = (UFP**2 + VFP**2)

```

C

```

DO 22 I=1,NO

```

```

DO 400 I = 1,NO
XI = X(I,1) /ARAD(I,1)
YI = Y(I,1) /ARAD(I,1)
XLI = XI
YLI = -YI
DX = XPC(J,JJ) - X(I,1)
DY = YPC(J,JJ) - Y(I,1)
DYL = YPC(J,JJ) + Y(I,1)
DXI = XPC(J,JJ) - XI
DYUI = YPC(J,JJ) - YI
DYLI = YPC(J,JJ) + YI
DSU = DX**2 + DY**2
DSL = DX**2 + DYL**2
DSUI = DXI**2 + DYUI**2
DSLII = DXI**2 + DYLI**2
UPRO = UPRO + AUK(I,1) * (DY/DSU -DYUI/DSUI -DYL/DSL +DYLI/DSLII)
VPRO = VPRO - AUK(I,1) * (DX/DSU -DXI/DSUI -DX/DSL + DXI/DSLII)
400 CONTINUE
C
C
C
      TRANSFORMATION OF VELOCITY
AA = XPC(J,JJ)**2 - YPC(J,JJ)**2
BB = 2. * XPC(J,JJ) * YPC(J,JJ)
DENOM = (AA - BETA)**2 + BB**2
CM = 1. + BETA * (AA - BETA) /DENOM
DM = BB * BETA/DENOM
UP(J,JJ)=CM*UPRO- DM * VPRO
VP(J,JJ)=CM*VPRO+ DM * UPRO
500 CONTINUE
C
DO 22 I=1,NO
X(I,1)= XE(I,1)
22 Y(I,1)= YE(I,1)
RETURN
END
/*
SUBROUTINE PAPP
      PRINT AND PLOT FOR LAUNCH PAD INTERFERENCE PROGRAM
C
C
      INTEGER DNC,HR,SEC
C
      COMMON NO,B(400,7),XDU,YDU,BETA,ALFAS
C
      COMMON /CTIMES/TIME,DELT,DELTC,DELTP,ACCDT,ACCPT,TFIN,DNC,CONKC
*
      COMMON /CGRAF/XXL,XR,YB,YT,DXGRA,DYGRA,NGRA,MGRA,LABX,LABY
*
      COMMON /CPAD/XP(20,50),YP(20,50),NP, XPC(20,50),YPC(20,50)
*
      ,UCYL,VCYL,XFP,YFP,CC,DD,UP(20,50),VP(20,50),NPRO
C
      DIMENSION X(400,1),Y(400,1),YL(200)
*
      , YGRA(400), UGRA(400), VGRA(400)
C
      EQUIVALENCE(B(1,2),X(1,1)), (B(1,3),Y(1,1))
C
      ACCPT =TPO
C
      DO 5 I= 1,400
      YGRA(I) = 0.0
      UGRA(I) = 0.0
      VGRA(I) = 0.0

```

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```

5 CONTINUE
C
WRITE (6,10)
10 FORMAT (1H1, 40X, 'VORTEX DATA'//)
CALL HOUR
C
WRITE (6,20)
20 FORMAT (1H-,8HCELL NO.,3X,          9X,3HX/A,15X,3HY/A,15X,
*      7HU/U INF,11X, 7HV/U INF,11X,8HK / U*A ,//)
C
WRITE(6,25) ((B(I,J),J=1,6),I=1,NO)
25 FORMAT (1H , 14,7X, 1X,1P5E18.7)
C
CALL PLOTPR
C
CALL GRIDIV( -3, XXL, XR, YB, YT, DXGRA,DYGRA, NGRA,MGRA,
*      LABX,LABY, 3,3)
CALL PRINTV(11, 'X/A - AXIS ', 472,4)
CALL APLOTV( NO, X,Y, 1,1,1,38,IERR)
CALL APLOTV( 45, CX, CYU, 1,1,1, 42,IERR)
CALL APLOTV( 45, CXN,CYU, 1,1,1, 42,IERR)
WRITE(16,60) NO,TIME,CASENO,DELTC
60 FORMAT (1H+ 6X, 'LOCATIONS OF' 14 ' CELLS TIME = 'F8.4,2X,3HA/U
* ,20X, 'SYM. CASE NO. ' F8.2 ,5X, 'DELTC = ',F5.3)
C
C
DO 6000 I=1,NO
IF (X(I,1) .GT. XR) GO TO 6005
6000 CONTINUE
GO TO 7000
C
6005 XRR = XR-XXL+XR
CALL GRIDIV( -3, XR, XRR,YB, YT, DXGRA,DYGRA, NGRA,MGRA,
*      LABX,LABY, 3,3)
CALL PRINTV(11, 'X/A - AXIS ', 472,4)
CALL APLOTV( NO, X,Y, 1,1,1,38,IERR)
WRITE(16,60) NO,TIME,CASENO,DELTC
DO 6010 I=1,NO
IF (X(I,1) .GT. XRR) GO TO 6015
6010 CONTINUE
GO TO 7000
C
6015 XRRR = XRR +XR-XXL
CALL GRIDIV( -3, XRR, XRRR,YB,YT, DXGRA,DYGRA, NGRA,MGRA,
*      LABX,LABY, 3,3)
CALL PRINTV(11, 'X/A - AXIS ', 472,4)
CALL APLOTV( NO, X,Y, 1,1,1,38,IERR)
WRITE(16,60) NO,TIME,CASENO,DELTC
C
7000 CONTINUE
C
RETURN
END
/*
SUBROUTINE KIKP
C      KICK ROUTINE FOR PAD INTERFERENCE PROBLEM
C
COMMON NO,B(400,7),XOU,YOU,BETA,ALFAS
COMMON /CTIMES/TIME,DELT,DELTC,DELTP,ACCDT,ACCP,TFIN,DNC,CONKC
COMMON /CGRAF/XXL,XR,YB,YT,DXGRA,DYGRA,NGRA,MGRA,LABX,LABY
*      .CX(45).CYU(45).CYL(45).CXN(45),CASENO

```



```
C      TIME = TIME - DELT
C
C      CALL PROF
C      CALL PAPP
C
C      WRITE(10) NO,((B(I,J), I=1,NO), J=1,7),CASENO,TIME
C      WRITE (6,10) CASENO
10  FORMAT(1H1,5X, ' DATA FOR CASE NO.' F10.4, ' ON LOGICAL TAPE 10'//
C      * 6X, 'RESERVE TAPE NO.(           ) ' ,//)
C      REWIND 10
C      WRITE (6,20)
20  FORMAT (1H1)
C      RETURN
C      END
/*
```

APPENDIX C. LEAST SQUARE CURVE FIT (CONLSQ)

In this section is presented the theory leading to a least squares polynomial intended to fit periodic data. It is assumed that one has in hand a random process whose mean or expected values depend on a parameter x which takes on values around the circle, i. e., 0-360 degrees. It is further assumed that a polar plot of the (unknown) locus of means is a smooth curve, i. e., has no jumps or kinks, in fact, that the locus of mean values is a polynomial of degree n in x that is constrained to have the same value, slope, and curvature at zero and 360 degrees. If the unknown polynomial is denoted by $P_n(x)$, and if m observations are taken at $x = x_1, x_2, \dots, x_m$, then the observations $y_i, i = 1, 2, \dots, m$, are given by $y_i = P_n(x_i) + e_i$, where the deviations e_i are independent with zero mean and common standard deviation σ .

If the deviations e_i are normally distributed, then the expectation of y_i is $P_n(x_i)$ and the joint probability density of y_1, \dots, y_m is

$$f(y_1, \dots, y_m; x_1, \dots, x_m) = \frac{1}{(\sigma\sqrt{2\pi})^m} e^{-1/2 \sum_{i=1}^m \left(\frac{y_i - P_n(x_i)}{\sigma} \right)^2}$$

This density is maximized when the quantity $\sum_{i=1}^m \left(\frac{y_i - P_n(x_i)}{\sigma} \right)^2$ is minimized. Hence the polynomial $\hat{P}_n(x)$ that minimizes the sum of squared deviations of y_1, \dots, y_m therefrom is the maximum likelihood estimate of the unknown locus of means $P_n(x)$.

The polynomial $\hat{P}_n(x)$ that minimizes the sum of squared deviations and is constrained to repeat value, slope and curvature is found with the aid of Lagrange multipliers.

For an arbitrary polynomial $P_n(x)$, the deviation of y_i therefrom is given by

$$e_i = P_n(x_i) - y_i$$

and the sum of squared deviations is

$$\sum_{i=1}^m e_i^2 = \sum_{i=1}^m \left(P_n(x_i) - y_i \right)^2 = \sum_{i=1}^m \left(\sum_{j=0}^n a_j x_i^j - y_i \right)^2$$

The constraints

$$y(0) = y(360)$$

$$y'(0) = y'(360)$$

$$y''(0) = y''(360)$$

reduce to

$$a_1 + a_2(360) + \dots + a_n(360)^{n-1} = 0$$

$$2a_2 + 3a_3(360) + \dots + na_n(360)^{n-2} = 0$$

$$2 \cdot 3a_3 + 3 \cdot 4a_4(360) + \dots + n(n-1)a_n(360)^{n-3} = 0$$

respectively. Denote these linear combinations of a_1, \dots, a_n by

$$L_1(a_1, \dots, a_n)$$

$$L_2(a_2, \dots, a_n)$$

$$L_3(a_3, \dots, a_n)$$

respectively.

To find the desired polynomial, we form the function

$$F(a_0, \dots, a_n) = \sum_{i=1}^n \left(\sum_{j=0}^m a_j x_i^j - y_i \right) + \lambda_1 L_1(a_1, \dots, a_n)$$

$$+ \lambda_2 L_2(a_2, \dots, a_n) + \lambda_3 L_3(a_3, \dots, a_n).$$

set each of its partial derivatives equal to zero, append the constraints

$$L_1 = 0$$

$$L_2 = 0$$

$$L_3 = 0$$

and solve this system of equations for a_0, \dots, a_n . The equations to be solved are then

$$\frac{\partial F}{\partial a_0} = 2 \sum_{i=1}^m \left(\sum_{j=0}^n a_j x_i^j - y_i \right) = 0$$

$$\frac{\partial F}{\partial a_1} = 2 \sum_{i=1}^m \left(\sum_{j=0}^n a_j x_i^j - y_i \right) x_i + \lambda_1 = 0$$

$$\frac{\partial F}{\partial a_2} = 2 \sum_{i=1}^m \left(\sum_{j=0}^n a_j x_i^j - y_i \right) x_i^2 + 360 \lambda_1 + 2 \lambda_2 = 0$$

$$\frac{\partial F}{\partial a_3} = 2 \sum_{i=1}^m \left(\sum_{j=0}^n a_j x_i^j - y_i \right) x_i^3 + (360)^2 \lambda_1 + 3 (360) \lambda_2 + 2 \cdot 3 \lambda_3 = 0$$

$$\frac{\partial F}{\partial a_k} = 2 \sum_{i=1}^m \left(\sum_{j=0}^n a_j x_i^j - y_i \right) x_i^k + (360)^{k-1} \lambda_1$$

$$+ k (360)^{k-2} \lambda_2 + k(k-1) (360)^{k-3} \lambda_3 = 0$$

$$k = 4, \dots, n$$

$$L_1 (a_1, \dots, a_n) = 0$$

$$L_2 (a_2, \dots, a_n) = 0$$

$$L_3 (a_3, \dots, a_n) = 0$$

Expanding sums, dividing the first $n+1$ equations by 2, and redefining λ_1 , λ_2 and λ_3 , the system of equations becomes, in matrix form, as shown in Figure C-1.

In practice, one usually does not know a priori what degree polynomial to use. However, the sum of squared deviations for various degrees may furnish a clue. Suppose the degree of the unknown polynomial is n . Then whether or not the deviations are normally distributed, the sum of squared deviations about the fitted curve divided by $m - n - 1$ is an unbiased estimate of the unknown variance σ^2 . In fact, unbiasedness obtains whenever the degree of the fitted polynomial is at least the degree of the unknown locus of means. Then as one proceeds upward from degrees too low, the estimate of σ^2 can be expected to steadily drop until the correct degree is reached and then level off and fluctuate irregularly around the value σ^2 as the degree of the fitted curve exceeds by more and more the degree of the unknown curve of expected values.

$$\begin{bmatrix}
 m & \sum x_i & \sum x_i^2 & \sum x_i^3 & \dots & \sum x_i^n & 0 & 0 & 0 & 0 \\
 \sum x_i & \sum x_i^2 & \sum x_i^3 & \sum x_i^n & \dots & \sum x_i^{n+1} & 1 & 0 & 0 & 0 \\
 \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \sum x_i^5 & \dots & \sum x_i^{n+2} & 360 & 2 & 0 & 0 \\
 \sum x_i^3 & \sum x_i^4 & \sum x_i^5 & \sum x_i^6 & \dots & \sum x_i^{n+3} & (360)^2 & (360)^2 & 3(360) & 0 \\
 \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\
 \sum x_i^n & \sum x_i^{n+1} & \sum x_i^{n+2} & \sum x_i^{n+3} & \dots & \sum x_i^{2n} & (360)^{n-1} & n(360)^{n-2} & n(n-1)(360)^{n-3} & 0 \\
 0 & 1 & 360 & (360)^2 & \dots & (360)^{n-1} & 0 & 0 & 0 & 0 \\
 0 & 0 & 2 & 3(360) & \dots & n(360)^{n-2} & 0 & 0 & 0 & 0 \\
 0 & 0 & 0 & 3 \cdot 2 & \dots & n(n-1)(360)^{n-3} & 0 & 0 & 0 & 0
 \end{bmatrix}
 =
 \begin{bmatrix}
 a_0 \\
 a_1 \\
 a_2 \\
 a_3 \\
 \dots \\
 a_n \\
 \lambda_1 \\
 \lambda_2 \\
 \lambda_3
 \end{bmatrix}
 \begin{bmatrix}
 \sum y_i \\
 \sum x_i y_i \\
 \sum x_i^2 y_i \\
 \sum x_i^3 y_i \\
 \dots \\
 \sum x_i^n y_i \\
 0 \\
 0 \\
 0
 \end{bmatrix}$$

Figure C-1. Matrix of Normal Equation

The degree of the fitted curve must be at least four or the curve will degenerate into a horizontal line through the means of all points. For, if the selected degree is three, then the second derivative is linear, hence constant in order to match at zero and 360. Hence, the curve will be a quadratic and the slope will be linear. Then the slope must be a constant in order to match. But then the curve is a straight line and must be constant for the values to match.

DESCRIPTION AND USE

The main program, CONLSQ, reads the wind azimuth and speed information for the various anemometer locations, the degree, or degrees, of the desired polynomials, and the number of evenly spaced points at which the fitted curve is to be computed, and prepares the data for subroutine SUMPOW. Each time SUMPOW is called, it solves the system of equations previously given for a_0, \dots, a_n , computes the fitted curve at the number of points requested, and plots the input data and fitted curve as an azimuth shift or a velocity ratio, depending on the value of a logical variable set in CONLSQ.

The inputs to CONLSQ are read in the NAMELIST format and include NTOP (the number of data points for the top anemometer), AZMTH (500, 4) (azimuths for the various anemometers), VELOC (500, 4) (speeds), DEGLow (the lowest degree polynomial desired), DEGHI (the highest degree polynomial desired), DEGINC (the step size desired going from DEGLow to DEGHI), and NGRAPH (the number of points desired on the fitted curve).

The first column in each of AZMTH and VELOC is for the top anemometer data, the second for the east anemometer, the third for the west anemometer, and the fourth for the deck level. The last was not used because of the paucity of data from the deck-level anemometer. If an azimuth for any of columns 2 through 4 is unavailable, a value greater than 370 should be entered and ignored; if a velocity is unavailable, a value of 500 should be entered and ignored.

The order of computation, first for the east anemometer and then the west:

1. Compute azimuth shift for the azimuths available (at the east or west anemometer), counting the number of "good" points NOGP and calling SUMPOW once for each degree polynomial from DEGLow to DEGHI in steps of size DEGINC;
2. Compute speed ratio for the number of speeds available (at the east or west anemometer) and proceed as in Step 1.

After these computations, the data for the east and west anemometers are pooled (referred to the east anemometer) and SUMPOW is called twice, once for azimuth shifts and once for velocity ratios.

The only output is in the form of CRT plots prepared in the subroutine SUMPOW. Typical graphs are Figures C-2 and C-3. There are no options concerning the scales, labeling, etc., of the CRT output.

The solution of the simultaneous equations is obtained by calling the double precision subroutine DMSEQ in SUMPOW.

Listings for the main program CONLSQ and subroutine SUMPOW are given at the end of this section.

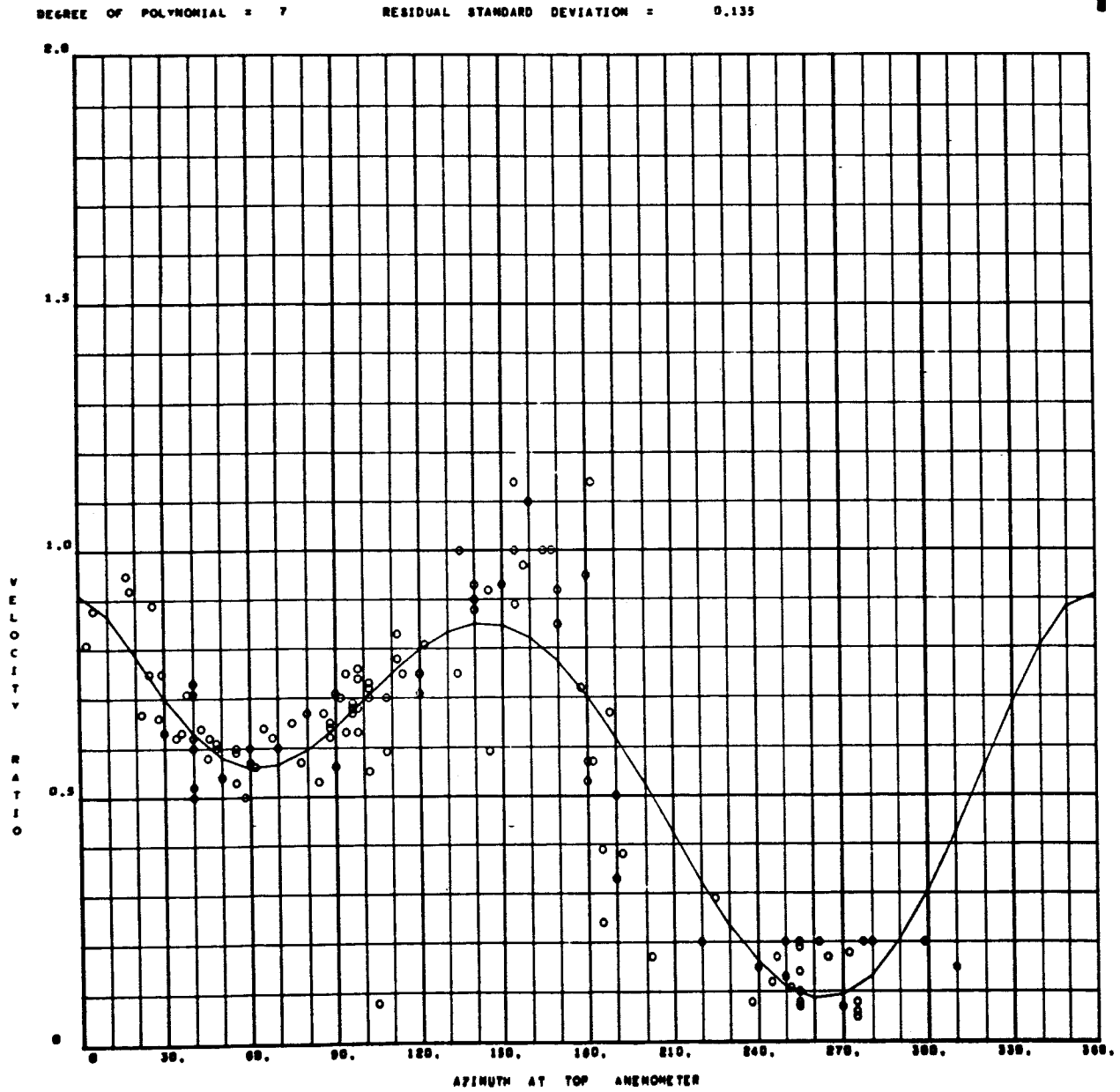


Figure C-2. Typical Least-Error Polynomial Output by CONLSQ Program

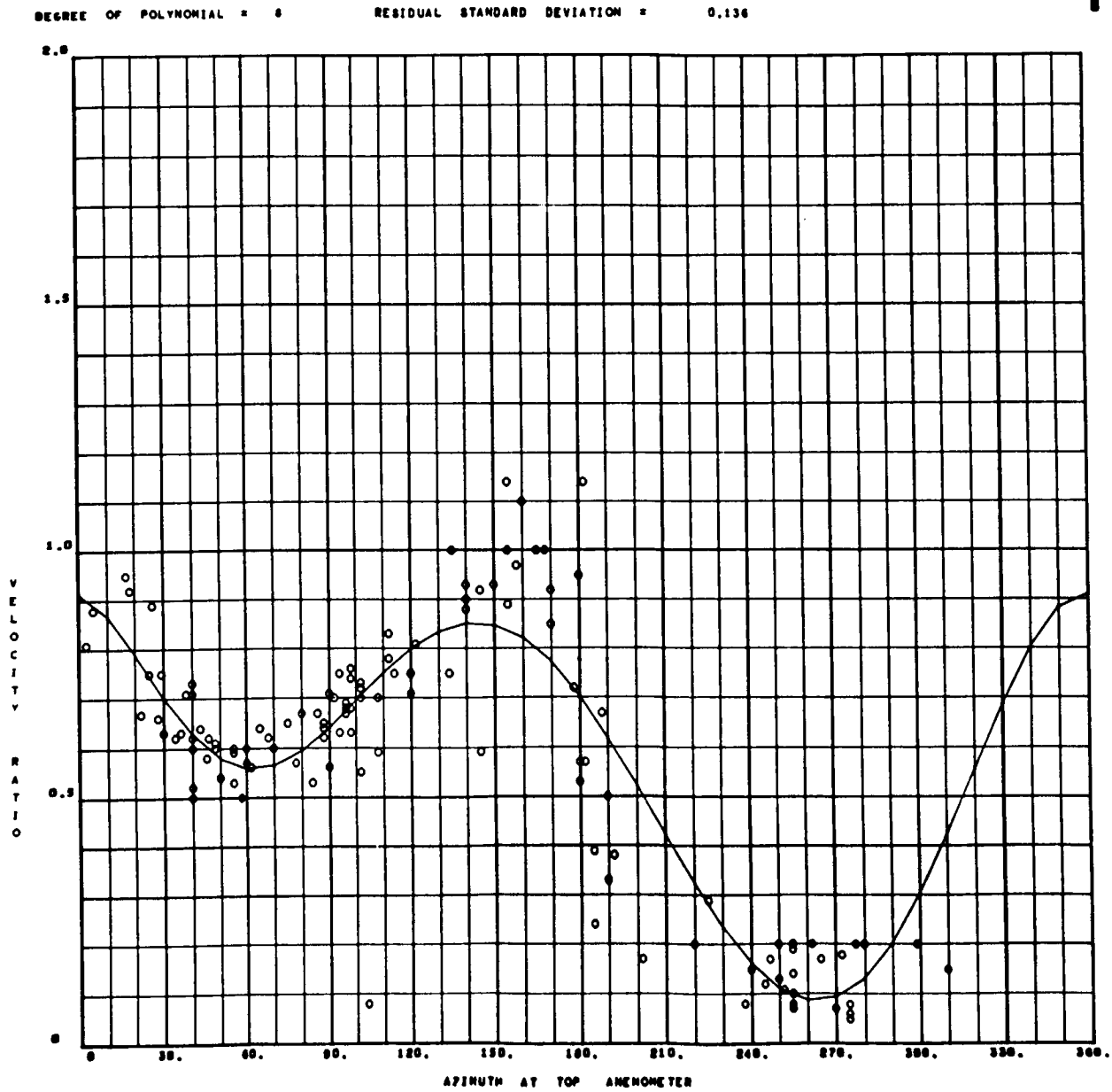


Figure C-3. Typical Least-Error Polynomial Output by CONLSQ Program

Listing of CONLSQ Program

==01

```

C      CONLSQ PROGRAM                J.E.DAVIS  190-220
C      CONSTRAINED LEAST FIT OF PERIODIC WIND DATA
C
C      REAL*8 X,Y,PDXC,PDXG
C      INTEGER DEGLW,DEGHI,DEGINC
C      LOGICAL AZTST
C      COMMON /SUB/ X(1000),Y(1000),NDEG,NOGP,RMS,NGP
C      *          ,XGRAPH(500),YGRAPH(500),NGRAPH,IBLK,JBLK
C      COMMON /CIP/ DEGLW,DEGHI,DEGINC,AZMTH,VELOC,NTOP,CASEND
C      COMMON / TEST / AZTST
C
C      DIMENSION IAZ(4), AZS(500,4),XAZ(500,4), AZT(500),
C      *          VELR(500,4), XVEL(500,4), IVEL(10),AZMTH(500,4),VELOC(500,4)
C
C      EQUIVALENCE (AZMTH(1,1),AZT(1))
C
C      CALL SCOUTV
C      CALL CAMRAV( 9 )
C
C      5 READ (5,DATA)
C
C      NGP = NGRAPH + 1
C      DO 8 I = 1, NGP
C      8 XGRAPH(I) = (I-1) * 360. / (NGRAPH)
C
C      DO 30 J=2,3
C      IAZ(J) = 0
C      DO 10 I=1,NTOP
C      IF(AZMTH(I,J) .GT. 370.) GO TO 10
C      IF(AZMTH(I,J) .GT. 360. .AND. AZMTH(I,J) .LE. 370.)
C      *          AZMTH(I,J) = AZMTH(I,J) - 360.
C      IAZ(J) = IAZ(J) +1
C      AZS(IAZ(J),J) = AZMTH(I,J) - AZT(I)
C      Y(IAZ(J)) = AZS(IAZ(J),J)
C      XAZ(IAZ(J),J) = AZT(I)
C      X(IAZ(J)) = XAZ(IAZ(J),J)
C      AYIAZJ = DABS(Y( IAZ(J) ))
C      IF ( AYIAZJ .GT. 90.) IAZ(J) = IAZ(J) -1
C      10 CONTINUE
C
C      NOGP = IAZ(J)
C      DO 15 JJ = DEGLW,DEGHI,DEGINC
C      NDEG = JJ
C      AZTST = .TRUF.
C      CALL SUMPDM
C      15 CONTINUE
C
C      IVEL(J) = 0
C      DO 20 N=1,NTOP
C      IF(VELOC(N,J) .EQ. 500.) GO TO 20
C      IVEL(J) = IVEL(J) +1
C      X(IVEL(J)) = AZT(N)
C      Y(IVEL(J)) = VELOC(N,J)/VELOC(N,1)
C      XVEL ( IVEL (J), J) = X ( IVEL (J))
C      VELR ( IVEL (J), J) = Y ( IVEL (J))
C      20 CONTINUE
C      X IS XVEL, Y IS VELR
C
C      NOGP = IVEL(J)
C      DO 25 JJ= DEGLW,DEGHI,DEGINC

```

==02

```
NDEG = JJ
AZTST = .FALSE.
CALL SUMP0W
25 CONTINUE
30 CONTINUE

C
C   POOL DATA FROM EAST AND WEST
NN = IVEL(2)
DO 40 I=1,NN
Y(I) = VELR(I,2)
X(I) = XVEL(I,2)
40 CONTINUE

C
NN = IVEL(3)
DO 50 I= 1,NN
Y(I+IVEL(2)) = VELR(I,3)
X(I+IVEL(2)) = 360. - XVEL(I,3)
50 CONTINUE
DO 55 JJ= DEGL0W,DEGHI,DEGINC
NDEG = JJ
NOGP = IVEL(2) + IVEL(3)
AZTST = .FALSE.
CALL SUMP0W
55 CONTINUE

C
NN = IAZ(2)
DO 60 I=1,NN
Y(I) = AZS(I,2)
X(I) = XAZ(I,2)
60 CONTINUE
NN = IAZ(3)
DO 70 I= 1,NN
Y(I+IAZ(2)) = -AZS(I,3)
X(I+IAZ(2)) = 360. - XAZ(I,3)
70 CONTINUE

C
C   DO 75 JJ= DEGL0W,DEGHI,DEGINC
NDEG = JJ
NOGP = IAZ(2) + IAZ(3)
AZTST = .TRUE.
CALL SUMP0W
75 CONTINUE

C
C   GO TO 5
END

/*
/*
/*
```

Listing of Subroutine SUMPOW

```

SUBROUTINE SUMPOW
INTEGER*4 E(50)
REAL*8 X,Y,POXC,POXG,POX,POXY,XGRA,YGRA,YCURVE,RESO,DERMS
REAL*8 A(18,18), SX(50), XP(50), SXY(50),B(18),DET,SCALE(50)
DIMENSION XS(1000),YS(1000)
COMMON /SUB/ X(1000),Y(1000),NDEG,NOGP,RMS,NGP
*      ,XGRAPH(500),YGRAPH(500),NGRAPH,IBLK,JBLK
COMMON / TEST / AZTST
LOGICAL SING , AZTST
C
C      COMPUTE SUMS OF POWERS OF X AND YTIMES POWERS OF X
C
DET = 1.000
SCALE(1) = 1.0 DO
NPX = 2*NDEG + 1
NVR = NDEG + 1
NEQ = NVR+3
C
DO 100 J = 1 , 50
SX( J ) = 0.0 DO
100 SXY( J ) = 0.000
C
DO 300 I = 1 , NOGP
POX = 1.0 DO
DO 200 J = 1 , NPX
SX( J ) = SX( J ) + POX
200 POX = POX*X( I )
300 CONTINUE
C
DO 500 I = 1 , NOGP
POXY = Y( I )
DO 400 J = 1 , NVR
SXY(J) = SXY(J) + POXY
400 POXY = POXY*X( I )
500 CONTINUE
C
C      INITIALIZE MATRICES
DO 520 I=1,18
B(I) = 0.0 DO
DO 510 J = 1 , 18
510 A(I,J) = 0.0 DO
520 CONTINUE
C
C      COMPUTE MATRIX OF COEFFICIENTS
DO 700 I = 1 , NVR
B( I ) = SXY( I )
DO 600 J = 1 , NVR
600 A( I , J ) = SX( I + J - 1 )
700 CONTINUE
C
XP( 1 ) = 1.0 DO
DO 800 I = 2 , NVR
800 XP( I ) = XP( I - 1 ) * 360.
C
DO 900 J = 2 , NVR
900 A( NEQ - 2 , J ) = XP( J - 1 )
C
DO 1000 J = 3 , NVR
1000 A( NEQ - 1 , J ) = ( J - 1 ) * XP( J - 2 )
C
DO 1100 J = 4 , NVR

```

==02

00000030

```

1100 A( NEQ , J ) = ( J - 1 )*( J - 2 )*XP( J - 3 )

```

C

```

NVRP= NVR +1
DO 1200 I = NVRP,NEQ
DO 1300 J = 1 , NVR

```

```

1300 A(J,I) = A(I,J)
1200 CONTINUE

```

C

```

RET = DMSEQ(18,NEQ,1,A,B,E,DET,SCALE)
IF(RET.EQ.0.0) WRITE(6,1350)

```

```

1350 FORMAT (1H- , 'A MATRIX IS SINGULAR' ,//)

```

C

C

C

```

      COMPUTE FITTED CURVE

```

```

DO 1500 I=1,NGP
YGRA = 0.000
XGRA = XGRAPH(I)
POXG = 1.0 DO
DO 1400 J= 1,NVR
YGRA = YGRA + A(J,1) * POXG

```

```

1400 POXG = XGRA * POXG

```

```

YGRAPH(I) = YGRA
1500 CONTINUE

```

C

C

```

      COMPUTE RESIDUAL STANDARD DEVIATION

```

```

RESD = 0.0 DO
DO 1700 I= 1,NOGP
YCURVE = 0.0 DO
POXC = 1.0 DO
DO 1600 J = 1,NVR
YCURVE = YCURVE + POXC * A(J,1)
1600 POXC = POXC * X(I)
RESD = RESD + (Y(I) - YCURVE) **2

```

```

1700 CONTINUE

```

```

DERMS = NOGP - NVR
ARG = RESD/DERMS
RMS = SQRT( ARG )

```

C

```

NNGR = NOGP

```

C

```

DO 1750 I = 1,NOGP
XS(I) = X(I)
1750 YS(I) = Y(I)
IF( AZTST ) GO TO 1800
XL = 0.0
XR = 360.0
YB = 0.0
YT = 2.0
DXGKA = 10.0
DYGRA = 0.1
NGRA = 3
MGRA = 5
LABX = -3
LABY = -5

```

```

CALL GRIDIV( -3 , XL , XR , YB , YT , DXGRA , DYGRA , NGRA ,
* MGRA , LABX , LABY , 4 , 3 )

```

```

CALL PRINTV( 31 , ' AZIMUTH AT TOP ANEMOMETER ' , 400 , 4 )

```

```

CALL APRNTV( 0 , -17 , 17 , ' VELOCITY RATIO ' , 4 , 500 )

```

```

CALL APLTV( NNGR , XS , YS , 1 , 1 , 1 , 38 , IEHR )

```

```

WRITE( 16 , 1900 ) NDEG , RMS

```

```

1900 FORMAT(1H+ , ' DEGREE OF POLYNOMIAL = ' , I2 , 10X , ' RESIDUA

```

```

*L STANDARD DEVIATION = ' , F10.3 )
GO TO 2010

```

==03

```

1800 XL = 0.0
      XR = 360.0
      YB = -100.0
      YT = 100.0
      DXGRA = 10.0
      DYGRA = 10.0
      NGRA = 3
      MGRA = 3
      LABX = -3
      LABY = -3
      CALL GRIDIV( -3 , XL , XR , YB , YT , DXGRA , DYGRA , NGRA ,
*           MGRA , LABX , LABY , 4 , 3 )
      CALL PRINTV( 31 , ' AZIMUTH AT TOP ANEMOMETER ' , 400 , 4 )
      CALL APRNTV( 0 , -16 , 16 , ' AZIMUTH SHIFT ' , 4 , 500 )
      CALL APLOTV( NNGR , XS , YS , 1 , 1 , 1 , 38 , IERR )
      WRITE( 16 , 2000 ) NDEG , RMS
2000 FORMAT(1H+ , ' DEGREE OF POLYNOMIAL = ' , I2 , 10X , ' RESIDUA
*L STANDARD DEVIATION = ' , F10.3 )
2010 CONTINUE
      DO 3000 I=2,NGRAPH
          IX1 = NXV(XGRAPH(I-1))
          IY1 = NYV(YGRAPH(I-1))
          IX2 = NXV(XGRAPH(I))
          IY2 = NYV(YGRAPH(I))
          CALL LINEV(IX1,IY1,IX2,IY2)
3000 CONTINUE
          IX3 = NXV(360.)
          IY3 = NYV(YGRAPH(1))
          CALL LINEV (IX2,IY2,IX3,IY3)
C
      RETURN
      END
/*
/*
/*

```

```

0000050
0000060

```

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