INVESTIGATION OF THE CANDLESTICK PARK WIND PROBLEM

Volume III

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and

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August 31, 1963

CER63JEC41

TECHNICAL REPORT

No. TR 102

31 August 1963

INVESTIGATION OF THE CANDLESTICK PARK WIND PROBLEM

Volume III

Conclusions, Recommendations
and Summary of Investigation

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ACKNOWLEDGEMENTS

Assistance provided by the offices of Director of Public Works and the City Engineer throughout the investigation has been most helpful and is gratefully acknowledged.

Numerous voluntary suggestions for solving the Candlestick Park wind problem have been received from private individuals not associated with the investigation. Each suggestion has been carefully considered and, where promising, has been included in the test program. Our sincere appreciation and thanks goes to all those persons who took the time and effort to submit their ideas for solving a complex problem.

ABSTRACT

The overall purpose of this investigation is to determine whether or not there are practical methods for controlling the afternoon winds at Candlestick Park in order to alleviate the unsatisfactory wind conditions which now exist.

Field observations have shown that two characteristic and distinctive wind flow patterns exist within the stadium. Each results from the interaction of Bay View Hill on the unidirectional air flow approaching the stadium complex.

These wind conditions have been reproduced in a 1:768 scale model of the Bay View Hill-stadium complex, demonstrating that the wind-flow patterns observed in the model are directly correlated with those in the stadium complex, i.e. the prototype. Accordingly, changes in the wind-flow patterns resulting from modifications in the model can be evaluated in terms of corresponding modifications in the prototype.

Approximately 150 different model-wind flow situations have been examined. From the results obtained it is evident that elimination of the objectionable features of the existing flow patterns, and a general reduction in wind speed within the stadium, can be achieved if <u>both</u> Bay View Hill and the stadium are modified as follows:

<u>Bay View Hill</u> - Cut a slot through the south end of the hill tangent to the left-field edge of the stands or, remove the southerly portion of the hill.

<u>Stadium</u> - Partially cover the stadium with a protective dome extending beyond the infield, or erect a vertical screen on top of the rim between 50 and 100 feet high, or install vanes on top of the rim to deflect the wind vertically.

Modifications which are not effective singly or in combination include:

Complete removal or reduction in elevation of Bay View Hill; partial or complete extension of the upper stands around the outfield; addition of solid, porous or deflecting barriers on Bay View Hill or across left field or completely around the outfield.

CONTENTS

CONTENTS (continued)

LIST OF FIGURES

PURPOSE AND OBJECTIVE OF THE INVESTIGATION

The purpose of this investigation is to determine what practical measures can be taken to alleviate the unsatisfactory wind conditions in Candlestick Park short of covering the entire stadium. Engineering concepts rather than design details are investigated with engineering feasibility rather than economic and aesthetic factors being given first consideration.

Because the unfavorable winds in the ballpark are a direct result of the strong westerly diurnal flow of marine air into the Bay Area, the first objective of the investigation was to define by field measurements the unknown circulation patterns within the ballpark originating from the westerly wind. The second objective was to determine through use of a wind-tunnel model of Bay View Hill and Candlestick Park the effectiveness of various terrain and structural modifications in reducing the wind speed or changing the existing circulation patterns within Candlestick Park. An essential part of the latter objective was the delineation of those modifications which are ineffective so that they can be eliminated from further consideration.

Results of the investigation are presented in three volumes and a seven-reel motion picture. Volume I is a detailed report of the prototype wind studies, Volume II is a detailed account of the wind-tunnel model study, Volume III presents the conclusions and recommendations together with a non-technical summary of the investigation. The motion picture shows prototype wind flow patterns and model performance for each of the 150 combinations of configurations and wind directions studied.

CONCLUSIONS

The following major conclusions apply to the afternoon wind conditions at Candlestick Park during the period April through September.

1. Two characteristic and distinctive wind flow patterns exist within the stadium. These are identified as Left-Field Control and Southerly Control. Left-Field Control occurs more frequently than Southerly Control; one or the other predominates during a given afternoon. Approximately 70 percent of the windy periods are accounted for by these two flow patterns; over 90% are accounted for if minor variations in the two patterns are included.

2. The predominant flow approaching the stadium--Bay View Hill complex is essentially constant in direction and varies within narrow limits. The two characteristic wind flow patterns within the stadium result from the diversion of the unidirectional flow by Bay View Hill.

3. Only those conditions arising from the unidirectional westerly wind need to be considered from the standpoint of wind control within the stadium. Conditions arising from other wind directions occur too infrequently to be of importance.

4. Existing wind-flow patterns in the stadium--Bay View Hill complex and within the stadium itself can be reproduced in a scale model with a high degree of reliability. Accordingly, the effectiveness of various model modifications for wind control can be considered representative of equivalent modifications made in the prototype. Thus, potential changes in the stadium and/or Bay View Hill can be evaluated in terms of their effect on the wind flow patterns.

5. Existing disagreeable wind conditions can be alleviated to a large degree by certain modifications in the stadium and Bay View Hill if taken together. Modification of the stadium alone is not sufficient. The most favorable combinations of modifications in decreasing order of effectiveness with respect to stadium additions are the following:

Hill	Stadium (See Fig. 13)
Cut through south end of hill down to parking lot level with axis parallel to left-field edge of stadium. (See Fig. 12)	a. Partial dome over ballpark
or	b. Vertical porous screen around edge of upper rim.
Removal of south end of hill down to parking lot level. (See Fig. 11)	c. Deflector vanes on top of upper rim.

The hill modifications listed above eliminate the Left-Field Control flow so that the resulting flow is of the Southerly Control type. Furthermore, some reduction in wind speed within the stadium is achieved through either of the hill modifications with the cut being somewhat more effective than the south end removal. Hence, hill modification alone may be considered a partial solution to the wind problem.

7. Completion of excavation on the slopes of Bay View Hill in accordance with present plans will not change the existing wind conditions in and around the stadium.

6. The following categories of modifications taken singly or in combination show either marginal improvement or no improvement. In some instances the resulting wind conditions are less favorable than at present.

a) Complete removal of Bay View Hill.

b) Removal of the north end of Bay View Hill.

c) Removal of the upper portion of Bay View Hill to the 188.6-ft contour level.

d) Addition of upper stands for partial or complete encirclement of the ballpark.

e) Addition of solid, porous or deflecting type barriers across the left-field opening or an extension of these barriers to enclose the entire ballpark.

f) Addition of deflecting barriers on Bay View Hill.

RECOMMENDATIONS

If steps are to be taken to control the wind problem at Candlestick Park it is recommended that:

1. Addition of a partial dome and modification of the southerly end of the hill should be given first consideration as a remedy for the wind problem. This solution gives the best reduction of wind speed and gustiness.

2. In the event that the construction of a partial dome is not economically feasible, consideration should be given equally to the addition of vanes or a vertical screen on the stadium rim in conjunction with the modification of the south end of the hill.

3. A wind control program based on the previous recommendations should proceed in two steps: first, modify Bay View Hill; second, complete the additions to the stadium.

4. Before architectural engineering plans are developed for the above modifications, detailed model studies should be completed to establish the optimum configuration of the stadium addition as well as the most effective grading plan for the changes in Bay View Hill.

5. Based on the extensive tests completed thus far, wind control plans cannot be recommended where such plans depend on:

   a) Use of barriers across the left field opening or around the entire outfield.

   b) An extension of the upper stands for either a partial or total enclosure of the stadium.

   c) Use of barriers or other type deflectors on Bay View Hill.

   d) Use of blowers to create a deflecting air stream.

   e) Complete removal of Bay View Hill.

   f) Removal of upper portion or northerly end of Bay View Hill.

SUMMARY OF INVESTIGATION

I. BACKGROUND

The present investigation was initiated 27 March 1962 under Order No. DPW 60596 between the Department of Public Works, City of San Francisco and Metronics Associates, Inc., Palo Alto, California. Mr. Reuben H. Owens, Director of Public Works, represented the City of San Francisco; Dr. W. A. Perkins, Metronics Associates, was Program Director. On the same date a subcontract was established between Metronics and Colorado State University Research Foundation for the wind tunnel and modeling phase of the program to be conducted in the Fluid Dynamics and Diffusion Laboratory under the direction of Professor J. E. Cermak.

Initially a one-year program was contemplated. However, because of the need for additional work and the desirability for testing control measures not originally planned, the investigation was extended five months without additional funds.

II. TECHNICAL APPROACH

A. Basic Considerations

An overall technical approach to this investigation was developed in 1961 based on the following considerations:

1) The wind at Candlestick Park is controlled by a generally westerly flow but its exact direction over the stadium complex (including Bay View Hill) was not known.

2) Wind-flow patterns in and around the stadium were not known but were thought to be strongly dependent on the mean direction of the free air flow across the complex. A slight shift from north of west to south of west would cause a major change in the relative amount of air flowing toward the stadium along the northeast and southwest sides of Bay View Hill and as a consequence cause major changes in the circulation patterns within the stadium.

3) The effectiveness of potential wind-control techniques could be determined only from appropriate measurements made on a scale model of the stadium complex in a low-speed wind tunnel. Thus, modifications in both the stadium and upwind terrain, particularly Bay View Hill, could be made on a scale model and their effects on the wind flow could be measured.

4) In order to be certain that the model results would be meaningful in terms of equivalent behavior in the prototype (stadium) it was essential to demonstrate that existing flow conditions in and around the stadium were duplicated in the model. The importance of this correlation cannot be over-emphasized.

In accordance with the above considerations the investigation was divided into two major parts namely the Prototype Study and Model Study. The major phases of each study are summarized briefly below. As the investigation proceeded it became evident that the basic considerations were correct and no change in the overall technical approach was required throughout the program.

B. Prototype Study

1. Meteorological Reference Measurements

Wind speed and direction were recorded continuously throughout the baseball season with research type equipment located on the McLaren Tank one and one-half miles west of Bay View Hill. These measurements showed the speed and direction of the air moving toward the stadium complex and were supported by periodic measurements taken on Bay View Hill itself. The free air flow observations served three purposes: a) to provide a reference direction for correlation with the circulation measurements taken in and around the stadium at selected times; b) to provide a correlation with climatic records in order to relate the current season with long term averages; and c) to provide reference directions for use in the model study.

Wind speed and direction were also recorded continuously on the stadium scoreboard throughout most of the 1962 season. These records were used primarily to establish the frequency of occurrence of specific circulation patterns in and around the stadium.

2. Circulation Patterns

Detailed measurements of the wind circulation patterns in and around the stadium, including the parking lot and portions of Bay View Hill were made on 12 selected days. The circulation patterns were based on the following types of observation:

a) Wind speed and direction with portable equipment.

b) Wind direction from cloth streamers at fixed locations (41 inside stadium; 25 in parking lot).

c) Wind direction from smoke plumes generated from continuous sources (6-8 minute duration) located at selected fixed positions inside and outside the stadium. Smoke plume behavior was recorded visually and with movies taken at two or more locations.

Normally, four or more hours of observation were taken each day to define the circulation patterns.

3. Collateral Data

Hourly wind speed and direction data were obtained from the U. S. Weather Bureau, Federal Office Building, San Francisco, for the 1962 baseball season and for the corresponding months for the past ten years. These records provide a correlation between downtown San Francisco and McLaren Tank data for the 1962 season and also a correlation between the 1962 season and previous years at the Federal Office Building. Supplementary records from Pacific Gas and Electric Company have also been examined.

Systematic reports were received from spectators attending afternoon games during the 1962 season. These reports included observations of wind speed and direction during the game as well as comments on general conditions and degree of discomfort from the spectators point of view.

Interviews were held with Mr. Alvin Dark, Giants Manager, and with several of the players with regard to the wind problem. The interviews were held with single individuals and with groups in order to estimate the uniformity of reactions and the strength of individual convictions.

C. Model Study

1. General

All model studies were conducted in a low speed recirculating wind tunnel with a test section 6 x 6 x 30 feet using wind speeds 18 to 30 mph. For most of the observations a 1:768 model was used which included the stadium, parking lot and all of Bay View Hill, as shown in Figs. 1 and 8. On this scale the stadium is approximately one foot across and the entire model is 6 x 6 feet. A 1:384 model of the stadium without Bay View Hill was used for those measurements requiring greater stadium detail and also to verify that the results obtained were independent of the scale used. Both models were mounted on a rotating platform in the tunnel floor in order to study the effect of wind direction.

Basic wind directions of 16° and 31° south of west were selected for the model study because the flows at these directions were characteristic of the observed prototype flows.

2. Similarity Considerations

Because of the sharp topographic and structural features of the local terrain and stadium, mean-wind patterns are determined primarily by the surface geometry. Thus, similarity of mean-flow patterns should result if the surface geometry is similar for model and prototype. Accordingly an undistorted scale model was used at air speeds having the same order-of-magnitude as speeds in the prototype being employed. A check of flow patterns in the stadium for the 1:384 and 1:768 scale models showed them to be similar as expected.

With the flow in the model being governed only by a characteristic length L_m and a characteristic wind speed U_m, the frequency of wind gusts in the model f_m is related to gust frequency in the prototype f_p as follows:

$$f_m = \frac{L_p}{L_m} \frac{U_m}{U_p} f_p$$

Therefore, using a scale of 1:768 and wind speeds nearly the same in model and prototype, gust frequencies in the model are about 800 times those of the prototype.

3. The Model

A scale of 1:768 was chosen to satisfy the need for including significant geometry (Bay View Hill) in a model limited by the wind-tunnel dimensions. The topography was constructed by cutting sheets of plywood to shapes determined from a contour map of the area. The sheets were stacked in proper order and the steps between successive sheets were smoothed with plaster of paris. This provided a basic model which could be cut easily to give the desired modifications. The stadium was modeled in essential detail from sheet metal and plaster. A black flat paint was applied to the surface to facilitate photography. The 1:384 scale model of the stadium used to check scale effects was constructed in a similar manner.

4. Measurement Techniques

Overall mean-flow patterns were determined primarily by attaching pieces of yarn pivoted on pins to the surface of the model. The direction of the yarn was recorded by motion-picture photography. Local mean wind speeds at four reference points in the stadium were obtained with a hot-wire anemometer. A reference air speed was measured above the model at a height where the flow was not influenced by the model.

Smoke was released from several locations and photographed to aid in comparing model flow patterns with prototype flows observed with smoke releases.

III. SUMMARY OF RESULTS

A. Prototype Study

1. Air Flow Approaching Stadium Complex

Results obtained at the McLaren Tank meteorological reference station clearly show that the air approaching the stadium complex is remarkably uniform in direction during the afternoon hours throughout the baseball season. These results are summarized in Fig. 2 in terms of the median (50%-ile) direction and range of directions based on half-hourly averages between 1300 and 1800 hours PDT. The median direction and direction of maximum frequency are equivalent for practical purposes. As shown, the direction range for each month includes 90% of all cases, i.e. the 5%-ile to 95%-ile limits. The following points may be noted in connection with these results.

i) From April to June the directions shift slightly into the south but remain essentially constant for the balance of the season. Thus, the predominant or median direction changes from 4° south of west early in the season to 21° south of west.

ii) The 90% range in April and May is approximately ± 22° and is less than half this value in the following months.

iii) Both the wider range and more westerly direction in April and May are the consequence of frontal passages. During the later months the wind flow is less affected by frontal activity and is controlled primarily by the diurnal marine flow into the Bay Area.

iv) The McLaren Tank wind speeds exceeded 15 mph during the afternoon hours over 85% of the time; hence, as expected, the uniform wind direction is associated with moderate to strong wind speeds.

v) The uniformity in direction is in accord with the U. S. Weather Bureau data (Federal Office Building); the monthly ranges cannot be compared directly because of differences in measurement techniques.

2. Circulation Patterns

a. Effect of Bay View Hill

Although the flow of air approaching Bay View Hill as well as the general flow above the hill is essentially unidirectional, there is a well defined separation in flow at low levels. Figure 3 shows the characteristic flow distribution around Bay View Hill. Its major features are as follows:

i) The main axis of the highest portion of Bay View Hill ridge is oriented 20° north of west, hence the predominant flow approaches the hill at approximately 40° south of the main axis.

ii) Along the southwest flank of the hill the flow is directed upward and is carried over the top of the ridge in approximately the same direction as the flow aloft. Flow around the southerly end of the ridge is diverted slightly more south of west than the main flow.

iii) At the northerly end of the ridge, the air is diverted and a well defined flow is directed toward the left field opening in the stadium. This flow is relatively shallow and does not extend above the ridge line. Its speed is comparable to that of the air approaching the hill.

iv) Between the stadium and the hill the flow is parallel to the hillside, i.e. along Jamestown Avenue. The speed in this area is relatively low. As expected, a semi-stationary vertical eddy persists in this region.

Insofar as the conditions within the stadium are concerned, the significant effect of Bay View Hill is to produce two potentially controlling wind directions across the stadium. One is from the diverted flow originating at the northerly end of the hill. The other is from the flow carried around the southerly end of the hill and approaches the stadium from approximately 30° south of west. Although the position of the stadium is in line with the approximate wind shadow of the hill, it is far enough removed to be in one or the other of the two flows around the hill.

b. Circulation within the stadium

Two characteristic and distinctive circulation patterns develop within the stadium at wind speeds (measured on the scoreboard) greater than 10 mph. One results from the flow of air along the northeast side of Bay View Hill which enters the stadium through the left field opening and is referred to as Left-Field Control. The other pattern is associated with air entering the stadium from around the southerly end of Bay View Hill and is referred to as Southerly Control. These two circulation patterns are described briefly below.

Left-Field Control. The flow pattern associated with Left-Field Control is shown schematically in Figs. 4 and 5. Air enters the stadium north of section 32 (upper stands) and diverges into two principal streams identified as A and B in Fig. 4. Stream A produces the persistent strong flow from left to right field. Stream B, approximately parallel to the third base line, continues across the playing field, is carried upward on reaching the stands and leaves the stadium over the rim between sections 5 and 13 (upper stands). Stream B is responsible for local circulation within the stands as follows:

i) Strong and persistent vortices are formed at the north end of the upper stands covering sections 26 to 32.

ii) Stream B is split on reaching the stands beyond home plate. A steady but relatively low speed flow extends from section 5 to section 18 (lower stands) in the area beneath the upper stands. Between sections 11 and 23 (lower stands) the flow from B is directed toward section 23 parallel to the rows of seats. However, this flow is intermittent and occasionally interrupts the main flow in this area coming directly from the field. Characteristic direction changes are indicated in Fig. 4 for section 23 (lower stands).

iii) In the upper stands the flow is clockwise under the rim with decreasing speed toward section 20.

iv) At the bottom of section 1 (upper stands), the speed is high and the direction alternates rapidly through 180°. The direct flow from stream B shifts the direction toward section 3; the reflected flow shifts the direction toward section 2.

v) At the right field end of the upper stands the speed is high and the direction changes in a similar manner to that in section 23 lower stands.

vi) At elevations varying from 50 to 200 feet above the stadium rim behind home plate, air flows toward the outfield; normally this air remains separate from the flow within the stadium.

<u>Southerly Control</u>. The flow pattern is shown schematically in Figs. 6 and 7. Air enters the stadium over the rim between sections 4 and 10 and flows downward over the stands contacting the field between the stands and home plate when the wind speed exceeds 20 mph. At lower speeds the line of contact moves out toward second base. Large-scale vertical eddies in the downward flow carry part of the incoming air back into the upper and lower stands.

After contacting the field the flow is toward the outfield and is divergent. At high wind speeds this outward flow has its maximum speed in the lowest 100 feet.

In the far left field and right field stands the flow is parallel to the rows of seats and is directed toward the ends of the stands. Speeds are greatest near the outfield ends particularly in the right field upper stands.

Certain general remarks can be made regarding these two flow patterns.

i) During any afternoon one or the other of these two patterns predominates. It is unusual to find both on the same day.

ii) Left-Field Control occurs more frequently than Southerly Control. During July, August and September 1962, the percentage occurrence of these two patterns during the afternoon is as follows (scoreboard wind speeds greater than 10 mph):

Left-Field Control	48%
Southerly Control	20%
Intermediate	19%
Other	13%

The intermediate condition is similar to Southerly Control except that the air enters the stadium over the rim north of section 10 (upper stands). The resulting flow pattern is comparable to but less well defined than for Southerly Control. In approximately 13% of cases, air enters the stadium from the northwest but generally at speeds between 10 and 15 mph. The resulting patterns are similar to those for Left-Field Control.

iii) Although the maximum wind speed (43 mph) was associated with Left-Field Control, strong winds (greater than 25 mph) occur with both Left-Field and Southerly Control.

iv) The schematic diagrams (Figs 4-7) indicate the average pattern for the two flow conditions. Flow conditions are not necessarily constant throughout a given afternoon and may vary about the average as drawn.

v) Data from spectator reports confirm the existence of the two circulation patterns although none of the spectators recognized that an organized and persistent flow pattern was present. Spectator discomfort during the afternoons was not limited to a specific flow pattern nor to a specific wind condition but discomfort was greater at higher wind speeds. Wind variability, i.e. gustiness, was secondary to the unpleasantness associated with wind speeds in excess of 18-20 mph.

vi) From the interviews with players and others regularly at the stadium, it is evident that certain features of the flow patterns are recognized but not the complete circulation pattern for the two types of control. Apart from the general objection to strong winds and the chilling which results, three specific flow features are particularly troublesome to the players. These are the strong flow along third base line toward home plate, the cross flow from left to right field and the strong flow toward the outfield resulting from Southerly Control.

vii) Based on the above considerations specific objectives for suitable wind control measures include: reduction of wind speed within the stadium by a factor of two; reduction or elimination of the third base flow and left to right field flow; elimination of the downward flow from rim to field under Southerly Control conditions. Obviously the control method should not introduce equally unsatisfactory conditions from another direction.

3. Wind Speeds Within the Stadium

Wind speed measurements taken at the scoreboard show the following percentage distribution of wind speeds during the afternoons from 1300 to 1800 hours PDT. All speeds are based on 30-minute averages.

Wind speed range (mph)	Percent of occurence
10 or less	16.9
11 - 15	29.2
16 - 20	23.3
21 - 25	17.8
26 - 30	9.1
31 - 35	2.7
36 - 40	0.8
greater than 40	0.2

B. Model Study

1. Correlation with Prototype

a. Bay View Hill flow pattern

Measurements obtained on the 1:768 model are in excellent agreement with prototype observations both in the overall flow pattern and its essential details.

Model tests included wind speeds from 10-30 mph and directions from 16° to 31° south of west. A typical comparison between model and prototype observations is shown in Fig. 8 for conditions corresponding to Left-Field Control.

Surface streamlines clearly show the flow separation at the northerly end of Bay View Hill and the strong flow along the northeast side of the hill which enters the stadium at left field. Flow around the southerly end of the hill is also present and becomes more pronounced at an angular orientation corresponding to 30° south of west. Local turbulence with large vertical eddies is found between the stadium and Bay View Hill. Smoke released in the wind tunnel shows that the flow over the ridge line corresponds closely to that observed in the prototype. These and other aspects of the Bay View Hill flow pattern described in section III A. were reproduced in the 1:768 model and were not significantly different over the wind speed range of interest.

b. Model-prototype wind correlation within the stadium

Streamers were placed at various locations on the playing field and stands in both the model and prototype. Figure 9 shows the average direction of these streamers on the playing field and lower stands for the typical Left-Field Control flow (mean wind W16°S in model). Comparison of the wind directions for model and prototype as indicated by the arrows reveals excellent correlation in the general circulation pattern. Local differences in direction for the streamers between home plate and the stands is not significant because the extreme variability of winds in this region make the directions indicated somewhat uncertain.

Figure 10 illustrates the ballpark flow pattern for the case of the Southerly Control flow (mean wind W31°S in model). Again there is excellent agreement between the model and prototype flows. Some differences appear to exist in the infield, but these are again judged to be insignificant because of the extreme variability of winds in this region.

Excellent model-prototype agreement for both types of flow, Left-Field and Southerly, was observed in the upper stands of the stadium in terms of the overall patterns as well as the detailed characteristics of the pattern. For example, the 180° reversal in direction noted at the bottom of section 1 in the stadium appeared in the model. Further, the reversal frequency in the model at this location was a fraction of a second and approximately that expected based on the scale factor used.

2. Model Modifications

a. Specific objectives of modifications

With the establishment of model-prototype flow similarity for both characteristic flow types, a series of modifications of Bay View Hill and/or the stadium could proceed with confidence that the resulting wind patterns observed in the model would be representative of potential prototype winds. Motivation for some of the modifications studied in the model resulted from ad hoc suggestions made by various people to the City of San Francisco and by various individuals working on the study; however, most of the modifications studied were the result of a definite effort to accomplish three objectives. These objectives were to eliminate the strong flow from left to right field, the strong flow along third base line toward home plate under Left-Field Control and to prevent air from flowing downward from the stadium rim directly onto the playing field under Southerly Control. The modification plan also included an investigation of the effects of stadium and terrain changes which might be made in the future for reasons other than wind control. Thus, additions to the stands to increase seating capacity and partial and complete removal of Bay View Hill have been included in the program.

b. Summary of modifications

All of the modifications of Bay View Hill and/or stadium were studied with wind approaching the model from either W16°S or W31°S. Details of all the results cannot be given here but are discussed in Volume II of this Report. However, the following tabulation lists the types of modifications studied. The degree of success in achieving all of the objectives listed in the previous paragraph is indicated as good, fair, or poor depending on improvement in both Left Field and Southerly wind flow patterns and reduction in wind speed within the stadium.

SUMMARY OF MODIFICATION RESULTS

Bay View Hill Modifications	Stadium Modifications	Effect
1. Unmodified	a. Extension of upper stands to Secs. 34, 44 and complete enclosure.	Poor
	b. Addition of solid and porous screens around various portions of ballpark.	Poor
	c. Addition of porous screens around top of upper stands.	Poor*
	d. Addition of solid and porous screens on hill.	Poor
	e. Addition of turning vanes on top of rim for vertical deflection and vanes across left field opening for horizontal deflection.	Fair
	f. Addition of turning vanes on rim with and without extension of upper stands.	Poor
	g. Addition of partial dome over stadium extending beyond infield.	Fair*
2. Hill removed and graded to parking lot elevation	a. Unmodified	Poor
	b. Extension of upper stands to Secs. 34, 44 and complete enclosure.	Poor
	c. Addition of solid and porous screens around various portions of ballpark.	Poor
	d. Addition of porous screens around top of upper stand.	Poor
	e. Addition of turning vanes on top of rim for vertical deflection and vanes across left field opening for horizontal deflection.	Fair
	f. Addition of partial dome over stadium extending beyond infield.	Good
3. Hill slopes excavated to final stage of present grading plan	a. Unmodified	Poor**

* Good for Southerly Control conditions.
** No significant change in present wind conditions.

Bay View Hill Modifications	Stadium Modifications	Effect
4. Hill top excavated to 188.6' elevation.	a. Unmodified	Poor
5. South end excavated	a. Unmodified	Poor
	b. Addition of porous screens around top of upper stands.	Good
	c. Addition of partial dome over stadium extending beyond infield.	Good
6. Cut through south end of Hill - flat bottom	a. Unmodified	Poor
	b. Addition of porous screens around top of upper stands.	Good
	c. Addition of turning vanes on top of upper stands with and without extension of upper stands.	Fair
	d. Addition of partial dome over stadium extending beyond infield.	Good
7. Cut through south end of Hill - V-shape	a. Unmodified	Poor
	b. Addition of screens on top of upper stands.	Poor

3. Elimination of Left-Field Flow Characteristics

Of all the modifications studied, only excavation of the south end of the hill or making a cut through the south end of the hill as shown in Figs. 11 and 12 effectively eliminated Left-Field flow characteristics without introducing equally unsatisfactory conditions not subject to control. Both of these hill modifications allow a current of air to pass around the south end of the hill, intercept the current of air flowing toward the stadium along the northeast side of the hill and divert it away from the stadium. The interaction of the air streams shown in Figs. 11 and 12 prevents strong flow onto the playing field from the left-field side. In effect, these hill modifications eliminate Left-Field Control and introduce a persistent Southerly Control which can be reduced or eliminated by other means.

The possibility of using blowers to divert the air flow into left field has been investigated and does not appear feasible or practical. Apart from the formidable engineering problems involved, the power requirement is excessive.

4. Elimination of Southerly Flow Characteristics

Elimination of the downward flow from the rim to the playing field and a general reduction in wind speeds within the stadium associated with Southerly Control was attained by the modifications listed below and shown schematically in Fig. 13:

a. Addition of partial dome over the ballpark extending beyond the infield.

b. Addition of a 50-100 ft vertical porous screen round the top rim of the stadium.

c. Addition of vanes on the stadium rim to turn air upward upon passing over the rim.

The relative effectiveness of each stadium modification is indicated by its position in the above list--a partial dome was most effective in reducing air speeds and gustiness.

In addition to the above modifications for controlling the conditions inside the stadium, small wind barriers probably would be required to protect exterior walkways around the south end of the stadium. However this is a minor wind problem and can be corrected with simple structures.

5. Modifications for Optimum Solution to Wind Problem

The studies showed conclusively that in order to obtain a solution to wind problems produced by both the southerly and left-field flow regimes, a modification of both Bay View Hill and the stadium should be made. That is to say excavations on the southerly end of Bay View Hill should be accompanied by the addition of a dome or screens or vanes to the stadium.

Figures 11, 12 and 13 indicate the scope and overall nature of the modifications required to achieve effective wind control, but are not intended to show these modifications in their final form. For example, existing roads and stadium approaches would have to be considered in developing the exact grading plan for the south end of the hill in order to reach a proper compromise between cost, appearance and wind control effectiveness. Likewise, the suggested stadium additions are subject to similar compromise. In particular the dome as tested, based on a preliminary plan submitted by Mr. David Miller, is probably larger than necessary. In the preliminary plan the dome extends 192 feet beyond home plate. It appears likely that the dome would be almost as effective if it did not extend beyond second base (i.e. 128 feet from home plate) and covered only the portion of the stadium bounded by the upper stands. In this case an extension of the upper stands would not be necessary although a barrier might be required in back of sections 24 and 26 in the lower stands.

As pointed out above, the unfavorable conditions associated with Left-Field Control can be eliminated by a cut through Bay View Hill or by removing a portion of the south end of the hill. In general, the latter is somewhat less effective than the former if no stadium modifications are made. Since the hill modification is required for a complete solution to the wind problem and is a partial solution by itself, the logical first step toward alleviating the present conditions is to proceed with the hill modification first.

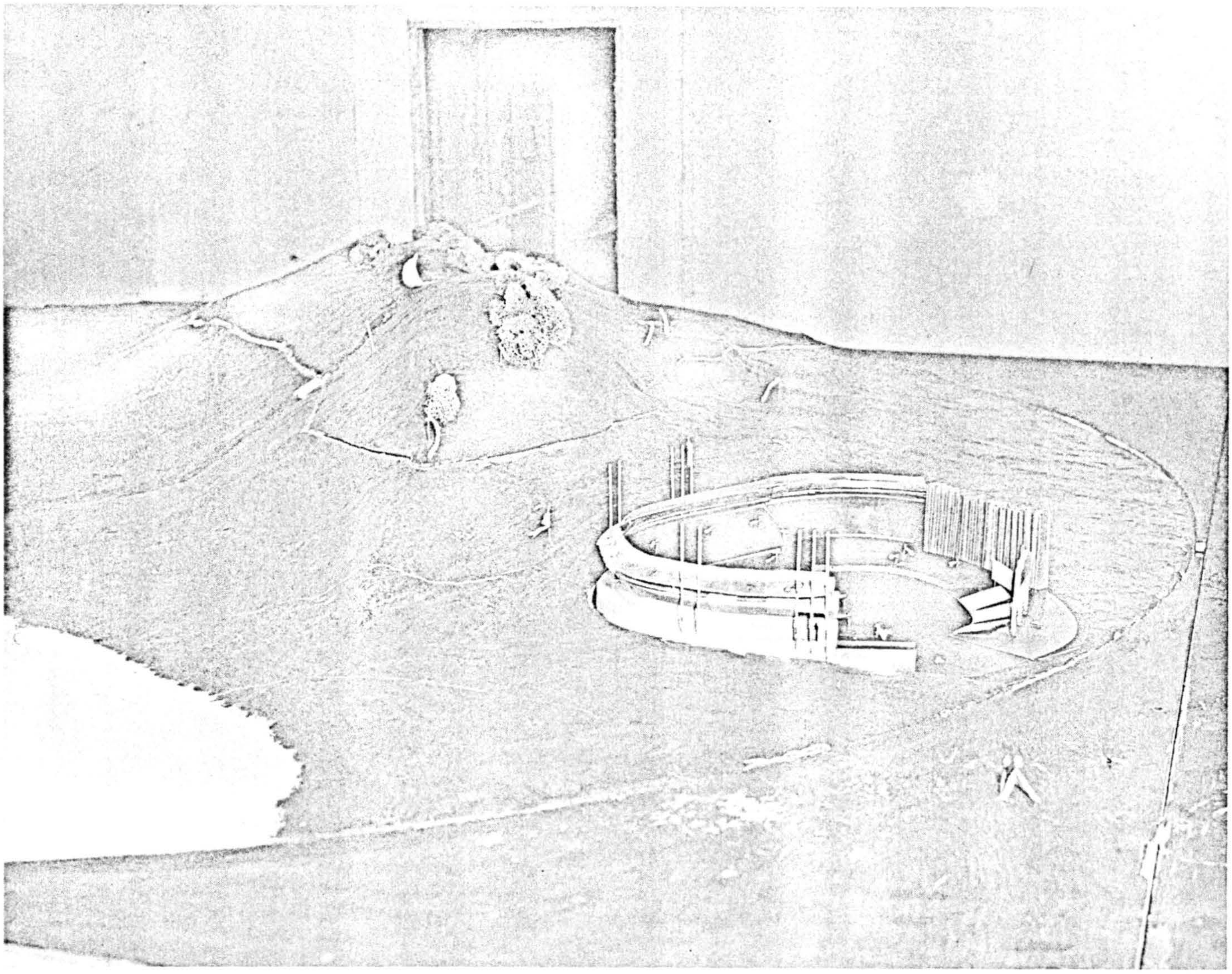


Fig. 1--Scale model of stadium and Bay View Hill placed in wind tunnel. The 1:768 model is shown with vanes attached to the rim for vertical deflection and vanes across the left field opening for horizontal deflection.

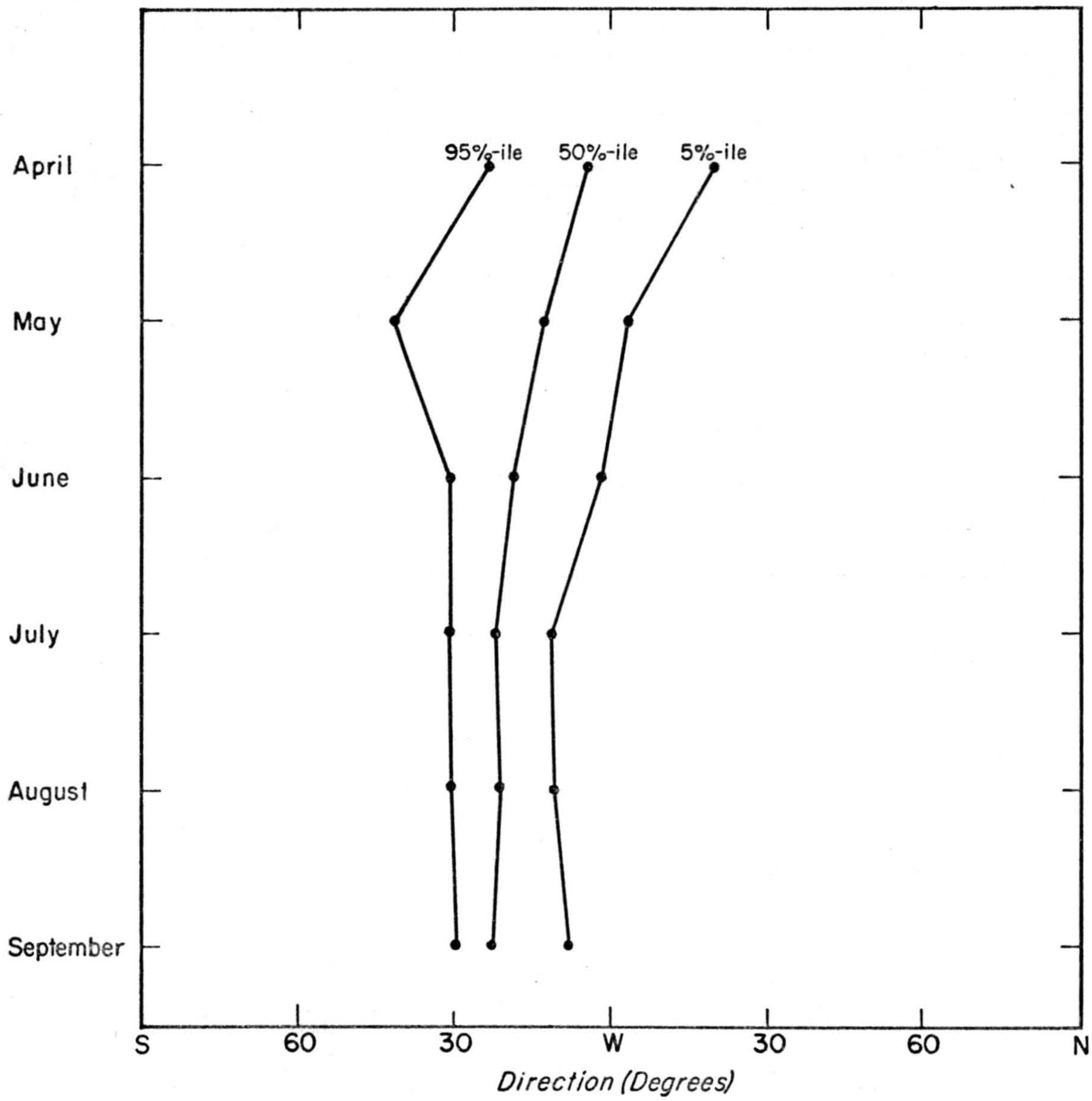


Fig. 2--Afternoon wind direction and direction range for air approaching Bay View Hill during the baseball season. Distribution of half-hourly average wind directions for each month between 1300 and 1800 hours PDT is given in terms of the median (50%-ile) and 90% limits. For example, the median direction during August was 21° south of west and 90% of the time the direction was between 11° and 30° south of west. Directions measured at McLaren Tank.

Fig. 3--Characteristic wind flow pattern around Bay View Hill based on field observations during the baseball season. Diversion of air below the ridge line at the northerly end of Bay View Hill produces a flow into left field and a characteristic circulation pattern within the stadium. A second characteristic pattern results from air reaching the stadium around the southerly end of the hill.

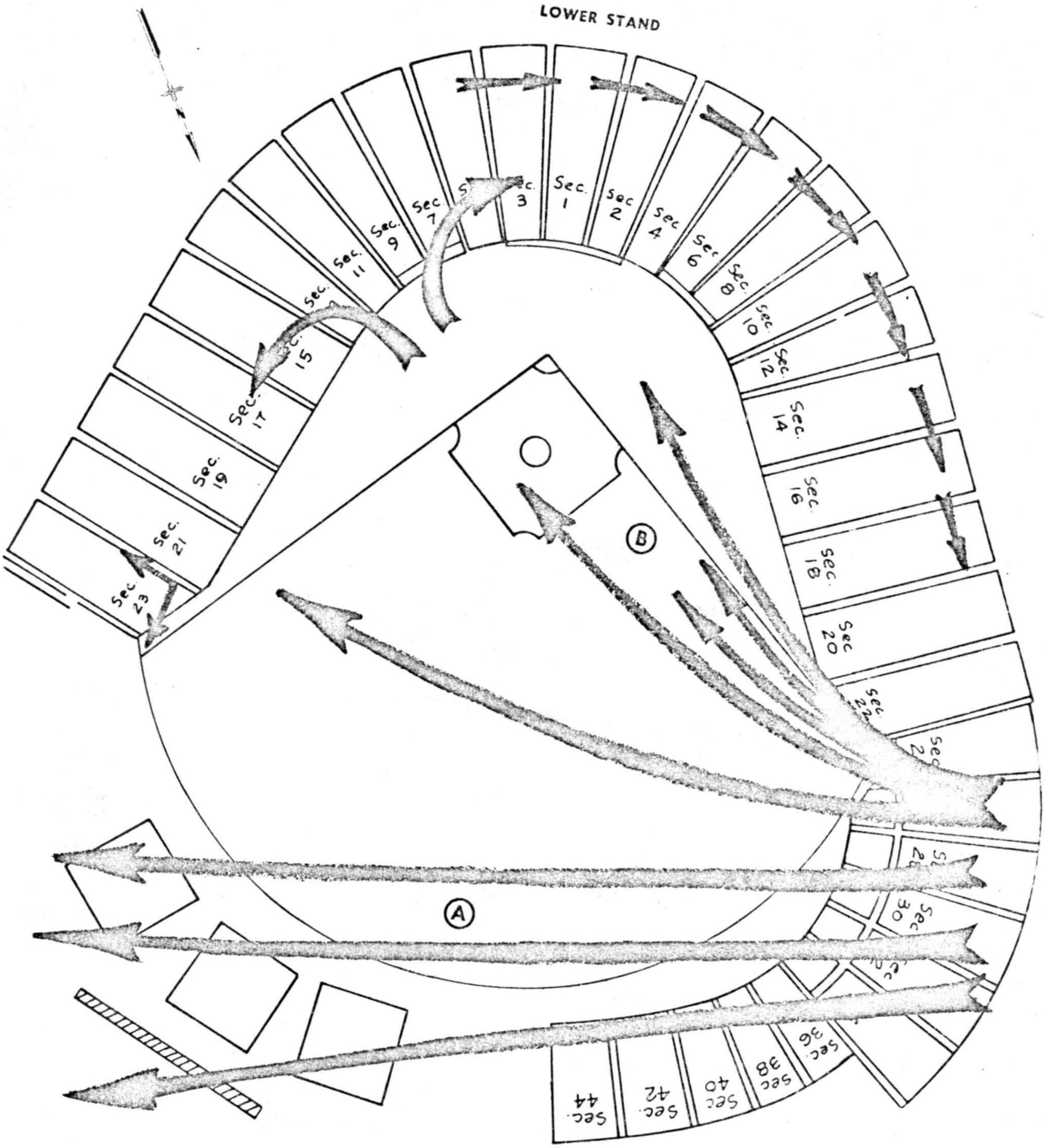


Fig. 4--Wind circulation pattern in the lower stands under Left-Field Control conditions.

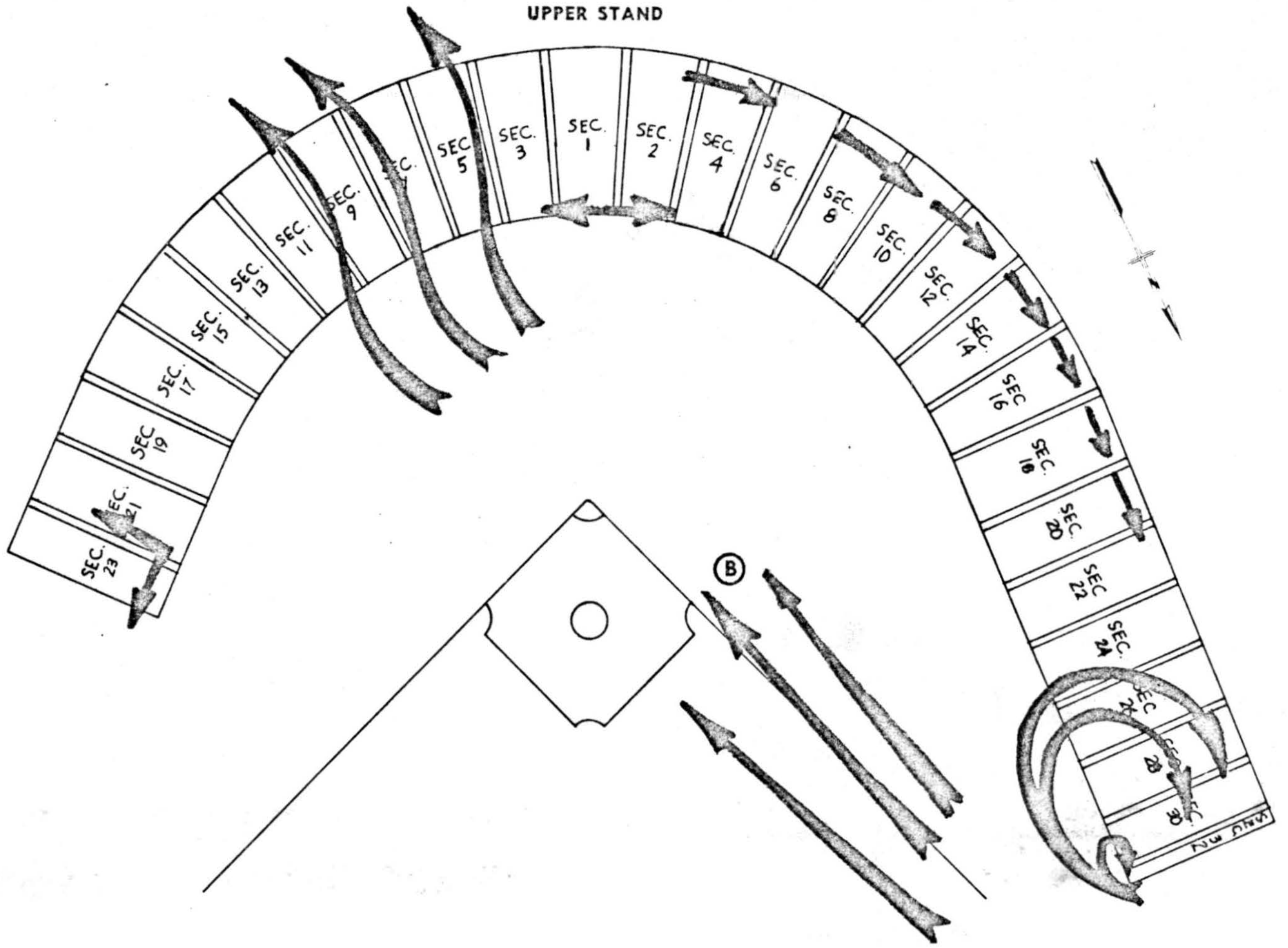


Fig. 5--Wind circulation pattern in the upper stands under Left-Field Control conditions.

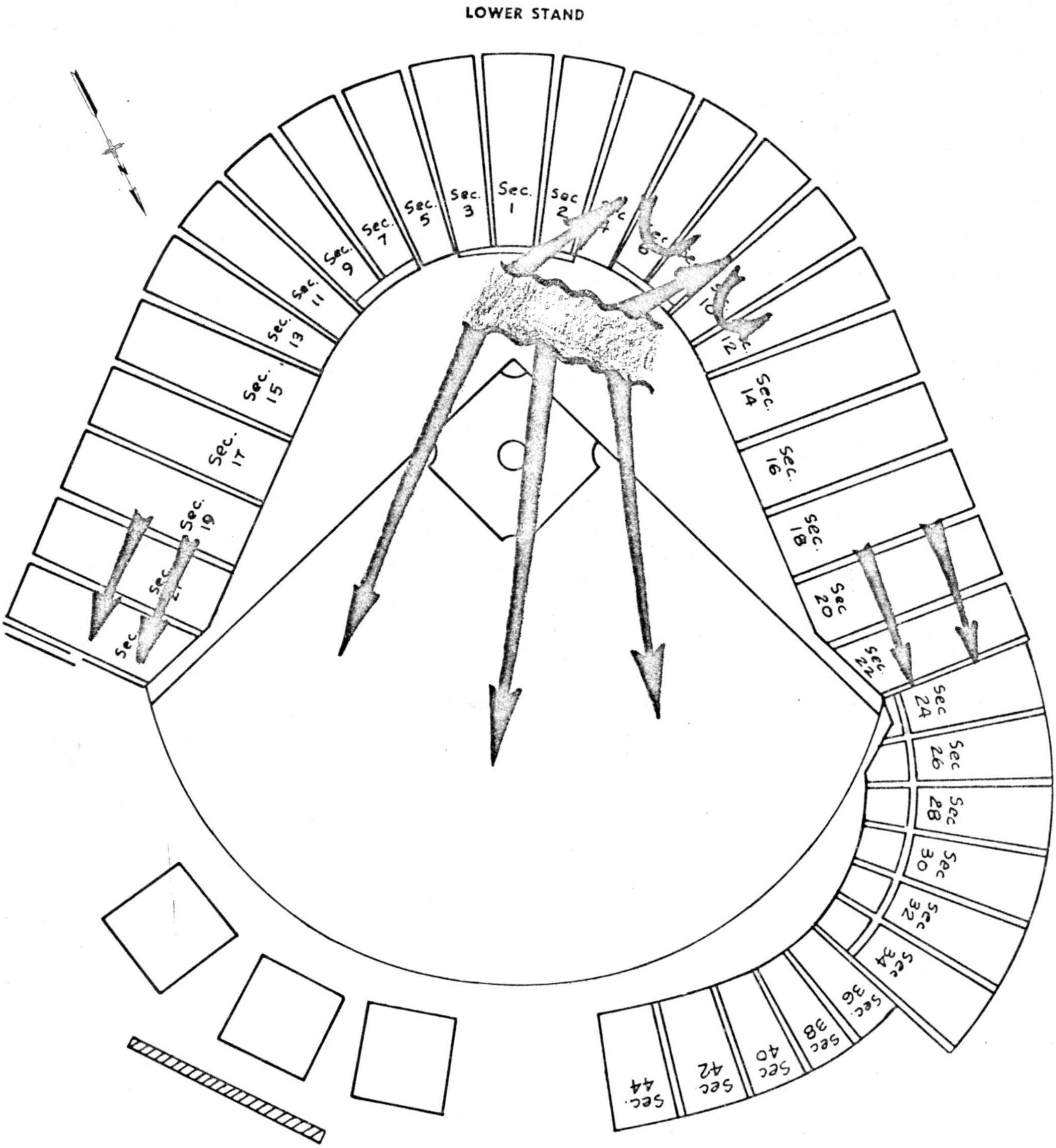


Fig. 6--Wind circulation pattern in the lower stands under Southerly Control conditions.

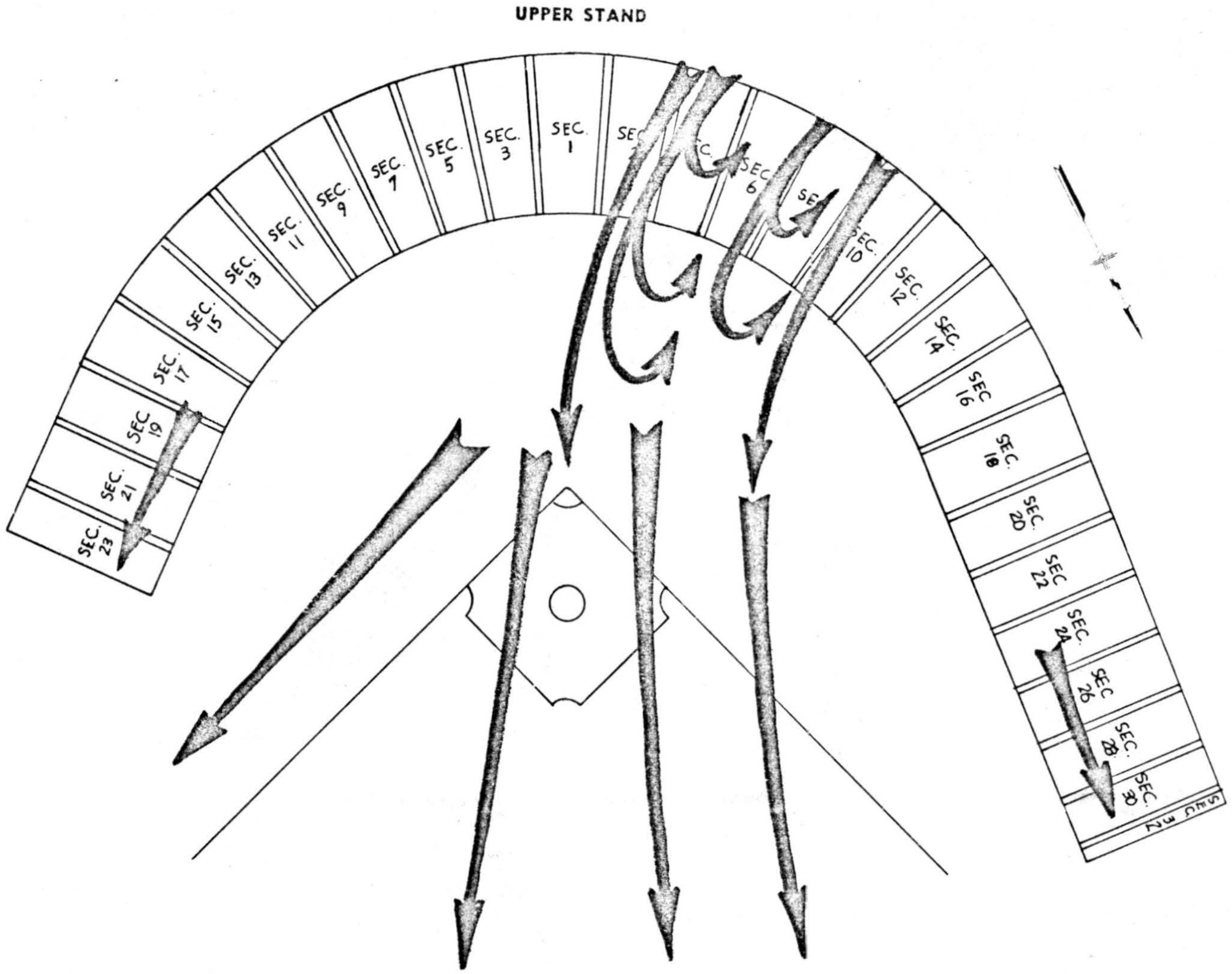


Fig. 7--Wind circulation pattern in the upper stands under Southerly Control conditions.

Fig. 8--Characteristic wind flow pattern around Bay View Hill based on model measurements at a mean wind direction of 16° south of west. The stream lines are superimposed on an aerial photograph of the prototype for comparison with Fig. 3. At 16° south of west the characteristic Left-Field Control wind pattern develops within the stadium model. Approximate boundary of entire model is shown by dashed line.

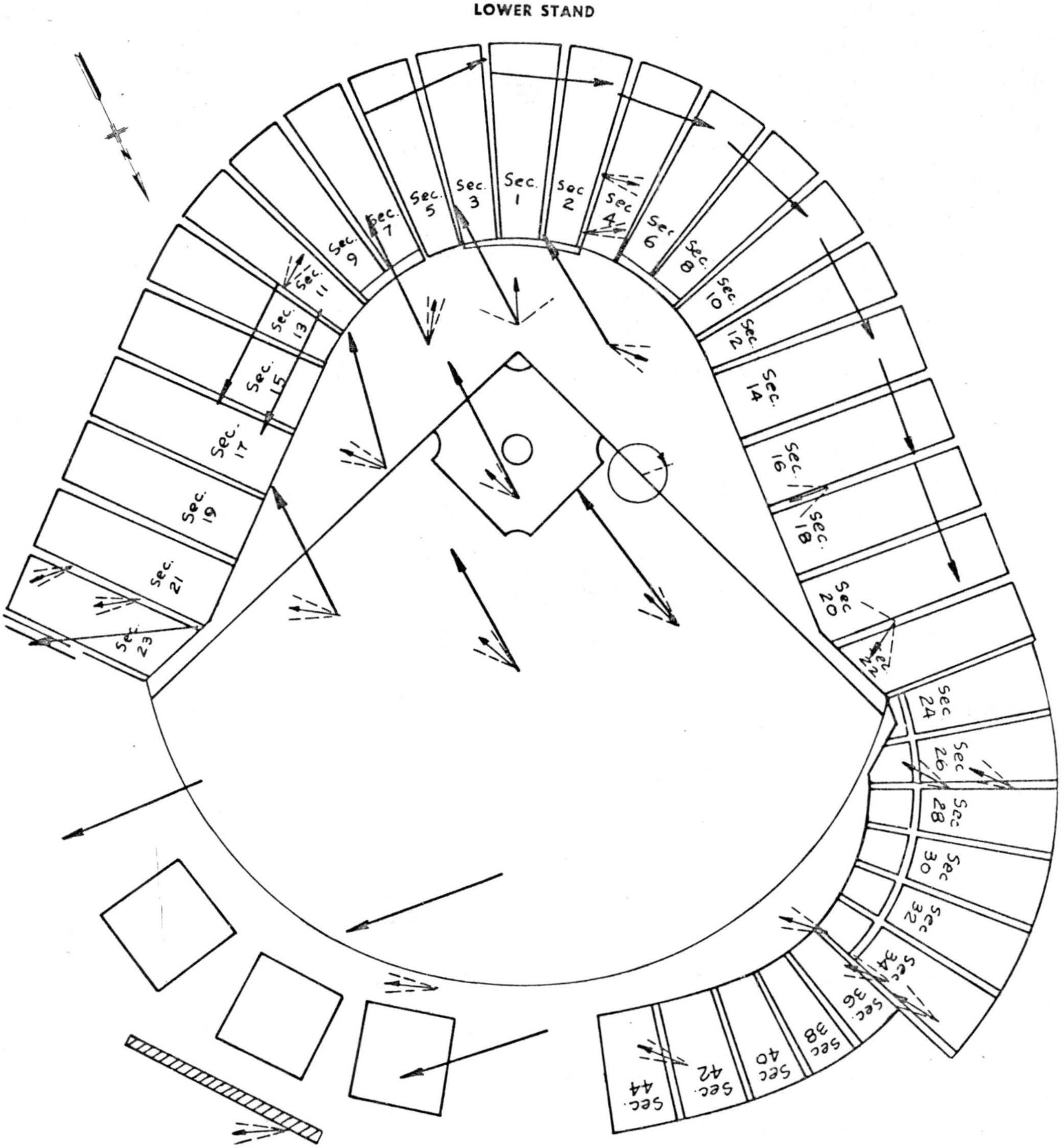


Fig. 9--Comparison between observed prototype and model wind flow patterns in the lower stands under Left-Field Control conditions.

LOWER STAND

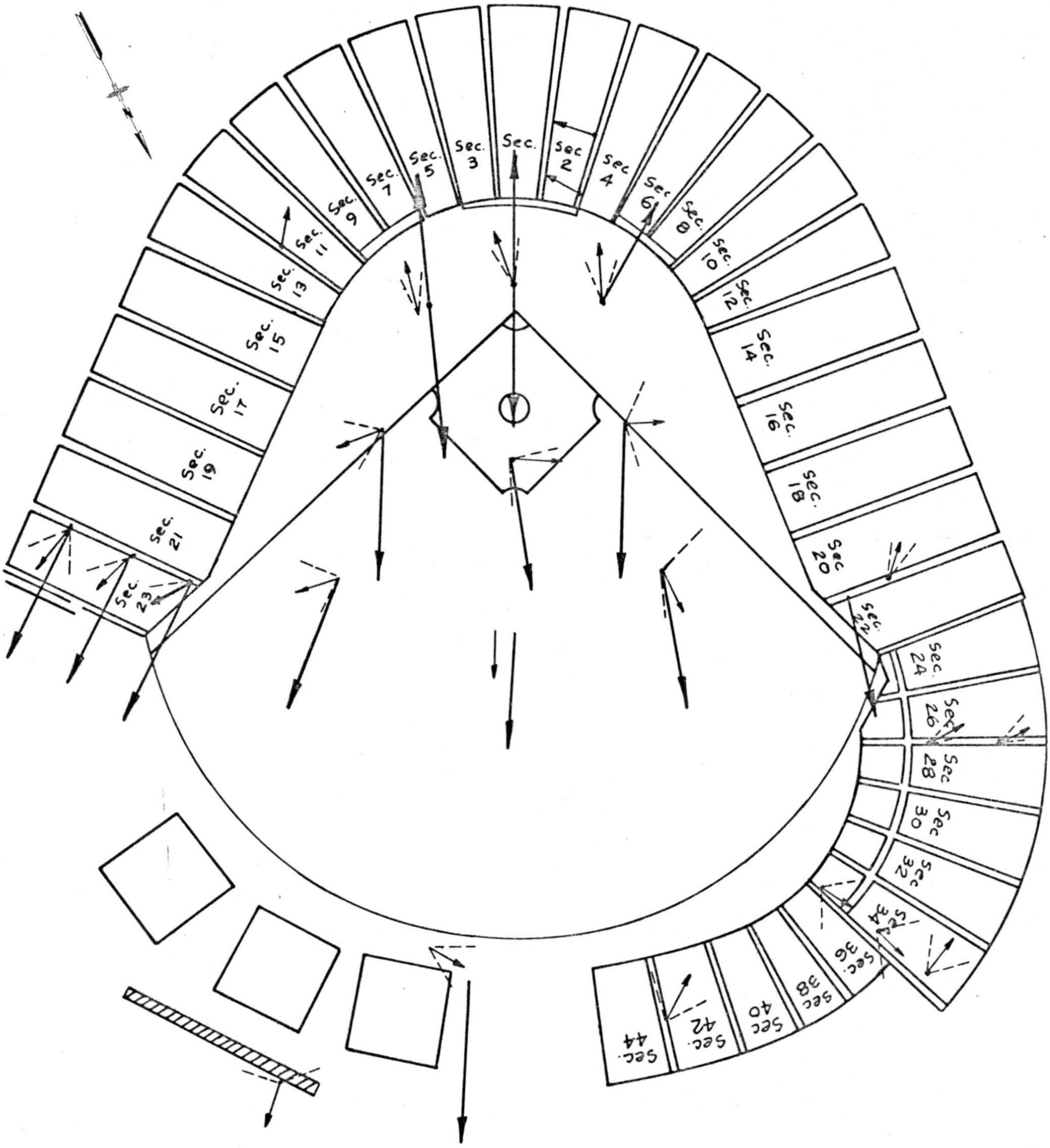


Fig. 10--Comparison between observed prototype and model wind flow patterns in the lower stands under Southerly Control conditions.

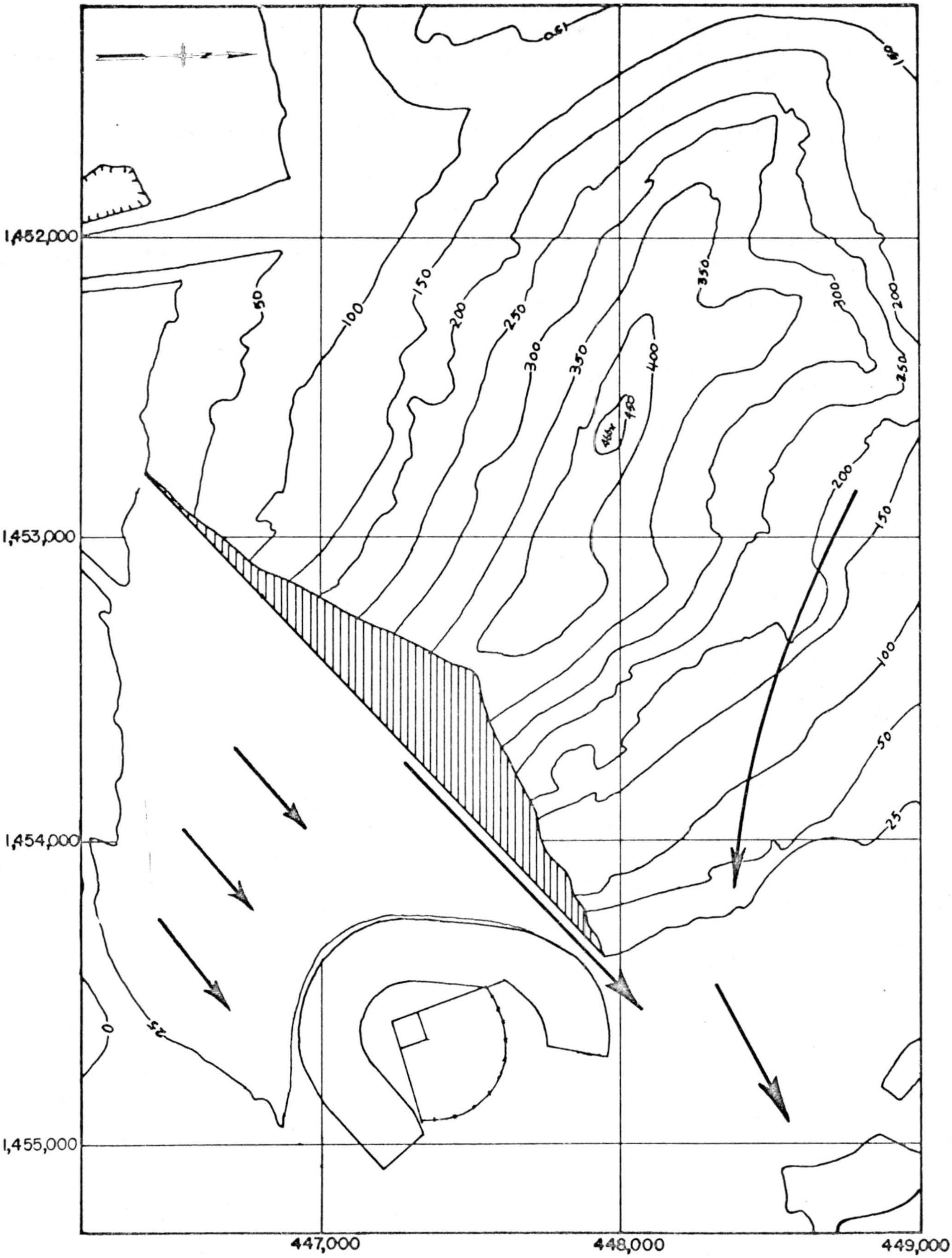


Fig. 11-Bay View Hill modified by removing southerly end. With the end removed the general wind pattern is altered to give a southwesterly flow across the stadium. As a consequence the flow normally entering left field is diverted away from the stadium. Contours and 1000-ft grid lines are from topographic map provided by Director of Public Works.

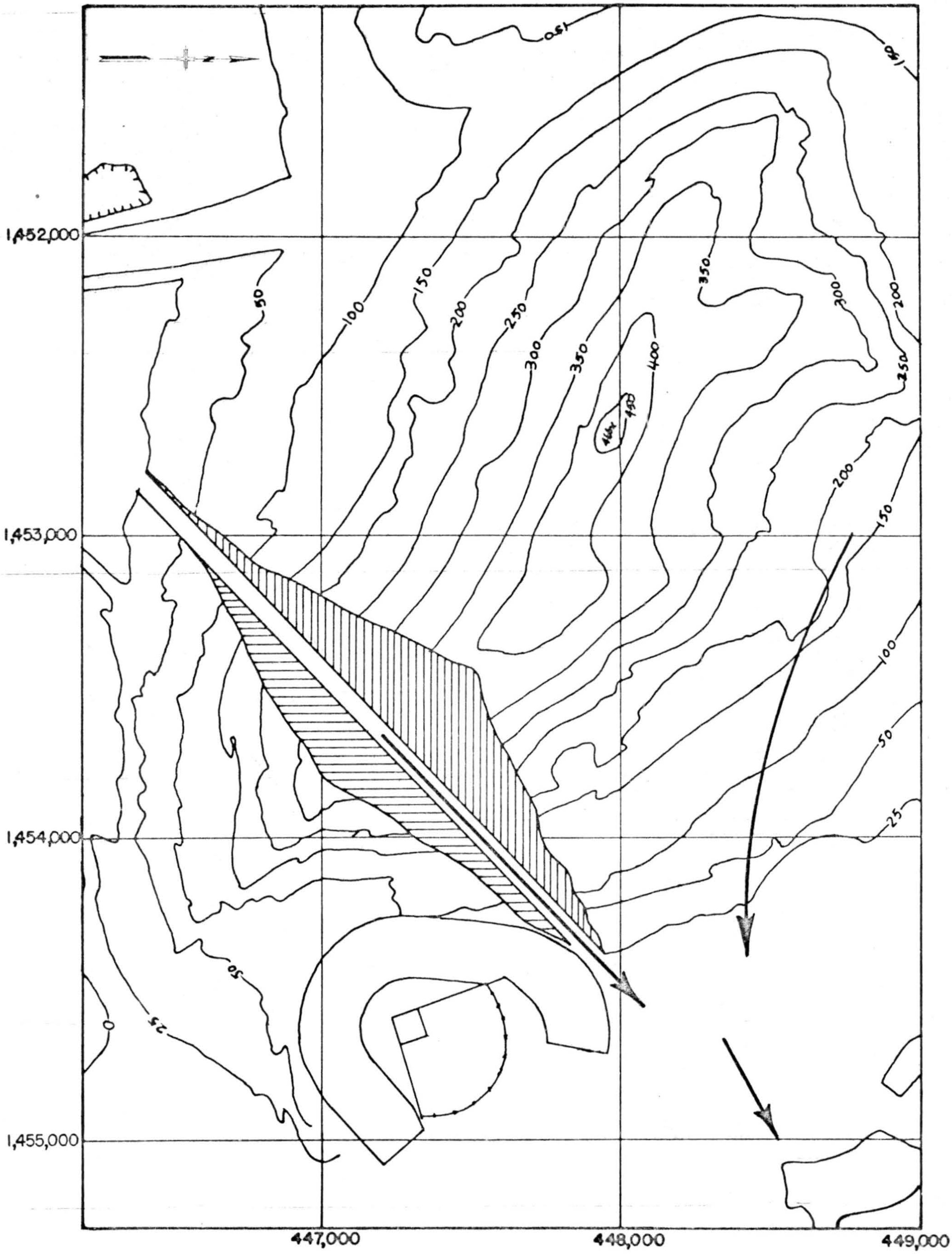
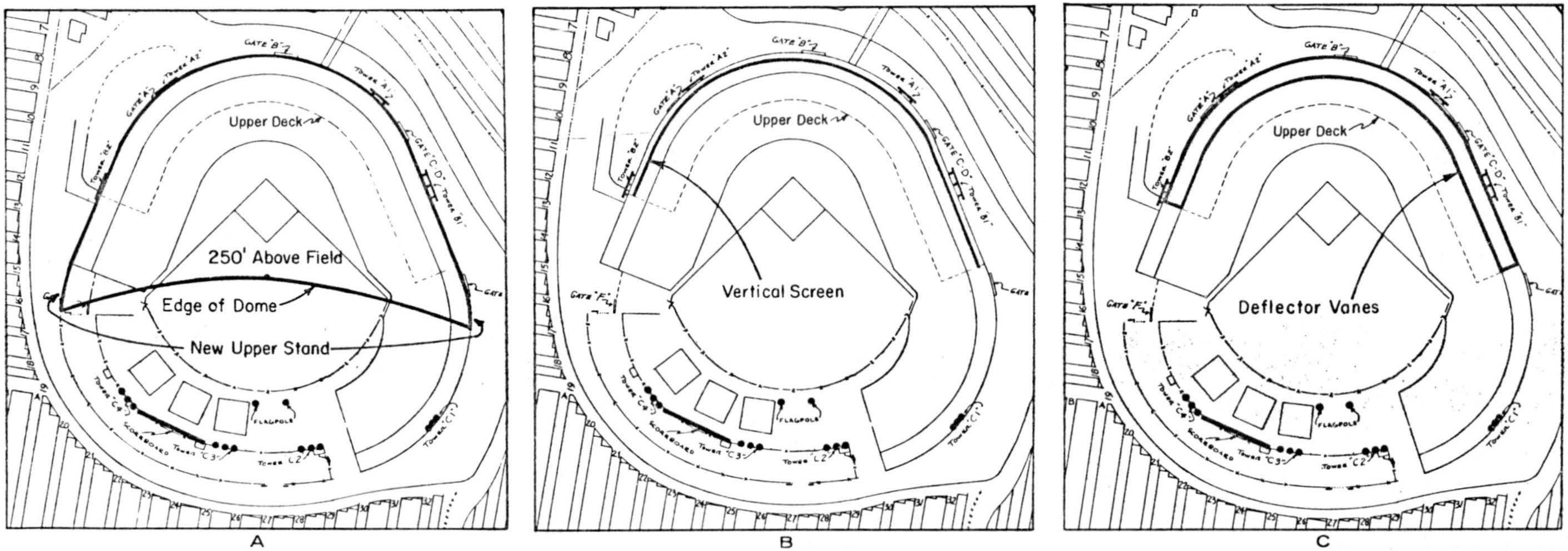


Fig. 12--Bay View Hill modified by cutting through south end. Air flow through cut diverts left field flow away from the stadium. Cut is approximately 100 feet wide at the bottom; slopes are 45°. Contours and 1000-ft grid lines are from map provided by Director of Public Works.



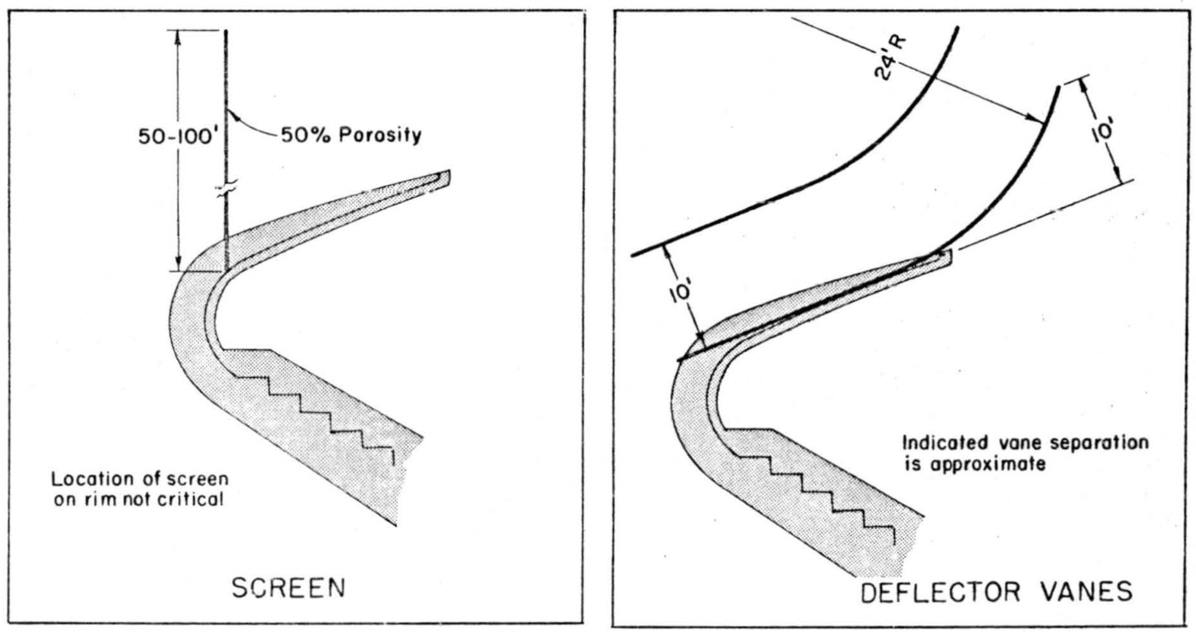


Fig. 13--Stadium modifications for the elimination of Southerly Control conditions. a) Partial dome ac.oss stadium. b) Vertical porous screen around existing rim. c) Vanes on rim to provide vertical deflection of the air across the stadium.