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A SURVEY OF THE AIR CURRENTS
IN THE
BAY OF GIBRALTAR
1929-30

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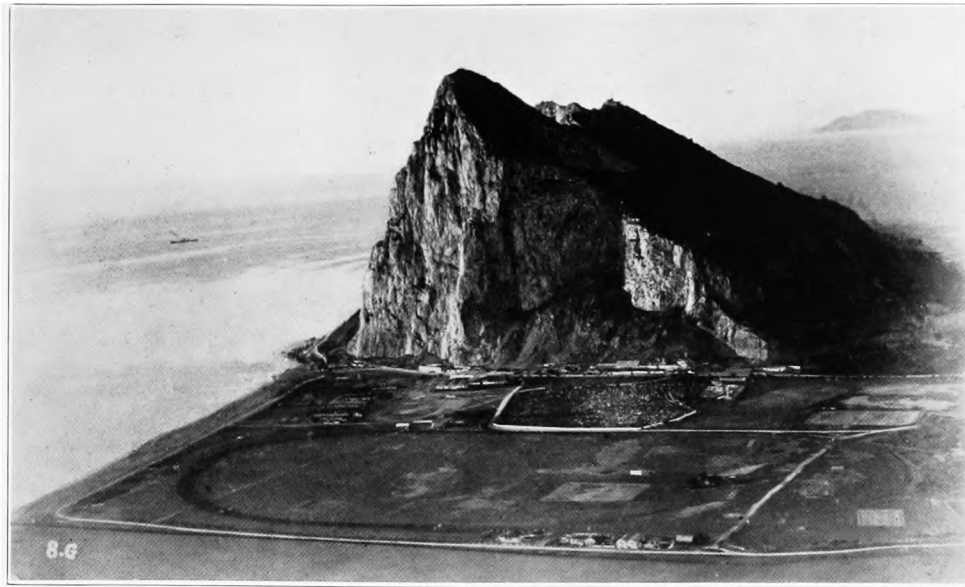
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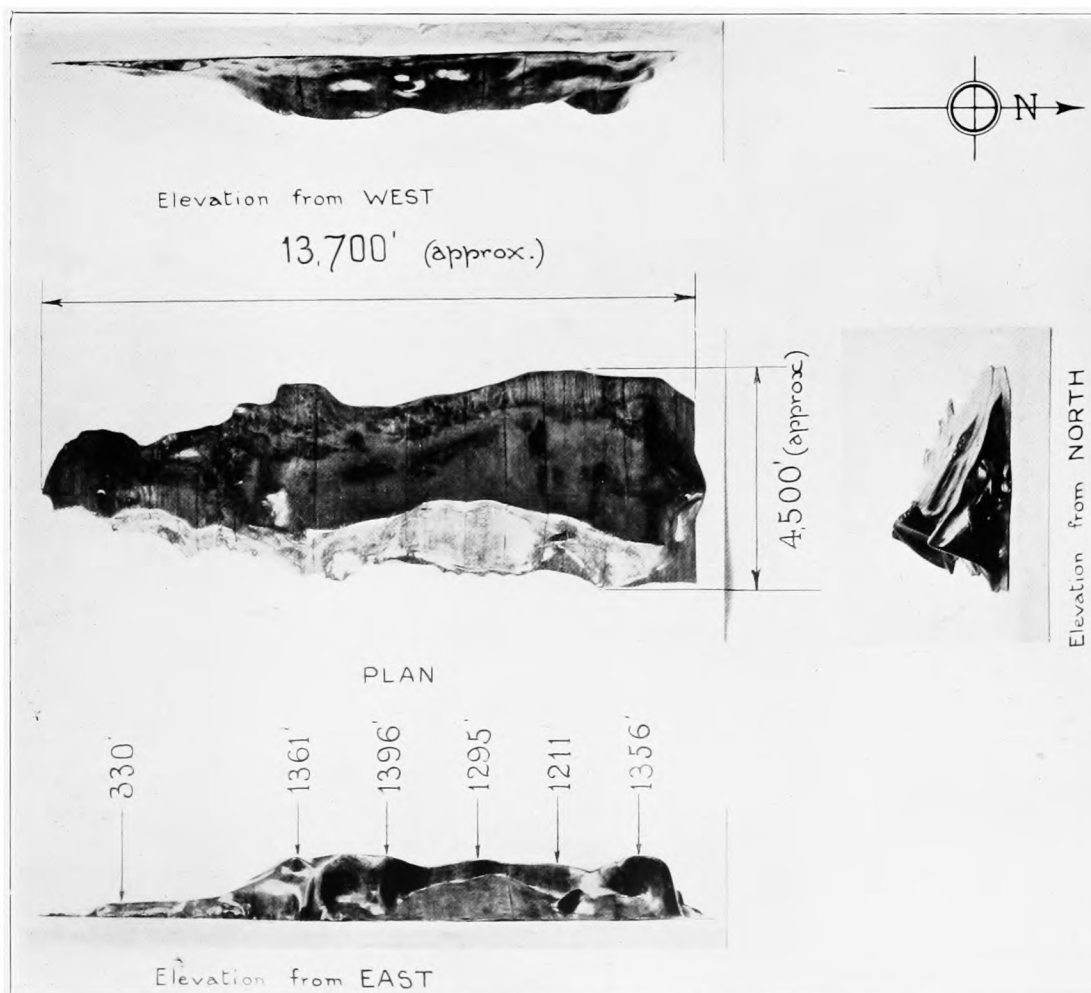
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GIBRALTAR: FROM THE AIR OVER NEUTRAL TERRITORY TO ITS NORTH.



PHOTOGRAPHS OF $\frac{1}{50,000}$ SCALE MODEL OF ROCK OF GIBRALTAR.



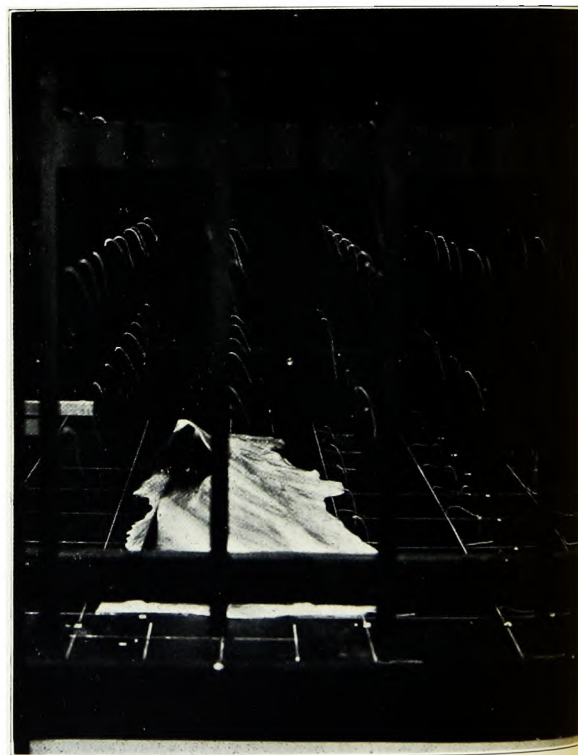
A.

MODEL OF GIBRALTAR ROCK IN WIND TUNNEL.

- A. PLAN. WITH 2,000 FT. MARKINGS ON SEA BASEBOARD.
- B. FROM NORTH-WEST: WITH "FLAGS" AT 2,000 FT. INTERVAL IN PLANES AT 100, 1,000 3,000, 5,000 AND 7,000 FEET ABOVE SEA BASEBOARD.
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B.



C.

A SURVEY OF THE AIR CURRENTS IN THE BAY OF GIBRALTAR

1929-30

I. INTRODUCTION

§ 1—OBJECT

Flying accidents in the immediate lee of the Rock of Gibraltar, and notably the accident to the Fairey III D machine on February 6, 1929, raised in that year the question of the degree of risk which attends flying or alighting in the neighbourhood of the Rock with winds of stated direction and strength ; and the Air Ministry undertook, at the instance of the Admiralty, to make an investigation. Two reports were issued, and this *Memoir* amalgamates the information they contained.

§ 2—THE INVESTIGATION

Winds at Gibraltar are prevailing E. or W., seldom N. or S., as is shown by Table I which gives the percentage frequencies from records of 72 years ;

TABLE I

	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm		N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm
Jan.	1	1	29	7	1	4	26	27	4	July	0	1	40	9	2	5	25	14	4
Feb.	0	1	30	10	1	5	28	22	3	Aug.	0	1	44	8	3	4	24	12	4
March	1	1	25	8	1	7	32	23	2	Sept.	0	1	46	7	2	5	24	10	5
April	0	1	26	10	1	6	29	24	3	Oct.	1	1	37	7	2	9	23	16	4
May	0	1	33	9	2	5	31	16	3	Nov.	0	1	34	6	1	5	29	20	4
June	0	1	34	11	3	5	25	18	3	Dec.	2	1	25	6	1	4	29	27	5

and although it is probable that westerly winds offer on the east of the Rock risks comparable with those on its west in an E. wind, it is commonly only on the west, the harbour and Bay, that aircraft have to descend into the turbulent currents of low levels with a view to alighting. It was accordingly decided to limit the inquiry to the troubled conditions on the west of the Rock when the free wind on open Mediterranean waters is from some easterly direction.

One of the present writers was asked to carry out the work, and, in the course of considering methods of attack to be undertaken at Gibraltar, believed that some preliminary examination of the behaviour of a model of Gibraltar Rock in a wind tunnel would be likely to help, by indicating the type and distribution of the disturbances to be dealt with. Reference on this point to Dr. Simpson of the Meteorological Office, Professor Bairstow of the Royal College of Science and Mr. E. F. Relf, Superintendent of the Aerodynamics Department, National Physical Laboratory (N.P.L.), confirmed this impression, and the interest of the Aeronautical

Research Committee was then invited in the matter. With their approval and the sanction of the Director, N.P.L., the proposed work with a model was carried out in one of the four-foot tunnels at Teddington.

The method of using models for the solution of aerodynamic problems is well established, and in the case of airships and aerofoils has been productive of valuable results not easily to be obtained otherwise; but the scale ratio, model/actual, has hitherto been comparable with the moderate figures $1/10$, $1/50$, or $1/200$ only, so that it has not been rash to infer from the model results what the full-scale behaviour would be, using the known laws of relationship in scale effect. But to pass from these moderate fractional values to the small ratio $1/5,000$ for the present model, with which a tunnel wind of 25 feet per second has as its equivalent on the full scale an almost imperceptible zephyr, was to raise doubts as to how far the results could be trusted to represent full-scale "actuals" on the spot at Gibraltar; and although experts at the N.P.L. were strongly of opinion that the general type and distribution of eddies and other wind troubles would be credibly illustrated, it was realised that the need would remain to test at Gibraltar a selection of characteristic effects in positions at sea corresponding with those on the model scale. The further point had also to be borne in mind that more information was required for the purpose in view than that of the mere distribution and type of the eddies; for the rates of formation and variation of the eddies, and the actual strengths of the observed up and down currents, must be essential features in flying troubles, and these features could not easily be measured on the model scale.

The wind survey came, therefore, to include both model-scale work at the N.P.L. and full-scale work in Gibraltar Bay, and in these the two present writers collaborated, working partly together and in part separately with the results shown below.

II. MODEL WORK

§ 3—APPARATUS AND METHODS

The model of the Rock, Plate I, on the scale $1/5,000$, was made in wood in the workshops of the Aerodynamics Department, N.P.L., by Mr. A. J. Webber, who built it up longitudinally from 36 transverse wood segments, each of which had been shaped on its boundary to the appropriate contour, as deduced from maps lent by the War Office.

The four photographs of the model on Plate I, and the aerial photograph above them, show the shape of the Rock. Excluding the low-lying part at its southern end, the Rock throughout its length rises precipitously, in places almost vertically, from its eastern shore to the ridge, which varies in height from 1,100 feet above sea to nearly 1,400 feet and then falls less sharply to its western shore. The ridge itself is concave to E. winds, and at its northern end is cut off abruptly, dropping almost sheer from 1,300 feet to nearly sea level. At the southern end the Rock falls away at some 35° from the ridge at 1,360 feet to 400 feet, then more gently to 300 feet and finally by a sharp drop of 200 feet down to the low-lying and flat tongue of the peninsula. Gibraltar harbour lies off the western shore, and the town itself stretches along the entire length on the western side of the ridge.

The model was screwed to a baseboard of plywood to represent the sea surface. This base was 80 inches long by 48 inches broad and $\frac{1}{4}$ inch thick, and, with the model in place oriented as for an E. wind in the tunnel, started some six inches up wind to the east of the Rock and extended 63 inches to the west of it, the equivalent of five miles on the full scale corresponding with the whole stretch of Gibraltar Bay. The leading edge of the base was shaped to give a good entry to the wind, and the whole, the base with its model, was fitted into slide grooves on the tunnel wall at 14 inches above the floor; a light longitudinal framework beneath the base along its middle line gave added rigidity. The whole system could be slid along the tunnel to allow easy observation from the tunnel windows of the wind behaviour

at any desired part of the Bay. For observations in an E. wind the model had its north/south axis lying across the tunnel, and for winds other than E. it was skewed upon its baseboard to the appropriate angle for each case. The baseboard sea area was marked off into squares of 4.8 inches (= 2,000 feet full scale) for the purpose of defining the geographical position of individual observations.

With these arrangements, then, the model was subjected to test in wind-tunnel draughts of various strengths, mainly 25 feet per second, to determine the reactions of the wind current in lee of the Rock over the wide field of Gibraltar Bay.

A standard method for measurement with models is to use Pitot heads and yaw meters, but the operation of these instruments in the present case would have been a very lengthy business and their accuracy is much beyond what was necessary. The two new methods now to be described were therefore brought into use, each with its own advantages.

§ 4—FIRST METHOD—FLAGS

In this case the object was to judge the degree of turbulence of the wind, and to record the pitch from the horizontal and yaw from the steady wind direction, for many representative spots in lee of the Rock; and thus to map out regions of danger as judged from the model scale. For this purpose fine silk fibres, attached at one end and free at the other, were liberally distributed as flags or wind indicators to leeward of the model. The flags were about two inches long (800 feet full-scale length), and were placed at regular intervals of latitude and longitude corresponding with a 2,000-foot rectangular spacing over Gibraltar Bay. This spaced system of flags occurred at the level of 100 feet above sea, and was repeated at each of the six higher levels 500, 1,000, 2,000, 3,000, 5,000 and 7,000 feet, while some additional flags were placed in intermediate positions where further information was found to be needed. In all, the flags numbered about eight hundred. The arrangement is shown in Plate II, where the silk flags are seen to be attached at their 2,000-foot intervals to fine transverse wires at several of the various stated levels above sea. The wires were of 7 mil nichrome, fixed horizontally across the tunnel between light open frames of wood attached to the tunnel sides; this material had the advantages of being ductile enough to let the wires be pulled taut without over-straining their attachment frames, and strong enough in this fine size to withstand the wind loads without stretching or breaking. To make the observation of the flickering flags as easy as possible, the silk used was white, and the sea base and sides of the tunnel were painted a dull black.

It may be said at once that the small-scale results with these distributed flags were exceedingly striking. Starting with the model removed, and testing the wind tunnel for steadiness by the grid of flags, with the sea-level baseboard alone present in the tunnel, a state of almost complete quiescence and freedom from turbulence was observed, the flags all trailing horizontally down wind with scarcely a shiver to show.

On inserting the model Rock to windward of the flag system, with its axis lying directly across the tunnel to experience the equivalent of an E. wind, a condition of indescribable turmoil ensued, the flags being fretted and tossed by violent local eddies and extended vortices, upward, downward and horizontal, as far westwards as a mile or more from the Rock, and showing also up and down periodic currents to a much greater distance, with emphatic travelling pulses which were still strongly marked some five miles to the west even at 7,000 feet above sea. Over a region extending from the Rock face to near the spot where the Fairey III D was lost, the vortices were wild and vicious, some from north, some from south, some alternately north and south; some upward, some downward, some alternately up and down, above a given spot; while longer fibres, representing full-scale lengths of 12,000 feet, placed just to windward of the Rock and starting from 3,000 feet

above sea, showed a turbulence over the harbour, and for a mile out over the Bay, which carried their ends with sudden sloping sweeps from heights of 4,000 feet downwards to lick the sea and up again. Within this "Witches' Cauldron" it seemed, as far as model evidence pointed, that all the conditions for flying accidents were present in easterly winds of any considerable strength.

With these dispositions, then, an extensive series of observations of the two-inch flags was made and recorded for wind direction E., taking each flag in turn (as far as necessary—of the 800 flags some in the higher levels could be observed as a class), and estimating by eye its main or predominant position and its total range of angle variation, both in pitch (up and down angles) and in yaw (angles in the horizontal plane). In general the range extended symmetrically on the two sides of the predominant position, but there were marked exceptions; and there were cases, also, where no predominant direction occurred, but merely continuous wildness between the recorded range limits, or even such complete madness of motion that the flag would simulate in its antics the appearance of a spherical mop-head.

With these E.-wind relations observed and recorded, the operations were repeated throughout for wind directions 15° , 30° , and 45° , both N. and S. of E., the seven sets of observations being thus for azimuth angles 045° , 060° , 075° , 090° , 105° , 120° , and 135° . As has been mentioned, the changes of wind direction were arranged by suitably skewing the model upon its baseboard without further alteration, and in some cases this necessitated duplication of observations to eliminate the effects of the tunnel wall on winds diverted from the skewed model, the northern conditions having to be recorded with the north end of the Rock at the maximum available distance from its adjacent wall, and similarly the southern conditions with the model displaced towards the north wall of the tunnel.

On completion of this model work with two-inch flags, it appeared probable that much further information of value could be obtained by using longer silks also, as long, in fact, as was consistent with their continuing to show the streamlines and not having their basal directions (near their attachments) too much disguised by the pull along the streamlines of their terminal portions. This view led to an extension of the model work on lines somewhat different from that just described, using a second method of dealing with the problem.

§ 5—SECOND METHOD—STREAMERS

In this case the object was to determine the features of the larger eddies and vortices induced by the Rock, using long streamers attached to thin steel pins which could be fixed upright in the baseboard at any desired position in relation to the model, and with the streamer attachments at any height up to 7 inches (3,000 feet) above sea. The streamers were to vary in length from about 7 inches (3,000 feet) to nearly 30 inches (say 12,000 feet), and at this stage it was accordingly decided to make various tests to choose the most suitable material for them, from among silk, artificial silk, cotton and wool. A 30-inch length of each was taken and all were fixed in a row across the tunnel, at a uniform height above the base, and with the model removed. Various wind speeds were used, and as there was no appreciable difference in the general steadiness of the streamers, the material showing the least loss of height along its length was regarded favourably. A second test applied was to show the relative values of the several streamers for following curved lines of flow, since differences in stiffness might reasonably be expected to affect the results. A wooden obstruction, 4 in. \times $1\frac{1}{2}$ in. \times 4 ft. 0 in., was placed on edge across the sea baseboard in the tunnel, at a position half way along the streamers down wind, and the reactions to the wind disturbance were noted. In both these tests woollen streamers were found to be the best, and the final choice was one strand of a fine 3-ply Botany wool. Several different lengths of this material were then tested together to see whether the slope of the streamer was independent of its length. This was found to be the case, and the

downward slope from the pin was observed to be about 1 in 30 at a wind speed of 25 feet per second. Replacing the model of the Rock in the tunnel, streamers of various lengths were placed in succession at several points in the disturbed air flow, and their behaviour was noted, with the result that it was decided to use streamers of 7·2 inches (3,000 feet full scale) just in lee of the model, and of 28·8 inches (12,000 feet) further down wind. These longer streamers were used, also, to fly from positions to windward of the model, at heights above sea varying from 800 to 3,000 feet, to show the type of disturbance over the Rock itself.

§ 6—RELATIVE ADVANTAGES OF FLAGS AND STREAMERS

Flags allow the air flow at a point to be precisely specified, for their indications are practically free from interference by the winds nearby, and, with a flag length of two inches as here used, it is easy to read with decision the main direction of the flow in pitch and yaw and the range of variation. Occasional duplication of series of readings, with and without interchange of observers, was found to introduce no material variation in the results recorded. In those cases where the turbulence was so great or rapid that directions could not be estimated, at any rate the record that this was so gave a definite piece of information, and it was judged to be unlikely that shorter flags would have helped more effectively. Flags do not, however, in all cases offer a connected idea of a field of flow, for it may happen, as in the present instance of the model Rock, that large differences of direction occur in closely adjacent planes over a given spot. The charts on Plate III for the levels 1,000 and 2,000 feet show a case in point: over at least two square miles in lee, the winds for the two levels differ strongly *inter se*, while still more emphatic contrasts are shown on the chart of Plate IV for chosen spots in the near neighbourhood of the Rock.

To fit a large number of flags in serried ranks, and to add special ones at interesting points, is a simple matter; and, with this done, the extent of the several disturbed regions in such a case as Gibraltar is at once effectively shown.

Streamers, on the other hand, are well able to give a connected view of the flow of air, and clearly draw attention to the larger eddies and vortices with their long extended limits. In all the streamer indications, however, it has to be borne in mind that for strongly curved streamlines the shapes denoted are compromises, since the terminal parts of the streamers are necessarily pulling out of their would-be shapes those parts which are nearer the fixture pins. To record the visual observations is not so straightforward a task as in the case of flags, and diagrams of the results have to be somewhat impressionistic, but it has been possible to gather and present on the diagrams herein a close idea of the boundary limits of the larger vortices and of their internal turmoil. The method adopted was to sketch as nearly as practicable the outer limits of streamer motion in any one vortex or eddy, and then to fill in the intervening space with an impressionist picture of the appearance presented to a critical observer, finally adding numerical estimates of the percentages of time of observation during which the streamer was within each of an indicated assortment of position ranges. As in the work with flags, a point was made of repeating by an independent observer the readings of streamers in regard to their limits of travel, for comparison of results. Agreement was in general close, the greatest divergence of measurement, in places of wild flow, not exceeding 200 feet in a free end movement of 2,000 feet or more. Estimates of percentage times were also within 10 per cent of each other.

§ 7—RESULTS OF THE WORK WITH THE MODEL

Limitations of space in the present *Memoir* have called for a restriction of the wind directions for discussion to 060°, 075°, 090°, as a selection from the more complete reports originally made to the Air Ministry and the Aeronautical Research Committee;

but the conclusions to be drawn from this restricted range of winds form a valid guide for extrapolation to other easterly directions at Gibraltar.

Tables III-V show most of the observations with flags on the model scale as recorded with these three wind directions, and the records, together with the indications of streamers, are plotted on charts of Gibraltar Bay in Plates V-XXII. The connection between chart plottings and their table figures will be seen, for the three wind directions, by Plates VI, X and XIV, where the grids of flags on their crosswires are shown in position. Plates V-XIII contain also certain full-scale observations made with pilot balloons at sea in the Bay itself, and described below.

Examining first the Plates V-IX, it will be seen that at all levels up to 3,000 feet a due E. wind shows an area of vortices and eddies which extends westwards of the Rock for about a mile and a half over the harbour and Bay, and is succeeded further west by a wide region of turbulent winds on a decreasing scale of trouble. These conditions have probably their maximum development between the levels 500 and 2,000 feet, but that they reach heights of at least 3,000 feet, or more than twice the height of the Rock, in very vigorous form, and descend to worry the 100-foot level, may be seen from Plates IX and V.

On the site itself, in Gibraltar Bay, the sea surface winds during easterly weather are notoriously dangerous for sailing craft, and it is frequently to be observed that the jack and the ensign on the same warship, at anchor in or near the harbour, will be flying strongly in opposite directions and continue to do so for some time; indeed, so close-packed is the detail of strong and persistent eddies that a local yacht owner assured one of the present writers of his experience of two yachts in the Bay approaching one another from opposite directions to within 20 feet distance, each running before a wind of gale force.¹ Such conditions are strongly suggested by the model work shown on the chart of Plate V, within the rectangular area lined out over harbour and sea, for in its eastern half are shown vortices travelling from the north (T.F.N.) meeting in Homeric conflict with vortices from the south (T.F.S.) on a common no-man's land within the harbour; and in its western half the winds show so little regard for one another's convenience that they clash from directions diametrically opposed. These vortices, charted at 100 feet, 500 feet, and higher levels, persistently swept down also to the sea surface in the model measurements, and an interesting comparison with Gibraltar "actuals" is afforded by a note from Lieut.-Commander G. A. M. Williams, R.N., the meteorological Officer of H.M.S. *Furious*, relating to a morning in March, 1930 when a due E. wind prevailed (measured later as 31 knots well out to sea on the south, when it had shifted to 075°):—

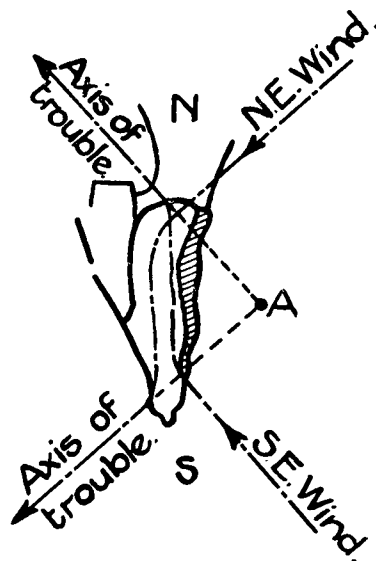
"The turbulence in the harbour, or rather Bay, was most interesting to watch. At about 7 a.m. two fellows saw a really good waterspout; at least they called it that, and said it was the best they had ever seen. The place we were lying in, about 800 yards almost due west from the light at the end of the South Mole, appeared to be more or less in the middle of things, squalls, eddies, etc., started to north and south of us and moved in various directions . . ."

Passing from the surface conditions of Plate V to the higher-level charts, Plates VI-IX, still for an E. wind, the increasing prevalence of vortices is seen strongly marked: for throughout the entire depth of air up to 2,000 feet at least, currents surge around the two ends of the Rock bound for the middle area, where their alternating mastery results in extreme horizontal turbulence, and in up and down currents, extensive and violent.

With the free wind from other directions between NE. and SE. there occur

¹An interesting paper by H. Harries in *London, Q.J.R. Meteor. Soc.*, January, 1914, contains a description on pp. 27-8 of an extremely narrow line of conflicting winds, of squall force, affecting the water surface of Gibraltar Bay and harbour over a length of a mile or more.

marked changes in the positions of the disturbed area (Plates X-XVII for directions 075° and 060°), and a point comes out which would not necessarily have been expected. A shift of wind through 15° , 30° , and 45° , N. and S. of E., not only rotates the axis of disturbance through corresponding angles, but causes also an actual translational shift, south and north respectively, so that for a NE. free wind the axis of disturbance starts from near the south end of the Rock, and for a SE. free wind from the north end. The winds are in fact diverted by the Rock as sketched below and thus show a virtual centre of turning, A, about one mile to the east of the middle point of the ridge.



The five diagrams on Plate XXIII show this feature clearly.

It is useful to pass from the close local detail of the flags, and appreciate the wider bird's-eye view of the evidence by streamers, as plotted on the Plates VI-XVII: these diagrams are impressive in illustrating the streamlines through considerable lengths of path, passing over the field of inquiry from flag to flag.

It has been pointed out that with long streamers the more violent detail given by the flags must necessarily be diluted, and the degree of this dilution can be clearly judged from the charts in general, and from Plate XXIV which has been separately drawn to illustrate the point. It is still the case, however, that the streamers, like the flags, emphasise strongly the areas of turbulence and of vortex motion.

Apart from dilution of the magnitude of effect, the agreement of indication between the two methods, flags and the long and short streamers, is close wherever the streamlines are not sharply curved; it is only in the immediate neighbourhood of the Rock that scrutiny will reveal any material discrepancies due to the streamline pulls considered above.

To examine an instance of discordance Plate VIII may be referred to; at the spot marked G there occurs an apparent clash of evidence in that the mean pitch of the flag is upwards while the streamer shows it exclusively downwards. But the terminal portion of the streamer is seen to be pulling strongly downwards between the levels 1,500 and 500 feet (the plate is to scale with 2,000-foot squares, and the levels of streamer ends can be judged), and this down-pull is required by Plate VII for 1,000 feet, and allowed by Plate VI for 500 feet. The flags were too short for their ends to reach the region of continuous down-pull.

In all these charts of flag and streamer plottings large vortices are indicated in lee of the Rock, with every direction of wind treated: 090° with nearly vertical axes, and all others, 060° - 120° , with axes progressively tending towards the horizontal with increasing shift of the wind from direction due E. But in some cases

they need looking for, by taking note of and following the pitch and yaw on the chart of several levels simultaneously. Some of these vortices, with axes horizontal, inclined or vertical, are well picked out and shown on the set of five charts in Plates XVIII-XXII for streamers of extreme length, representing 12,000 feet on the full scale; these charts are very informative, for the vortex portion of the streamer occurs at its end and there is but little of the masking of true range or true shape which would have occurred, for reasons already explained, had the vortex motion been confined to the earlier part of the streamer.

The long streamers start just upwind of the model, at various heights from 800 to 3,000 feet, and their most suitable positions were found by carefully adjusting the fixed end of each until its free end in lee of the Rock remained wholly within a region of eddy. They therefore indicate the approximate boundaries of the eddies in both pitch and yaw, and the series shows the dominant effect of the wind direction on the position and attitude of the axis in the eddy produced.

With the wind from due E. two nearly equal eddies with axes vertical were formed, making with the main ridge of the Rock a roughly symmetrical arrangement. The axes took up their positions 2,000 to 2,500 feet to the west of the ridge, and roughly that same distance from the ends of it. In Plate XX C where the eddy in pitch is shown with a dotted section of the Rock at each place, it is clear that the eddies throw their backwash up the sloping west face of the Rock and actually reach its crest, their other peripheries extending westwards to a distance of 6,000 or 7,000 feet. The almost vertical downsweep of the wind into the centre of the eddy is a conspicuous feature with this due E. direction.

As the wind changes towards either N. or S. of E., Plates XVIII-XXII, the eddy near that end of the ridge which is moving relatively into the wind increases in size and the other lessens, while both axes gradually turn from the vertical towards the horizontal plane. In Plate XIX, for instance, for wind 075° , where the bluff north end of the Rock is moving relatively into the wind, the northern eddy magnifies itself at the expense of its southern neighbour, and this effect is completed, Plate XVIII, with the further wind change to 060° , where the southern vortex has become suppressed. In the complementary case of the winds shifting towards S. of E., the same effect is noticed (Plates XXI and XXII) though perhaps not so markedly in the intermediate stage 105° (Plate XXI). It has been pointed out that the southern end of Gibraltar Rock subsides towards the sea at the mild angle of about 35° , while the northern end falls almost sheer, and it seems reasonable to suppose that this difference might affect the relative behaviour of the two eddies in the way indicated on the diagrams.

Mention has been made in § 4 that with the model arranged for a due E. wind the turbulence over the Bay was extreme for at least a mile out to sea westwards from the harbour, and that sudden sloping blasts of air would carry a streamer end from the 4,000-foot level down to the sea surface and up again. This case is illustrated on Plate XX A with the two streamers (e) (d) flying midway between the two vortices shown on Plate XX C, which have their vertical axes ending blindly in the sea, and it became a matter of interest to see what happened far to the west with those vortices also (Plates XVIII and XXII) which in winds 060° and 120° had turned their axes into the horizontal, and so might show great extension over the Bay.

The long streamer was therefore moved down wind, with the model skewed for wind angle 120° , and it was then seen that the vortical motion continued for a distance of at least four miles to leeward of the ridge. With wind from direction 060° the disposition in the tunnel was not so convenient for close observation of the results at the end of the streamer, but the appearance presented left little doubt that in this case also the vortical motion was equally extended. In each of these cases, 060° and 120° , that end of the harbour which faced into the wind was clear of the vortex, and over the Bay the winds outside the limits of the vortex were smooth, seemingly untroubled by the presence of the Rock.

III. THE WORK AT GIBRALTAR

§ 8—OBSERVATIONS BY PILOT BALLOONS

The next object was to verify or criticise these model results by work at Gibraltar on the full scale, and to add to them the information, referred to above as not readily accessible through models, on the degree of wind violence in the eddies, and on the rates of formation and variation of the eddies and vortices.

One of the present writers, with Mr. A. E. Mayers, B.Sc., of the British Meteorological Office, as assistant, arrived on the spot on October 15, 1929, with equipment for pilot-balloon observations, i.e. hydrogen, rubber balloons and theodolites, and with other apparatus. They were accorded locally all possible naval and military help; transport facilities were given by Army Headquarters; the Royal Corps of Signals provided between theodolite stations a telephone communication which worked well throughout; the R.A.S.C. allowed the use of s.s. *May* with her kite-flying equipment in the skilled control of her Master, Mr. J. J. Day, on occasions when kites were more suitable than balloons; and O.C., R.A., was good enough to arrange for his own calls on the services of s.s. *May* to fit in with the meteorological programme of work as far as service requirements allowed. The Naval Command lent a launch and an intelligent A.B. seaman to fill and release pilot balloons at sea in the Bay on practically all days when they were asked for by telephone in the early morning; and the Crown Surveyor, Captain H. St. C. Garrood, M.C., allotted a room in his office as working quarters and spared two of his junior technical assistants for theodolite operations on days when pilot balloons were in use.

The season was singularly poor in days of the easterly wind that was desired for the work, but it may be noted that the number of suitable occasions missed from non-availability of any part of staff or equipment was as small as all this kindly assistance could make it.

The wind directions for which observations were required lay between 045° and 135° , and according to the table of normal frequencies in § 2 an average of 38 per cent of the days from November to March show directions lying within this sector. In the season of the present work, however, there occurred a monthly average of only 26 per cent. as recorded at 7 a.m., i.e., early enough to get together by telephone an expectant observing staff, commonly otherwise employed, for a day's work with theodolites; and of these available days only 2 in 3 had winds of strength 15 miles per hour or more. Easterly winds at Gibraltar do not normally bring rain, though much cloud may form and visibility may be poor. But when rainfall does occur from the east it is usually heavy, and in the experience of 1929-30 some of the available days were too wet for successful work with balloons. A few other days were also unfavourable, for with winds of force 6 or more (27 miles per hour and upwards) the eddy and gust conditions at theodolite stations were so violent as seriously to interfere with the work of observation that was attempted.

Three theodolite stations were set up on the moles at positions marked A, B, C on Plate XXVI C, giving base lines AB and AC of convenient length for accuracy over the whole Bay, and allowing a choice of orientation to suit the wind conditions of the day. Balloon ascents began on November 2, and the local observing staff, new to the work, was practised on ten days that month, though only two of these days offered easterly winds: the remaining eight days' work that month was by way of practice only.

In the whole season, November to March, 138 balloons were sent up for theodolite observation, and of these 77 have proved to give service for winds from 072° to 120° , the range within which easterly winds were found to lie during the period of work. Reduced plan trajectories of most of these are plotted on Plate XXV A to give a general idea of the courses, and at the heights above sea 100 feet, 500 feet, 1,000 feet . . . 7,000 feet points are marked 1, 5, 10 . . . 70. In addition there are available the trajectories, the second diagram (B) on Plate XXV, of a number of pilot balloons sent up and observed in Gibraltar Bay by naval officers shortly after the accident to the Fairey III D.

The 77 flights of the working season were closely analysed for wind directions

at the various levels, and for vertical currents in eddies and vortices; the results were plotted by arrows on those of the model charts which relate to free wind directions 060° , 075° , 090° , 105° , and 120° . Of these it is the wind-tunnel charts for directions 060° , 075° , 090° that are reproduced here, but as no winds of 060° occurred on the site at Gibraltar during the season of work, the plottings of pilot-balloon arrows are herein confined to the charts of directions 075° and 090° . These contain, however, the bulk of the pilot-balloon results obtained during the whole period of full-scale work.

§ 9—COMPARISON OF "ACTUALS" WITH THE MODEL RESULTS

In considering these charts for the purpose of comparing model results with "actuals" on the site at Gibraltar, it has to be borne in mind that the tunnel wind is homogeneous in direction and strength throughout its section, while winds on the larger scale are liable to show material variations on these two points from sea level up to the ridge top of the Rock, and also to show changes in the course of the day. It has been noted above, § 2, that variations in wind strength are not to be held to influence greatly the general type and distribution of the eddies and vortices induced by the Rock; but changing directions between different levels remain as a feature affecting any comparison between the two scales of observation. Marked instances of this occurred; on November 25, for instance, the lower wind was 090° and very light, while at 1,500 feet a somewhat abrupt change took place to 225° and cut short the useful range of height; while on March 26 the ground wind was 120° , though at 2,000 feet the direction was 090° or 095° .

In the plottings of "actuals" at Gibraltar as arrows upon the charts of model results, Plates V-XIII, it has been necessary to group together days with somewhat varied directions of free wind: thus the charts of Plates V-IX for model wind 090° contain days of 090° , 095° , and 098° "actuals," and those of Plates X-XIII for 075° model wind contain days of 072° and 080° "actuals."² For these two reasons, real variation upwards of free wind direction, and the grouping of days with slightly different free direction, the correspondence between the model-scale winds and the "actuals" at Gibraltar must suffer, but the charts show nevertheless that the model observations made at the N.P.L. did actually forecast in a very remarkable way the real winds on the site. It is true that over considerable areas of the field a large amount of choice is offered by the model results, both in yaw and pitch, so that where in such cases the "actuals" occur singly, the latitude for agreement is wide, but there are only some 24 instances of discordance, many of them slight, in a total of 360 plottings of balloons; while in regions where the "actuals" are numerous enough to combine their evidence, the accordance is certainly striking. We may refer, for instance, to the charts of Plate X, yaw and pitch, wherein the points marked J K on the Rock show six "actuals" covering a considerable range; in pitch these six winds support the whole range of the model movement, and in yaw four of them support it and two differ. As the most marked case of discordance point L on Plate XI may be looked at, where two winds are opposed to those of the model observations. But reference to spot L in Plate XII, also, discloses that the wind direction was critical between 1,000 feet and 2,000 feet, for the two direction segments are exactly reversed: and further, a lateral shift of equivalent amount, 1,000 feet, on Plate XI, from spot L to spot N, also introduces a direction change which would admit the two winds in question. Examination of the balloon course itself³ has shown further that at 850 feet above sea, 150 feet lower down than in Plate XI, the wind was exactly reversed and so lay entirely in the segment on the chart in question. The region is therefore one of rapidly changing wind direction with change of height and plan position, so that the weight to be attached to this discordance is slight.

If we return now to the favourable points J K at the 500-foot level, to judge whether they are equally critical and should have their favourable evidence corres-

²These five directions are only approximate: probably within 5° of true actuals.

³It was one balloon only, and the two arrows mean that at 1,000 feet the course changed sharply through a small angle from the one arrow to the other. The free wind direction was 072° , and the trajectory does not, therefore, appear on Plate XXV.

pondingly discounted, it is seen that the change in model yaw between 500 and 1,000 feet, Plates X, XI, is comparatively small, and that consequently the evidence here is more weighty than that at spot L.

From the whole available evidence it seems reasonable to conclude that the model observations at scale ratio 1/5,000 give a very definite picture of the vortex and eddy distribution that will be found on the full scale.

§ 10—AREAS OF STRONG UP AND DOWN WIND COMPONENTS

From the balloon courses for easterly winds in general (080°-098°, first chart in Plate XXV) the details of Plate XXVI have been deduced; the up currents, down currents and nearly level winds are differently lined in, and numerics indicate vertical components to the nearest unit of 100 feet per minute: a numeric 5 therefore shows 500 feet per minute (say 450 to 550 feet up or down) irrespective of the horizontal wind component with which it is combined, and level winds are those with less than 50 feet per minute of rise or fall. It is evident that, in spite of the amalgamation of wind directions over some 20° of arc, there are areas where up and down winds are respectively dominant, roughly according to the outlines shown; and comparison with the model-work charts of pitch in Plates VI, VII and VIII, and XX, shows marked correspondence with the model results.

Some further evidence on the vertical circulation was gathered from cloud formation over the Bay. An easterly wind (locally, the "Levanter") may be dry enough to be cloudless there, but is commonly not so; and a frequent condition is that a "banner" cloud forms⁴ over an area starting at the ridge of the Rock and stretching westwards over the harbour and Bay as far as a mile or more. Then follows an area of clear sky (or a thinning of the cloud), and still further down wind a point is reached, or perhaps two points in succession, where cloud forms and becomes true cumulus. Observation seems to show that this cloud in its early stages of formation is temporarily a secondary banner cloud separated by the gap of clear sky from the main and permanent banner, or that it forms at the extreme end of the banner; it develops rapidly without appreciable movement down wind, but at a given stage of growth, or rather after a given interval of time, about four or five minutes from its first appearance, it travels away westwards leaving its place of generation to become the site where a fresh cloud forms in a similar manner. The rate of travel down wind seems to be only about $\frac{1}{3}$ of the free wind velocity of the day, at any rate within a few miles of the starting point at the end of the banner, and this reduction in rate has probably a connection with the general turbulence which provides for evacuation of air otherwise than directly down the free wind course.

Opportunities for undisturbed observation of Levanter clouds were few, for these could only be well seen from a mile or two to the north or south, and on days of their occurrence the work with balloons and kites left little leisure for excursions; but an occasion of watching them from below may be mentioned. On a night in March, a Levanter cloud was showing, with base at 1,400 feet, just clear of the ridge, and was thin enough here and there for the stars and moon to show through: its development and movements could therefore be clearly judged against a fixed background. As seen from the west shore line half way along the Rock, the cloud well out to sea on the west was moving off actively in the prevailing E. wind; but at 25° or 30° up, at a distance of half a mile or three-quarters to the west, cloudlets were forming, remaining stationary during growth, and then moving off down wind. At intervals of a few minutes the original places became the generating points of fresh cloudlets, but with lateral shifts of some 15° either north or south, so that

⁴A "banner" cloud is one that forms in lee of an obstruction causing a forced up-draught of wind, the clear but damp air being then dynamically cooled by its ascent to the point of cloud formation. Commonly a descent and reheating of the air will follow at some distance further down wind, and there the banner terminates. The condition is, then, that a banner cloud, though stationary itself, has a free flow of air constantly through it, often of the full velocity of the free wind prevailing.

the area of origin stretched to about 1,500 feet as seen from that spot. It may have stretched further to include more simultaneous centres, but to a solitary observer the area for watch was restricted.

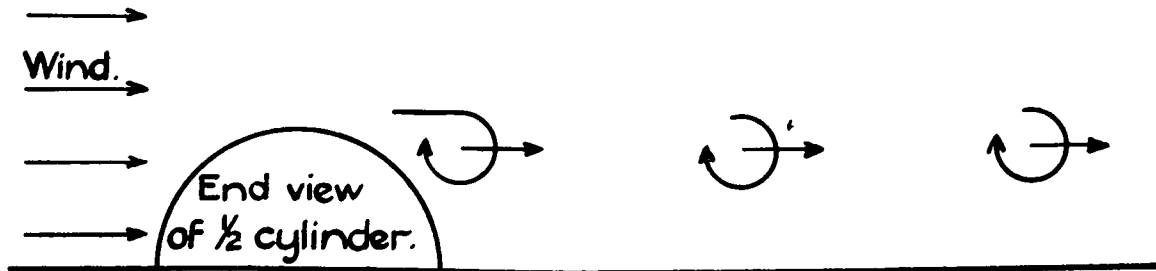
On the morning of March 3 a sketch was being made of the cloud bank as seen from the deck of H.M.S. *Furious*, on an approximate scale of angle readings, when Lieut.-Commander G. A. M. Williams, R.N., offered to photograph the Bay, and the excellent set of four photographs, Plate XXVII, resulted. In photograph A, March 3, at time 15h. 15m., the Levanter cloud has freshly appeared after an interval of high-cloud weather and it is in an early stage of development. Photograph B, taken from two miles further south, shows the stronger condition $1\frac{1}{2}$ hours later, and C and D are for the early morning of March 4 when the cloud has thickened and is heavily draping Gibraltar Bay. In B the permanent banner has become well formed and ends in a growing cumulus hump, ready to break away and move down wind as that seen in A has already done. The wind was 21 knots, and the distance in A of the moving cloud from the nearly completed new hump forming at the banner end affords an example of the slow rate of travel referred to above; taking the period between successive hump formations to be four or five minutes as timed on other occasions, the speed of travel is about 10 miles per hour, or roughly $\frac{1}{3}$ of the free wind speed of the day.

At the time when photograph B was taken the wind direction was 075° , so that the cloud axis pointed approximately towards the late afternoon sun, and a glance at the sunshine and shade on the cloud shows that where the banner thickens vertically it also broadens sideways. On the basis of this broadening the cloud photograph has been sketched to measure as a plan view on Plate XXVI B, in position fixed by the probable assumption that the cloud axis lay along the line of maximum turbulence to the west of the model rock. It has been necessary to orient it east-west, as the chart on the same plate for up and down currents, with which the cloud is to be compared, is for easterly winds in general (072° to 098°) since there are too few observations of vertical currents in a wind of purely 075° direction. Though this artificial change, 15° , of orientation must be borne in mind, the model charts on Plates VII and XI, VIII and XII, show that for this amount of shift the change for the stratum 1,000 to 2,000 feet is not very great within the area where the cloud would lie, bounded by the two respective axes of greatest disturbance for winds 075° and 090° . Accepting this compromise in order to allow some comparison to be made, it will be seen that the main body of the banner cloud, and its developing terminal hump B, cover regions of up current, and that each of them ends where down current begins on the chart; and also that the secondary hump C tends to agree with the vertical air movement.

When the photographs taken by Lieut.-Commander Williams were received, it was realised that much might be learnt from a regular series of pictures taken from a fixed position at sea, with uniform intervals of time; and an attempt was made early in April to get such a series from s.s. *May* several miles south in the open sea. Forty exposures were made at one-minute intervals, but the day offered poor visibility and the results were indifferent. The last six photographs of this series, times 35-40 minutes, are shown in Plate XXVIII and, though they are failures as pictures, they do show the genesis of the hump (b_1 b_2) forming at intervals on the end of the banner cloud (a), and that the subsequent development of the hump in height calls for vertical velocities of at least 300 feet per minute within the cloud mass; they give also an indication that the period is about four or five minutes from b_1 to b_2 .

A point of interest in regard to this periodicity of development and breakaway is that Mr. Relf of the N.P.L. had told the writers before the model work began that on theoretical grounds he would expect a period of something like 3 minutes for

disturbances in the lee of a bluff obstacle of the height of Gibraltar placed in the path of a steady wind. An inverted half cylinder laid prone with its axis across the wind is a known case in model form ; eddies form in lee of its ridge and at a given stage of development, or after a given time interval, they break off and travel down wind to make a way for their successors to form. The Rock is more bluff



than a half-cylinder, as is seen from the photograph on Plate I taken from the air over the Neutral Territory, but the period relationship was expected to hold approximately, as it now appears to do.

It is certain that a series of sixty one-minute photographs of the quality of Lieut.-Commander Williams' results, would be full of information of value, if taken on a clear day with typical cloud, as in Plate XXVII, from a single fixed position two or three miles south of Europa Point ; and if a second series with simultaneous exposures could be taken from another ship at a known point a mile due west of the first position, its stereoscopic effect would add greatly to the results and allow conclusions to be drawn on many points of turbulence. Or two such simultaneous series might be taken a mile apart from the Spanish shore line along the north of the Bay, looking southwards, though without the advantage of direct sunlight on the flank of the cloud ; this it had been arranged to do should a day of suitable cloud conditions occur, but no such day was found up to the time of closing work at Gibraltar. In the absence of these helps to observation, it is not possible to express certainty, but the general impression on the formation of Levante cloud is as above described ; it would be interesting to have material from which to settle definitely these several points of periodic development and breakaway, rate of travel and detail of turbulence.

§ 11—STRENGTHS OF VERTICAL COMPONENTS OF WINDS

The up and down velocities indicated on the charts of Plate XXVI do not represent the maximum values attained by the wind. Actual peak values cannot be measured by pilot balloons and theodolites : they can only be approached. The shortest time interval that can be dealt with in theodolite practice with 3 observers at each instrument (following, circle reading, recording and timing) is a quarter minute, the period between circle readings ; and any such single reading is subject to doubt if it stands by itself in declaring some startling feature. It may be taken, then, that two consecutive quarter-minute readings supporting one another are desirable at each end of a time interval from which any important deduction is to be made, and consequently that the strength of the transient vertical wind velocities in vortices and eddies will be very much undermeasured in work with pilot balloons.

In the present work much detail of this kind was encountered, and in 77 balloon flights in easterly winds, mostly of about force 3 (13 miles per hour at ground level) there occurred 233 cases of well marked vertical components of currents, or changes in those components, with an average duration of $1\frac{1}{2}$ minutes as the balloon passed upwards ; they were found at all heights up to 5,000 feet and probably persisted higher still. Of currents exceeding 150 vertical feet per minute there were 67, 42 downward and 25 up, ranging up to maximum values of 680 and 760 feet⁵ per

⁵This was an isolated high value (760) for up current, and the conclusion on p. 20 is still correct, that down currents are stronger than up currents and are considerably more frequent.

minute for down and up currents respectively, as measured by the theodolite, and it would not be unreasonable to infer that peak values may have been twice as strong. Table II gives the majority of these measurements of strong up and down currents and shows the approximate relationship of each to the free wind strength of the day:—

TABLE II—STRONG VERTICAL CURRENTS: EXCEEDING 150 FEET PER MINUTE

DOWN CURRENTS			UP CURRENTS		
A_d	B	C	A_u	B	C
Free wind force 3 (average 900 ft./min.)			Free wind force 3		
5	180	.2	6	170	.2
6	160	.2	6	200	.2
9	300	.3	6	200	.2
10	400	.4	8	230	.3
12	180	.2	9	180	.2
13	180	.2	9	200	.2
13	230	.3	13	350	.4
13	480	.5	13	460	.5
14	160	.2	14	420	.5
14	180	.2	18	160	.2
14	290	.3	19	310	.3
14	500	.6	22	560	.6
16	680	.6	23	400	.4
17	200	.2	30	200	.2
17	260	.3	40	300	.3
17	590	.7	60	240	.3
23	360	.4	Free wind force 4		
23	640	.7	7	160	.1
24	320	.4	15	380	.3
25	410	.5	18	400	.3
26	390	.4	67	360	.3
29	330	.4	Free wind force 6		
31	180	.2	5	170	.1
33	420	.5	6	220	.1
37	240	.3	12	430	.2
40	420	.5	20	760	.3
43	430	.5	A_d = Downward angle of air current. A_u = Upward angle of air current. B = Measured vertical velocity of air current. C = Ratio $\frac{\text{vertical velocity of current}}{\text{velocity of free wind.}}$		
45	500	.6			
47	530	.6			
48	450	.5			
50	620	.7	Free wind force 4 (average 1,400 ft./min.)		
52	600	.7	11	200	.1
55	470	.5	20	230	.2
59	630	.7	45	340	.2
Free wind force 6 (average 2,500 ft./min.)			5	180	.1
			6	230	.1
			12	460	.2

The cases in the table under force 3 are culled from a long series of flights during several months of work, fairly distributed over the more troubled area of the Bay, but those for forces 4 and 6 result from a single day's work for each of these wind speeds. On these two days attempts to penetrate into the more disturbed regions at sea met with but little success, and the figures in the table for forces 4 and 6 are representative mainly of the outskirts of turbulence. It is to the records for force 3, therefore, that we must look for an indication of the relationship between vertical velocity and the free wind speed of the day, and this in the case of down currents is seen from column C frequently to reach 0.6 or 0.7 for the descents of steeper angle. So high a value for the result of pilot balloons, as observed by theodolites, indicates that actual short-period vertical gusts in Gibraltar Bay must frequently exceed in speed the free wind of the day.

The vertical currents, as now found for the winter season 1929/30 are not nearly so vigorous as some reported by naval officers who used balloons in 1929 (Plate XXV B) near the spot where Fairey III D disappeared, but their most drastic cases were in winds of forces 6 and 7, and we may take it that the strength of air turmoil would be proportional to the free wind speed at the surface. With these two reasons to support the probability of much more vicious conditions than were found in the gentler winds of the winter season, 1929-30, namely, that flying winds may be up to force 7 or 8, and the certainty that peak values greatly exceed those measured by pilot balloons, there is no cause to doubt that vertical components of velocities may reach 1,500 feet per minute⁶ in lee of the Rock; and, on the evidence of the N.P.L. model measurements in a wind tunnel with long streamers, that these currents may here and there sweep in a single stroke from the 3,000-foot level down to the sea within a horizontal wind travel of 4,000 feet.

The full inferences from these measurements are for pilots to draw, but it does seem to the writers that an aeroplane passing from level flowing air into one of these vortices will not only be heavily bumped, but may refuse control too long if the diameter of the vortex core is extended enough to retain the pilot for an appreciable time. Plates XVIII to XXII show that the diameter of a vortex may exceed a mile near the sea level, and that what may be regarded as its more violent core will measure 500 feet across at 1,500 feet up, and more lower down.

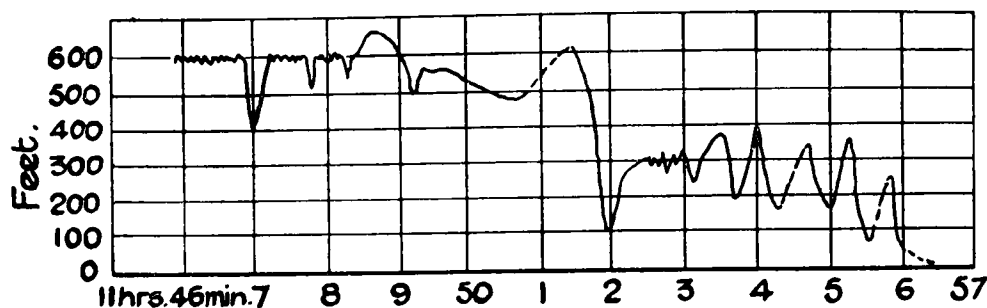
It is known that the pilot of Fairey III D was engaged in turning just before he lost control and dived, and it seems probable that this turning movement may have removed his chance of emerging from a descending vortex core and regaining control. The later accident to the Fairey postal machine just over the brow of the Atlas Mountains in north Africa may have been another case with the same cause; the core itself may have been definitely involved.

Here may be mentioned some notes from eye observations of cloud movement and of the flying behaviour of kites, as extracted from many similar notes made in the course of the work. On March 4, Levanter cloud stretched well across the Bay in an E. wind of force 5, and vigorous horizontal swirls were visible in the clouds at 2,000 feet in position D on the third chart of Plate XXVI, having only 1° diameter, i.e., the swirl was limited to a cross measurement of some 35 feet; similar swirls, though probably larger, occurred as far west as point E and two complete turns of a corkscrew twist with horizontal axis were visible at F. These are samples of observations which may be recorded in scores over the Bay on any Levanter day of strong wind.

On March 28 and April 1 the regions along lines GH and JK were tested for instability in free wind directions 090° and 056° respectively, using a kite flying between 300 and 600 feet up, one observer watching it and giving remarks every few seconds to be jotted down by a second observer who recorded watch times also. The line GH lay nearly on the southern boundary of any considerable turmoil for an E. wind, but the variations of rise and fall of the kite, flying at about 350 feet

⁶Pilots have reported being carried up 800 feet in less than half a minute when flying at 3,000 feet in the neighbourhood of the Rock of Gibraltar.

up, showed that phases of wind were mostly as short-lived as five seconds : the line JK for April 1 lay well within the region of turmoil for a wind 056° and showed the flying record which is plotted below :—



On that day, also, the southern boundary wall of the hump cloud at the banner end (equivalent to B in the second chart of Plate XXVI for March 3) was seen to be violently disrupted by descending currents tearing cloud bands from the upper surface and carrying them downwards as long vertical streaks over the southern flank of the cloud to dissolve away at the level of the cloud base.

§ 12—A FURTHER METHOD OF EXAMINATION OF EDDIES

So far, then, we have information to connect actual winds with those shown by models in a tunnel, as regards general type and distribution of vortices or eddies, up and down currents and trend of streamlines in Gibraltar Bay ; and a very close and useful connection it seems to be, for it opens up the possibility of forecasting with considerable accuracy the suitability of any new and untried site for an aerodrome or sea base, at much less expense than would be involved in testing it on the site itself.

We have also from the pilot balloons a limited assortment of measures of velocities for vertical currents, and these again are important ; they cannot well be obtained from work with models.

But more information is desirable ; for any single balloon in passing upwards at a known rate experiences only the instantaneous values for winds, vertical and horizontal ; it gives no information, when viewed by theodolites, either as to the rapidity of changes of direction in eddies at any one height and position, or as to the frequency of recurrence of given conditions at any one such spot.

To secure this further information an instrument was designed during work at Gibraltar, to record on a permanent time chart, the instantaneous values, throughout a kite flight, of yaw, pitch and velocity of the wind. It was found that the instrument could not be constructed locally, and its importance was judged to warrant a journey to England, while observational work with pilot balloons continued at Gibraltar. So the return to England was made, a sample instrument was completed and modified under test, partly in a N.P.L. wind tunnel, and three copies were provided by the workshop of Kew Observatory ; the four were then taken out to Gibraltar.

Under test on the open Bay with kites flown from s.s. *May* the instrument was further modified and made to function well. A condition for its use in the present case was that the kite should first be raised in the steady sea winds well to the south of the Rock until it had reached such a height (e.g., 4,000-5,000 feet above sea) as should allow the return of s.s. *May* into the troubled Bay area, with the kite flying stably above the turbulent region, and with the instrument attached to the kite-wire at about 500 feet above sea. The *May* would then have cruised about the whole Bay, stopping for a 10-minute record at each of a series of measured positions, and it was considered that a single day's such work in a suitable wind would give more information on the problem in hand than many months of work with pilot balloons. But these wind conditions were not met during the season's work, for

despite many trials on every likely-looking day there was one occasion only when the wind was strong enough for the purpose, and then it was also too strong: the kite broke its cable and had to be recovered later from the Spanish littoral on the west of the Bay.

Considerable attention had been paid to the design and development of this instrument recorder (see Plates XXX, XXXI and Appendix), which had not only to note steady and slow changes of wind character, but to be itself aerodynamically balanced so that rapid and violent changes would leave its standard azimuth plane unaffected and its attitude vertical. This balance was partly effected by alterations of shape after trials of the first sample instrument in a wind tunnel at the N.P.L., and was completed by further modifications in Gibraltar. In the result it appears to the writers that a powerful tool is now available for dealing with similar inquiries in future, but that in view of the need to raise the large kite to some such height as 4,000 feet, where the winds over turbulent regions are steady enough in direction and strength for the kite to function well, considerable periods of waiting for suitable weather would commonly be involved. If, however, a small kite balloon were to be made for a light lift (say 500 to 800 lb.) to give when standing at height 4,000 feet a cable angle at 500 feet up of about 45° , there is little question that a single day's work in a wind of the required direction would give more information than could be obtained by six months' work with pilot balloons. An expert on kite balloons, whom the writers consulted on the matter, regarded its feasibility as clear, and it is believed that the Air Ministry already has designs prepared for small kite balloons. The expense of making and using such miniature kite balloons might be considerable, but so also is that of a balloon-theodolite programme lasting many months; and as there must be in prospect many a question of site suitability for aerodromes or sea bases for aircraft, it has seemed worth while to express this opinion. With first a test by model of the surrounding country in any particular case, and then, if the model indicates in favour of the site, some full-scale work with a kite, or kite balloon, carrying this recording instrument, warning would be given in time to avoid unprofitable expenditure on a site destined to prove dangerous in continued practice. A case corresponding with that of Gibraltar would be, for instance, Table Bay, where banner cloud (the well-known "Tablecloth") forms, and dangerous conditions prevail, when a "southeaster" blows over the mountain from the direction of Simonstown; one hears rumours, sometimes, of cases having occurred where great public expenditure on an aerodrome site has had to be regretted on account of dangerous alighting conditions discovered too late.

IV. SUMMARY

1. Accidents to aircraft in lee of the Rock of Gibraltar led to a survey in 1929-30 of the winds causing them, and the survey included a preliminary examination with a model of the Rock on the scale 1/5,000 in a wind tunnel at the N.P.L., and full-scale work in Gibraltar Bay with pilot balloons and theodolites, and with kites carrying a new form of recording instrument.

It was found that the measurements with the model closely forecast what occurred in nature at Gibraltar, in regard to wind directions and the distribution of vortices and vertical currents. The inference follows that model measurements would in future cases be a good preliminary, when the suitability of a proposed aerodrome or sea base is to be considered.

2. In the model examination two methods were used to determine the wind reactions caused by the Rock. In the first, an extensive grid of some 800 "flags," two-inch silk fibres, was fixed within the wind tunnel with regular spacing intervals of position and height, and these flags were observed for range and violence of movement and for prevailing directions in pitch and yaw. In the second method long streamers of fine wool fibres were placed in various critical positions, and records of streamline shapes were made.

The wind speed used was mostly 25 feet per second, and the wind direction was varied from NE. through E. to SE. by suitably orienting the model in the tunnel: the range of height of the observations was from sea level up to 7,000 feet above it.

3. In regard to the further features of the winds, actual strength and rapidity of changes in direction and strength, measurements with models will not readily give a forecast; determinations of these must in general be made on the full-scale site itself, as was done in the present case in Gibraltar Bay. Between November and March 138 pilot balloons were sent up there and observed by theodolites, and in addition kites were flown to carry the new instrument, herein described, for recording yaw, pitch and wind strength, on a time-scale diagram.

4. At Gibraltar the winds are turbulent for two miles at least in lee of the Rock in an easterly wind, and from sea level up to 5,000 feet or more. Areas of strong turbulence extend to a mile outside the harbour, and a mile from north to south; and the disturbed area shifts its position with any change of the free wind direction of the day.

With a due E. wind, two large permanent vortices, with curved axes ending vertically on the sea shore, spread their rotating cones well out to sea over the harbour and Bay; while with changes of the free wind to N. or S. of E., the vortices progressively shift their axes towards the horizontal and the up-wind vortex grows in size at the expense of its neighbour, until with a wind 30° N. or S. of E., 060° or 120° , a single large vortex persists, with an axis which stretches horizontally for four miles or more over the Bay, in the direction of the prevailing wind.

In some cases these vortices are 6,000 feet in diameter, and in the contiguous regions of turmoil the winds sweep from the 3,000-foot level, at least, down to the sea, within a horizontal travel of three-quarters of a mile.

5. Vertical components of wind velocities in Gibraltar, as measured by pilot balloons in the present case of a particularly mild season, reached nearly 800 feet per minute, and this implies that they probably attain 1,500 feet per minute or more, up or down, over short intervals of time such as a quarter of a minute, even on days when the free wind does not exceed a strength of force 6.

Down currents are stronger than up currents, and are considerably more frequent.

6. In the course of work at Gibraltar the conclusion was reached that the best way, after preliminary work with a model, to tackle any further problem of this nature would be by means of kites and the new recorder, or better still by a kite balloon and the recorder, rather than by pilot balloons. With kites it is necessary to await a day when the wind is strong enough to maintain steady flight at a really high level, well above the turmoil in which the instrument itself has to be hung, and make its measurements; and this condition may involve a considerable period of marking time: but with a kite balloon it seems probable that a single day's work would provide more precise and informative results than could be had with many months' work with pilot balloons and theodolites.

7. The attached map, Plate XXIX, shows the areas of greatest flying risks for seven wind directions from NE. to SE.

NOMENCLATURE IN TABLES AND PLATES

RESULTS WITH MODEL IN WIND TUNNEL.

First method: using indicating flags.

	Pitch	Yaw
Positive angle	Up current	Deviation towards north side of free easterly wind in tunnel, indicating a wind from S. of E.
Negative angle	Down current	Deviation towards south side of free easterly wind in tunnel.

Examples of symbols:—

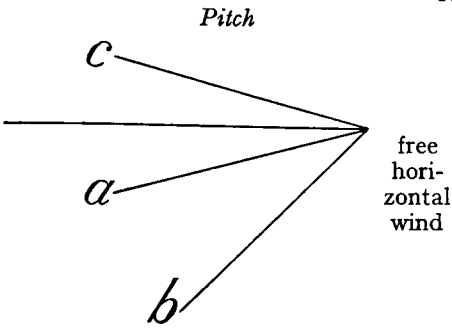
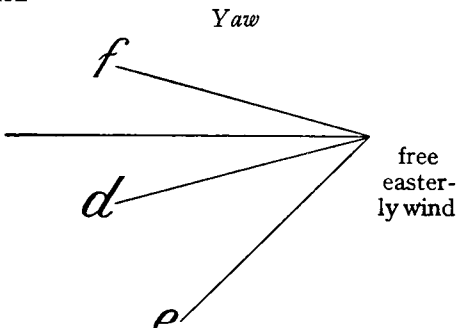
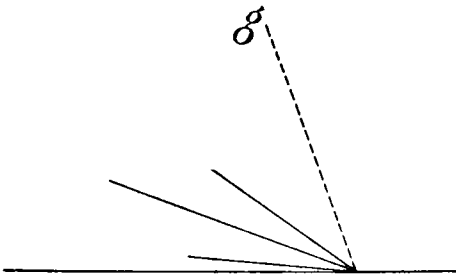
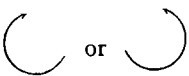
TABLE	PLATE	
	<p>Pitch</p>  <p>free horizontal wind</p>	<p>Yaw</p>  <p>free easterly wind</p>
-15/30	<p>The horizontal line represents a free horizontal wind. Predominant pitch is <i>a</i>, 15° downwards, and the variation range is <i>bc</i>, 30° on either side of <i>a</i>.</p>	
-15/+30 -40	<p>As above for predominant direction, but with unsymmetrical variation range on the two sides of it.</p>	
-15/30, E±90	<p>As above for predominant direction and variation, but with occasional excursions (E±90) to angles +90°, -90°, from the free wind direction.</p>	
-15/30, E	<p>As above, but with occasional excursions of indeterminate extent.</p>	
+45/ -80/	<p>Extreme ranges on the two sides of the free wind direction, when no predominant direction was shown.</p>	
+20/15 p. 50	<p>A motion +20/15, and in addition a periodic pulse of 50°, as shown by <i>g</i>. The pulses, noticed chiefly in the higher planes, were sharp flicks, usually in pitch, in the upward direction, with comparatively slow return.</p> 	

TABLE TN or TS	PLATE T.F.N. T.F.S.	Indicates that the flag persisted in twisting round the cross-tunnel attachment wire, from north or south respectively: a rotating eddy from N, or S.
T		Indicates that the flag took up all positions in the circle (pitch or yaw) as in rotating eddies upward or downward, or by general unordered wildness.

W = 1 to 10	An estimate of the wildness (irregularity) of the flag motion, W = 10 being the maximum wildness.
V, v = 1 to 10	An estimate of the periodicity of motion, V = 10 being the minimum period, or sharpest oscillation.

Second method: using long streamers.

The following symbols have been used on the plates:—

- | | | |
|--|-------------------------|------------------|
| V.S. very steady. | S. steady. | V.W. very wild.* |
| S.W. slightly wild. | W. wild. | |
| E. eddying. | | |
| E 50. eddying for 50% of its time. These estimates of percentages have a large range in value in the plates; they are used also for non-eddying flags where applicable to the motion observed. | | |
| ST. straight. | SL. sluggish in motion. | |
| P. pulsing: i.e., with a pulse running along the streamer. | | |
| ND. showing no definite or predominant direction of flow between the extreme positions of the streamer drawn in the diagram. | | |

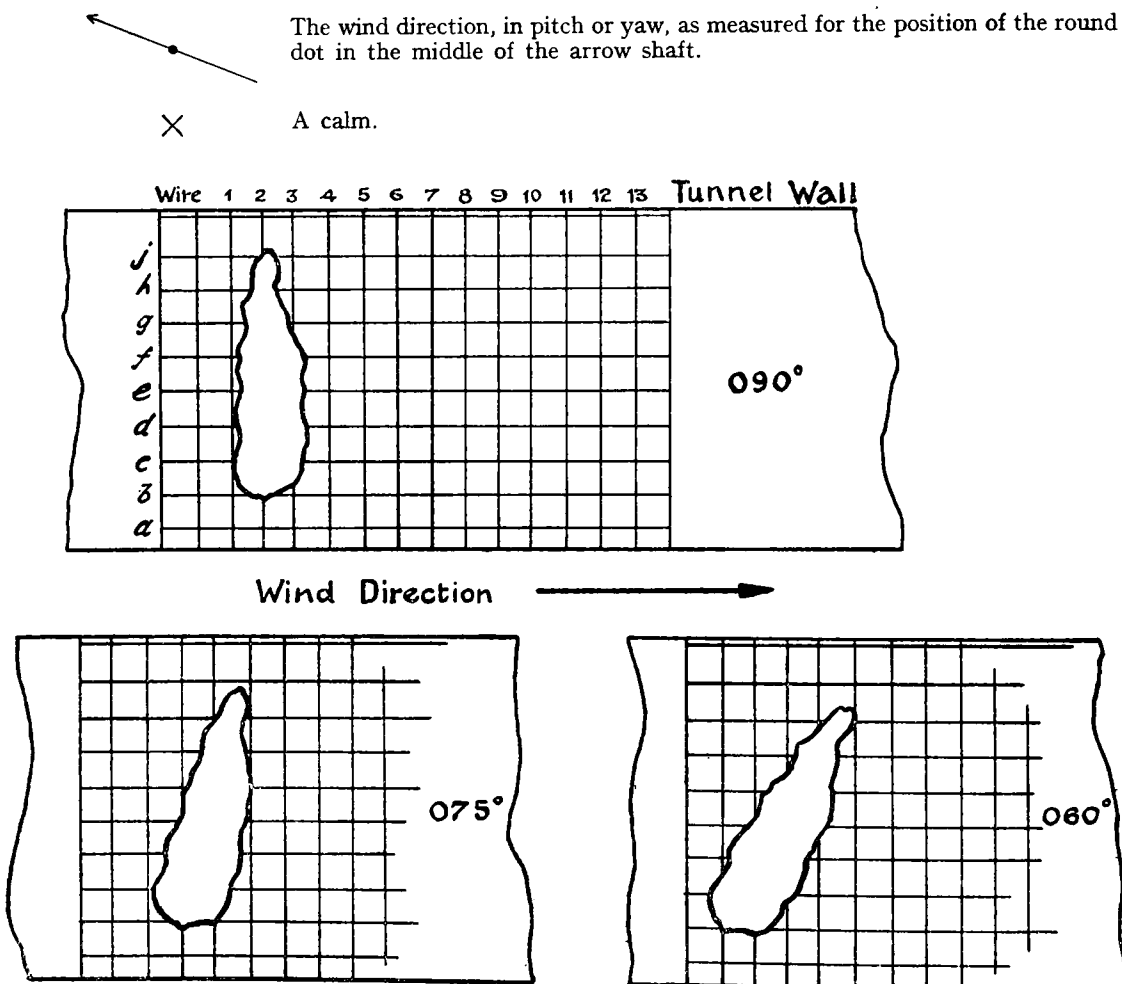
v=1 to 10 the same character as in the case of flags.

In using the plottings of flags and streamers as shown on the plates, it is necessary to bear in mind that the plottings of pitch are for angles of pitch only, and that the directions shown have no reference to the directions assumed in plan view.

Both yaw and pitch must be consulted in the plates to see what is happening at a given point, and where the free end of the flag or streamer really is.

In some few cases of pitch plottings it has even been necessary, in order to avoid too much overlapping, to draw them pointing *towards* the Rock, when actually in yaw view they point away from it.

PLOTTINGS ON PLATES V-XIII OF FULL-SCALE RESULTS OBTAINED AT GIBRALTAR
BY MEANS OF PILOT BALLOONS.



PLAN VIEW SHOWING ORIENTATION OF THE MODEL IN THE WIND-TUNNEL TO GIVE EXPOSURE TO WINDS OF THE THREE DIRECTIONS OF TABLES III, IV AND V: AND SHOWING THE RELATIONSHIP OF THE RANKS OF FLAGS *a*, *b*, *j*, TO THEIR ATTACHMENT WIRES 1, 2, 14, AT THE HEIGHTS ABOVE SEA 100 ft., 500 ft., 1000 ft., 2000 ft., 3000 ft., 5000 ft. AND 7000 ft.

*For example on Plate XIX A and B the entry "0 to 7000' steady, rest V.W." means that for 7000 feet horizontally west of the origin the streamer was steady, beyond that it was very wild.

TABLES III, IV and V

Figures of PITCH and YAW obtained in a four-foot wind tunnel at the National Physical Laboratory, using a model of Gibraltar Rock exposed to winds from directions 060°, 075° and 090°.

(Italics are the figures for yaw.)

TABLE III.

WIND E.: 090°

100 ft. above sea level.

Flag	Wire : 3	4	5	6	7	8	9
a	0/2	0/2	0/2	0/2	0/2	0/2	0/2
b	- 10/15	- 15/15	- 5/15	0/15	+ 3/15	+ 3/15	+ 3/15
c	180/80 E	-120/50 E : TN	- 80/90 E	-30/40 E+70	0/45	0/40	0/40
d	180/60	-165/35 TN	-170/45 E-90	-90/90 E. T.	-30/90	-10/50	0/50
e	-170/70	+170/70 TS	+150/60 E+45	+60/60	+45/45	+30/30	+25/30
f	*	+110/60 TS	+ 70/70	+30/45	+15/25	0/25	0/20
g	{ +45/60 +70/60	+ 30/35	0/20	0/20	0/20	0/15	0/15
h	+15/10	+ 5/5	+ 5/5	0/4	0/4	0/4	0/4
j	0/2	0/2	0/2	0/2	0/2	0/2	0/2

* Towards Rock, nearly calm.

500 ft. above sea level.

Flag	Wire : 2	3	4	5	6	7
a	0/2 0/2	- 2/2 0/4	0/2 -4/4	-2/2 -4/4	- 2/2 - 2/4	0/2 0/4
b	-5/2 +2/2	- 5/20 - 8/15	-5/20 -10/15	-3/5 -10/15	- 3/4 - 8/15	-2/6 - 5/15
c		T. V4 T. slow	TN : W10 -130/90	TN : W10 TN	0/80 TN TN	TS TS
d		180/20 V6 180/30	180/45 TN 180/45	180/90 TN TN	0/140 TN. TS. TN. TS	0/90 TS TS
e		T V4* 180/50 E. T	+160/30 TS +160/90	+200/W10. TS +135/90	W10. TN. TS* TN. TS	0/60 TN +45/45 TN
f		TS. V4 +130/T	- 45/W10. TS +90/60	- 30/30 V10 +50/50	-10/30 TS TS	-5/25 TS
g		- 10/15 0/20	- 10/10 +10/15	- 10/10 +15/15	- 3/6 +10/10	-5/10 +10/10
h		- 5/5 0/4	-5/5 0/4	- 5/5 +3/3	- 2/2 + 3/3	-3/3 + 2/3
j		0/2 0/2	-2/2 0/2	- 2/2 0/2	- 2/2 0/2	0/2 0/2

* Mainly towards Rock.

* Mainly down and towards Rock.

500 ft. above sea level.

Flag	Wire : 8	9	10	11	12	13	14
a	0/2 0/4	0/2 0/8	0/2 0/8	0/2 0/8	0/2 0/8	0/2 0/8	0/2 0/8
b	0/5 - 5/15	0/5 - 2/8	0/5 0/8	0/5 0/8	0/5 0/8	0/5 0/8	0/5 0/8
c	0/30 -10/30	0/25 - 5/20	0/15 - 5/20	0/10 - 2/20	0/10 0/15	0/8 0/15	0/8 0/10
d	+10/50. E +10/70	+10/50. E 0/45	0/40 0/35	0/30 0/35	0/15 0/30	0/10 0/30	0/10 0/30
e	0/25 +30/45	0/25 +15/40	0/25 +10/30	0/20 +10/30	0/15 +10/30	0/15 +5/30	0/10 +5/25
f	- 5/15 +15/15	- 5/10 +10/15	-5/8 + 5/15	-3/6 + 5/15	0/5 0/15	0/4 0/15	0/3 0/10
g	- 5/5 + 8/10	- 5/5 0/10	-3/4 0/8	-3/4 0/8	-4/2 0/8	-2/2 0/8	-2/2 0/8
h	- 3/3 0/3	- 3/3 0/4	-2/3 0/4	-2/2 0/4	0/2 0/4	0/2 0/4	0/2 0/4
j	0/2 0/2	0/2 0/2	0/2 0/2	0/2 0/2	0/2 0/2	0/2 0/2	0/2 0/2

1,000 ft. above sea level.

Flag	Wire : 3	4	5	6	7
a	0/2	0/2	0/2	0/2	0/2
b	0/20 -5/15	-4/15 - 10/15	- 4/15 - 10/5	- 2/10 - 5/5	0/7 - 5/5
c	{ +20 -180	+135/45 T TN : TS 180/T	TN* - 50/90	{ +20 -40/	-55/55 - 30/TN -30/40
d	*	+170/40 { +135/TN { +170/40 E+80	TNφ -170/90	T* T	+ 80/TN 0/90
e	—	-160/80 T* +170/70	TSφ +130/90	Tφ +70/100	+ 70/-100/ +45/90
f	T T	- 90° T + 90/90	-30/30 + 45/45	-15/+10 -30	+35/30 -10/15 +25/25
g	-3/5 0/20	-5/5 + 10/10	- 4/6 +5/5	- 5/6 +5/5	-4/6 + 5/5
h	-2/2 0/2	-2/2 + 3/2	- 4/2 +3/2	- 4/2 +3/2	-2/2 0/2
j	0/2 0/2	0/2 0/2	0/2 0/2	0/2 0/2	0/2 0/2

* Mainly down and towards Rock.

* Mainly towards Rock.

* Mainly away from Rock.
φ Mainly towards Rock.* Wild : largely up.
φ Wild : largely down.

TABLE III.—*continued.*

WIND E.: 090°

1000 ft. above sea level—*continued.*

Wire :	8	9	10	11	12	13	14
Flag							
a	0/2	0/2	0/2	0/2	0/2	0/2	0/2
b	0/6	— 3/5	0/5	0/3	0/3	0/3	0/3
c	0/20	— 10/30	— 5/30	0/15	0/15	0/10	0/10
d	±80*	0/60	0/45	+20/ —30/	0/20	0/20	0/20
e	0/40	+30/45	+20/40	—10/20	—10/15	—5/15	0/15
f	— 5/10	+15/15	+10/15	— 4/7	— 4/7	—4/7	—4/7
g	— 2/4	+ 3/5	+ 3/5	0/3	0/3	0/3	0/3
h	— 2/2	0/2	0/2	0/2	0/2	0/2	0/2
j	0/2	0/2	0/2	0/2	0/2	0/2	0/2

* Mainly up.

2,000 ft. above sea level.

Wire :	1	2	3	4	5	6
Flag						
a	0/2	0/2	0/2	0/2	0/2	0/2
b	+ 3/2	+ 6/2	+ 2/2	+ 4/2	— 2/2	0/5
c	+15/2	+ 2/2	+12/2	+15/4	+60/ —30/	+15/5
d	+15/2	0/2	+20/2	+ 5/5	TS. W10	TS
e	+15/2	— 2/2	+18/2	— 7/5	TN	TN
f	+13/2	—10/2	+13/2	—15/4	+20/ —30/	TN
g	+ 5/2	— 7/2	+ 2/2	— 4/2	— 5/3	0/2
h	+ 2/2	— 4/2	0/2	— 3/2	— 2/2	0/2
j	0/2	0/2	0/2	0/2	0/2	0/2

2,000 ft. above sea level.

Wire :	7	8	9	10	11	12	13	14
Flag								
a	0/2	0/2	0/2	0/5	0/4	0/5	0/4	0/5
b	— 2/3	— 3/3	— 2/3	0/3	— 3/3	0/3	— 3/3	0/3
c	— 5/+60 —50	0/45	— 5/+40 —30	0/45	— 5/+40 —30	—5/40	— 5/30	—5/35
d	±80/TS	0/90	+60/ —30/	0/60	+60/ —30/	—5/50	+45/ —30/	—5/40
e	±90/T	+10/90	+80/ —50/	+5/60	+70/ —40/	0/45	+45/ —30/	0/35
f	—15/15	+10/20	— 5/15	+8/15	— 3/10	+2/15	— 5/5	+2/15
g	— 3/3	+ 2/2	— 2/2	0/2	— 2/2	+2/5	— 2/2	0/4
h	0/2	+ 2/2	0/2	0/2	0/2	0/2	0/2	0/2
j	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2

3,000 ft. above sea level.

Wire :	2	3	4	5	6
Flag					
a	0/2	0/2	0/2	0/2	0/2
b	0/2	+2/2	0/2	0/2	— 3/2
c	+ 5/2	+5/2	+3/3	+8/4	— 5/+30 —15
d	+10/2	0/3	+3/15	0/3	TS
e	+ 8/2	—5/2	+3/+20 —3	—5/5	+80/TN
f	+ 5/2	—8/2	0/4	—5/2	— 8/5
g	+ 2/2	—5/2	0/2	0/2	— 5/2
h	0/2	—2/2	0/2	0/2	— 2/2
j	0/2	0/2	0/2	0/2	0/2

TABLE III—continued

WIND E.: 090°

3,000 ft. above sea level—continued.

Flag	Wire :	7	8	9	10	11	12	13	14
a	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2
b	0/2	0/4	0/2	0/4	0/2	0/4	- 2/2	- 2/2	- 2/2
c	± 40/	+ 5/30	0/30	+ 5/30	0/20	+ 5/30	- 3/15	- 3/15	0/15
d	+170/TN	-10/90 TN	+90/TS	0/60	+90/TS	0/50	+60/	+50/	+40/
e	+170/TS	+10/80 TS. E+100	-40/	0/60	-40/TS	0/50	-30/	-30/	-30/
f	- 10/+ 5	+ 3/10 P-25	- 4/10	+ 3/10 P-25	- 4/10	+ 3/10 P-25	- 5/10	- 2/8	- 2/6
g	- 4/2	0/4	- 3/2	0/4	- 3/2	0/4	- 3/2	- 2/2	- 2/2
h	- 2/2	0/2	- 2/2	0/2	- 2/2	0/2	0/2	0/2	0/2
j	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2

5,000 and 7,000 ft. above sea level.

Pitch and yaw in these planes were small. The chief features of disturbance were recurrent pulses, probably due to small travelling eddies, showing in the case of pitch as sharp upward flickers of the flags with slower downward returns. In yaw there were somewhat corresponding sharp movements.

The pulses were observed to rise in level from the Rock as they travelled westwards, and to increase in size. Thus at 3,000 ft. they were recorded as 15° at wire 4, flag *f*, and increased to 25° by wire 7 and onwards: at 5,000 ft. they were first recorded at wire 5 in both of flags *d* and *e*, increased in strength to wire 9 where they measured $\begin{cases} +45, \\ -10, \end{cases}$ and further increased westwards to wire 14 where they embraced flags *cde* and *f*. At 7,000 ft. they showed from wire 7 onwards, and at wire 14 they were read as 30° in the upward direction, or about four times as strong as in the earlier wire 9 at the same level, 7,000 ft.

They were regularly recurrent, with a period of about one second of time in the model field.

TABLE IV.

WIND E. 15° N.: 075°

100 ft. above sea level.

Flag	Wire :	3	4	5	6	7	8	9	10	11	12	13	14
a	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/3	0/3	0/3	0/3	0/3	0/3
b	- 5/5	- 5/5	- 2/4	0/5	0/5	0/5	0/5	0/3	0/3	0/3	0/3	0/3	0/3
c	- 55/10	- 40/10	- 10/10	- 5/10	0/8	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5
d	- 90/30	- 90/30	- 50/40	- 25/30	- 10/20	- 5/20	- 5/20	0/10	0/10	0/10	0/10	0/10	0/10
e	-135/45	-120/60	- 90/60	-50/90	-30/40	0/35	-10/30	-10/30	0/30	0/25	0/25	0/25	0/25
f	-180/20	180/30	-170/120	-45/100	-20/60	-10/40	-15/35	-10/30	-5/30	-5/30	-5/30	-5/30	-5/35
g	- 90/60	- 10/90	+ 5/100	0/60	-10/40	- 5/30	- 5/20	- 5/20	-5/20	0/20	0/20	0/20	0/15
h	- 15/15	0/15	0/20	- 5/20	- 5/20	- 5/20	- 2/15	- 2/15	-2/15	-2/15	-2/15	-2/15	0/15
j	0/2	0/2	0/2	0/3	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5

500 ft. above sea level.

Flag	Wire :	3	4	5	6	7
a	0/2	- 2/4	0/2	- 2/4	0/2	0/4
b	0/2	-10/2	0/2	- 8/2	0/2	- 4/2
c	-10/30	- 55/30	-10/15	- 40/20	- 5/10	- 20/10
d	0/30	- 90/45	- 5/40	- 90/30	-15/60	- 70/50
e	0/40	-120/50	+10/45 E-60	-110/40	-10/100	-120/90
f	+ 5/45	-170/60	+15/45 E-70	-180/90	-20/100 T	180/180 T
g	-35/45	- 20/180 TN	-15/45 E±100	+ 10/90 TN	-15/45	+ 20/90 T
h	0/2	- 3/8	0/10	0/15	0/15	0/15
j	0/2	0/2	0/2	0/2	0/2	0/2

500 ft. above sea level.

Flag	Wire :	8	9	10	11	12	13	14
a	0/2	0/4	0/2	0/4	0/2	0/4	0/2	0/4
b	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2
c	0/4	- 2/4	0/4	0/4	0/4	0/4	0/2	0/4
d	-5/15	-10/15	-2/15	- 5/15	-2/10	- 5/15	-2/10	- 5/15
e	-5/40 E-60	-15/50	-5/35	-15/35	-5/30	-15/30	-5/25	-10/30
f	-5/40	0/55	-5/35	- 5/35	-5/30	- 5/35	-5/25	- 5/30
g	-5/30	+ 5/30	-5/25	0/35	0/20	0/35	0/20	0/30
h	0/15	0/20	0/15	0/20	0/15	0/20	0/15	0/20
j	0/2	0/3	0/2	0/8	0/4	0/8	0/4	0/10

TABLE IV—continued.

WIND E. 15° N.: 075°

1,000 ft. above sea level.

	Wire : 3		4		5		6		7		8	
Flag												
a	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2
b	0/2	— 5/2	0/2	— 3/2	0/2	— 3/2	0/2	0/2	0/2	0/2	0/2	0/2
c	+45/ —60/	— 45/30	—20/20	— 30/20	—10/8	—20/10	— 8/6	—10/5	— 4/5	— 5/3	0/4	— 2/2
d	T	—150/50	T	—160/70	T	—80/60	0/45	—30/60	0/30	—30/40	0/10	—25/40
e	T	—160/60	T	—170/90	T	T	±120/	—20/100	+80/ —70/	—30/60	0/50	—20/60
f	T	—170/50	T	—170/90	T	T	TN	TN	+80/ —90/	0/50	0/50	0/60
g	+60/ —30/	0/60	45/45	0/60	+80/ —40/	0/45	+80/T —30/	0/45	+70/ —70/	+ 5/35	+40/ —30/	+ 5/30
h	0/3	0/3	0/3	0/5	— 2/5	+ 2/7	— 2/5	+ 2/5	— 2/5	0/8	— 2/5	0/10
j	0/1	0/2	0/1	0/2	0/1	0/2	0/1 p	0/2	0/2 p +5	0/2	0/2 p	0/3

1,000 ft. above sea level.

[illegible]

Extra flags. 1,000 ft. at d , wire position $4\frac{1}{2}$; motion over whole sphere, but largely downward and from north.

at <i>a</i> ,	where position	42:	motion over whole space,	but mainly towards Rock. V 10.
" <i>e</i> ,	" "	41:	" " "	"
" <i>f</i> ,	" "	40:	" " "	but very strongly towards Rock. V 10.

„ f „ „ 4½: „ „
 „ d „ „ 5½: +80/-40/40

"	e,	"	"	51	motion over whole sphere, but mainly towards west.
"	f	"	"	51	" " " " " largely up-current.

500 ft. between *d* and *e*, wire position $4\frac{1}{2}$ and $5\frac{1}{2}$, down current, largely from north. V 10.

2,000 ft. above sea level.

Flag	Wire : 1	2	3	4	5	6
a	0/2	0/2	0/2	0/2	0/2	0/2
b	- 2/2	+ 2/2	- 4/2	- 2/2	0/2	- 2/2
c	+ 5/2	+ 15/2	- 4/5	+ 12/4	- 5/4	- 2/4
d	+ 20/2	+ 8/2	+ 15/6	+ 15/4	- 15/55	- 15/45
e	+ 20/2	0/2	+ 20/6	0/4	- 15/55	0/45
			- 15/45	+ 90/90 TS	- 35/100 W10	+ 10/90
f	+ 15/2	- 6/2	+ 15/6	- 8/5	+ 5/40	0/30 TN
g	+ 5/2	- 3/2	+ 4/2	- 6/4	0/15	- 2/15
h	0/2	- 2/2	+ 2/2	- 4/2	0/2	- 2/2
j	0/2	0/2	0/2	0/2	0/2	0/2

2,000 ft. above sea level.

[illegible]

TABLE IV—continued.

WIND E. 15° N.: 075°

3,000 ft. above sea level—continued.

	Wire : 1		2		3		4		5		6		7	
Flag														
a	0/2	0/0	0/2	0/0	-2/2	0/0	-2/2	0/0	-2/2	0/0	-2/2	0/0	-2/2	0/0
b	0/2	0/0	0/2	0/0	-4/2	0/0	-4/2	0/0	-4/2	0/0	-2/2	0/0	-2/2	0/0
c	+2/2	+5/2	+2/2	+5/2	-4/2	+2/2	-4/2	0/2	-4/2	0/2	-4/3	0/2	-4/2	0/2
d	+8/2	+2/2	+6/2	+2/2	0/4	+5/3	-4/8	+5/5	-4/10	+10/15	-4/8	+10/20	-4/8	+10/20
e	+12/2	0/2	+10/2	0/2	+2/5	+2/5	-4/12	+10/20	-4/12	+5/30	-4/45	+5/30	+60/-40	
f	+8/2	-2/2	+8/2	-3/2	+2/6	0/8	0/30	0/20	0/30	+5/30	0/45	+5/30	+45/-30	+5/45
g	+5/2	-2/2	+5/2	-2/2	+2/4	0/5	+2/6	0/8	+2/10	0/10	+2/10	0/20	+15/-10	0/15
h	+2/2	-2/2	+2/2	-2/2	+2/2	-0/2	+2/2	0/2	+0/2	0/2	0/2	0/3	-2/3	0/3
j	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2

3,000 ft. above sea level

Wire :	8	9	10	11	12	13	14
Flag							
a	0/2	0/0	0/2	0/2	0/2	0/2	0/2
b	0/2	0/0	0/2	0/2	0/2	0/2	0/2
c	0/2	0/2	0/2	0/4	0/2	0/3	0/2
d	0/10	+5/20	+40/-20	0/20	+30/-20	0/30	+20/-15
e	+45/-30	+5/30	+60/-20	0/35	+60/-20	+5/35	+50/-20
f	+45/-30	+5/35	+60/-30	0/40	+60/-30	0/30	+50/-30
g	+30/-15	0/15	+20/-10	0/20	+20/-15	0/15	+20/-10
h	+5/0	0/5	0/3	0/5	0/3	0/5	0/8
j	0/2	0/2	0/2	0/2	0/1	0/2	0/1

3,000 ft. level : pulses were strong from wire 4, flags *e* and *f* up to wire 8 flags *e* and *f* : thereafter decreasing towards west.5,000 ft. level : pulses occurred from wire 5 to wire 9, flags *e*, *f*, *g*.7,000 ft. level : weak pulses occurred from wire 6 to wire 9, flags *f*, *g*.

TABLE V.

WIND E. 30° N.: 060°

100 ft. above sea level.

Wire :	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Flag														
a	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/5	0/5	0/5	0/5	0/5
b	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/5	0/5	0/5	0/5	0/5
c	-30/15	-10/5	-3/3	-2/2	0/2	0/2	0/2	0/2	0/2	0/5	0/5	0/5	0/5	0/5
d		-55/20	-45/30	-30/30	-5/30	0/20	0/15	0/10	0/5	0/10	0/10	0/10	0/10	0/5
e			-80/30	-65/30	-40/30	-25/30	-5/30	-5/20	-5/20	-5/15	-5/15	0/15	0/15	0/15
f			-75/90	-70/50	-60/50	-50/40	-40/30	-35/30	-30/30	-25/25	-20/25	-10/25	-10/20	-5/15
g			-45/50	-35/50	-35/40	-30/50	-40/40	-40/40	-30/30	-30/30	-25/25	-25/25	-15/20	-15/15
h			-20/20	-15/20	-10/20	-30/30	-25/30	-25/30	-15/30	-20/20	-15/20	-15/25	-15/20	-10/15
j			0/2	0/2	0/3	-3/10	-2/10	-2/15	-5/15	-5/15	-5/15	-5/15	-5/15	-5/15

500 ft. above sea level.

Wire :	0	1	2	3	4	5	6
Flag							
a	0/4	0/2	0/2	0/4	0/2	0/4	0/4
b	-2/2	-10/3	-2/2	-2/2	0/2	-2/2	0/2
c		-15/6	-30/10	-6/4	-20/5	-2/2	-5/2
d			+20/25	+10/30	-65/30	-15/30	-45/30
e			+15/30			+5/50	-70/35
f					+10/60	E-90	-65/90
g					-15/30	TN	-15/45
h					0/4		0/10
j					0/2		0/2

TABLE V—continued.

WIND E. 30° N.: 060°

2,000 ft. above sea level—continued.

Flag	Wire : 8		9		10		11		12		13		14	
a	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4
b	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2
c	- 2/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2
d	- 2/5	0/20	0/5	0/15	0/4	0/15	0/5	0/15	0/5	0/10	0/5	0/10	0/5	0/5
e	-10/25	0/30	-5/20	0/30	-5/20	0/25	-5/20	0/20	—	0/20	—	0/15	—	0/15
f	-10/40	0/35	-5/30	0/40	-5/35	0/35	-5/30	0/30	-5/30	0/25	-2/30	0/20	-2/30	0/20
g	0/35	0/30	0/35	0/35	0/30	0/35	0/30	0/35	0/30	0/30	0/30	0/30	0/30	0/25
h	0/15	0/10	0/15	0/20	0/15	0/20	0/20	0/25	0/20	0/25	0/20	0/25	0/20	0/25
j	0/2	0/2	0/4	0/4	0/3	0/4	0/5	0/6	0/5	0/8	0/5	0/8	0/5	0/10

3,000 ft. above sea level.

Flag	Wire : 1		2		3		4		5		6		7	
a	-2/2	0/0	-3/2	0/0	-3/2	0/0	-2/2	0/0	-2/2	0/0	-2/2	0/0	-2/2	0/0
b	-4/2	0/0	-3/2	0/0	-4/2	0/0	-2/2	0/0	-2/2	0/0	-2/2	0/0	-2/2	0/0
c	-5/2	0/0	-4/2	0/0	-5/2	0/0	-4/2	0/0	-4/2	0/0	-2/2	0/0	-2/2	0/0
d	-3/2	+5/2	-5/2	+2/2	-8/8	0/5	-6/5	0/5	-5/4	0/5	-5/4	0/5	-3/4	0/5
e	+5/2	0/2	0/10	+3/3	-6/10	+8/8	-4/10	+10/10	-5/15	+10/10	-4/15	+8/10	-3/12	+5/10
f	+4/2	0/2	+3/5	0/5	0/12	+8/10	0/15	+10/10	0/20	+15/15	0/20	+15/20	0/20	+10/25
g	+3/2	0/2	+3/2	0/2	+3/3	0/5	+2/5	0/5	0/10	0/10	0/15	+2/10	0/15	+2/15
h	+2/2	0/2	+2/2	0/2	+2/2	0/2	+2/2	0/2	+2/2	0/5	+2/4	0/5	0/8	0/8
j	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2

3,000 ft. above sea level.

Flag	Wire : 8		9		10		11		12		13		14	
a	0/2	0/0	0/2	0/0	- 2/2	0/0	- 2/2	0/0	- 2/2	0/0	- 2/2	0/0	- 2/2	0/0
b	0/2	0/0	0/2	0/0	- 2/2	0/0	- 2/2	0/0	- 2/2	0/0	- 2/2	0/0	- 2/2	0/0
c	0/2	0/0	0/2	0/0	- 2/2	0/0	- 2/2	0/0	- 2/2	0/0	- 2/2	0/0	- 2/2	0/0
d	-2/4	0/5	-2/3	0/2	- 2/2	0/3	- 2/2	0/3	- 2/2	0/3	- 2/2	0/3	- 2/2	0/3
e	-2/9	+ 3/10	-5/10	0/10	- 3/10	+5/10	- 2/10	+5/10	0/8	+5/10	0/8	+5/10	0/8	+5/10
f	0/18	+10/30	0/15	+5/30	- 2/15	+3/15	0/12	0/15	0/12	0/15	0/12	0/15	0/12	0/15
g	0/15	0/30	0/15	0/25	0/15	+3/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15
h	0/8	0/8	0/10	0/10	+10/	0/5	+20/	0/10	+30/	0/10	+30/	0/15	+30/p	0/15
j	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/p+10	0/2	0/p+15	0/5	0/p+20	0/5

3,000-ft. level : in addition to the pulses in the table, wires 12-14, flag j, pulses were recorded from wire 9 to wire 14, flags e, f, g, h : they were most active at wire 9, flags f, g, and at 12-14, j.

5,000-ft. level : pulses were recorded beginning at wire 4, flag f, and through 5 f g, 6-8 f g h increasing to wire 14 where they were three times as strong as at wire 9.

7,000-ft. level : mild pulses were recorded from wire 6 to wire 14, flags g h j.

At 5,000 ft. and 7,000 ft., pitch and yaw values were small throughout.

APPENDIX

DESCRIPTION OF A KITE INSTRUMENT FOR RECORDING WIND FEATURES IN EDDIES
(SEE PLATES XXX AND XXXI)

The instrument is mainly of aluminium, weighs 1.24 kg., and measures 19 cm. by 23 cm. by 5.5 cm. over its box-like body.

A strong pivot, A, attached to the back of the body, works freely in the bearing of a stout aluminium strap, B, which is flexibly hung upon the kite wire, C, the strap accepting the angle of the kite wire and allowing the instrument to hang vertically, counterpoised by weight Z.

Below the body is a fixed tube, E, ending in the wind-vane fitment, the vane itself, F, being a shell, square in section, of thin aluminium sheet attached to a wooden arm, G, which is pivotted to turn up and down and counterbalanced at H.

An upright tube, D, above the instrument body, carries a celluloid ball which balances the whole instrument aerodynamically, so that in gusty winds the vertical aspect is retained with very little disturbance.

The features to be recorded are yaw, pitch and velocity against time.

In the case of yaw it is necessary that the vane shall be free to revolve without limit in the horizontal plane, and this is effected by attaching the arm of the vane through its pivot and pivot-frame, K, to a tube, J, free to rotate within the lower vertical fixed tube, E, with which it is concentric. Inside the instrument box the rotating tube, J, is capped by two eccentrics, L, and their sheaves, arranged to operate bell-crank levers, M, from which thin steel wires, N, pull upon the two spring-controlled glass pens, O, seen at the top of the record diagram, P.

The eccentric motion for yaw introduces a sine curve of sensitiveness into the records, and it was on the suggestion of Mr. A. E. Mayers that twin eccentrics were employed, set at 90° apart and each with its own yaw pen, to provide suitable sensitiveness throughout the horizontal rotation of the vane. At his suggestion, also, the small balloon (shown by the photograph) within the vane was replaced by the cone of oiled silk referred to below.

The zero plane of yaw is then the plane in which lie the kite wire and its kite flying in the steady and undisturbed upper wind of the day, and it is in relation to this steady direction that the vane records the disturbances in yaw of the wind at lower levels.

The pen, Q, for recording pitch is worked by a further inner tube, R, concentric with that for yaw, and the vane arm, G, moves this tube up and down to correspond with its own motion in pitch, which can extend from about 70° upward to 70° downward. Tube R, though free to move longitudinally through tube J, is rotated by J by means of a connecting featherway, in order to avoid twisting the bottom thread which operates tube R, when the vane rotates in yaw.

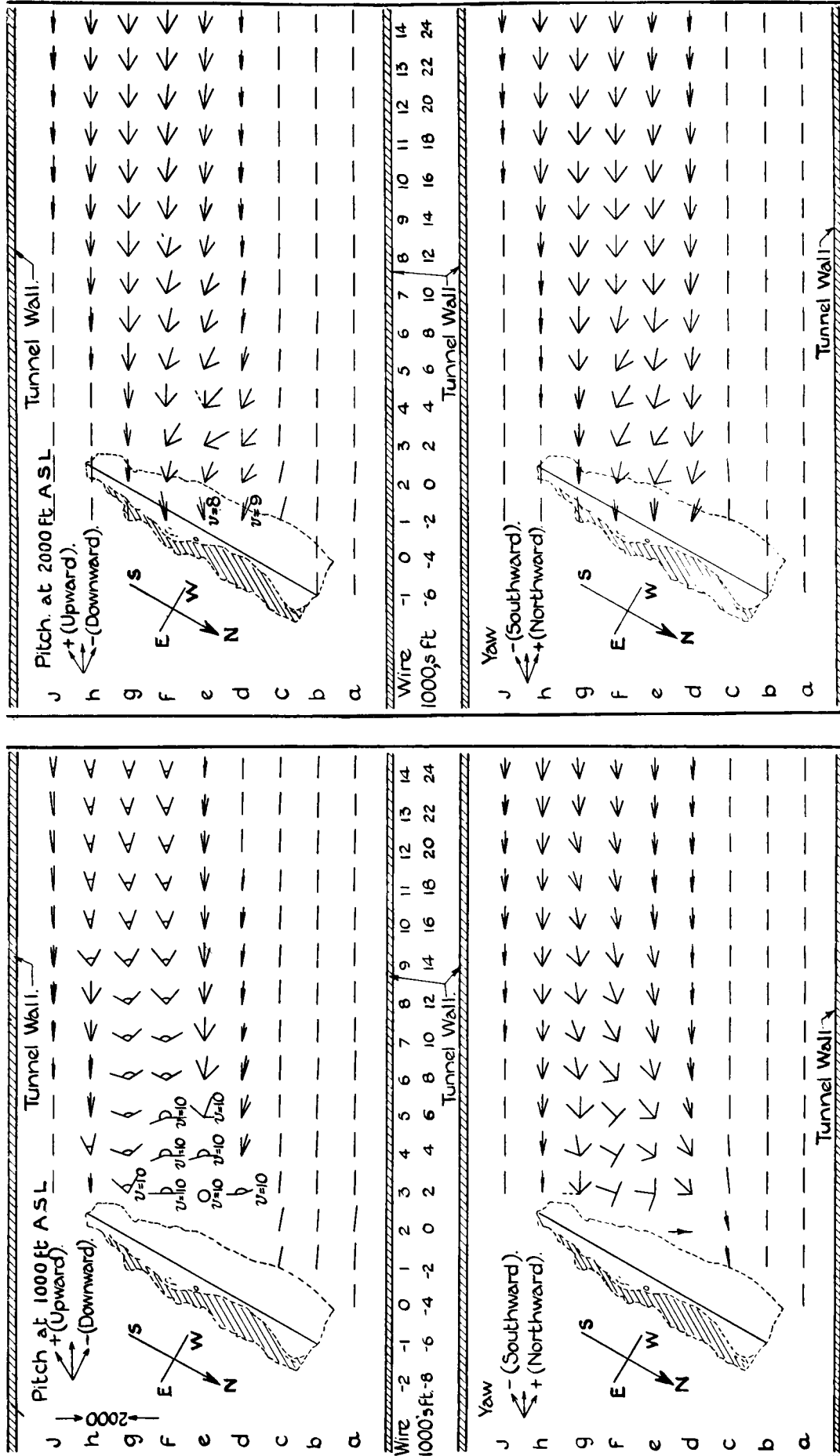
For measures of velocity a central silk thread, S, communicates to the velocity pen, T, the pull of a small cone of oiled silk, Y, closed at its larger end and with its smaller end open and facing up wind. The cone is loosely housed within the vane itself, and twisting of the silk thread, as the vane rotates in yaw, is limited by a swivel inserted between the thread and its velocity pen. There is no objection to some little twisting of this thread (as there would be in the case of the thread pulling tube R for pitch), since the velocity calibration is in terms of deflection of the pen spring, and is quite independent of constancy in length of the connecting thread.

The record is made on wax-coated coloured paper, P (Stylograph Corporation, Rochester, New York), by fine glass pens drawn out in the flame of a spirit lamp and fused into ball ends of diameter about $\frac{1}{2}$ mm. With the action independent of pencil and ink, no question arises of drying up or failure to mark; the glass pens slide with a minimum of friction on the wax coating, and under their spring pressure of a few grams lightly score the surface, so that the coloured background of the paper shows through and gives a permanent trace.

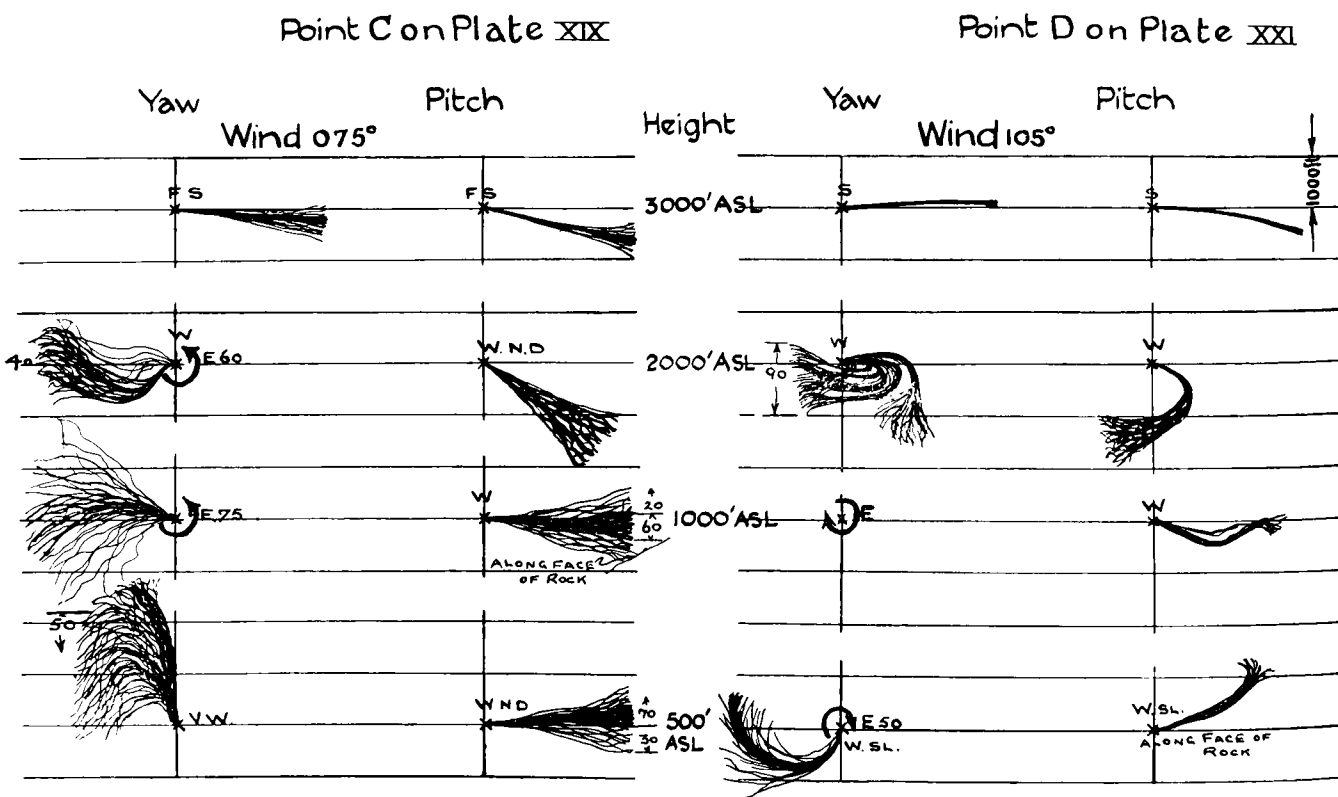
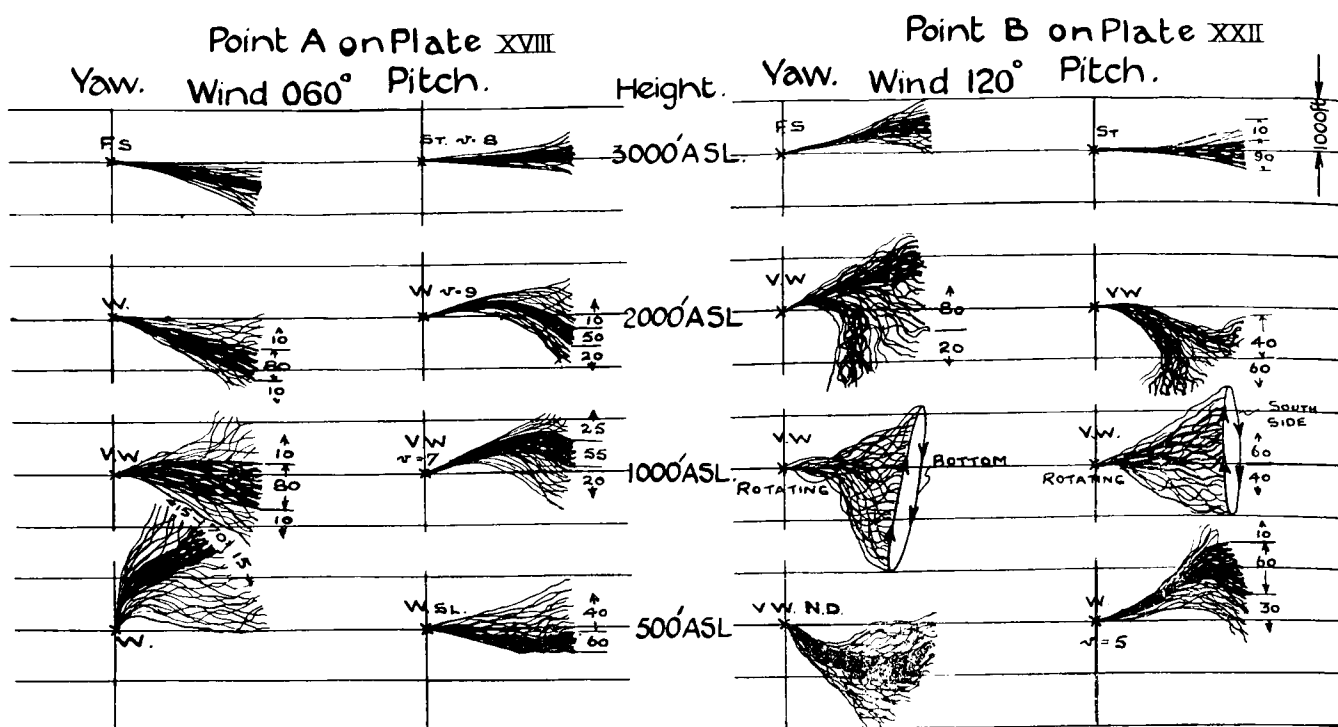
The record paper is friction driven by a Bee clock, U, once round in four hours.

The whole instrument has to hang very freely on the kite wire, for this wire or cable continually twists as the kite goes up, and also when the kite varies its pull. The method of attachment found most suitable was to hook the two ends of the strap, B, loosely on the kite wire, and to provide a fixed buffer, V, on the wire, against which the strap could rest with freedom for the wire and buffer to twist without disturbance to the instrument.

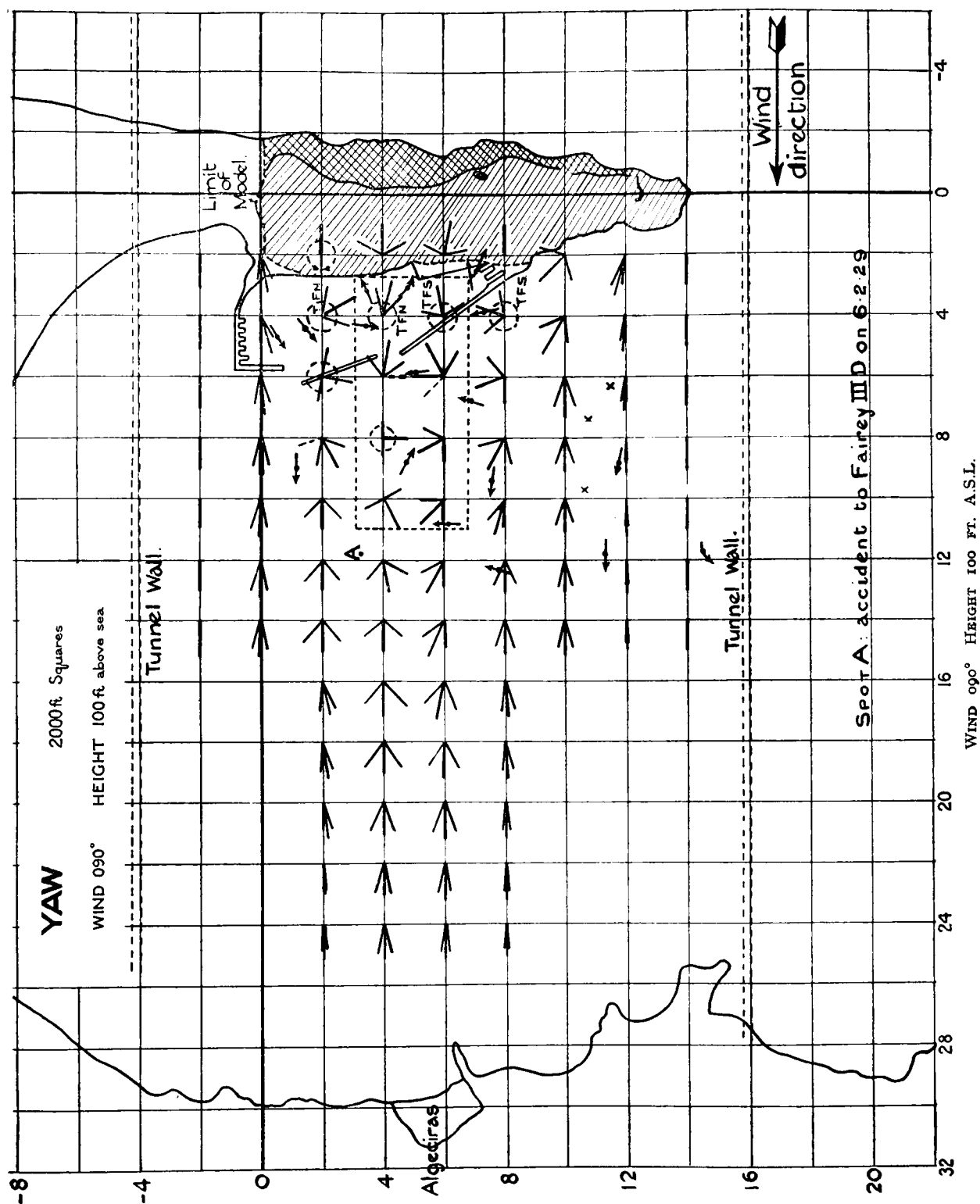
No tendency was found for pendulum swinging to occur in a plane at right angles to the instrument plane; and the tendency to swing in the plane of kite wire, as the kite varied its pull, was got over by introducing a film of viscous material, resin and oil, between two plates, W, X, in contact, attached respectively to the instrument body and the aluminium strap, B.

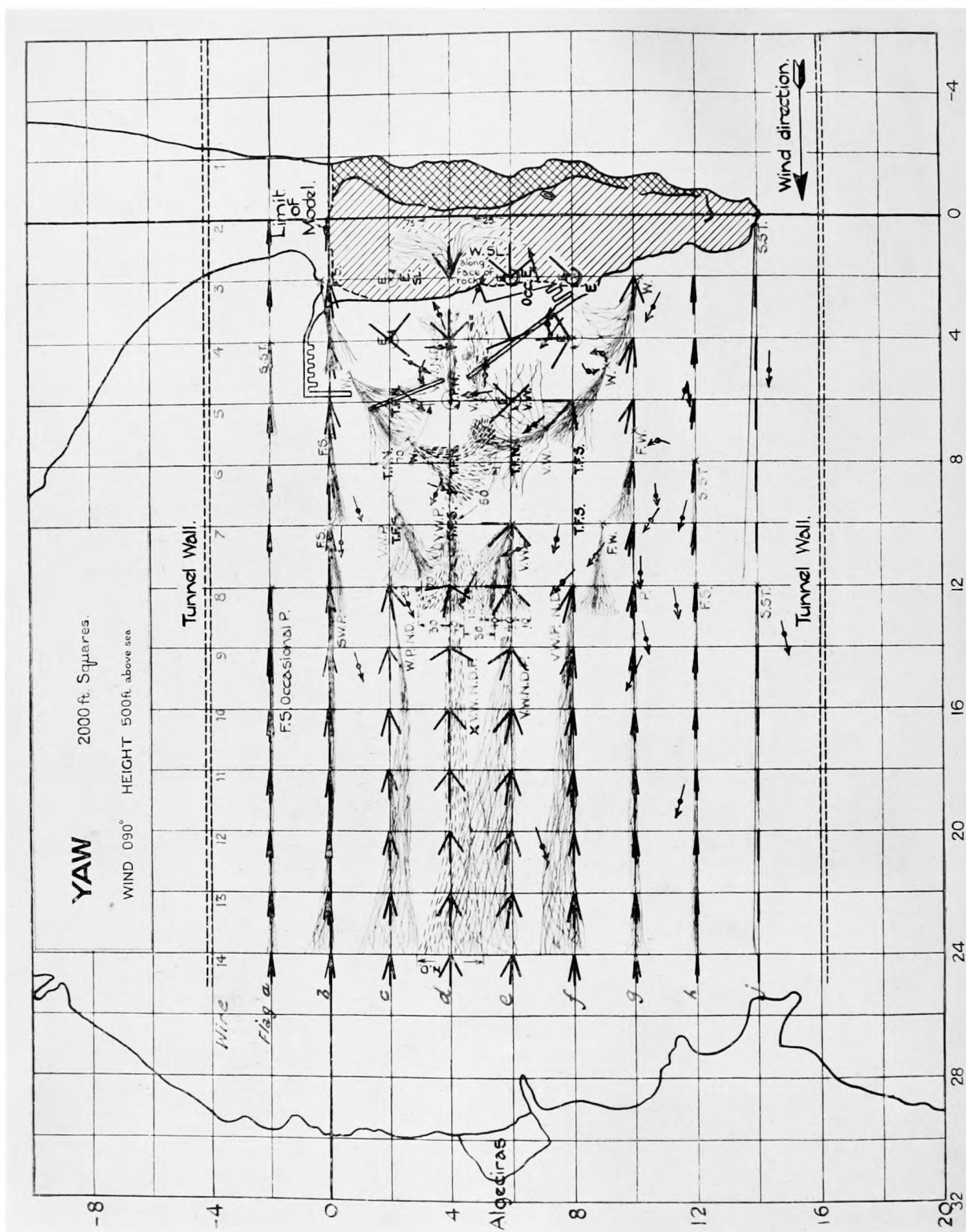


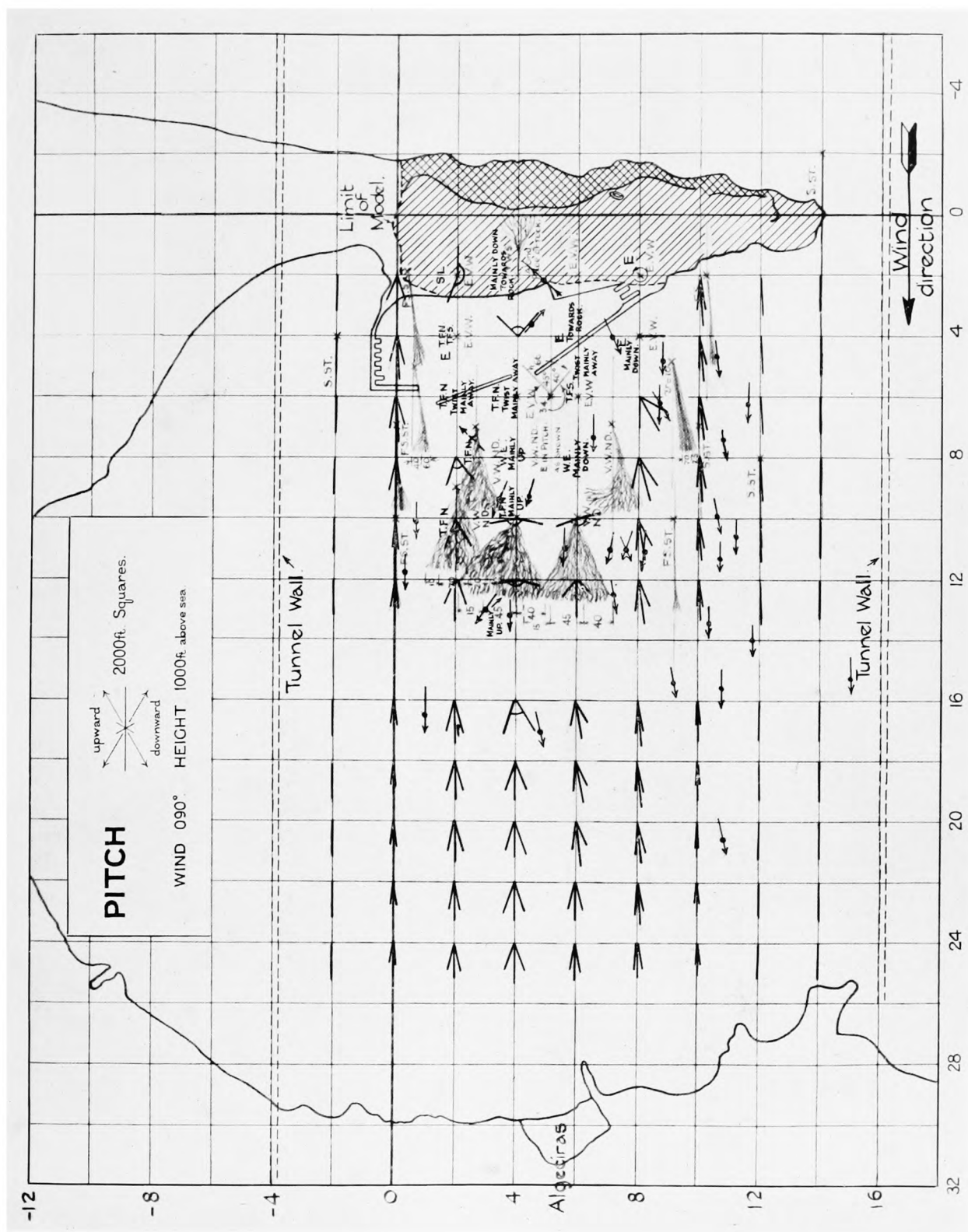
EXAMPLE OF LARGE DIFFERENCES IN PITCH AND YAW BETWEEN DIFFERENT LEVELS. WIND 060°. LEVELS 1,000 AND 2,000 FT. ABOVE SEA.

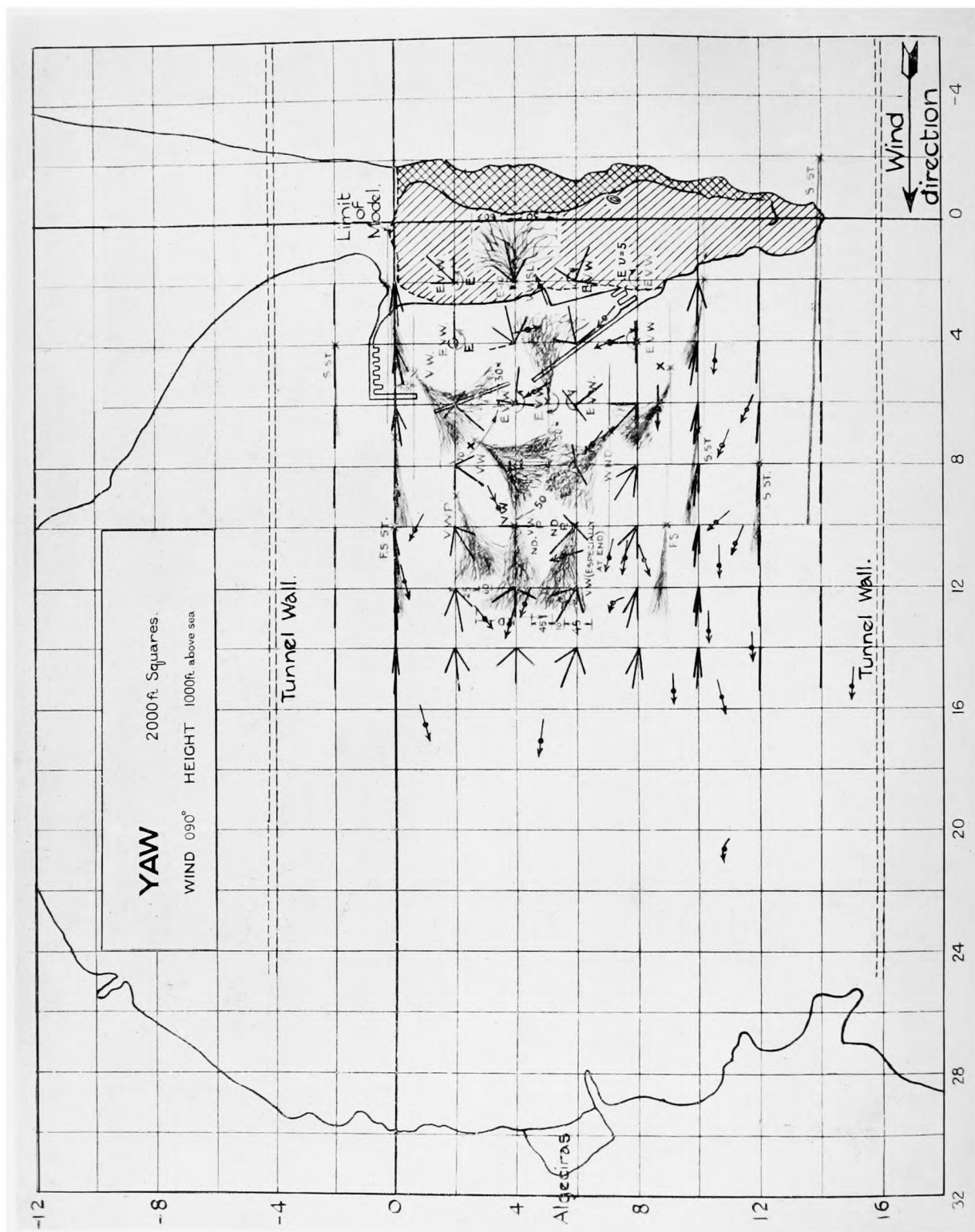


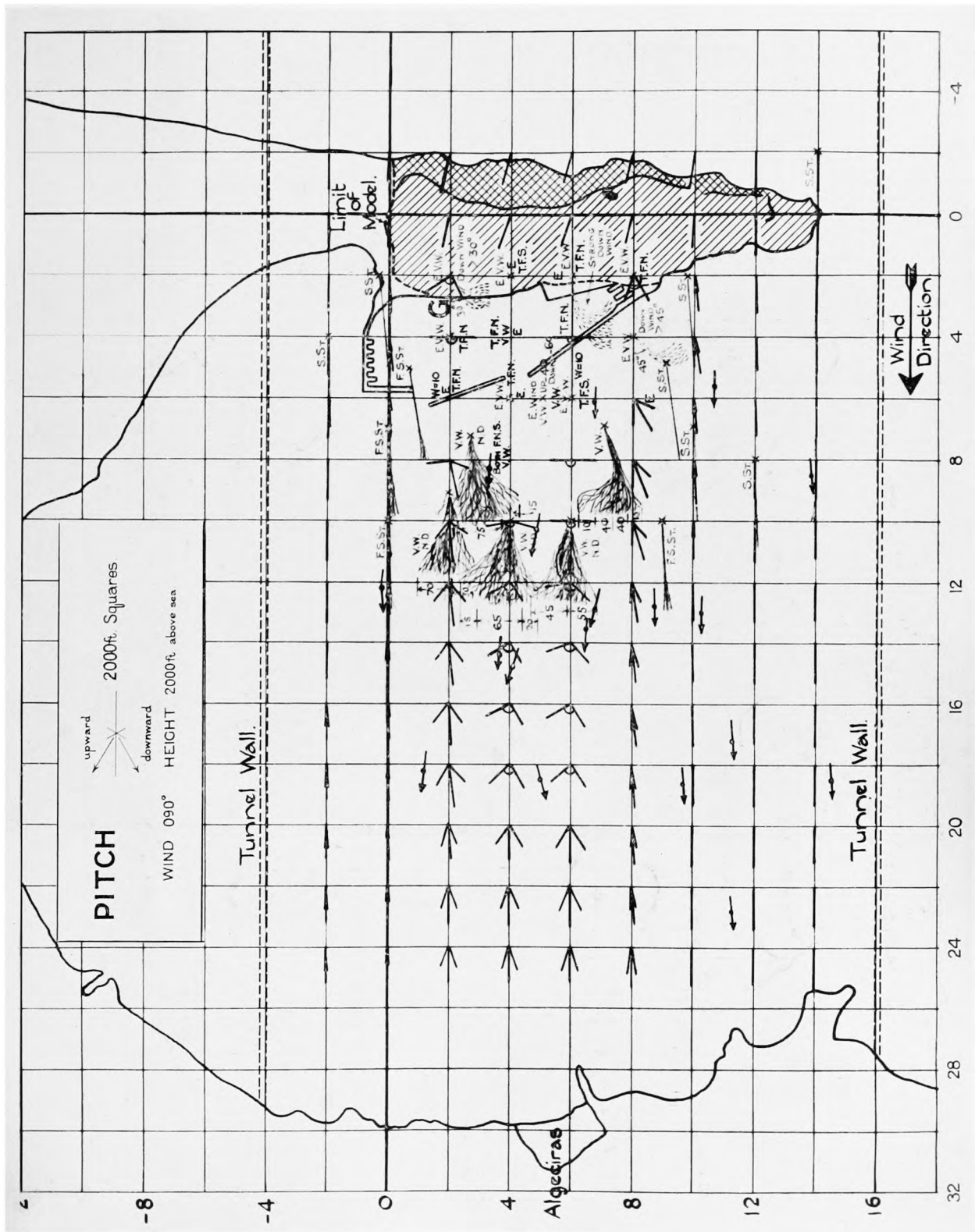
EXAMPLE OF VARIATION IN WIND DIRECTION WITH HEIGHT IN THE TURBULENT REGIONS.

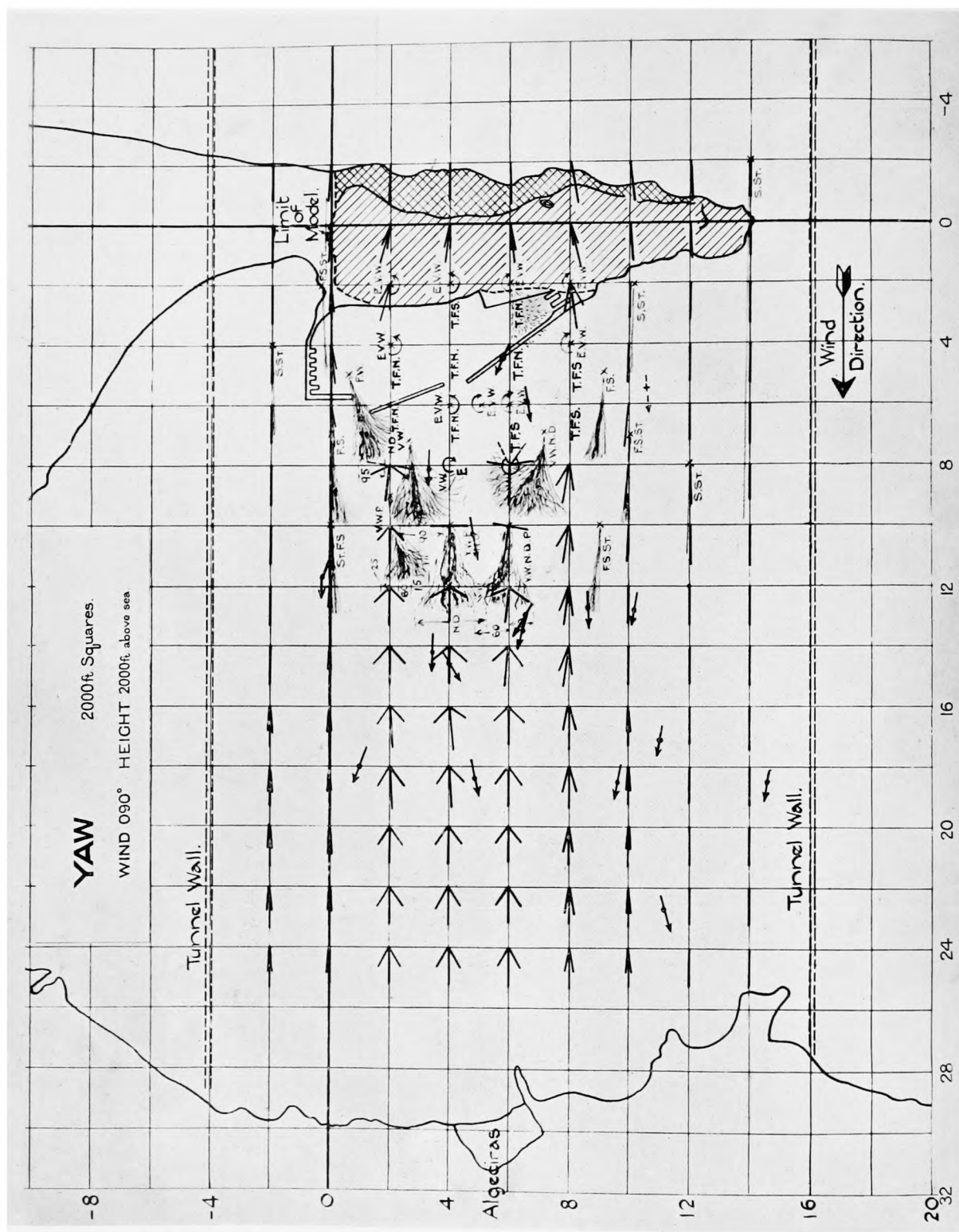












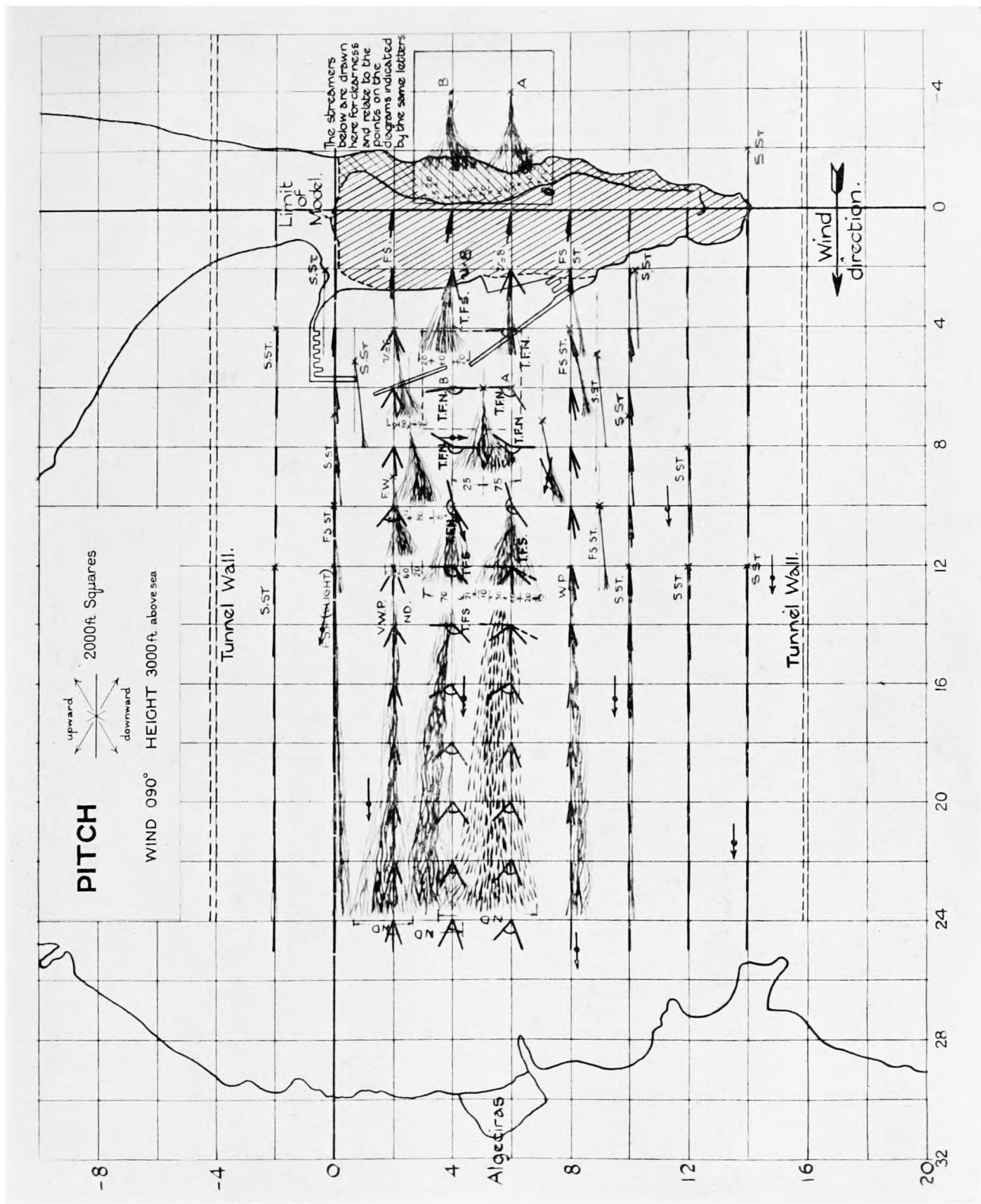
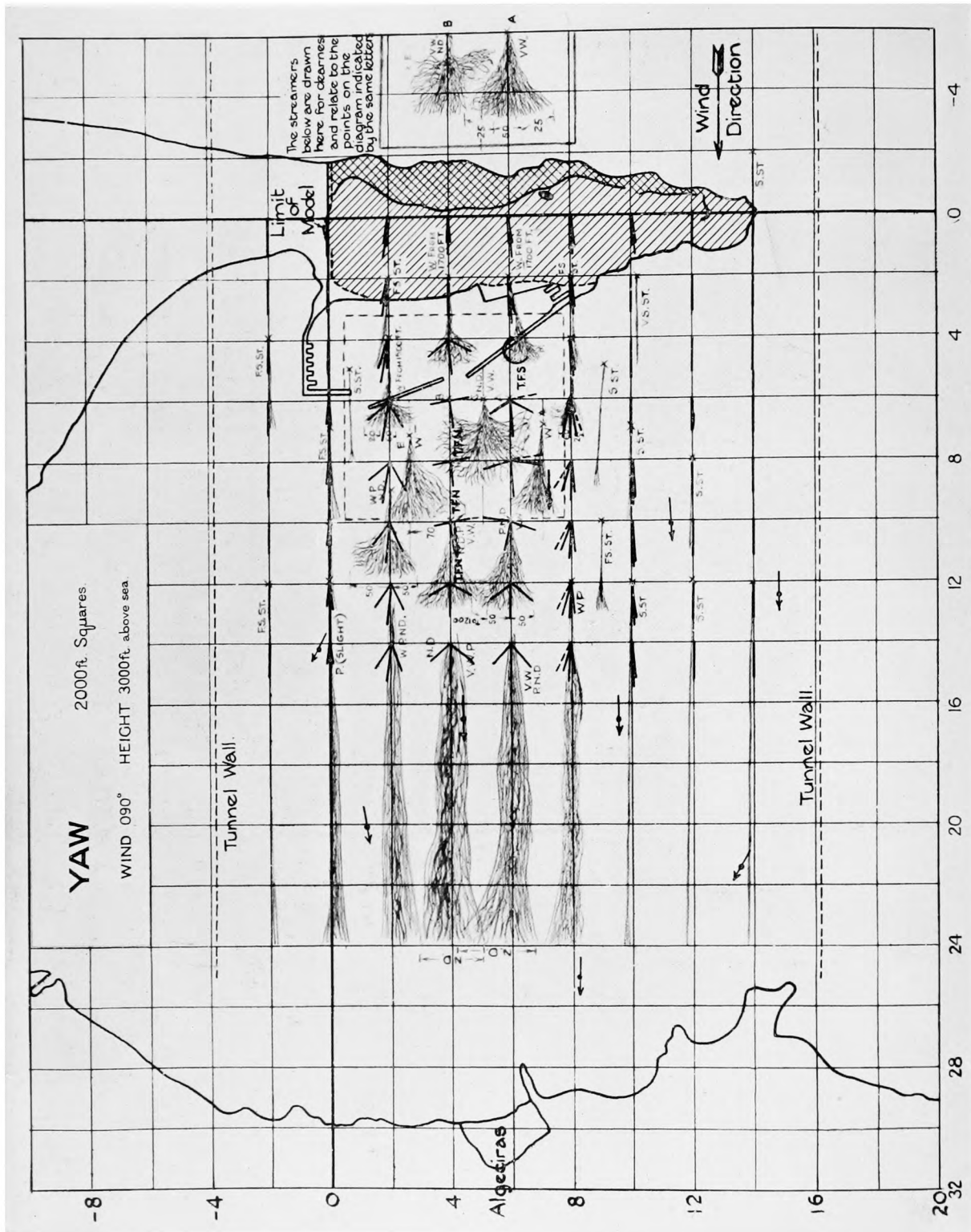


Plate IXB.



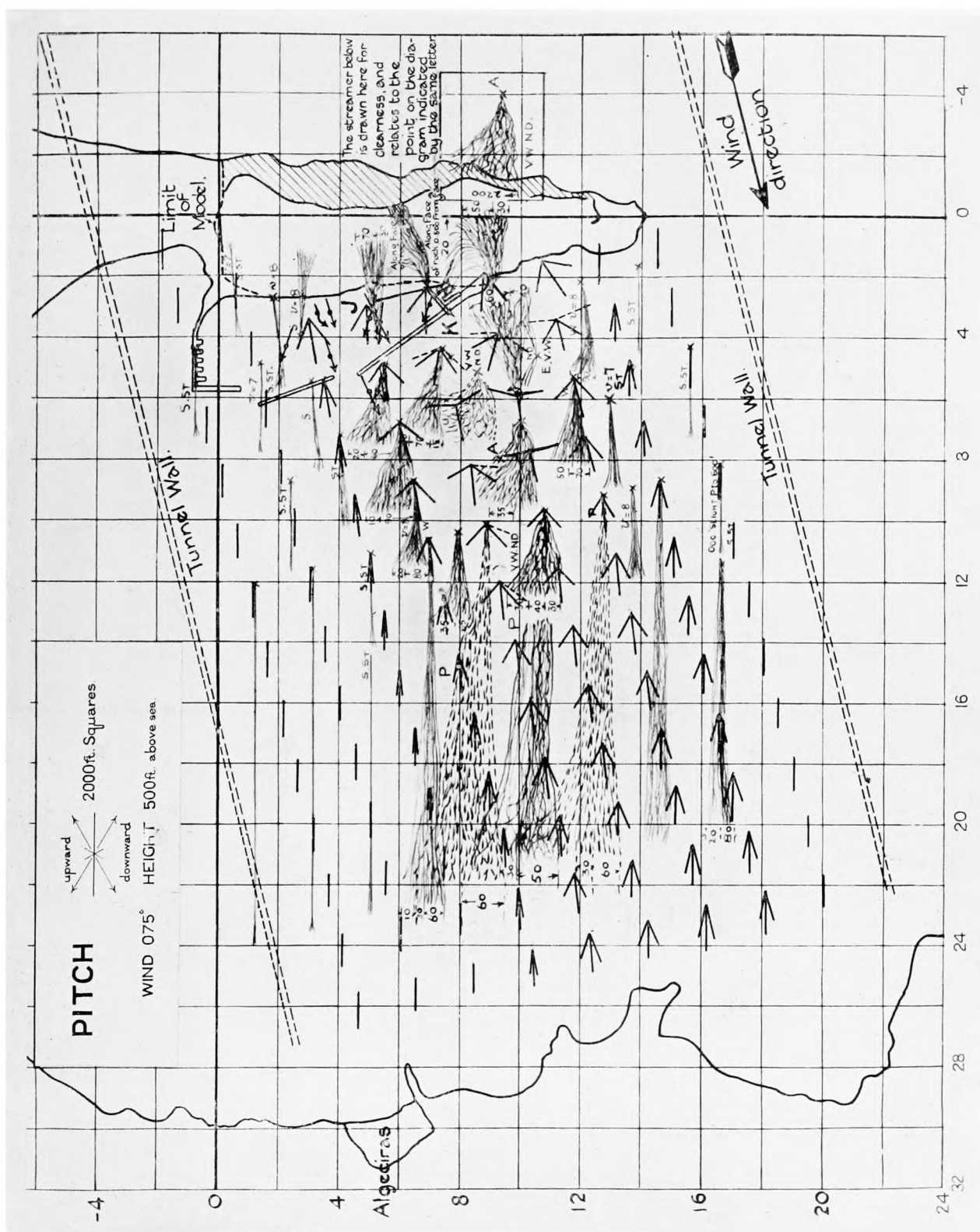
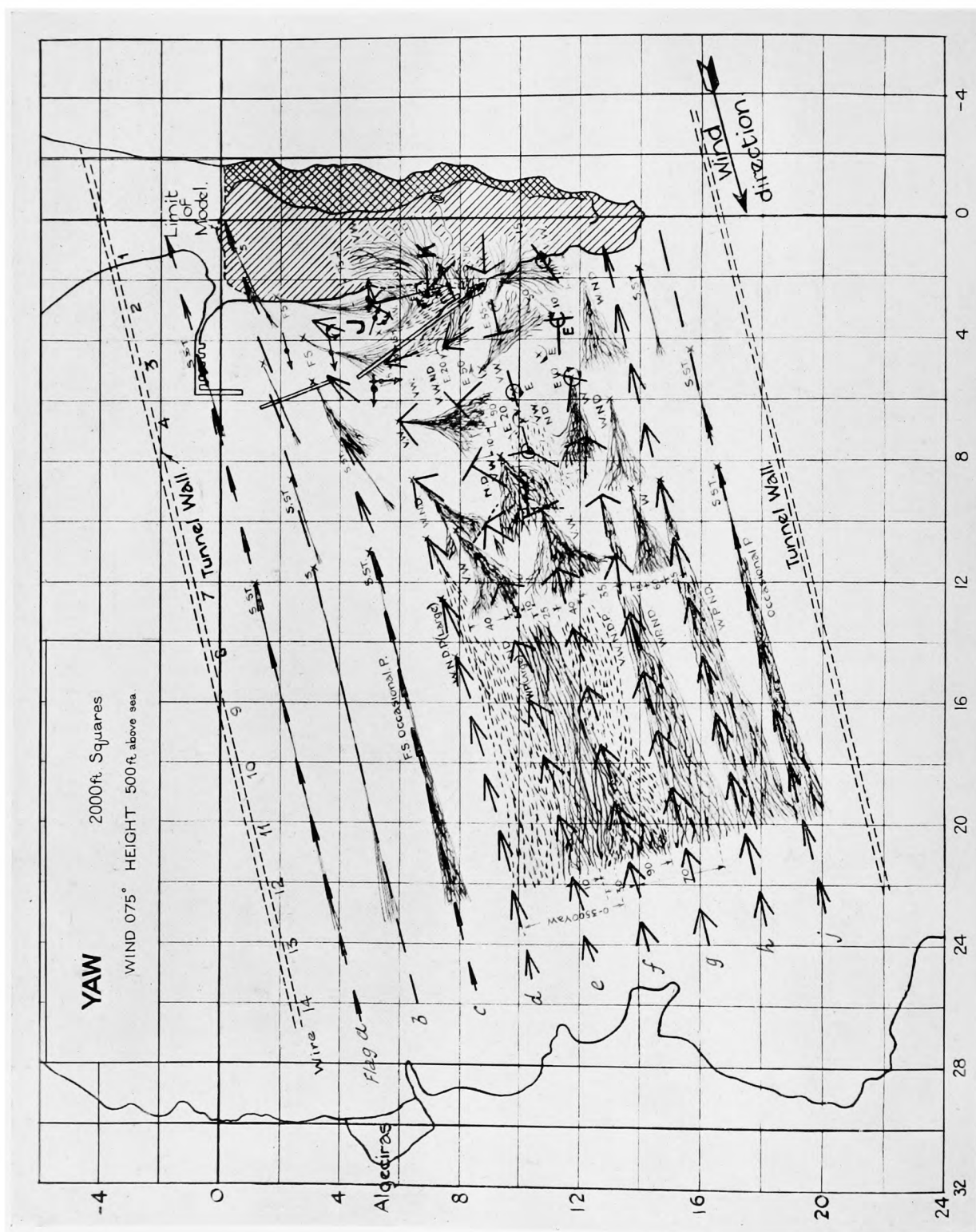


Plate XB.



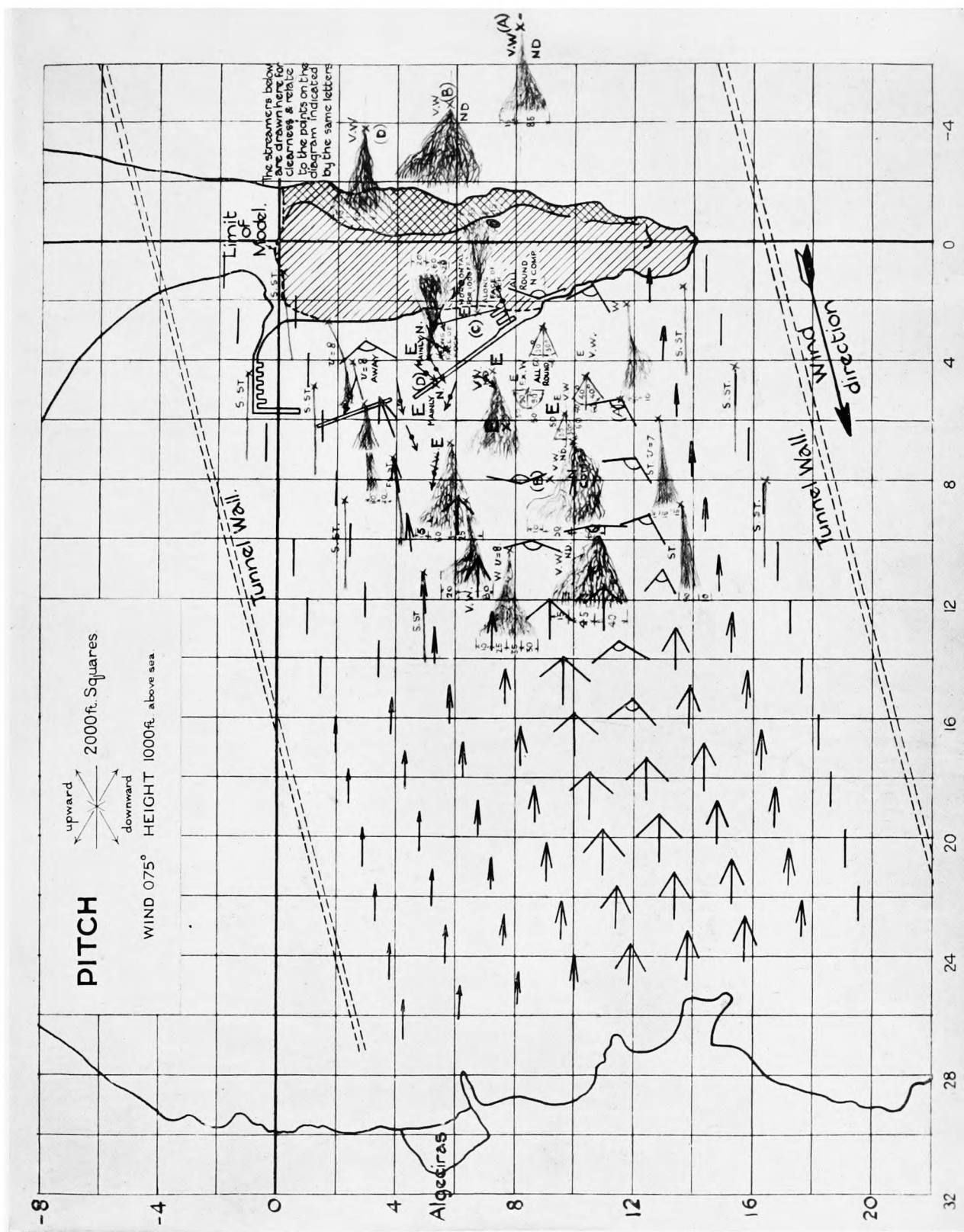
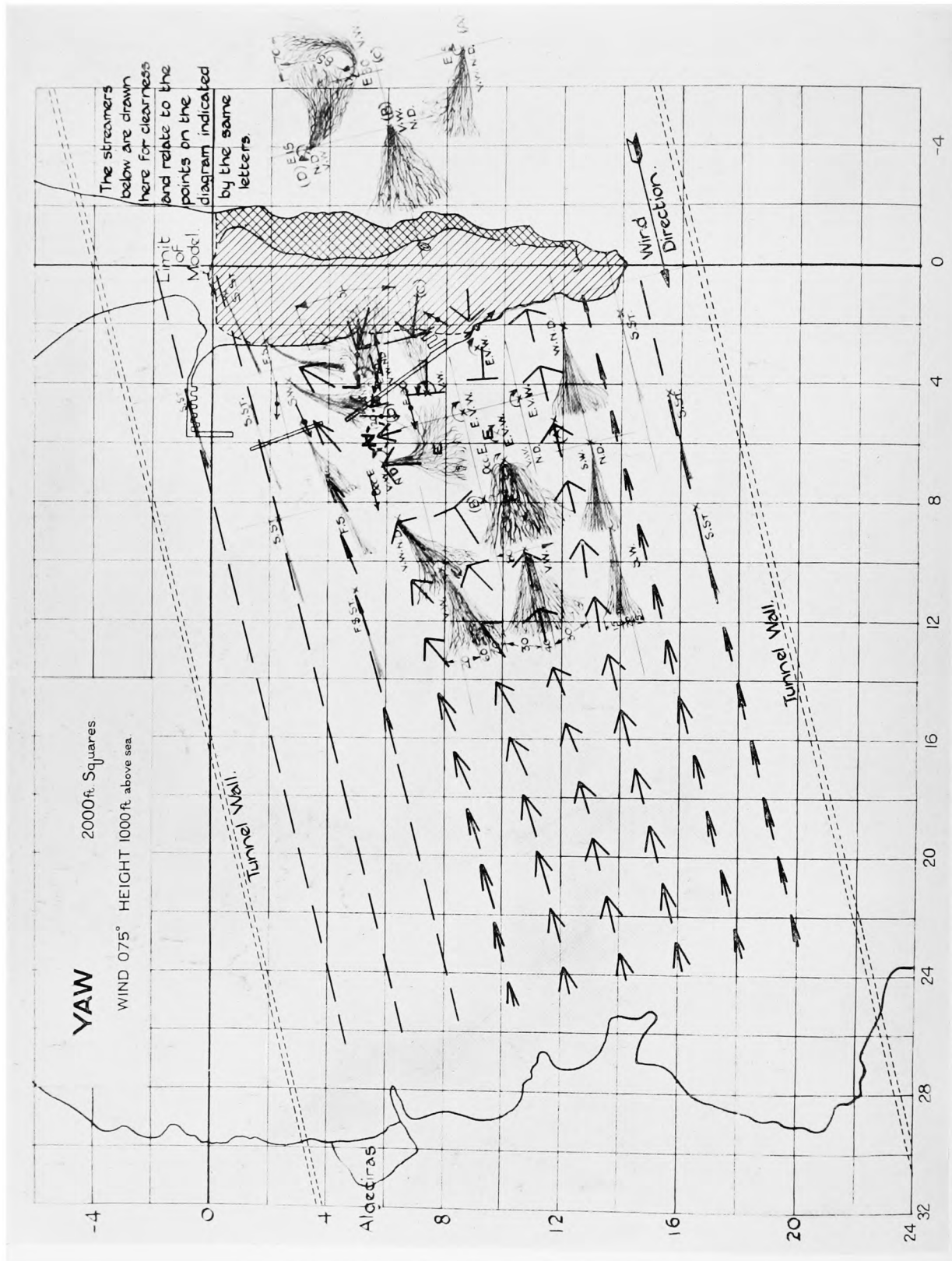
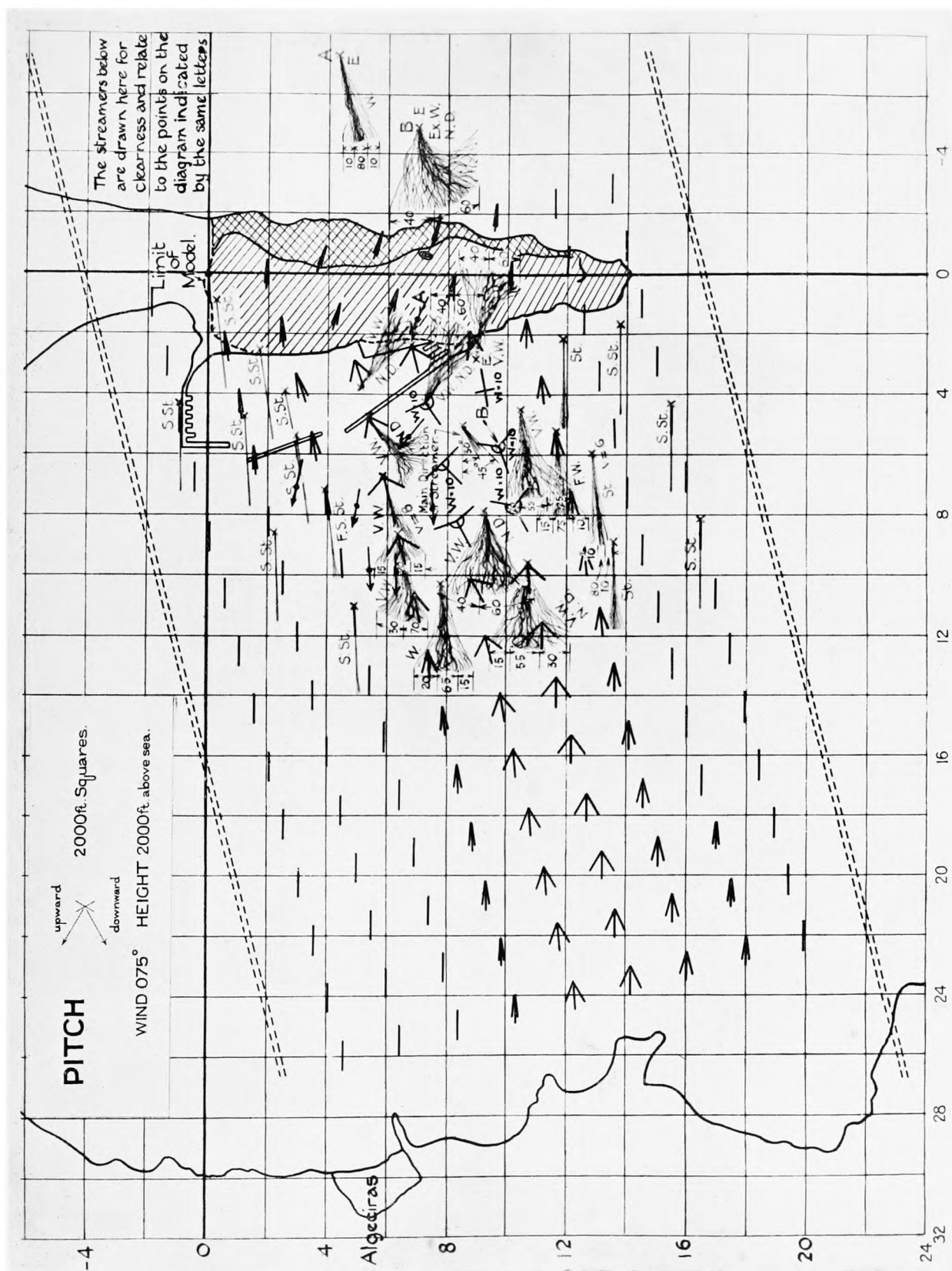
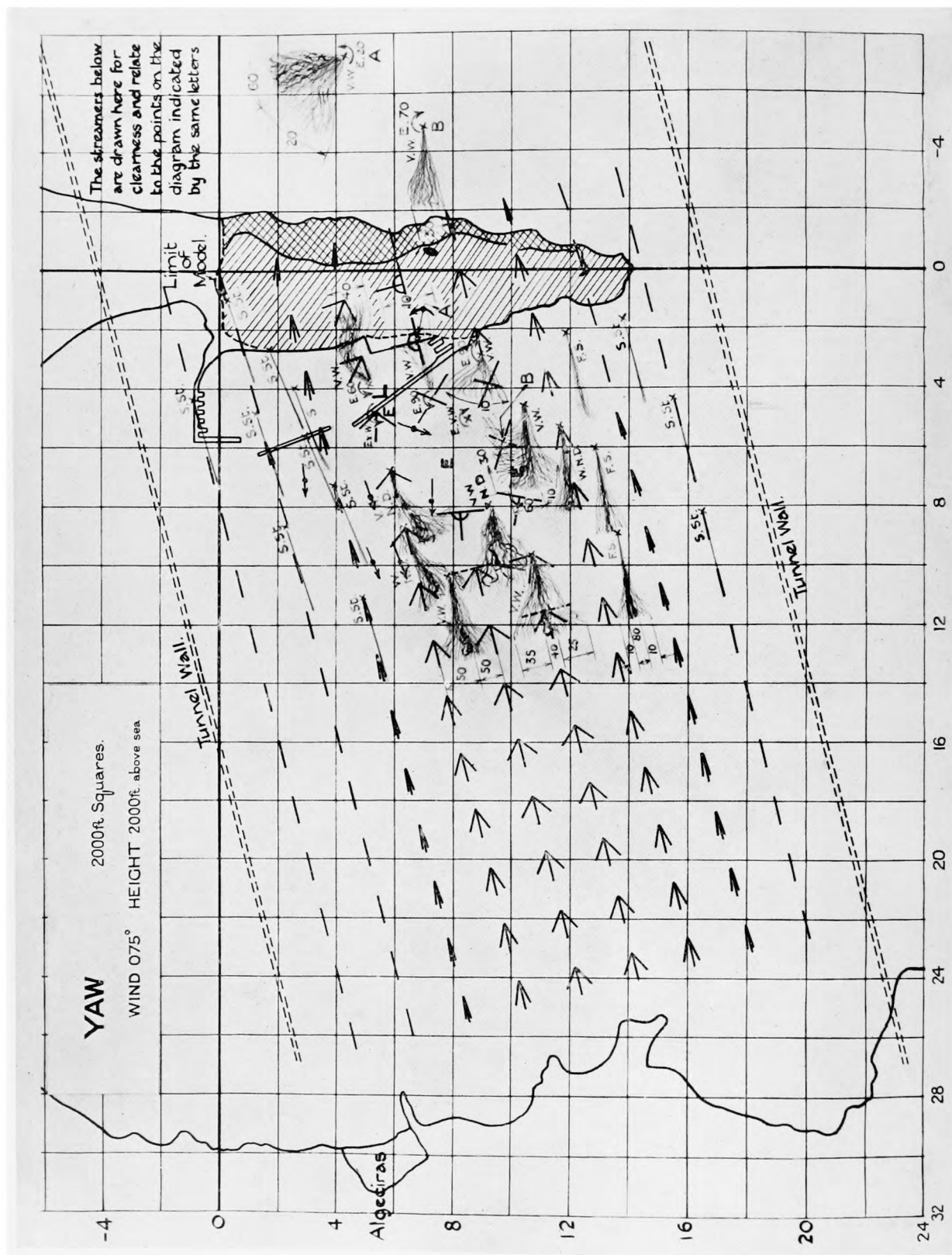


Plate XIB.







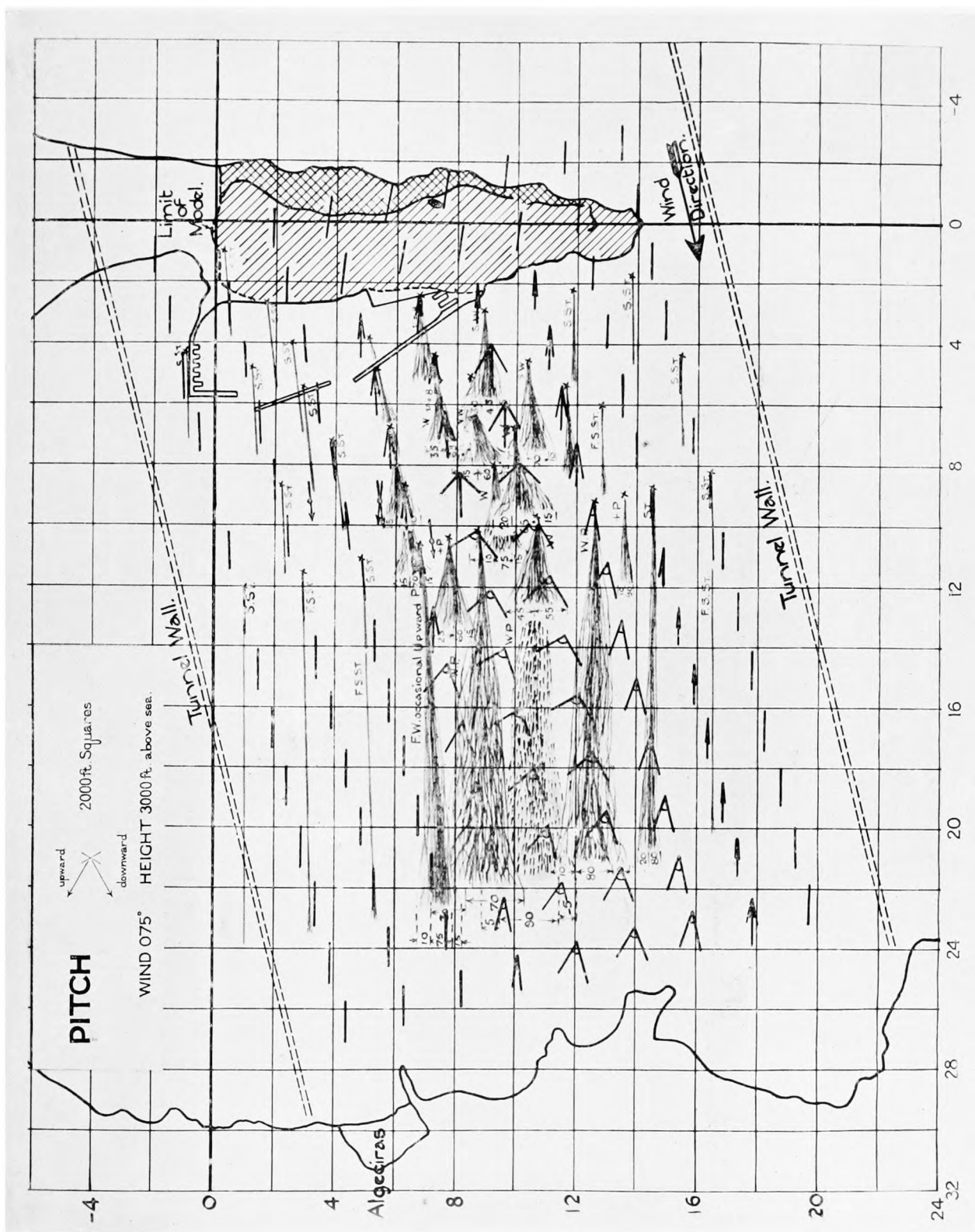
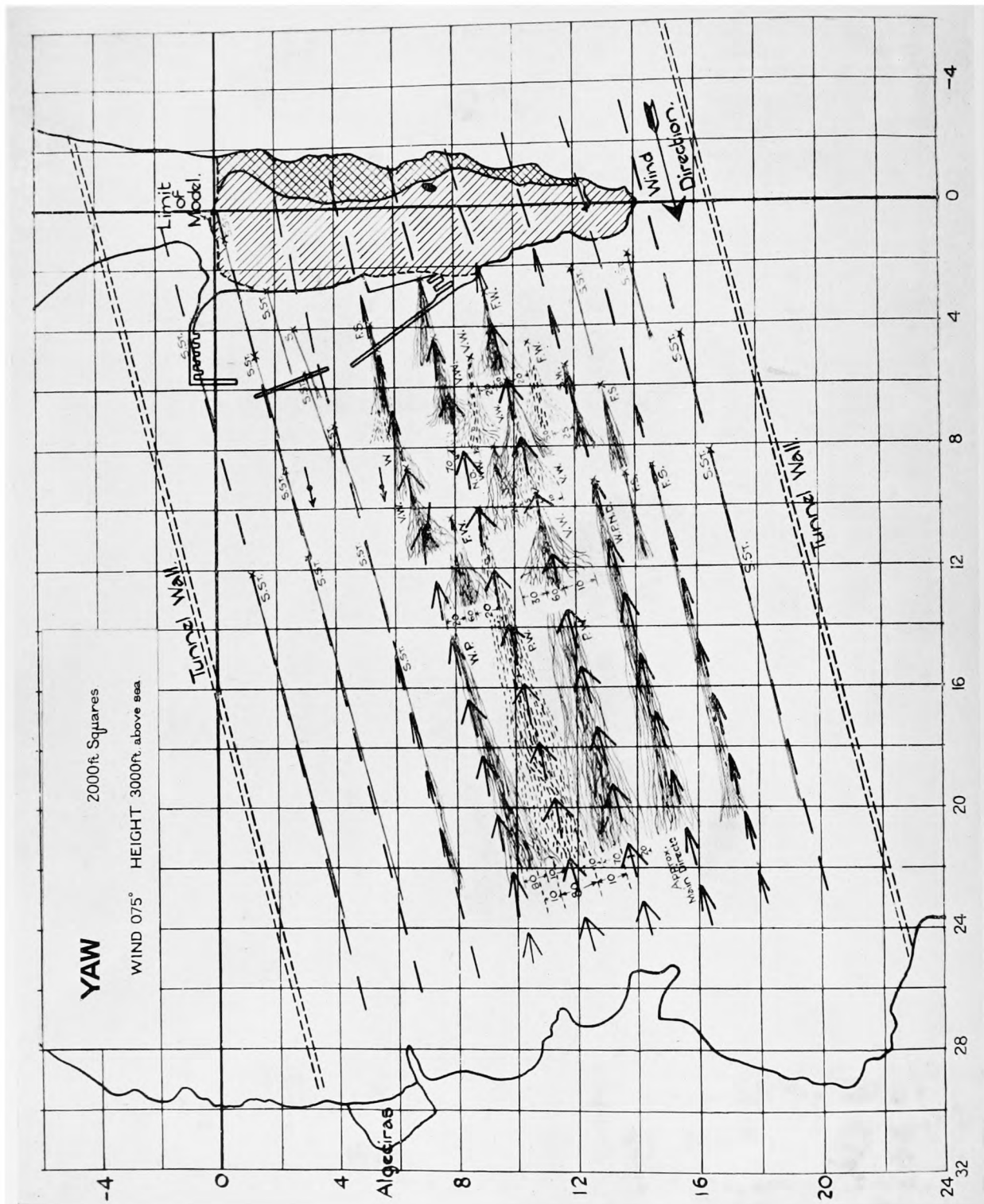


Plate XIII B.



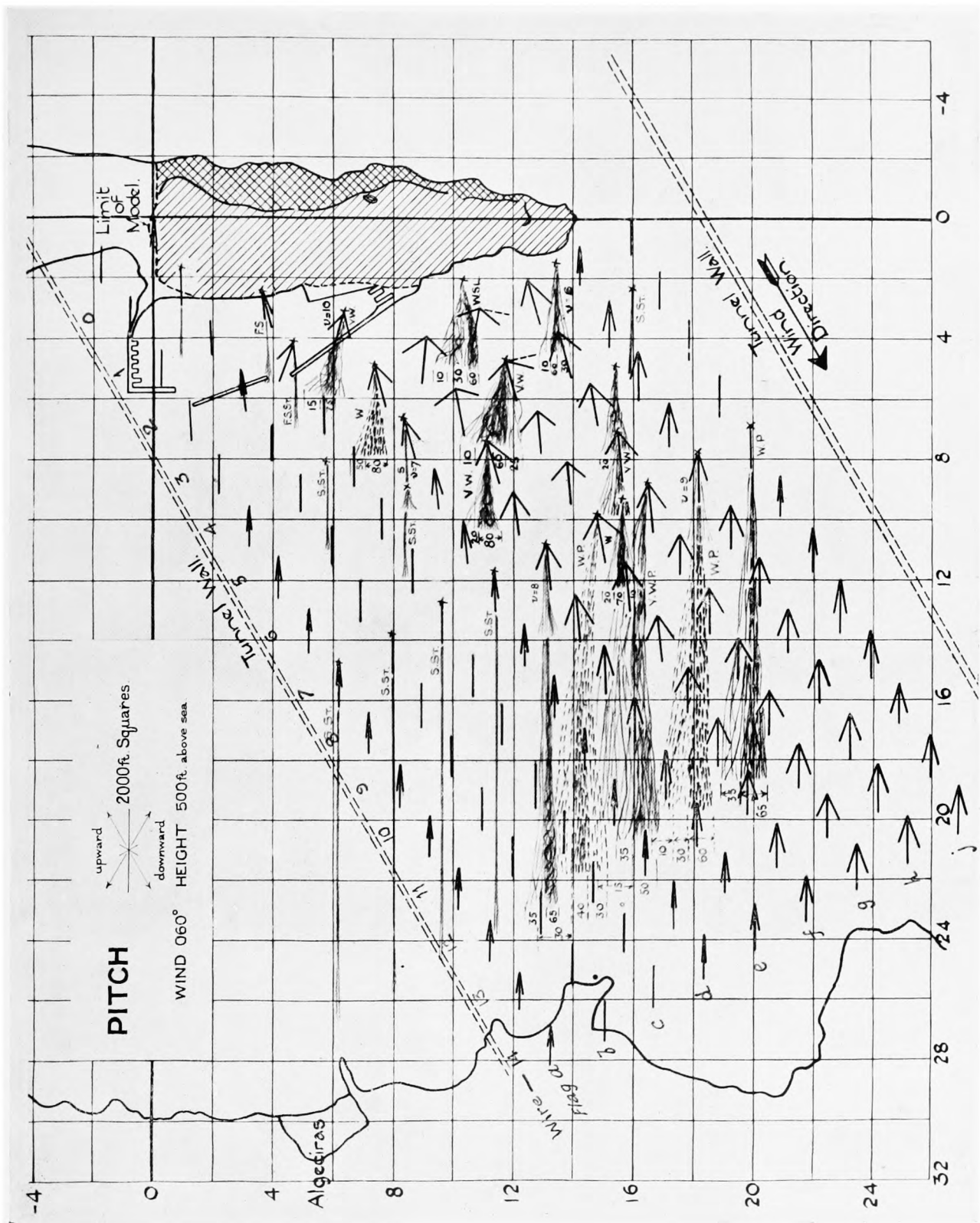
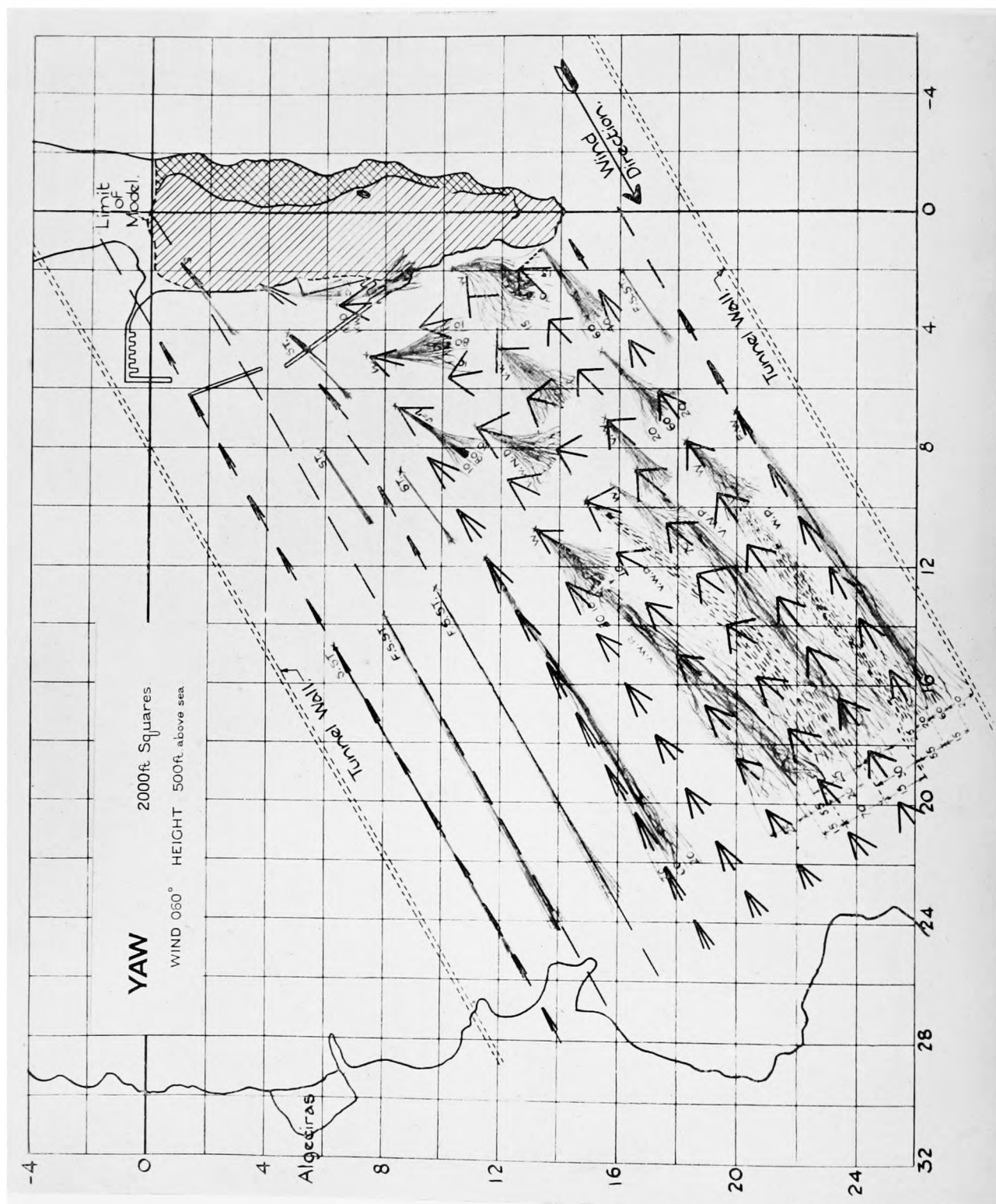


Plate XIV B.



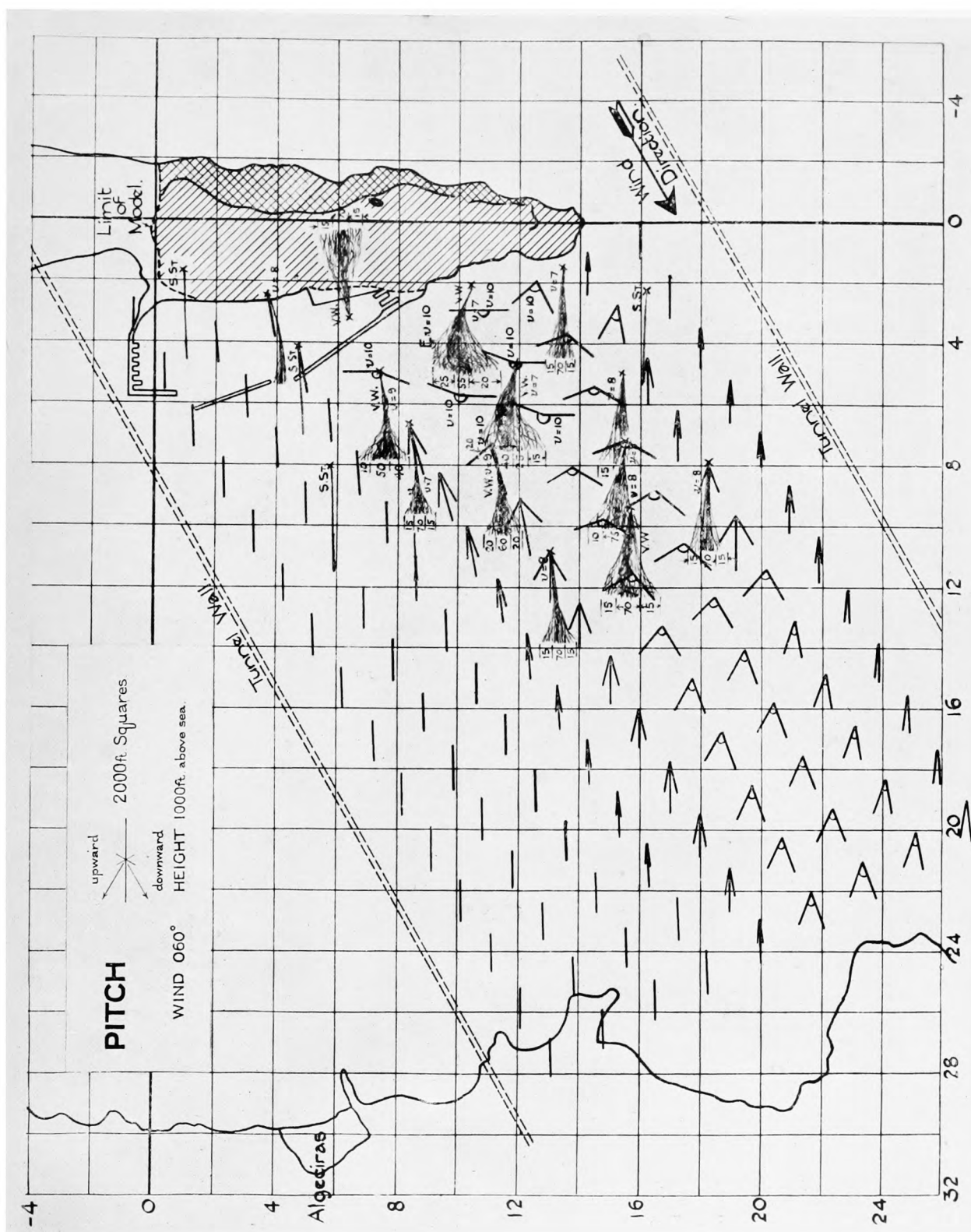
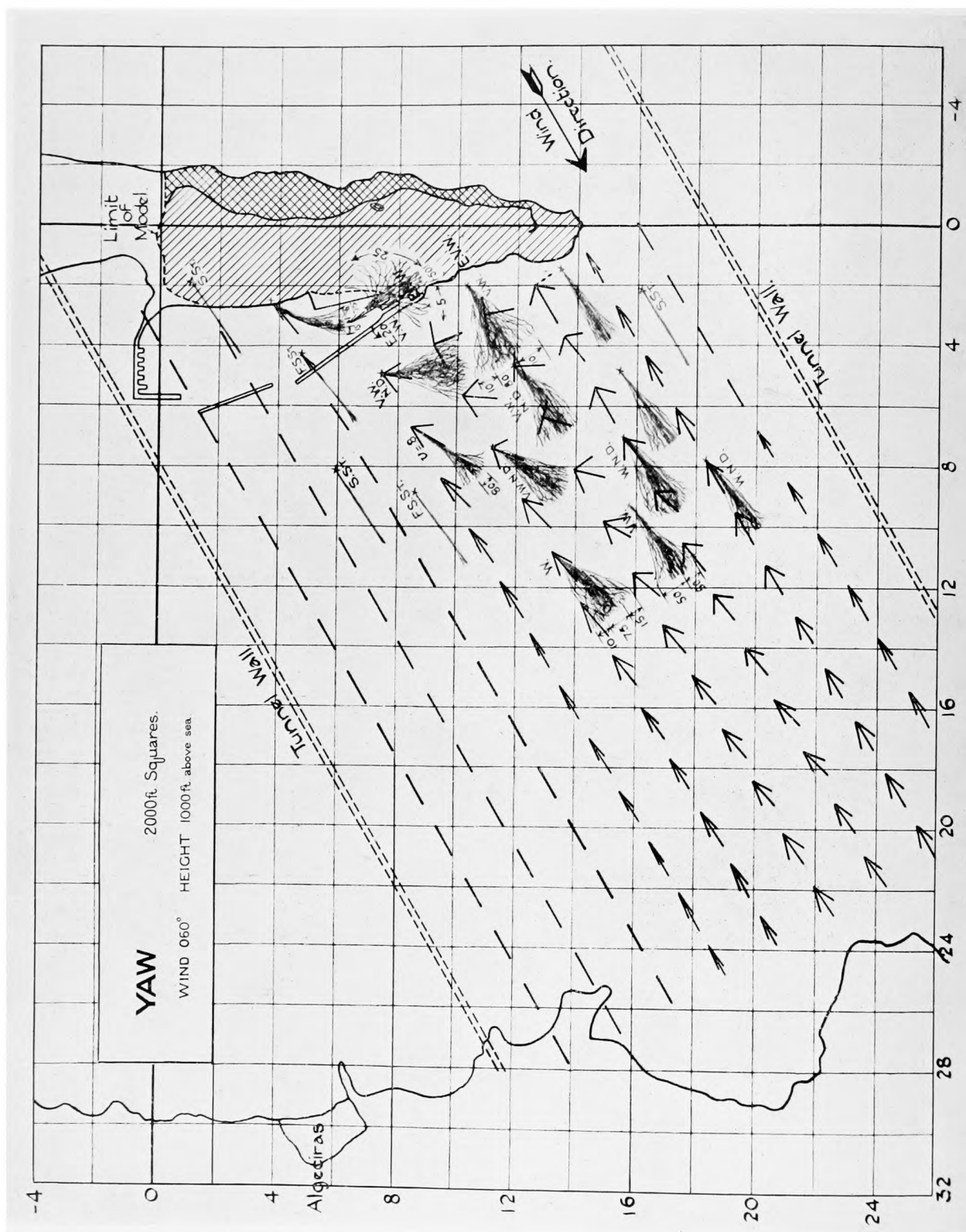
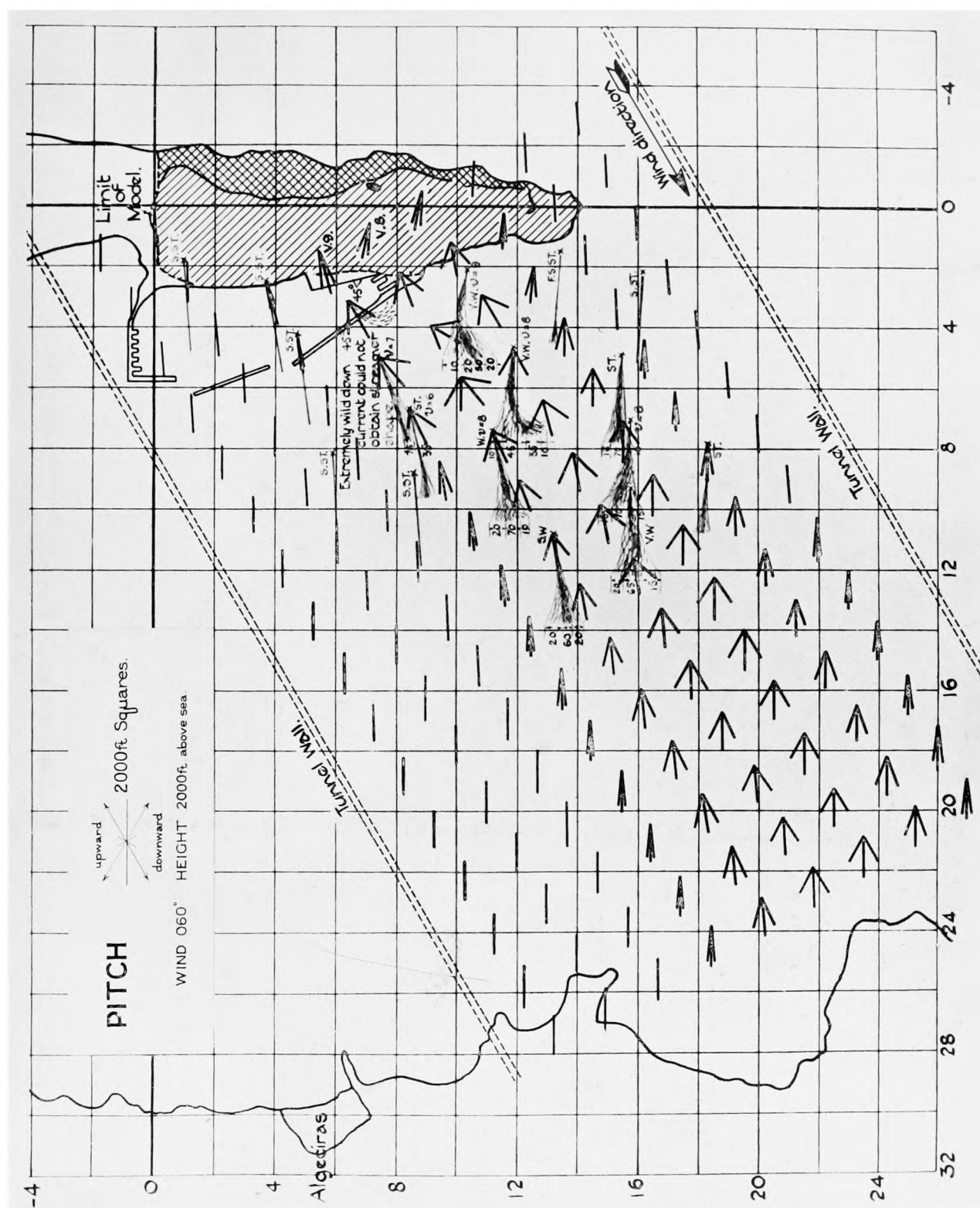
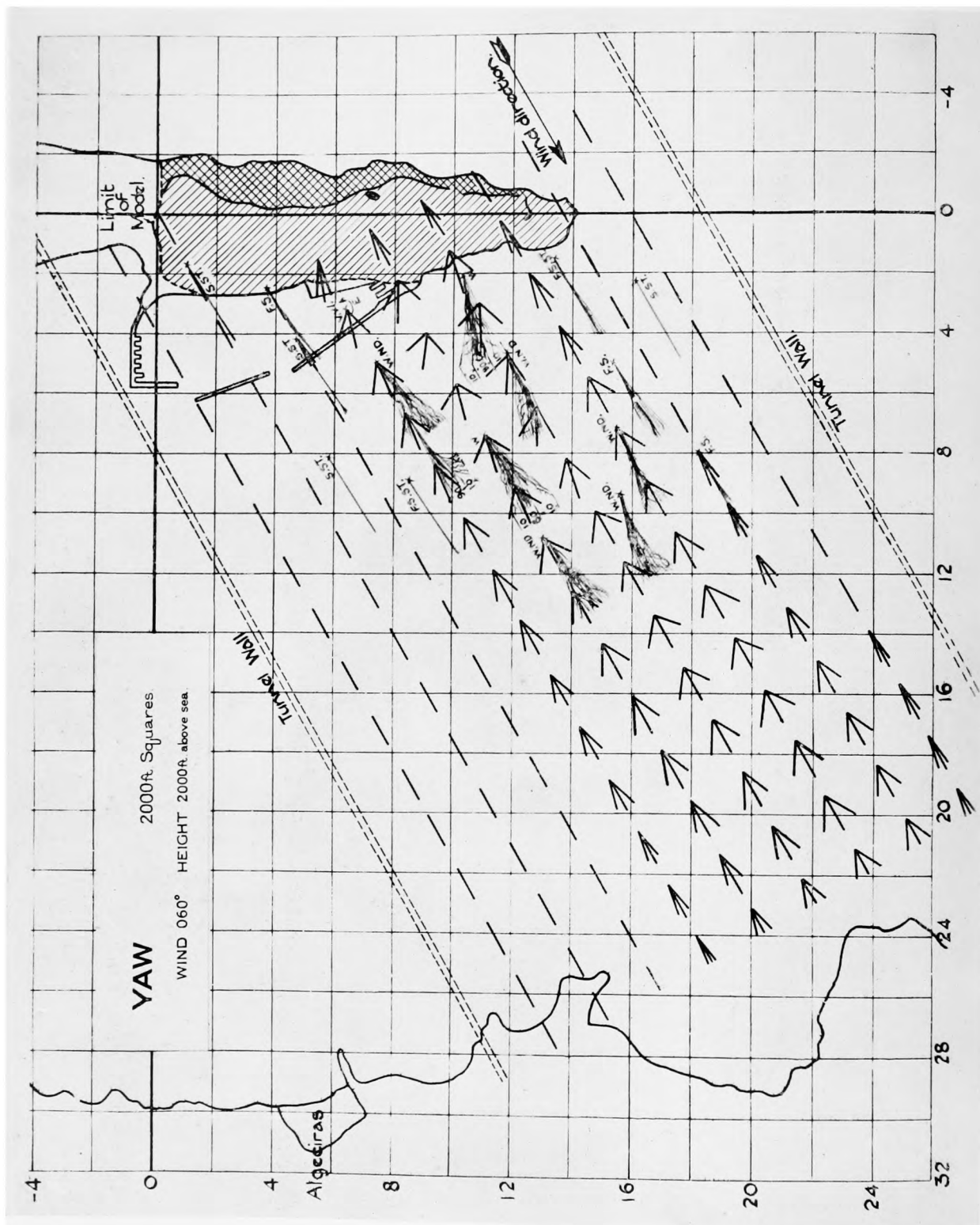
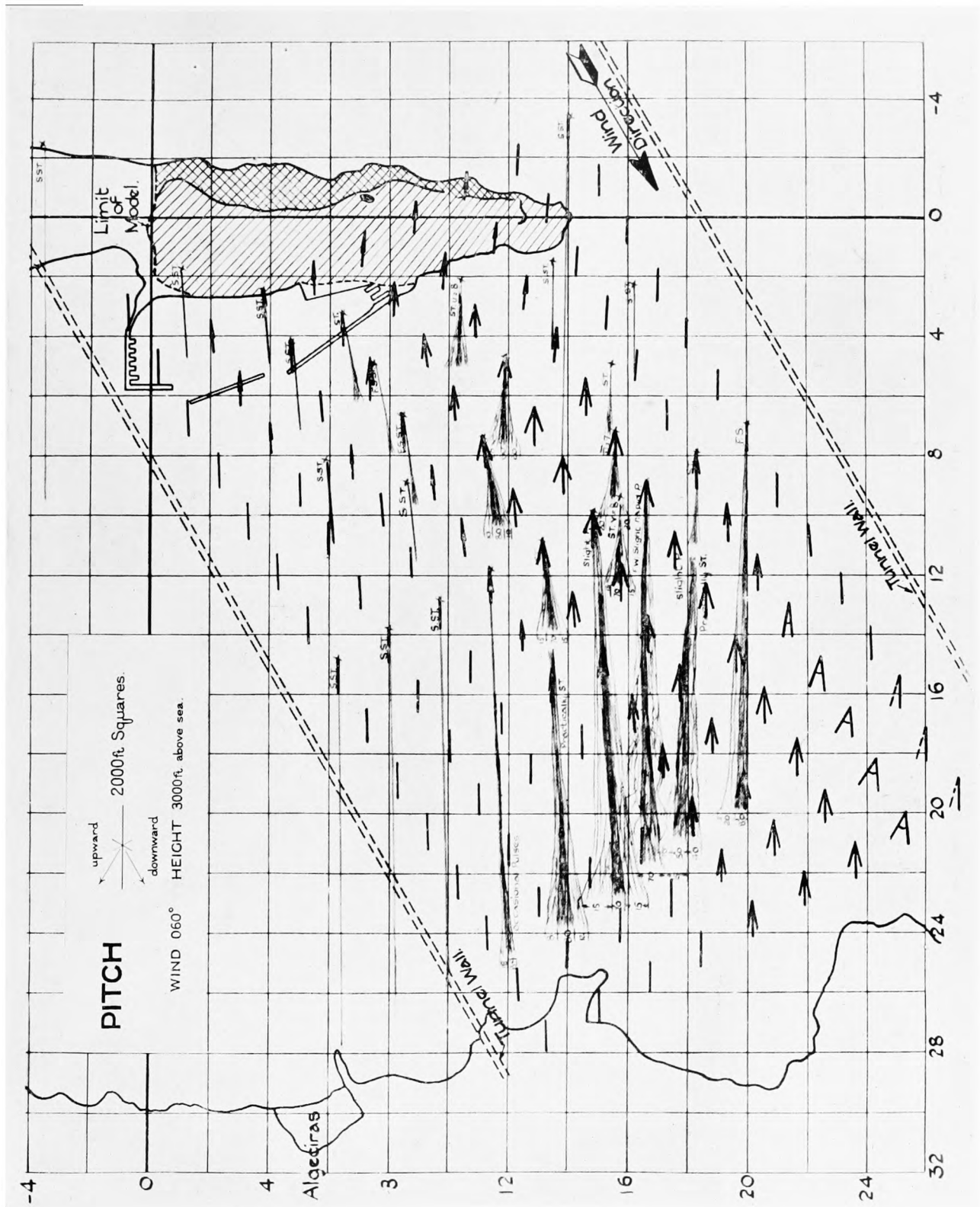


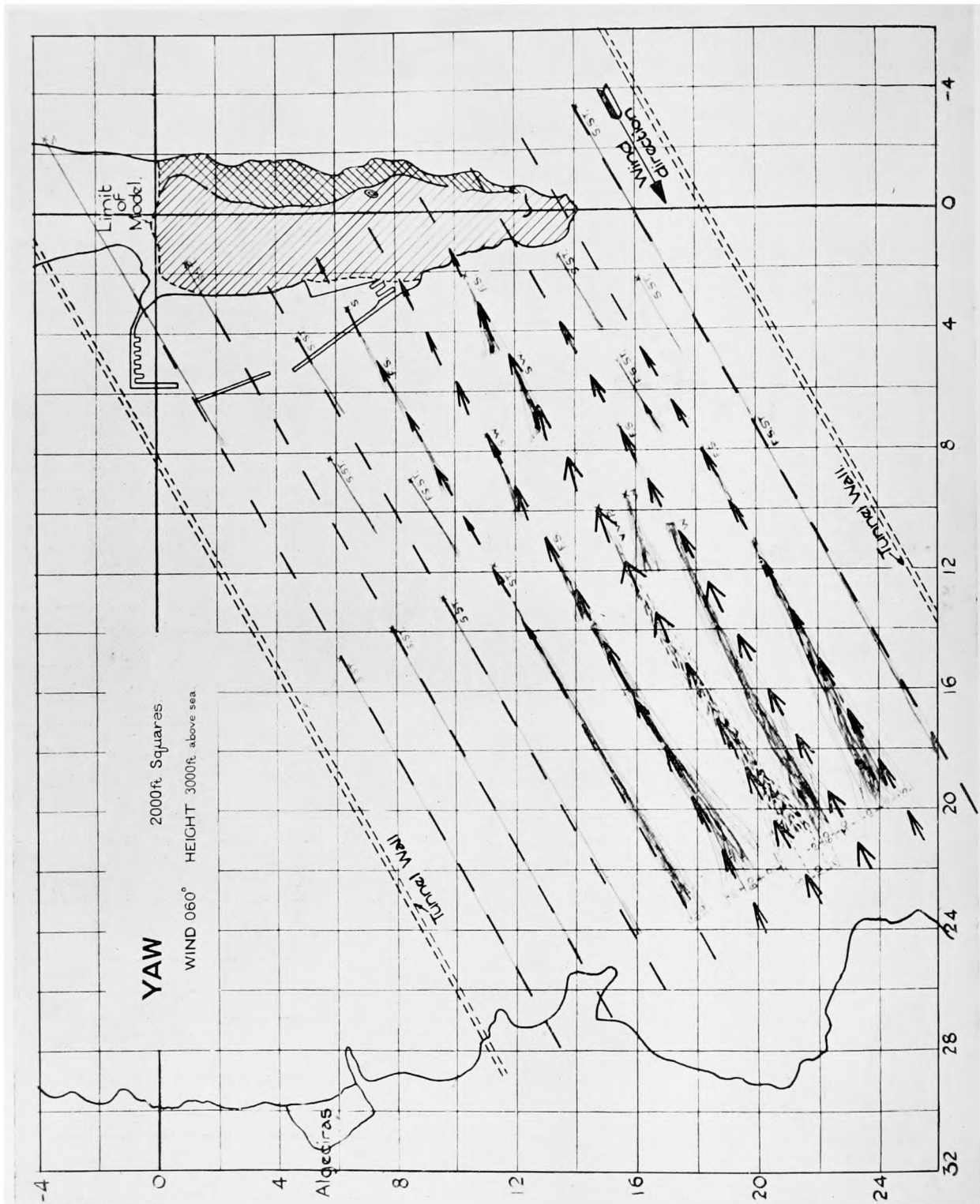
Plate XV B.

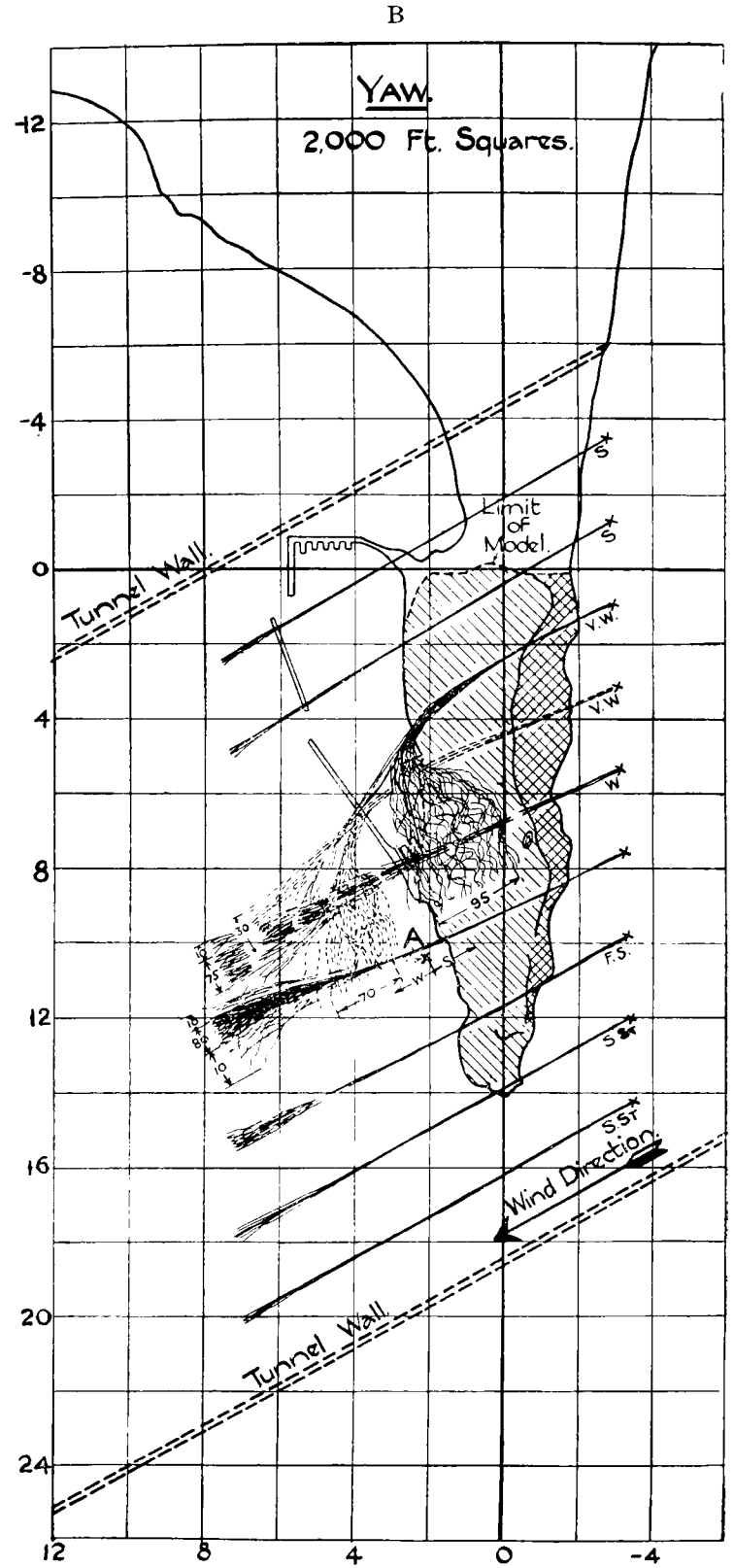
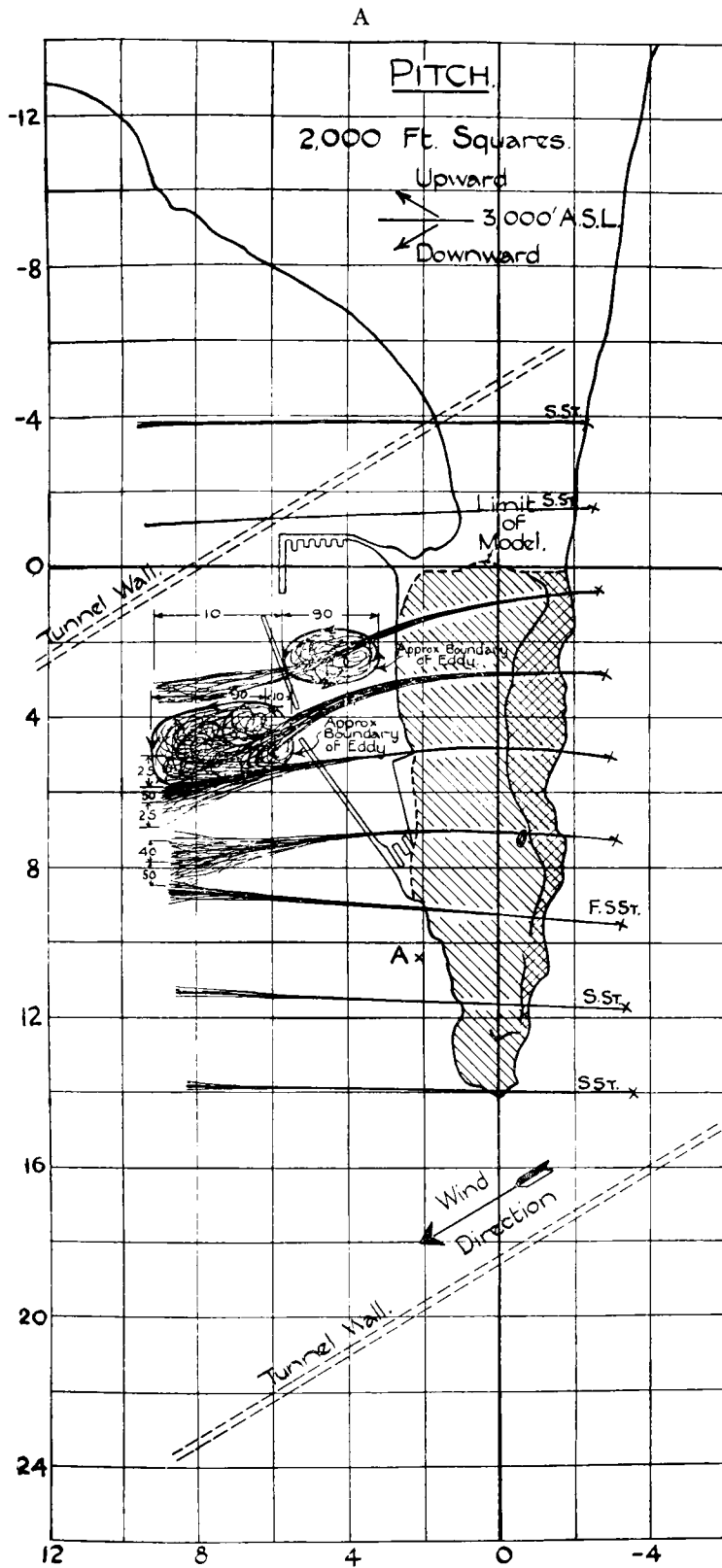






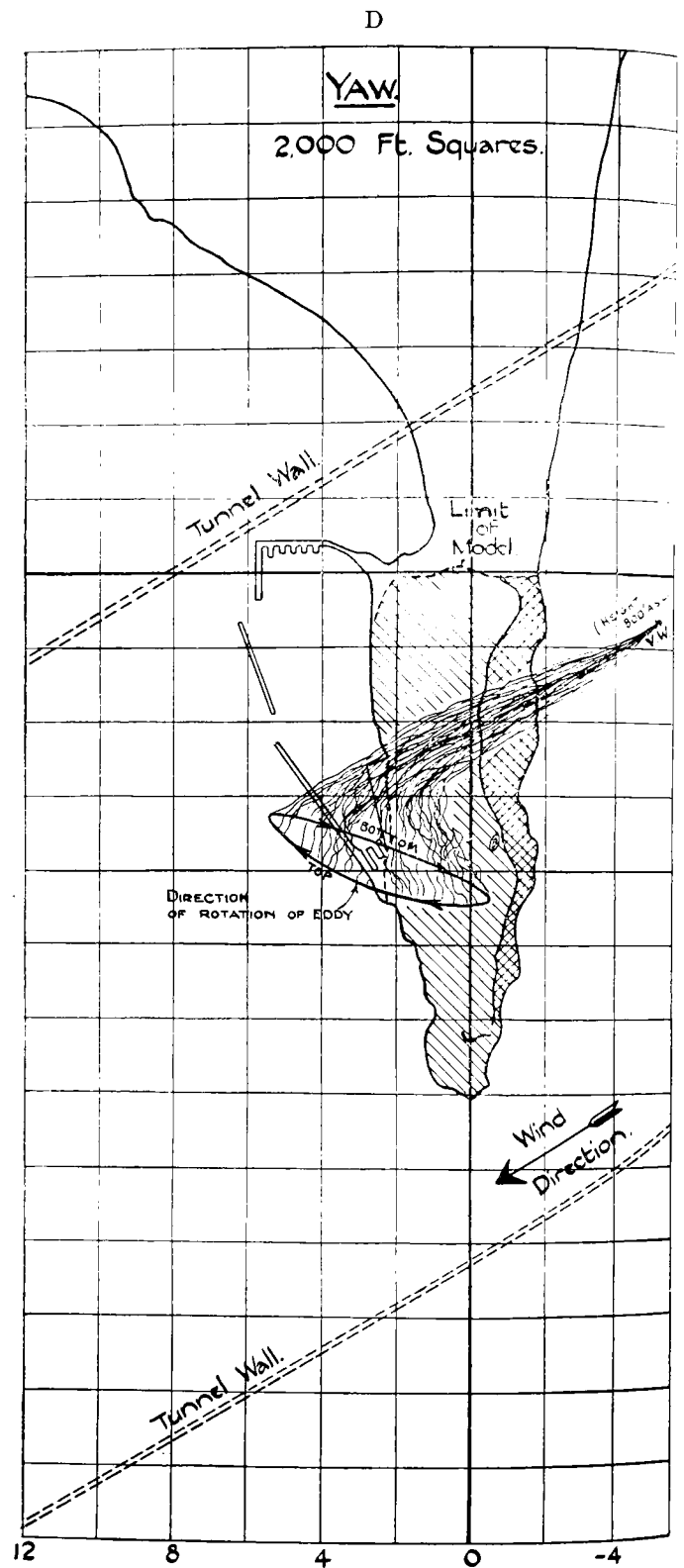
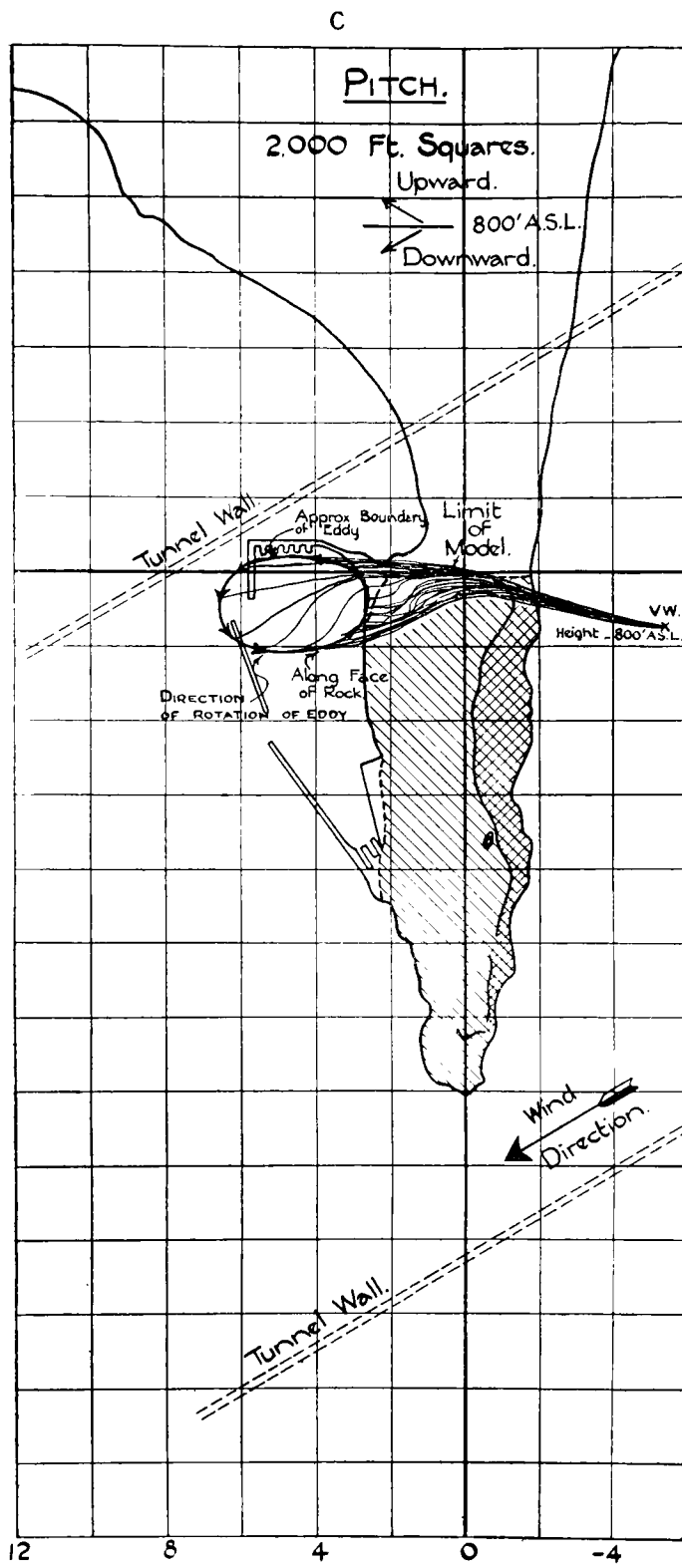




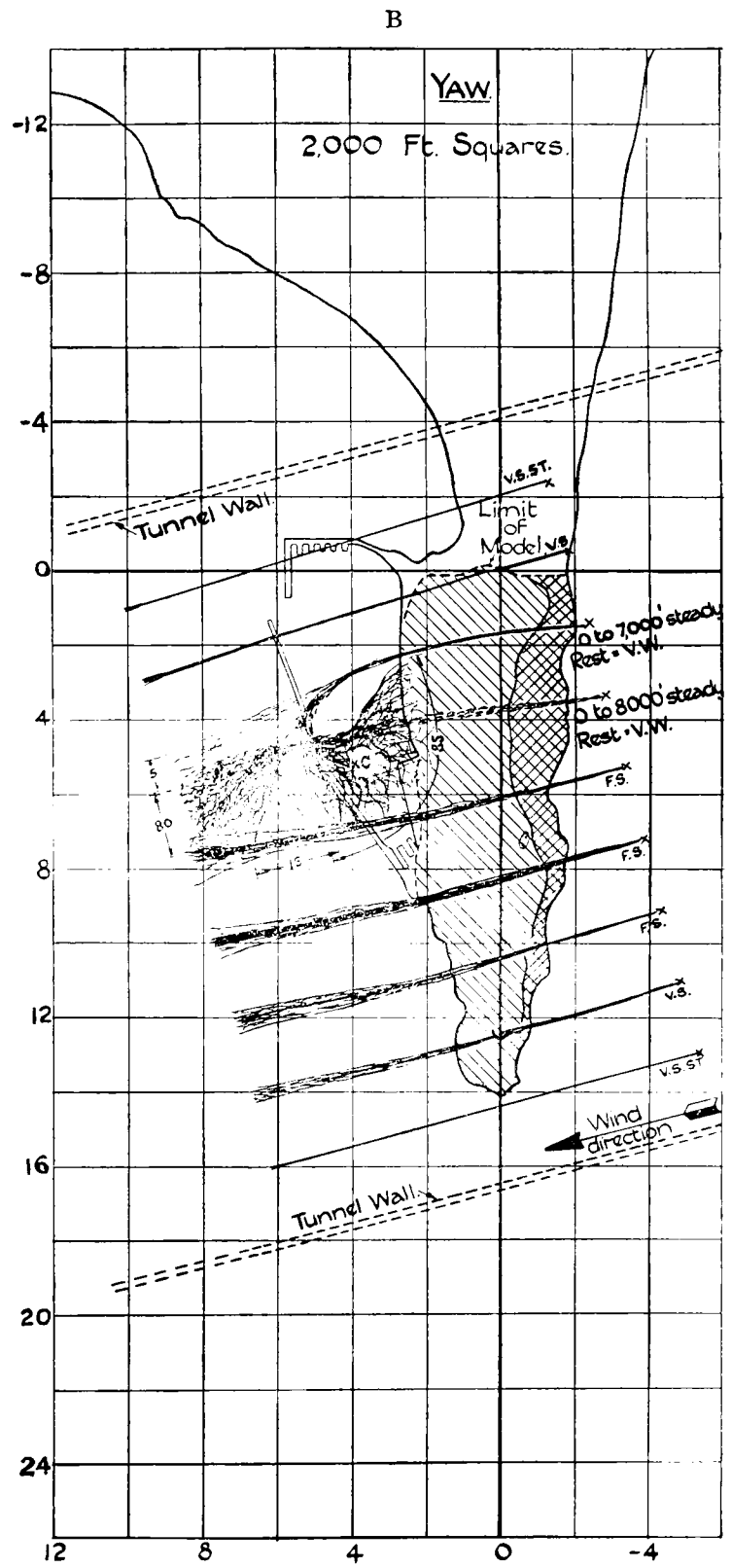
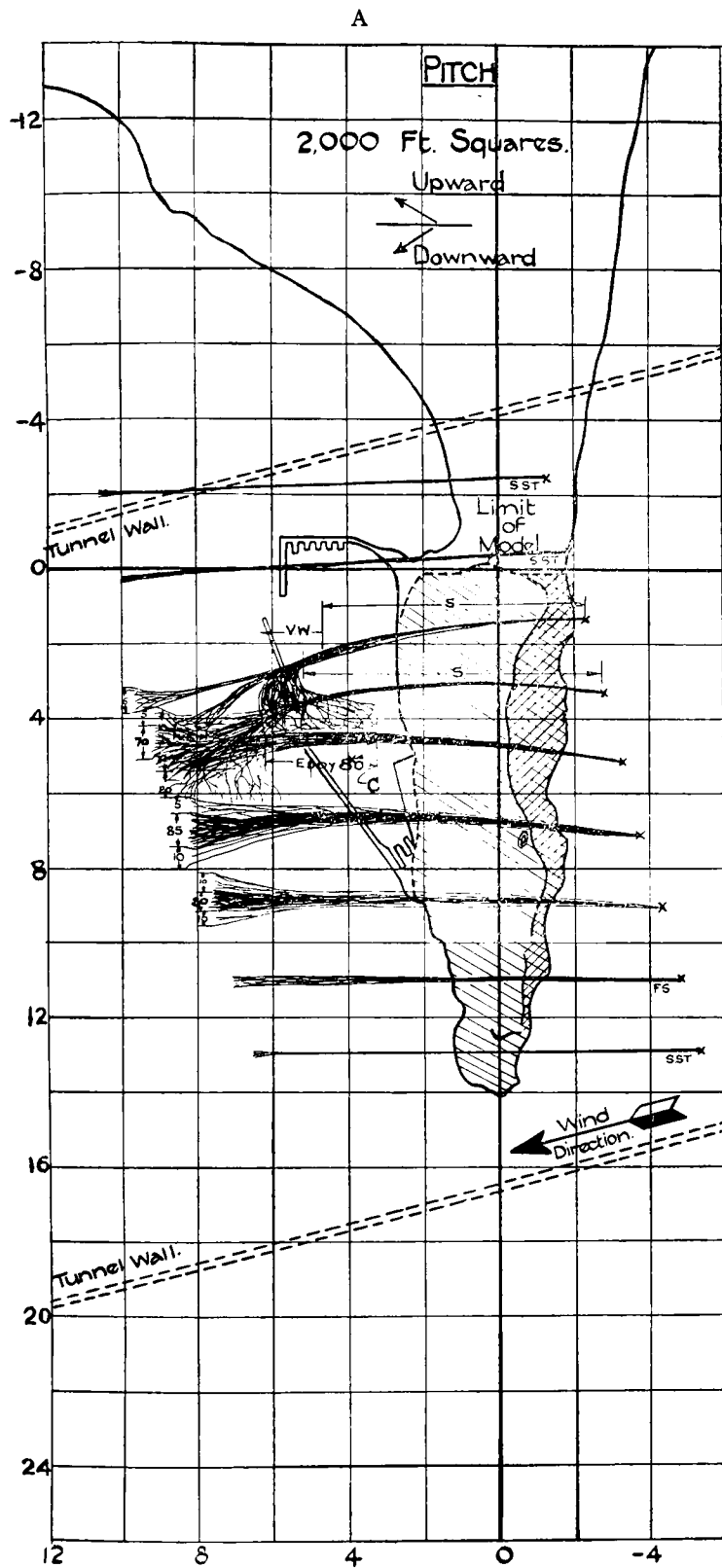


WIND 060°. EDDIES AS SHOWN BY STREAMERS OF GREAT LENGTH.

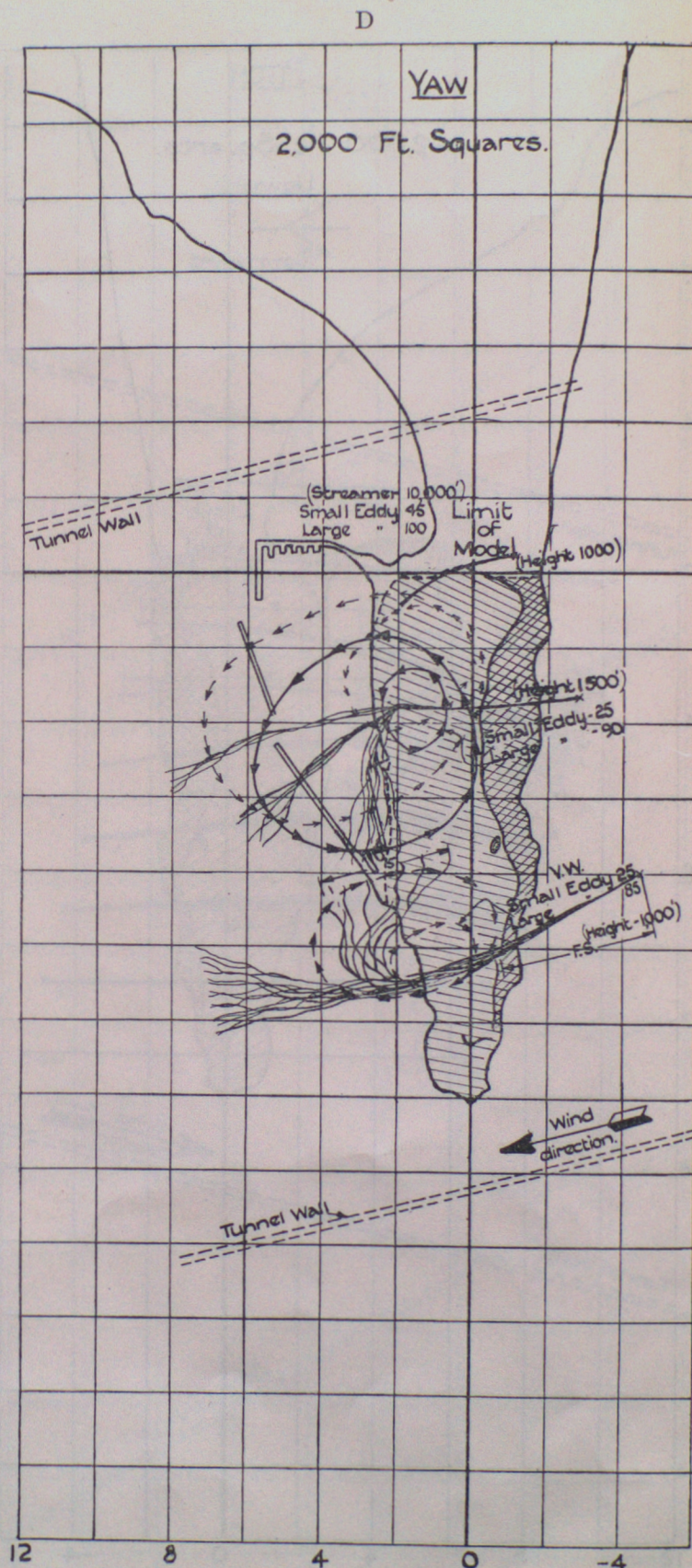
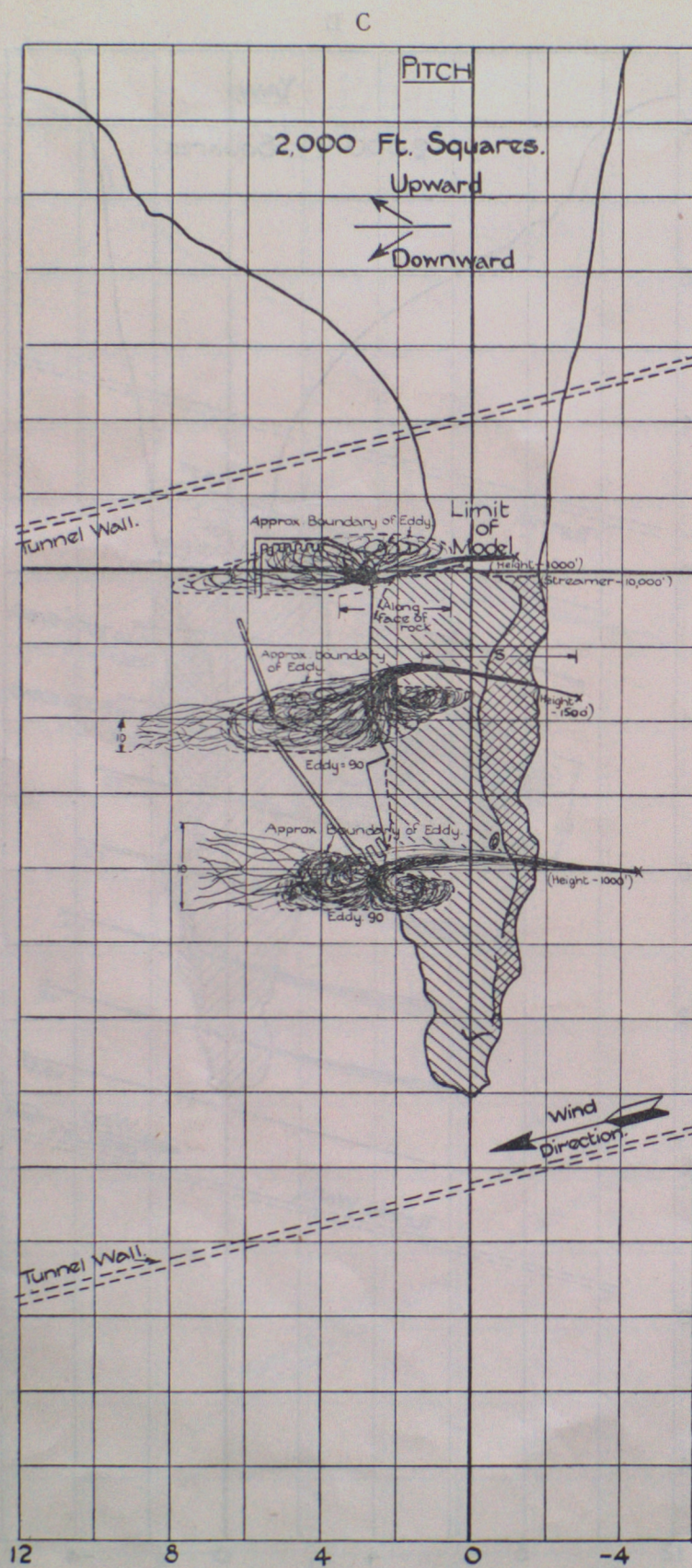
(Height of origin of streamers 3000 ft.)



WIND 060° EDDIES AS SHOWN BY STREAMERS OF GREAT LENGTH.

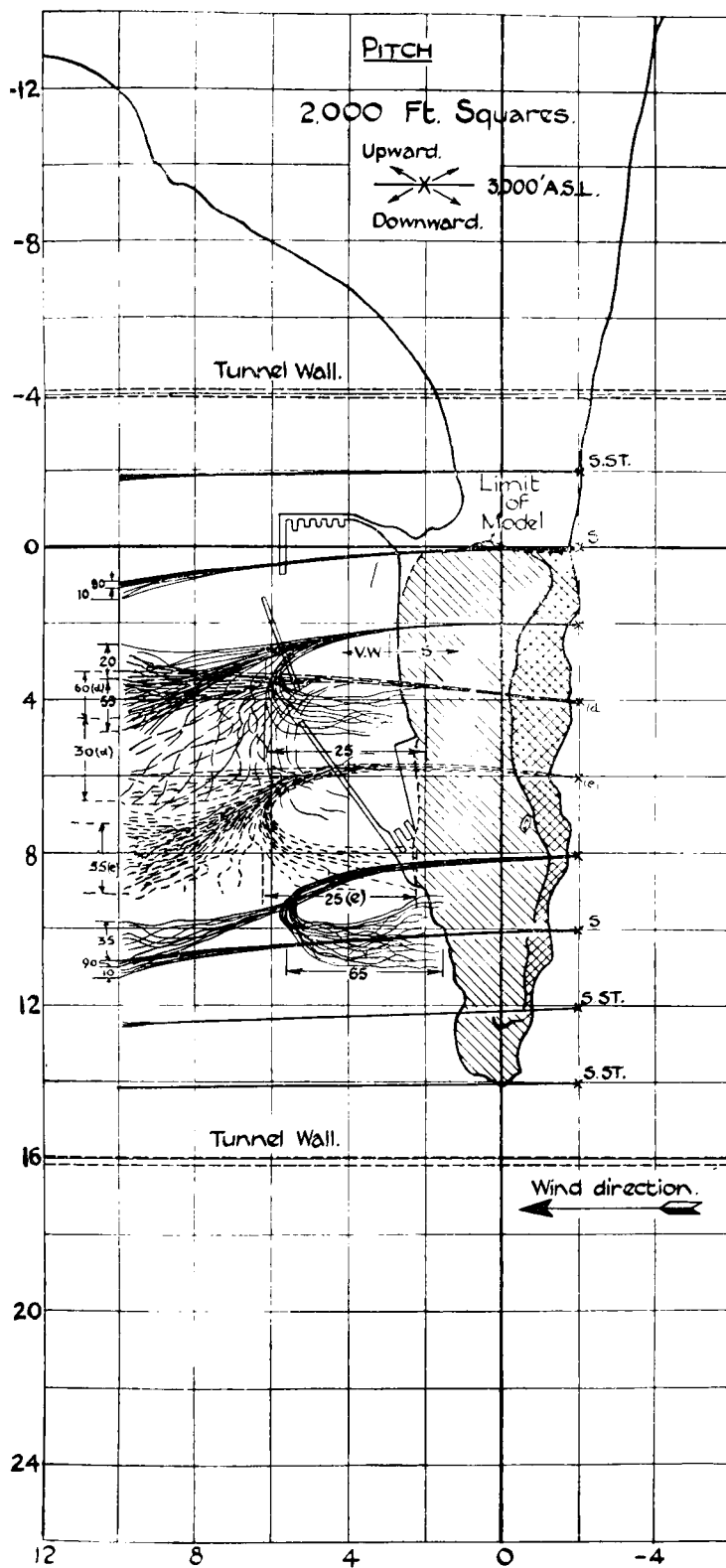


WIND 075° EDDIES AS SHOWN BY STREAMERS OF GREAT LENGTH.
(Height of origin of streamers 3000 ft.)



WIND 075°, EDDIES AS SHOWN BY STREAMERS OF GREAT LENGTH.

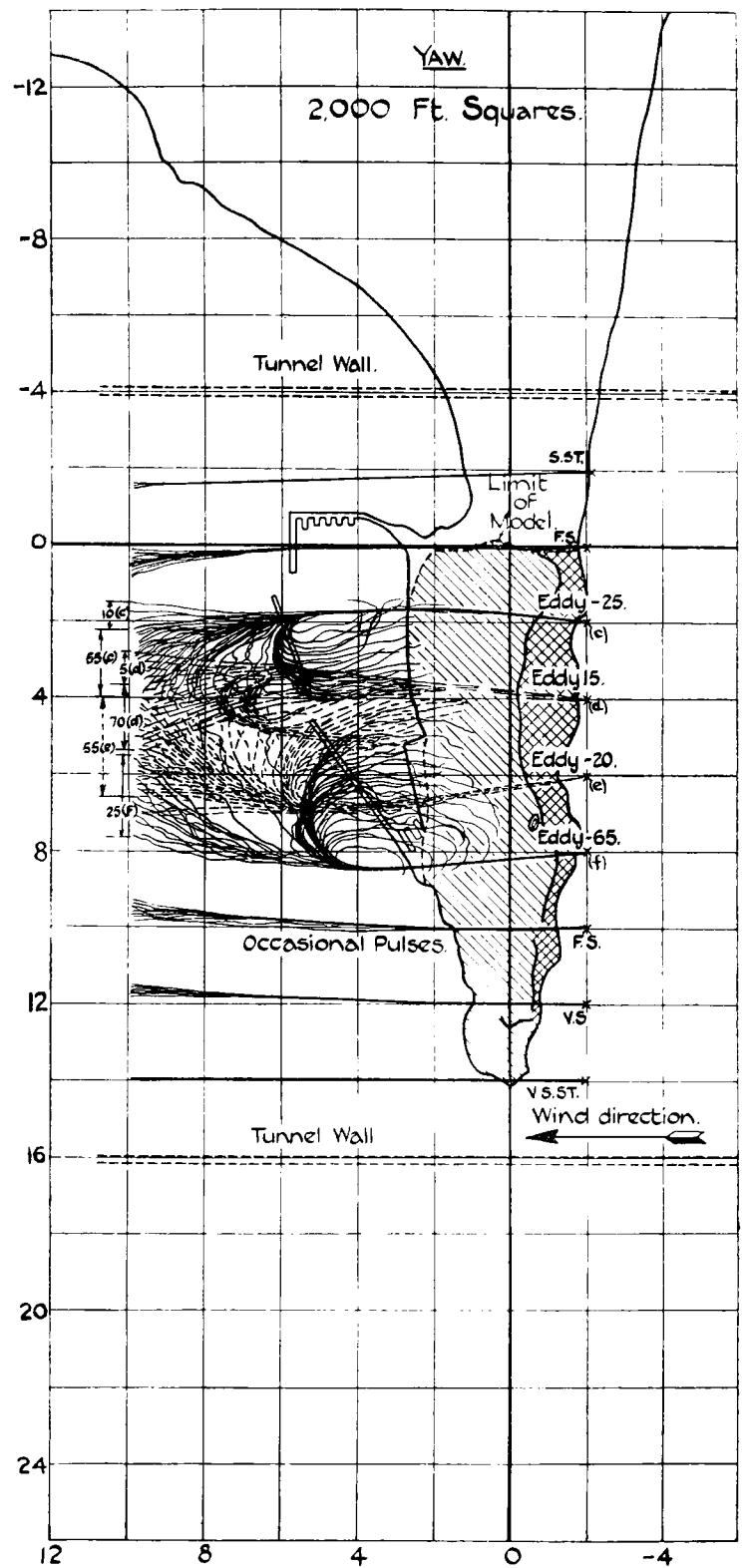
A

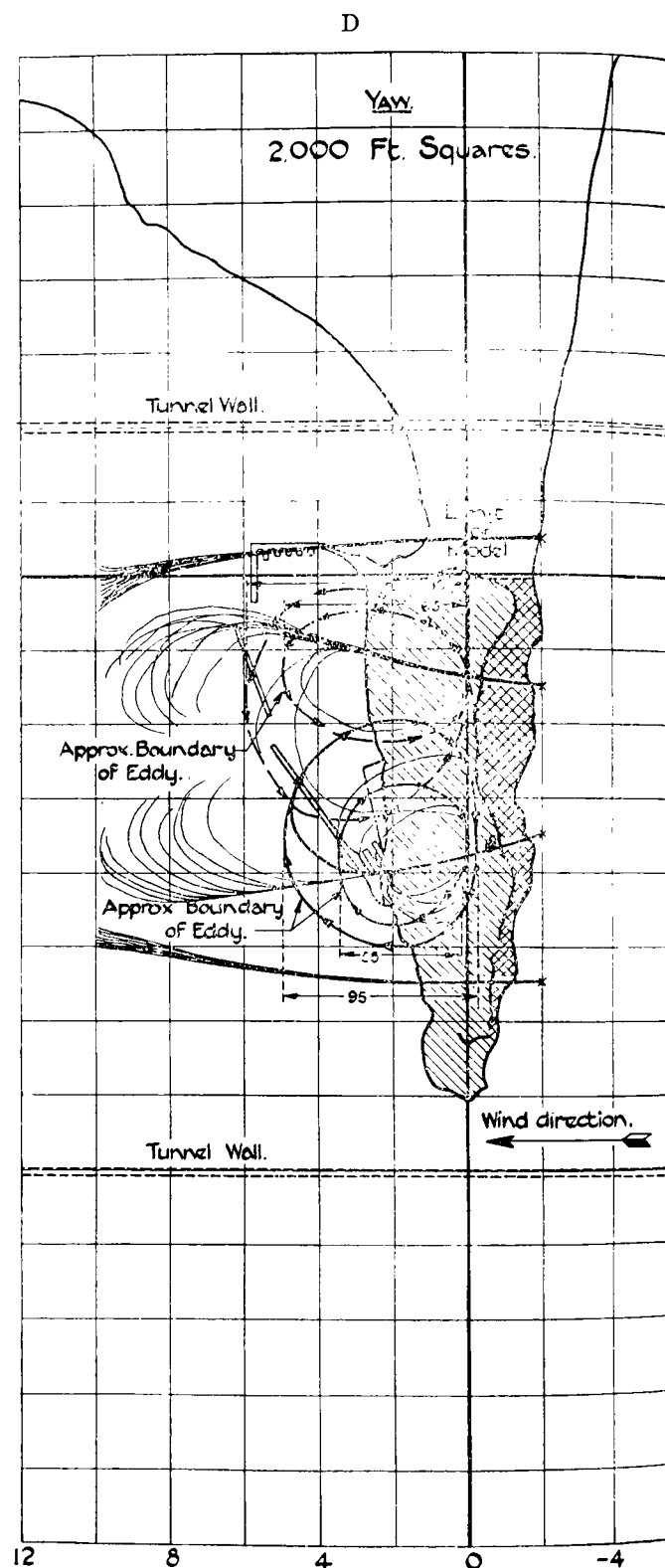
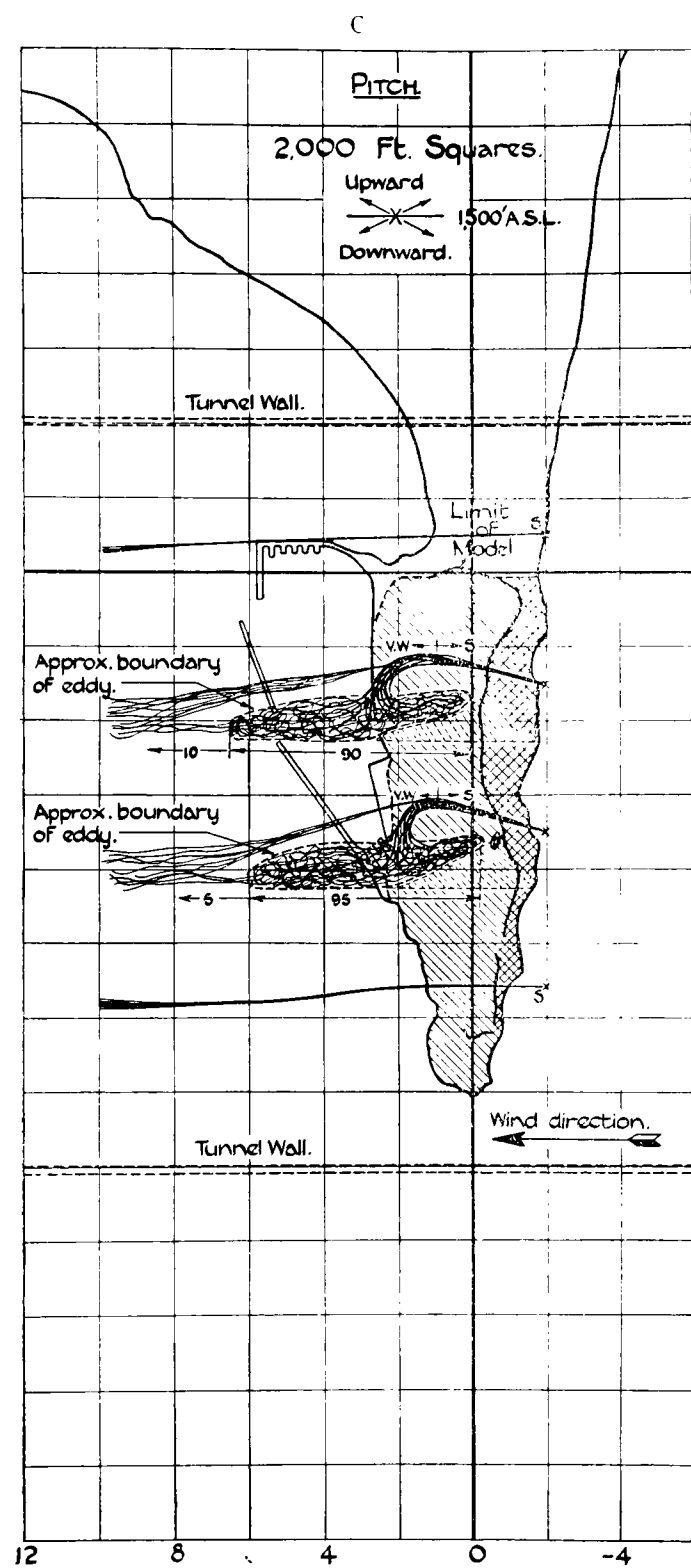


WIND 090° EDDIES AS SHOWN BY STREAMERS OF GREAT LENGTH.

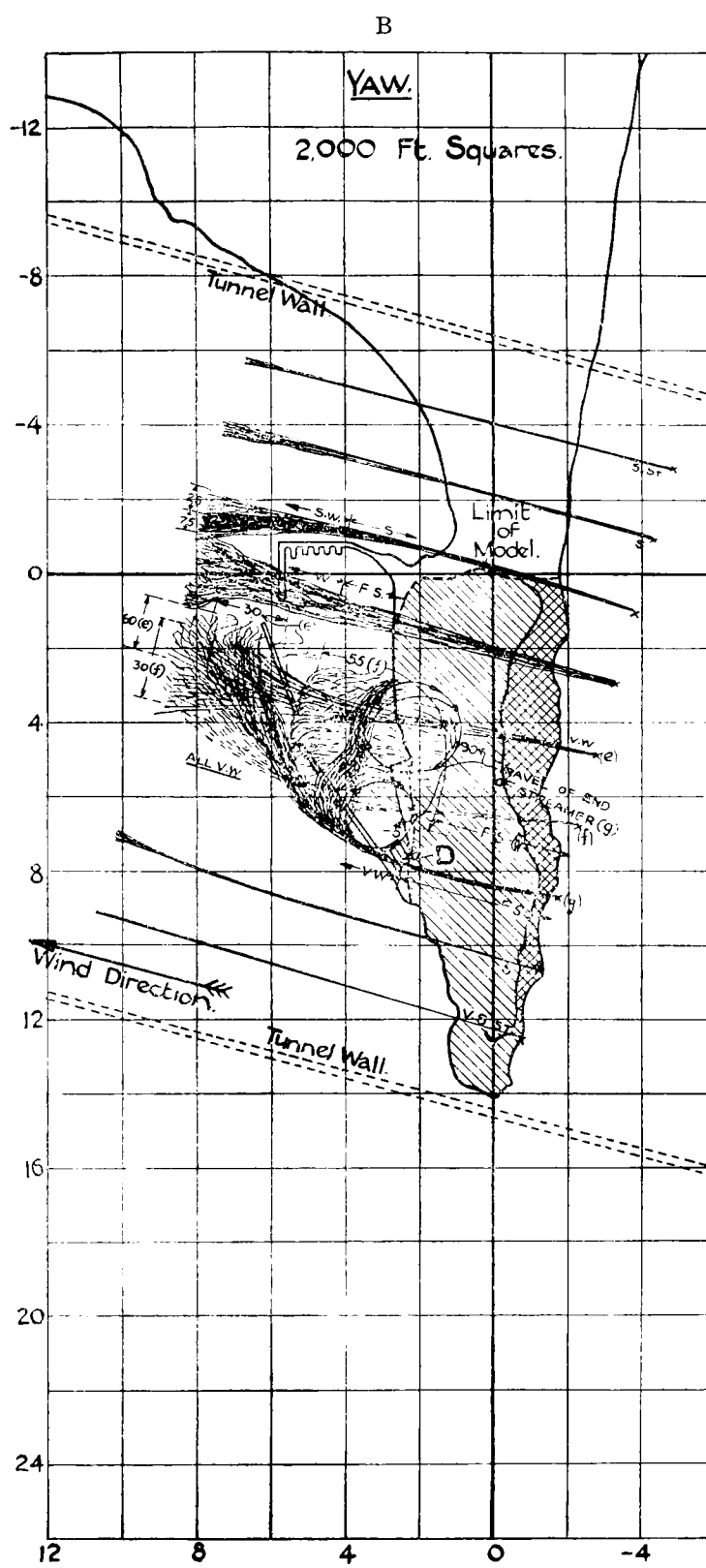
(Height of origin of streamers 3000 ft.)

B

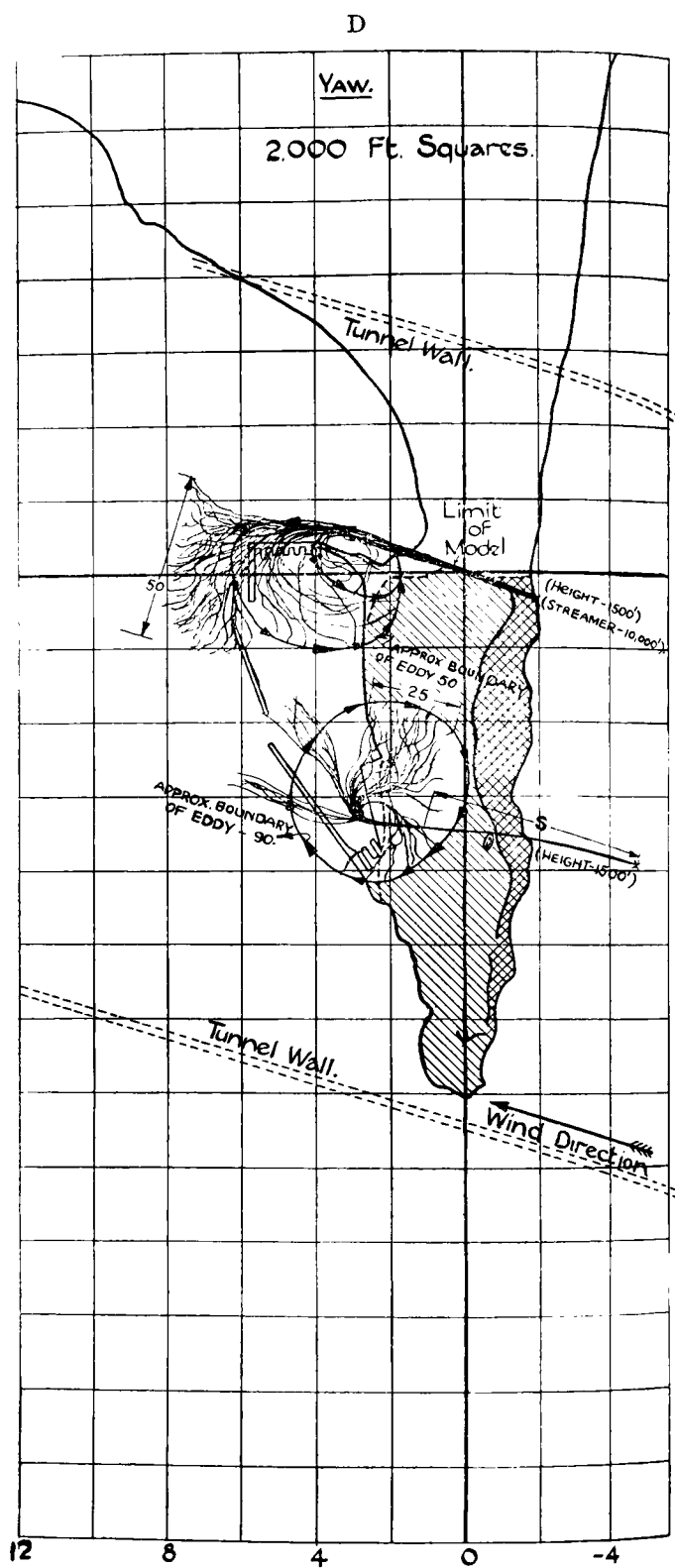
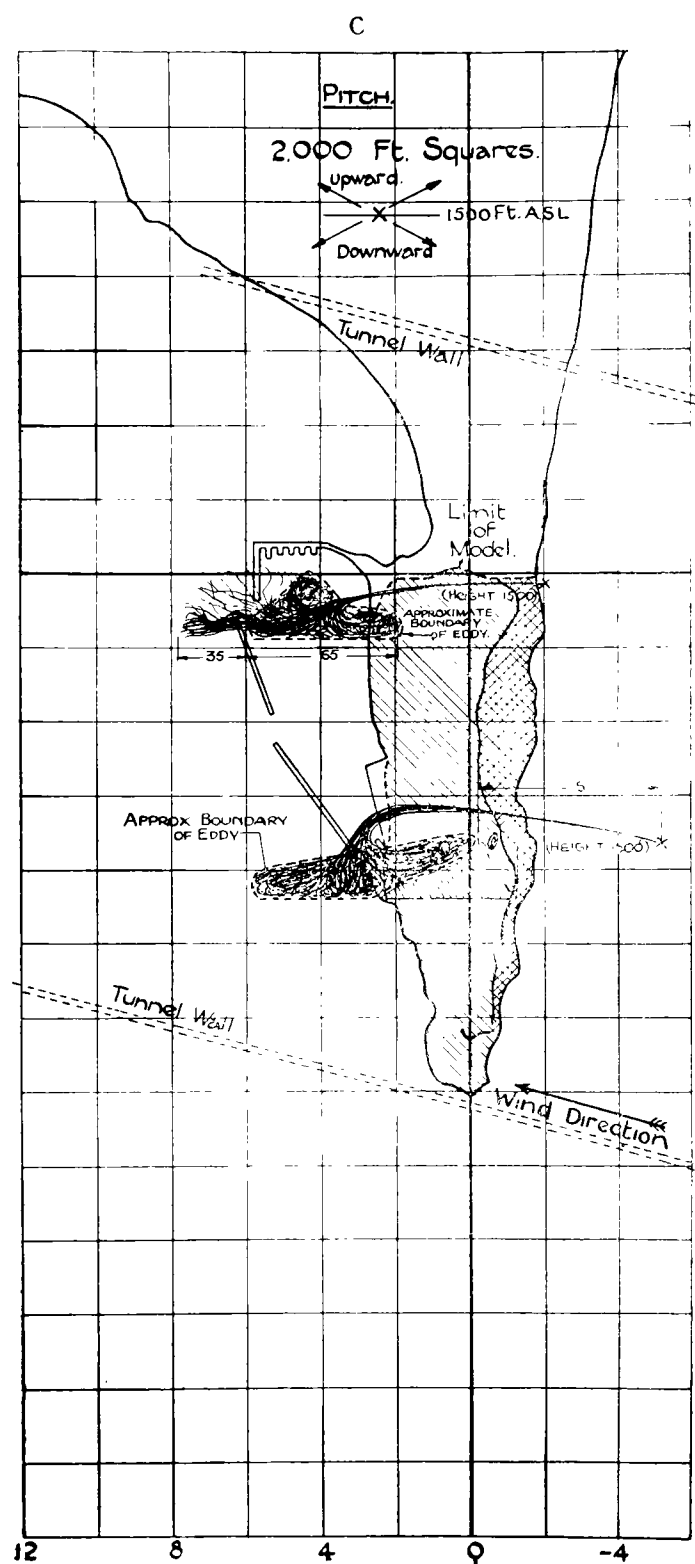




WIND 090°. EDDIES AS SHOWN BY STREAMERS OF GREAT LENGTH.
(Height of origin of streamers 1500 ft.)

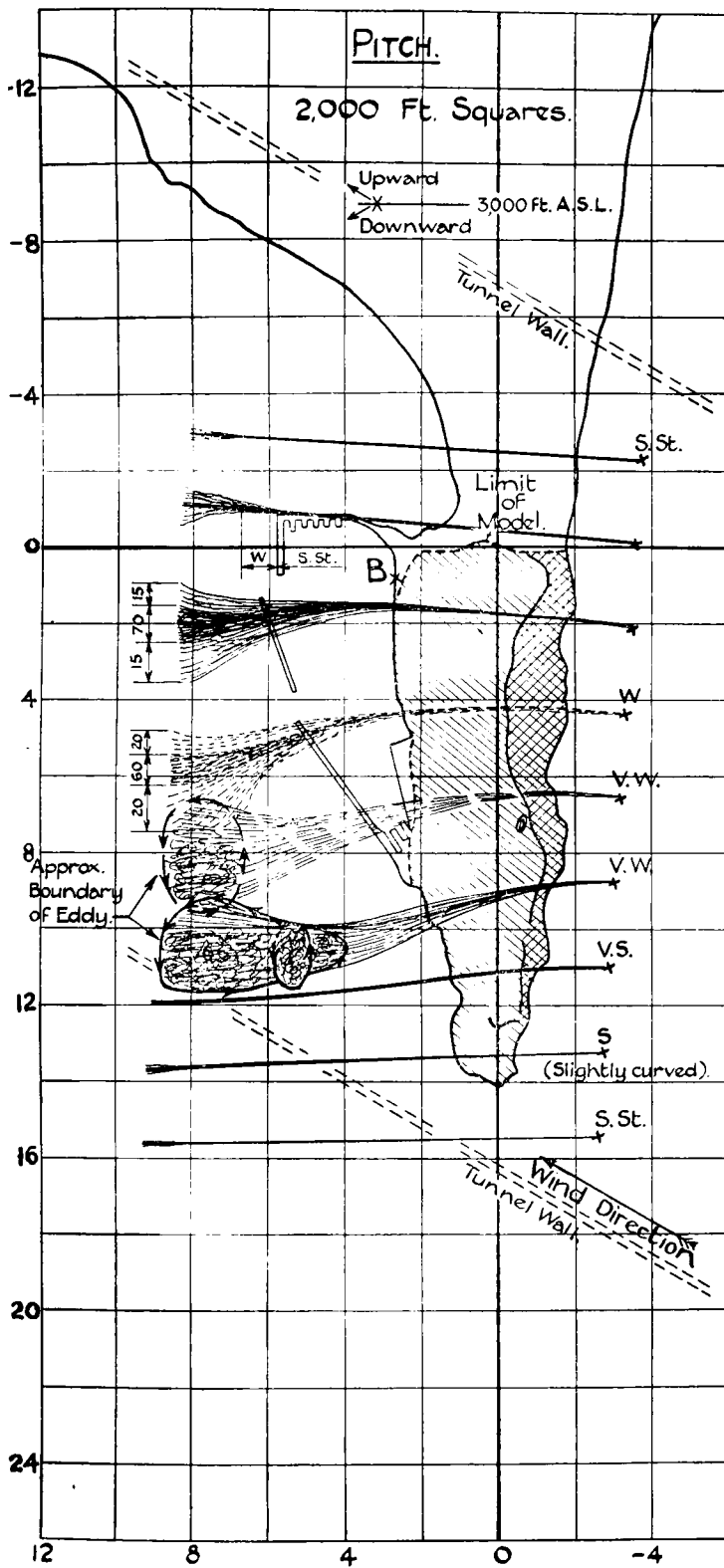


WIND 105°. EDDIES AS SHOWN BY STREAMERS OF GREAT LENGTH.
(Height of origin of streamers 3000 ft)

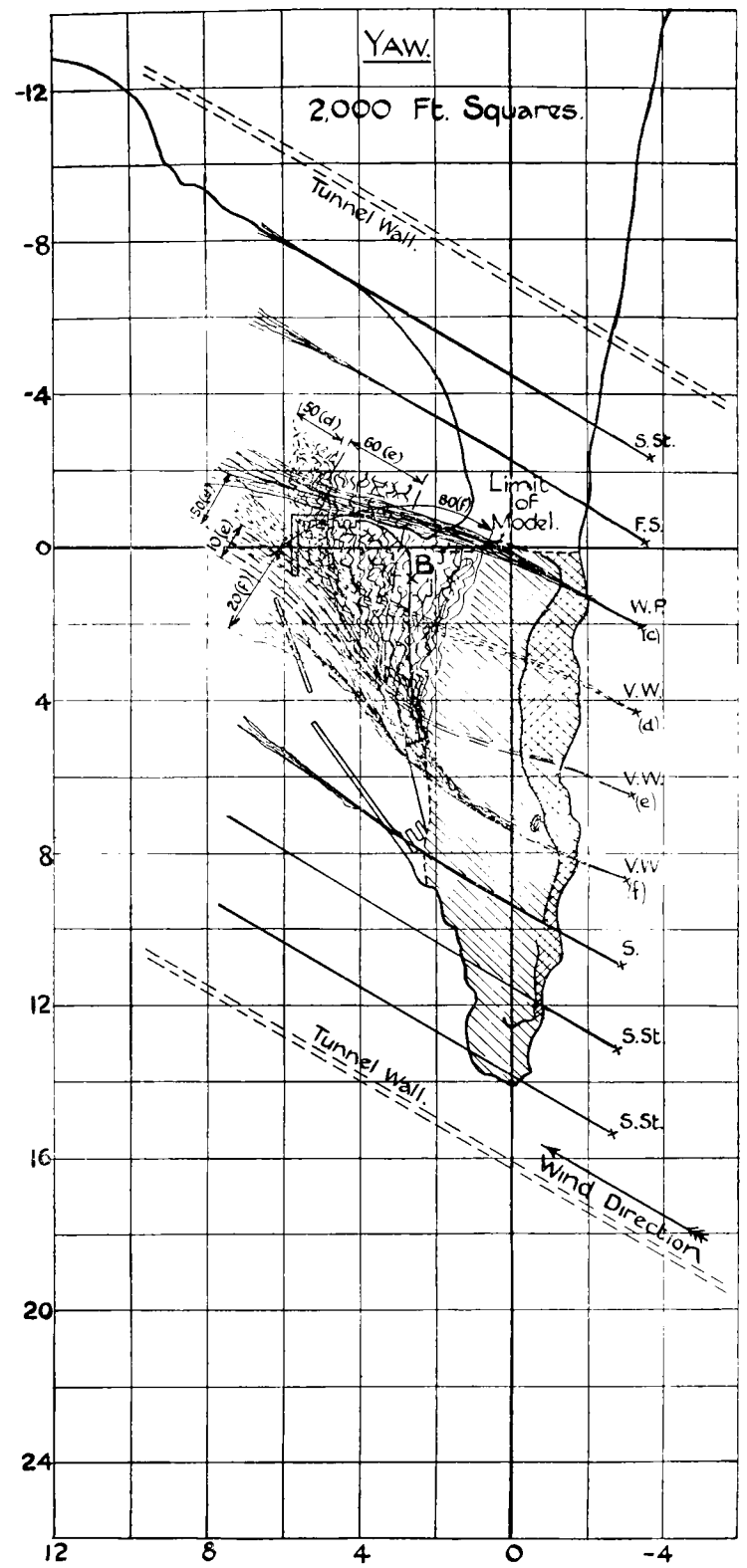


WIND 105° EDDIES AS SHOWN BY STREAMERS OF GREAT LENGTH.

A

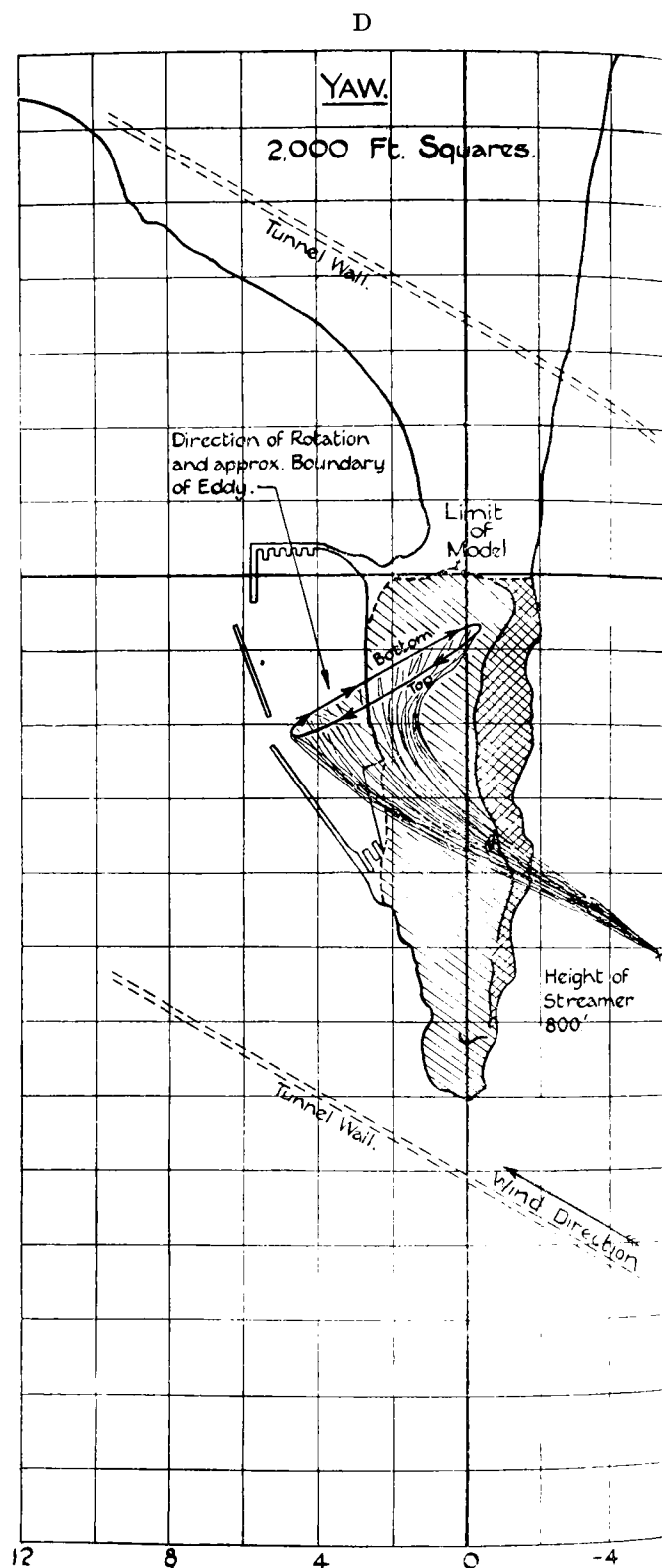
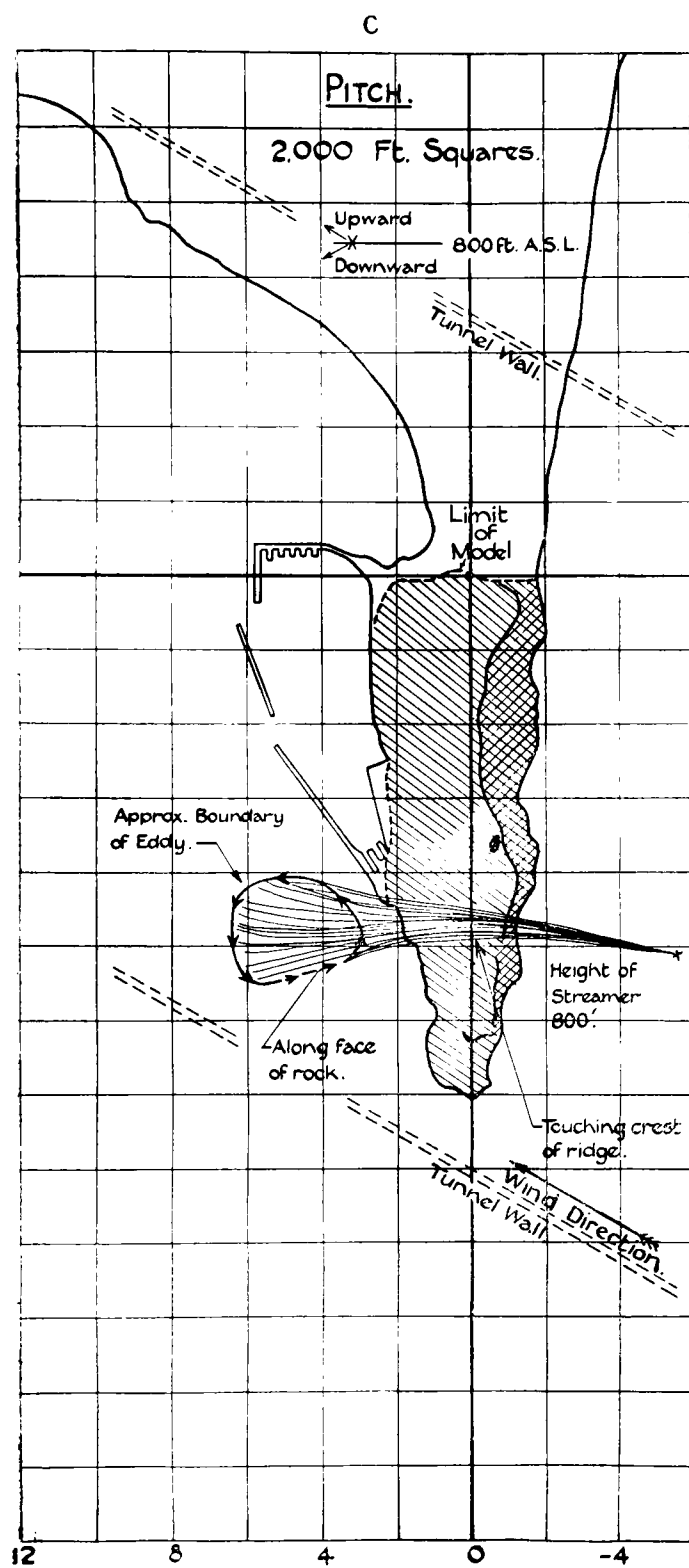


B

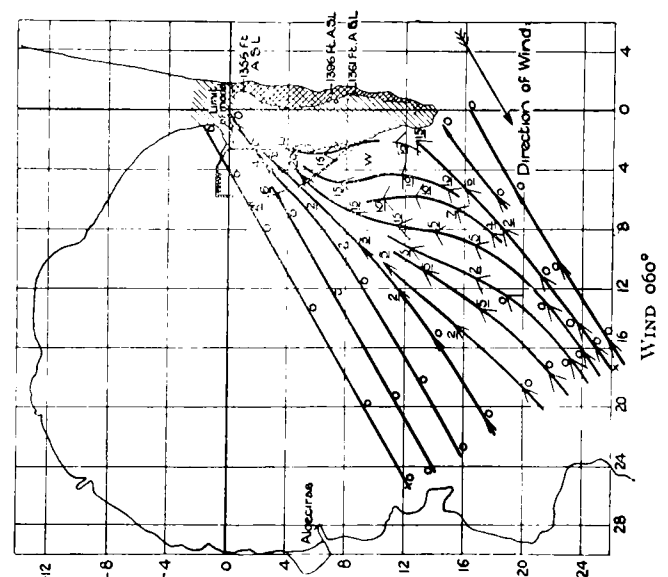
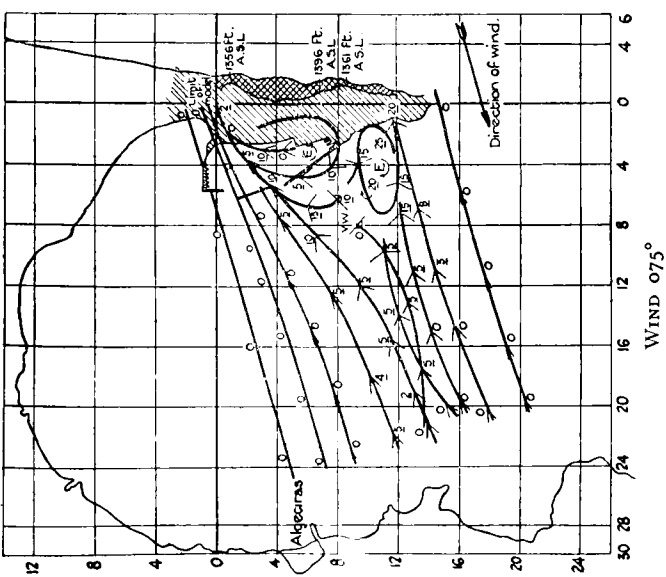
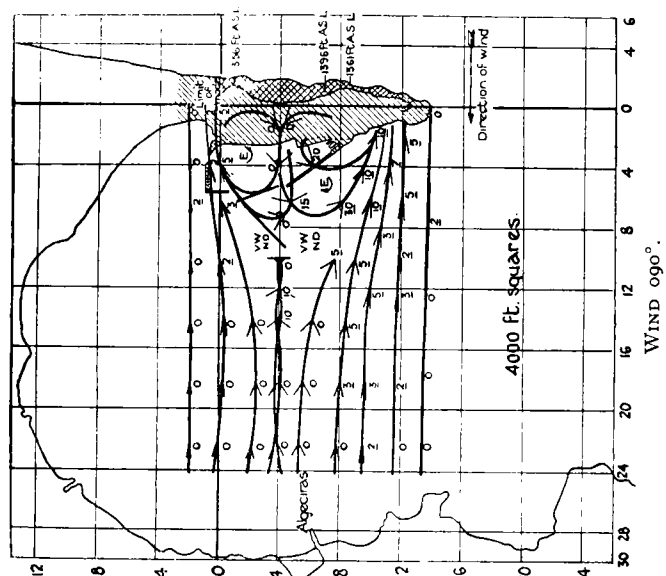
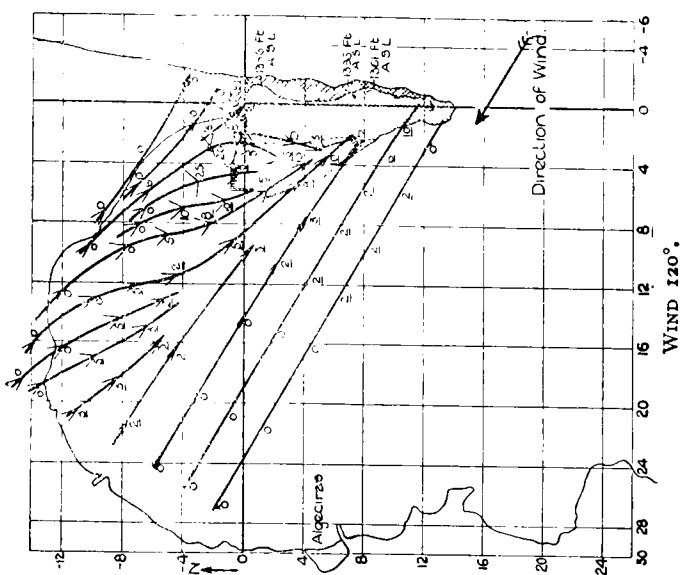
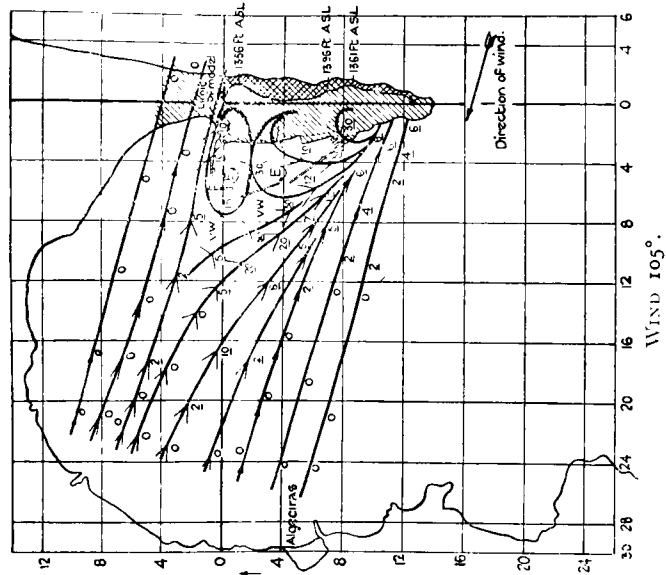


WIND 120°. EDDIES AS SHOWN BY STREAMERS OF GREAT LENGTH.

(Height of origin of streamers 3000 ft.)



WIND 120°. EDDIES AS SHOWN BY STREAMERS OF GREAT LENGTH.



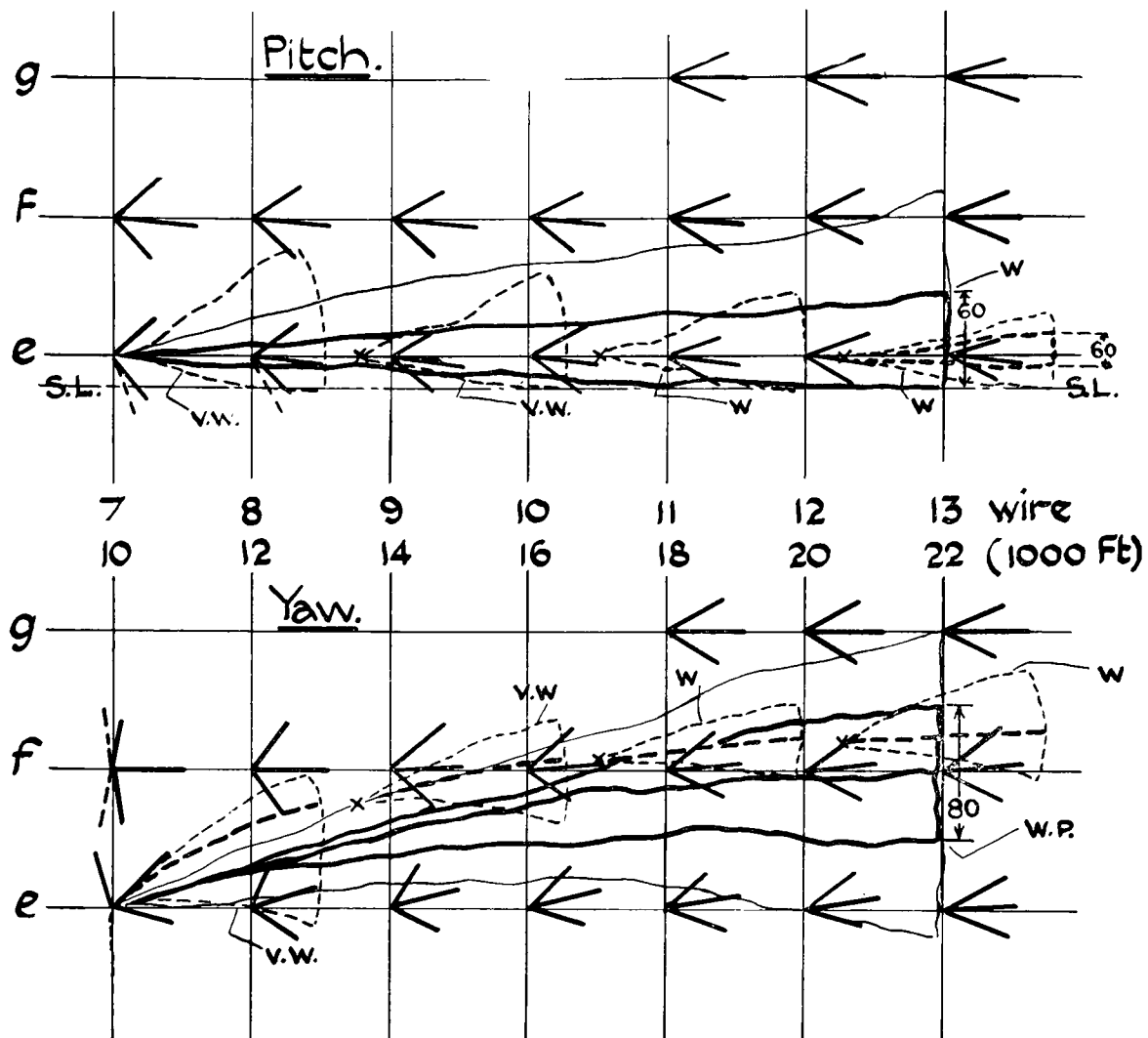
SIMPLIFIED DIAGRAMS OF THE FLOW AROUND THE ROCK OF GIBRALTAR AT A HEIGHT OF 500 FEET ABOVE SEA.

Heavy lines show the lines of flow in YAW.

— is the angle of oscillation in YAW.

15 is a negative PITCH in degrees (downward from horizontal).

15 is a positive PITCH in degrees (upwards from horizontal).



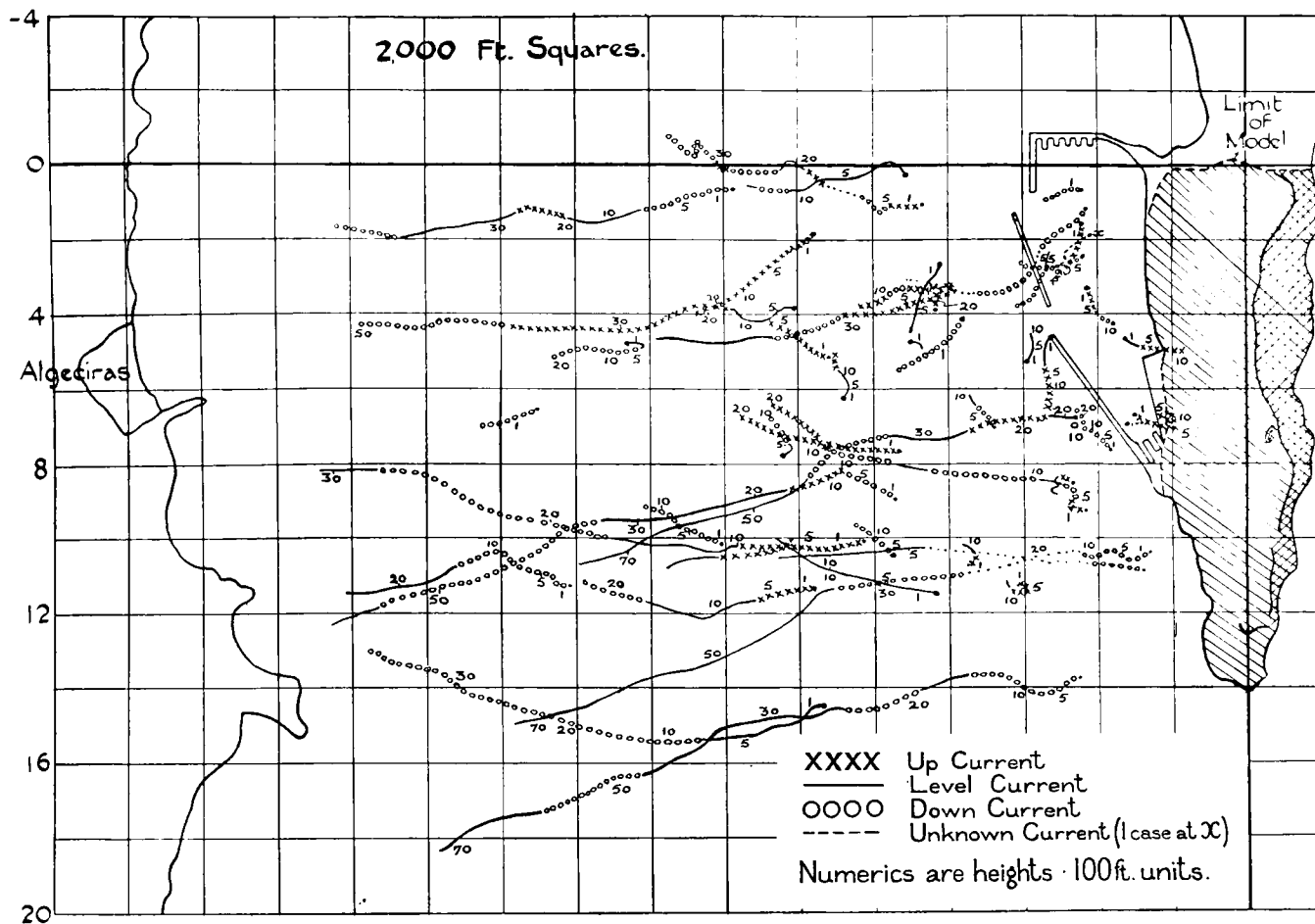
Wind 075°

Height 500 Ft. A.S.L.

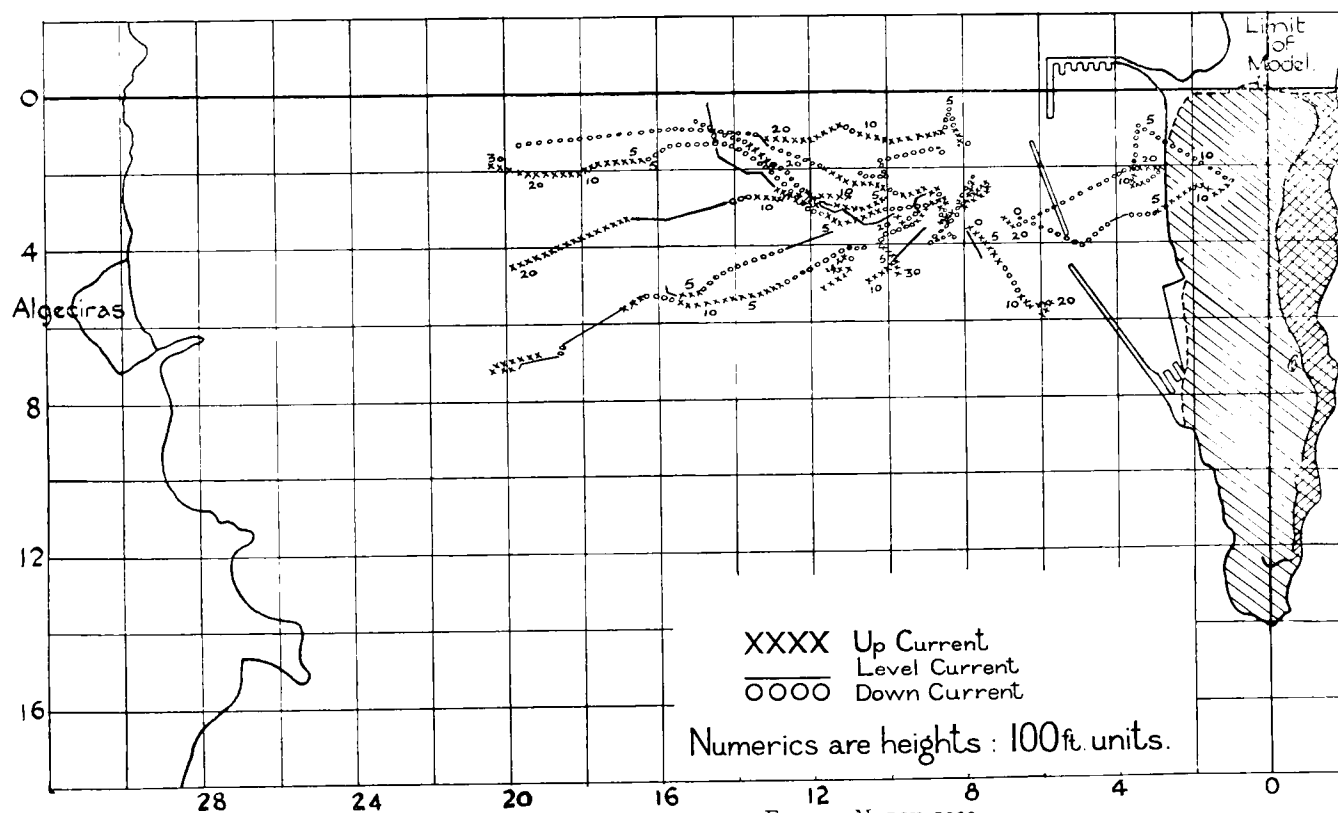
← Flag Investigation.

----- Streamers 3,000 Ft. (7.2 in) long. { Main direction
 _____ Streamers 12,000 Ft. (28.8 in) long. { of Flow shown
 in heavy lines.

COMPARISON OF RESULTS OBTAINED WITH FLAGS AND STREAMERS OF DIFFERENT LENGTHS.



A. BALLOON TRAJECTORIES: NOV. 1929 TO MARCH 1930.
 WINDS 080° TO 098°: FORCES 2 TO 6. HEIGHTS UP TO 7,000 FEET ABOVE SEA.



B. NAVAL BALLOON TRAJECTORIES: FEB. TO MARCH 1929.
 WIND 090°: FORCES 2 TO 7. HEIGHTS UP TO 3,000 FEET ABOVE SEA.

Algerias

Limit of Model.

Cloud

Up Current

Level

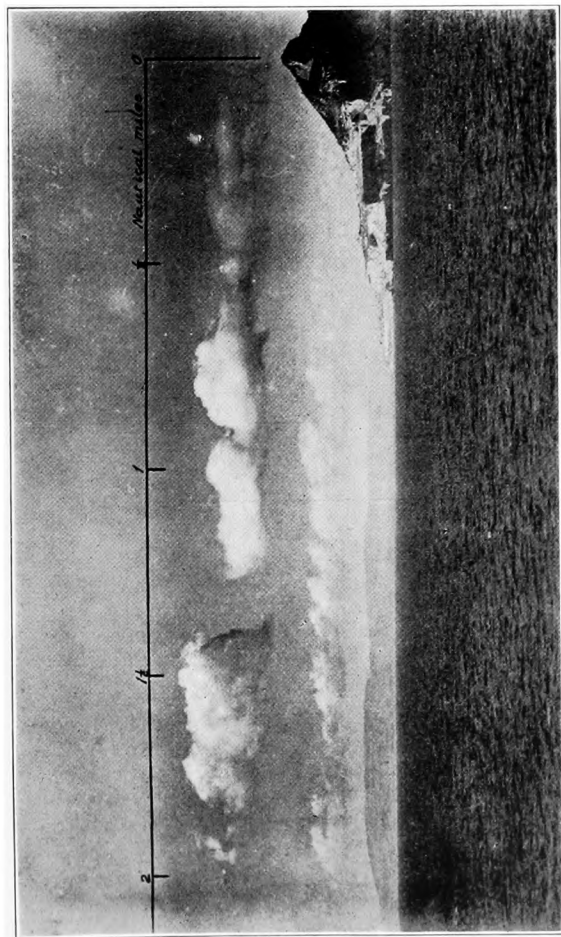
Down

Numerics indicate speed of current in 100's ft per min.

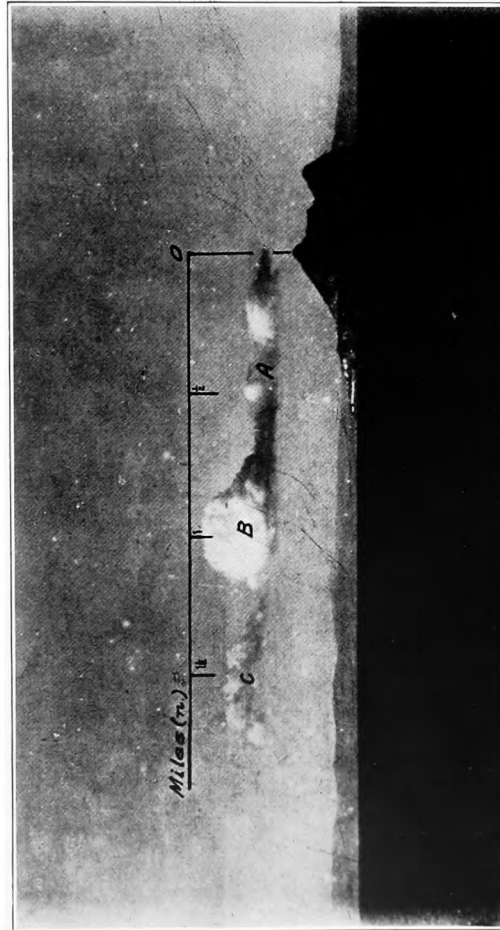
A map of the Mediterranean Sea with a grid. The vertical axis (latitude) is on the left, ranging from 0 to 16. The horizontal axis (longitude) is at the bottom, ranging from 28 to -4. The map shows the coastlines of North Africa and Europe. A shaded region on the right side of the map is labeled "Limit of Model." Various points and lines are marked: "GE" and "SEF" are in the upper left; "Algerias" is on the left coast; "C" is near the top right; "D_a" is below "C"; "A" is a point on a line segment; "J" is below "A"; "April" is to the left of "J"; "B" is on the line segment; "G" is below "J"; "K" is below "G"; "March 29" is to the left of "K"; "H" is at the bottom right; and "Limit of Model." is at the top right.

C.

THEODOLITE BASELINES AB, AC; AND OTHER POINTS REFERRED TO.



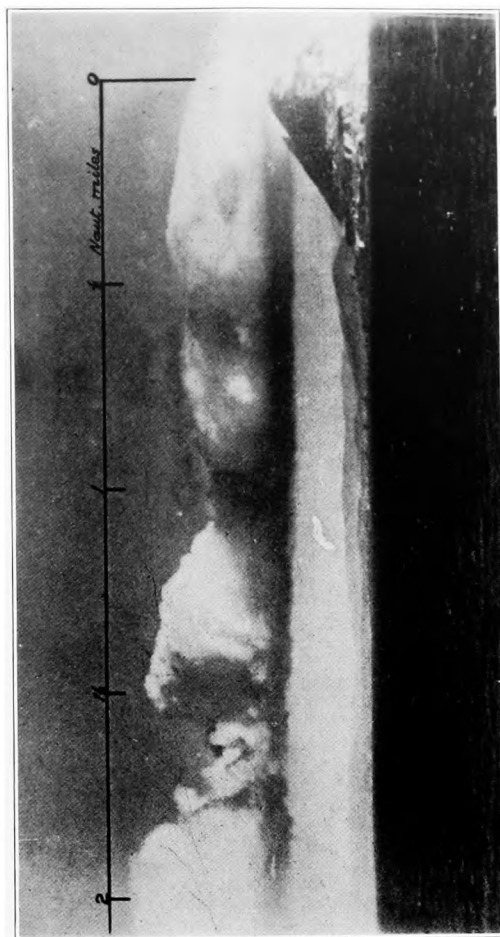
A. LEVANTER CLOUD 3 3.30 AT 15.15; WIND 21 KNOTS 075



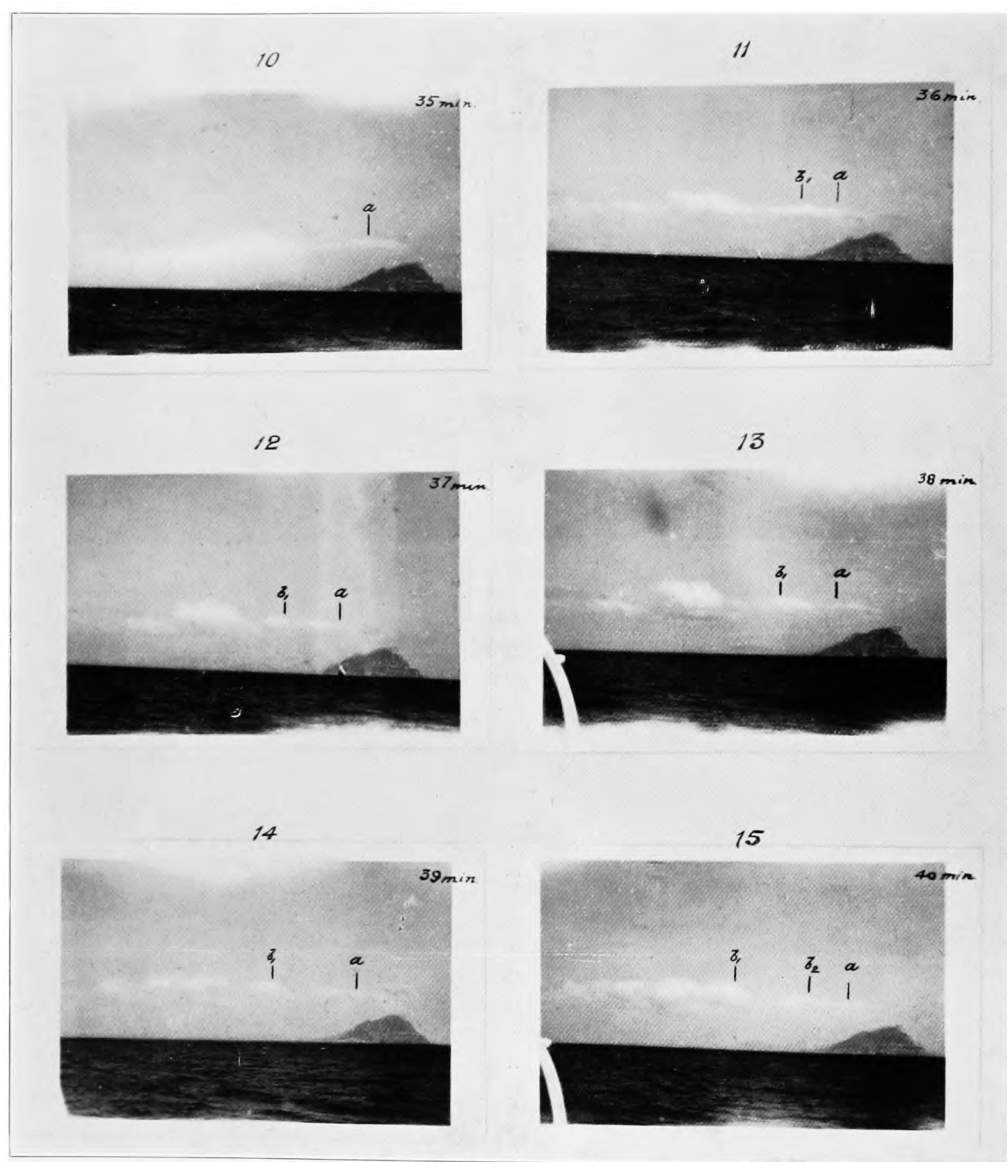
B. LEVANTER CLOUD 3 3.30 AT 16.45 WIND 21 KNOTS 075



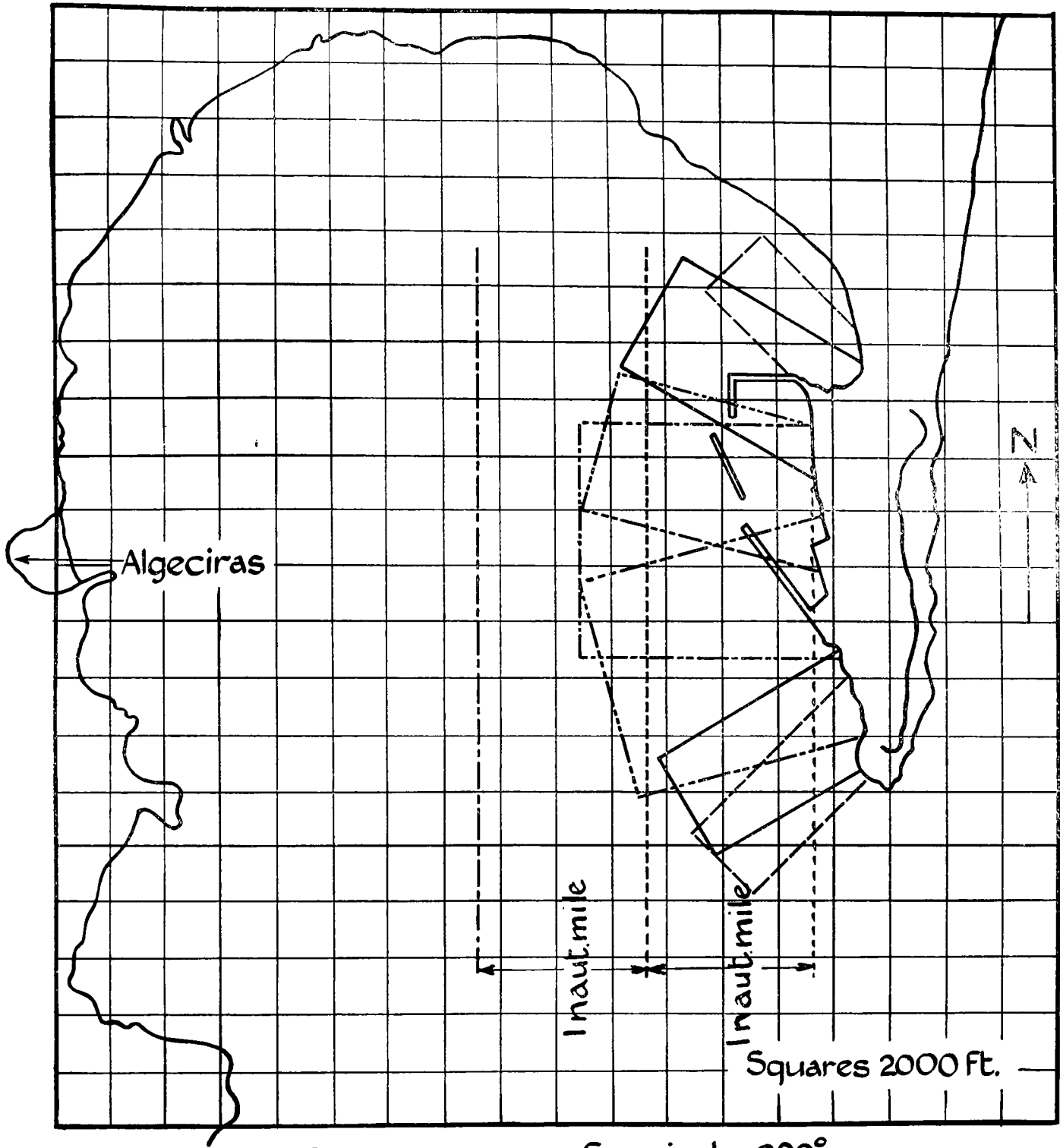
C. LEVANTER CLOUD 4 3.30 AT 07.40; WIND 24 KNOTS 074



D. LEVANTER CLOUD, WELL DEVELOPED 4 3.30 AT 07.45; WIND 24 KNOTS 074

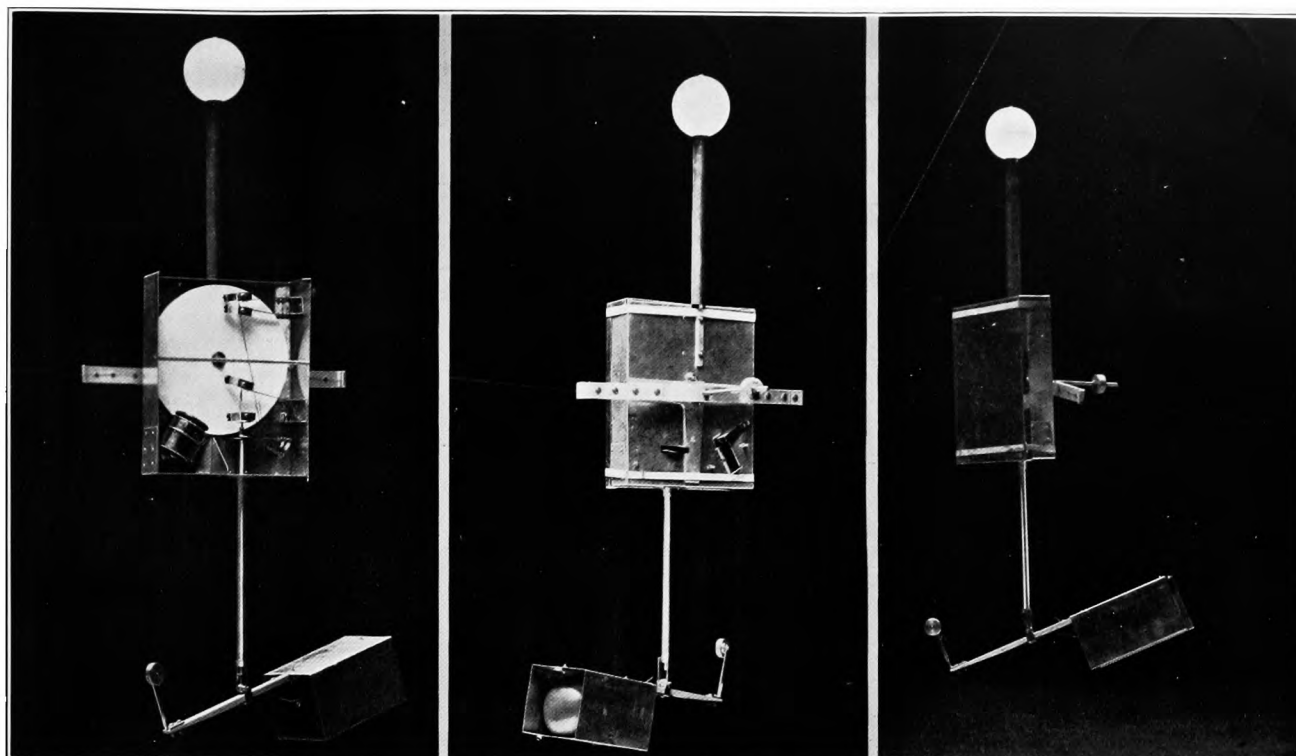


LEVANIER CLOUD AT 1 MINUTE INTERVALS, 1.4.1930 WIND 13 KNOTS.



- Danger Areas
- for wind 090°
 - for wind 075° and 105°
 - for wind 060° and 120°
 - for wind 045° and 125°

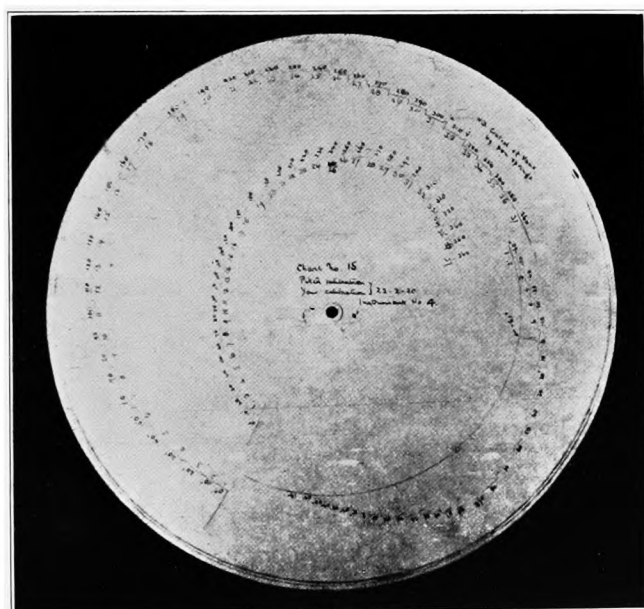
DANGER AREAS FOR WINDS FROM VARIOUS DIRECTIONS.



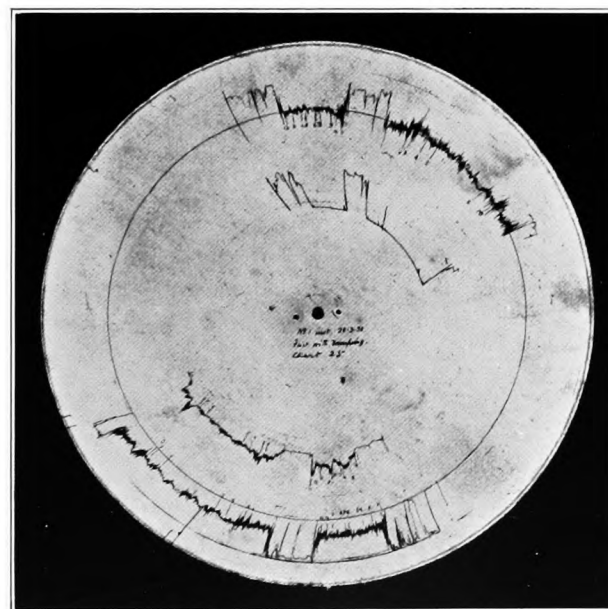
OPEN : FRONT VIEW.

RECORDING INSTRUMENT
CLOSED : BACK VIEW.

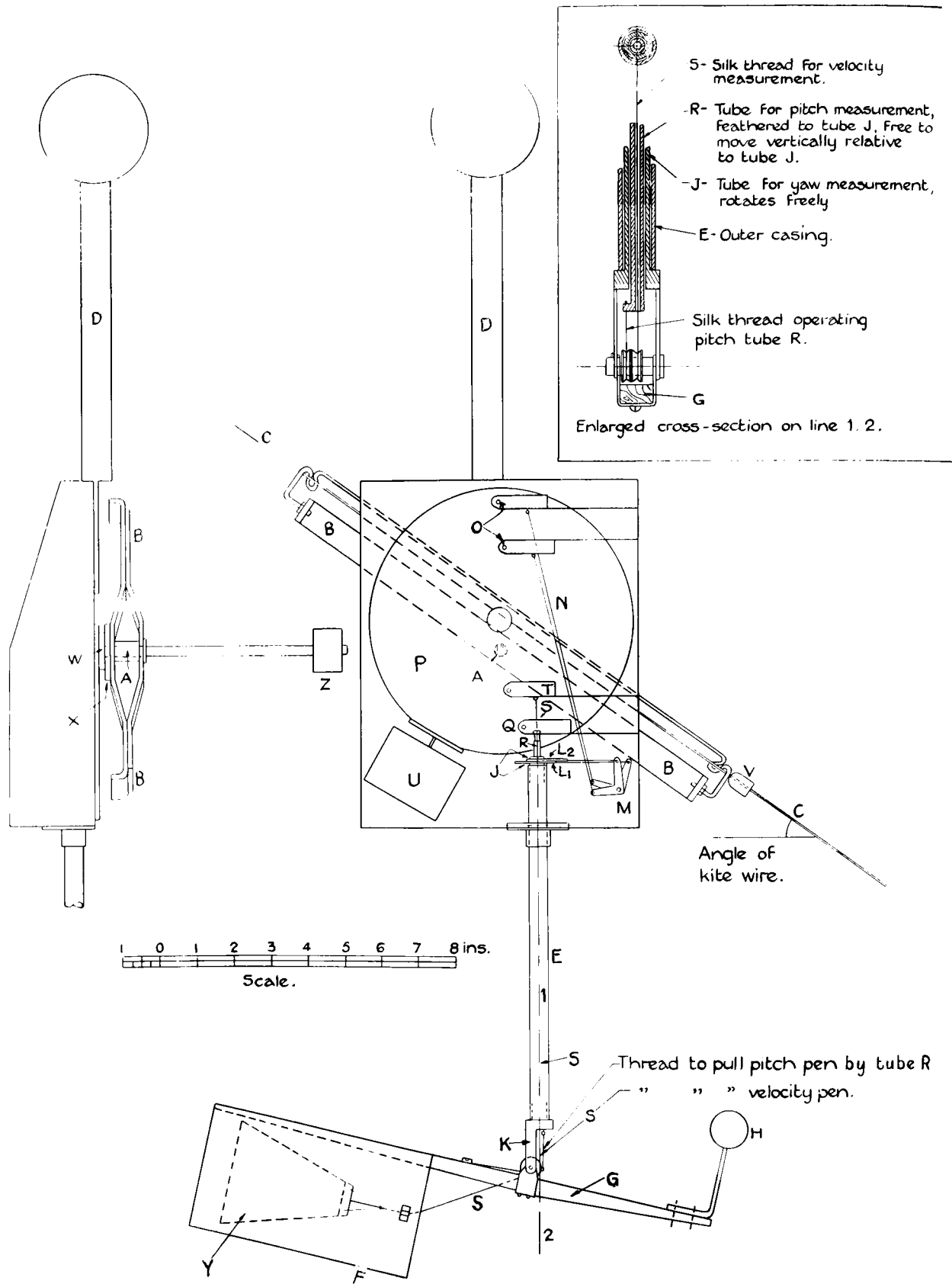
CLOSED : $\frac{1}{4}$ -SIDE VIEW.



CALIBRATION : PITCH AND TWO YAW RECORDS FOR WIND.
VELOCITY CALIBRATION OMITTED.



A KITE-FLOWN RECORD IN A WEST WIND OVER
GIBRALTAR BAY, WITH PITCH, VELOCITY AND TWO YAW TRACES



DIAGRAMMATIC ARRANGEMENT OF KITE RECORDING INSTRUMENT.

