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SOME OBSERVATIONS ON THE PROBLEM OF DEFINING MEAN WIND SPEEDS REPRESENTATIVE OF FLOW OVER URBAN AND SUBURBAN TERRAIN.

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Summary

The problem of defining a mean wind speed which reflects the general characteristics of the surrounding terrain is examined for the particular case of the area around Sheffield University. This problem has arisen in connection with the data analysis procedures for a full scale wind force measurement project where a reference wind speed is required for data presentation.

The mean wind structure over the area has been assesed using wind tunnel modelling techniques. The results of this exercise are compared with an analysis of the data from three anemometers on the site, one of which is responsible for supplying wind data to the Meteorological Office.

The results of this project imply that considerable uncertainty is associated with any definition of a supposed 10m mean wind speed in an area whose terrain is composed of objects of the same order of magnitude. It is concluded that a representative mean wind speed for urban/suburban areas can only be defined for heights considerably in excess of 10m.

Contents

1. Introduction

This report presents some preliminary results of investigations into the relationship between the wind velocity measured at three points on the site of a full scale wind loading test. These investigations were initiated in order to assist with the data analysis programme associated with a wind loading experiment. The building concerned, the 20 storey Arts Tower at Sheffield University has been the subject of an extensive programme of research whose aim has been to determine the dynamic wind loads which act on the structure. The method of determination of these dynamic wind loads is fully described in ref. (1).

It is important that during the measurement of the wind loads that simultaneous records of the wind speed and direction are made, in order to determine the levels of load which are associated with various combinations of wind speed and direction and that for a given wind direction, how the dynamic load and the wind speed are related. Ideally it would be preferable to be able to relate the dynamic wind force data to a wind velocity measured at a height of 10m above open, level ground which properly reflected the general characteristics of the terrain in the vicinity of the test site. Such a definition of the reference wind speed would then conform to current Meteorological Office practice and might enable a straightforward application of the projects results.

2. Sources of Wind Data

The wind speed recordings, used as a reference for calculating building response to given levels of wind activity have, in the past, been obtained from two sources. The principal source, i.e. the wind speed which is recorded together with building acceleration levels thus providing the basic data for modal force analysis, has been obtained from a Casella cup anemometer mounted on a 6m mast located on the roof of the Arts Tower, see Plate 1. The height of this anemometer is 84m above street level. The positioning of this anemometer is well within the 'building induced' interference to the wind flow, the magnitude of this interference being strongly directional. This necessitates the inclusion of an incident wind direction correction factor for the wind speed during data analysis. The correction used to date was determined by a wind tunnel investigation of the variation of mean wind speed with direction, measurements having been made on a 1:400 scale model of the isolated building, with no modelling of the buildings on the surrounding site. One of the aims of the present investigation is to attempt to identify and measure any significant site induced wind speed variations which should be included in the correction factor.

Wind direction data are obtained from recordings available from the Weston Park Museum, Plate 2, which has a Dines anemograph mounted on a 10m mast on the roof, 22m above street level. It is worth noting here that although the Weston Park anemometer station has been superseded by that situated on the University's Geography Building, Plate 1, as the official source of Meteorological Office data for Sheffield it nevertheless possesses long term recordings of the area which, it is envisaged, may prove a useful data source.

The instrument situated on the Geography Building is a Munro 3 cup anemometer on a 6m mast and is 31m above street level. The relative horizontal dispositions of the three instruments are shown in Figure 1.

The adjustment of the velocity indicated by the Arts Tower roof anemometer, used in the dynamic force data analysis programme, to a representative height of 10m, as reported in reference (1), has been performed with the aid of a vertical wind speed relationship established from a very brief survey of simultaneous recordings of both the Arts Tower and Weston Park Museum instruments. This survey, taken during a small number of heavy storms, indicated a ratio of 2.44:1 for the wind speeds, measured for a range of wind directions, at the Arts Tower and Weston Park, respectively. The Meteorological Office convention of assuming the Weston Park Museum anemometer to indicate an equivalent 10m wind speed was followed.

Investigations into the relationship between the wind velocity measured at the three anemometers on the site (Arts Tower, Geography and Weston Park) of the full scale test have, therefore, been initiated in an attempt to characterise any major peculiarities of the site in so far as they may affect the full scale wind loading tests and to provide a means of normalising the force data with respect to a reproducible characteristic wind velocity parameter.

The general aims of this investigation are then:

1. To determine the variation in mean velocity with incident wind direction measured by the Arts Tower anemometer and, by comparing this with the undisturbed wind flow, attempt to separate 'building induced' variations and 'site induced' variations.

2. To compare this information with the mean wind speeds measured at the two other anemometer stations in an attempt to identify the major flow characteristics of the site, and to define a vertical mean wind speed relationship.

3. From this information and, given the long term recordings available from Weston Park, it may be possible to estimate the probability of occurrence of given levels of dynamic activity of the Arts Tower.

Investigations into the wind structure of the area have consisted of a combination of measurements carried out on wind tunnel site models together with a simple statistical comparison of the full scale data obtained from the three anemometer stations. These two comparative studies are described in the following sections.

3. The Wind Tunnel and Models

3.1 The Wind Tunnel

The experiments were carried out in the Sheffield University 1.2 x 1.2m Boundary Layer Wind Tunnel. The simulation of the dominant characteristics of the natural wind flow over the suburban/urban area was achieved by the inclusion of flow mixing devices and roughness sheets in the forward part of the working section. Both the wind tunnel and the method of atmospheric boundary layer simulation are fully described in (2). The majority of the tests were performed at a scale of 1:1000, in order to include the maximum site area on the wind tunnel turntable. However, in order to examine the influence of roof detail and anemometer location on the measured wind speed some tests were performed with larger models, at a scale of 1:350.

The modelled anemometer speed measurements were made with a miniature NPL type pitot-static tube connected to a Betz manometer. These measurements were all checked using a linearised DISA hot wire anemometer fitted with a straight wire probe. The wind tunnel reference speed was monitored by a further NPL type pitot-static tube connected to a Betz manometer and located at the modelled gradient height, 900mm above floor level.

3.2 The Models

A linear modelling scale of 1:1000 was used for the majority of the tests in order to accommodate the extent of the relevant site on the 1.1m diameter wind tunnel turntable. This scale enabled all major buildings within a radius of 550m of any of the anemometer stations to be modelled.

Figure 1 shows a plan of the major buildings on the site. All other buildings, usually less than about 15m in height, were modelled as simple scaled blocks and, for the sake of clarity, are not included here. The site model was not contoured.

The desirability of presenting each of the 3 anemometry stations with, in the absence of any surrounding modelled buildings, nominally identical wind patterns (i.e. so that the effect of tunnel variables were minimised) dictated the use of a sectional model layout. This was constructed such that each of the measuring stations in turn could be positioned in the centre of the turntable and still be surrounded with an accurate representational model of all major buildings within a scaled radius of 550m. The model sections are indicated by the circles in Figure 1 and can be seen in Plate 3, the photo of the 1:1000 site model. The lettering on Plate 3 indicates the buildings as follows, AT (Arts Tower) WP (Weston Park Museum), G (University Geography Building) and RHH (Royal Hallamshire Hospital). This last building referred to, the Royal Hallamshire Hospital, is a major site feature and is shown in Plate 4.

The RHH building was only modelled on the turntable for the model section centred on the Weston Park Museum anemometer, since for the other two sections it lay outside their 550m radii. For these two sections of the model the RHH building was positioned in the wind tunnel working section at the appropriate distance and orientation upstream of the turntable centre. It was necessary to reposition this building following each turntable rotation.

4. Results of Wind Tunnel Measurements

4.1 The Arts Tower Anemometer - Speed Measurement

Figure 2 shows the variation of measured wind speed, U_A, with flow direction for the Arts Tower anemometer for the 1:1000 site model. The speed is shown non-dimensionalised by U_0, the undisturbed wind speed at the anemometer height. It should be noted that the anemometer is not centrally located above the building's roof and so a degree of asymmetry will arise from this source, amongst others which may be due to the site.

A number of characteristics of this graph are worth noting.

a) The peaks of the graph appear to correspond to the wind flow being incident on the building corners. A simple geometrical estimate of the expected peak separation, i.e. from the position of the anemometer with respect to the building corners, predicts angular separations of approximately 55^o, 120^o, 75^o and 110^o. These values compare favourably with the experimentally observed values of 55^o, 110^o, 80^o and 115^o, the differences being well within the limit of expected experimental error.

b) Minima in the graph correspond to the wind flow being incident normally onto the building faces. The difference between the true compass direction shown in Figure 2 and the direction of the nominally north face of the building is 20^o, with the building north facing 340^o.

c) The minimum at $\doteqdot 350^o$ is of particular significance to the wind loading programme. This direction corresponds to the wind being incident normally onto the northerly broad face of the building and also corresponds with a common wind direction. With the wind in this direction the speed measured by the anemometer on the Arts Tower would indicate only approximately 50% of the true wind speed at that height. This is especially significant in the data analysis since wind force is proportional to the square of wind speed.

When the Arts Tower building was removed from the 1:1000 site model it was found that the measured wind speed at the anemometer height remained approximately constant with wind direction, Figure 3. An examination of Figure 3 shows that the inclusion of the RHH building, located 600m away from the Arts Tower on a bearing of 225^o, in the working section produces only a barely discernable effect.

A comparison of the variation of mean wind speed with incident direction made at the modelled location of the Arts Tower anemometer, both with and without the Arts Tower model in position indicate this variability to be almost entirely building dependent. Very little contribution to the mean wind variation is considered to be generated by the surrounding site.

Clearly small errors in positioning of measuring devices at a modelling scale of 1:1000 are likely to introduce significant errors in the magnitudes of measured speeds in regions of high shear variability such as that known to exist near the roof of the Arts Tower. In order to illustrate this, the anemometer position was moved 2mm north (on the model scale) and the variation of mean wind speed with direction re-examined. Figure 4 shows the effect of this movement of the anemometer position on the measured wind speed and is compared with the original position data presented in Figure 2. Figure 4 shows that, whilst the general shape of the curve remains similar, the magnitude of the minimum at 350^{o} changes dramatically. This would seem to indicate that whilst the general properties of the graph may be confidently accepted the actual magnitudes of all the peaks and troughs require more careful examination.

Further tests have been conducted on a model of the Arts Tower at a scale of 1:350, the larger model enabling a more accurate anemometer positioning to be maintained. These tests at the larger scale have not been performed in the presence of a site model, following the conclusions reached from Figures 2 and 3. The initial 1:350 Arts Tower model had a flat roof, unlike the actual building whose roof surface is a complex group of small shapes housing lift motor rooms, water tanks, flue housings, etc.

Figure 5 shows the variation of the measured wind speed with wind direction for the flat roofed 1:350 model compared with the 1:1000 model data from Figure 2. Whilst the angular locations of the maxima and minima remain the same, it is evident that their magnitudes are different, with less overall variability in the larger scale building results. Since it was considered that the differences shown in Figure 5 may well have been due to inaccuracies in the location of the anemometer above the 1:1000 model it was thought useful to investigate the effect of small differences in anemometer height above the roof using the larger model. The influence of small changes in anemometer height, or mast height, are shown in Figure 6 where the directionally dependent speed variations are shown for mast heights of 4m, 6m and 8m full scale. The very large speed differences at 170^{o} and 350^{o} caused by reducing the 6m mast height to 4m imply that very small errors in vertical positioning on the 1:1000 model tests could be responsible for large errors in their results.

The last test with the 1:350 model was to inspect the influence of the actual roof structure as opposed to the flat roof model used so far. The results of this test are shown in Figure 7 where the true roof structure model and the flat roof model are compared. With the exception of the minimum at 70^{o} the two models produce very similar results.

This final data set, i.e. of the 1:350 true roof structure model, is recommended as the basis for the directionally dependent wind speed correction factor to be applied in the analysis of the full scale experimental data. The application of this set of correction factors, repeated in Table 1, will convert the measured wind speed at 84m above street level to an equivalent undisturbed wind speed at a height of 84m which reflects the general terrain characteristics of the area.

Table 1

Wind Direction Speed Correction Factor

Arts Tower Anemometer

DIRECTION INTERVAL	CORRECTION FACTOR		DIRECTION INTERVAL	CORRECTION FACTOR
1- 5	1.28		181-185	0.90
6- 10	1.25		186-190	0.89
11- 15	1.19		191-195	0.88
16- 20	1.12		196-200	0.88
21- 25	1.04		201-205	0.87
26- 30	0.99		206-210	0.87
31- 35	0.94		211-215	0.88
36- 40	0.93		216-220	0.89
41- 45	0.93		221-225	0.91
46- 50	0.95		226-230	0.93
51- 55	1.01		231-235	0.95
56- 60	1.05		236-240	0.97
61- 65	1.14		241-245	0.99
66- 70	1.19		246-250	1.00
71- 75	1.22		251-255	1.00
76- 80	1.20		256-260	0.99
81- 85	1.15		261-265	0.98
86- 90	1.08		266-270	0.96
91- 95	0.97		271-275	0.94
96-100	0.93		276-280	0.93
101-105	0.92		281-285	0.90
106-110	0.92		286-290	0.89
111-115	0.93		291-295	0.88
116-120	0.93		296-300	0.87
121-125	0.96		301-305	0.88
126-130	0.97		306-310	0.90
131-135	0.98		311-315	0.94
136-140	0.98		316-320	0.99
141-145	0.98		321-325	1.08
146-150	0.97		326-330	1.12
151-155	0.96		331-335	1.18
156-160	0.95		336-340	1.22
161-165	0.94		341-345	1.27
166-170	0.93		346-350	1.28
171-175	0.92		351-355	1.30
176-180	0.91		356-360	1.30

4.2 The Arts Tower Anemometer - Direction Measurement

Some preliminary tests have been conducted on a 1:1000 model of the Arts Tower in order to estimate the accuracy of the full scale wind direction vane. In these tests a small vane, approximately 3mm square, was mounted on a jewel watch bearing on the model roof and the direction of the vane relative to the tunnel axis was monitored for different building orientations. It was found that for some directions, notably those for which a roof corner lay upstream of the vane position, a very large angular difference, up to 60^o, existed between the vane indication and the tunnel axis. A visual inspection of the vane behaviour also indicated a far greater degree of oscillation for some building orientations than for others.

The tentative conclusion drawn from these preliminary tests is that the full scale vane indication is unlikely to be a reliable source of information and that it is not possible at present to produce a vane measurement correction factor. It is recommended that another wind direction data source in the vicinity of the test site is used in preference to that provided by the Arts Tower instrument.

4.3 The University Geography Building Anemometer

The University Geography Building anemometer is a Munro 3 cup anemometer mounted on a 6m mast attached to the 25m roof and is thus 31m above street level. The output data from this instrument are used by the Meteorological Office as a source of wind data for the Sheffield area. The authors of this report are not aware of any wind speed corrections applied by the Met Office to these data either for anemometer height or for wind direction.

Tests, carried out using the 1:1000 site model, have been conducted in a manner similar to those described in the preceding sections. The variations of measured wind speed with wind direction are shown in Figure 8 where the speed, U_G, is shown non-dimensionalised by the average undisturbed wind speed at that height for all wind directions, U_0. In order to distinguish between wind speed variations due to the building proximity itself and separately, those due to the characteristics of the site, the 1:1000 model of the Geography building was removed from the site model and the measurements were repeated. The two sets of results are shown together in Figure 9 where it can be clearly seen that all the major features reported in Figure 8, for wind speeds measured above the building, are due to the site features alone and not to the building proximity itself. This conclusion is the reverse of that found in the case of the Arts Tower anemometer.

Figures 8 and 9 show a number of interesting features:

a) The minimum at 120^o corresponds to the Geography building being downstream of the Arts Tower. This proximity effect is dramatically visualised in Plate 1.

b) A small, but measurable, reduction in the indicated wind speed may be attributable to the presence of the RHH building, Plate 4, situated 600m away on a bearing of 210^o.

c) The minimum seen at 170° occurs when the building is downstream of the fairly high density University complex which is nominally 30m high and 100m away from the Geography building, see Figure 1.

d) The trace maximum at 270° corresponds to the wind incident across the Crookes Park just west of the site, seen in Plate 3.

In order to check the main conclusion of the comparison shown in Figure 9, i.e. that the directionally dependent speed variation of the Geography building anemometer is site rather than building dependent a further test at 1:350 scale was performed. This test utilised a larger scale model of the building without the site present. The results, shown in Figure 10, demonstrate the validity of the earlier finding.

4.4 The Weston Park Museum Anemometer

The Museum viewed from the Arts Tower is shown in Plate 2. The tests carried out on the 1:1000 model of the Weston Park Museum anemometer complete with its surrounding site, including the RHH building, were performed as described in the preceding sections. Figure 11 shows the variation of mean wind speed, U_W, with direction. Two large minima are easily identified on bearings of approximately 80° and 180°. The first of these appears when the high density University complex is upstream, see Figure 1. The second minimum, slightly greater than the first, is associated with the RHH building 300m away, Plate 4.

Although no separate test on a 1:350 model of the museum building has been carried out it seems most likely to the authors that the major features of Figure 11 can be explained with reference to the site details and that the directionally dependent variations are unlikely to be building dependent to any significant extent. It is, therefore, worth commenting on the statement by J.S. Hopkins (3) "The museum roof above which it (the Dines anemograph) is mounted has a 'zig-zag' profile and so can be expected to create more turbulence than a roof of conventional shape. This defect of exposure contributed to the Meteorological Office's decision to cease publication of the Weston Park anemograph data in the Monthly Weather Report with effect from January 1975 and to replace it with data from an electrical cup instrument mounted on a nearby University building (the Geography Building).

The conclusions drawn from Figure 11 seem to suggest that Hopkins unsupported estimate of the effect of the 'zig-zag' roof is a significant over-estimate. An inspection of the museum roof reveals the 'zig-zag' profile to consist of 4 rows of north facing roof lights 1m high, which, since the anemograph mast is 10m high, might be considered negligible, particularly in comparison with the new Met Office data source which is only a 6m mast.

In general, the wisdom of the removal of the Met Office data source from the Museum building to the Geography building can be judged from Figure 12 which compares the corresponding velocity variations reproduced from Figures 11 and 8 respectively. The overall directionally dependent speed variation of the new data source is seen to be greater than that of the old one. Incidentally it must not be forgotten that the construction of the RHH building took place during the decade prior to change of data source location and so Figure 11 cannot be used as the single correction for all Weston Park Museum data prior to 1975.

5. Full Scale Wind Data Analysis

The second part of the investigation has been a comparison of the data gathered from the three anemographs on the site.

Hourly mean wind speeds and wind directions have been compared for periods of significant wind activity. Data has been chosen initially so as to give a representative cross-section of incident wind directions. The data presented here has been extracted from recordings made during the period September 1978-April 1979. The authors of this report are aware that the sampling method used in this data collection exercise is neither random nor a true reflection of the frequency of directional winds for the Sheffield area. Furthermore, they acknowledge the restricted size of the data set. However, the results gained from this part of the project so far are considered sufficiently interesting to warrant inclusion here.

5.1 The Arts Tower Anemometer and Geography Building Anemometer Comparison

The Arts Tower anemometer, 84m above street level, and the Geography building anemometer, 31m above street level, are both shown in Plate 1. Both anemometers are on 6m masts above the roofs of their respective buildings and are separated by a horizontal distance of 140m.

Figure 13 shows the comparison of the hourly mean wind speed recorded at Geography with that recorded at the Arts Tower. Initial examination of this graph indicates the possible presence of two populations. In order to investigate this further, the data shown in Figure 13 were grouped via wind direction using 20^{o} class intervals. Figure 14 shows the variation of the ratio of the hourly mean wind speed measured by the Arts Tower anemometer to that measured by the Geography building anemometer, U_A/U_G, with incident wind direction. Plus and minus one standard deviation is included on the diagram for each class interval. Examination of this figure indicates a minimum in the ratio U_A/U_G lying in the wind sector $20^{o}<\theta<120^{o}$. Returning then to the data displayed in Figure 13 and plotting the two assumed populations separately results in Figures 15 and 16. Statistical analysis of these data indicates the difference in the two blocks of data to be significant at better than the 0.1% level.

A plot of U_A/U_G versus hourly mean wind speed at the Arts Tower, Figure 17, gives no evidence of a 'wind speed dependence' of U_A/U_G. It is worth noting here that with wind incident from approximately North East, the mean speed measured at Geography exceeded the mean speed measured at the Arts Tower on some occasions.

5.2 The Arts Tower Anemometer and Weston Park Museum Anemometer Comparison

The Weston Park Museum anemometer, seen from the Arts Tower in Plate 2, is situated on a 10m mast on the building's roof and is 22m above street level. The horizontal distance between the anemometers is 380m, see Figure 1.

A comparison of hourly mean wind speeds measured at Weston Park and the Arts Tower is shown in Figure 18. Figure 19, a plot of the ratio of mean wind speeds at the two sites, U_A/U_W, against the hourly mean at the Arts Tower, indicates that the large scatter present at low wind speeds, i.e. less than 15 knots measured at the Arts Tower, becomes significantly less with higher speeds.

5.3 The Geography Building Anemometer and Weston Park Museum Anemometer Comparison

The comparison of thehourly mean wind speeds measured by the anemometers at the Geography building and the Weston Park museum is shown in Figure 20.

5.4 The Full Scale Indication of Wind Direction

In section 4.2 the results of a model test on the flow direction indicated on top of the Arts Tower were discussed and it was suggested that the corresponding full scale data should be viewed with some suspicion. The wind direction data corresponding to the full scale wind speed survey presented in section 5.2 is shown in Figure 21 where the indicated wind direction at the Arts Tower and Weston Park Museum are compared. An inspection of Figure 21 reveals that there are a number of major discontinuities in the comparison particularly for the Arts Tower indicated directions of 40^o-60^o, 150^o-170^o and 210^o-240^o. Furthermore there is a clear zeroing error between the two direction indicators.

Figure 22 presents a similar comparison between the directions indicated by the Arts Tower and Geography building anemometer. Here the zeroing error is rather smaller, though the discontinuities in the relationship remain substantial.

6. Discussion of Results

From the wind tunnel tests the following relationships between the wind speeds measured by the three different anemometers, have been evaluated.

$U_A/U_G = 1.28, \quad \sigma = 0.30$

$U_A/U_W = 1.39, \quad \sigma = 0.25$

$U_G/U_W = 1.10, \quad \sigma = 0.20$

These ratios have been averaged for all wind directions and have the standard deviations, σ, as indicated.

The following tentative relationships between the hourly mean wind speeds measured at the three anemometer locations are suggested from the full scale records.

$U_G = 1.2\,U_W + 3 \qquad$ all θ values

$U_W = 0.7\,U_A - 3 \qquad$ all θ values

$U_G = 0.6\,U_A + 1 \qquad 20^o > \theta > 120^o$

$U_G = 0.8\,U_A + 3 \qquad 20^o < \theta < 120^o$

The constants in these regression equations may indicate differences in starting speeds between the 3 anemometers.

In the introduction to this report it was stated that one of the objectives of this study was to arrive at a vertical mean wind speed relationship which would enable the dynamic force results to be presented in terms of a speed at 10m above open level ground which was representative of the general characteristics of the surrounding terrain. Such a vertical relationship had previously been arrived at from a very brief survey of some full scale wind storm records from the Arts Tower and Weston Park anemometers and has been given as

$$U_A/U_W = 2.44$$

In comparison with the values now available from both the wind tunnel and full scale data surveys this early value is clearly erroneous. The sources of error may include the fact that no directional speed corrections were applied to the data.

It is required then to produce a relationship from the available information which will enable a directionally corrected 84m wind speed from the Arts Tower to be reduced to a corresponding 10m wind speed. The power law equation is the most convenient form for establishing such a vertical wind speed relationship, and states in its general form

$$\frac{V_H}{V_{10}} = \left(\frac{H}{10}\right)^{\alpha}$$

For areas with sizeable obstructions in the terrain this equation can be amended to read

$$\frac{V_H}{V_{10}} = \left(\frac{H - d}{10}\right)^{\alpha}$$

where V_H is the wind speed at any height H in metres

V_{10} is the 10m wind speed

d is the zero-plane displacement

α is the power law exponent.

The values of V_{10} obtained from this relationship are critically dependent on the value of d chosen to represent the adjacent terrain. The Wind Loading Code of Practice (4) gives some guidance in making this choice suggesting a value of average roof height of 10m for terrain described as surfaces covered by numerous large obstructions such as towns and their suburbs and the outskirts of large cities. Whilst such a description may be considered appropriate to the sites of the three anemometers, it would be useful to know of the effect of using values of d both greater and smaller than 10m, since there is known to be a degree of uncertainty associated with the value given implicitly in (4). Using values of d of 7m, 10m and 15m, the power law equation has been used, together with the results of the wind tunnel study, which gave three relationships between the speeds measured by the three anemometers, to yield a set of values of the power law exponent α. These values varied from 0.116 to 0.212. The data from the full scale data analysis exercise have not been used in order to calculate equivalent values of α since the regression equations given earlier in this section cannot be manipulated to give a simple ratio of indicated speeds between two anemometers. If, however, the slopes of the regression equations were used in this manner, corresponding values of α as high as 0.44 may be obtained.

Applying the values of the power law exponent given in the preceding paragraph to a real situation has the following results. If a mean wind speed measured by the Arts Tower anemometer has a value, corrected for wind direction, of say 50 Knts, this may then be translated into a velocity at 10m, thought to be representative of the site terrain, which varies between 32.4 Knts and 40.1 Knts depending on the values chosen for α and d. If values for α based on the full scale data regression equations were used, the indicated velocity at 10m could be as low as 20.7 Knts.

It is clear to the authors that this degree of possible error in the stipulated normalising velocity renders the use of a nominal 10m wind speed inappropriate for the purposes of the experiments being carried out in this instance.

In a wider context the authors would question the validity of any nominal 10m wind speed claimed to be representative of the terrain characteristics in suburban or urban areas in which the average obstruction height is itself of the order of 10m.

7. Conclusions and Recommendations

1. Measured mean wind speeds from the Arts Tower anemometer should be corrected for directional effects by the application of the correction factors given in Table 1.

2. The practice of presenting the results of the dynamic force measurement exercise in terms of a nominal 10m wind speed, considered to represent the general terrain characteristics of the site, should cease. All previous data should be re-analysed and presented in terms of a mean wind speed at 84m corrected for directional effects. This change in the format for the presentation of data has the added advantage that it will make the task of matching wind tunnel results to full scale dynamic force results simpler. Furthermore, this change is in keeping with the current practice of the wind loading code.

3. It is recommended that the Sheffield University Department of Geography and the Meteorological Office apply corrections to the measured data from the Geography building anemometer which take account both of the directional characteristics of the wind as well as the height of the instrument.

4. Great care should be exercised in future in the use of the Weston Park Museum anemometer records particularly over the periods of time during which the RHH building has been constructed, since this has a dominant influence on the measured speed over a significant angular range.

Acknowledgement

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References

1. Jeary, A., Lee, B. and Sparks, P., 'The Determination of Modal Wind Loads from Full Scale Building Response Measurements'. Paper V-8, 5th International Conference on Wind Engineering, Colorado State University, July 1979.

2. Lee, B.E., 'Atmospheric Flow Simulation in the Sheffield University 1.2m x 1.2m Boundary Layer Wind Tunnel'. Report No. BS38, Sheffield University, Department of Building Science, 1977.

3. Hopkins, J.S., 'Extreme Wind Data'. Letters to Editor, Weather, pp. 165-166, April 1979.

4. B.S.I., CP3, Chapter V, Part II. Wind Loads. 1972.

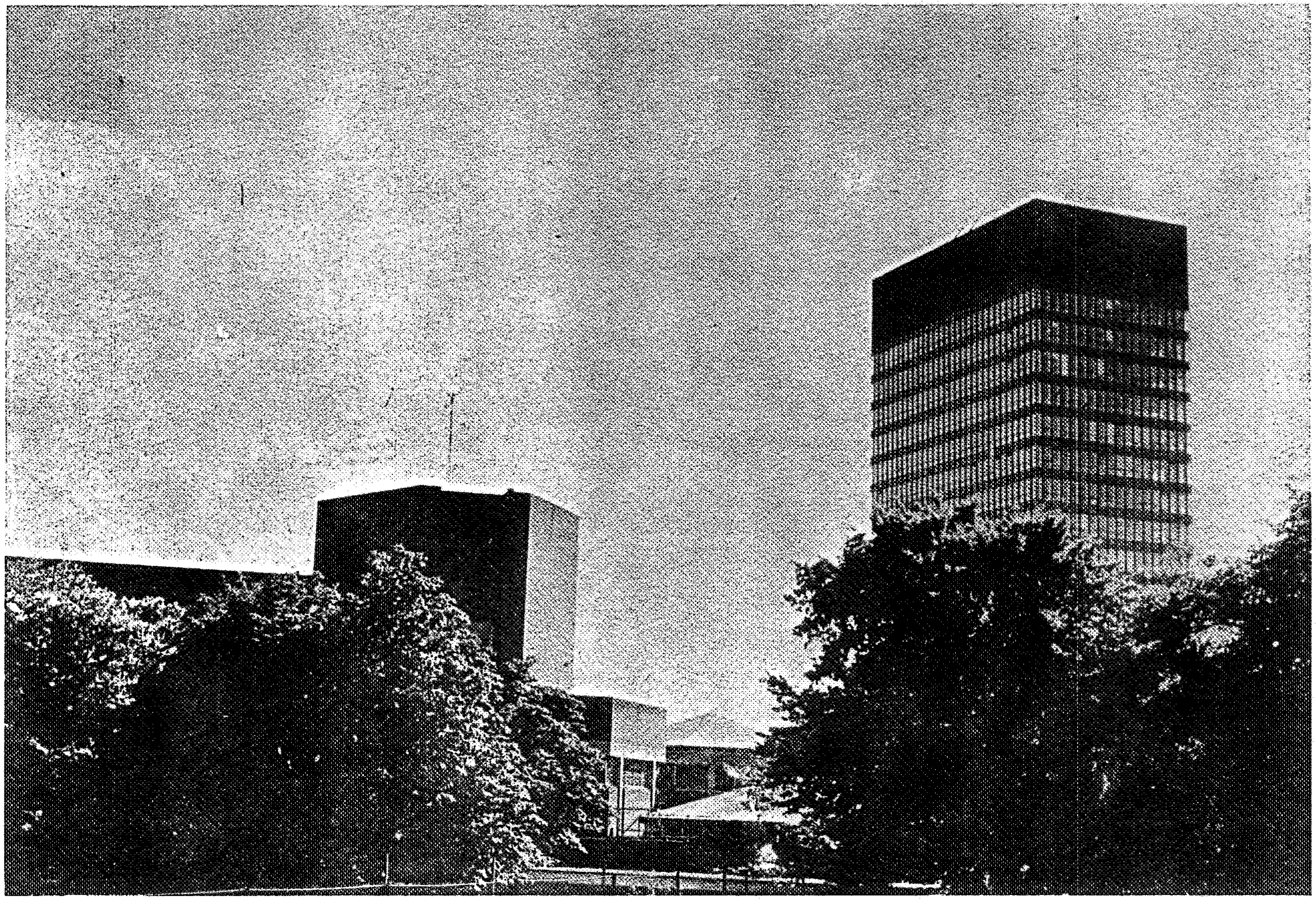


PLATE 1 GEOGRAPHY BUILDING AND ARTS TOWER

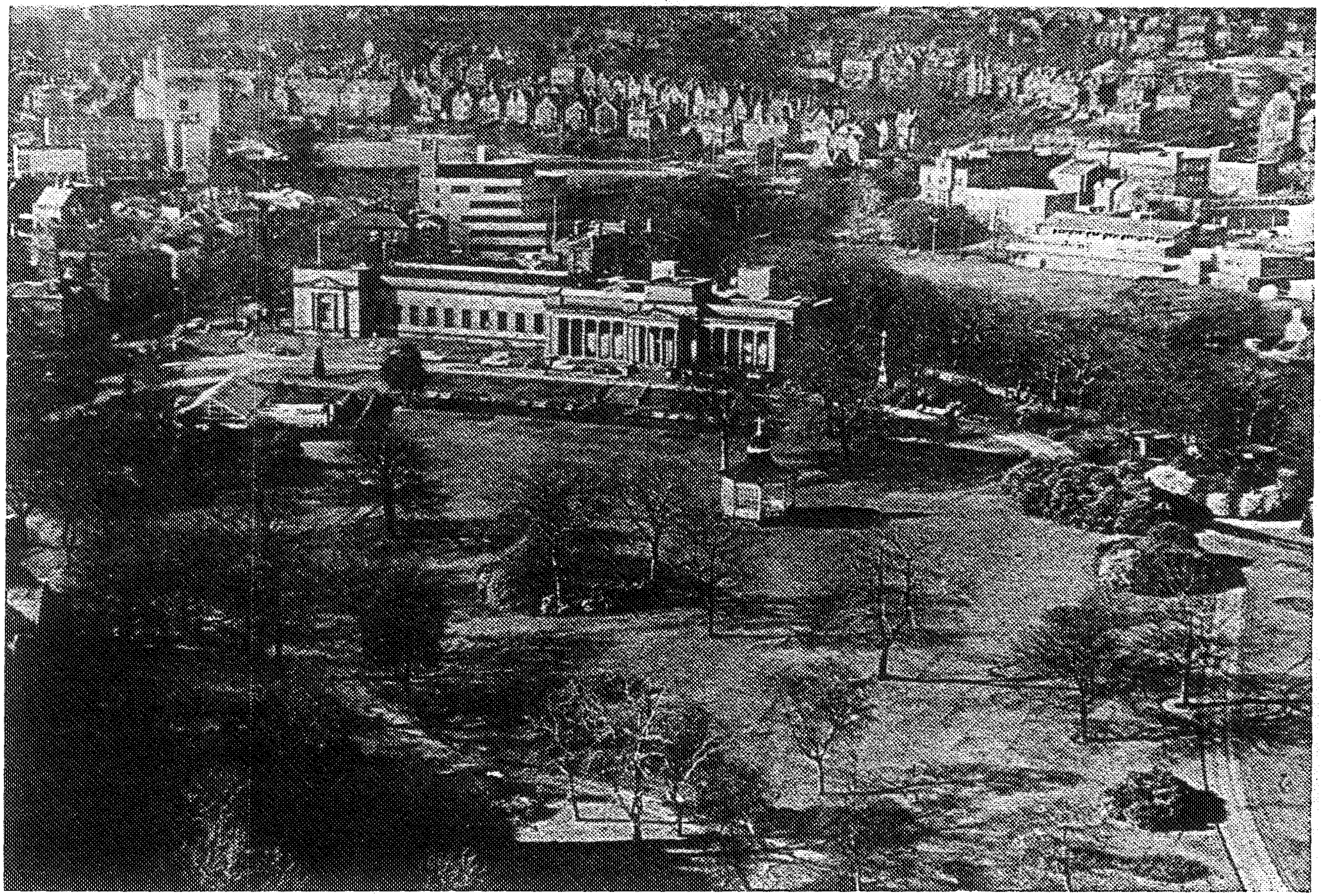


PLATE 2 WESTON PARK MUSEUM

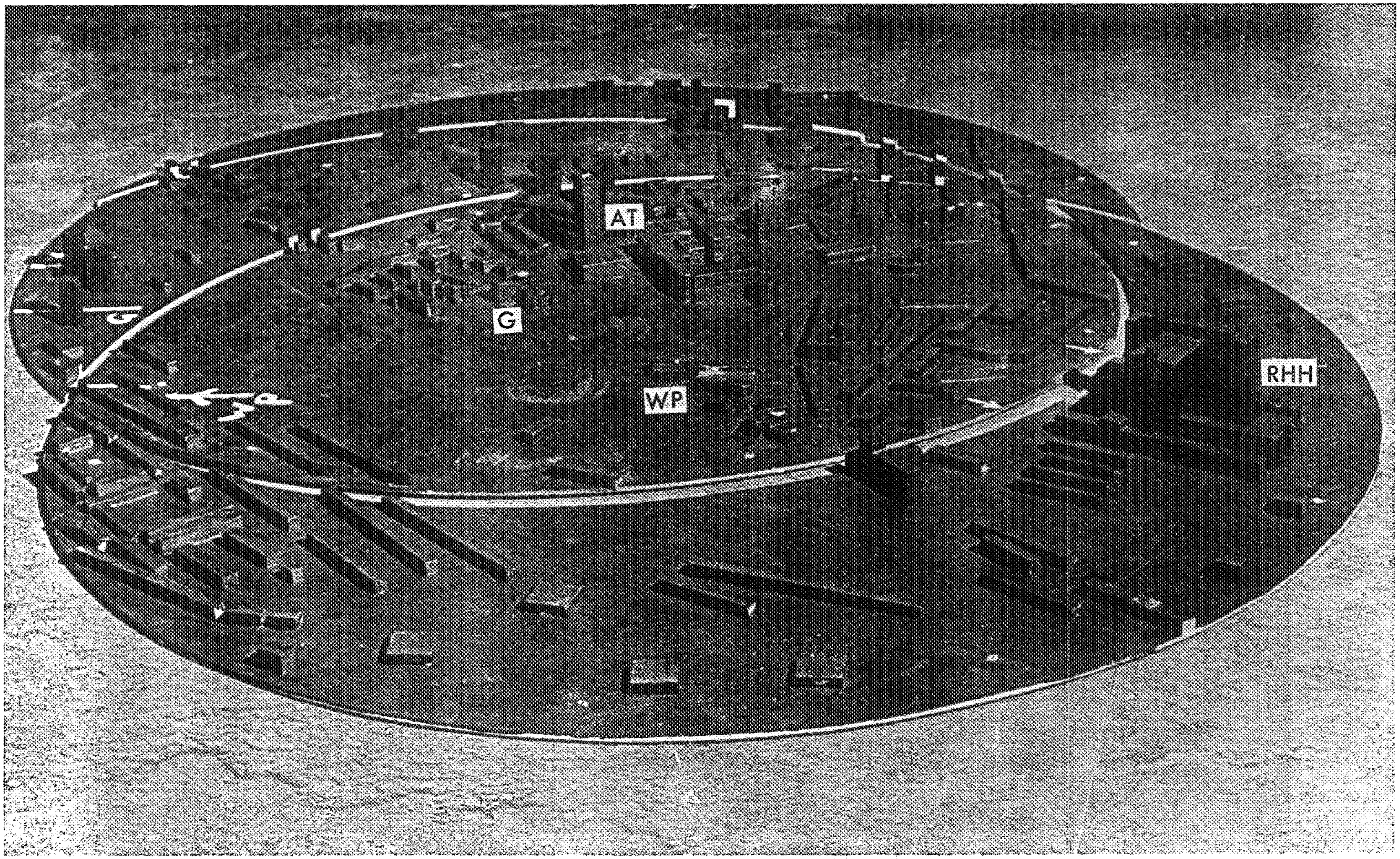


PLATE 3 WIND TUNNEL SITE MODEL

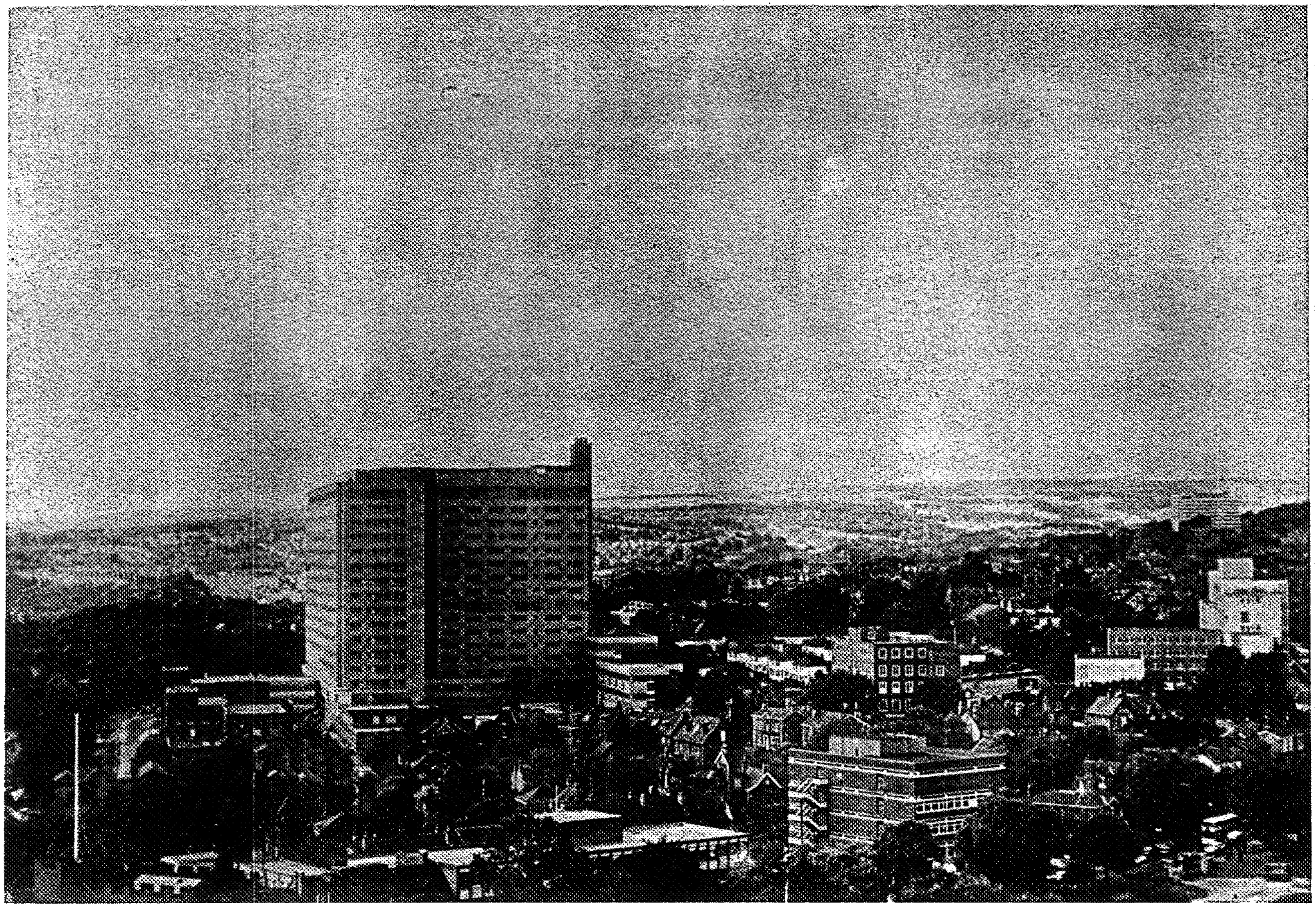


PLATE 4 ROYAL HALLAMSHIRE HOSPITAL

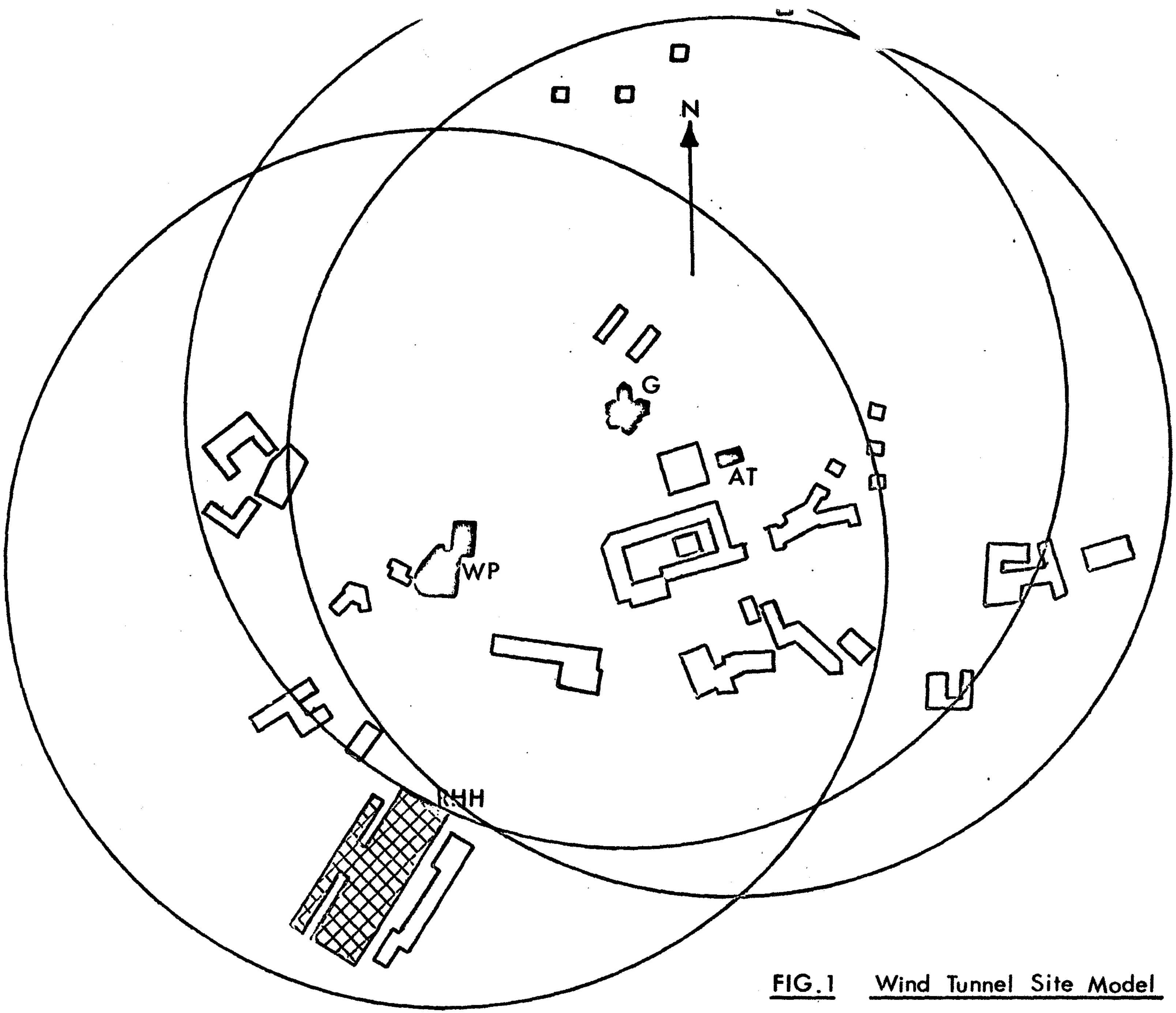


FIG.1 Wind Tunnel Site Model

FIG 2 – Variation of mean wind speed with direction

ARTS TOWER 1 : 1000 model

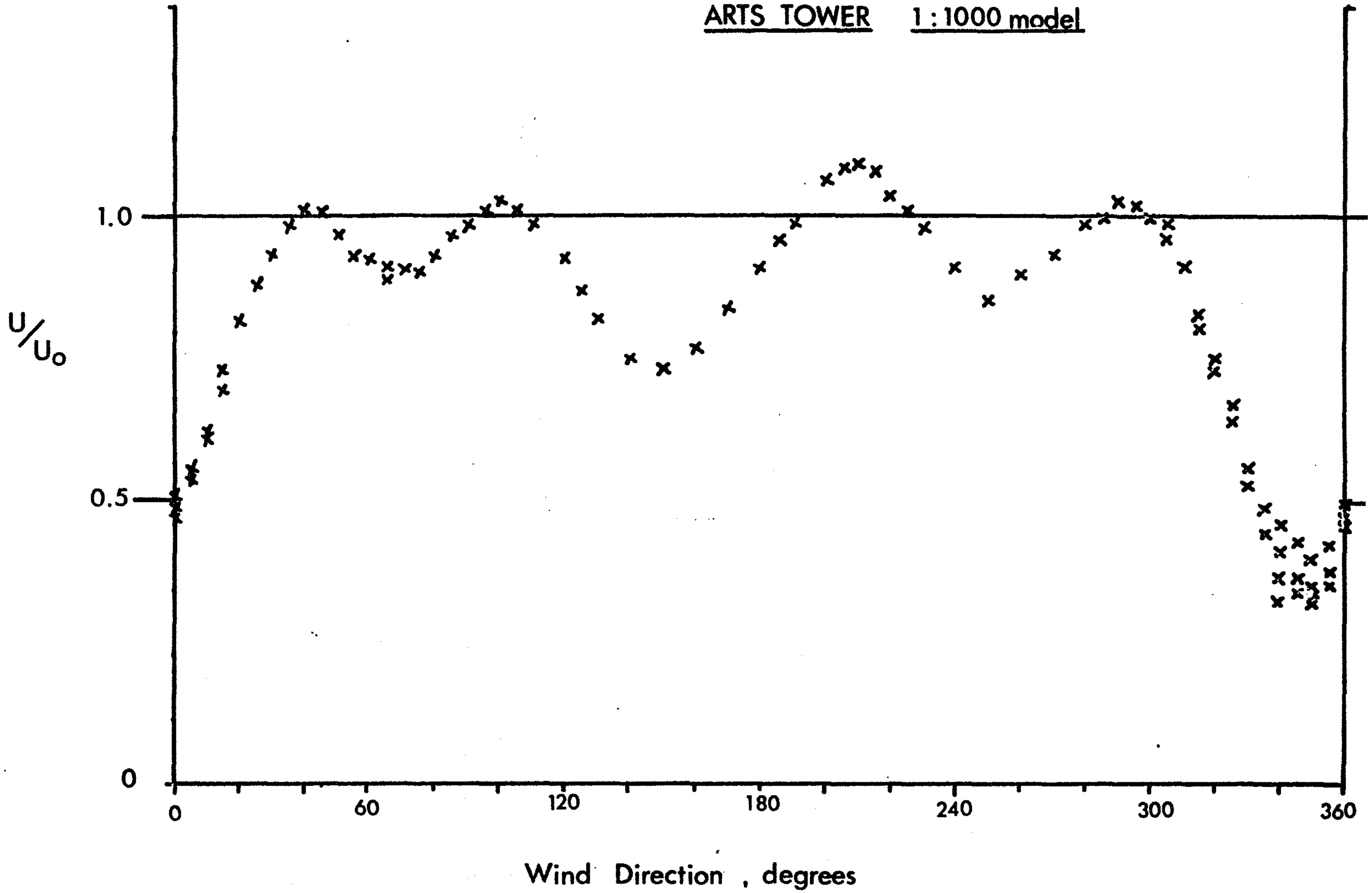


FIG 3 - Variation of Mean Wind Speed with Direction

ARTS TOWER SITE ONLY 1:1000 model

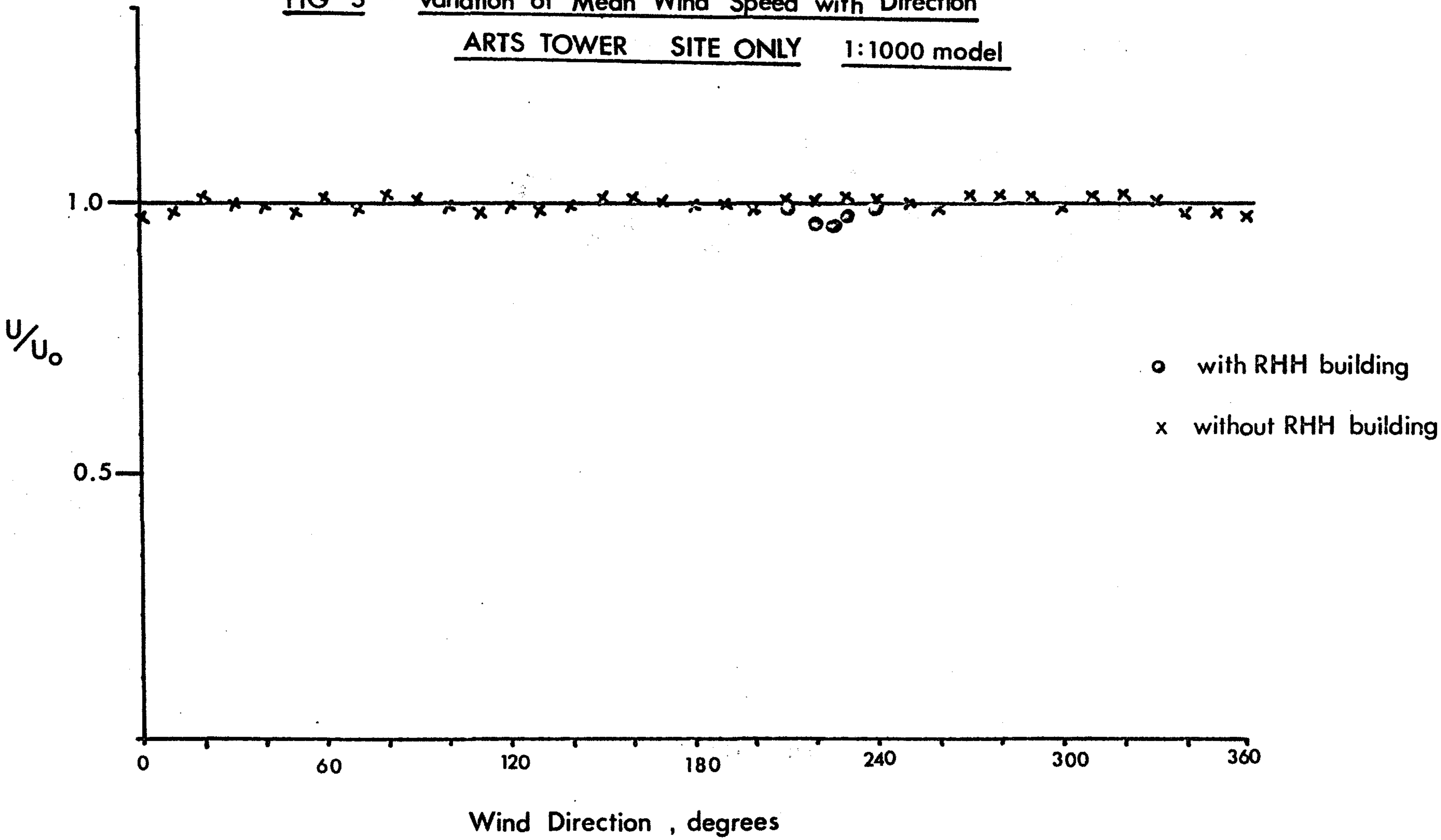


FIG 4 - Variation of Mean Wind Speed with Direction

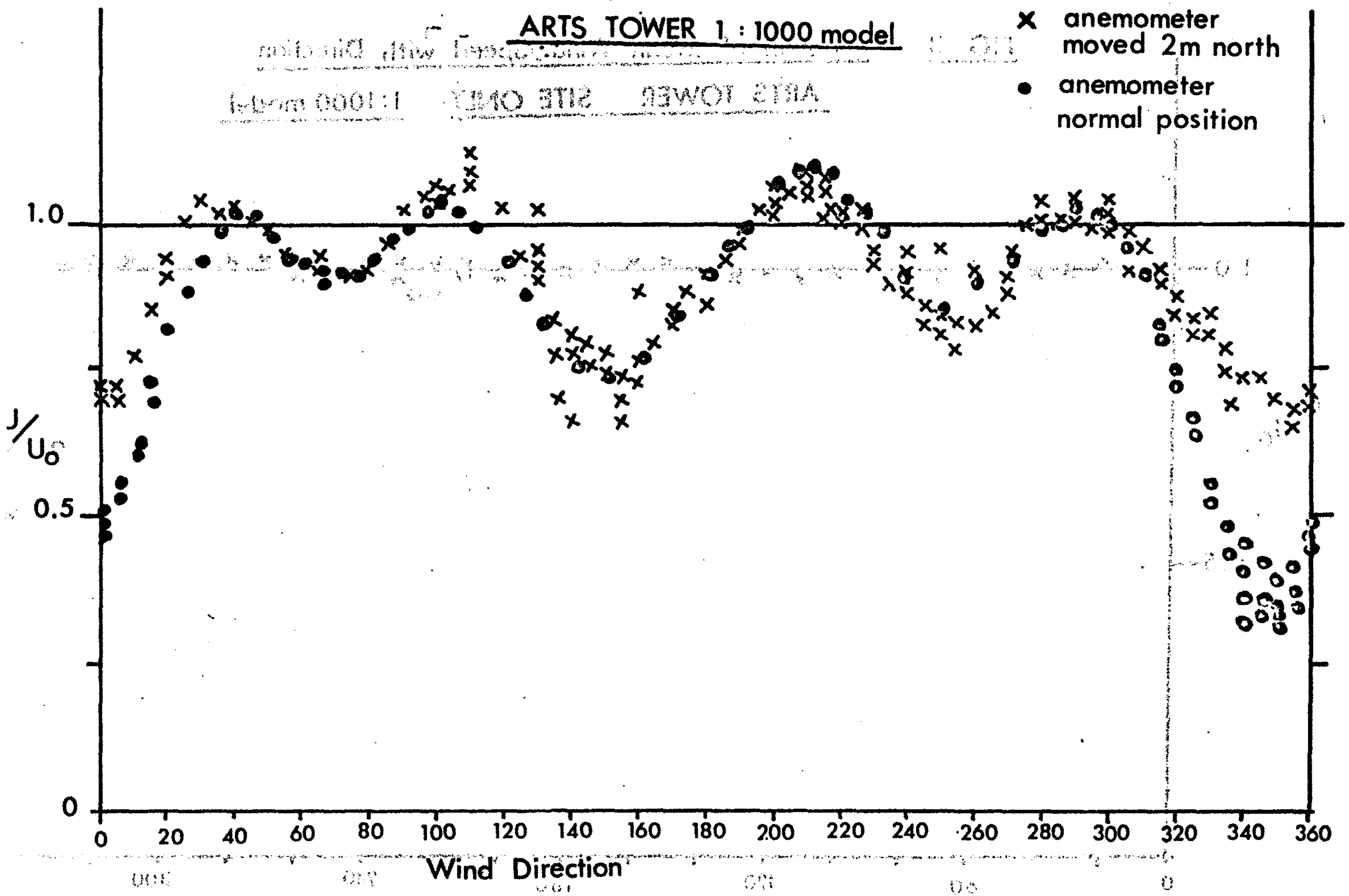
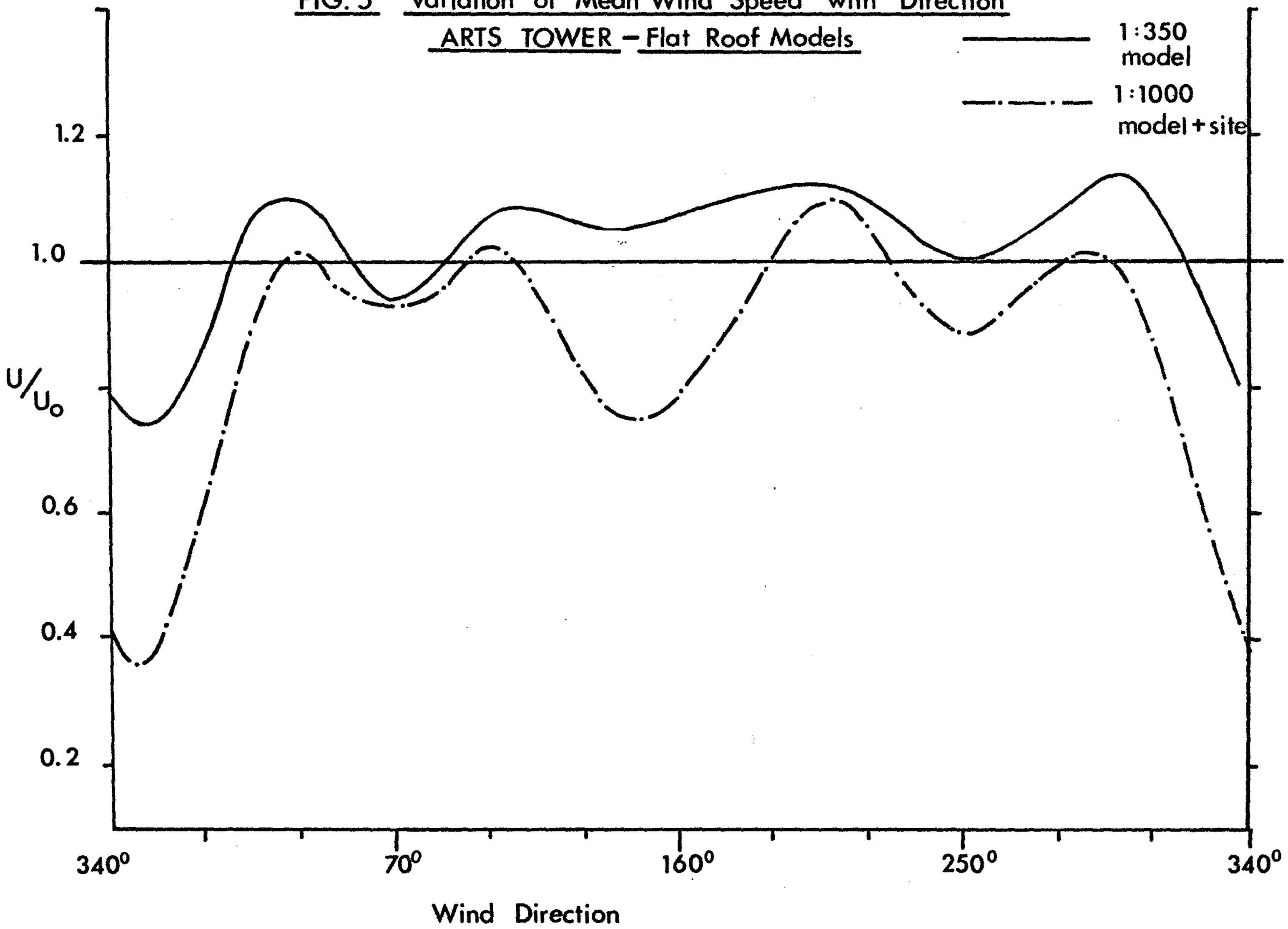


FIG. 5 Variation of Mean Wind Speed with Direction

ARTS TOWER – Flat Roof Models



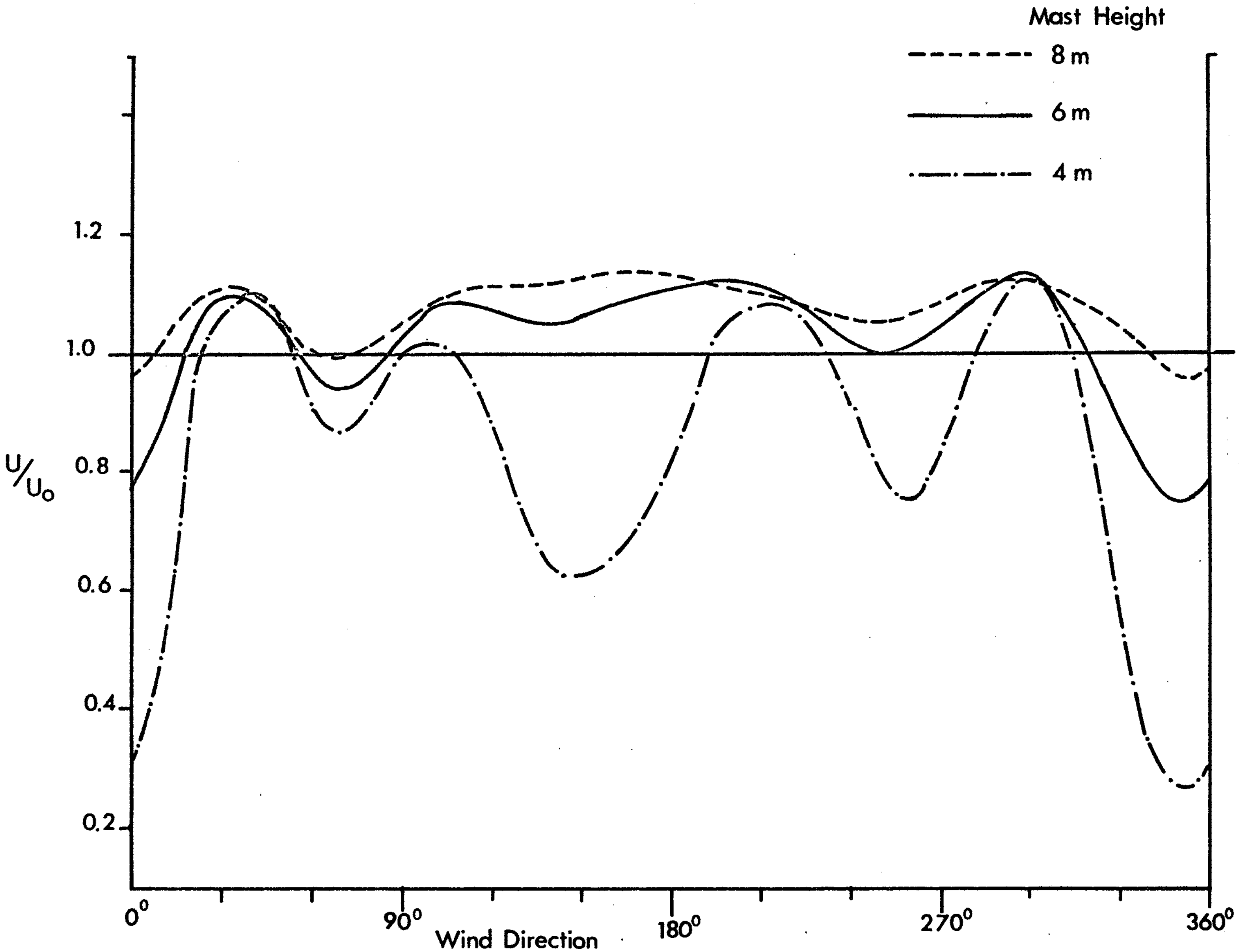


FIG. 6 Effect of Mast Height on Variation of Wind Speed with Direction – ARTS TOWER

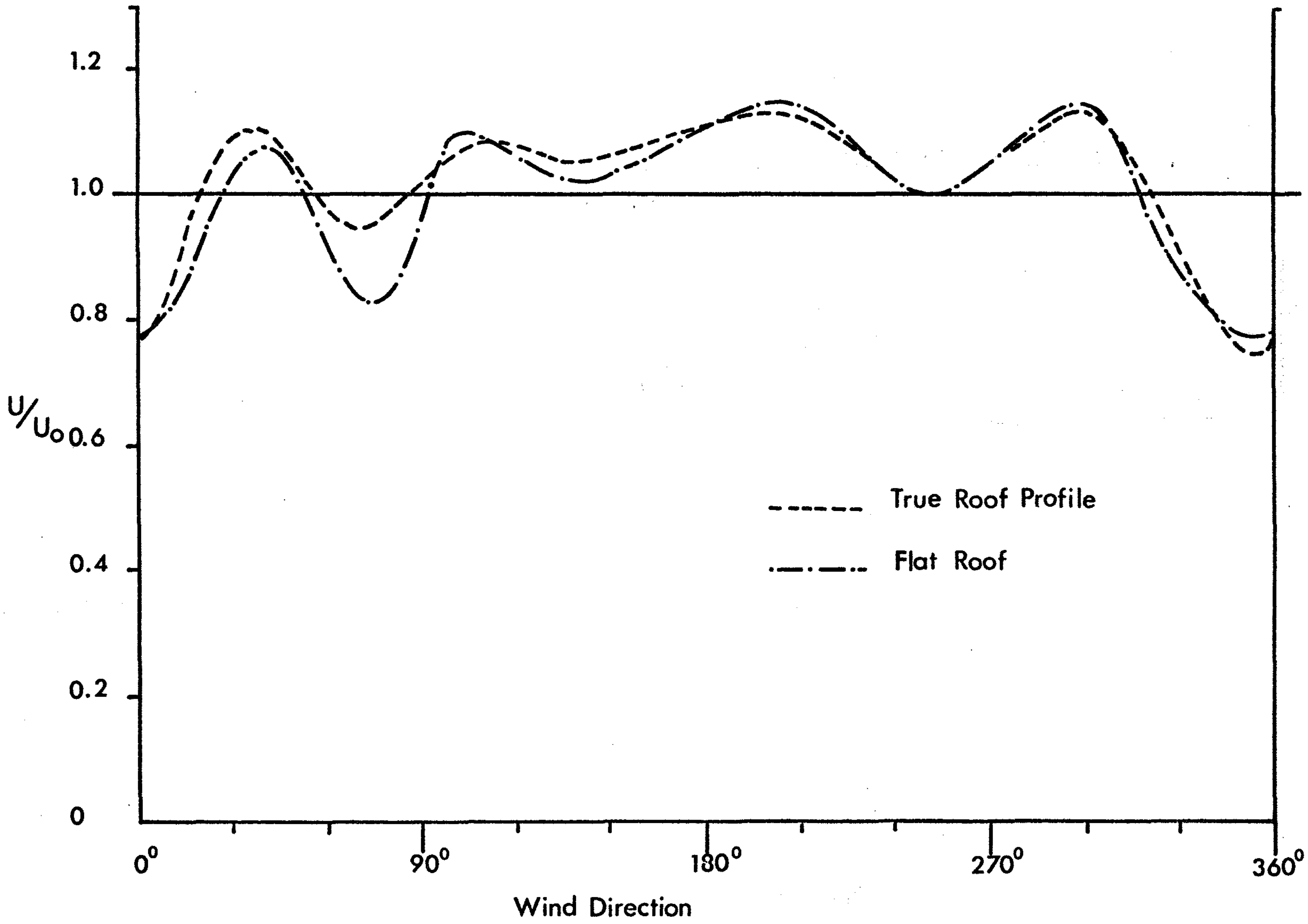
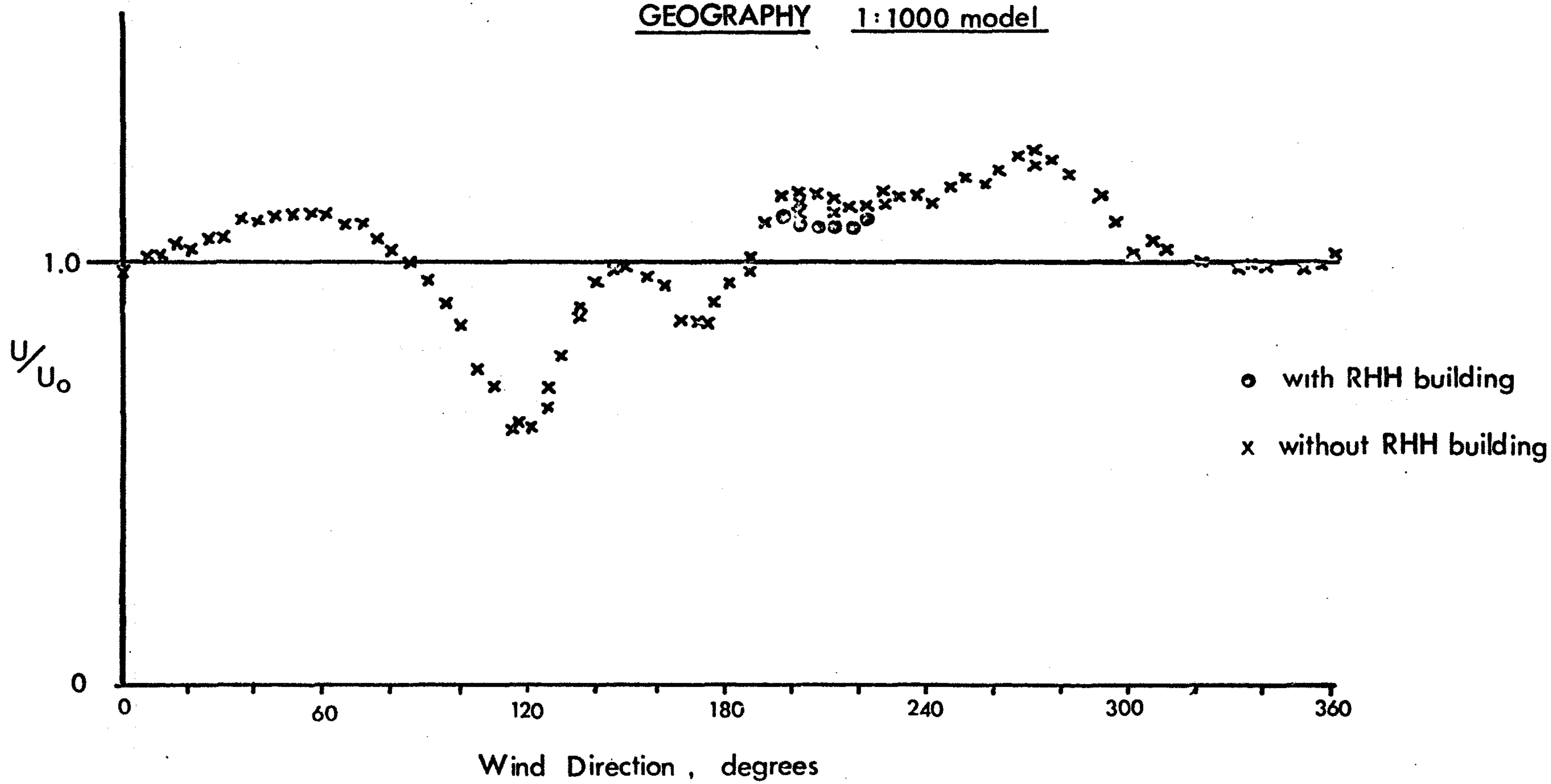


FIG. 7 Effect of Roof Shape on Variation of Wind Speed with Direction – ARTS TOWER

FIG 8 - Variation of Mean Wind Speed with Direction
GEOGRAPHY 1:1000 model



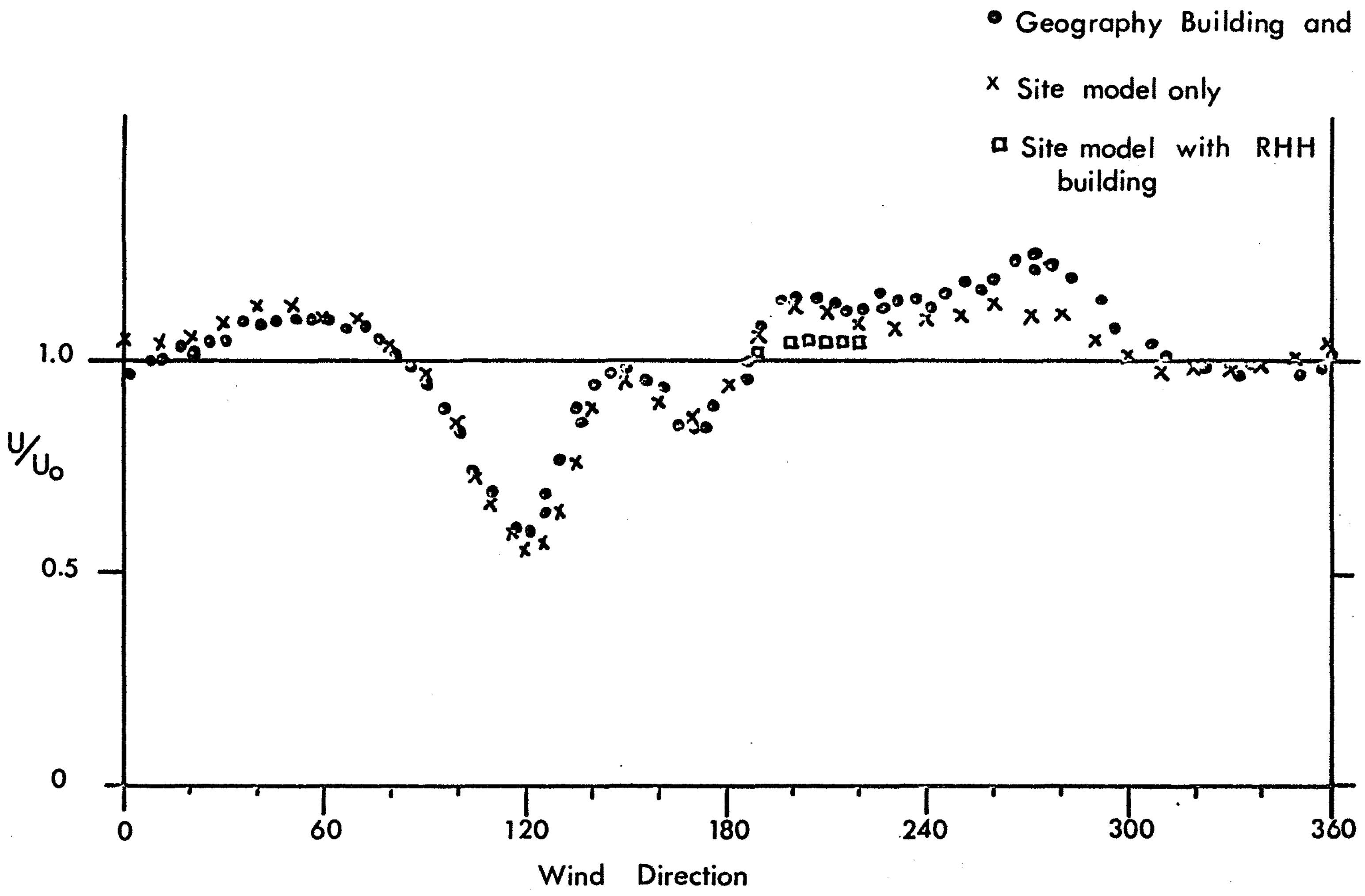


FIG. 9 Effect of Building Presence on Variation of Wind Speed with Direction - GEOGRAPHY 1:1000 model

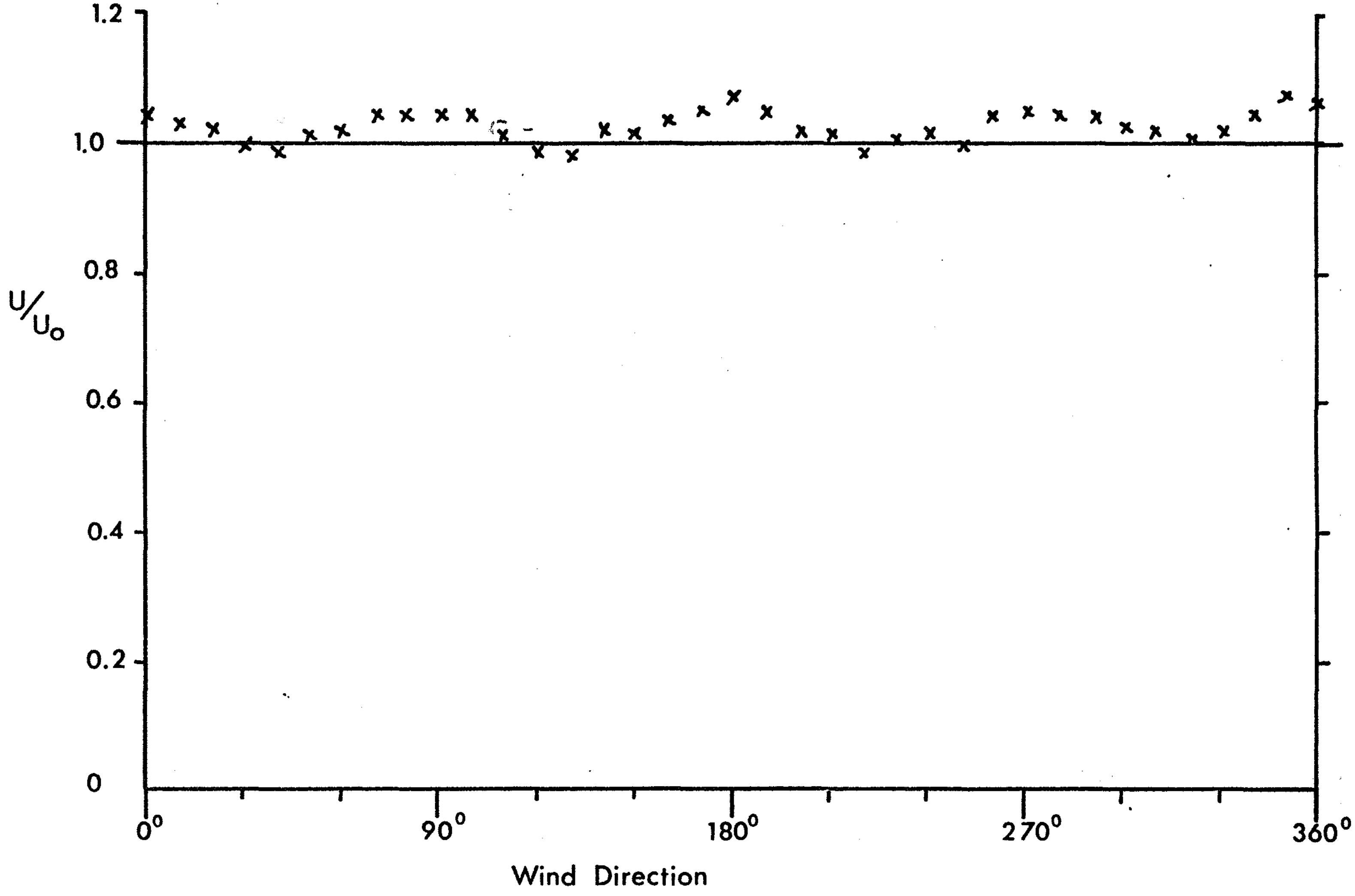
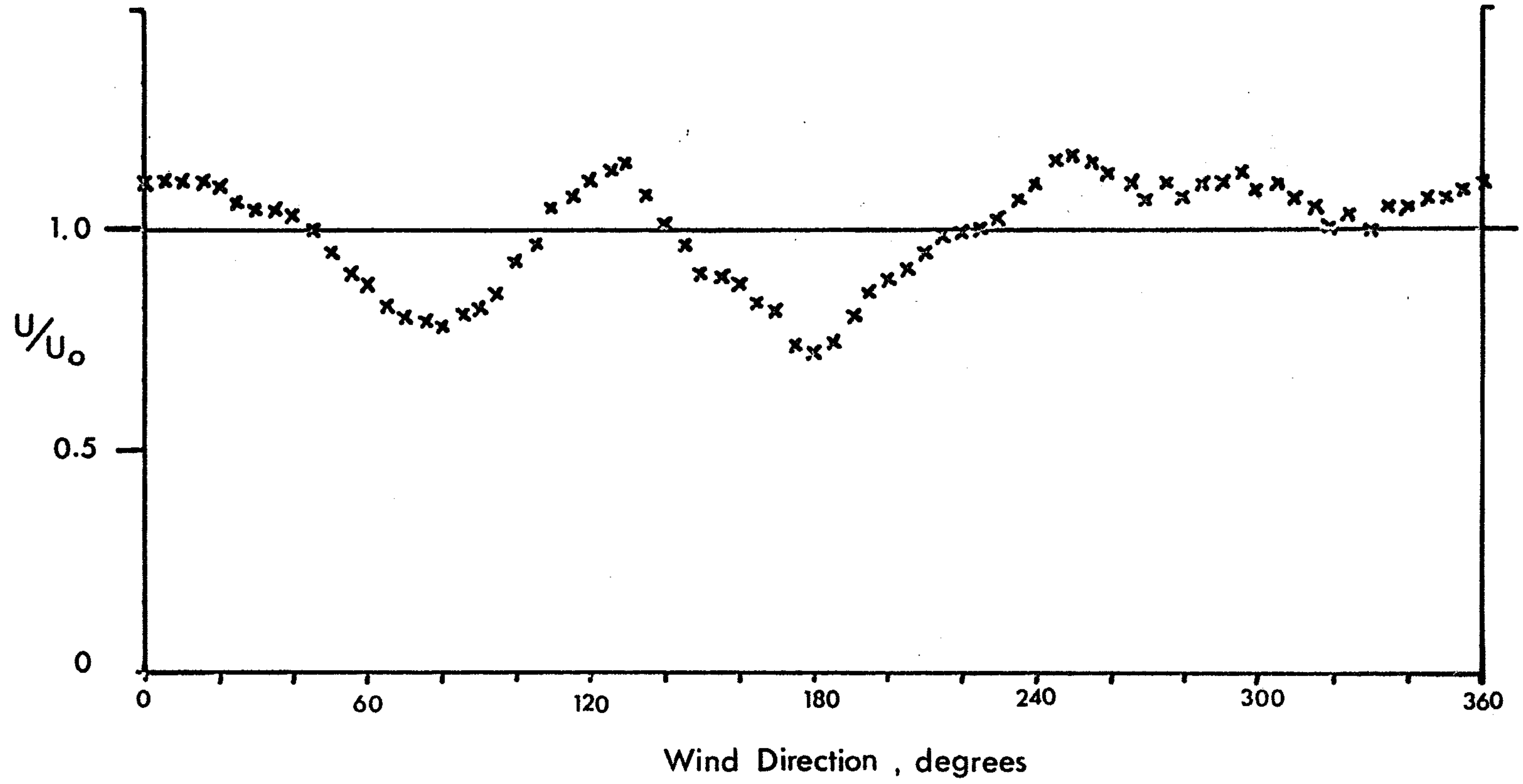


FIG. 10 Variation of Mean Wind Speed with Direction

GEOGRAPHY 1:350 Model alone

FIG 11 - Variation of Mean Wind Speed with Direction

WESTON PARK 1:1000 model



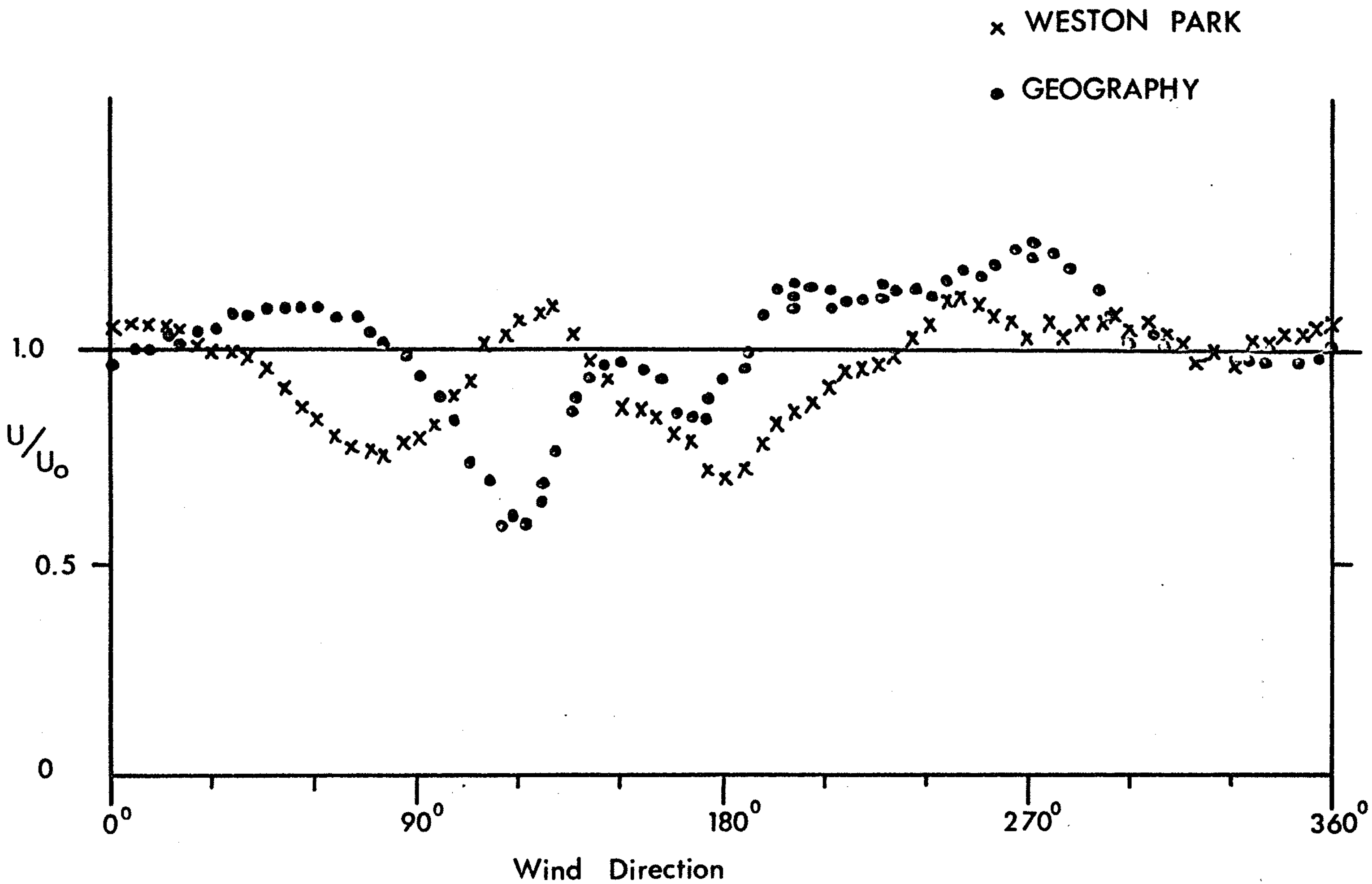
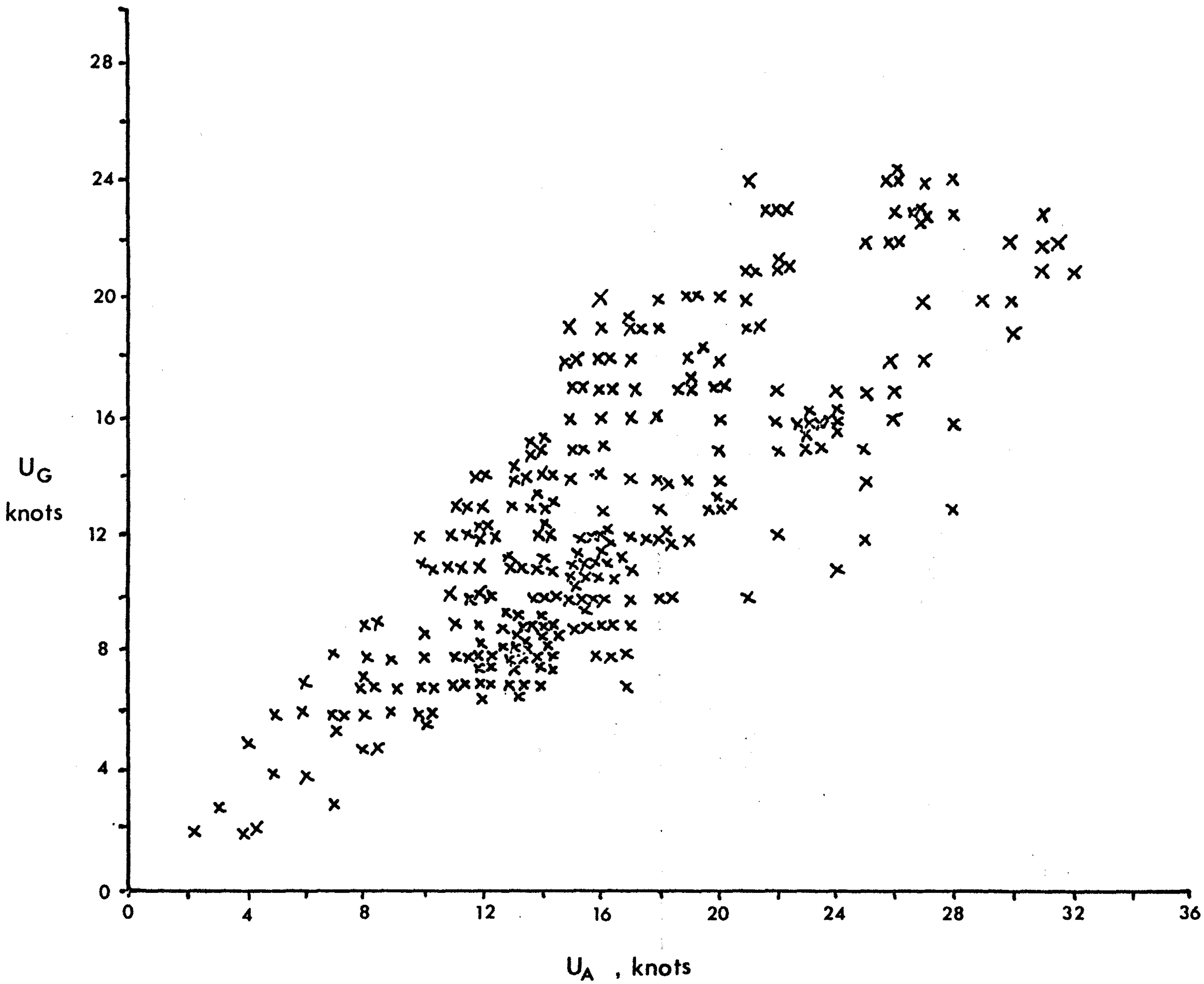


FIG. 12 Variation of Mean Wind Speed with Direction. Comparison of Weston Park and Geography.

Fig.13 Full Scale Data, Comparison of Geography and Arts Tower Anemometers.



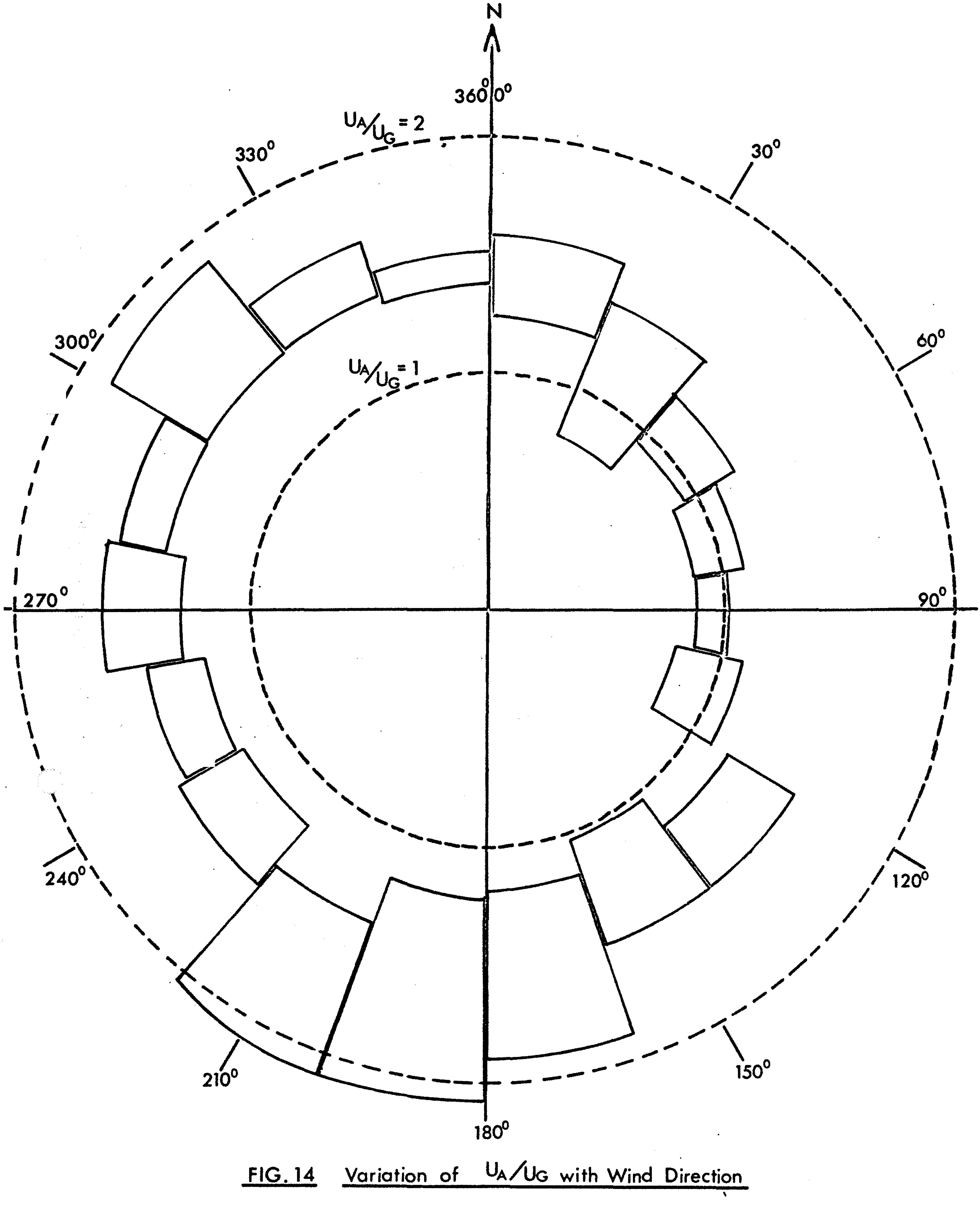


FIG. 14 Variation of U_A/U_G with Wind Direction

FIG 15 Full Scale Data. Comparison of U_G and U_A

$120^0 < \theta < 20^0$

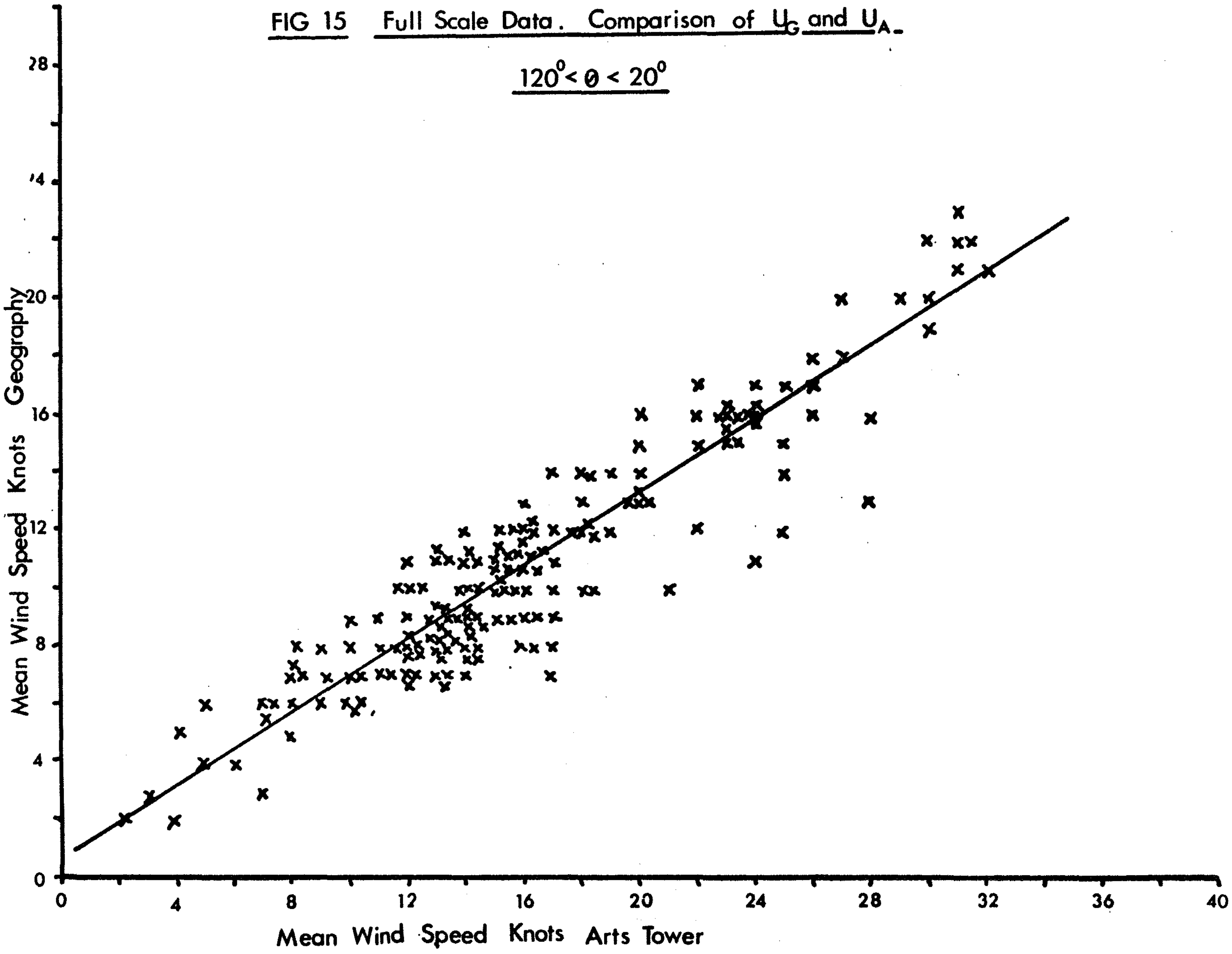
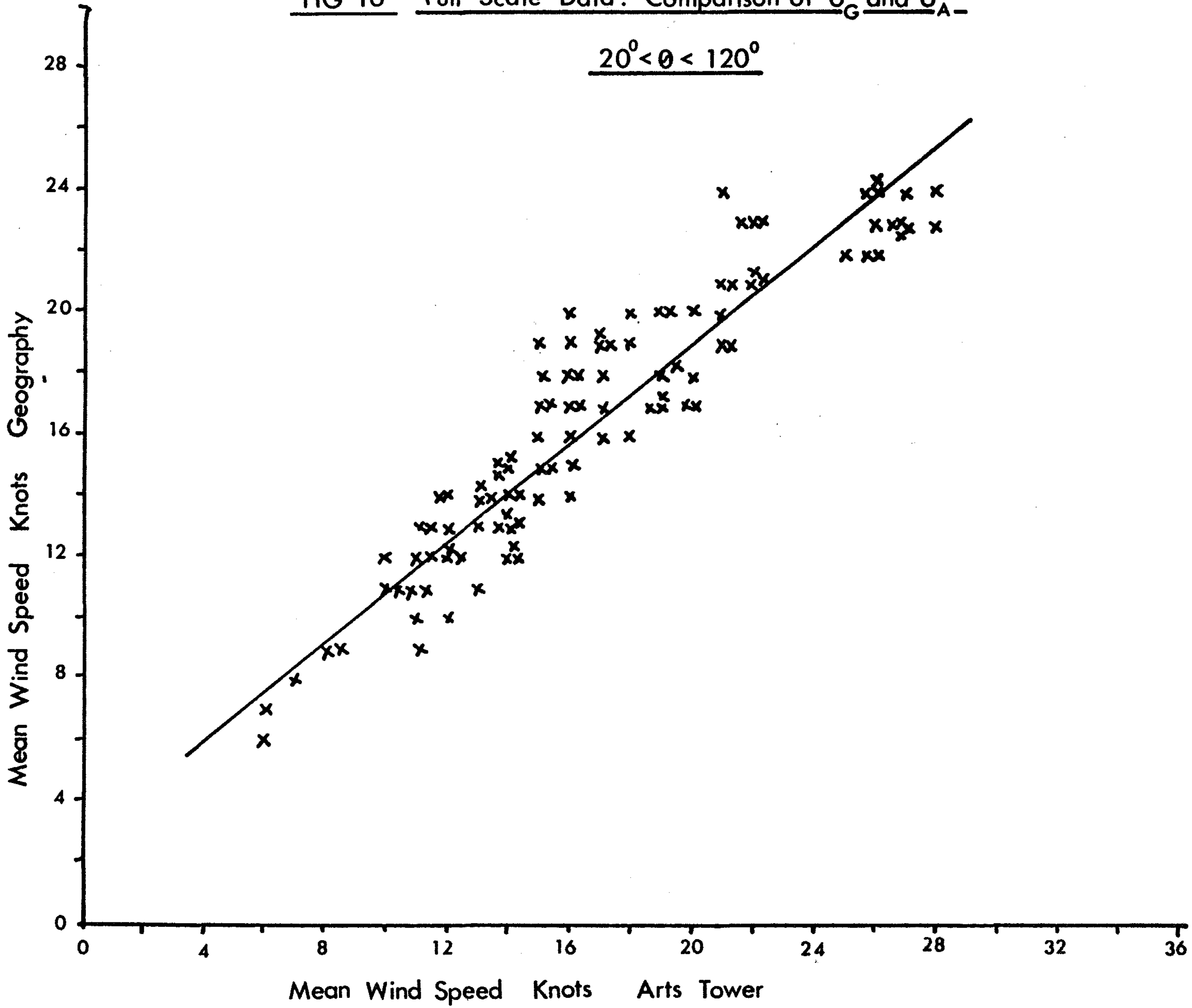


FIG 16 Full Scale Data. Comparison of U_G and U_A –

$20^0 < \theta < 120^0$



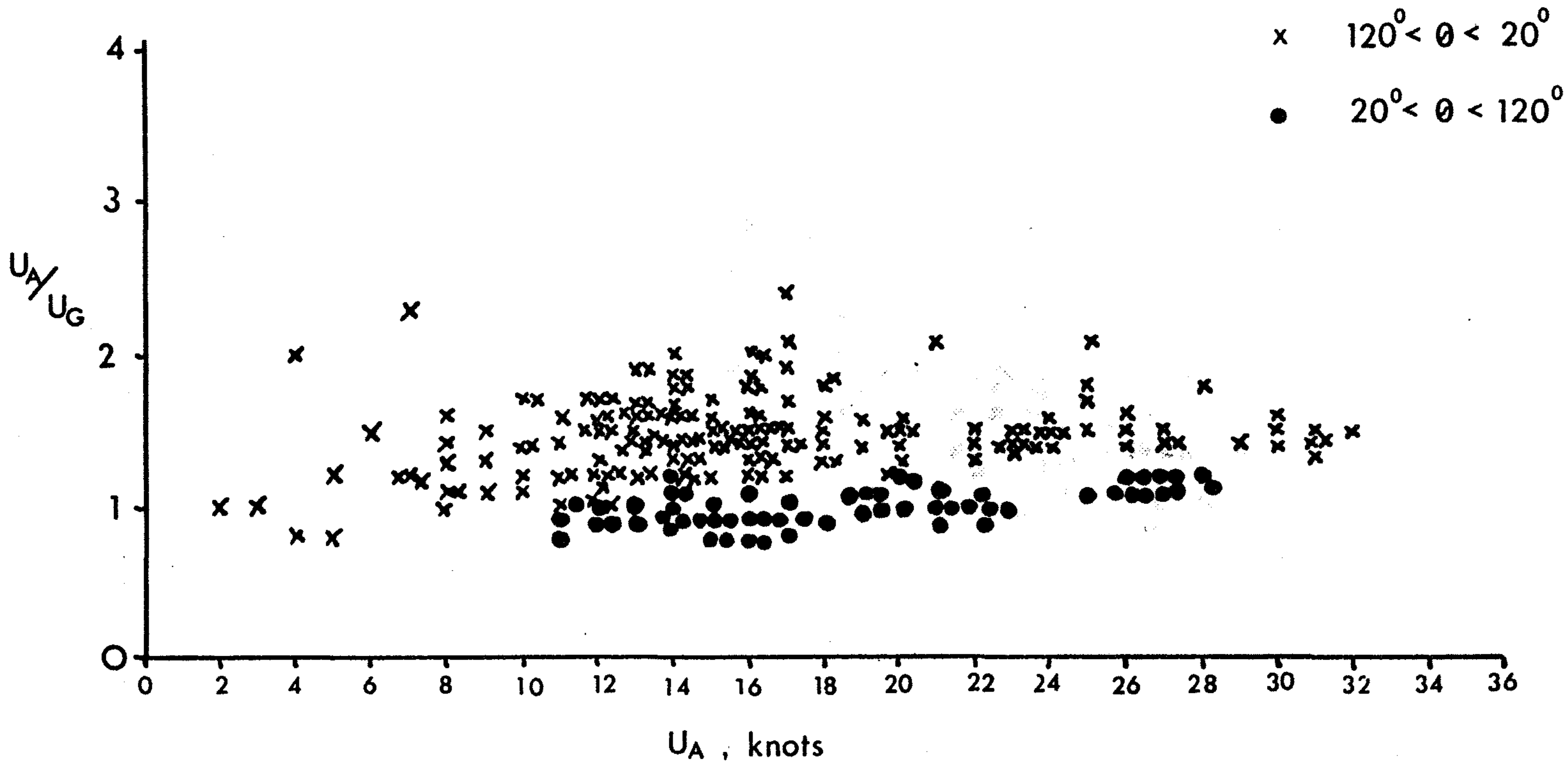


Fig.17 Full Scale Data. Comparison of the ratio U_A/U_G with U_A

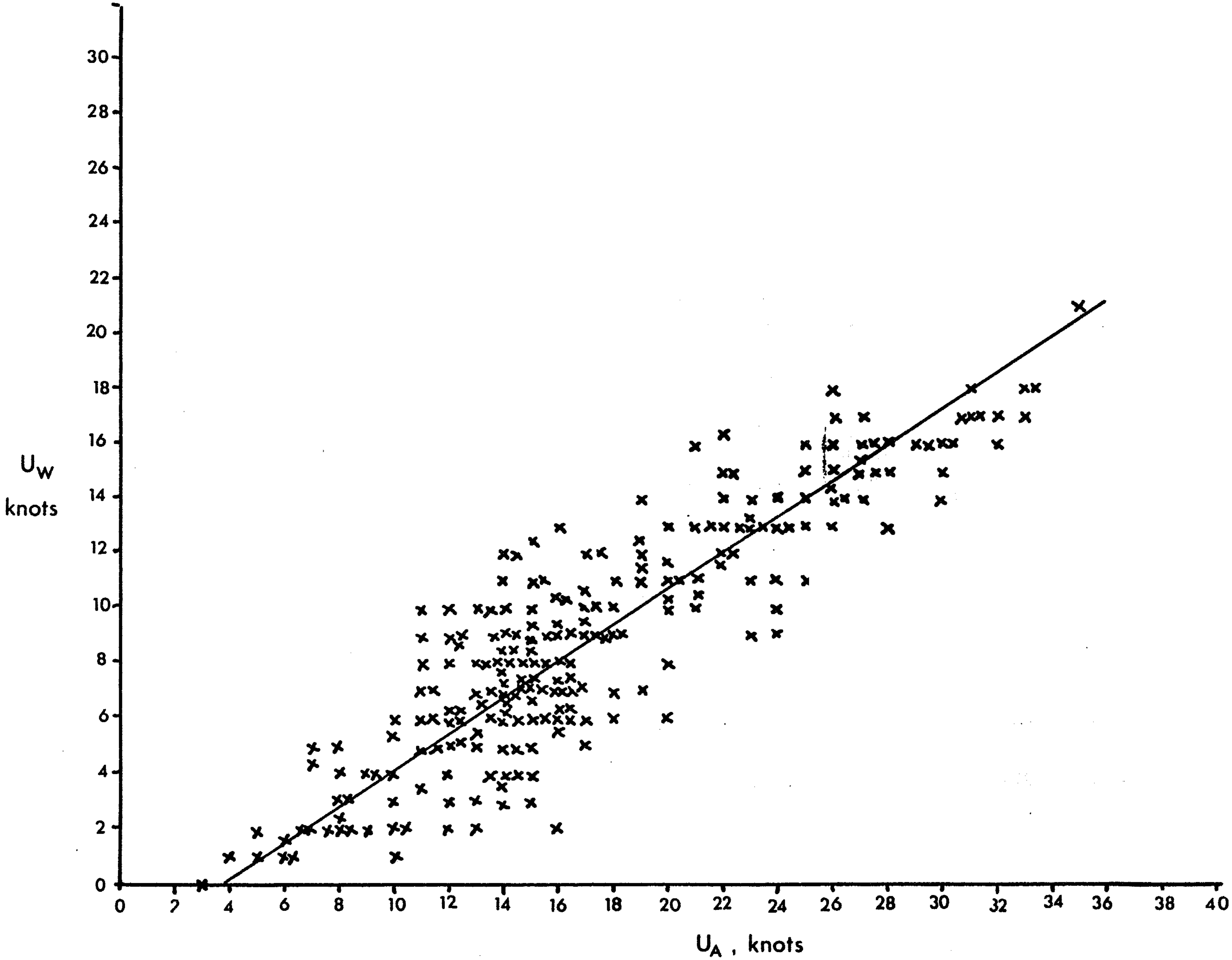


Fig. 18 Full Scale Data. Comparison of U_A nd U_W

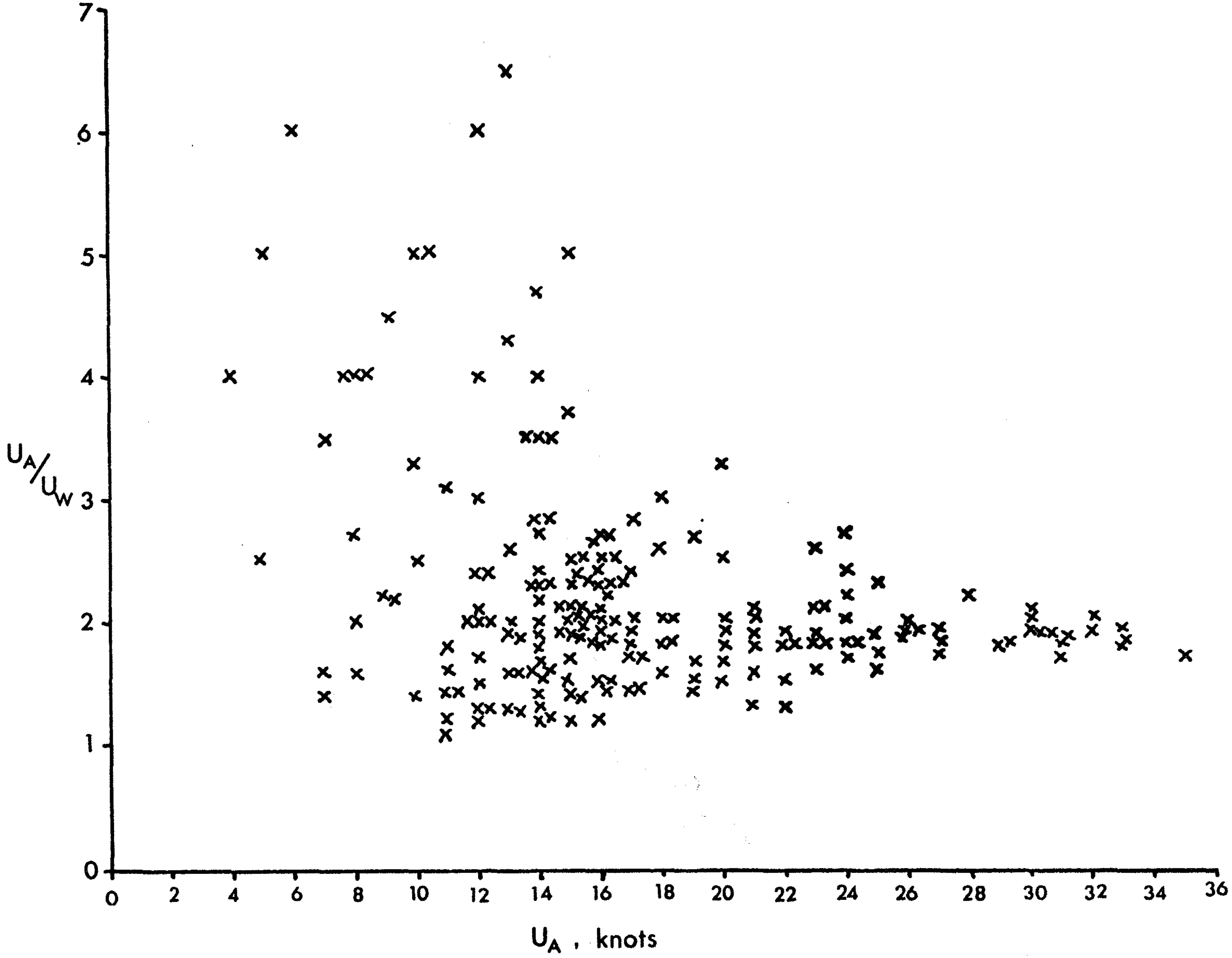


Fig. 19 Full Scale Data. Comparison of the ratio U_A/U_W with U_A

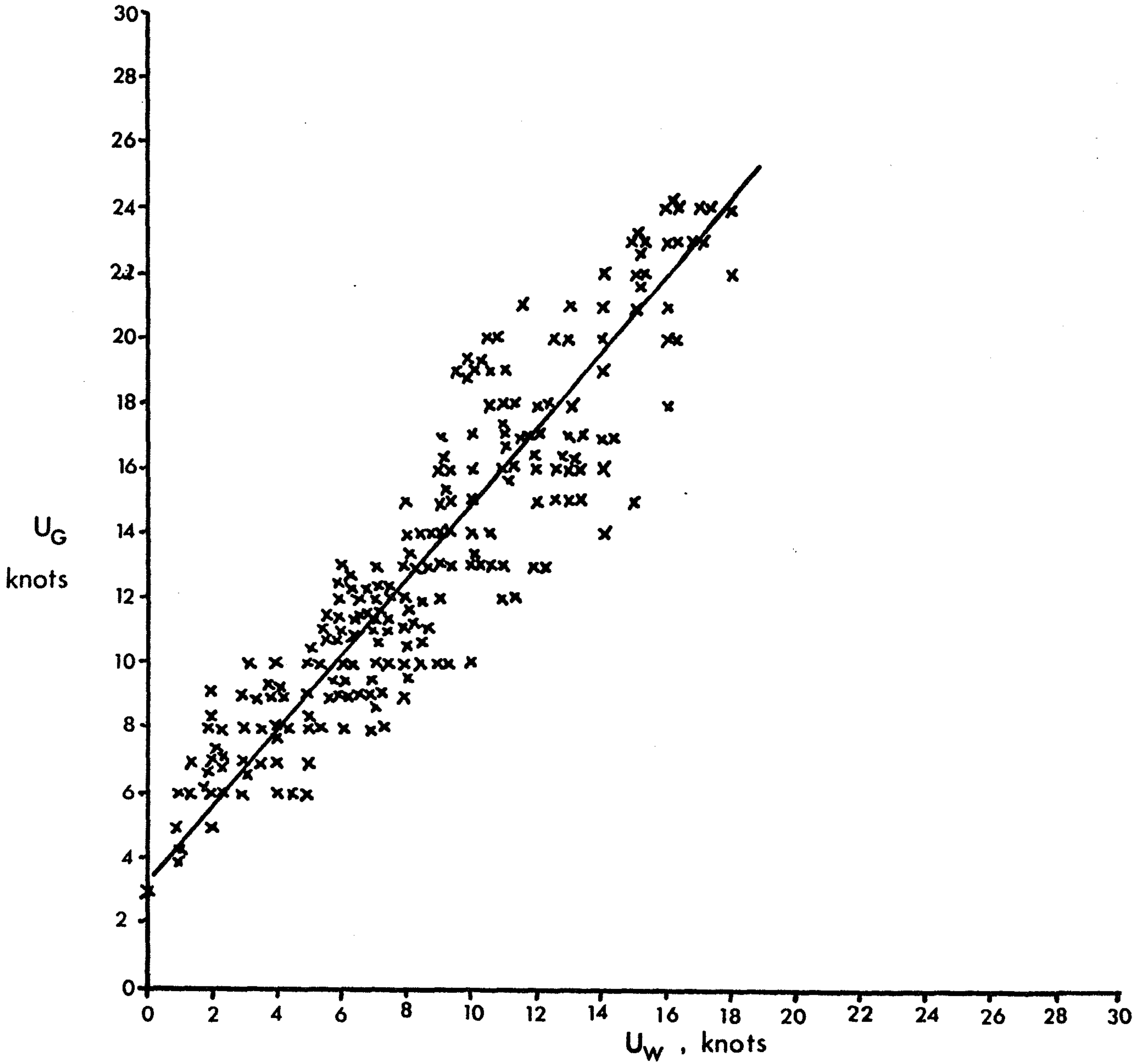


Fig. 20 Full Scale Data. Comparison of U_G and U_W

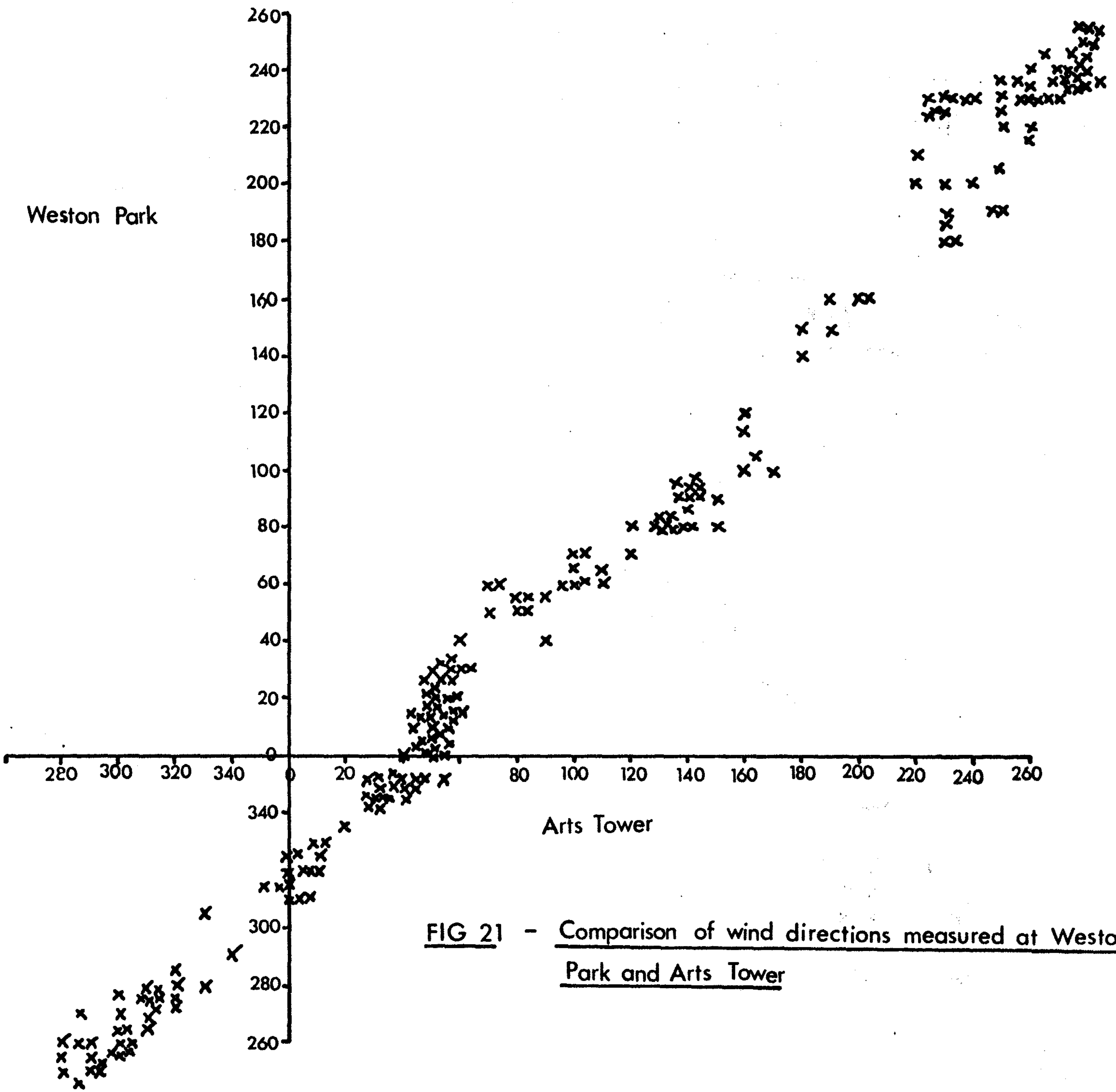


FIG 21 - Comparison of wind directions measured at Weston Park and Arts Tower

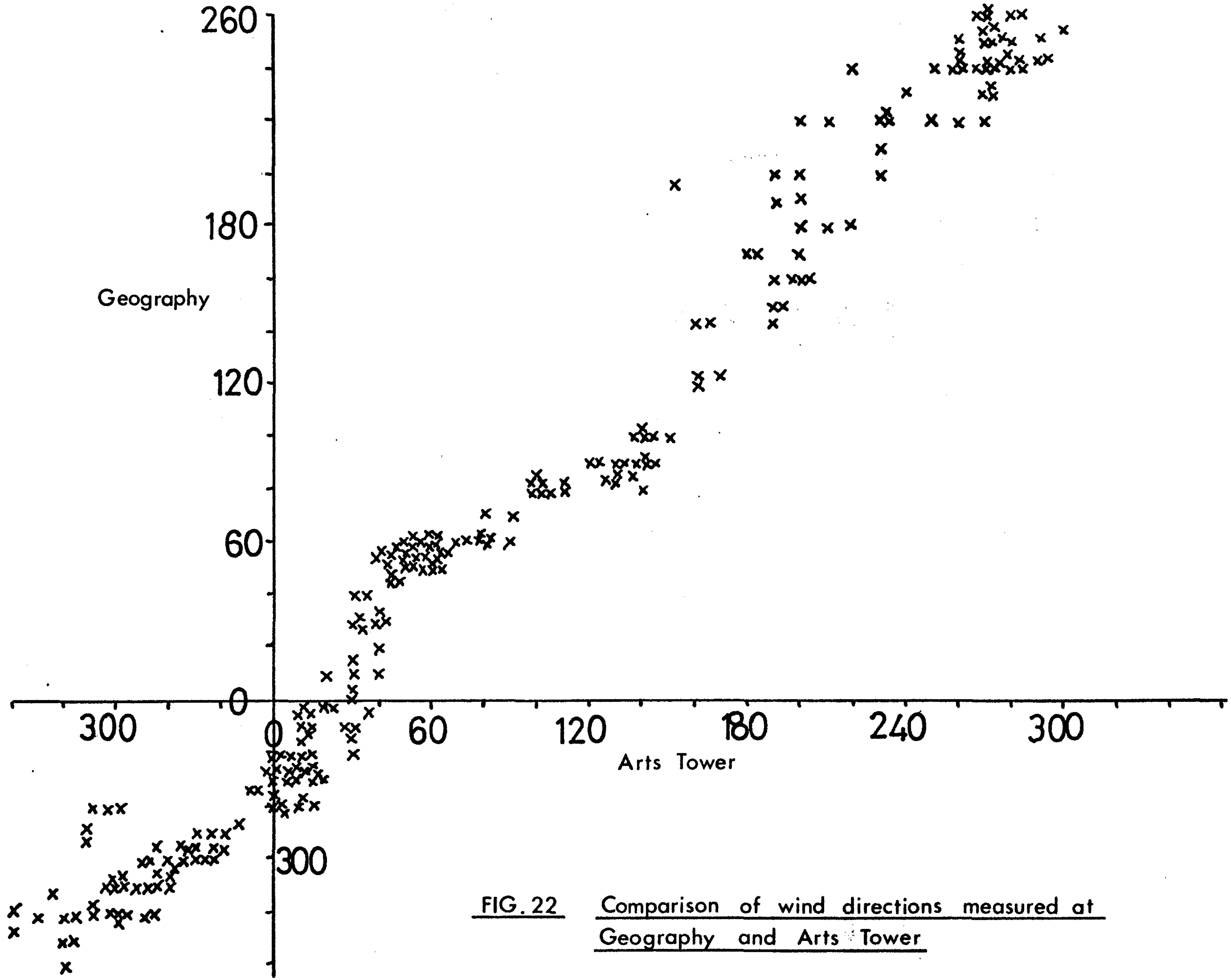


FIG. 22 Comparison of wind directions measured at Geography and Arts Tower