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WIND-TUNNEL STUDIES

WIND-TUNNEL STUDIES
of
WINDS IN CANDLESTICK PARK

by
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ABSTRACT

The purpose of this investigation is to determine if any low-cost, light-weight modification can be made either to the existing structure of Candlestick Park or to the proposed addition to improve the disturbing wind conditions now experienced in the stadium. The proposed addition will extend the upper spectator stands to completely enclose the playing field.

A previous wind-tunnel study of winds in Candlestick Park found that the modeling technique yields wind patterns which correlate well with prototype patterns measured in a field study. The study conducted in 1963 also revealed that a combination of modifications to Bay View Hill and a partial dome over the stadium or a 60 ft high screen around the upper stands would be effective in elimination of objectionable features of the wind flow within the stadium. It proved impractical to make these modifications at that time. Since 1963, the southeast end of Bay View Hill has been modified further by excavations in a manner which the model study showed would improve the wind conditions. Therefore, the present study was undertaken with the hope that improvement of wind conditions might possibly be achieved through small changes in the existing or new portions of the stadium structure.

This investigation has confirmed findings of the previous study that simply extending the upper stands around the entire playing field will result in only a small improvement and that the modifications to Bay View Hill have not been extensive enough to be of significant consequence. As found previously, it was observed that a 50 to 100 ft screen around much of the upper stands and extending above the roof has a beneficial effect. None of the minor modifications investigated appeared to offer any significant level of wind control.

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PURPOSE AND OBJECTIVES OF THE INVESTIGATION

The purpose of this investigation was to determine if some simple, light-weight modification could be made to the existing structure of Candlestick Park and/or if some feature might be incorporated into the proposed upper-stand addition* (complete encirclement of the playing-field area with spectator stands) which will decrease wind intensity within the stadium.

Through use of a scale model of Candlestick Park Stadium and Bay View Hill placed in an environmental wind tunnel, the study was directed toward attainment of the following objectives:

1. Determine wind characteristics in the ballpark if the stand modifications were to be made in accordance with the proposed architectural plan.
2. Determine how wind characteristics change from those found under Objective 1 if minor modifications of the upper-stand geometry were to be made.
3. Evaluate wind data obtained from the model under Objective 2 to determine if significant wind speed and gustiness reduction could be achieved with any of the minor modifications.
4. Explore the possibility of decreasing winds in the ballpark by other than minor modifications.

* Architectural plans prepared by John S. Bolles Associates, 14 Gold Street, San Francisco, California 94133

I. INTRODUCTION

Since the construction of Candlestick Park in 1959, the wind has annoyed both spectators and players because of the peculiar wind condition found during summer afternoons. Typically, a strong afternoon flow of cool marine air from the Pacific Ocean into the Bay area is found. This flow is modified by the geometry of Bay View Hill, which is elongated along a northwest line and lies to the west of the stadium, and by the stadium itself. Previous studies described in References 1, 2 and 3 found that a combination of an extensive modification of Bay View Hill, removal of the southerly end or excavation at a deep cut just north of the stadium, and a partial dome over the stadium would provide a complete solution to the wind problem. Since that time, excavations on the southerly end of Bay View Hill has continuously modified the geometry. It was hoped that this modification coupled with the enclosure of the entire playing field area by spectator stands matching the existing structure might afford substantial relief from the uncomfortable wind patterns, if small changes in the upper stand geometry were incorporated in the new construction. The main purpose of this wind-tunnel study was to determine if any small changes can achieve this end.

Since correlation of the model and field winds had been well established during the previous study, this investigation was concerned only with a search for some modifications of the architectural features which would give comfort to spectators and players alike. A summary statement of this investigation in the form of a Letter Report was presented to the City Architect on January 1970 -- Reference 4.

II. PREVIOUS STUDIES

Reference has already been made to the previous study conducted in the Fluid Dynamics and Diffusion Laboratory at Colorado State University--Ref. 2. The reader should also refer to Refs. 1 and 3, for a complete review of previous wind studies in Candlestick Ballpark. Motion pictures of the flow, made visible by introduction of smoke in both the model and prototype, were made to permanently record the findings of these studies.

The studies of 1963 revealed the existence of two distinct wind patterns. For winds coming from about 255° north azimuth the stadium was found to be in the region of influence of low-level winds flowing around the southerly end of Bay View Hill and low-level wind coming from the northwest in the lee of Bay View Hill. This condition results in an extremely unsteady, gusty flow within the stadium. When the wind approaches more from the south (about 240° north azimuth), a strong wind impinges upon the upper edge of the stands and a jet of air flows down into the stadium over the upper stands. This jet is unsteady and sweeps back and forth from near the pitcher's mound to the outfield. Three distinct flow types were found to occur in both the wind-tunnel model and in the atmosphere.

The many combinations of modifications to Bay View Hill and the stadium investigated, included an exploratory observation of winds in the stadium with the field completely encircled by upper-level spectator stands. With no other modifications, this configuration gave only a slight improvement in wind conditions.

III. EXPERIMENTAL EQUIPMENT

A. Wind Tunnel

This investigation was made in the environmental wind tunnel of the Fluid Dynamics and Diffusion Laboratory at Colorado State University (see Figs. 1 and 2). This is a new facility which has a test section measuring 12 ft wide, 7 ft high and 52 ft long. It is powered by a 150 hp variable-pitch, constant-speed vaneaxial fan. To eliminate static pressure changes down the length of the tunnel and, in particular, over models which may offer significant blockage of the wind flow, the roof of the test section can be lowered or raised within the limits of 6 ft to 9 ft high above the floor, or some combination of heights. The air enters the test section through an entrance section 18 ft wide and 13 ft high. The air first passes through a screen, then a flow straightener consisting of a stack of 3 ft long, 3 in. diameter tubes, and then through another screen. Following this unit there is a smooth contraction to the 12 ft x 7 ft test section. This gives a contraction ratio of 2.78 to 1.

Measurements were made at room temperatures. No thermal stratification of the air stream was necessary since the topography and structures dominate the flow patterns which are essentially independent of atmospheric stability under conditions of strong winds (30 mph).

B. Models

The model was constructed to the same horizontal and vertical scale and prototype wind speeds of 30 mph were used in the testing. The reference wind speed was measured at the 800-ft level. The

scale chosen, 1:384, was the largest consistent with the size of the test section which would permit inclusion of the major portion of Bay View Hill. This scale allowed use of the larger of the stadium models used in the previous study (Ref. 1) and proved to be convenient for modeling of the hill.

The 1:384 stadium model used in the previous study was refurbished and the necessary additions* constructed of wood to model the proposed addition to the Park. All additions were made removable so various configurations could be studied. Models of the various escalator configurations were made and changes were made along the roof using modeling clay, balsa wood and screen wire, as well as by drilling holes in the roof overhang.

Bay View Hill was modeled in expanded polystyrene using a combination of the topography from the USGS San Francisco South quadrangle map and a topographic map (furnished by the City of San Francisco), showing the latest changes in Bay View Hill. The polystyrene sheets were cut along contour lines with a hot-wire. The successive sheets were glued together with a white glue and the edges sanded off. Along the south edge of the hill, terraces were preserved. The model was painted with a black latex paint and the 100 foot contour lines marked with white paint as shown in Fig. 3. The hill and stadium models were mounted on a plywood base representing the playing field elevation. The base was so sectioned that it could be mounted in the wind tunnel to permit wind from directions of either 255° N or 239° N (north azimuth).

* See architectural plans prepared by John S. Bolles Associates, 14 Gold Street, San Francisco, California 94133.

A number of wind-direction indicators were constructed of small glass tubing formed into a glass bearing and mounted on a vertical needle point, as shown in Fig. 4. Thread was tied around the glass and glued. Great care was necessary to insure that the needle point was vertical. These make a very sensitive flag to indicate wind direction and they are quite responsive to direction changes. Careful study of motion pictures taken of these flags in action yield very useful information about the wind flow and its characteristic gustiness.

C. Measurements and Photographic Equipment

The reference wind speed of the wind tunnel was monitored continually by a pitot-static tube connected to a MKS "Baratron" Type 77 electronic differential pressure meter. The pitot tube was placed in the free stream in a location where the flow was unaffected by the model and/or modifications.

Velocity and turbulence parameters were recorded using a Disa constant temperature anemometer, Model 55D. Tungsten wire 0.00035 in. in diameter with a length of 0.08 in. was used for the sensing elements.

A Hewlett-Packard Moseley Model 136A X-Y-Y' recorder was used to plot the output of the Disa anemometer and the output of a Disa True RMS Voltmeter simultaneously against the probe height above the playing field area. The output of the anemometer, in volts, is a function of the velocity, and the output of the RMS meter, also in volts, is a function of the turbulence intensity.

Smoke was generated by pouring titanium tetra-chloride into shallow pans placed on the model. The $TiCl_4$ hydrolyzes in air (with only a trace of moisture required) to give TiO_2 , a finely divided white powder or smoke, and HCl vapor. A shallow pan containing ammonium hydroxide was placed at the intake of the tunnel to provide ammonia vapor to neutralize the hydrochloric acid and reduce corrosive action of the $TiCl_4$.

Motion pictures were taken through the tunnel windows, mainly in the roof, using a 16 mm Paillard Bolex Reflex motion picture camera. A normal lens ($f = 10$ mm) and a closeup lens ($f = 25$ mm) were used to give a combination of views of the entire area and detailed pictures of the action within the stadium itself. Kodak Tri-X Reversal Film No. 7278 was used in all filming. The contents of the motion pictures made are described in Table II.

Hot-wire probes were traversed vertically within the tunnel by a CSU built traversing mechanism featuring variable speed and a voltage output proportional to probe height above the floor. This permitted the probe position to be plotted as one axis of the X-Y plotter.

D. Techniques of Measurement

In order to judge the effectiveness of the various modifications on the wind conditions within the stands, three positions were chosen for measurement of vertical traverses of velocity and turbulence intensity. These three locations (A, B and C) are shown in Figs. 6 and 7. As the hot-wire probe was slowly moved up from the floor, its position was fed into the X input of the X-Y-Y' recorder, the

output of the hot-wire anemometer was fed into the Y input and into a true-RMS meter. The output of the RMS meter was fed into the Y' input and thus a profile of voltages vs height (also by voltage) was obtained where the X voltage is directly proportional to height, the Y voltage is a function of velocity and the Y' voltage a function of turbulence intensity.

It is recognized that the hot-wire anemometer does not lend itself readily to the technique of continuous velocity and turbulence profiling and, in order to obtain the best information from the hot-wire anemometer, the point by point method should be used. However, this is an extremely time-consuming process and, since we sought comparisons between one modification and another, continuous plots of velocity and turbulence intensity with height were used. A low traverse speed was chosen and kept the same during all runs. Therefore, only a single variable, i.e., the modification being observed, was changed between one run and the next and profiles run under these conditions represent good qualitative comparisons of the effect of that single variable upon the wind conditions.

Because the mean wind direction for some cases changed rapidly with height, vertical profiles of mean velocity and turbulence intensity were taken with the hot-wire sensor aligned both parallel and perpendicular to the upper-level wind direction. Figure 5 gives sketches which define the hot-wire positioning. No attempt was made to differentiate between the contribution to the output signal made by each vector component of the velocity. This was not considered to be necessary since differences in the output signal levels resulting from the various modifications were of primary concern.

However, in interpreting the responses from the hot-wire anemometer in a parallel and a perpendicular orientation relative to U_∞ , the following information is helpful:

<u>HWA Orientation</u>	<u>Wind Components Giving Major Contributions to Output</u>
Parallel	i) Vertical ii) Horizontal--normal to U_∞
Perpendicular	i) Vertical ii) Horizontal--parallel to U_∞

IV. PROGRAM OF STUDY AND FINDINGS

Essentially twelve modifications and combinations of modifications were investigated for two wind directions--239° and 255° north azimuth. The modification designations and descriptions are listed in Table I. Results of the investigation are presented in two forms--graphical representation of mean wind speed and turbulence intensities (Figs. 13 through 81) and pictorial representation (motion pictures listed in Table II). The motion pictures of smoke and vane motions over the ballpark provide an excellent overview of the entire wind field. Simultaneous reviewing of Reel 3 (new upper stands plus modifications) with Reel 1 (existing stadium) or 2 (new upper stands with no modifications) projected side-by-side on the same screen provides the best qualitative comparison of wind fields for the modified and unmodified ballpark.

The small general surface flow patterns for Modifications 1 through 5 are sketched in Figs. 13 through 16 for the two wind directions studied. Characteristics of these surface flows are in fair agreement with those observed in the earlier study reported in Ref. 2. However, the removal of additional material from the south end of Bay View Hill since the earlier study was made has resulted in the surface patterns for the two wind directions being more similar than was found in 1963.

A careful study of the motion pictures of smoke and vanes and the measurements of mean wind speed and turbulence permits comparisons to be made of winds in the stadium for the different modifications considered. The most significant observations are summarized in the four sections which follow.

A. Existing Stadium

Flow over the existing stadium was examined for two primary purposes--1) to determine if flow over the new 1:400 scale model was similar to flow over the 1:800 scale model (see ref. 2) and 2) to provide a reference flow for comparison of flows produced by extending the upper stands to enclose the playing field and by modifications of the upper-stand geometry and addition of fences on Bay View Hill. Vertical profile of velocity and turbulence intensity (gustiness) are presented in Figs. 17 through 37. New data are found to be generally consistent with the findings of the 1963 study. However, the flow differences found for the two wind directions (239° and 255° N azimuth) in the early study were not as distinct in the present study. Modifications of Bay View Hill due to additional excavations on the south end which were included in the present model are probably the cause of this result. Generally speaking, the flow is highly variable in time and space over the playing field and the seating area with a turbulence level (gustiness) of about 10 percent of the mean wind speed as measured 800 ft above the playing field.

B. Stadium with Proposed Additional Upper Stands (no modifications of proposed architectural features)

An overview of flow in the stadium is given in Figs. 13 and 14 for winds from 255° N and 239° N, respectively. The dominant features are a circulation of flow in the stadium (rotary motion) with a region of strong upward flow and a region of strong downward motion. Although the regions of up and down draughts are indicated to be at specific locations, they are unsteady in position and move over wide areas.

Vertical profiles of mean velocity and turbulence intensity (gustiness) for locations A, B and C are shown in Figs. 17 through 28. A study of these figures and Reels 1 and 2 of the motion pictures show only small differences between the magnitudes of these quantities for the existing stadium and the proposed stadium. The most pronounced improvement is found at point C (center field of the baseball field) where a small reduction in wind speed and turbulence will result when the proposed new seating has been constructed. Some reduction in large-scale velocity fluctuations is evident from the behavior of vanes in Reels 1 and 2 of the motion pictures. However, the overall distribution of flow disturbances and wind speeds will remain essentially as those now experienced at Candlestick Park.

C. Stadium with Proposed Additional Upper Stands with Minor Architectural Modifications

The variety of architectural configurations investigated are described in detail in Table II--Configurations C through K. The basic minor modifications consisted of the following additional features along the upper lip of the stadium:

1. Fins (Mod. 1, Fig. 8)
2. Upturned lip (Mod. 2, Fig. 9)
3. Cusp (Mod. 3, Fig. 10)
4. Cusp with holes through upper surface (Mod. 4, Fig. 11)
5. Modifications 1, 2, 3 and 4 with fences on Bay View Hill (Fig. 6).

Examination of Reel 3 simultaneously with Reel 2 reveals that these modifications have slight but not significant effect upon the general flow pattern in and near the stadium. Consequently, the

general flow is essentially the same as that described for the proposed stadium with no modifications (Sec IV.B) and is indicated by the sketches shown in Figs. 13 and 14.

The vertical mean wind speed and turbulence intensity (gustiness) profiles for all the configurations with minor modifications at locations A, B and C (Fig. 7) are presented in Figs. 17-28, 38-49, and 54-77. Careful examination and comparisons of these data reveal that for a particular wind direction, a particular location (A, B or C) and a particular hot-wire orientation differences in wind speed and turbulence intensity produced by the modifications were not more than 10-15 percent of the values for the unmodified proposed stadium (Configuration B). Consequently, the minor modification would not produce a significant improvement in the wind environment within the stadium.

D. Stadium with Proposed Additional Upper Stands with Major Architectural Modifications

In the previous wind-tunnel study of winds at Candlestick Park reported in Ref. 2, the simplest modification which produced substantial improvement of the wind environment was a vertical porous screen about 100 ft high erected around a major portion of the existing stadium. Consequently, this same type of modification was investigated when incorporated with the proposed stadium. Details of this modification are given in Figs. 7 and 12. Two screen heights were investigated, 32 ft and 64 ft which are labeled Modifications 5 and 6, respectively (Configurations L and M, Table I). No other major modifications short of construction of a partial or complete dome over the stadium was considered to have sufficient merit to

justify detailed model studies; therefore, the vertical screen was the only major modification investigated in this study.

The general region within the stadium affected by the screens at the two wind directions 255° N and 239° N is shown in Figs. 15 and 16. Observation of Reel 3 and of the motion picture reveals that the vane activity is small and that the mean flow pattern is organized weakly compared to observed activity without the screens.

Vertical profiles of mean velocity and turbulence intensity (gustiness) for points A, B and C are given in Figs. 17 through 28. Comparable profiles for Modification 4 are given with those for Modifications 5 and 6 on these figures to facilitate an evaluation of screen effectiveness. Excepting for data shown in Fig. 17 both the turbulence intensity and mean velocity are generally less for configurations including the vertical screen with the decrease being greatest for the highest screen. Decreases up to 30 percent are not uncommon. The increase in mean velocity with screens indicated by Fig. 17 is interesting to mean that a substantial change in wind direction has been effected by the screen, i.e., the mean wind direction is more nearly parallel to the upper-level wind direction of 239° N. Figures 50 through 53 and 78 through 81 indicate that the difference in behavior of the screen for the two wind directions investigated, 239° N and 255° N, is generally negligible.

The most significant effect of the vertical screens, even surpassing the substantial reduction in wind speed and turbulence intensity, is stabilization of flow over the stadium. This is revealed by comparative observation of vane activity in Reels 2 and 3 (last

few feet--see Table II). Stabilization reduces the large-scale fluctuations of flow within the stadium and hence should effect a large improvement in human confort.

V. CONCLUSIONS

The wind-speed and turbulence intensity data (gustiness) presented as part of this report and the motion pictures produced bring the course of this study support the following conclusions:

1. Construction of the proposed additional stands to completely enclose the playing field will produce only a slight improvement in the wind environment. The sensible effect of the wind changes as experienced by players and spectators may result in negligible improvement of the comfort level.
2. None of the minor architectural modifications of the proposed structural form investigated in this study proved to be effective for alleviation of wind speed or gustiness within the stadium. Consequently, no modification of the proposed structural form for the upper-stand addition which is a harmonious continuation of the existing structure can be justified on the basis of wind control.
3. The addition of a vertical porous screen rising from 50 to 100 ft above the upper stands and extending around the existing stands can produce substantial improvement of the internal wind environment of the stadium. If upon completion of the proposed stadium addition winds continue to be a major source of human discomfort during the baseball season, construction of a vertical screen as a separate structure should be considered. However, the cost of such a structure with its limited wind-control effectiveness should be compared critically with the cost of a covering structure and the positive environmental control which could be provided.

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TABLE I -- Description of Modifications Studied Through Use of Wind-Tunnel Model

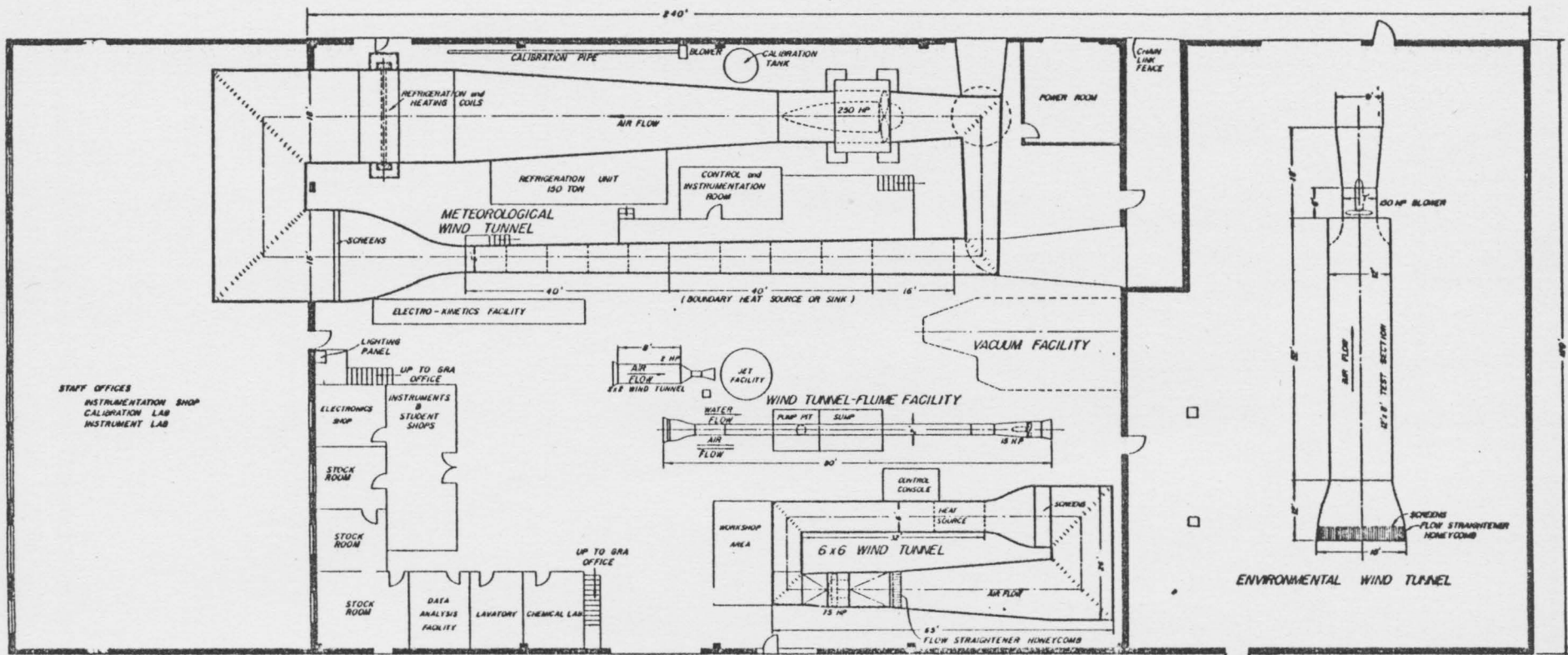
<u>Configuration</u>	<u>Description</u>
A. Existing	Existing structure of the stadium <u>without</u> the proposed additional upper stands.
B. Proposed	Existing structure of the stadium <u>with</u> the proposed additional upper stands.
C. Modification 1	Stadium with additional upper stands with <u>fin additions</u> 30 ft wide at 7 ft c/c along the upper lip of the roof section as detailed in Fig. 7 (plan-view) and Fig. 8 (sectional view)
D. Modification 2	Stadium with additional upper stands with a smooth continuous <u>upturn of upper lip</u> as detailed in Fig. 7 (plan-view) and Fig. 9 (sectional view).
E. Modification 2 with Low Fence (L.F.)	As detailed in Configuration D together with 18 ft high by 280 ft long fence with 33% porosity fixed on the Bay View Hill as shown in Figs. 6 and 7 (plan view) and Fig. 9 (sectional view).
F. Modification 3	Stadium with additional upper stands together with a <u>smooth cusp</u> fixed along the upper lip of the roof as detailed in Fig. 7 (plan) and Fig. 10 (sectional view).
G. Modification 3 with Low Fence (L.F.)	As detailed in Configuration F together with 18 ft high by 280 ft long fence with 33% porosity fixed on the Bay View Hill as shown in Figs. 6 and 7 (plan view) and Fig. 10 (section).
H. Modification 3 with High Fence (H.F.) (Labeled 3b in Reference 4)	As detailed in Configuration F together with 70 ft high by 328 ft long fence with 33% porosity fixed on Bay View Hill as shown in Figs. 6 and 7 (plan view) and Fig. 10 (sectional view).

TABLE I -- Description of Modifications Studied Through Use of Wind-Tunnel Model

<u>Configuration</u>	<u>Description</u>
I. Modification 4	As detailed in Configuration F together with 4 ft dia. holes at 15 ft centers in the roof as shown in Fig. 11 (sectional view).
J. Modification 4 with Low Fence (L.F.)	As detailed in Configuration I together with 18 ft high by 280 ft long fence with 33% porosity fixed on Bay View Hill as shown in Figs. 6 and 7 (plan view) and Fig. 11 (sectional view)
K. Modification 4 with High Fence (H.F.)	As detailed in Configuration F together with screen 32 ft high above the roof top with 33% porosity fixed on Bay View Hill as shown in Figs. 6 and 7 (plan view) and Fig. 11 (sectional view).
L. Modification 5	As detailed in Configuration F together with screen 32 ft high above the roof top with 33% porosity as shown in Fig. 7 (plan view) and Fig. 12 (section).
M. Modification 6	As detailed in Configuration F together with screen 64 ft high above the roof top with 33% porosity as shown in Fig. 7 (plan view) and Fig. 12 (sectional view).

TABLE II -- Motion Pictures (16mm black and white) of Flow Made Visible by Addition of Smoke

REEL I		
Existing Stadium	Wind from 255°	
" "	Wind from 239°	
REEL 2		
Proposed Construction	Wind from 239°	Baseball configuration
" "	Wind from 255°	Football Configuration
" "	Wind from 255°	Baseball Configuration
REEL 3		
Modified Construction	Wind from 239°	Modification 1
" "	Wind from 255°	Modification 2
" "	Wind from 255°	Modification 2 with Low Fence
" "	Wind from 239°	Modification 2 with Low Fence
" "	Wind from 239°	Modification 2
" "	Wind from 239°	Modification 3 with Low Fence
" "	Wind from 239°	Modification 3
" "	Wind from 255°	Modification 3
" "	Wind from 255°	Modification 3 with Low Fence
" "	Wind from 255°	Modification 3 with High Fence
" "	Wind from 255°	Modification 4
" "	Wind from 255°	Modification 4 with Low Fence
" "	Wind from 255°	Modification 4 with High Fence
" "	Wind from 255°	Modification 5
" "	Wind from 239°	Modification 5



FLUID DYNAMICS AND DIFFUSION LABORATORY

Fig. 1. Fluid Dynamics and Diffusion Laboratory -- Floor Plan.



Fig. 3. Model of Candlestick Ballpark and Bay View Hill (1:384 scale).

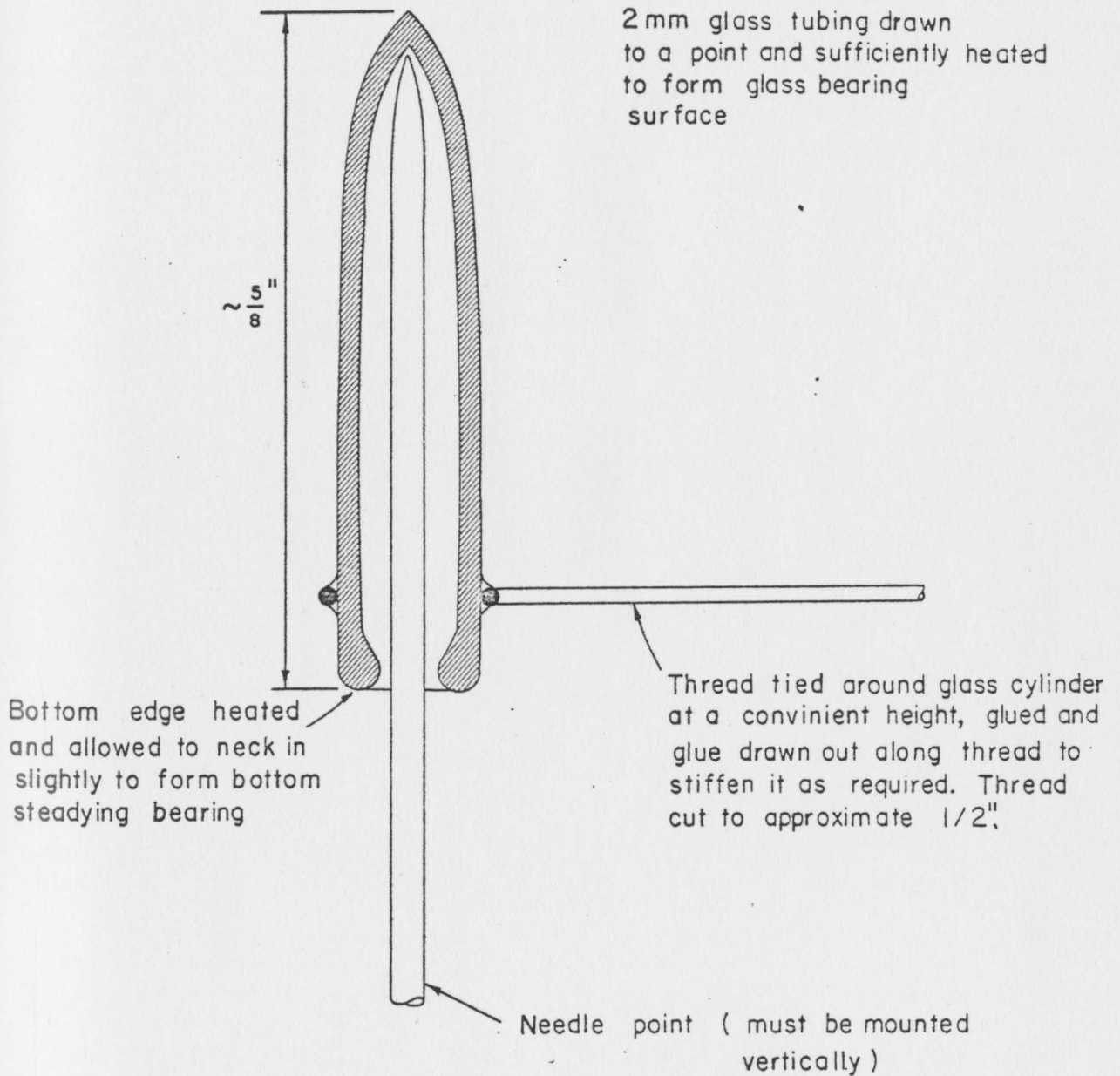
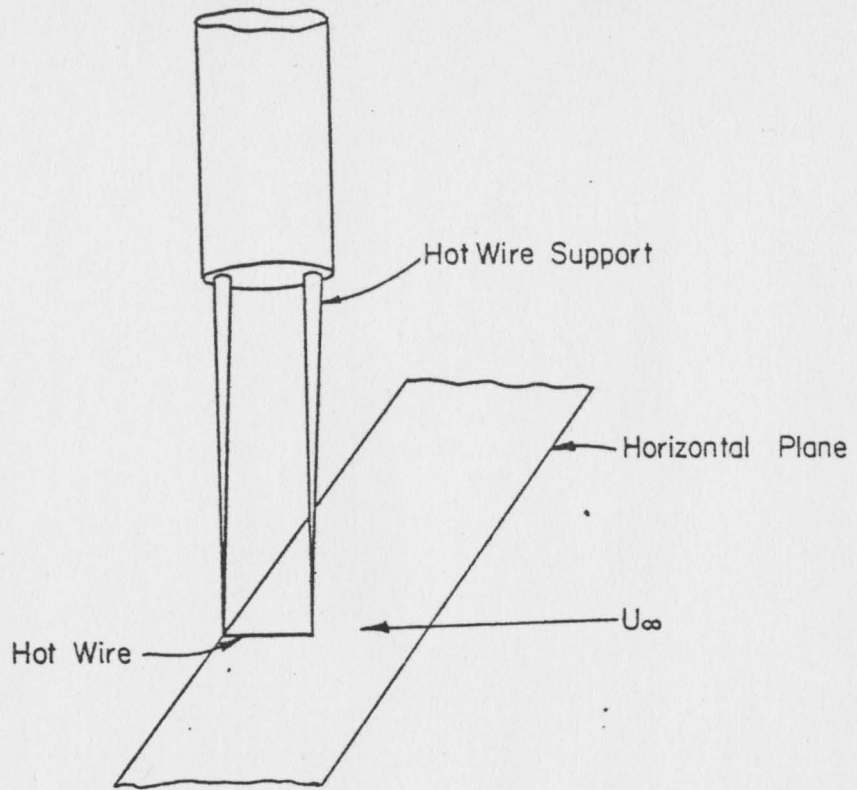
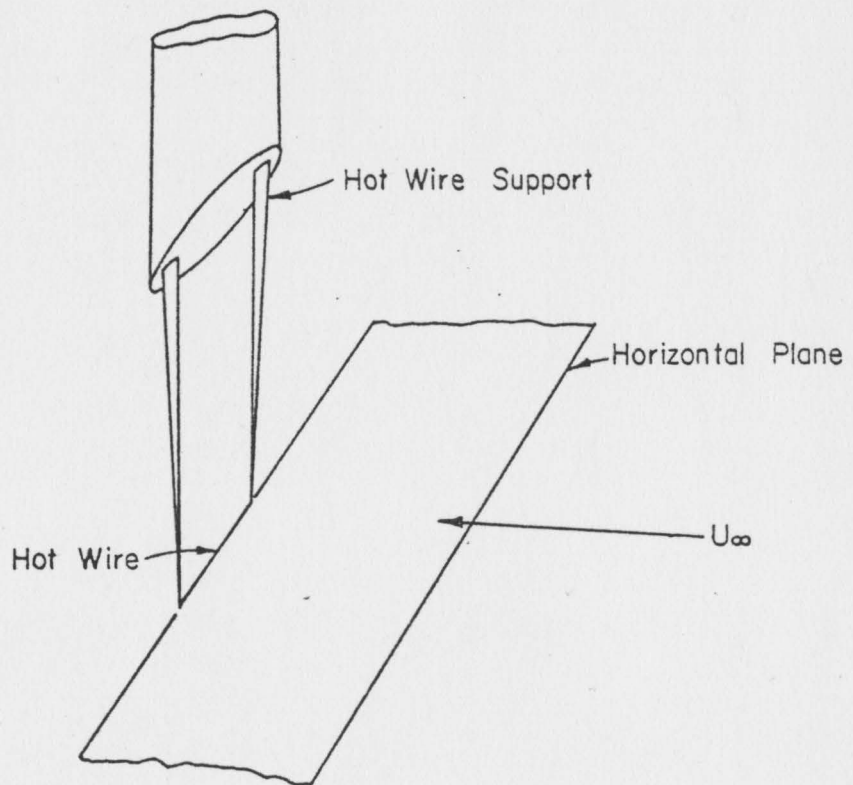


Fig. 4. Details of Flag Arrangement.



Hot Wire Parallel to Ambient Wind Direction



Hot Wire Perpendicular to Ambient Wind Direction

Fig. 5. Details of Position of Hot Wire.

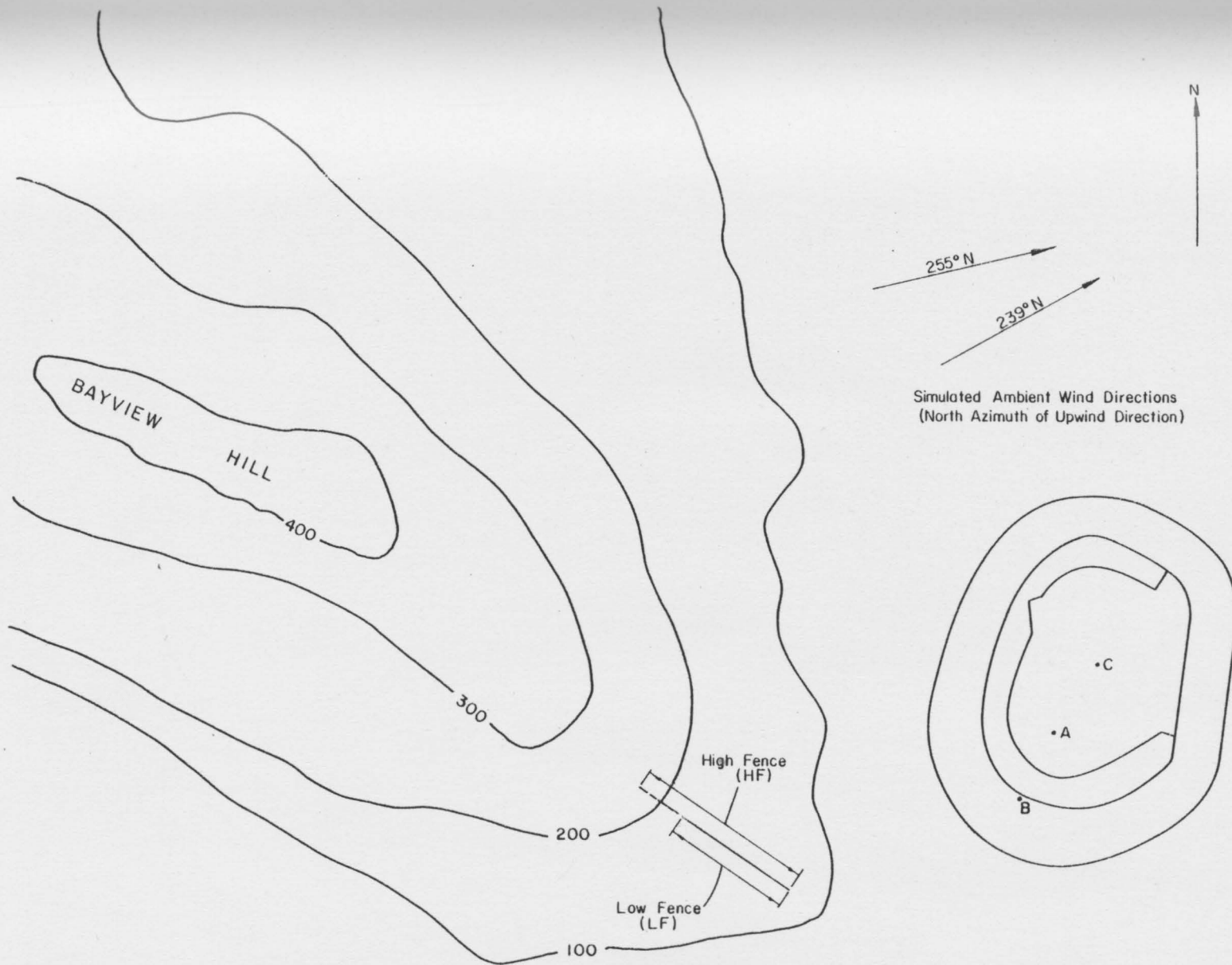
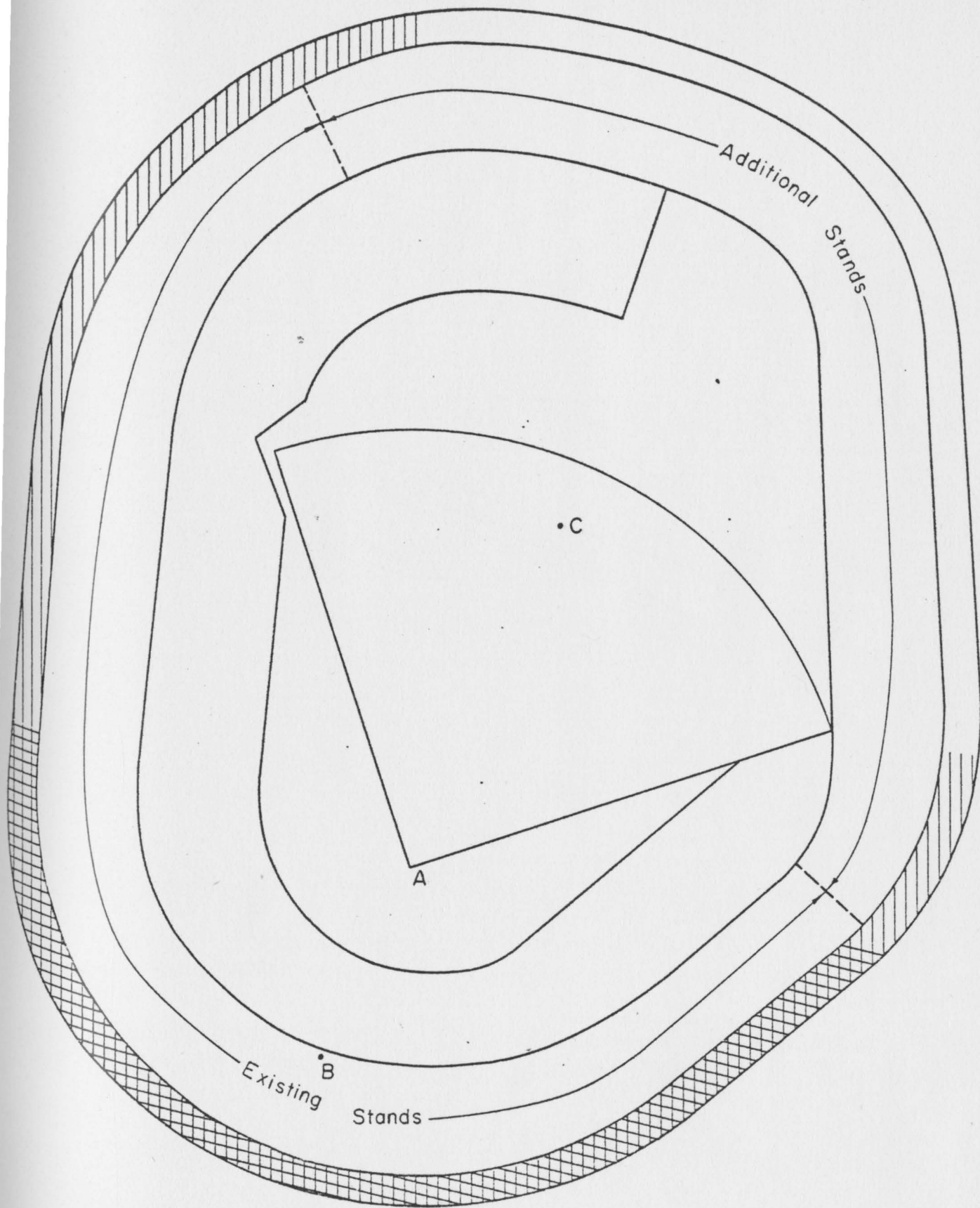
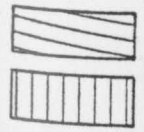


Fig. 6. Plan View of Bay View Hill and Candlestick Park.



Additional Stands

Existing Stands



Area for Modification 1

Area for Modification 2, 3, 4, 5, and 6

Fig. 7. Plan View of Candlestick Park Showing Sectors Modified for Model Study.

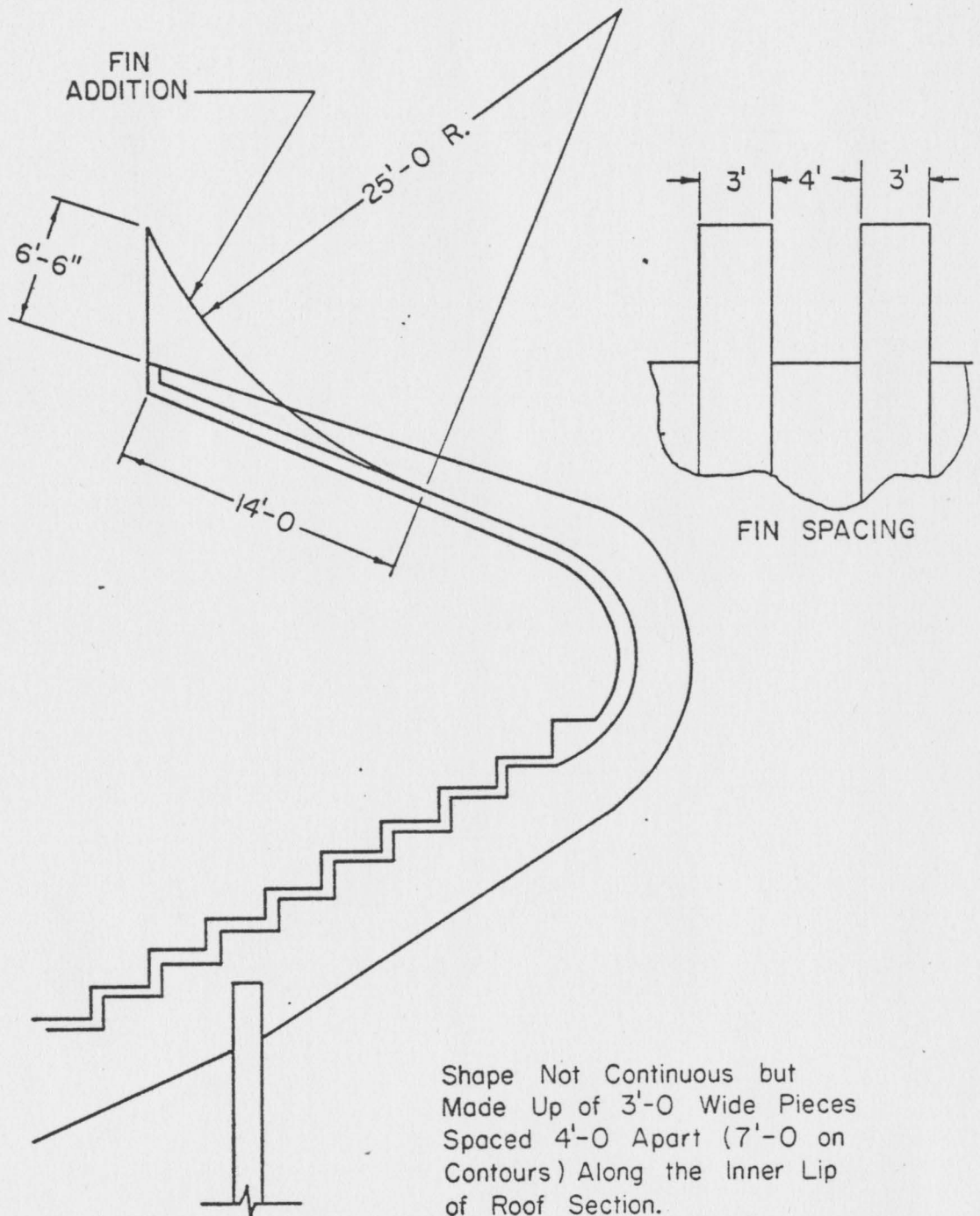


Fig. 8. Modification 1 -- Fin Addition to Upper Lip.

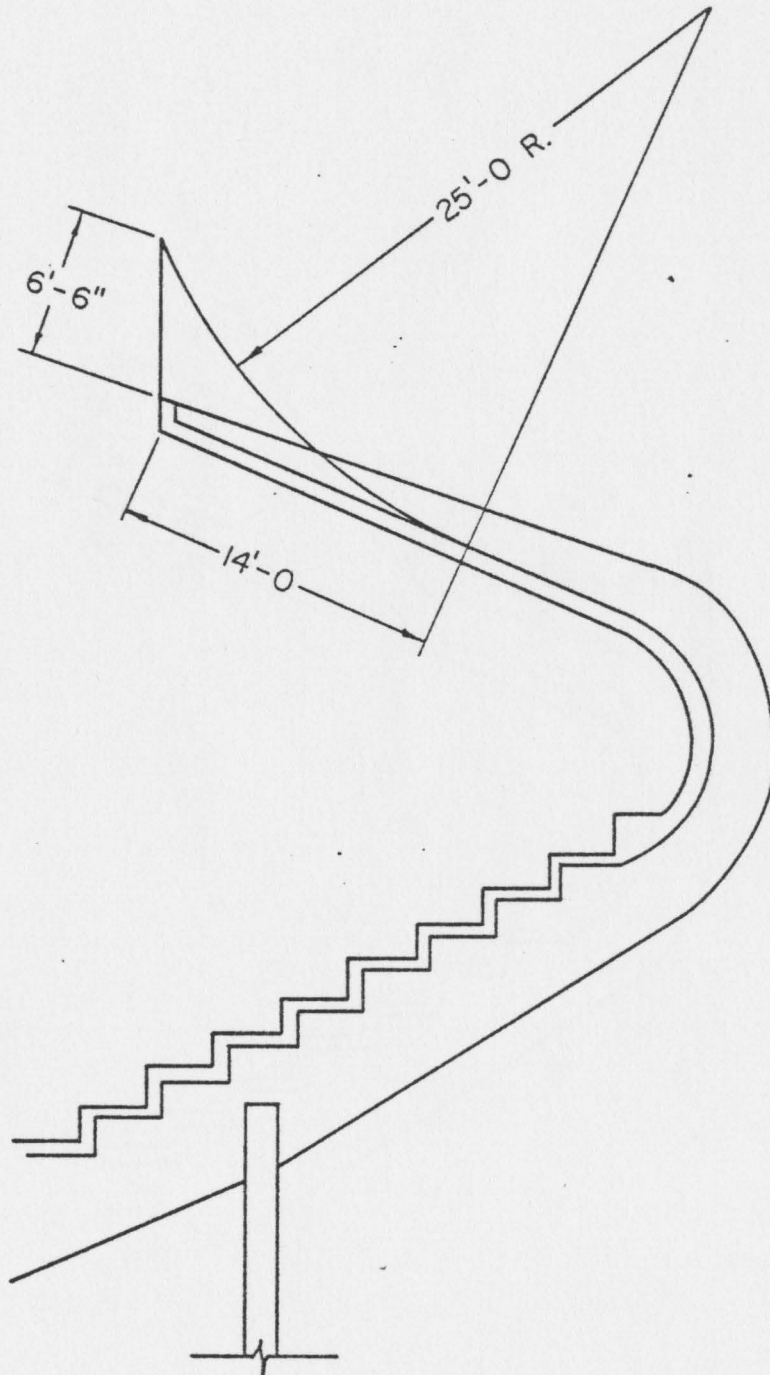


Fig. 9. Modification 2 -- Continuous Upturn of Upper Lip.

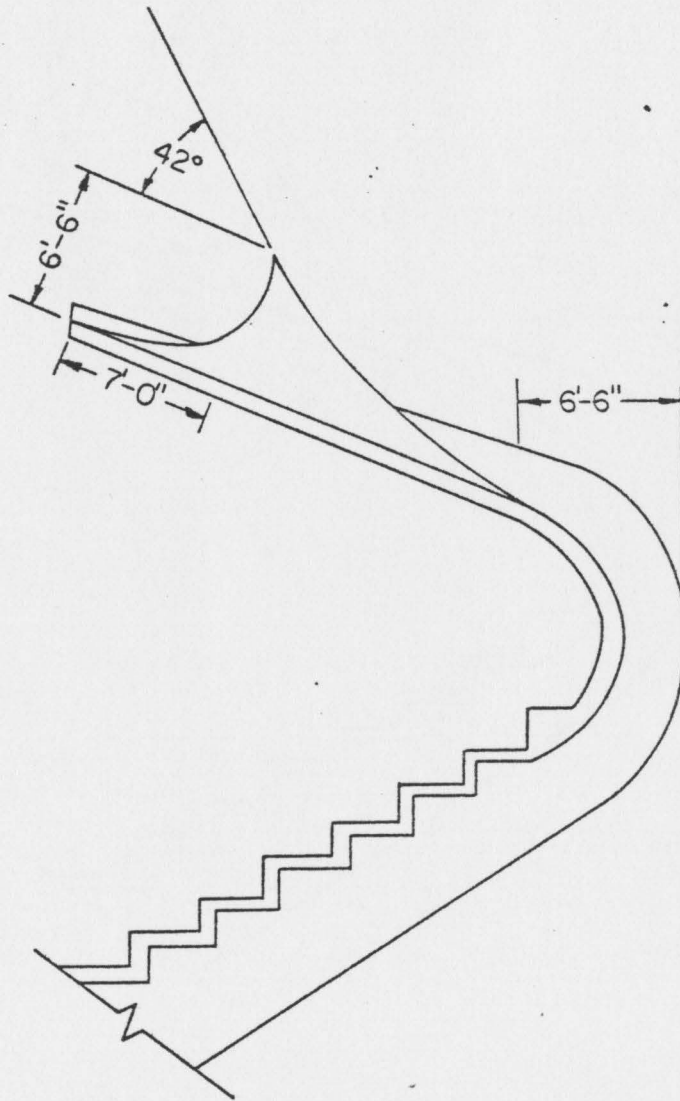


Fig. 10. Modification 3 -- Smooth Continuous Cusp on Upper Lip of Roof Section.

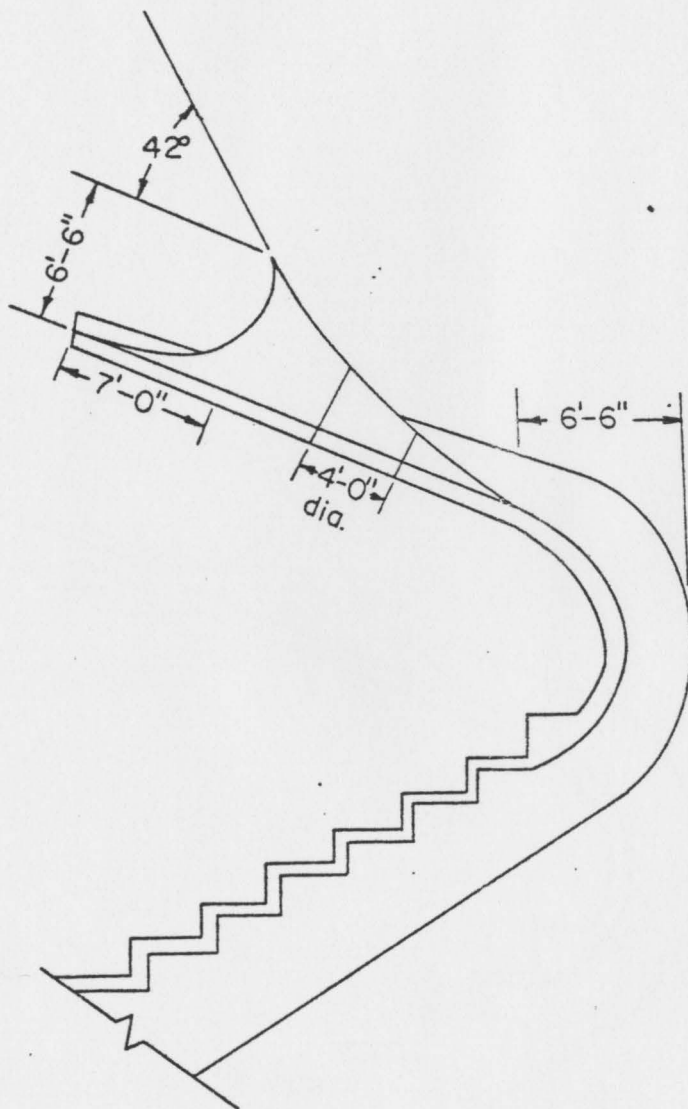


Fig. 11. Modification 4 -- Cusp on the Upper Lip & Holes in Roof Section.

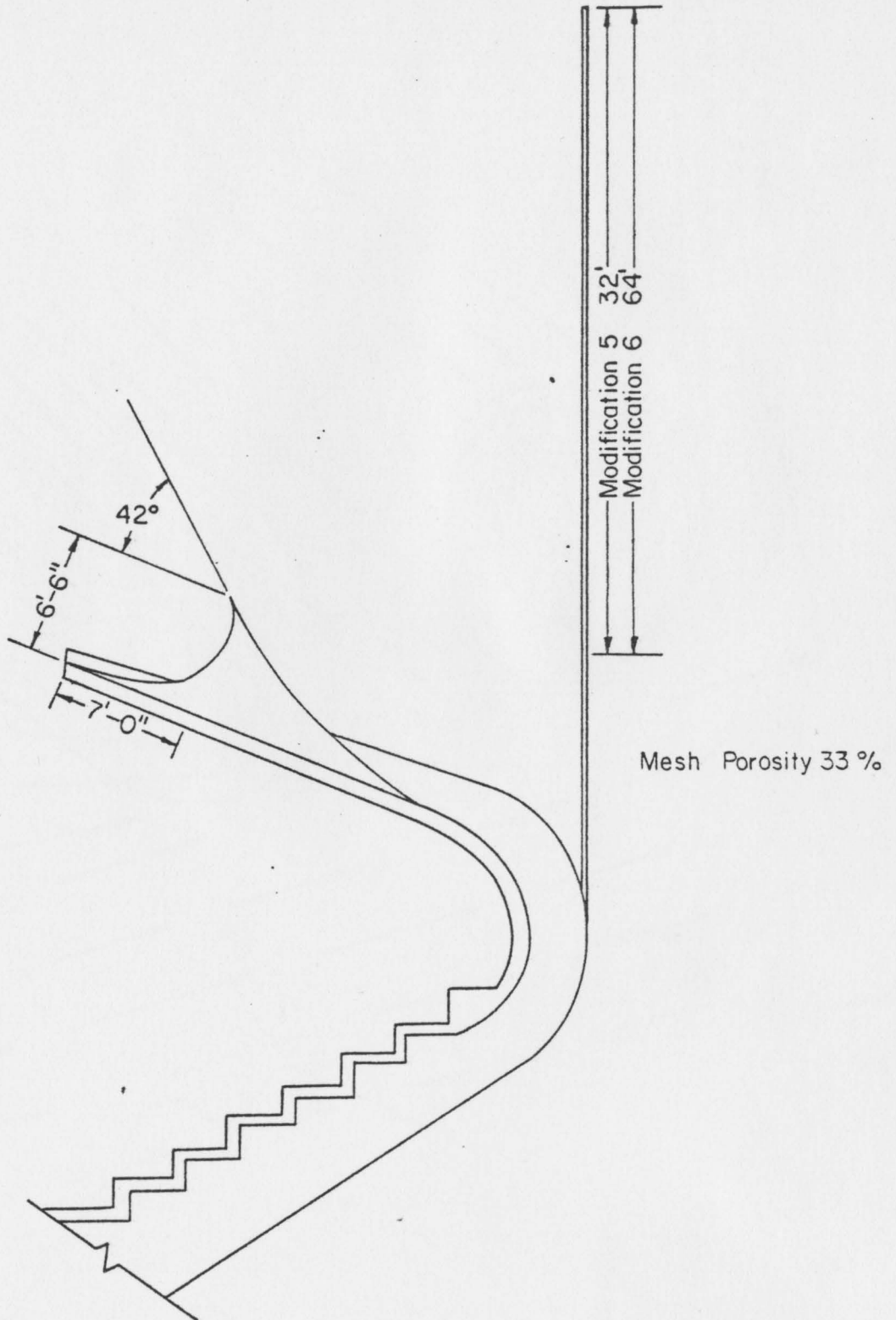
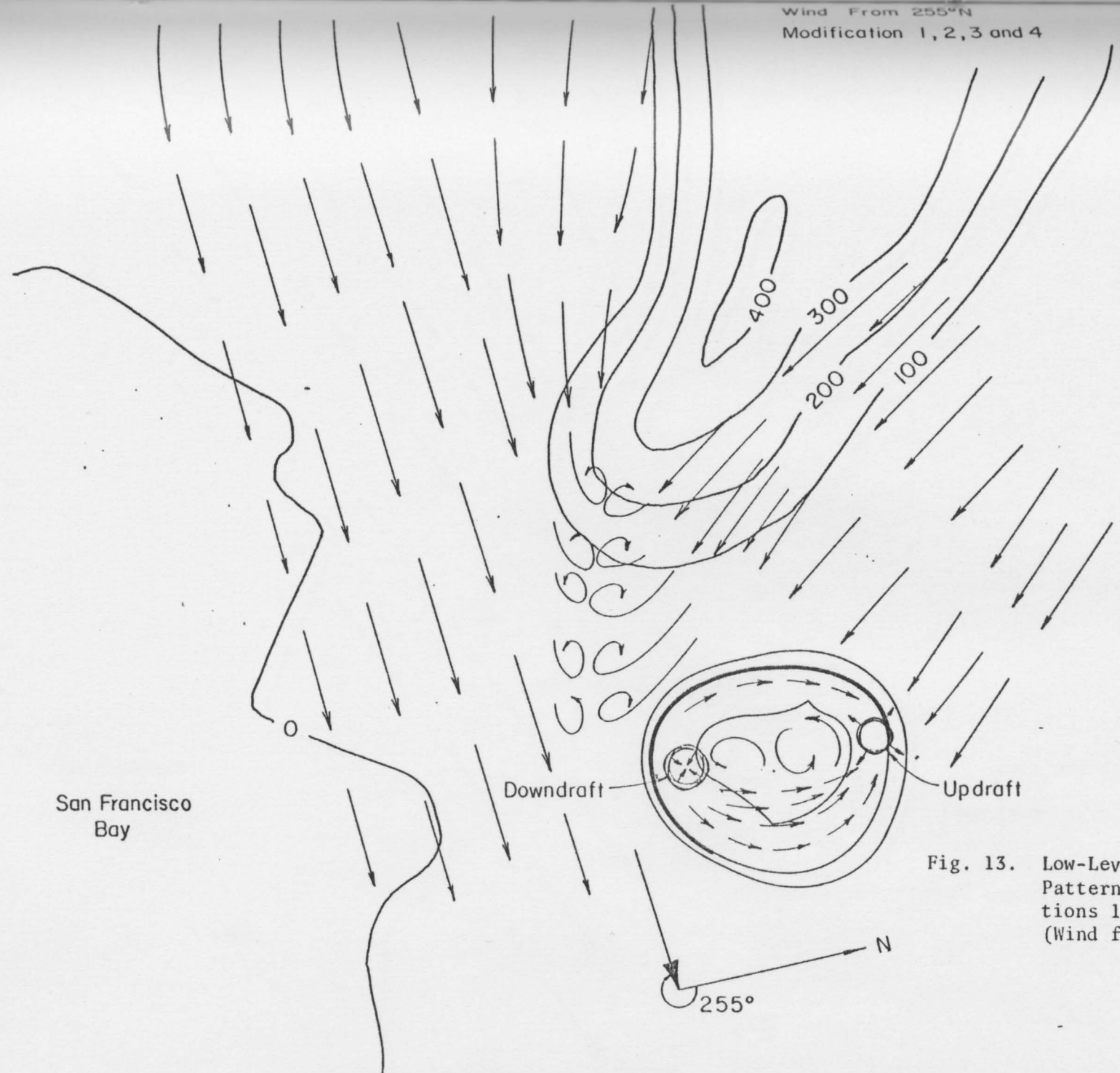


Fig. 12. Modification 5 & 6 -- Cusp on the Upper Lip & Screens 32 ft and 64 ft High.

Wind From 255°N
Modification 1, 2, 3 and 4



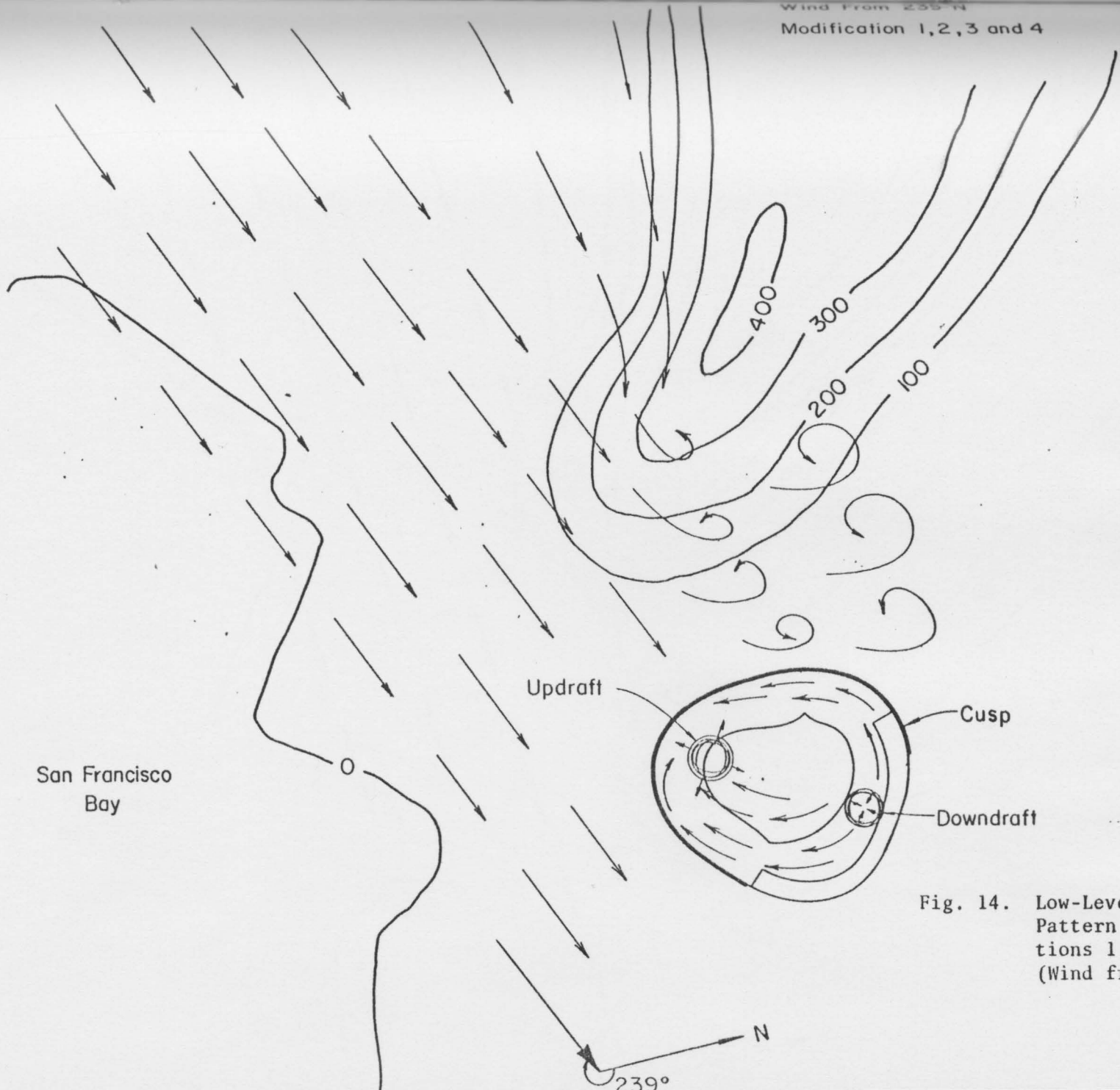
San Francisco Bay

Downdraft

Updraft

N
255°

Fig. 13. Low-Level Wind-Flow Pattern for Modifications 1, 2, 3, & 4 (Wind from 255°).



San Francisco Bay

Updraft

Cusp

Downdraft

N
239°

Fig. 14. Low-Level Wind-Flow Pattern for Modifications 1, 2, 3, & 4 (Wind from 239°).

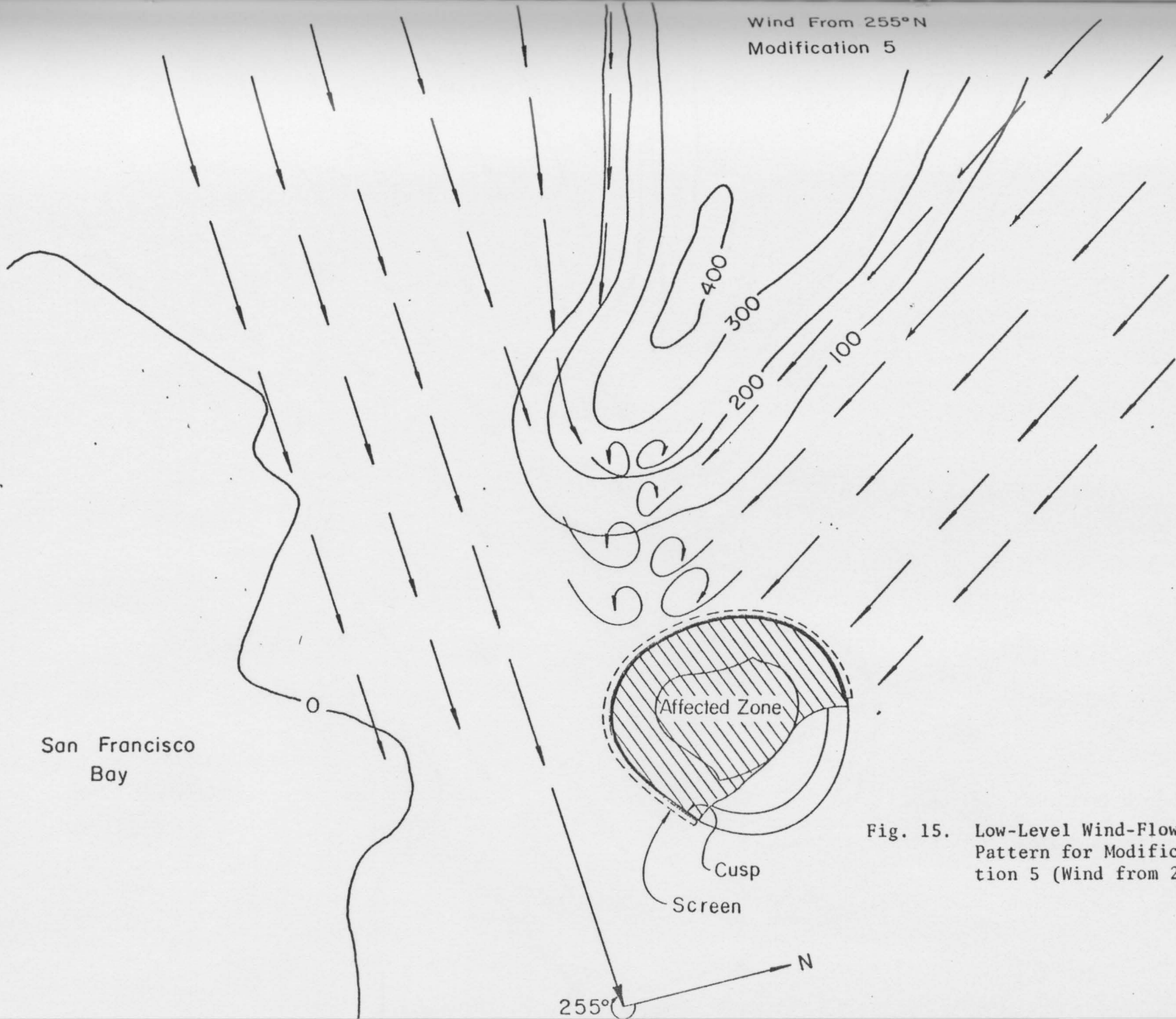
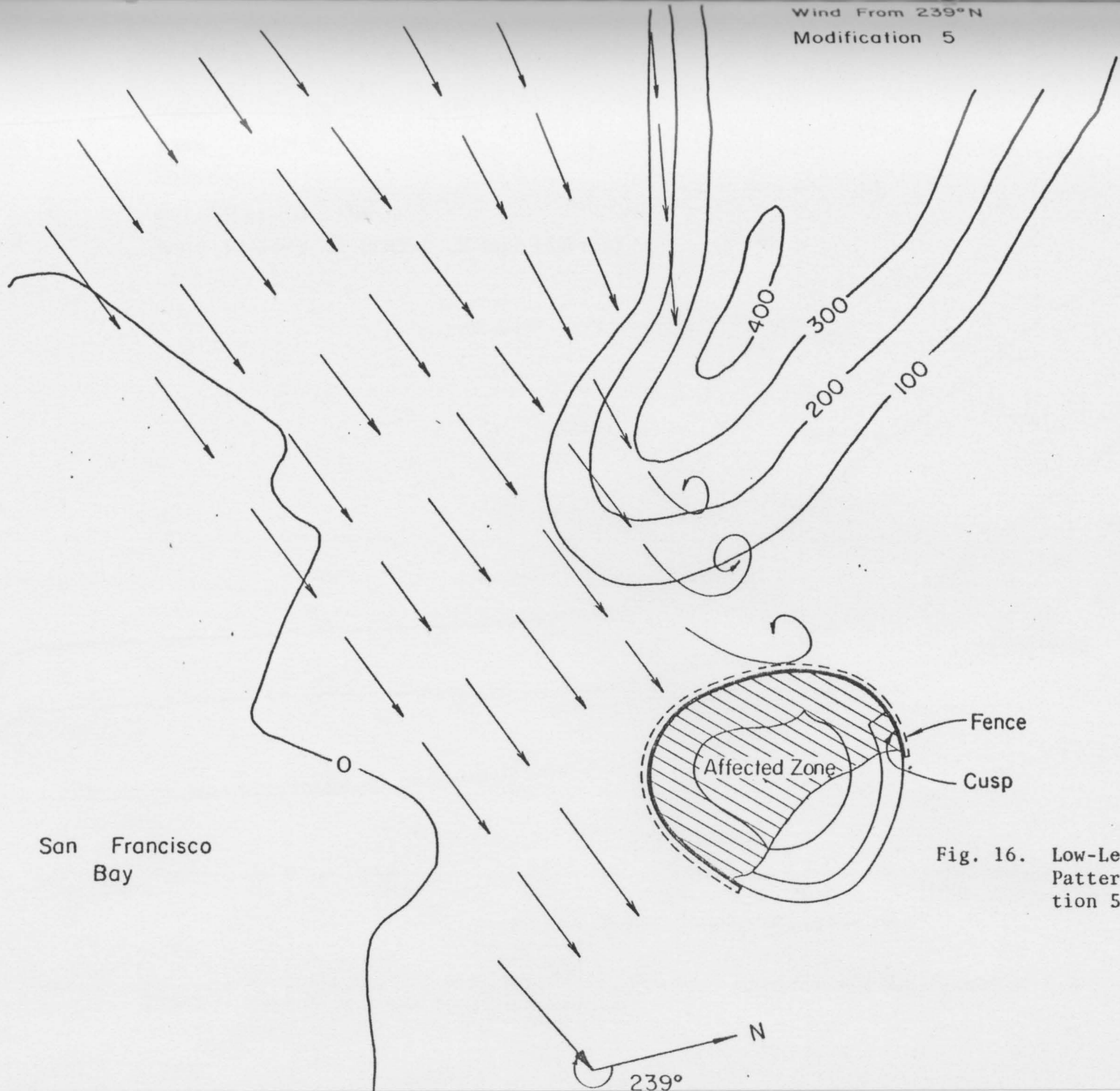


Fig. 15. Low-Level Wind-Flow Pattern for Modification 5 (Wind from 255°).

Wind From 239°N
Modification 5



San Francisco Bay

Fig. 16. Low-Level Wind-Flow Pattern for Modification 5 (Wind from 239°).

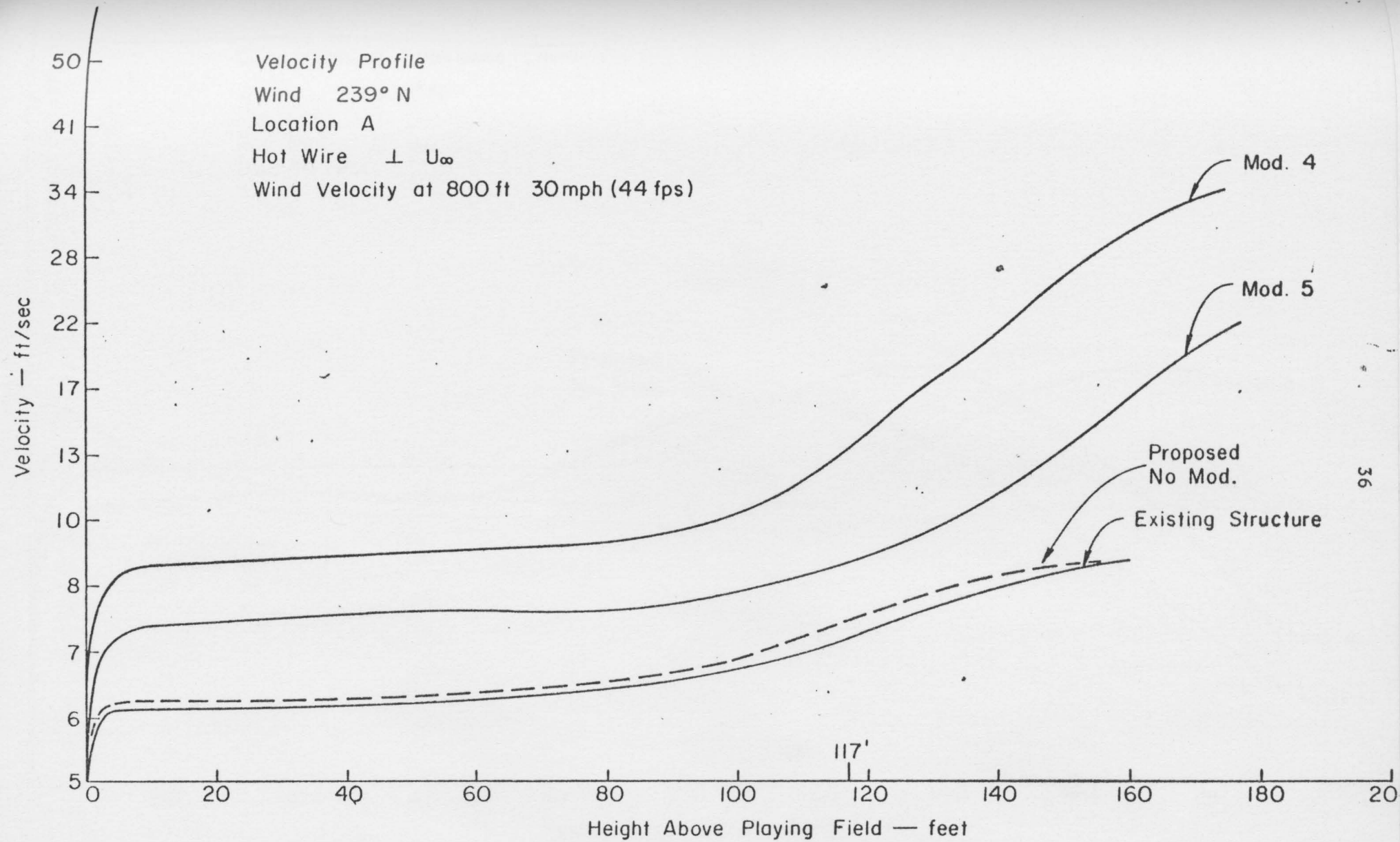


Fig. 17. Velocity Profiles for Existing Structure, Proposed Addition and Modifications 4 & 5 -- Wind at 239° -- Location A - Hot Wire Perpendicular.

Comparison of Turbulence Levels

Wind 239° N
Location A
Hot Wire ⊥ U_∞
U_∞ = 44 ft/sec

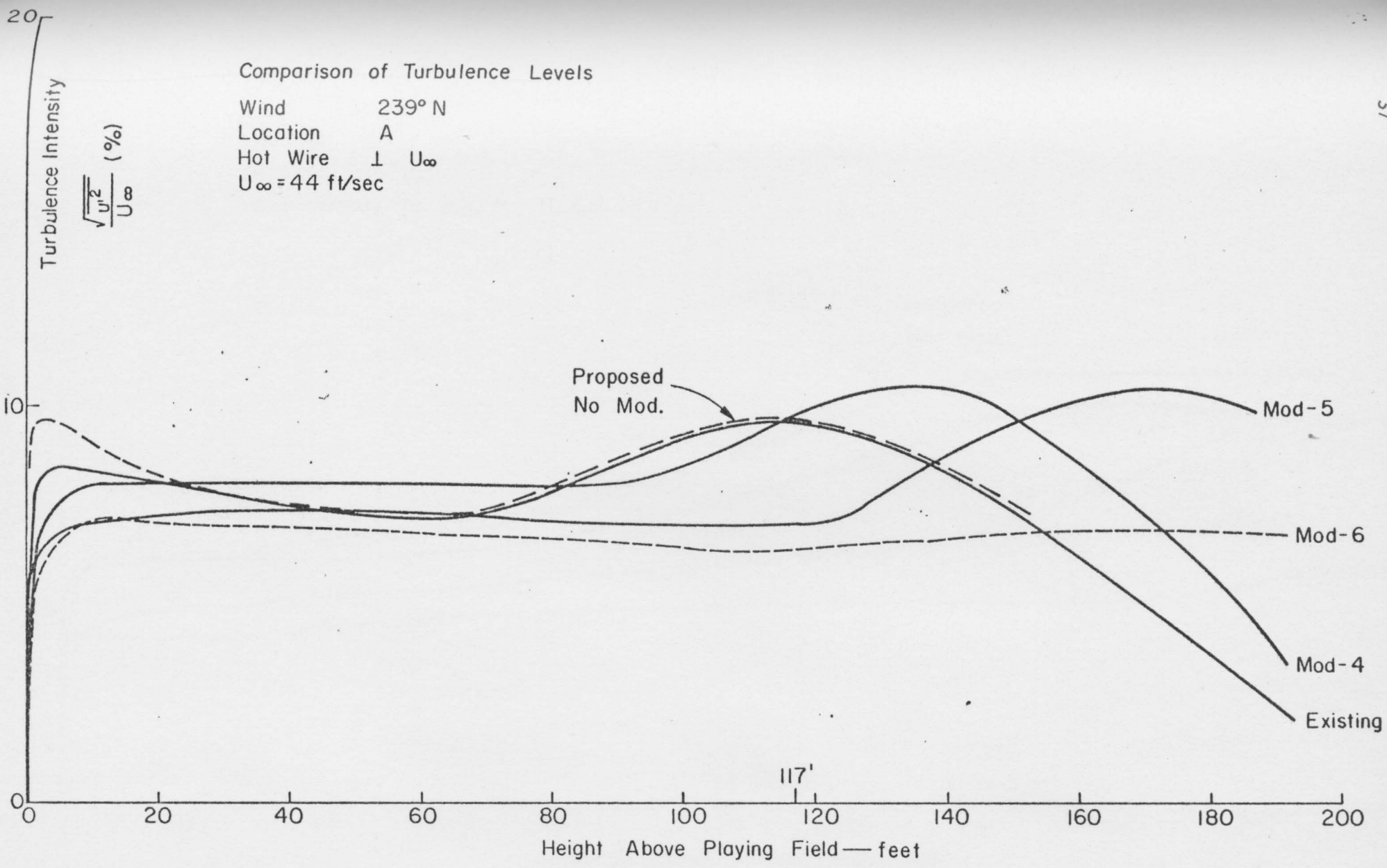


Fig. 18. Comparison of Turbulence for Existing Structure, Proposed Addition and Modifications 4, 5 & 6 -- Wind at 239° -- Location A - Hot Wire Perpendicular.

Velocity Profile
Wind 239° N
Location A
Hot Wire $\perp U_{\infty}$
Wind Velocity At 800 ft. 30 mph (44 fps)

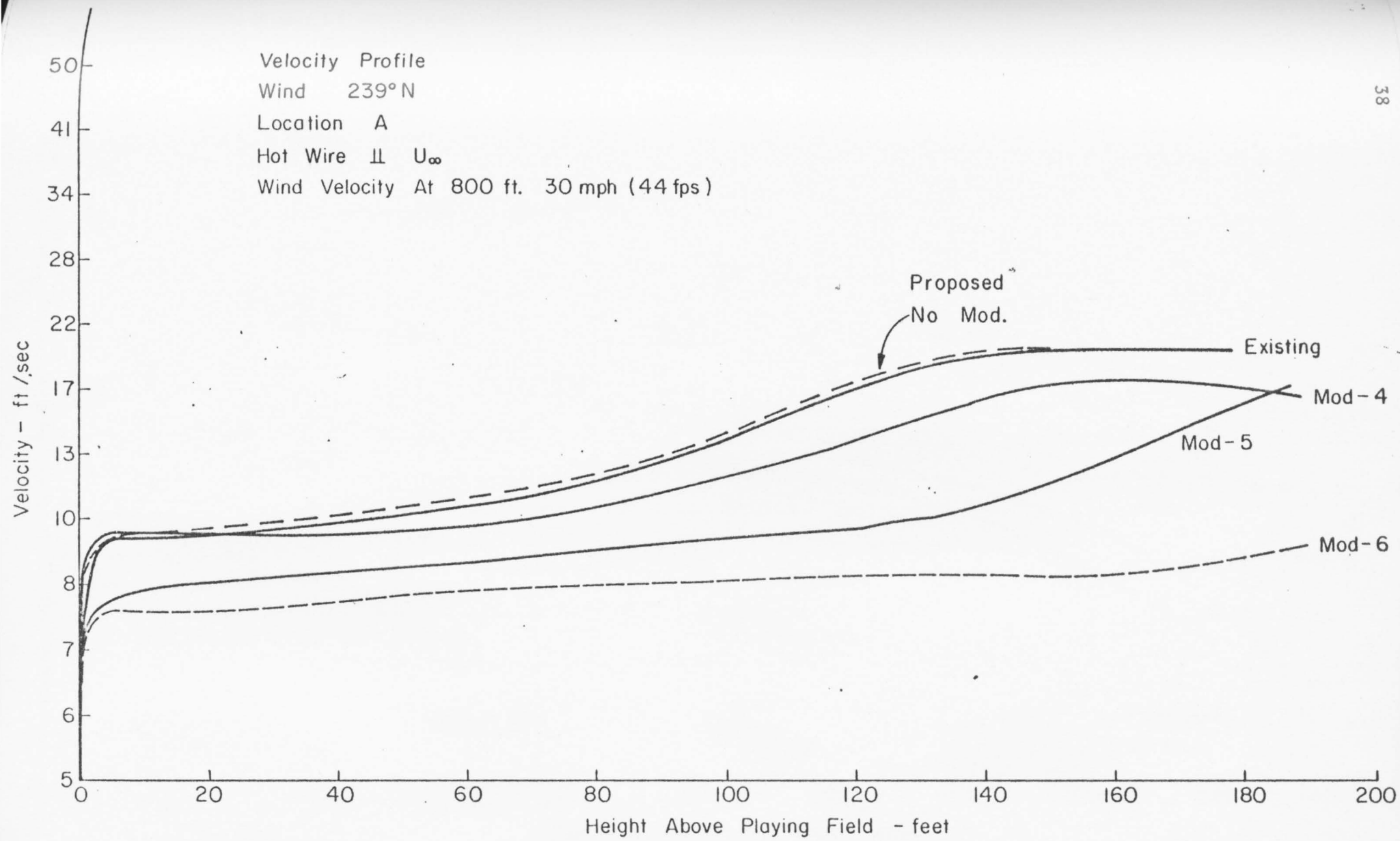


Fig. 19. Velocity Profiles for Existing Structure, Proposed Addition and Modifications 4, 5, & 6 -- Wind at 239° -- Location A -- Hot Wire Parallel.

Comparison of Turbulence Levels
Wind 239° N
Location A
Hot Wire $\perp U_{\infty}$
 $U_{\infty} = 44 \text{ ft/sec}$

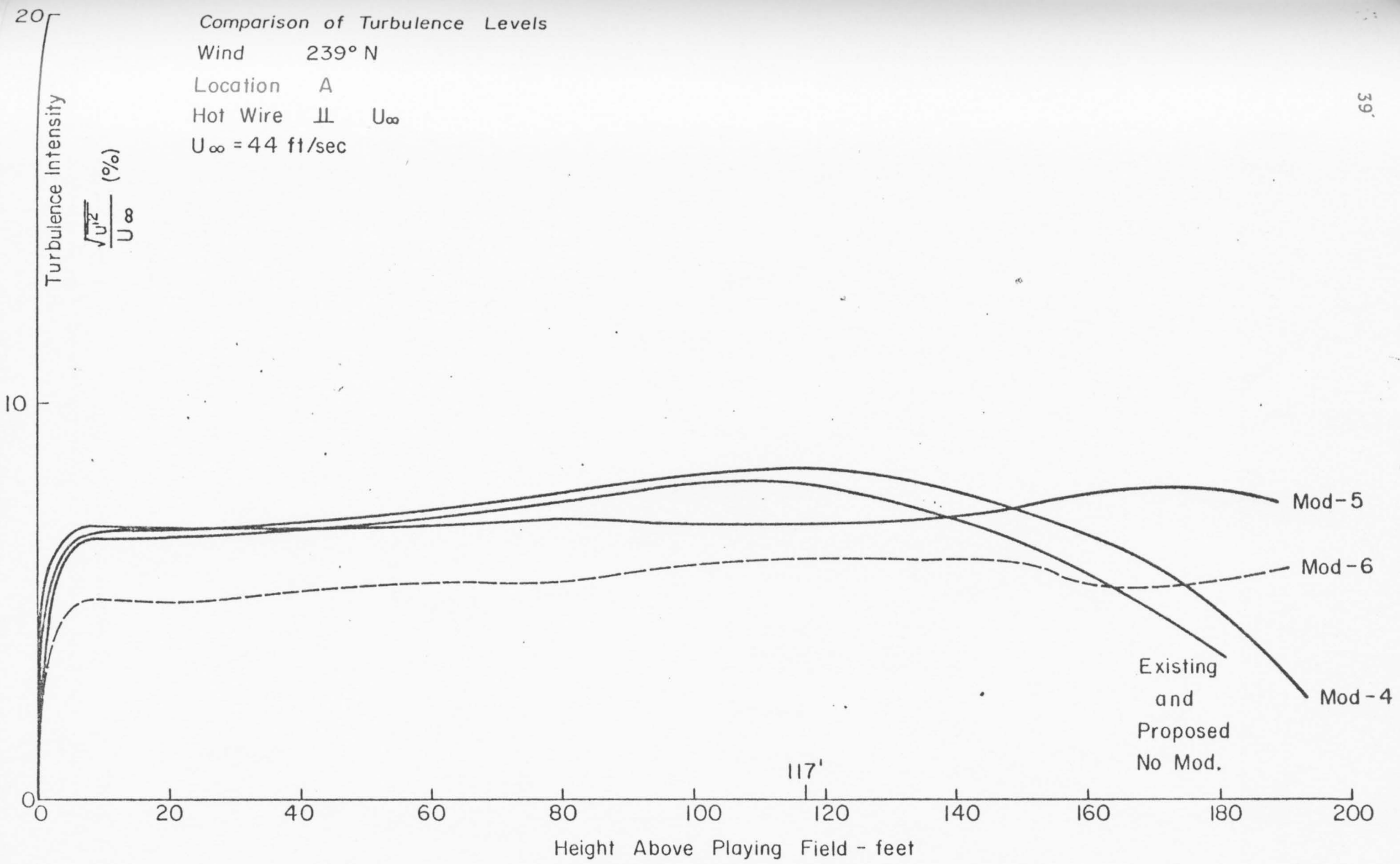


Fig. 20. Comparison of Turbulence for Existing Structure, Proposed Addition and Modifications 4, 5, & 6 -- Wind at 239° -- Location A -- Hot Wire Parallel.

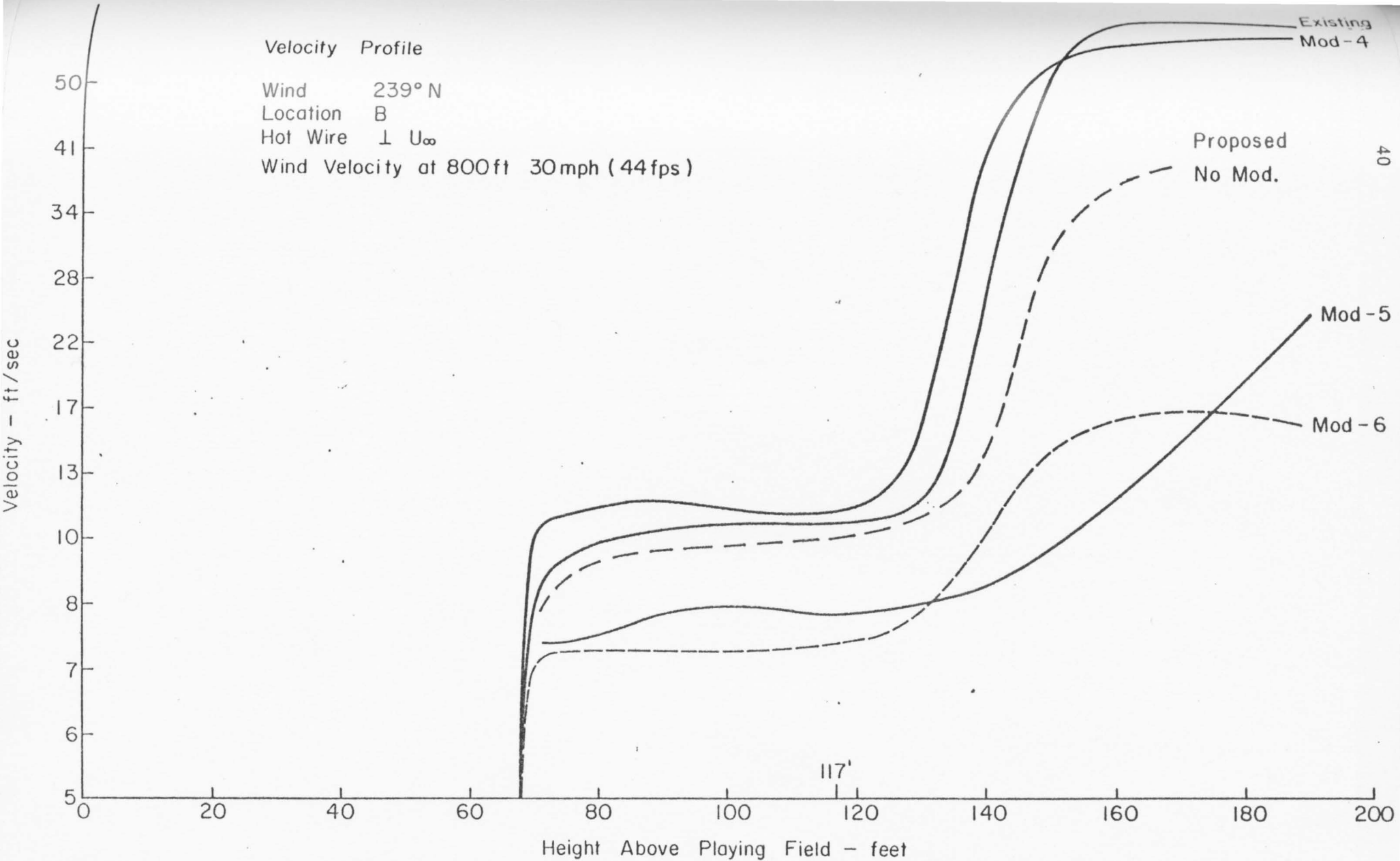


Fig. 21. Velocity Profiles for Existing Structure, Proposed Addition and Modifications 4, 5, & 6 -- Wind at 239° -- Location B -- Hot Wire Perpendicular.

Comparison of Turbulence Levels

Wind 239° N

Location B

Hot Wire $\perp U_{\infty}$

$U_{\infty} = 44$ ft/sec

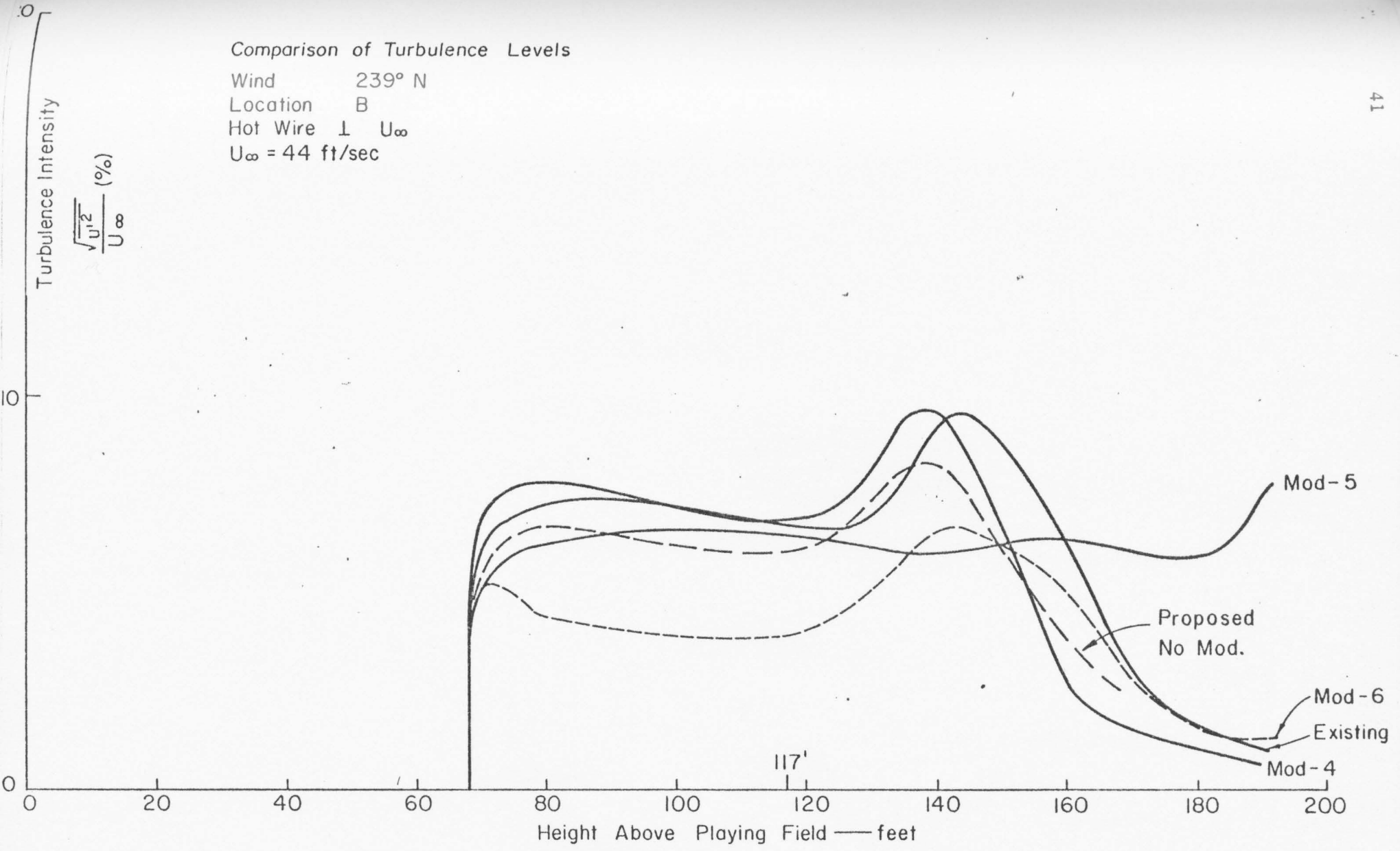


Fig. 22. Comparison of Turbulence for Existing Structure, Proposed Addition and Modifications 4, 5, & 6 -- Wind at 239° -- Location B -- Hot Wire Perpendicular.

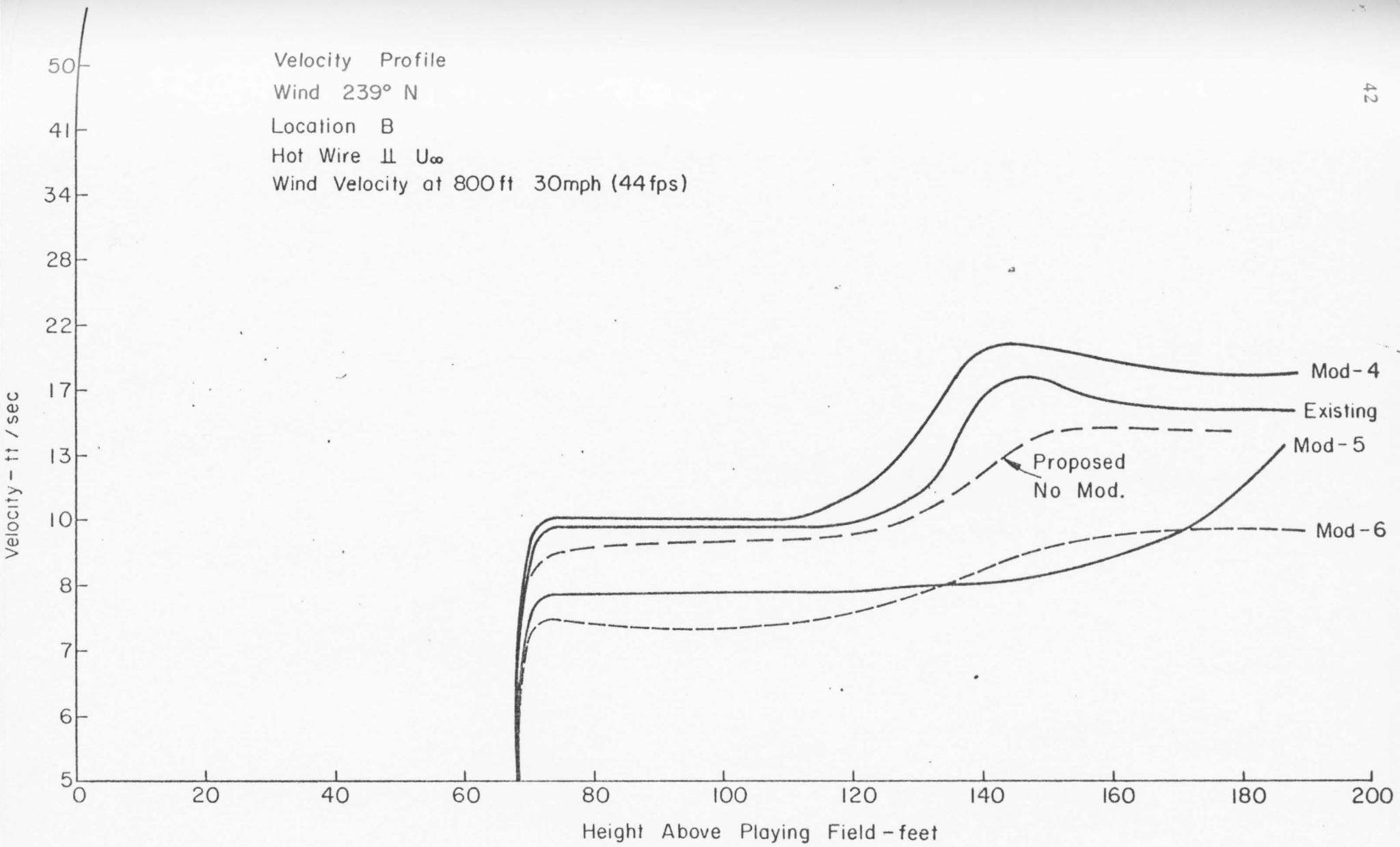


Fig. 23. Velocity Profiles for Existing Structure, Proposed Addition and Modifications 4, 5, & 6 -- Wind at 239° -- Location B -- Hot Wire Parallel.

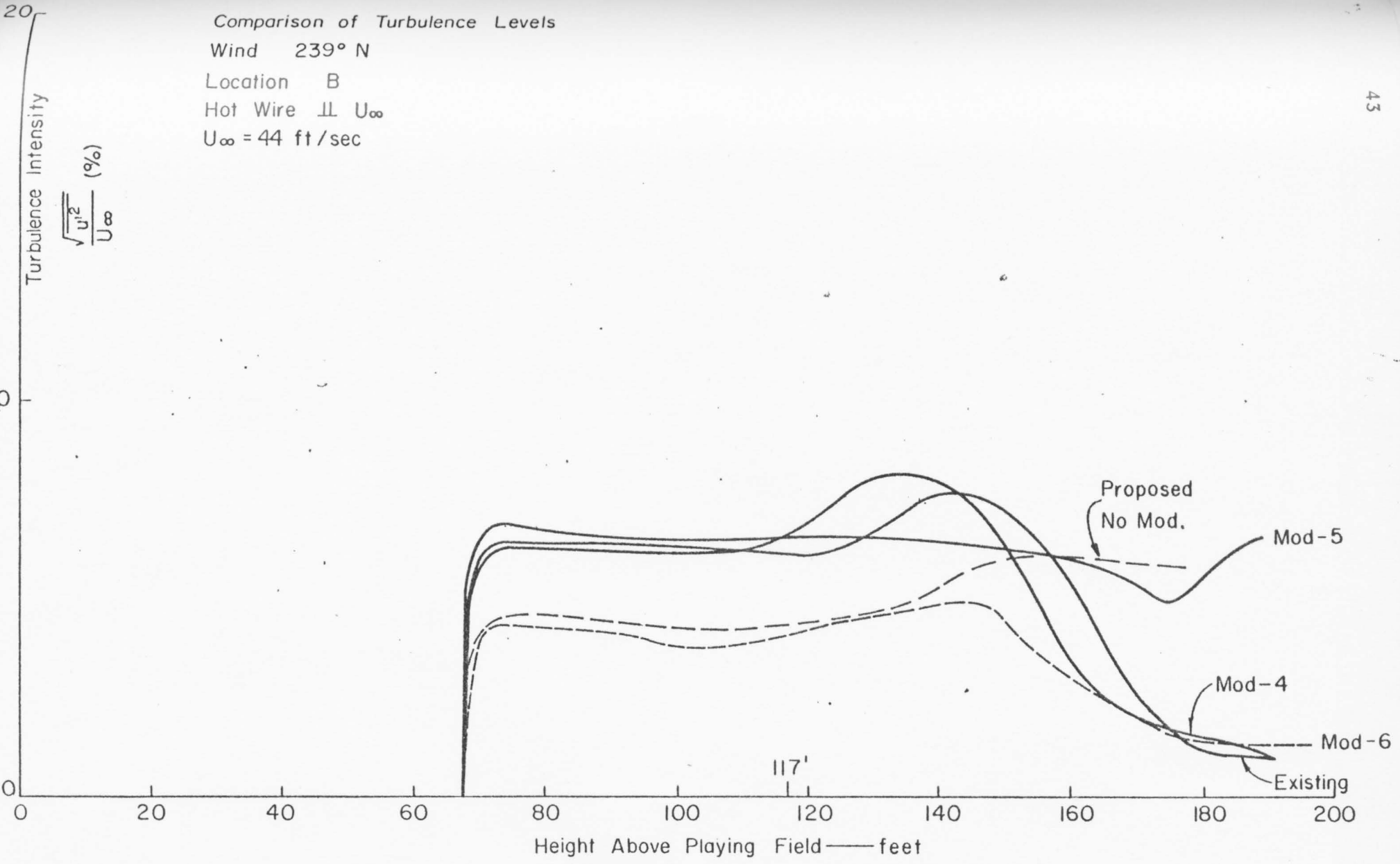


Fig. 24. Comparison of Turbulence for Existing Structure, Proposed Addition and Modifications 4, 5, & 6 -- Wind at 239° -- Location B -- Hot Wire Perpendicular.

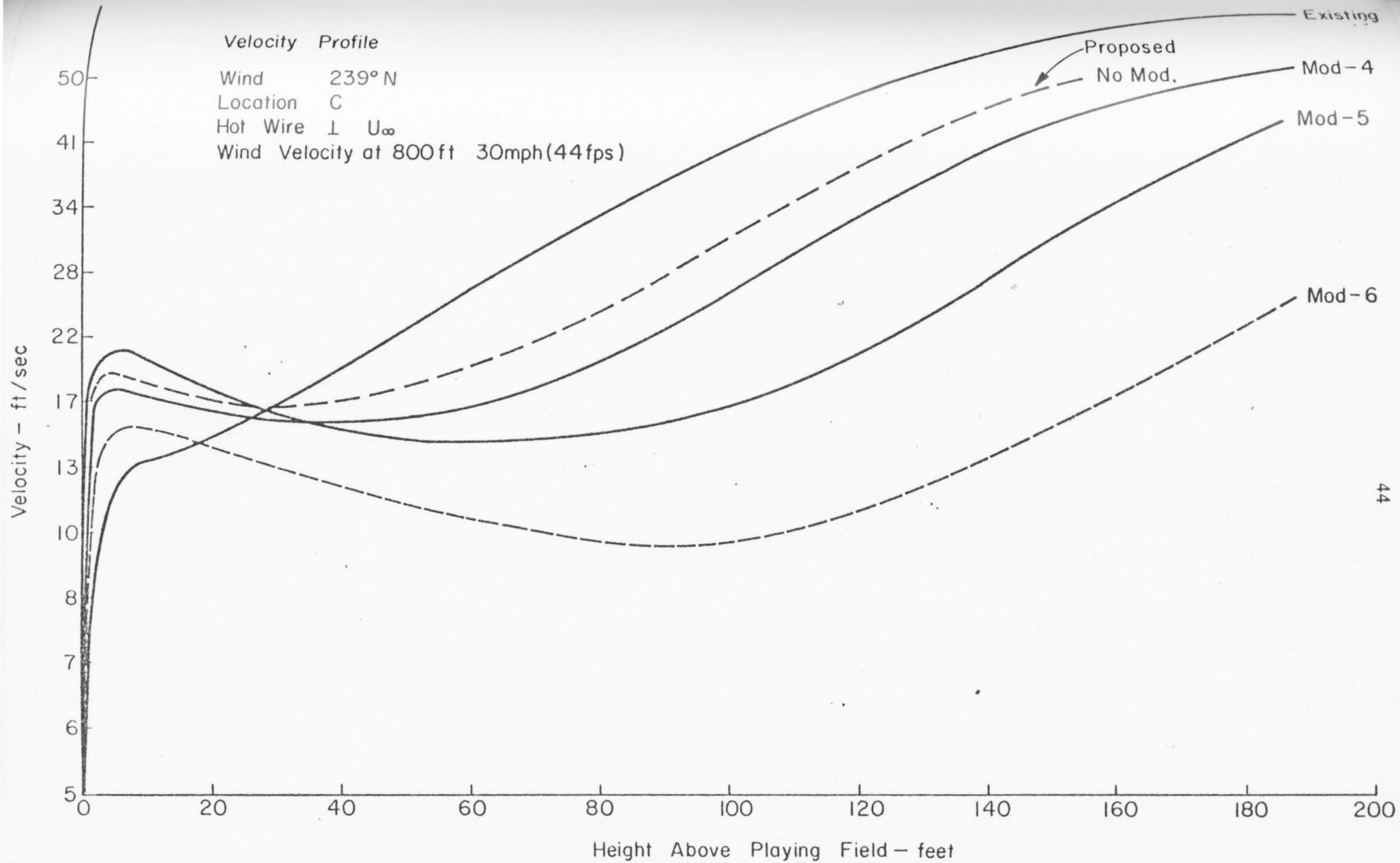


Fig. 25. Velocity Profiles for Existing Structure, Proposed Addition and Modifications 4, 5, & 6 -- Wind at 239° -- Location C -- Hot Wire Perpendicular.

Comparison of Turbulence Levels

Wind 239° N
Location C
Hot Wire $\perp U_{\infty}$
 $U_{\infty} = 44 \text{ ft/sec}$

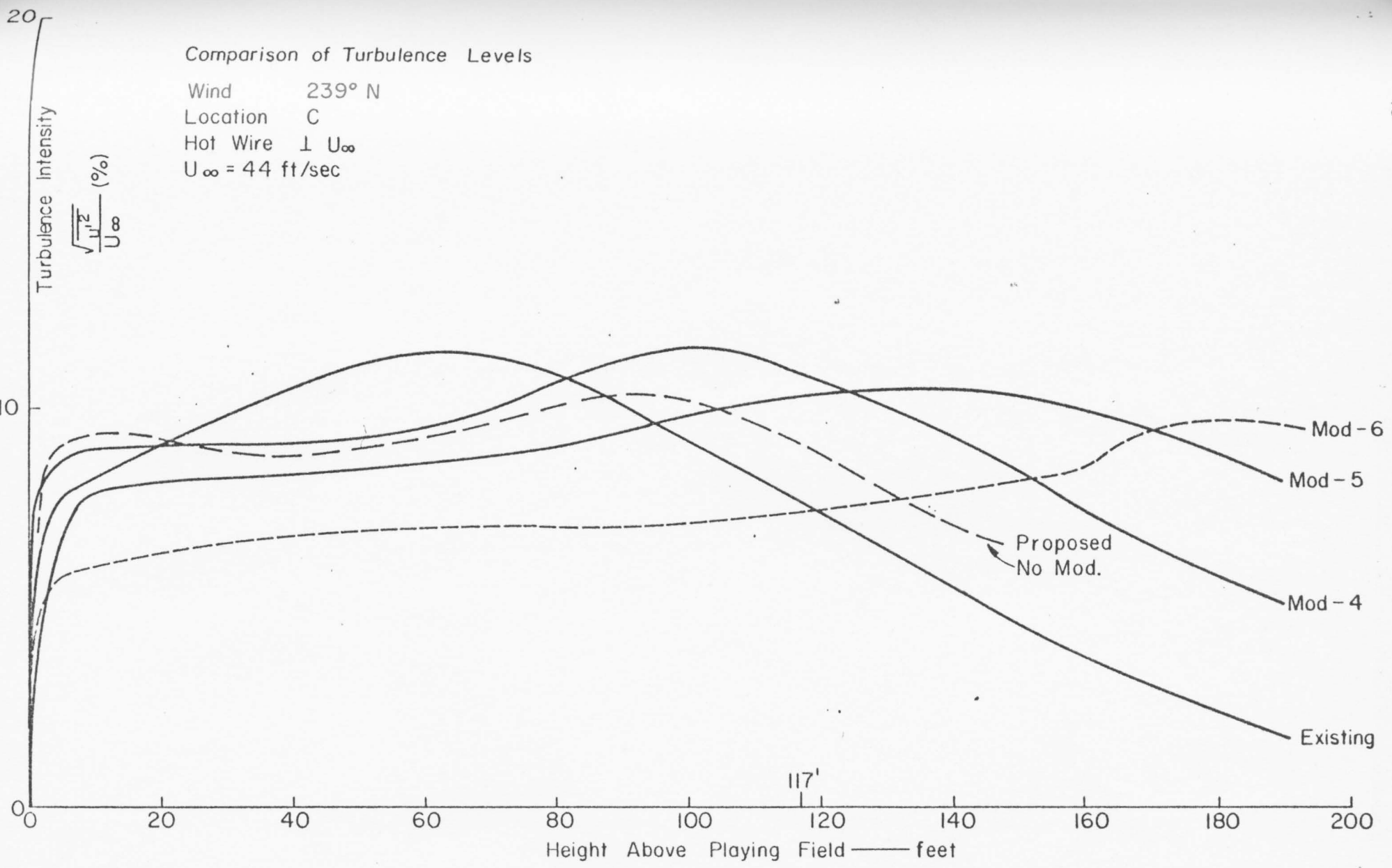


Fig. 26. Comparison of Turbulence for Existing Structure, Proposed Addition and Modifications 4, 5, & 6 -- Wind at 239° -- Location C -- Hot Wire Perpendicular.

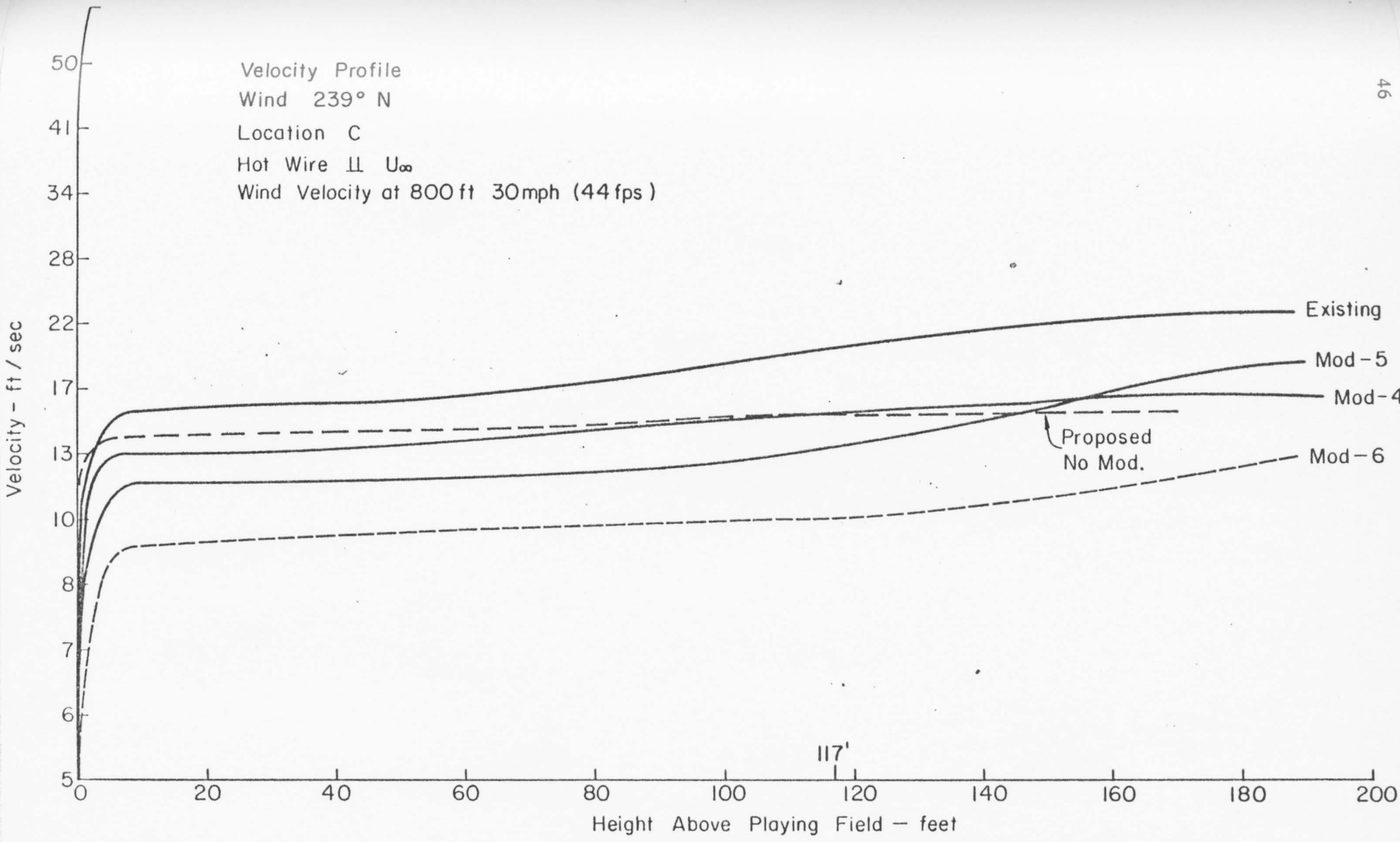


Fig. 27. Velocity Profiles for Existing Structure, Proposed Addition and Modifications 4, 5, & 6 -- Wind at 239° -- Location C -- Hot Wire Parallel.

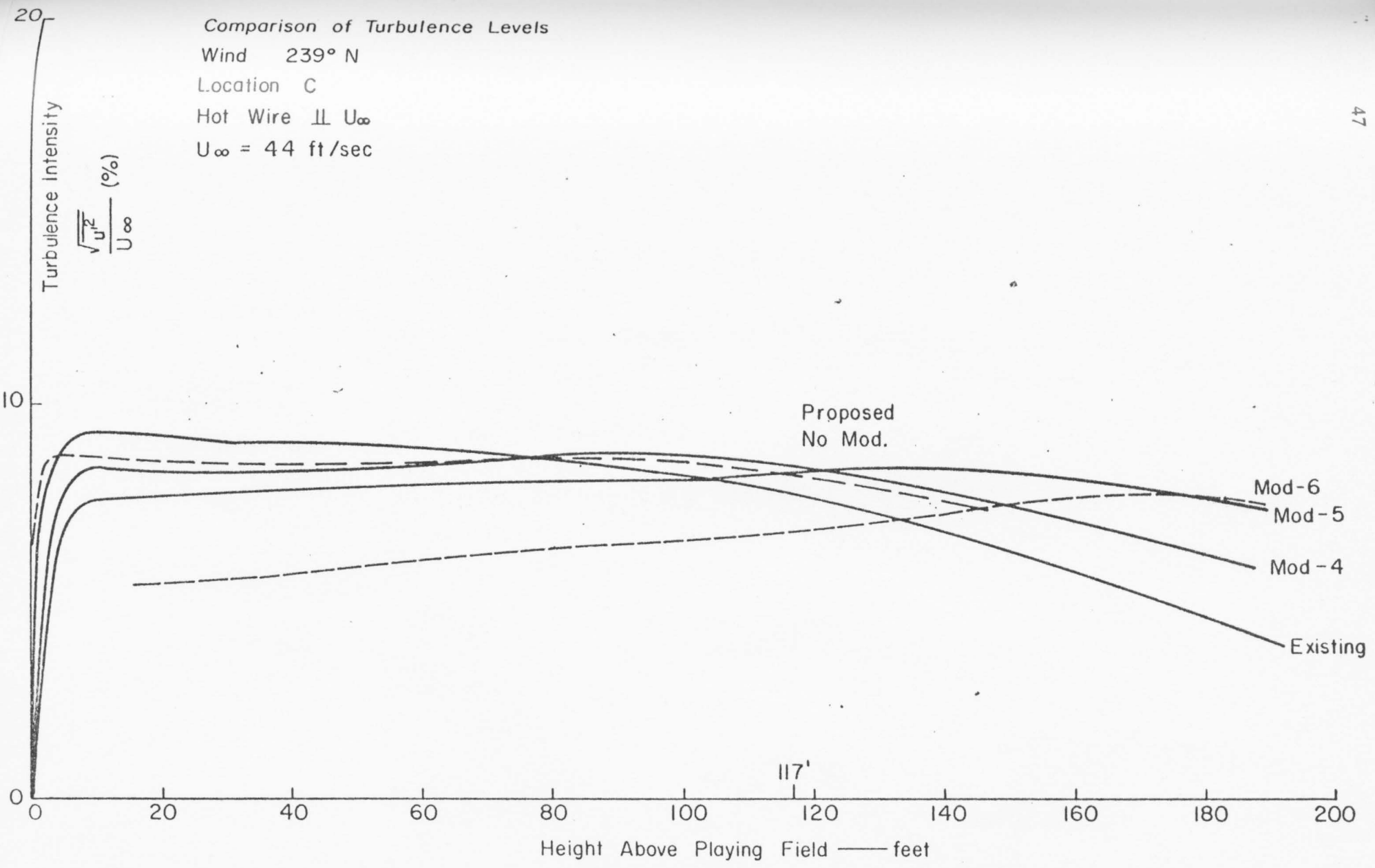


Fig. 28. Comparison of Turbulence for Existing Structure, Proposed Addition and Modifications 4, 5, & 6 -- Wind at 239° -- Location C -- Hot Wire Parallel.

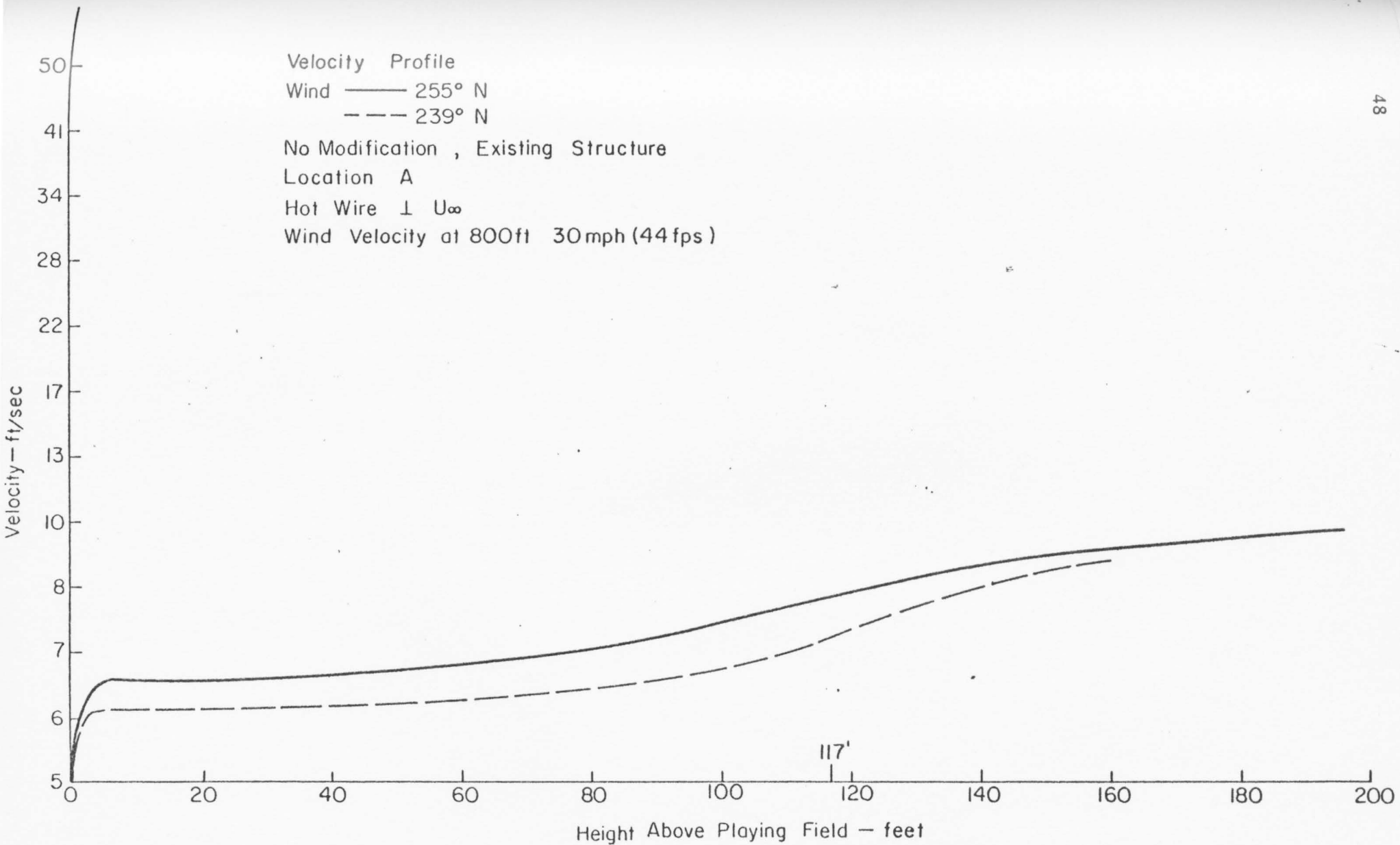


Fig. 29. Velocity Profiles for Existing Structures, and Proposed Addition -- Wind at 239° & 255° -- Location A -- Hot Wire Perpendicular.

Comparison of Turbulence Levels

Wind — 255° N

--- 239° N

No Modification, Existing Structure

Location A

Hot Wire $\perp U_{\infty}$

$U_{\infty} = 44$ ft/sec

Turbulence Intensity
 $\frac{\sqrt{u'^2}}{U_{\infty}}$ (%)

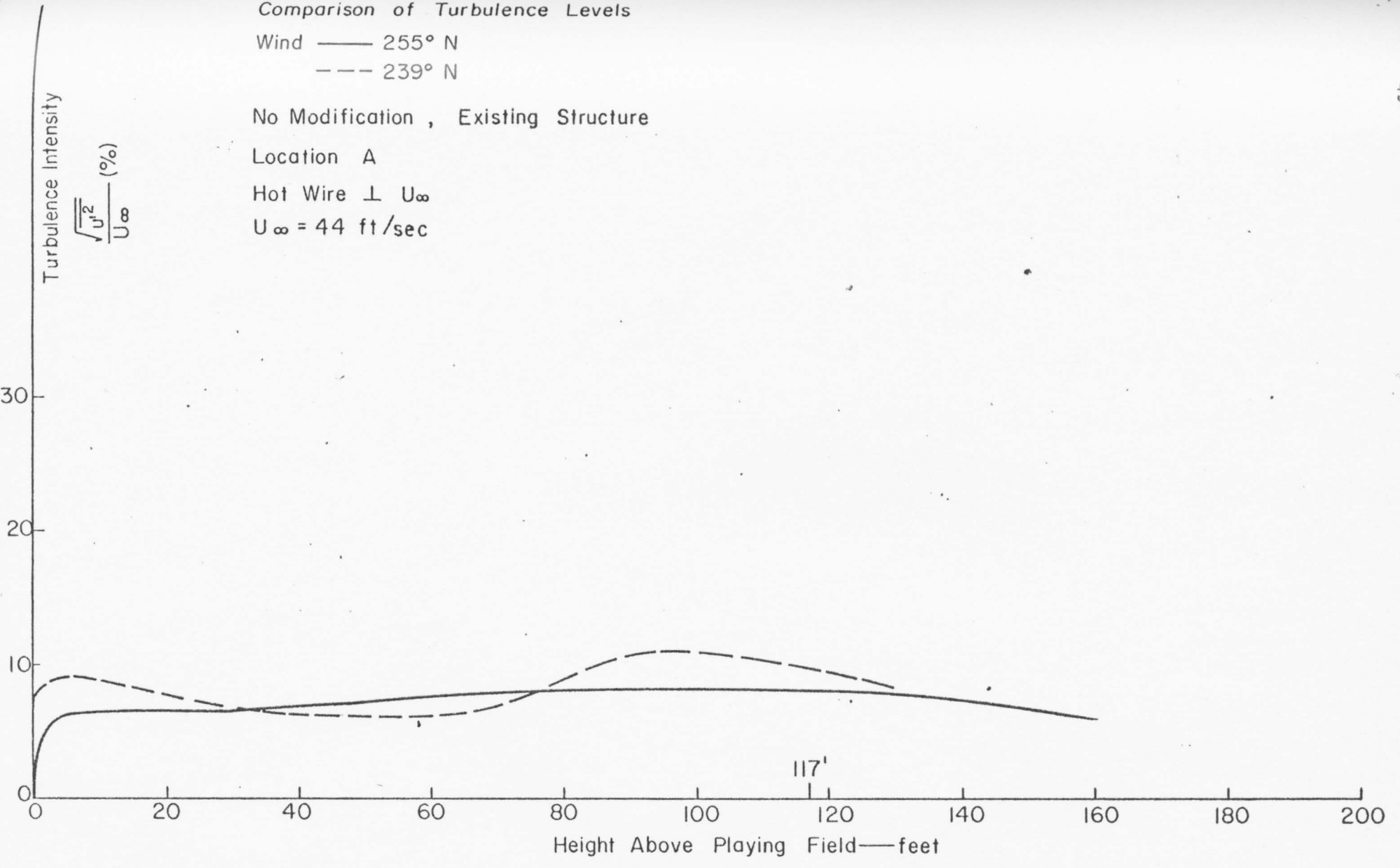


Fig. 30. Comparison of Turbulence for Existing Structures and Proposed Addition -- Wind at 239° & 255° -- Location A -- Hot Wire Perpendicular.

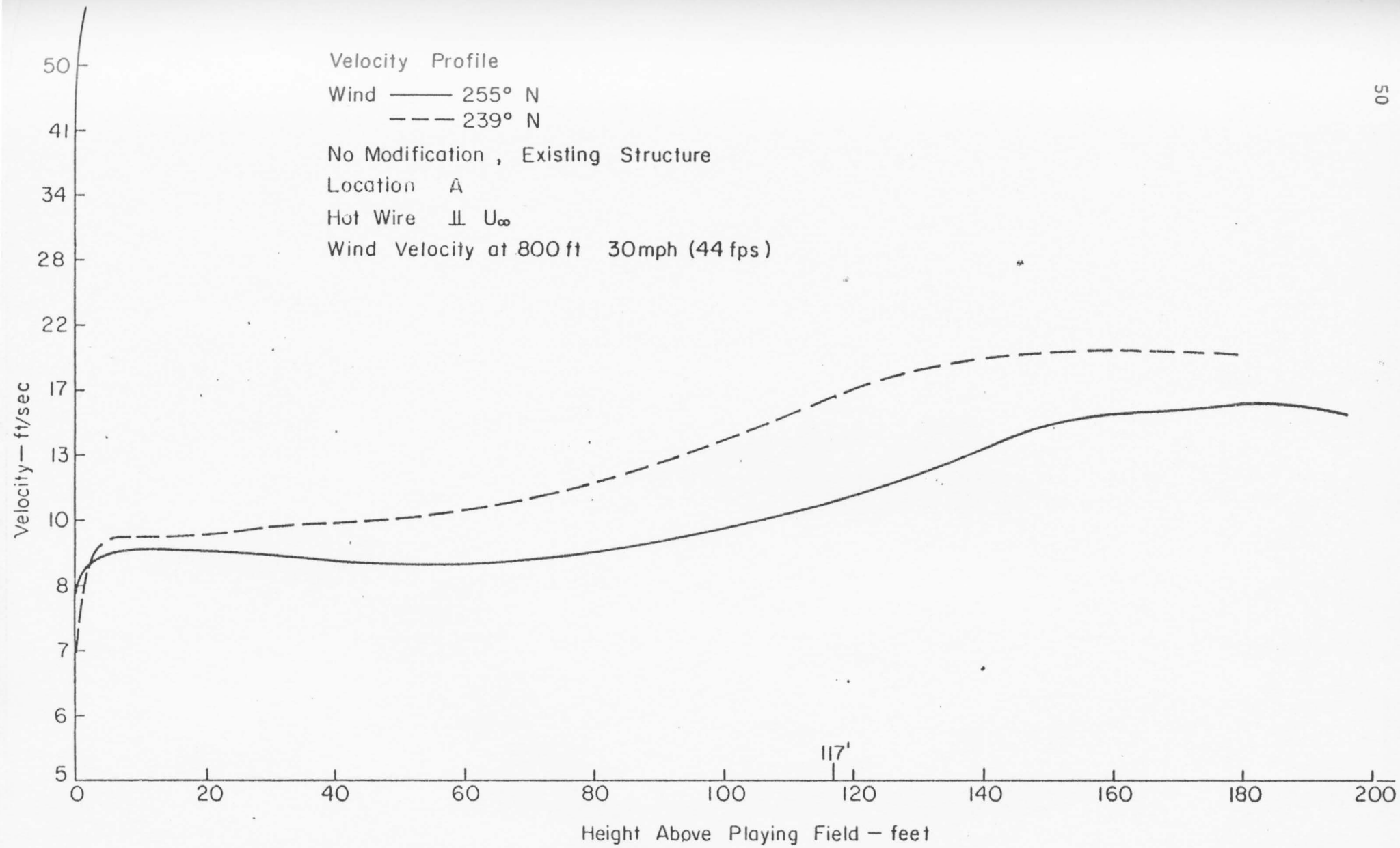


Fig. 31. Velocity Profiles for Existing Structures and Proposed Addition -- Wind at 239° and 255° -- Location A -- Hot Wire Parallel.

Comparison of Turbulence Levels

Wind — 255° N

--- 239° N

No Modification, Existing Structure

Location A

Hot Wire $\perp U_{\infty}$

$U_{\infty} = 44$ ft/sec

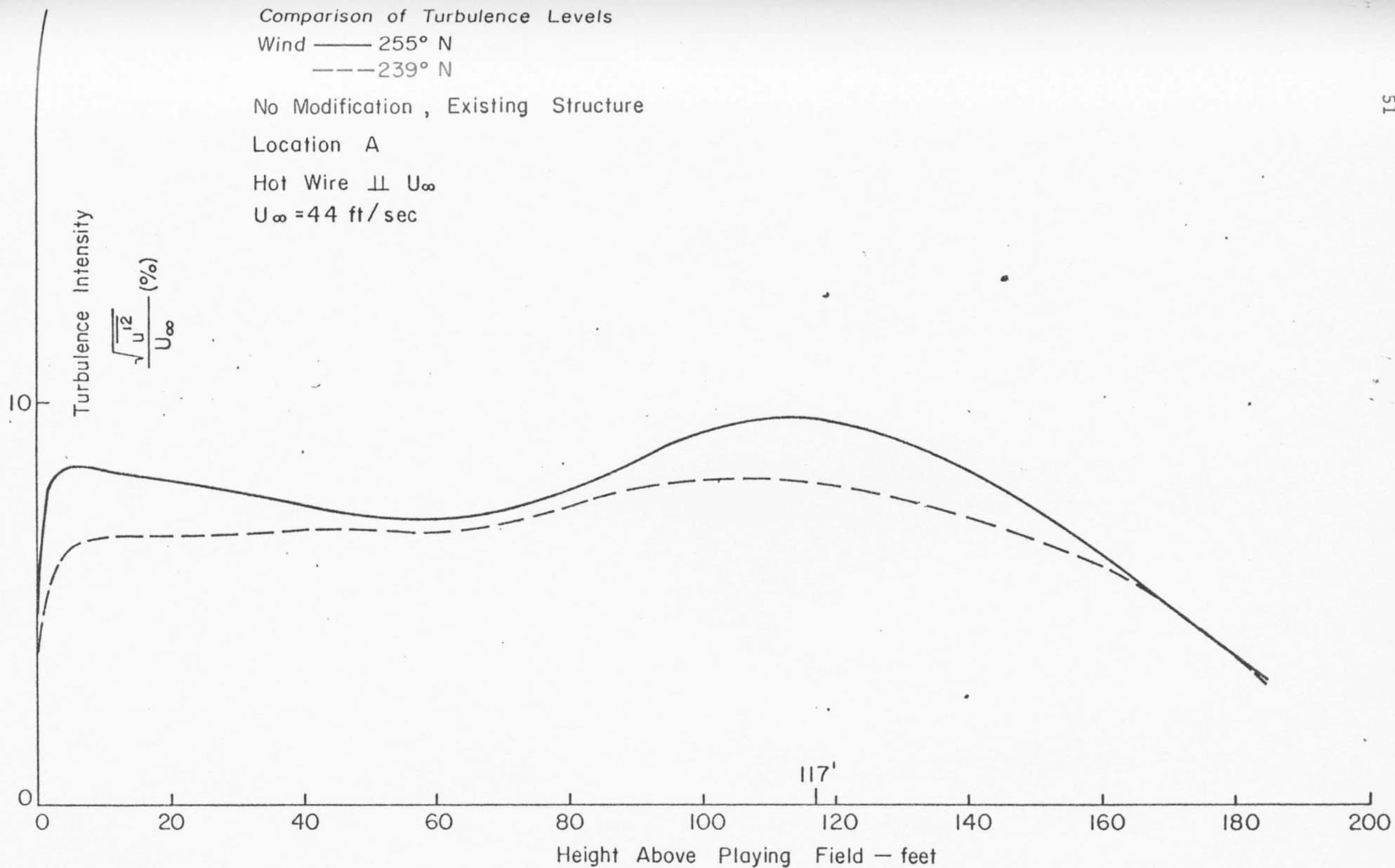


Fig. 32. Comparison of Turbulence for Existing Structures and Proposed Addition -- Wind at 239° & 255° -- Location A -- Hot Wire Parallel.

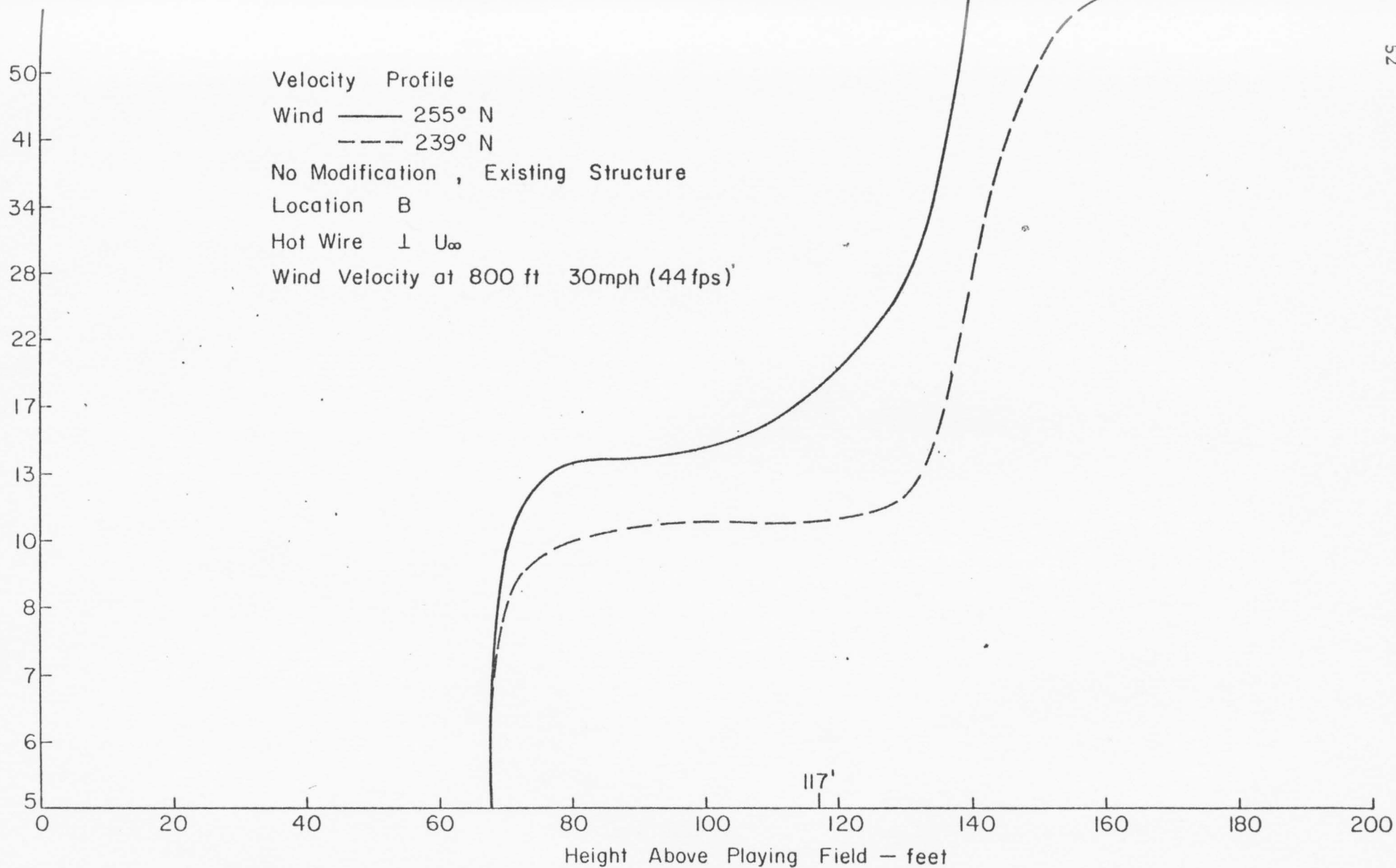


Fig. 33. Velocity Profiles for Existing Structures and Proposed Addition -- Wind at 239° & 255° -- Location B -- Hot Wire Perpendicular.

Comparison of Turbulence Levels
 Wind 255° N
 No Modification, Existing Structure
 Location B
 Hot Wire $\perp U_{\infty}$
 $U_{\infty} = 44$ ft/sec

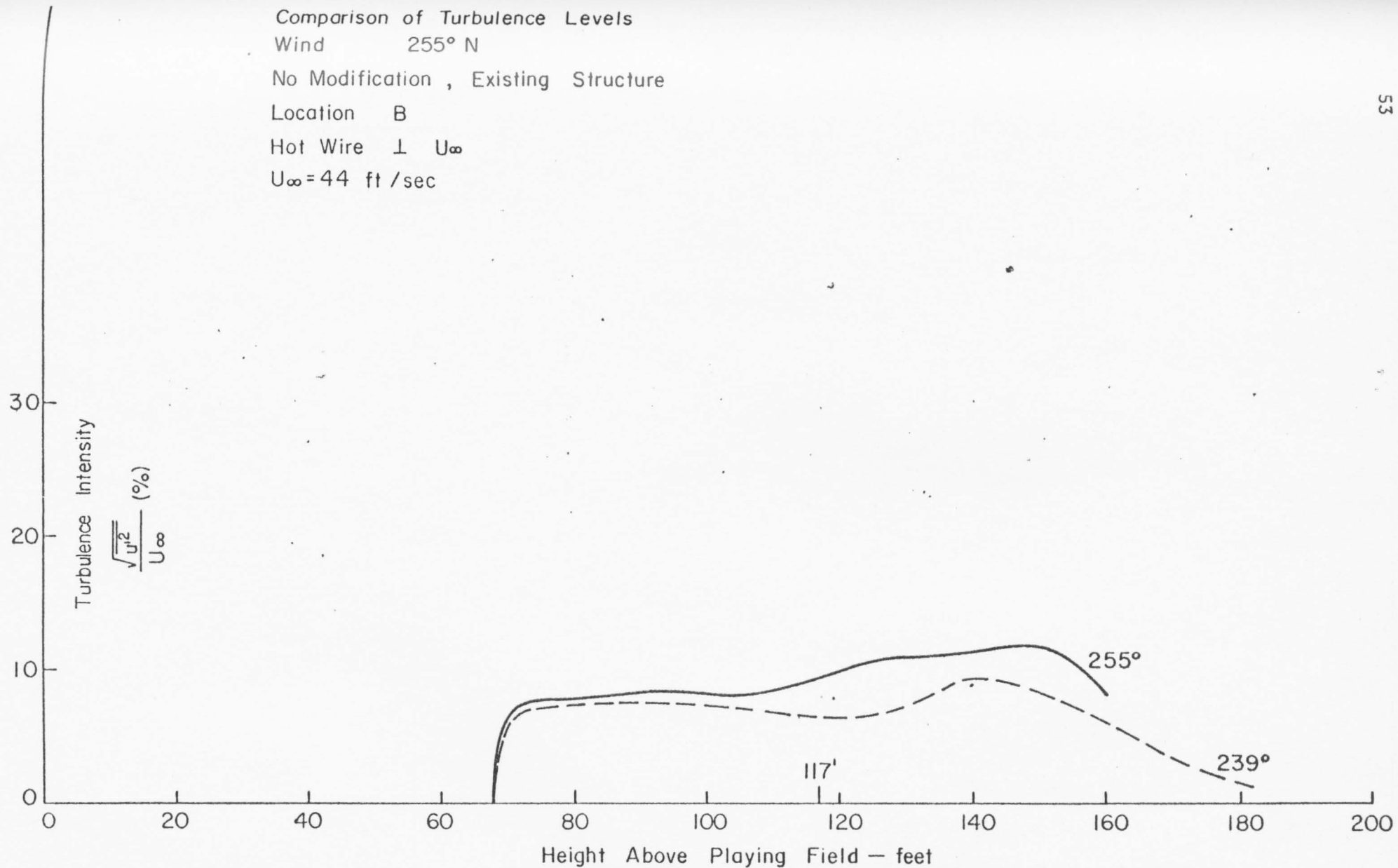


Fig. 34. Comparison of Turbulence for Existing Structures and Proposed Addition -- Wind at 239° & 255° -- Location B -- Hot Wire Perpendicular.

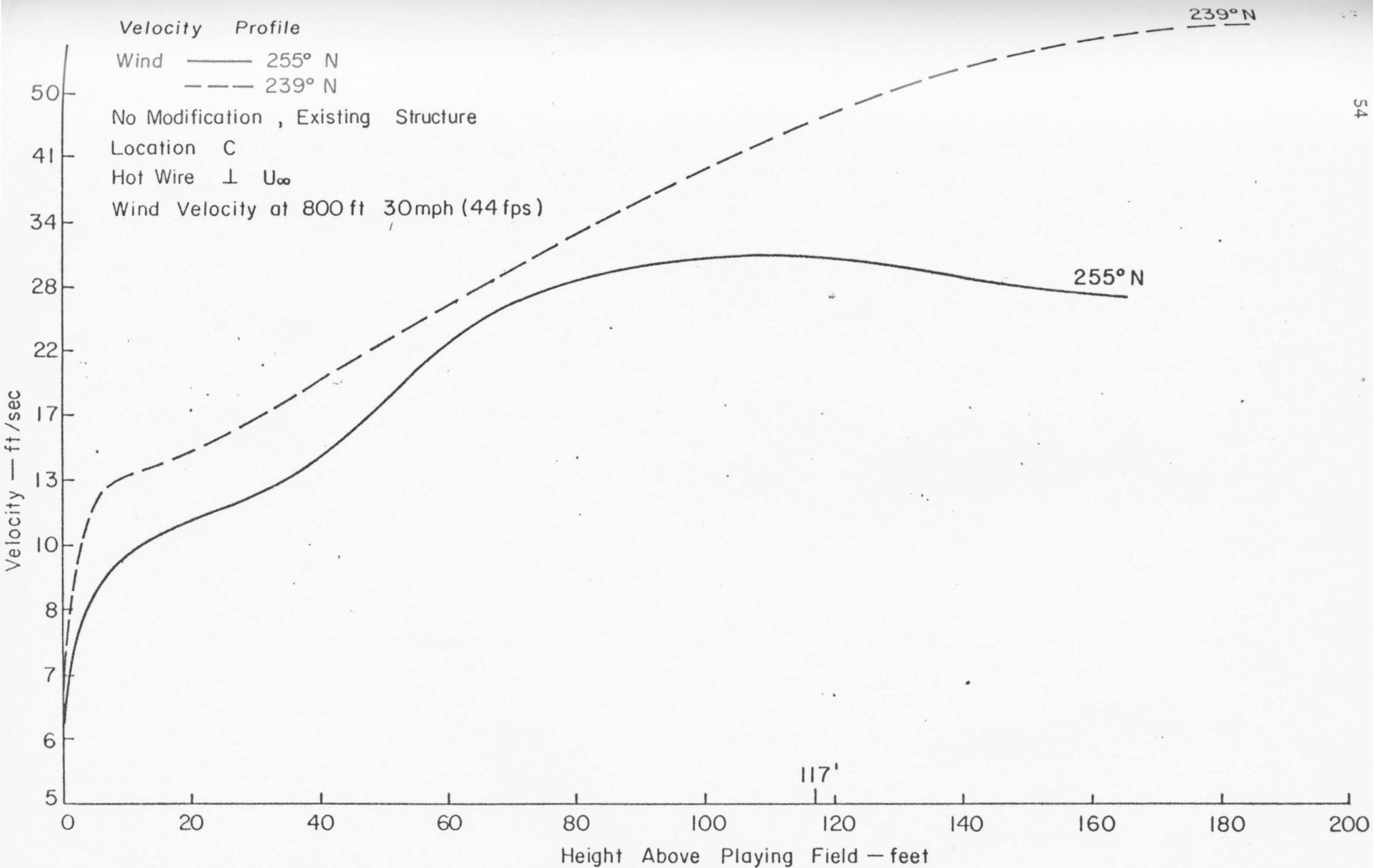


Fig. 35. Velocity Profiles for Existing Structures and Proposed Addition -- Wind at 239° & 255° -- Location C -- Hot Wire Perpendicular.

Comparison of Turbulence Levels

Wind ——— 255° N

--- 239° N

No Modification , Existing Structure

Location C

Hot Wire ⊥ U_∞

U_∞ = 44 ft/sec

Turbulence Intensity
 $\frac{\sqrt{u'^2}}{U_\infty}$ (%)

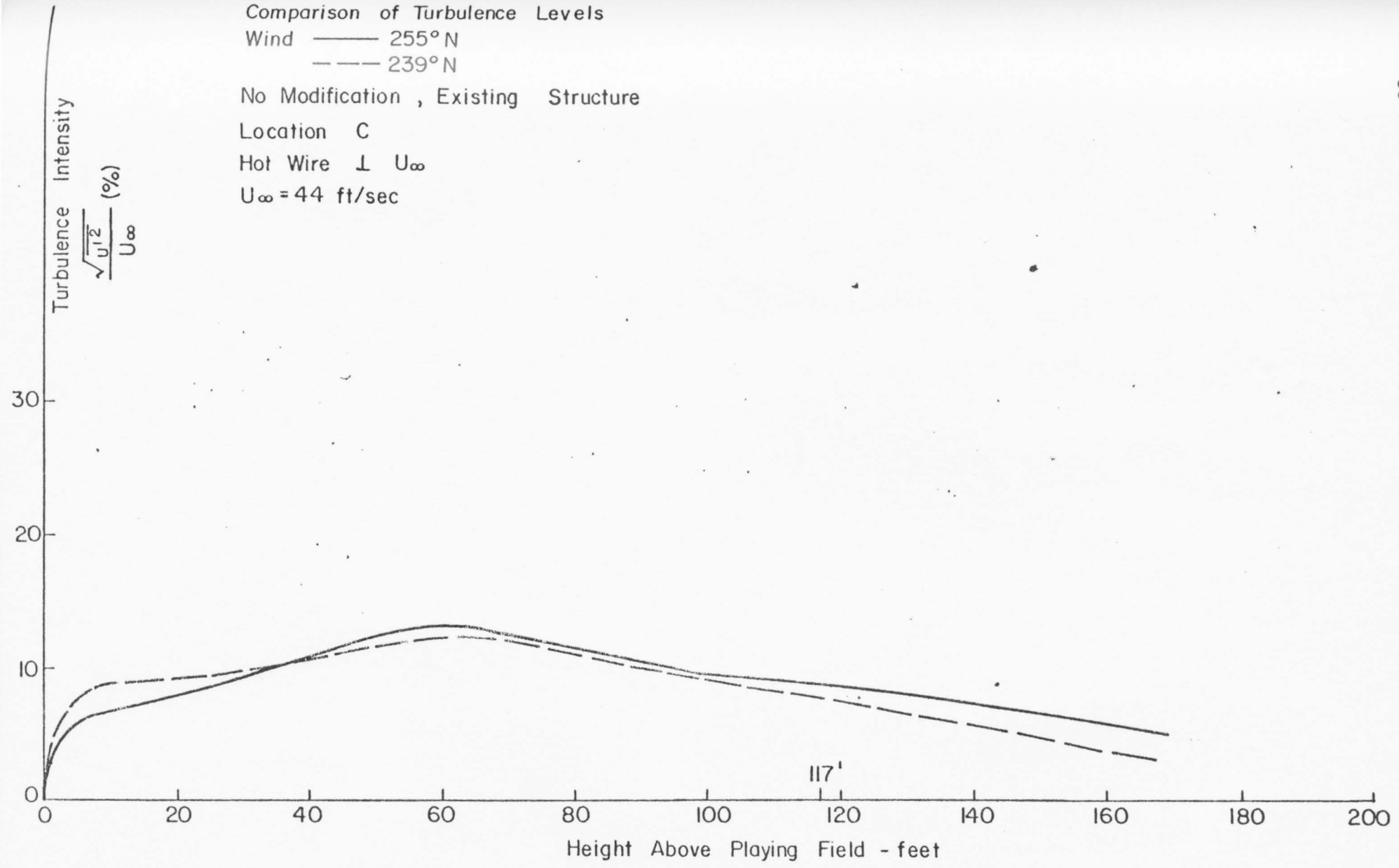


Fig. 36. Comparison of Turbulence for Existing Structures and Proposed Addition -- Wind at 239° & 255° -- Location C -- Hot Wire Perpendicular.

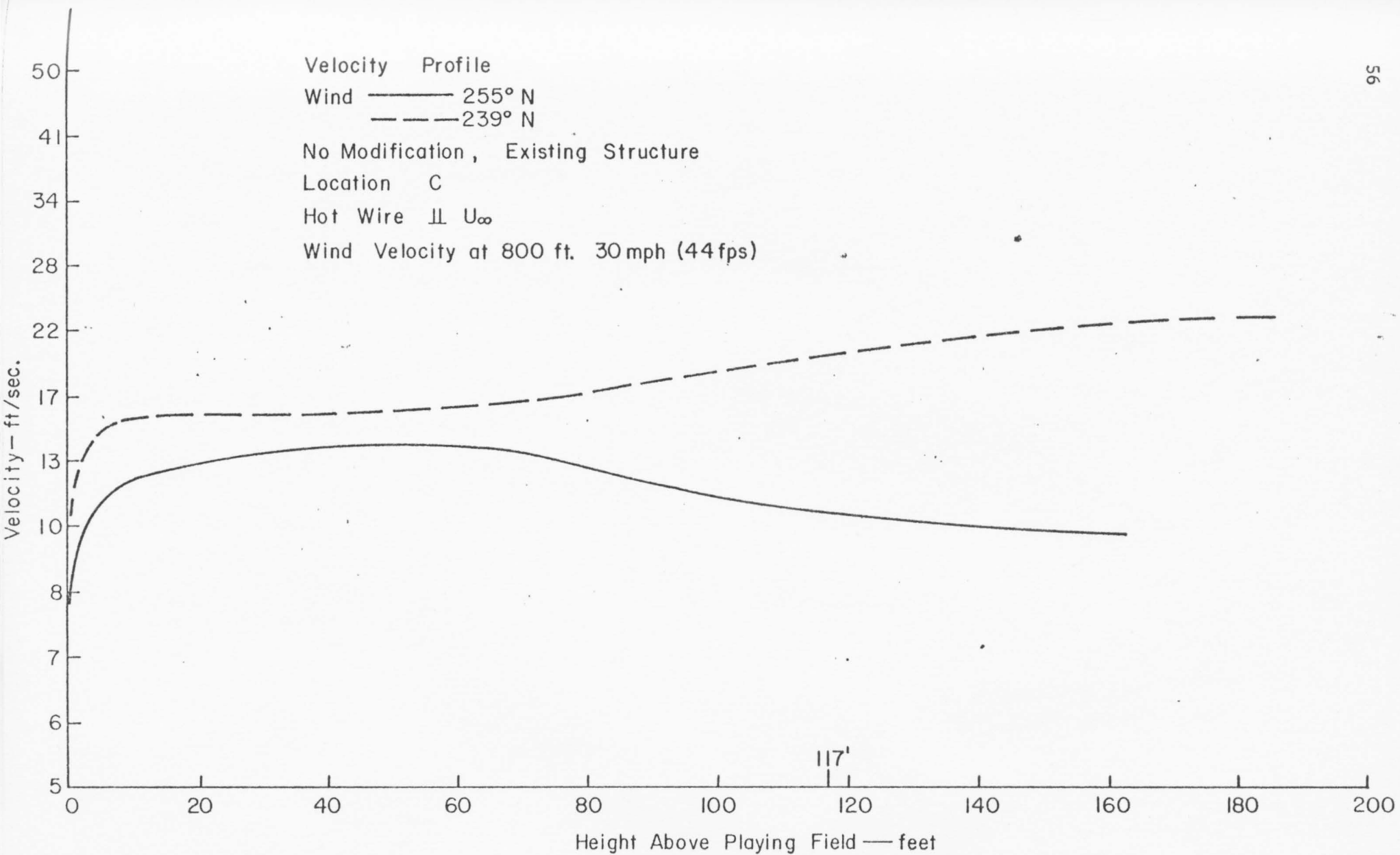


Fig. 37. Velocity Profiles for Existing Structures and Proposed Addition -- Wind at 239° & 255° -- Location C -- Hot Wire Parallel.

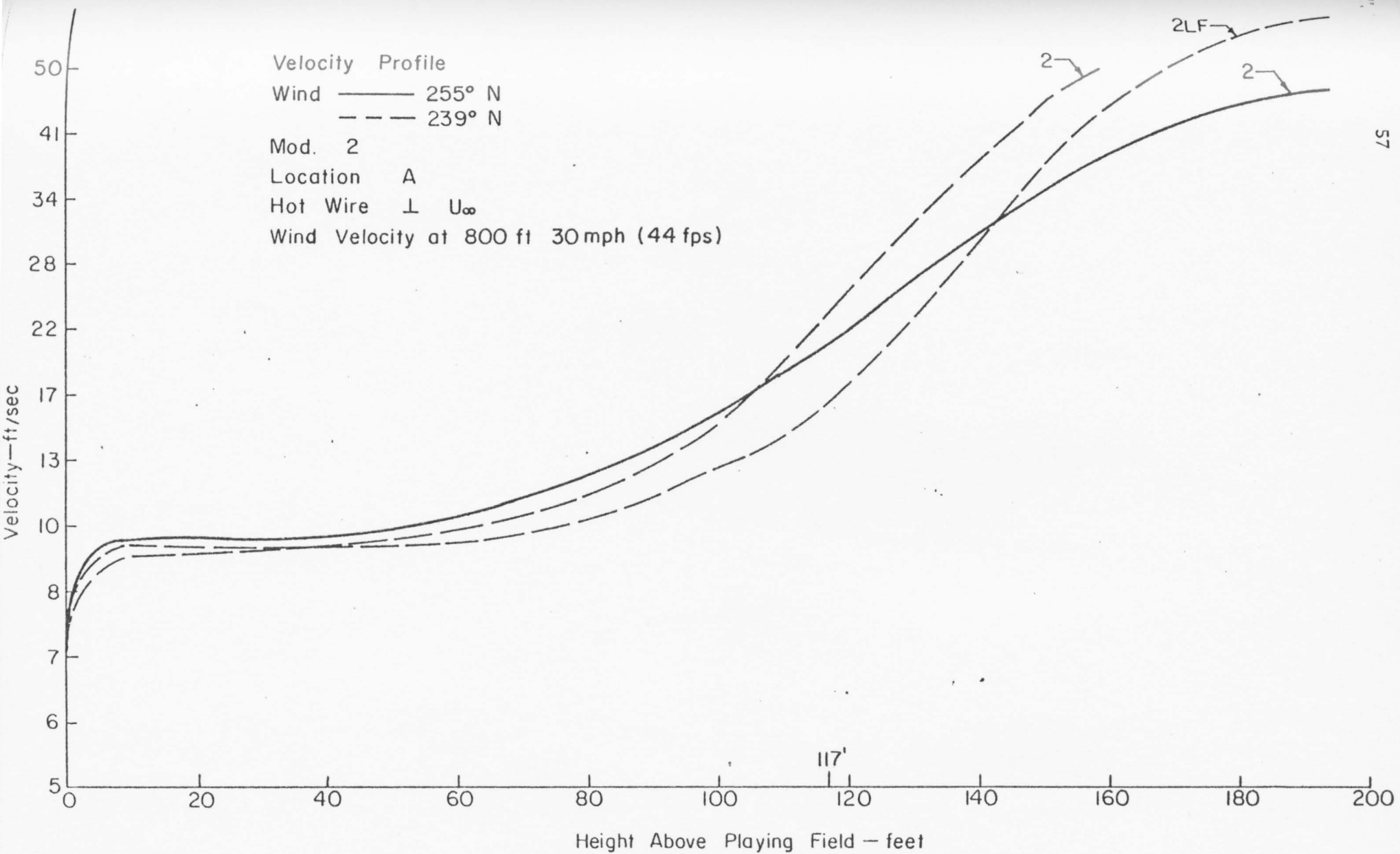


Fig. 38. Velocity Profiles for Modification 2 -- Wind at 239° & 255° -- Location A -- Hot Wire Perpendicular.

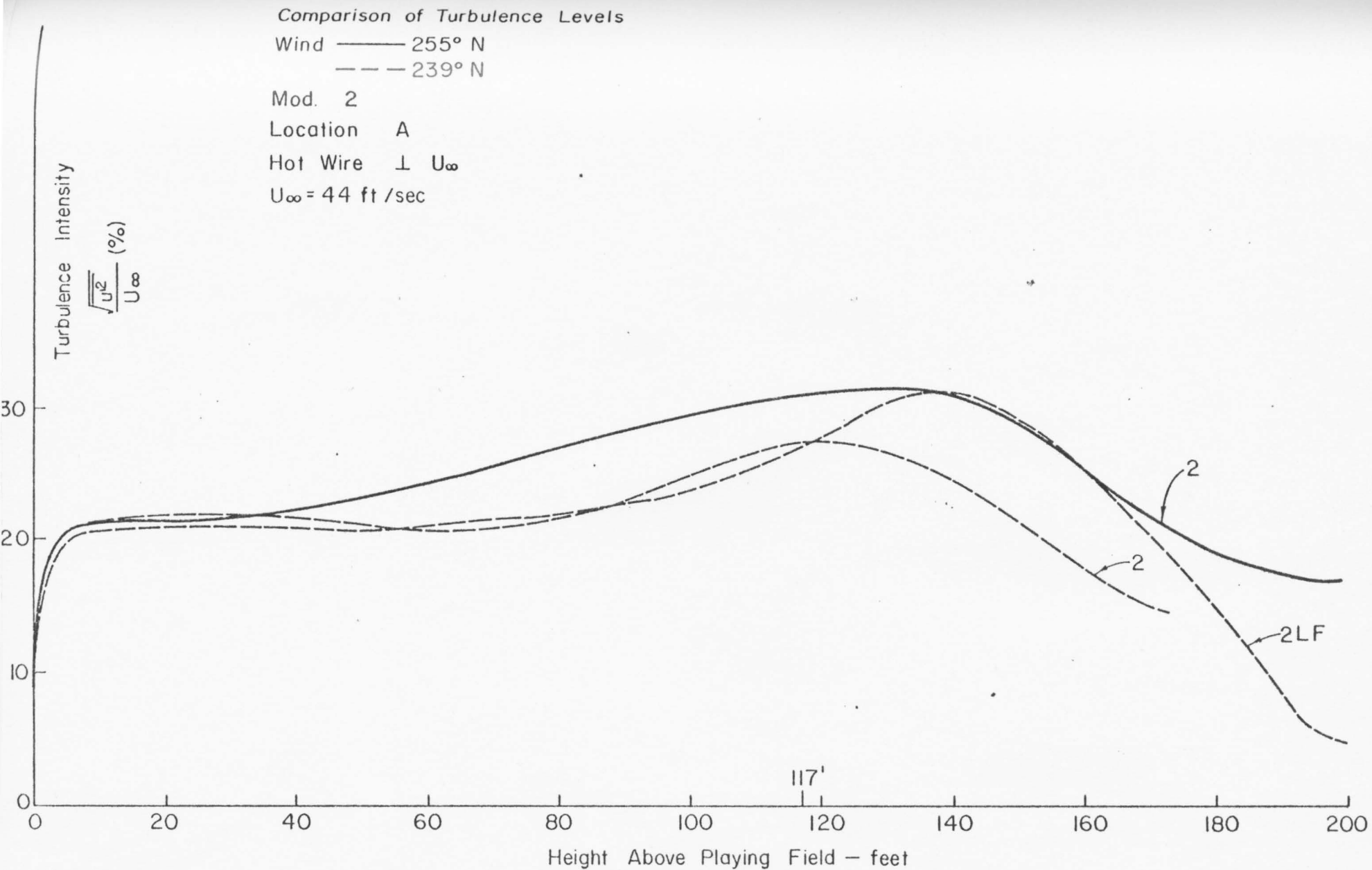


Fig. 39. Comparison of Turbulence for Modification 2 -- Wind at 239° & 255° -- Location A -- Hot Wire Perpendicular.

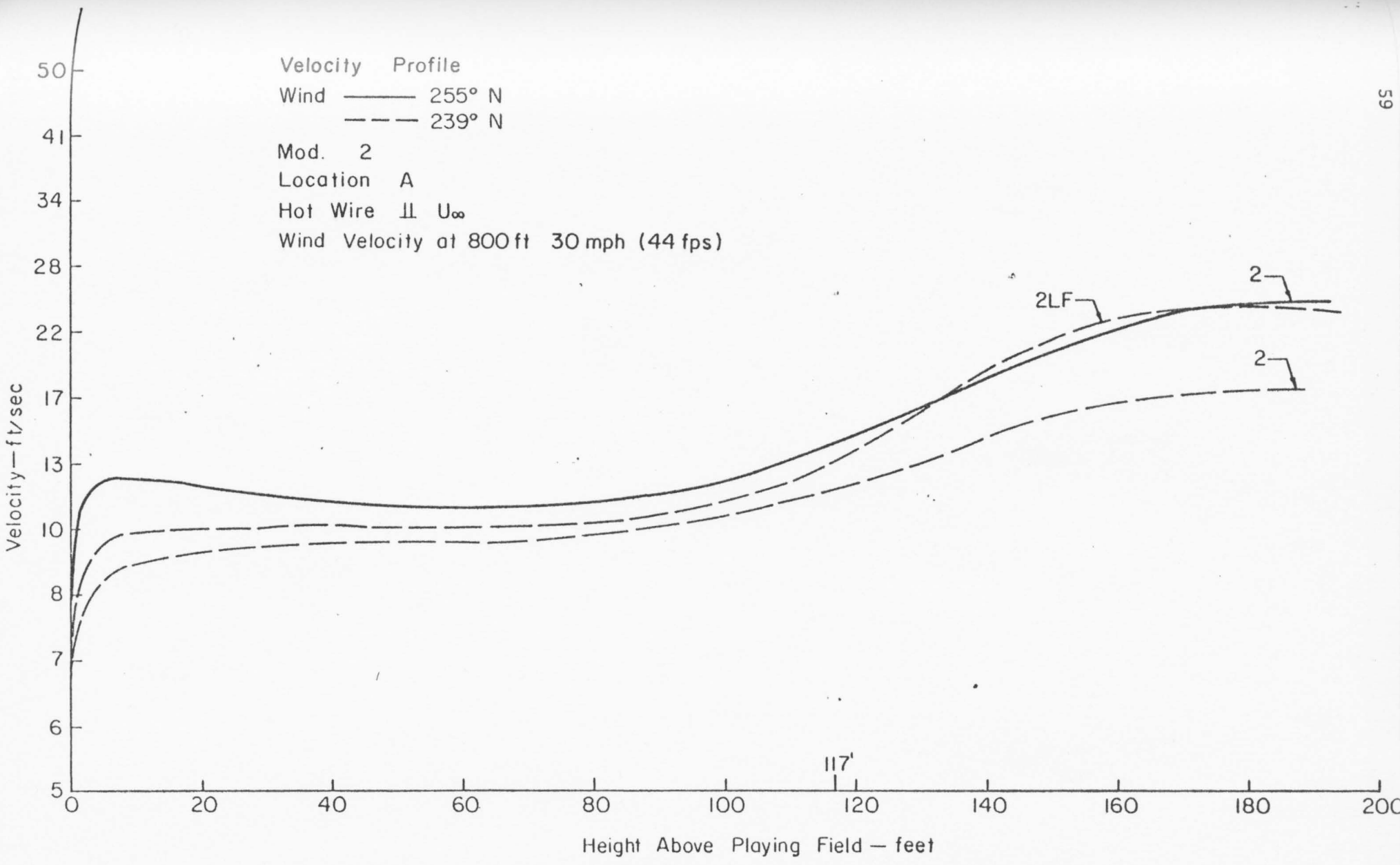


Fig. 40. Velocity Profiles for Modification 2 -- Wind at 239° & 255° -- Location A -- Hot Wire Parallel.

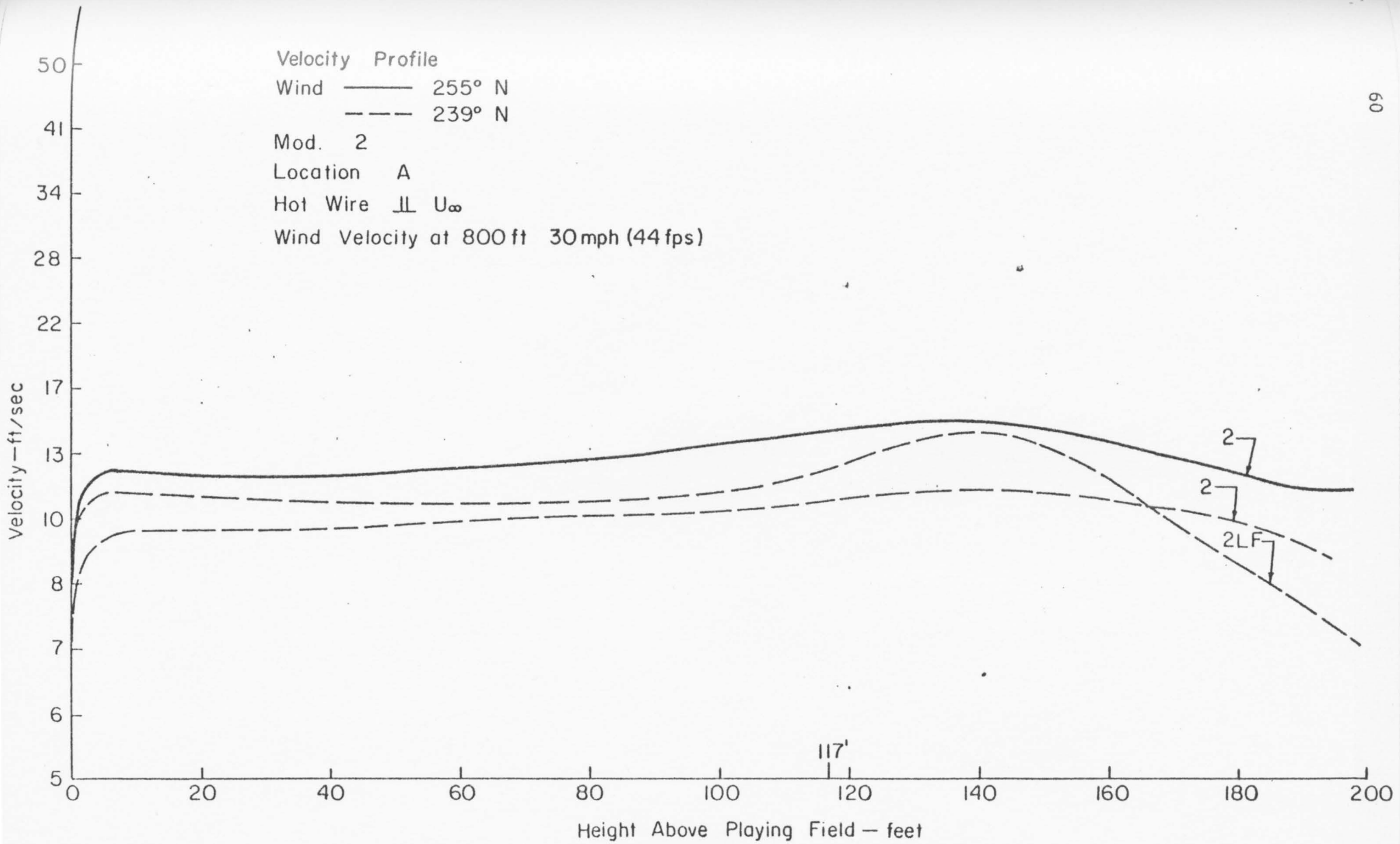


Fig. 41. Velocity Profiles for Modification 2 -- Wind at 239° & 255° -- Location A -- Hot Wire Parallel,

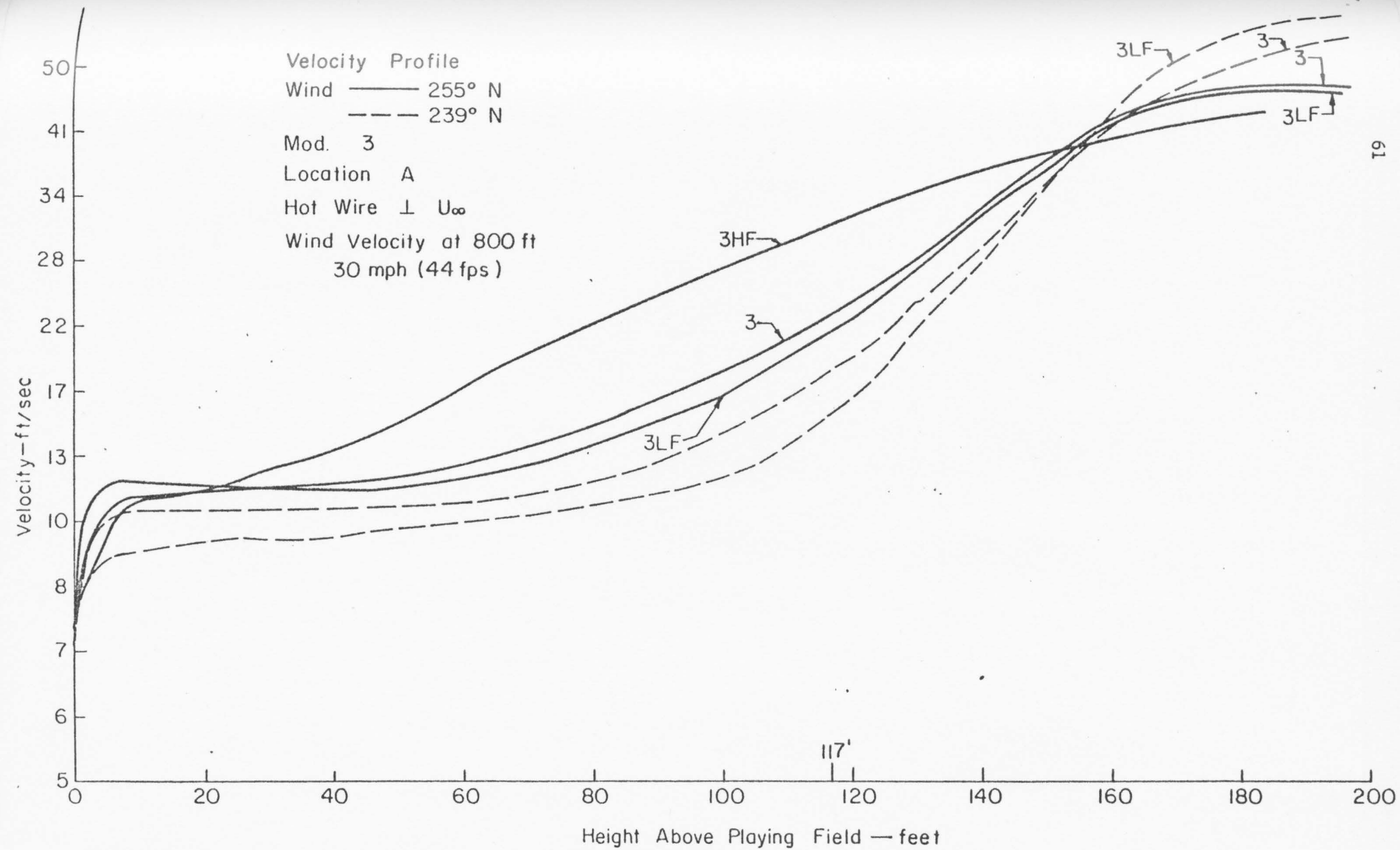


Fig. 42. Velocity Profiles for Modification 3 -- Wind at 239° & 255° -- Location A -- Hot Wire Perpendicular.

Comparison of Turbulence Levels

Wind ——— 255° N

----- 239° N

Mod. 3

Location A

Hot Wire $\perp U_{\infty}$

$U_{\infty} = 44$ ft/sec

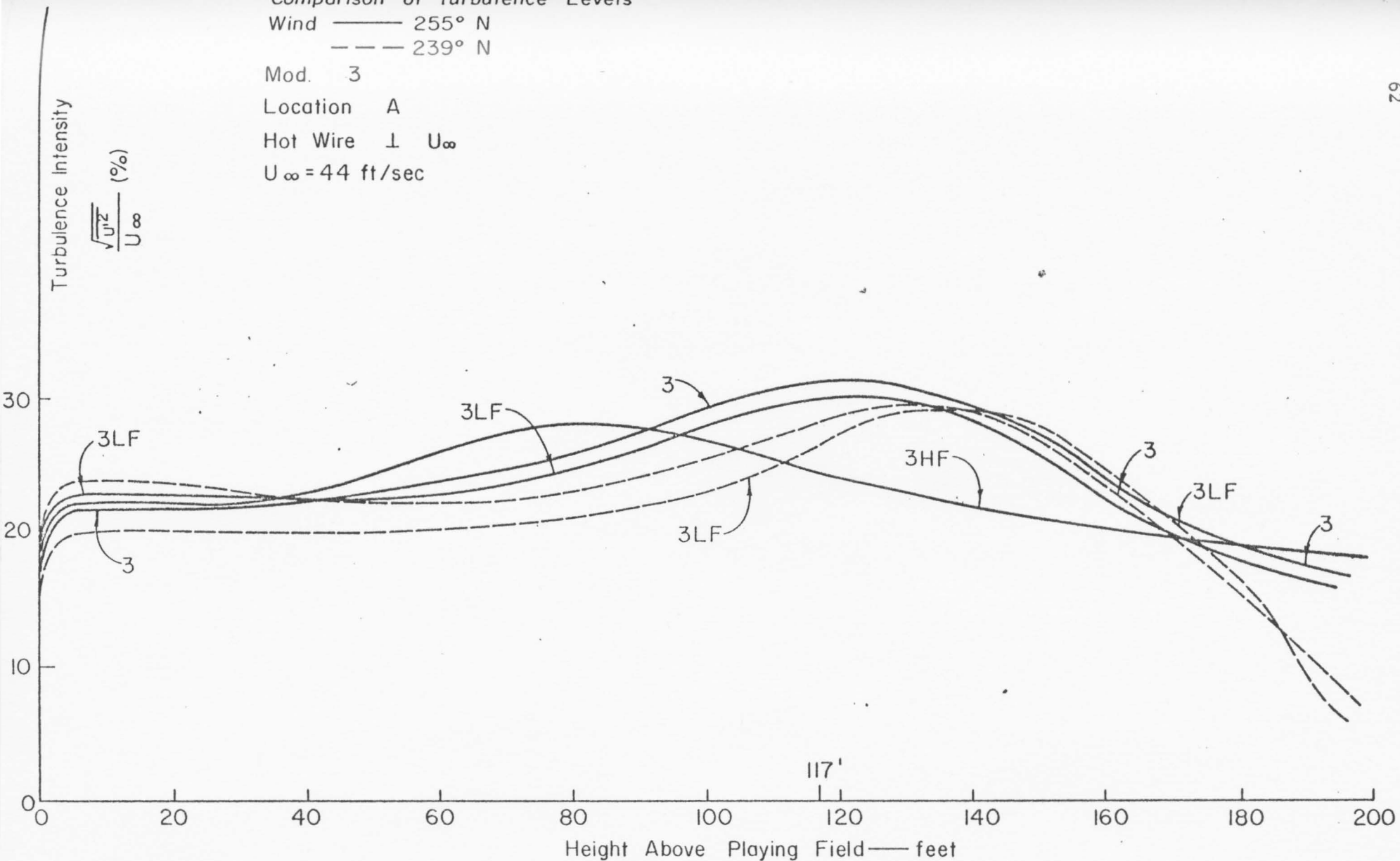


Fig. 43. Comparison of Turbulence for Modification 3 -- Wind at 239° & 255° -- Location A -- Hot Wire Perpendicular.

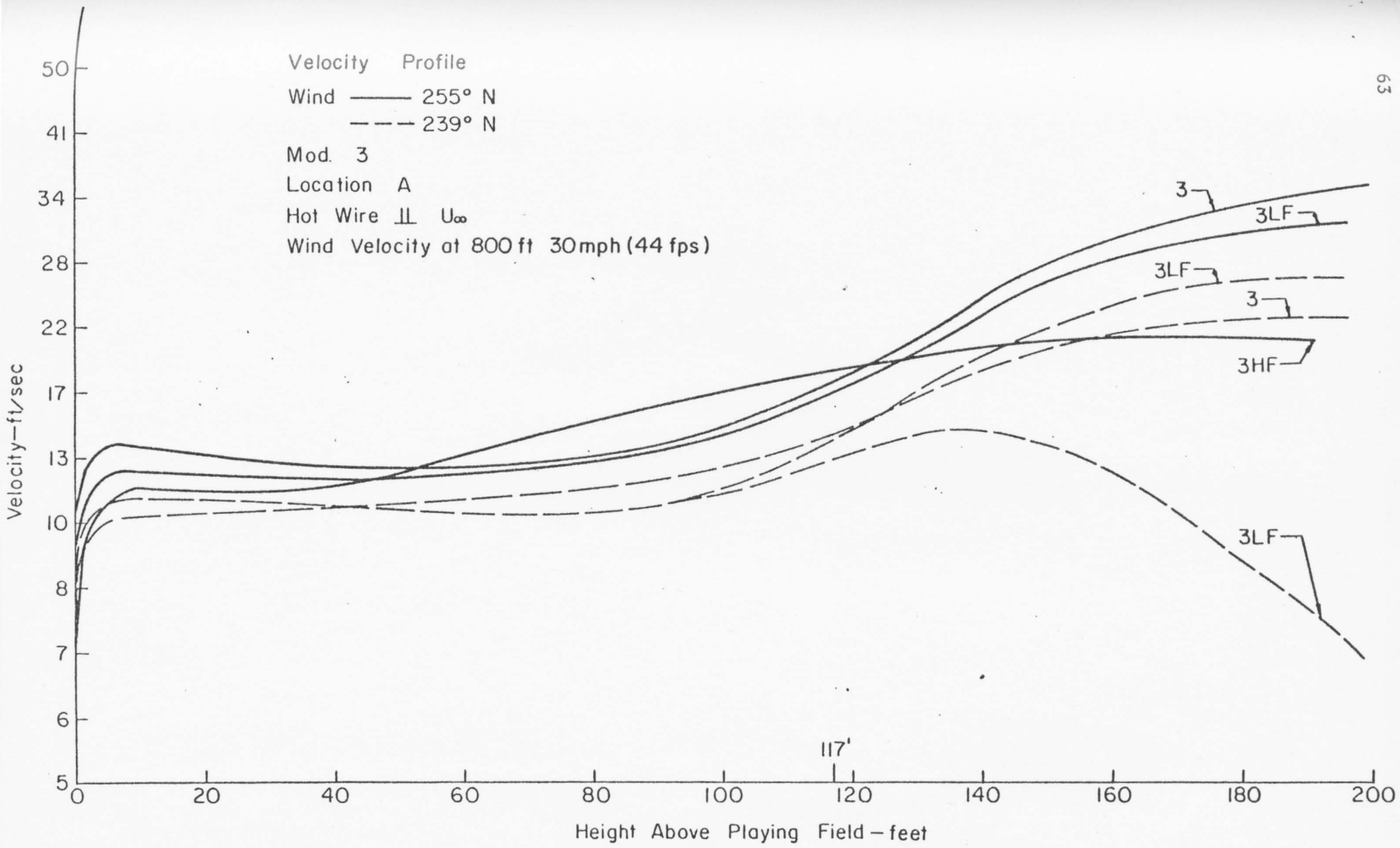


Fig. 44. Velocity Profiles for Modification 3 -- Wind at 239° & 255° -- Location A -- Hot Wire Parallel.

Comparison of Turbulence Levels

Wind ——— 255° N

--- 239° N

Mod. 3

Location A

Hot Wire $\perp U_{\infty}$

$U_{\infty} = 44$ ft/sec

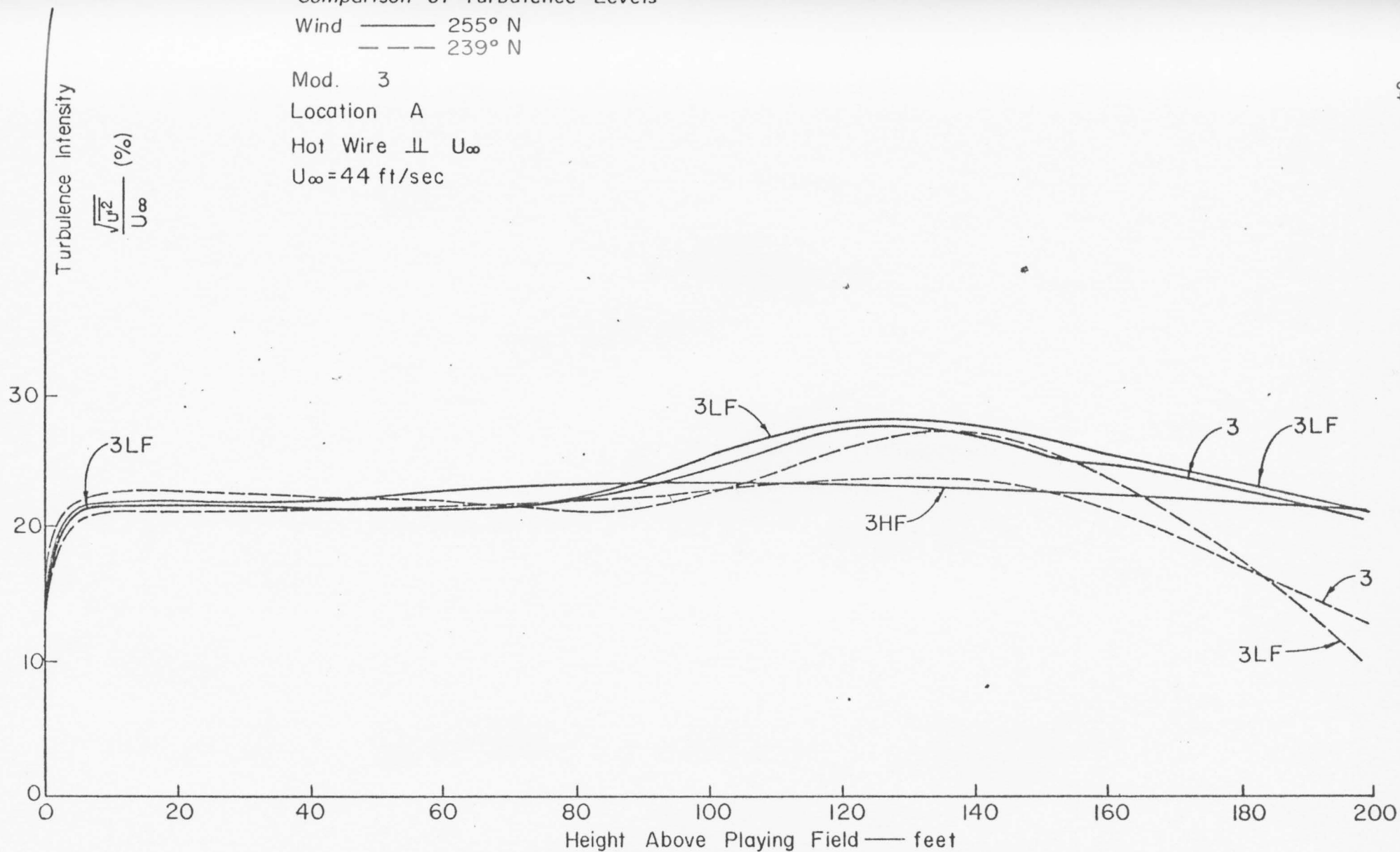


Fig. 45. Comparison of Turbulence for Modification 3 -- Wind at 239° & 255° -- Location A -- Hot Wire Parallel.

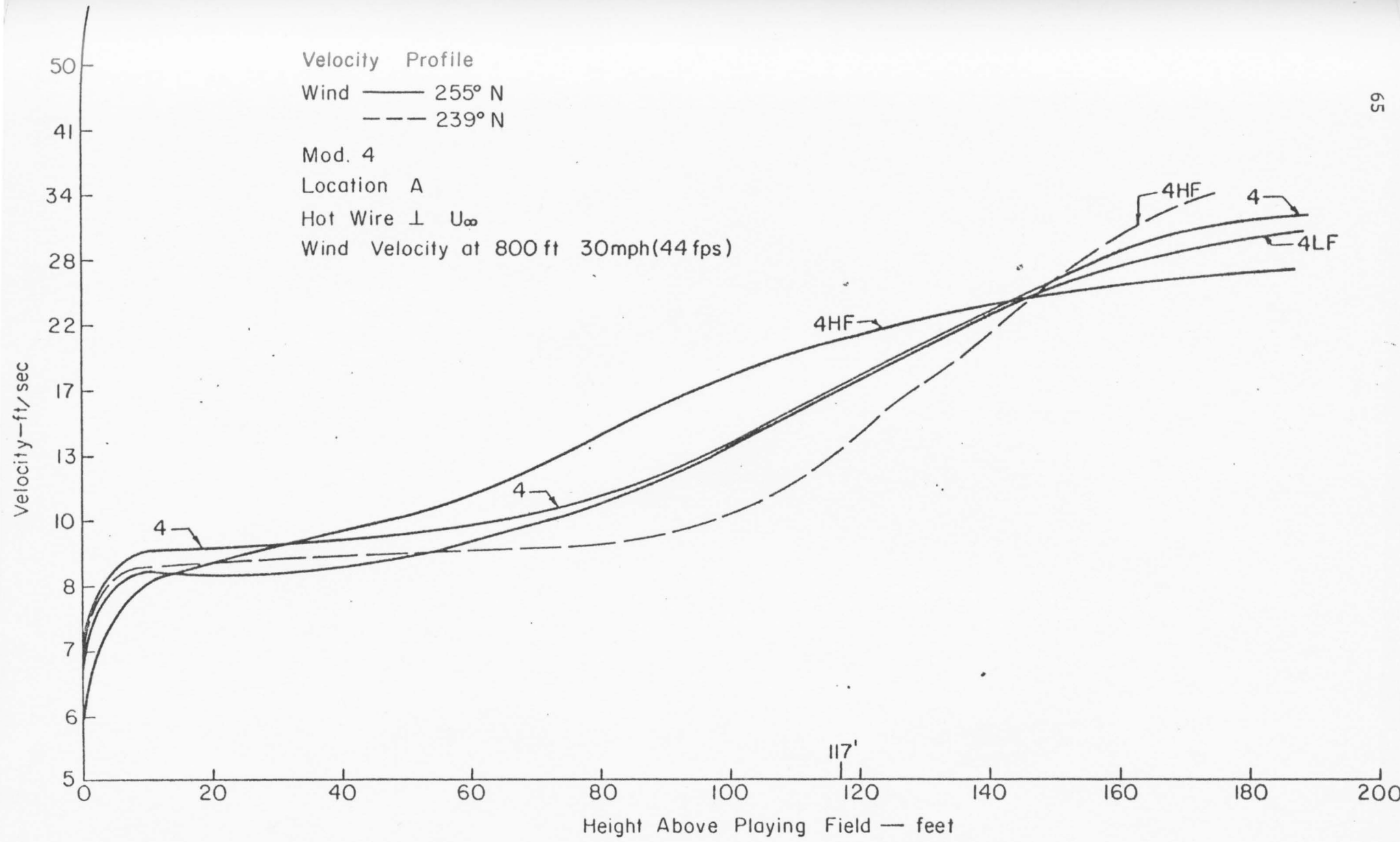


Fig. 46. Velocity Profiles for Modification 4 -- Wind at 239° & 255° -- Location A -- Hot Wire Perpendicular.

Comparison of Turbulence Levels

Wind ——— 255° N
----- 239° N

Mod. 4

Location A

Hot Wire ⊥ U_∞

U_∞ = 44 ft/sec

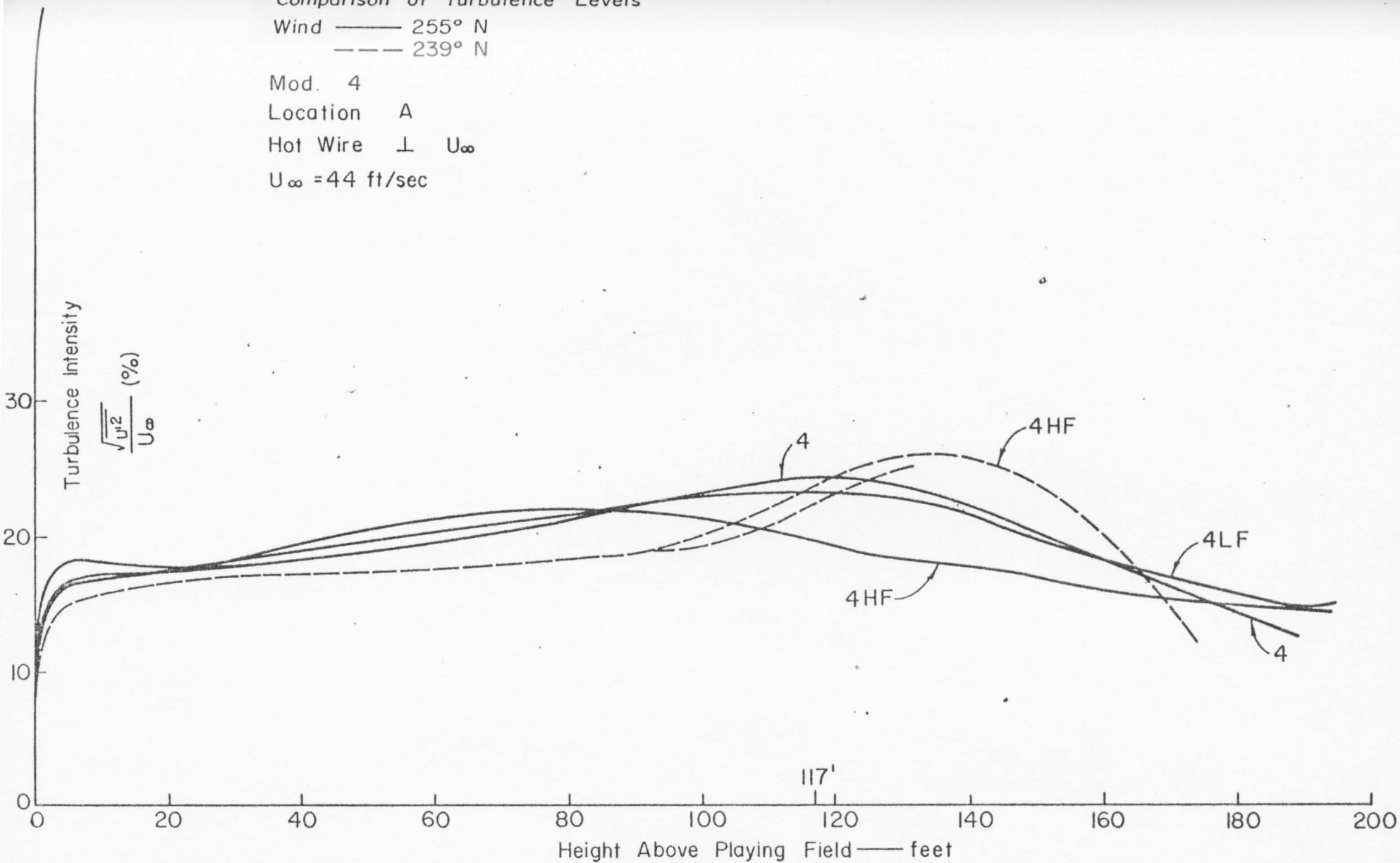


Fig. 47. Comparison of Turbulence for Modification 4 -- Wind at 239° & 255° -- Location A -- Hot Wire Perpendicular.

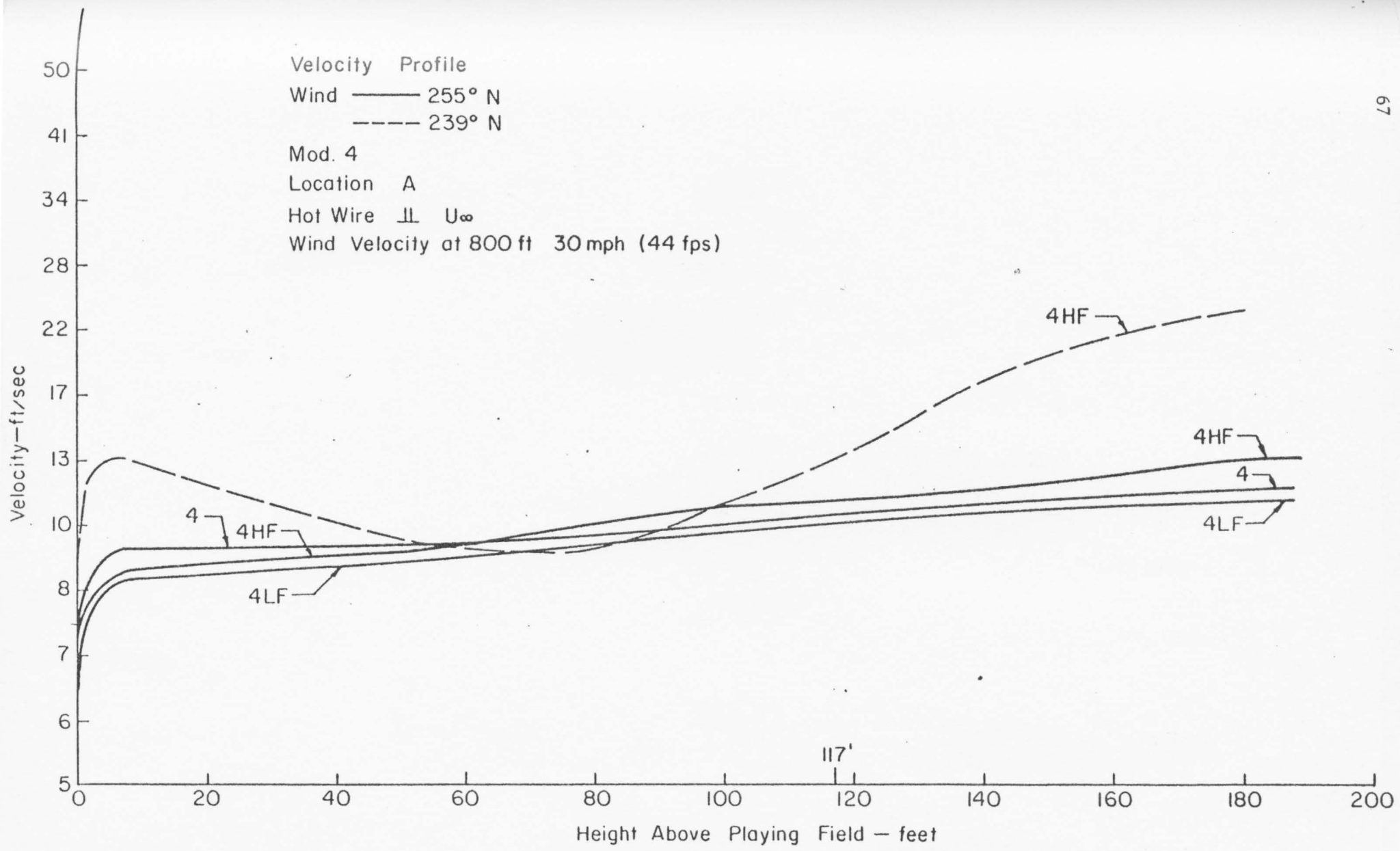


Fig. 48. Velocity Profiles for Modification 4 -- Wind at 239° & 255° -- Location A -- Hot Wire Parallel.

Comparison of Turbulence Levels

Wind ——— 255° N

----- 239° N

Mod. 4

Location A

Hot Wire \perp U_{∞}

$U_{\infty} = 44$ ft/sec

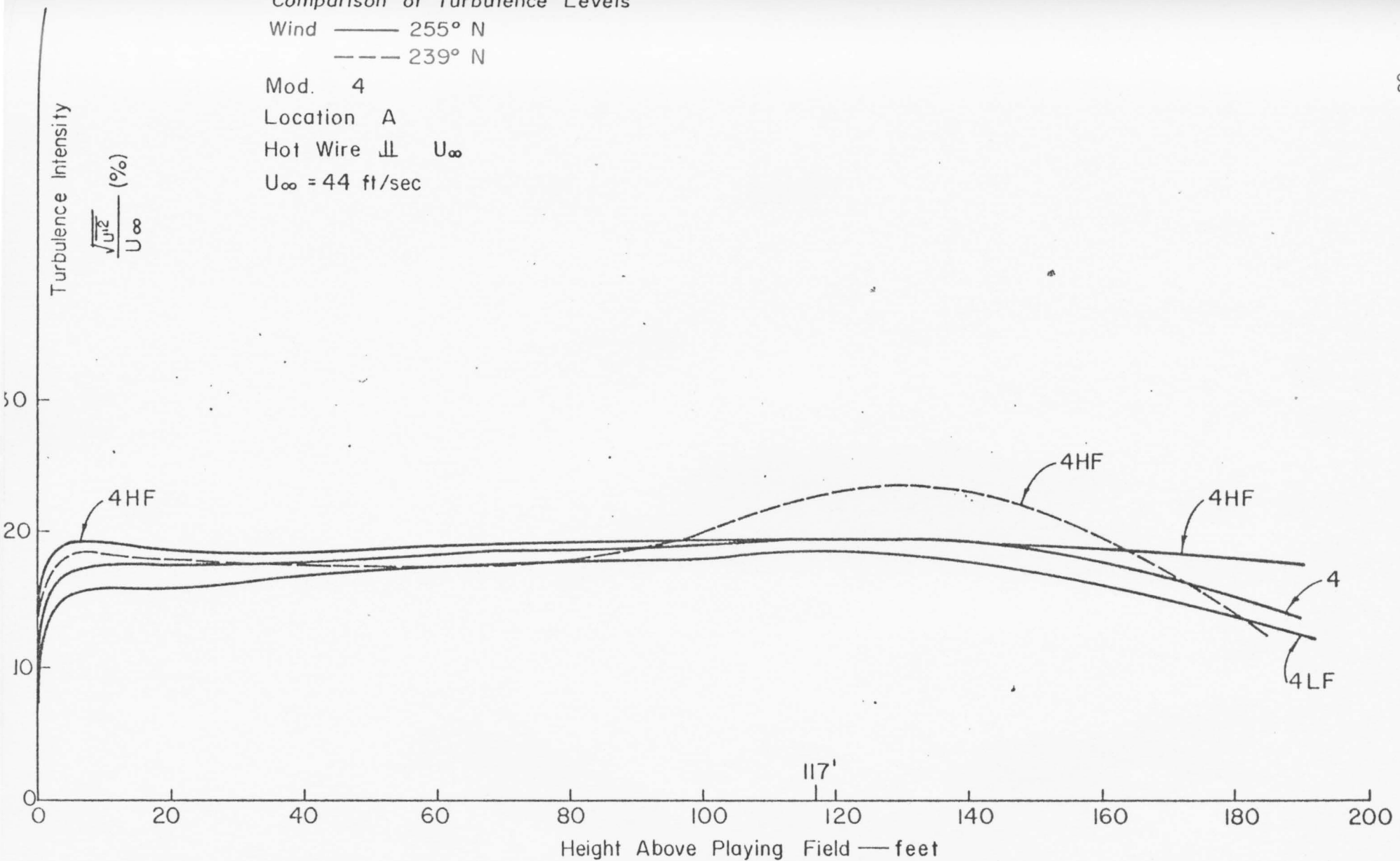


Fig. 49. Comparison of Turbulence for Modification 4 -- Wind at 239° & 255° -- Location A -- Hot Wire Parallel.

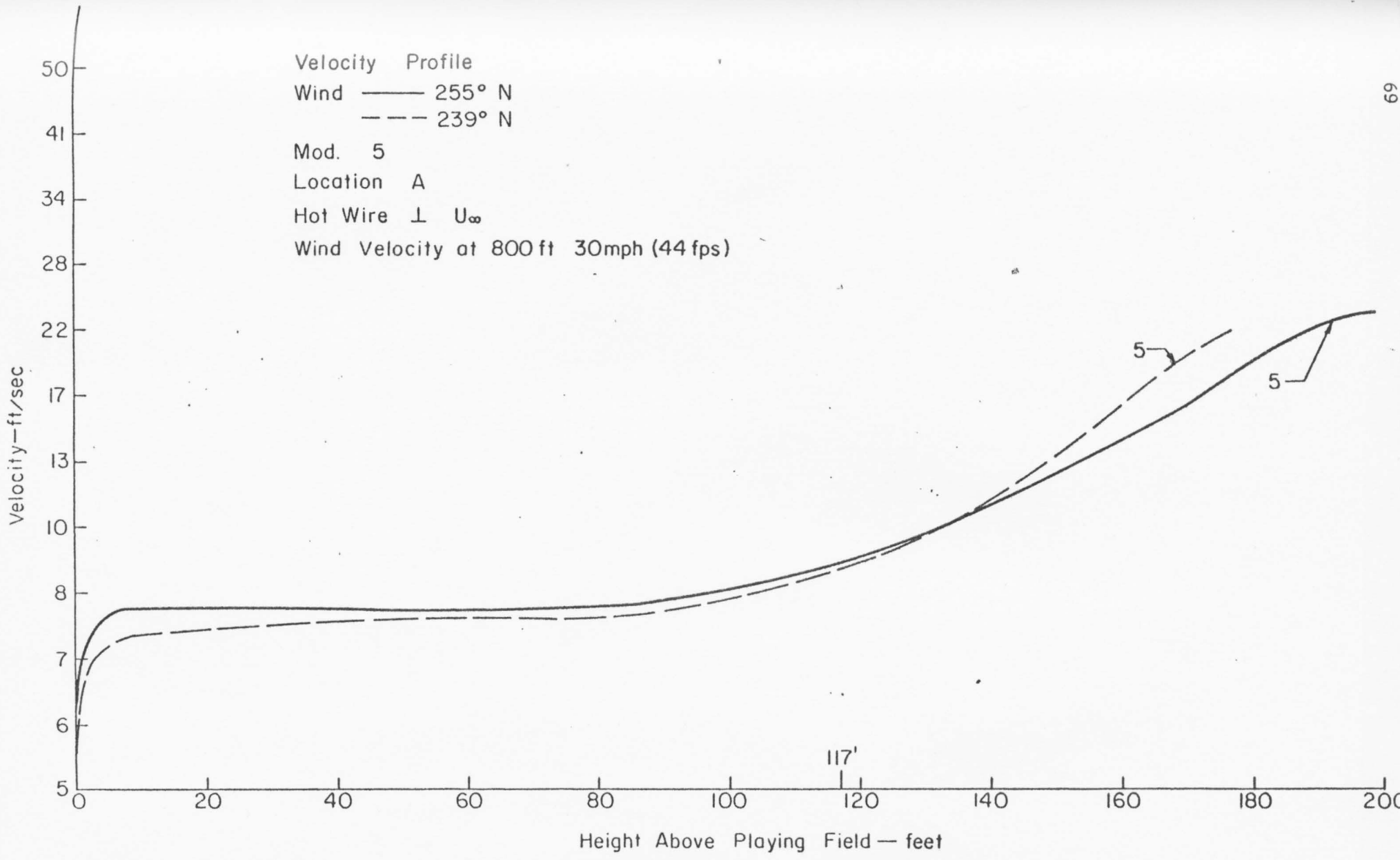


Fig. 50. Velocity Profiles for Modification 5 -- Wind at 239° & 255° -- Location A -- Hot Wire Perpendicular.

Comparison of Turbulence Levels

Wind — 255° N

--- 239° N

Mod. - 5

Location A

Hot Wire ⊥ U_∞

U_∞ = 44 ft/sec

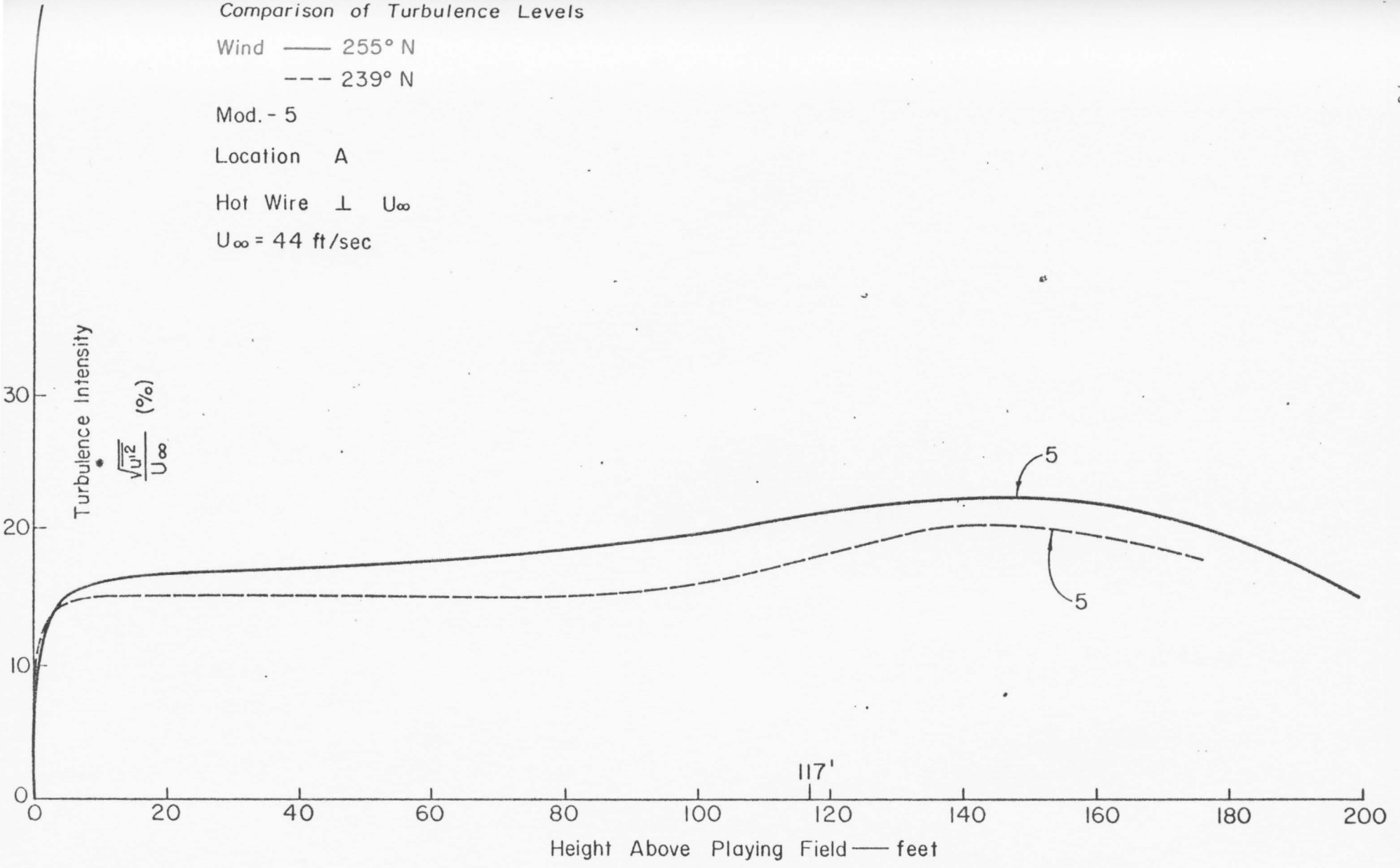


Fig. 51. Comparison of Turbulence for Modification 5 -- Wind at 239° & 255° -- Location A -- Hot Wire Perpendicular.

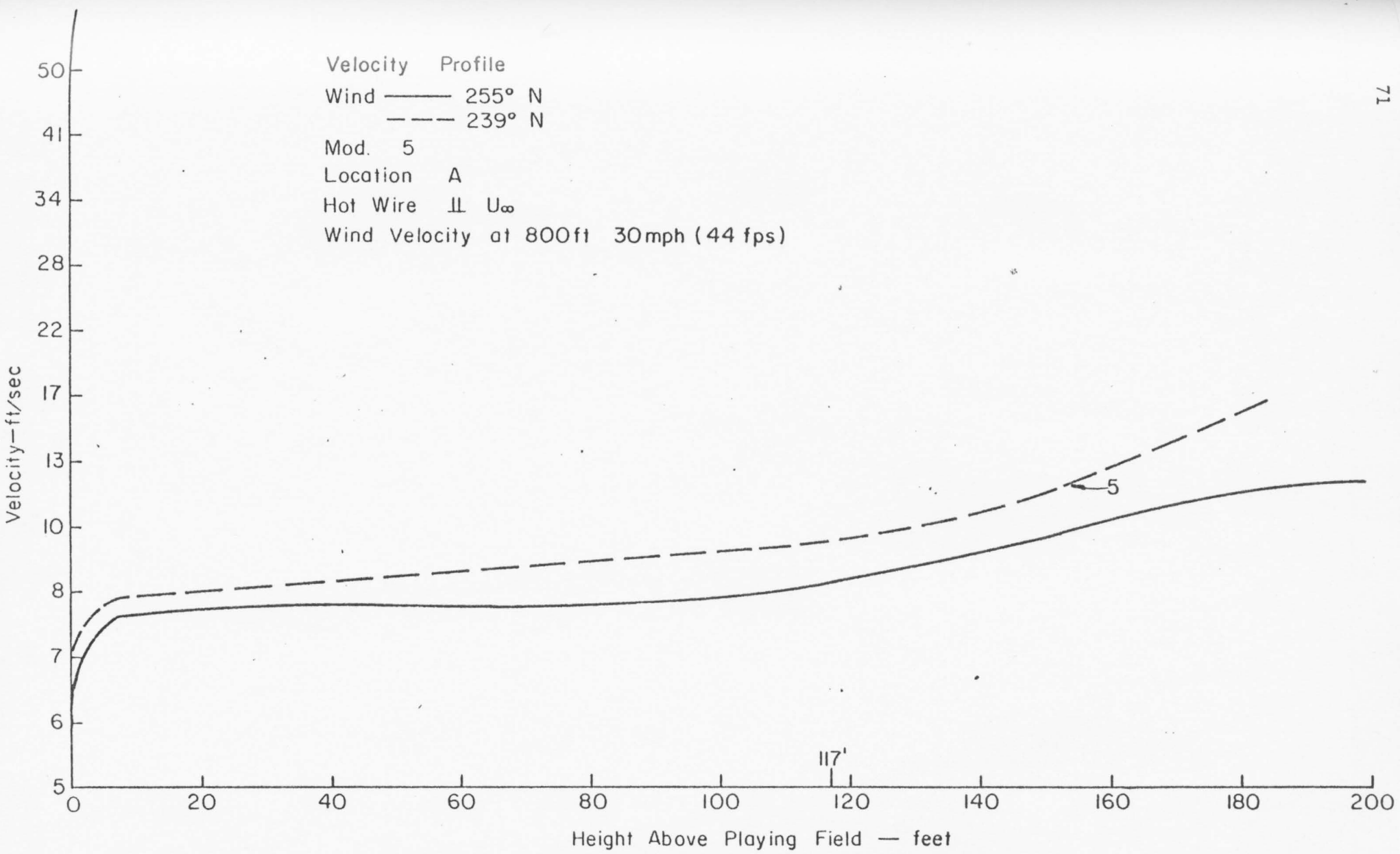


Fig. 52. Velocity Profiles for Modification 5 -- Wind at 239° & 255° -- Location A -- Hot wire Parallel.

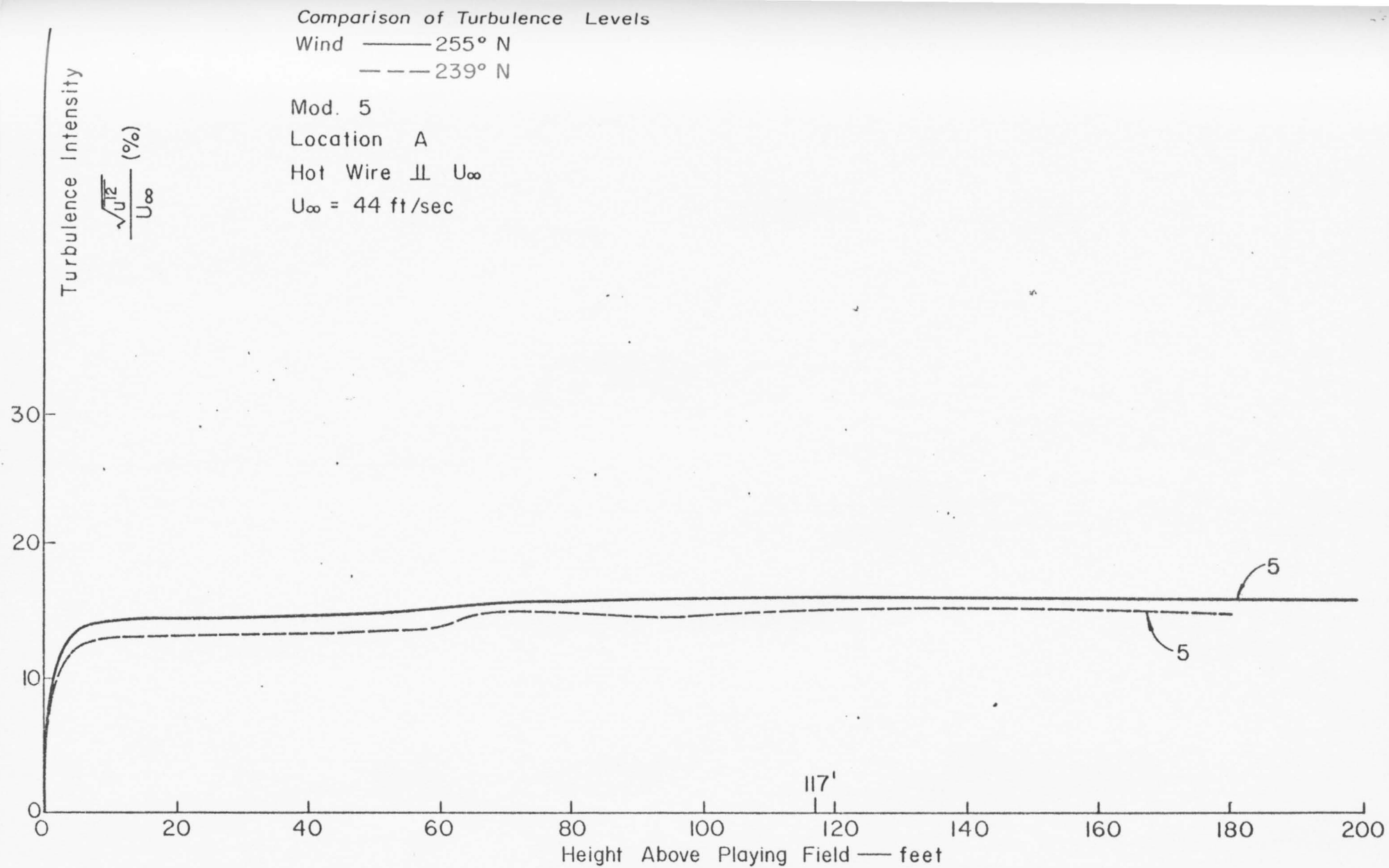


Fig. 53. Comparison of Turbulence for Modification 5 -- Wind at 239° & 255° -- Location A -- Hot Wire Parallel.

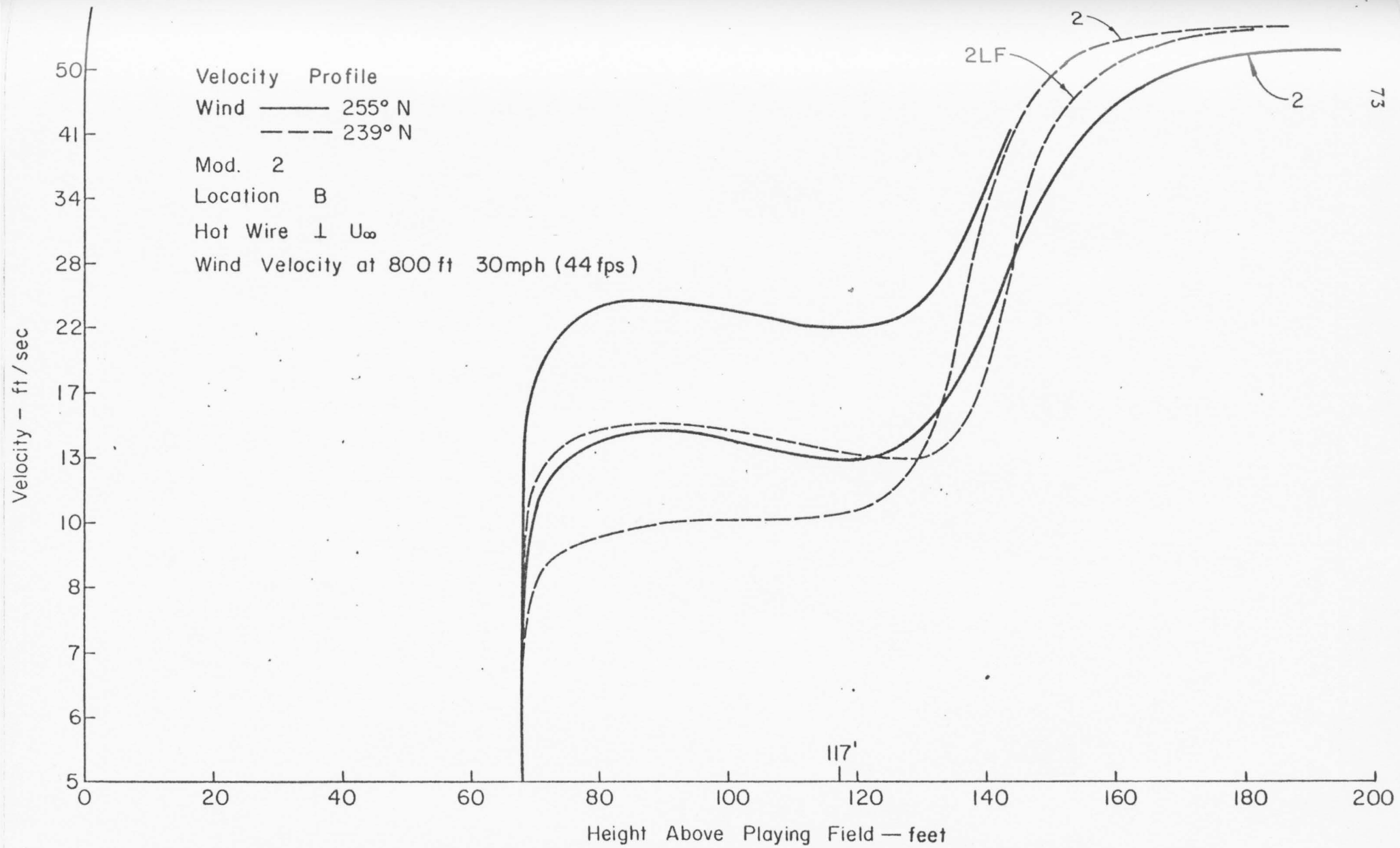


Fig. 54. Velocity Profiles for Modification 2 -- Wind at 239° & 255° -- Location B -- Hot Wire Parallel.

Comparison of Turbulence Levels

Wind ——— 255° N

----- 239° N

Mod. 2

Location B

Hot Wire ⊥ U_{∞}

$U_{\infty} = 44$ ft/sec

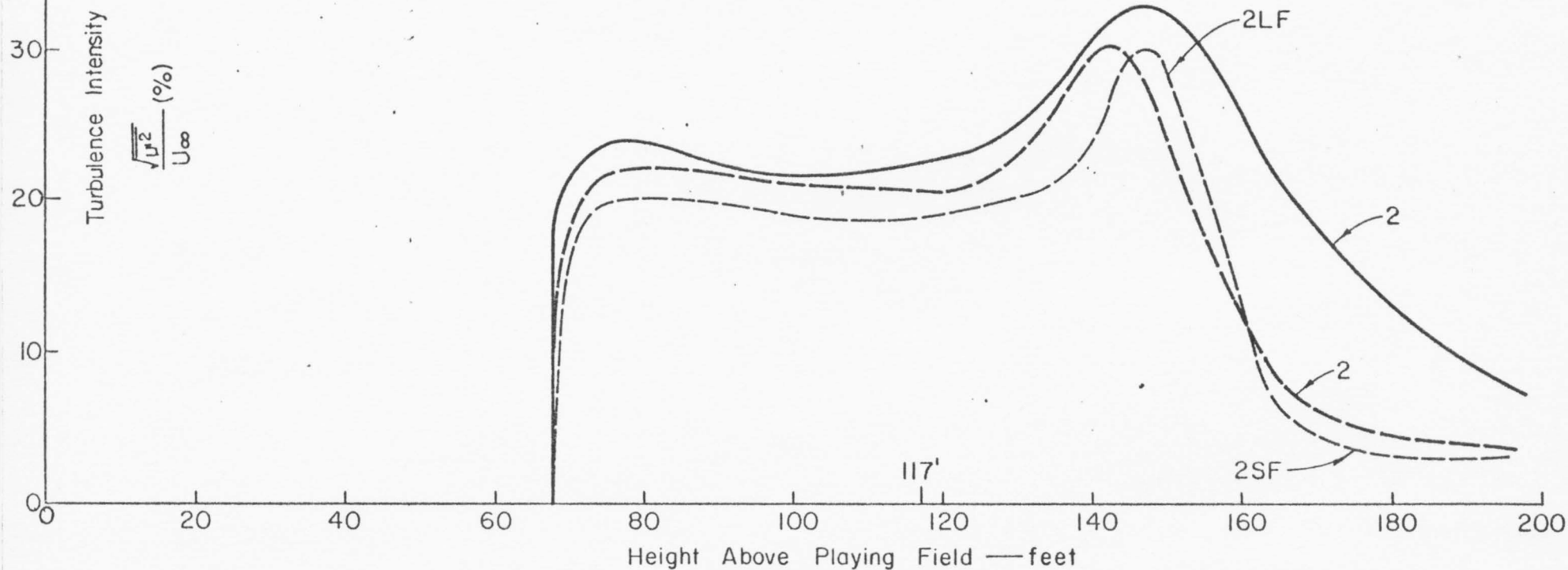


Fig. 55. Comparison of Turbulence for Modification 2 -- Wind at 239° & 255° -- Location B -- Hot Wire Perpendicular.

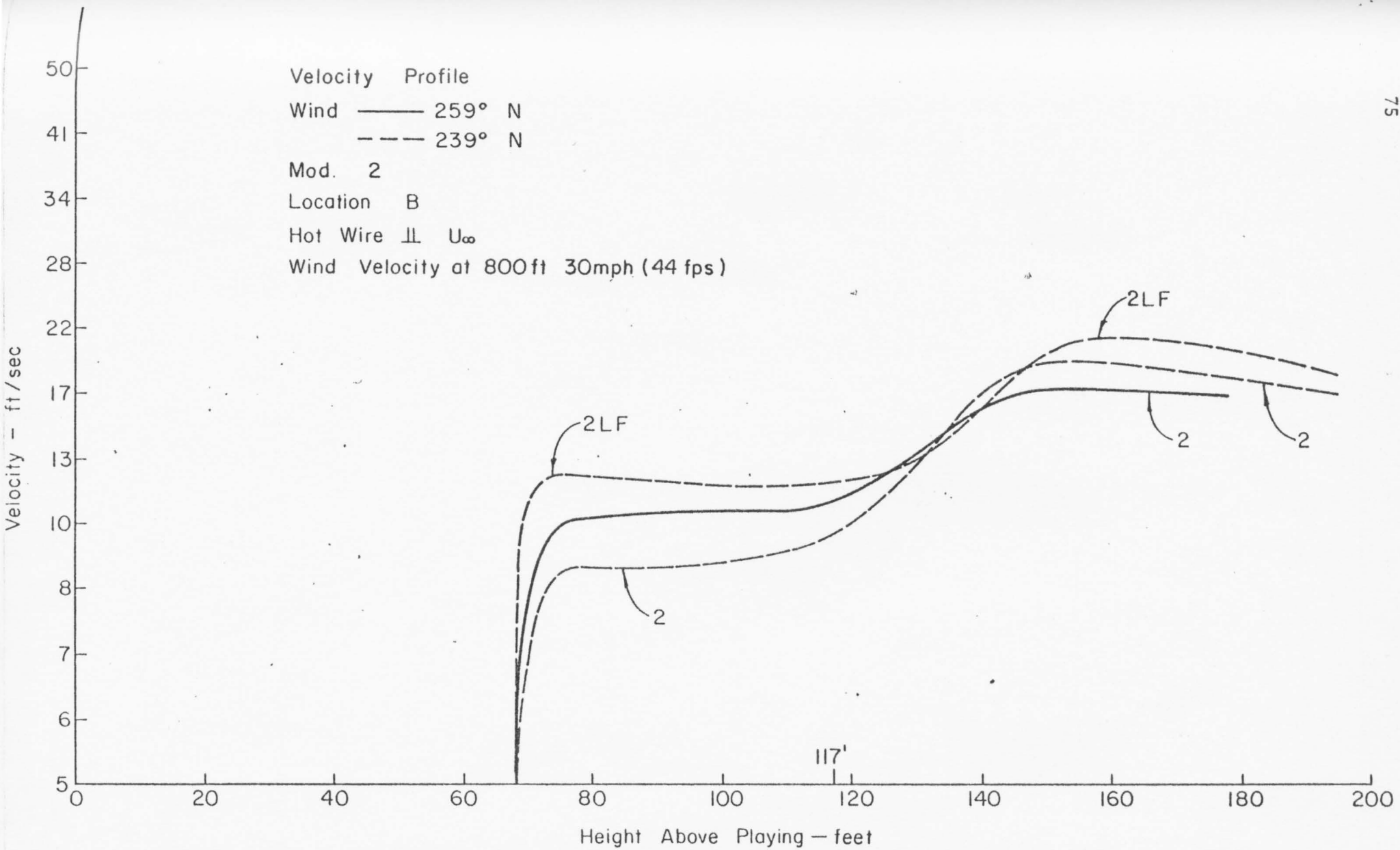


Fig. 56. Velocity Profiles for Modification 2 -- Wind at 239° & 255° -- Location B -- Hot Wire Parallel.

Comparison of Turbulence Levels
Wind ——— 255° N
 - - - - 239° N
Mod. 2
Location B
Hot Wire \perp U_{∞}
 $U_{\infty} = 44$ ft/sec

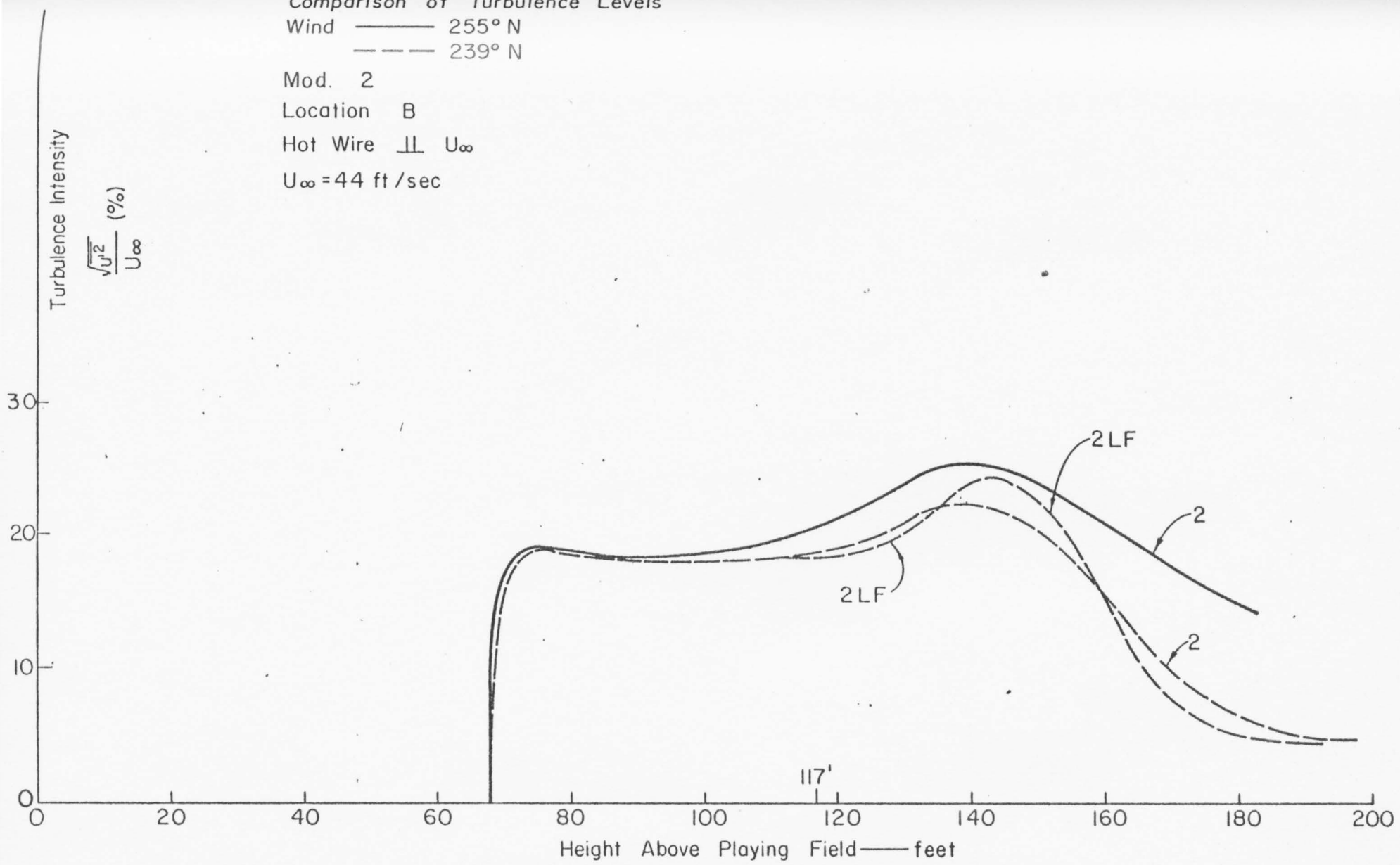


Fig. 57. Comparison of Turbulence for Modification 2 -- Wind at 239° & 255° -- Location B -- Hot Wire Parallel.

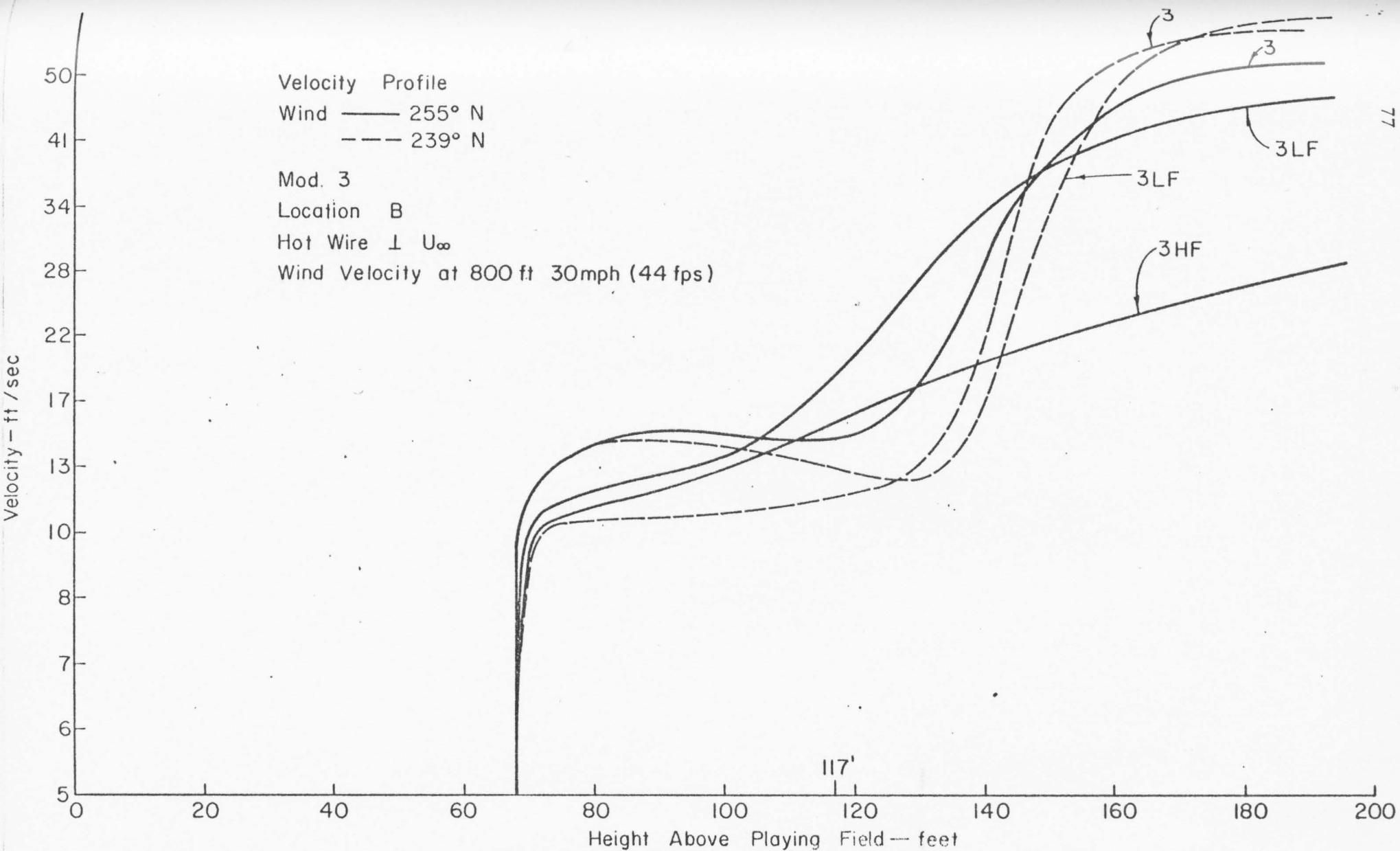


Fig. 58. Velocity Profiles for Modification 3 -- Wind at 239° & 255° -- Location B -- Hot Wire Perpendicular.

Comparison of Turbulence Levels

Wind ——— 255° N

----- 239° N

Mod. 3

Location B

Hot Wire $\perp U_{\infty}$

$U_{\infty} = 44$ ft/sec

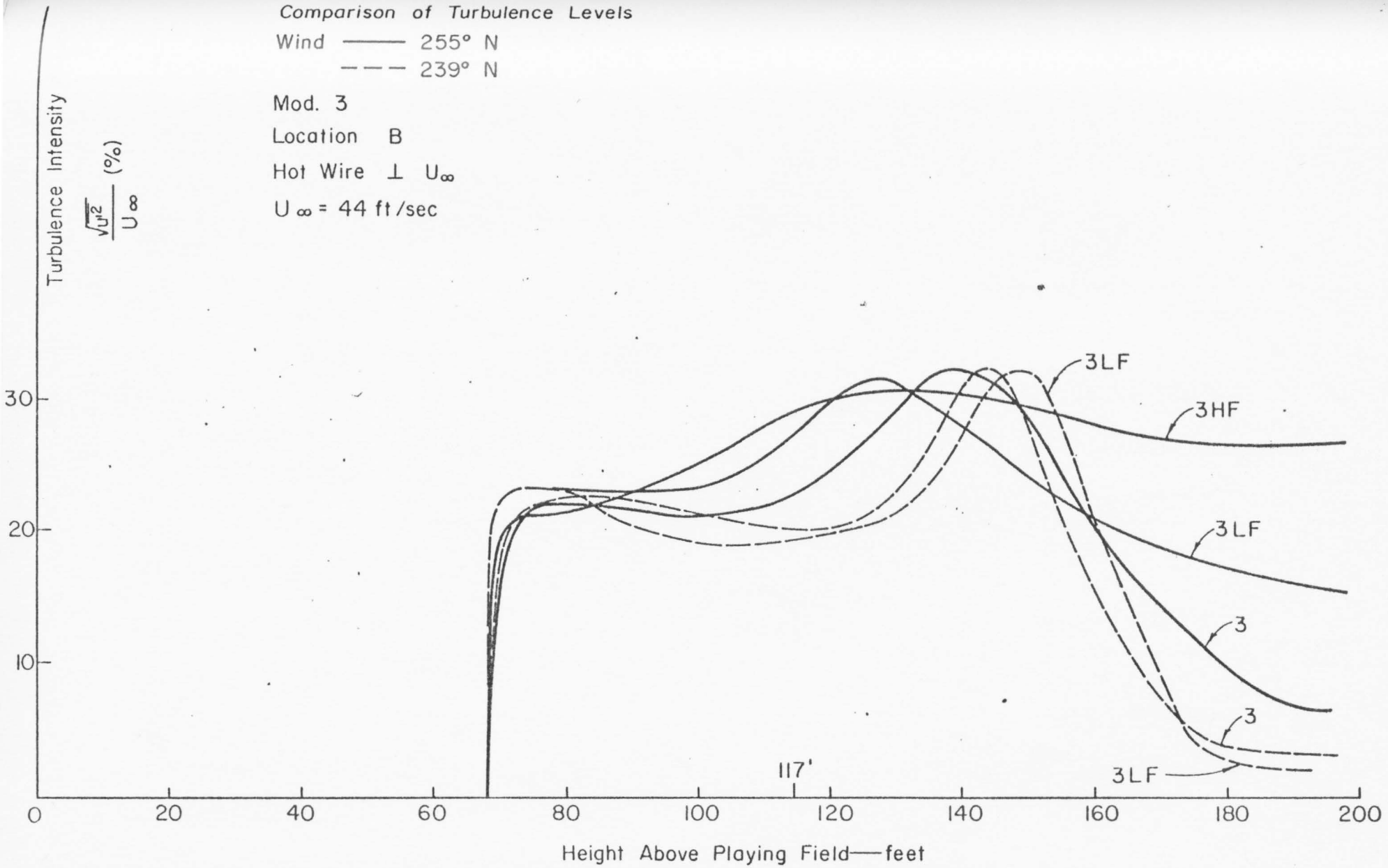


Fig. 59. Comparison of Turbulence for Modification 3 -- Wind at 239° & 255° -- Location B -- Hot Wire Perpendicular.

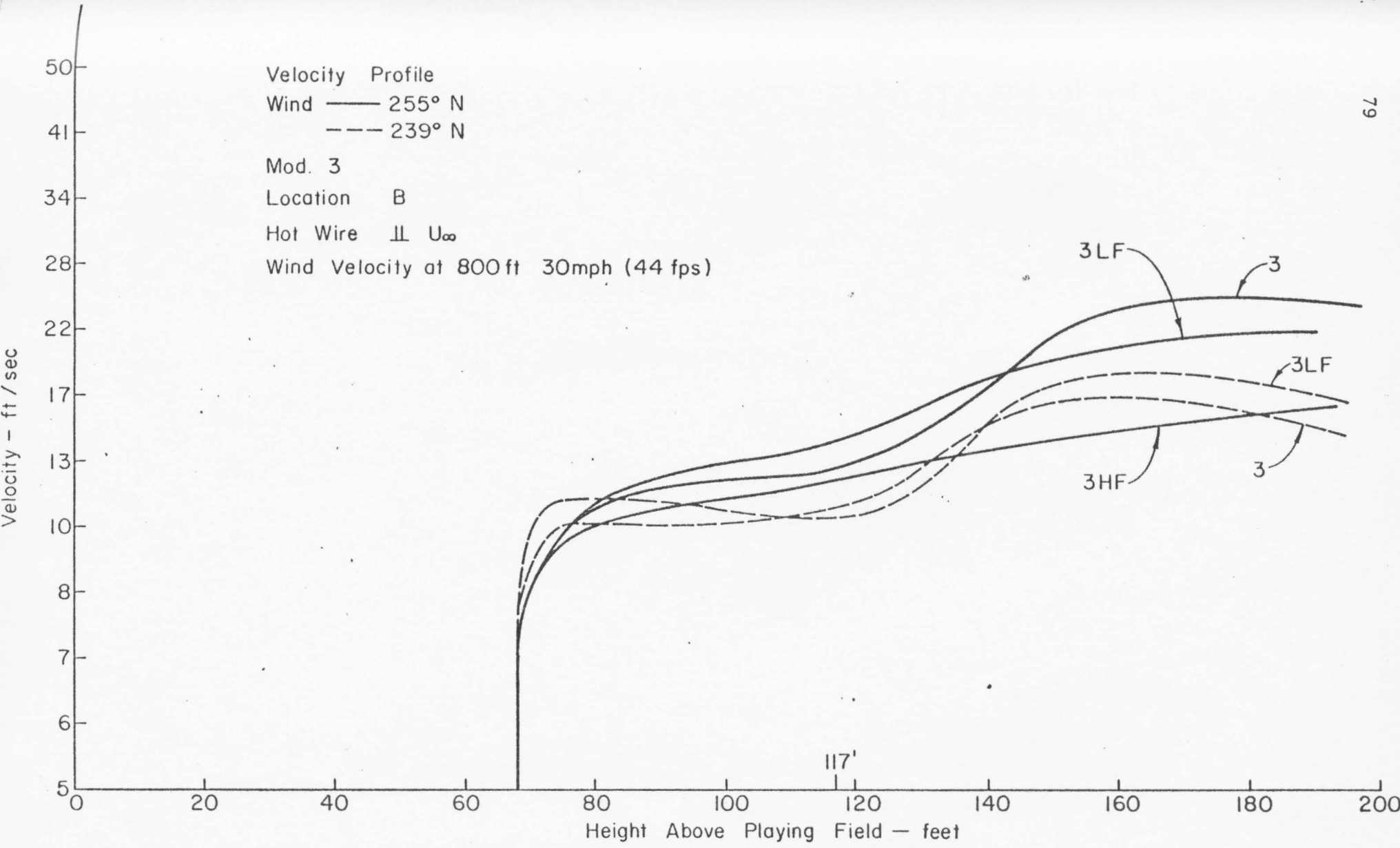


Fig. 60. Velocity Profiles for Modification 3 -- Wind at 239° & 255° -- Location B -- Hot Wire Parallel.

Comparison of Turbulence Levels

Wind ——— 255° N

----- 239° N

Mod. 3

Location B

Hot Wire $\perp U_{\infty}$

$U_{\infty} = 44$ ft/sec

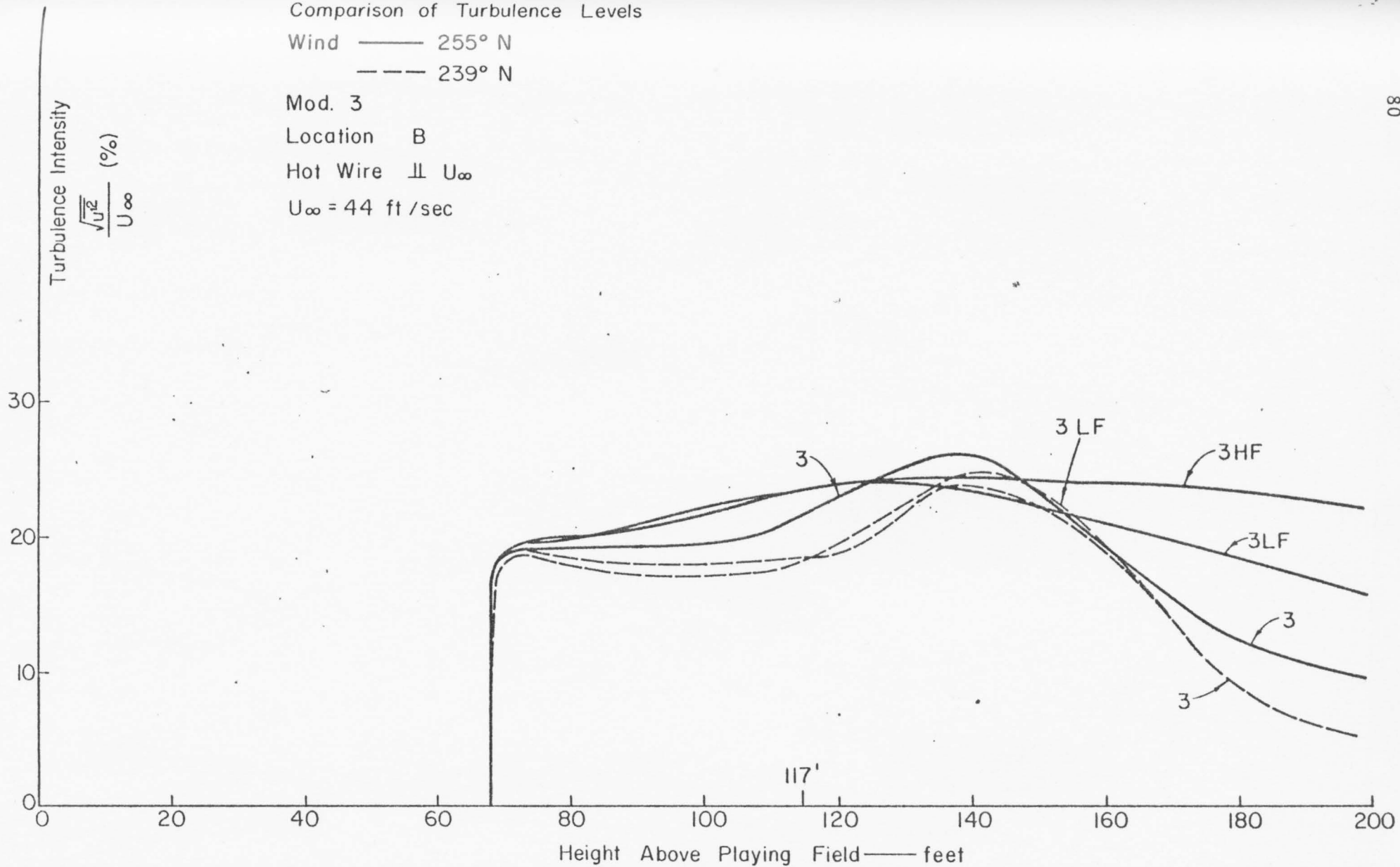


Fig. 61. Comparison of Turbulence for Modification 3 -- Wind at 239° & 255° -- Location B -- Hot Wire Parallel.

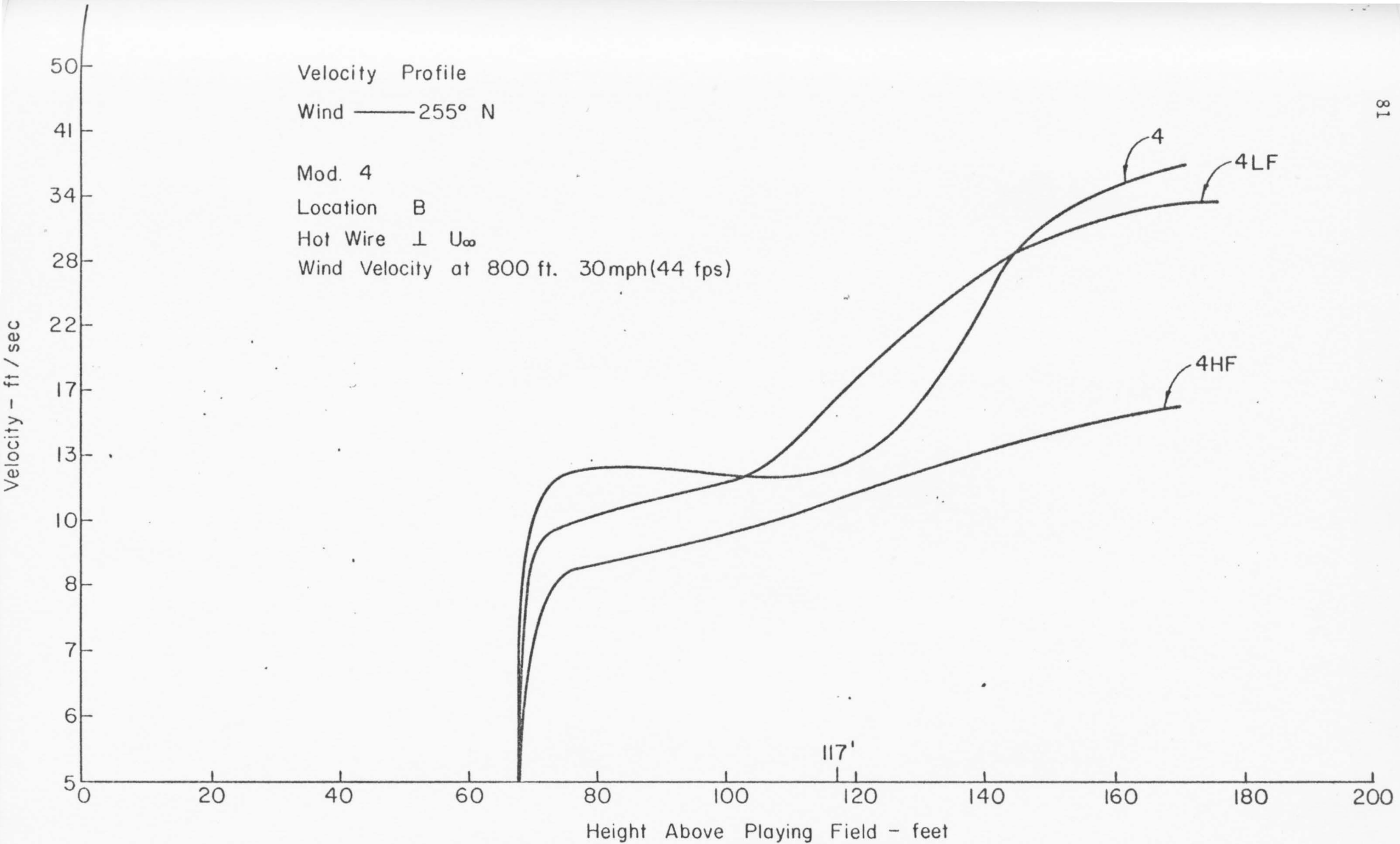


Fig. 62. Velocity Profile for Modification 4 -- Wind at 255° -- Location B -- Hot Wire Perpendicular.

Comparison of Turbulence Levels

Wind — 255° N

Mod. 4

Location B

Hot Wire $\perp U_{\infty}$

$U_{\infty} = 44$ ft/sec

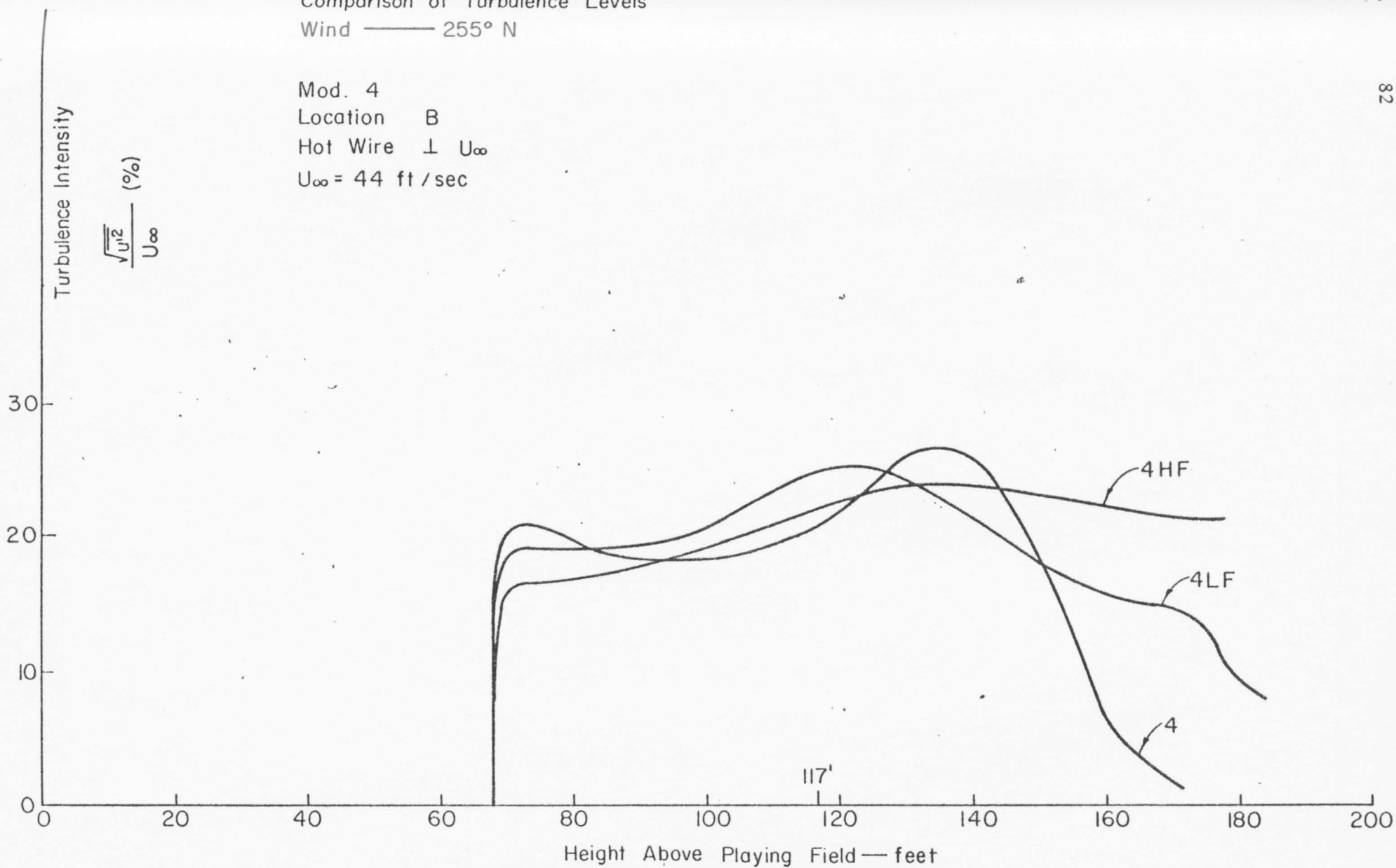


Fig. 63. Comparison of Turbulence for Modification 4 -- Wind at 255° -- Location B -- Hot Wire Perpendicular.

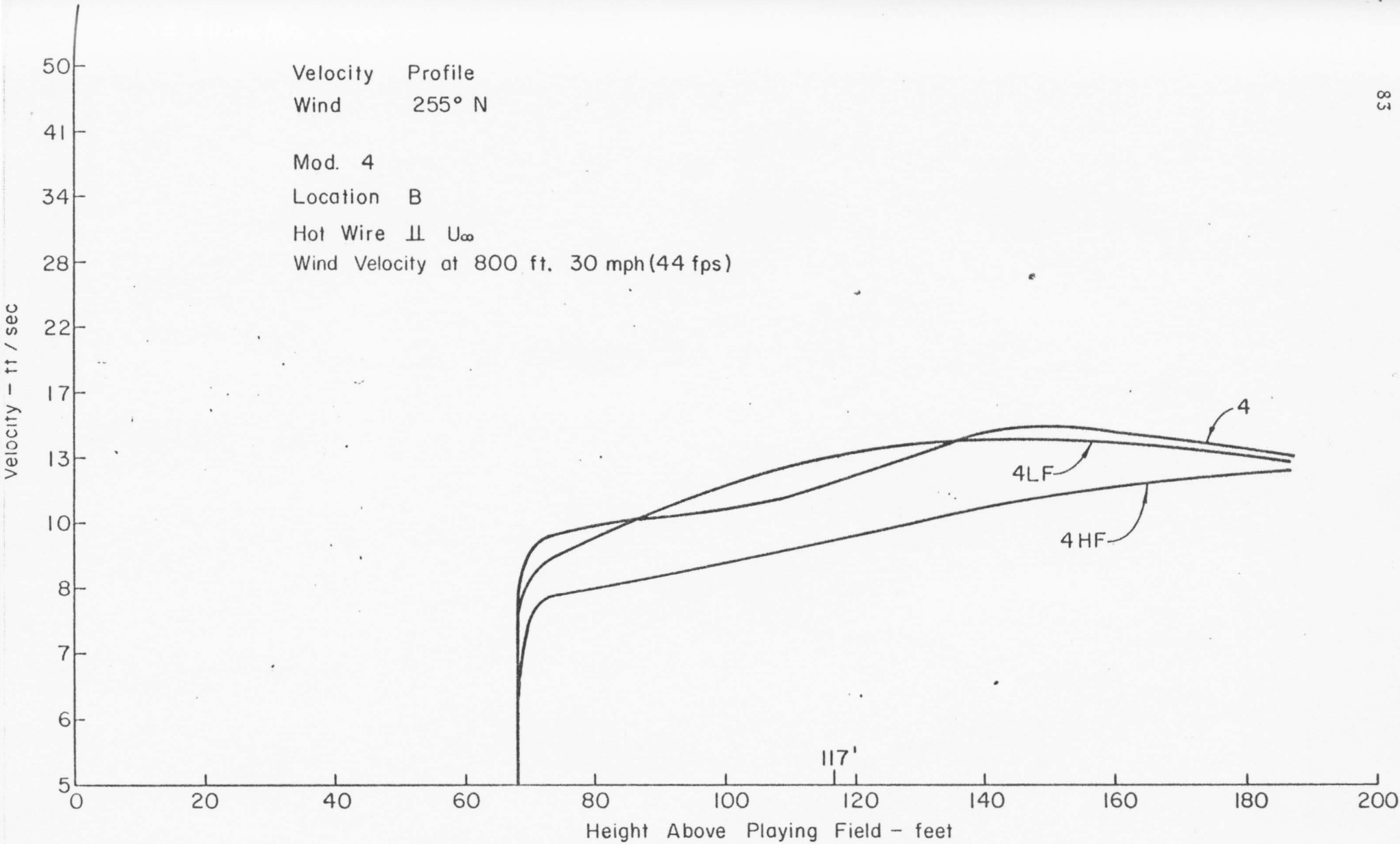


Fig. 64. Velocity Profiles for Modification 4 -- Wind at 255° -- Location B -- Hot Wire Parallel.

Comparison of Turbulence Levels

Wind 255° N

Mod. 4

Location B

Hot Wire $\perp U_{\infty}$

$U_{\infty} = 44$ ft/sec

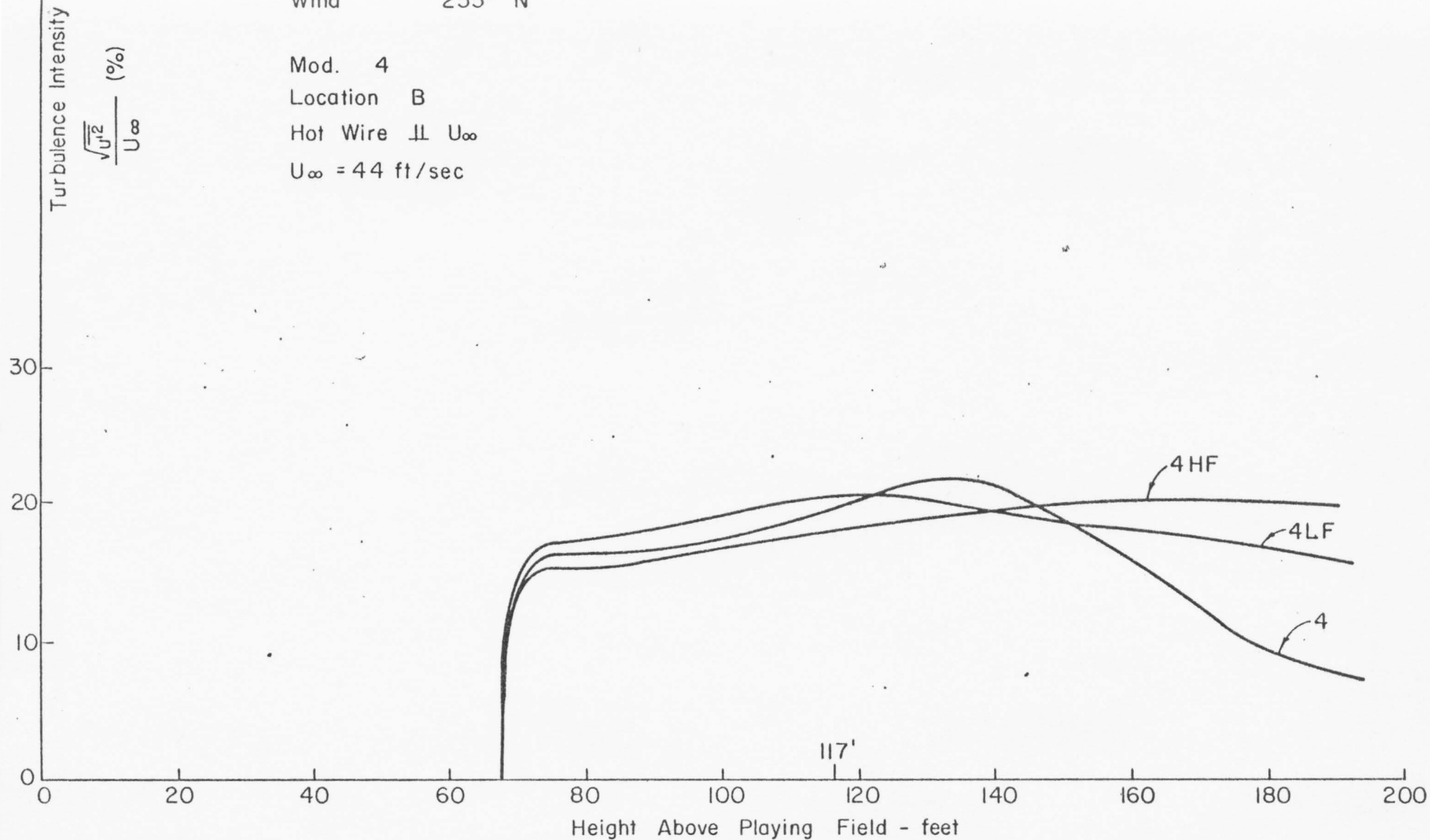


Fig. 65. Comparison of Turbulence for Modification 4 -- Wind at 255° -- Location B -- Hot Wire Parallel.

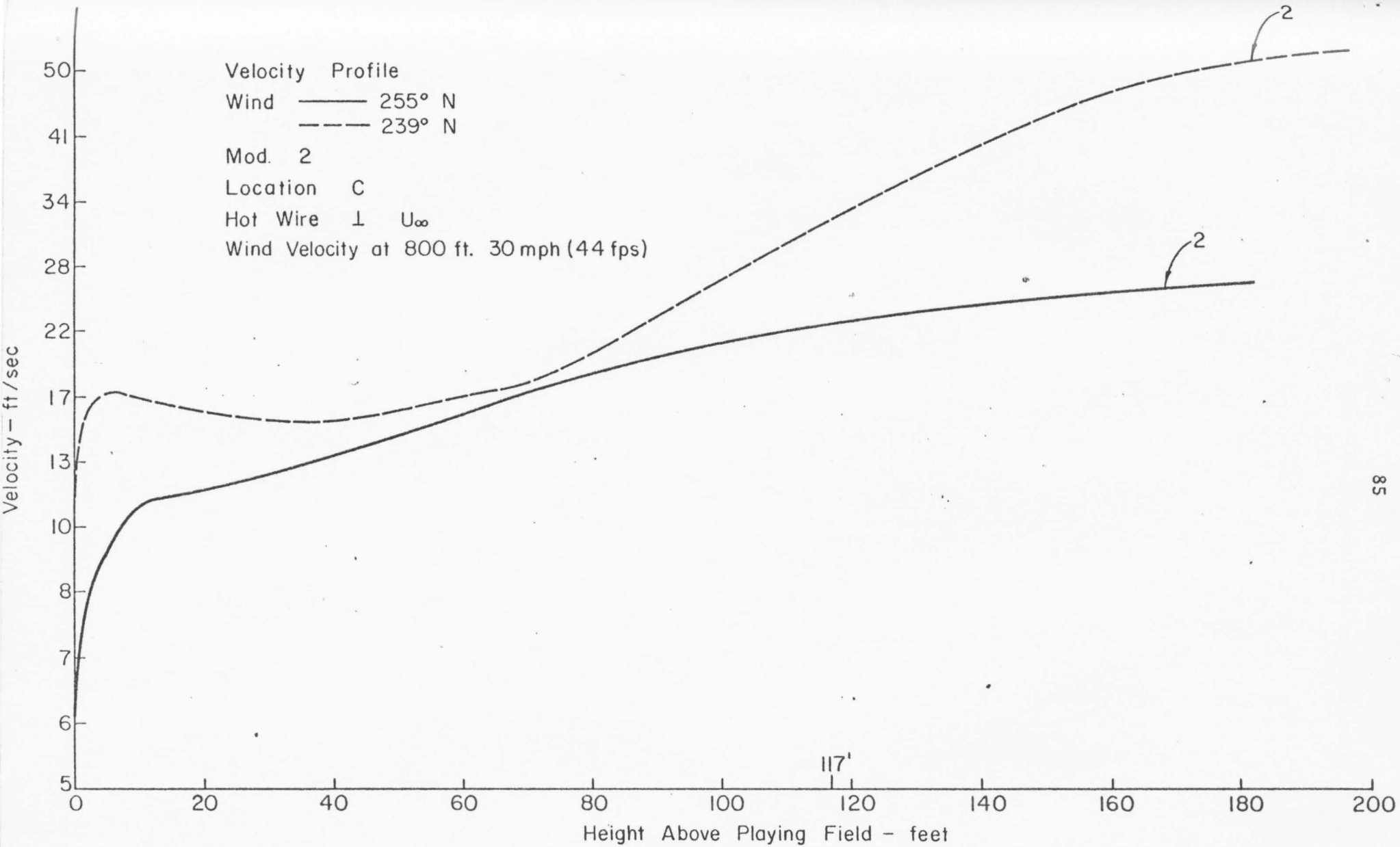


Fig. 66. Velocity Profiles for Modification 2 -- Wind at 239° & 255° -- Location C -- Hot Wire Perpendicular.

Comparison of Turbulence Levels

Wind ——— 255° N

----- 239° N

Mod. 2

Location C

Hot Wire $\perp U_{\infty}$

$U_{\infty} = 44$ ft/sec

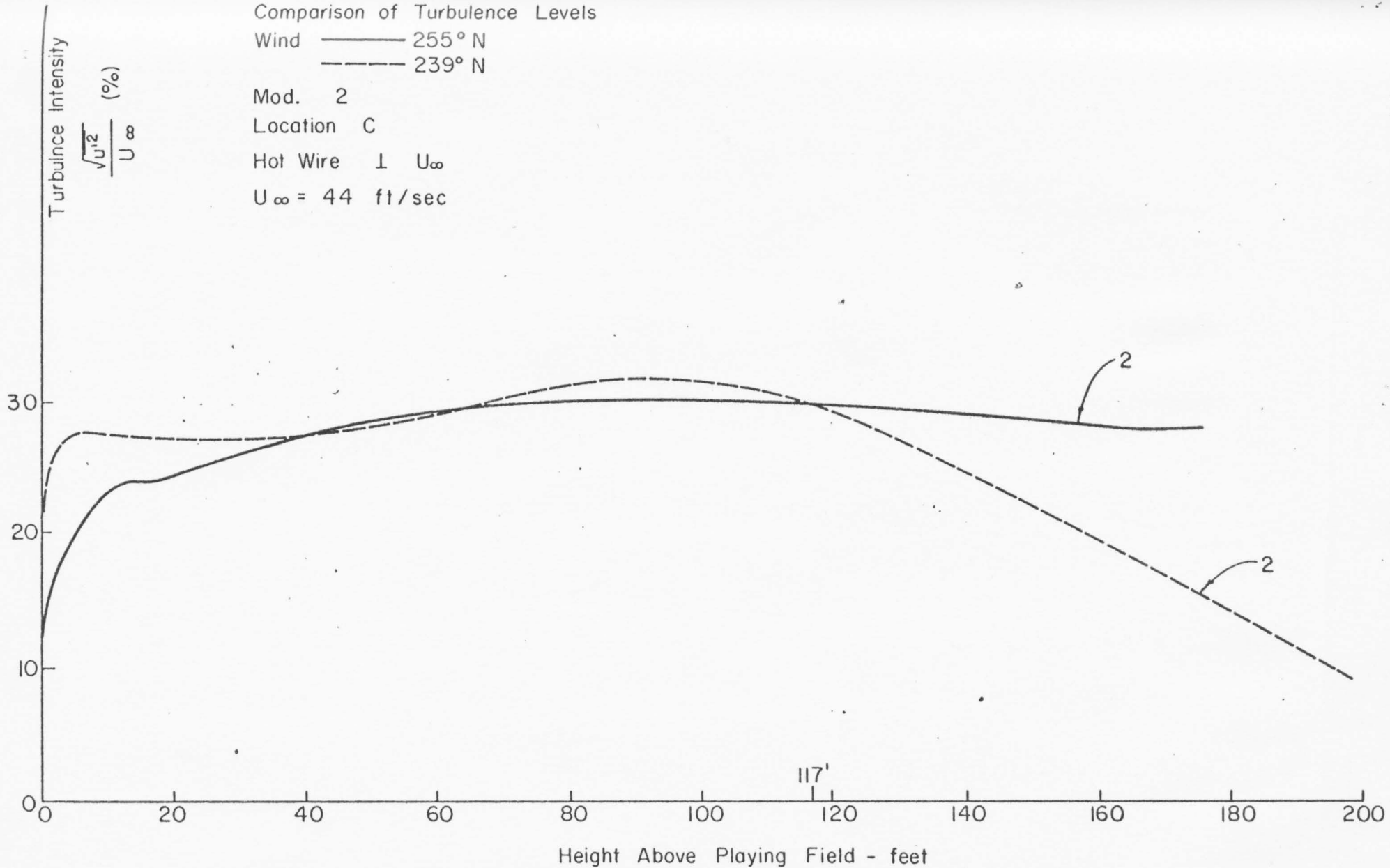


Fig. 67. Comparison of Turbulence for Modification 2 -- Wind at 239° & 255° -- Location C -- Hot Wire Perpendicular.

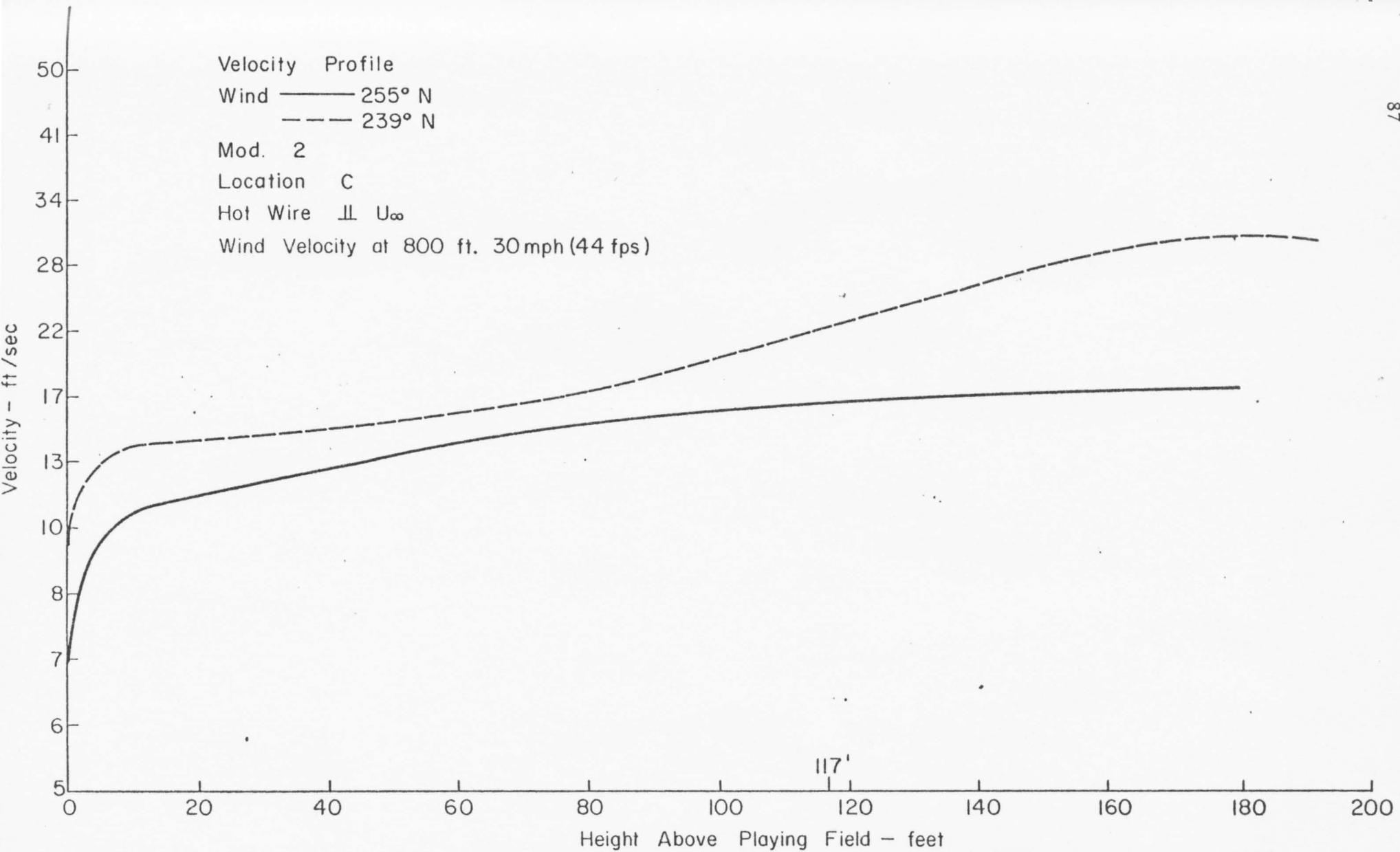


Fig. 68. Velocity Profiles for Modification 2 -- Wind at 239° & 255° -- Location C -- Hot Wire Parallel.

Comparison of Turbulence Levels

Wind ——— 255° N

----- 239° N

Mod. 2

Location C

Hot Wire $\perp U_{\infty}$

$U_{\infty} = 44$ ft/sec

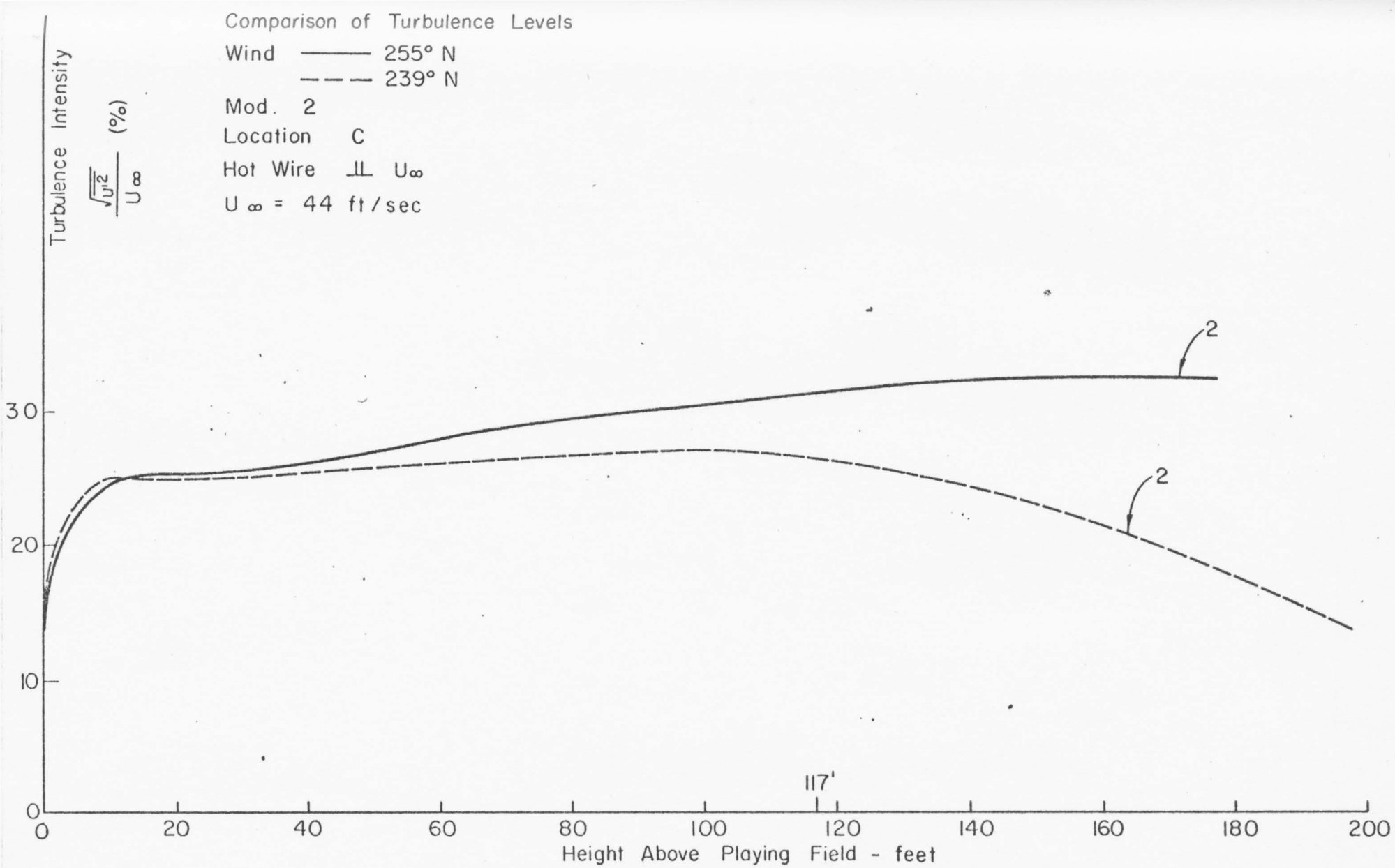


Fig. 69. Comparison of Turbulence for Modification 2 -- Wind at 239° & 255° -- Location C -- Hot Wire Parallel.

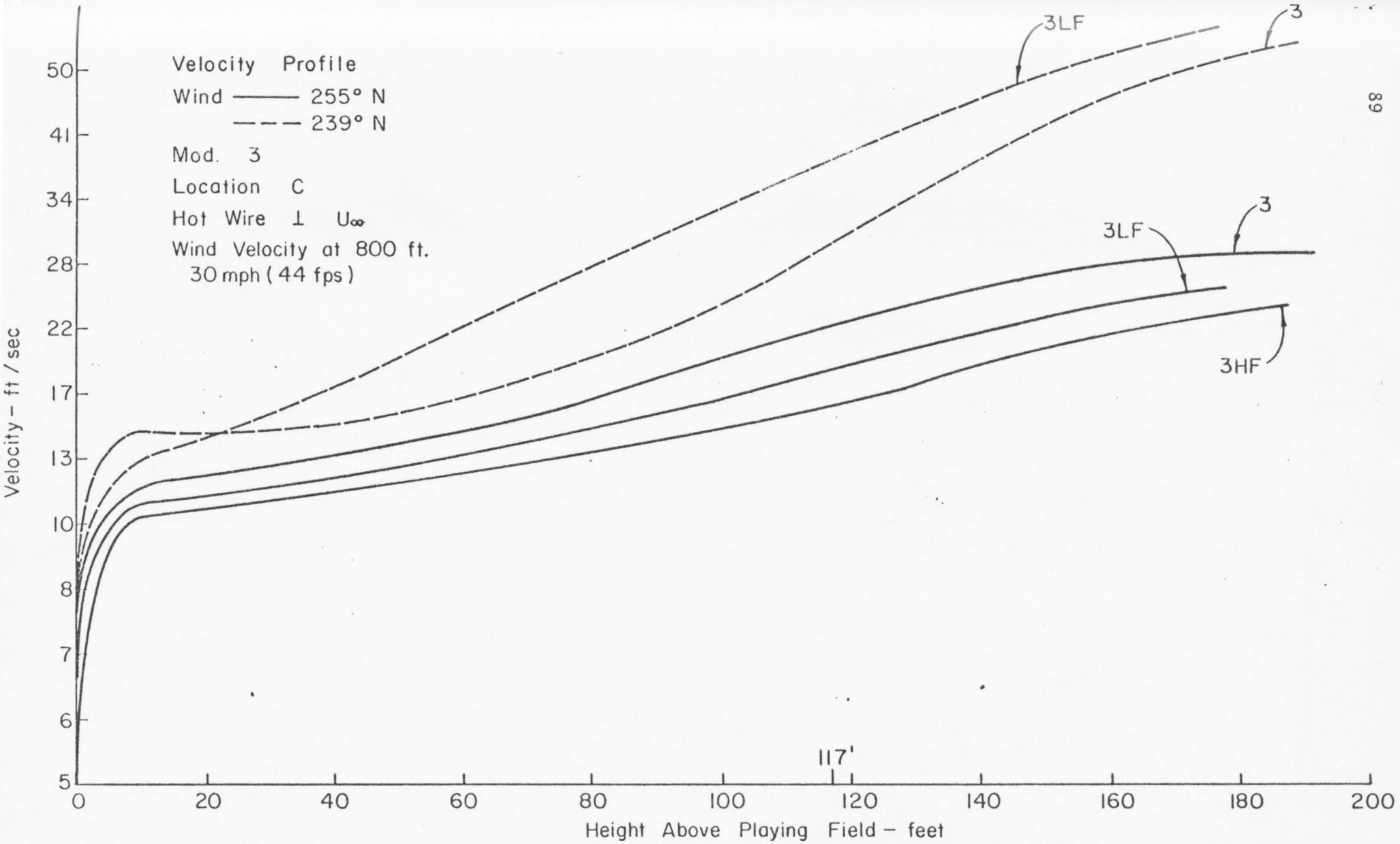


Fig. 70. Velocity Profiles for Modification 3 -- Wind at 239° & 255° -- Location C -- Hot Wire Perpendicular.

Comparison of Turbulence Levels
Wind ——— 255° N
 - - - - 239° N
Mod. 3
Location C
Hot Wire $\perp U_\infty$
 $U_\infty = 44 \text{ ft/sec}$

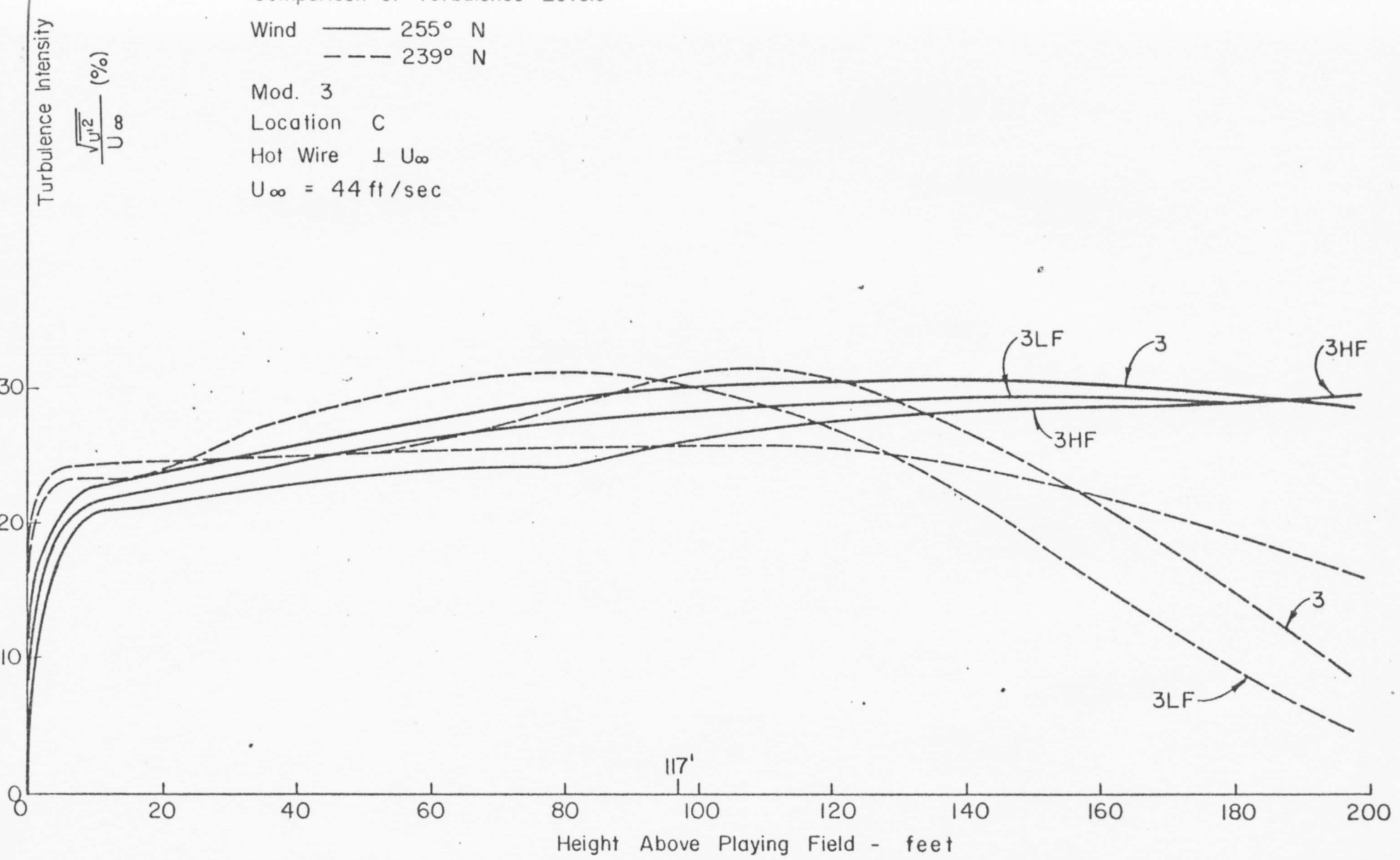


Fig. 71. Comparison of Turbulence for Modification 3 -- Wind at 239° & 255° -- Location C -- Hot Wire Perpendicular.

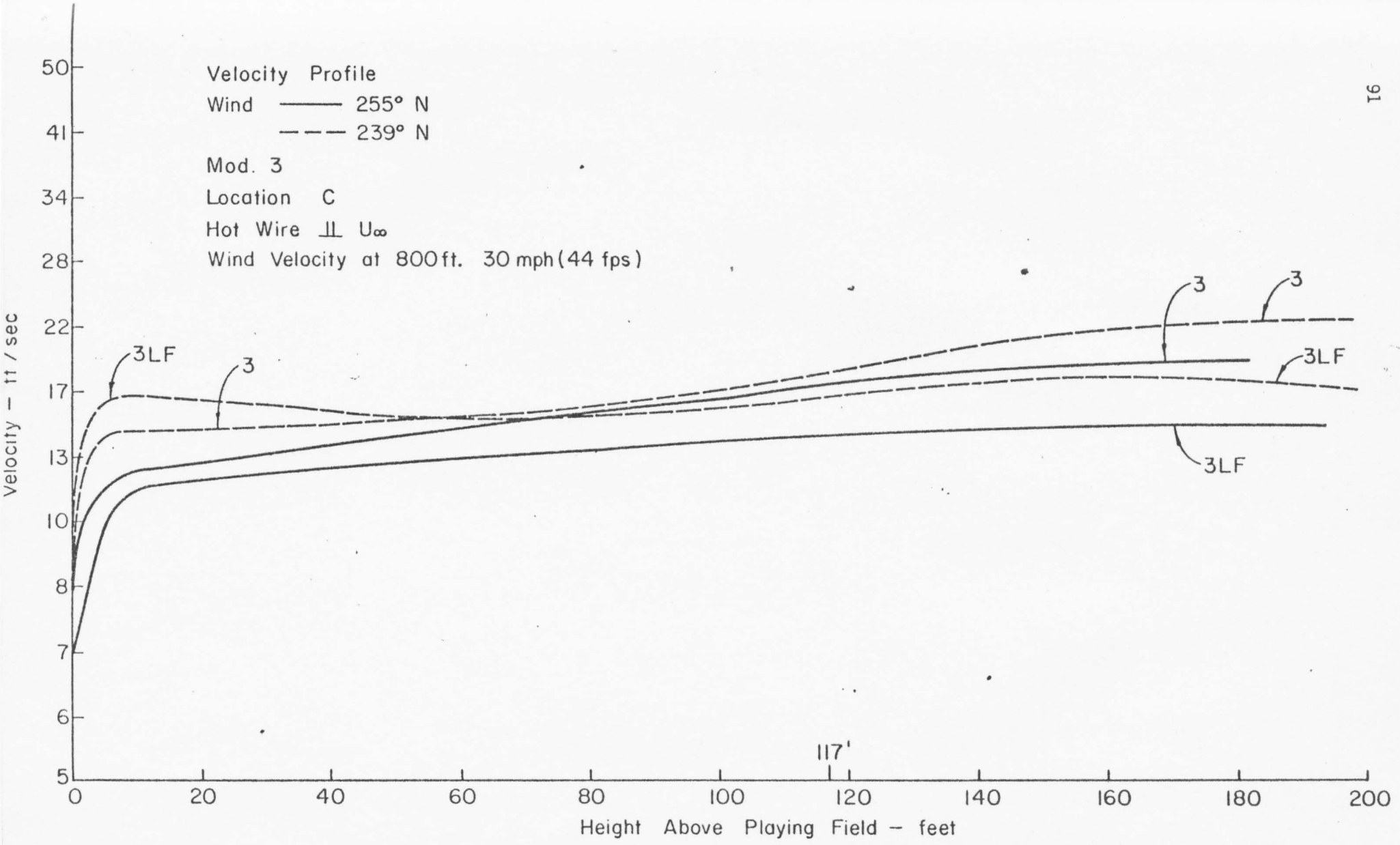


Fig. 72. Velocity Profiles for Modification 3 -- Wind at 239° & 255° -- Location C -- Hot Wire Parallel.

Comparison of Turbulence Levels

Wind ——— 255° N

----- 239° N

Mod. 3

Location C

Hot Wire $\perp U_{\infty}$

$U_{\infty} = 44 \text{ ft/sec}$

Turbulence Intensity
 $\frac{\sqrt{u'^2}}{U_{\infty}} (\%)$

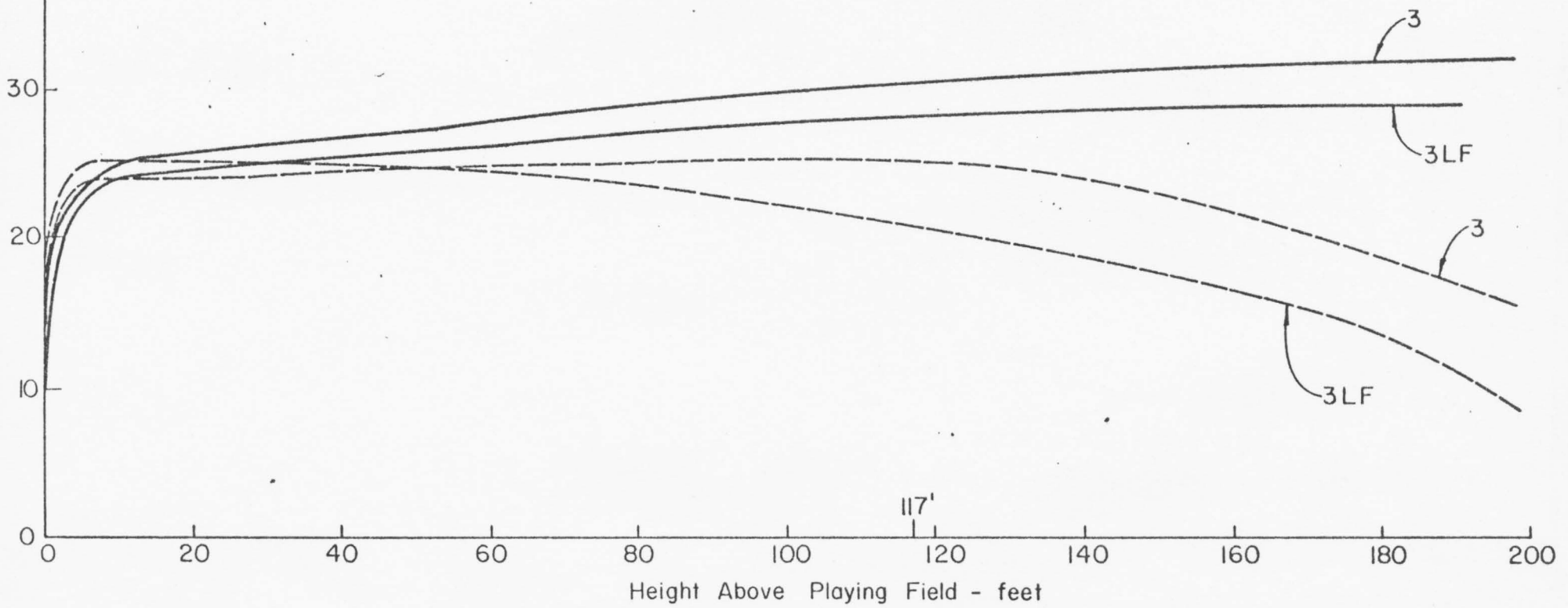


Fig. 73. Comparison of Turbulence for Modification 3 -- Wind at 239° & 255° -- Location C -- Hot Wire Parallel.

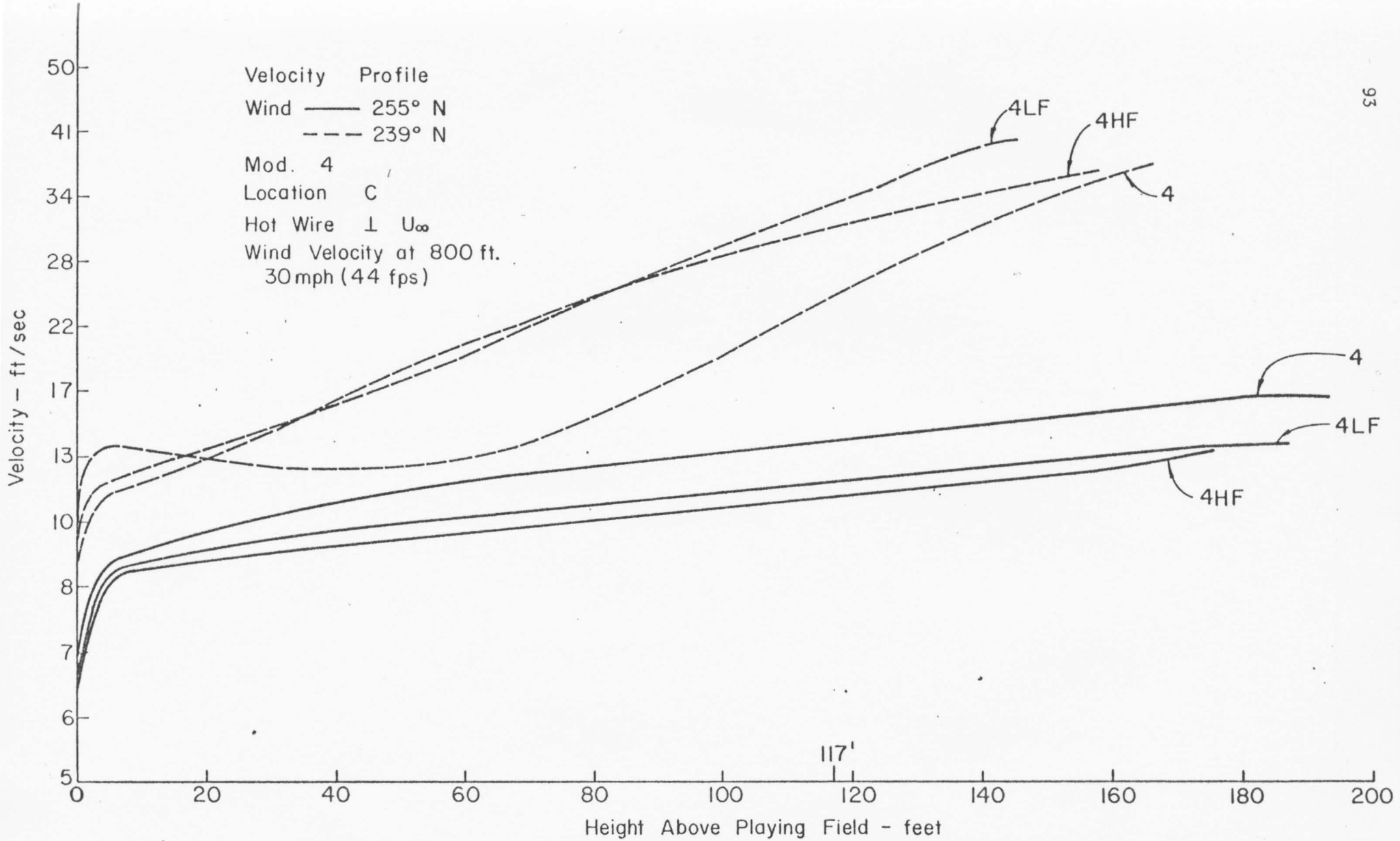


Fig. 74. Velocity Profiles for Modification 4 -- Wind at 239° & 255° -- Location C -- Hot Wire Perpendicular.

Comparison of Turbulence Levels

Wind ——— 255° N

--- 239° N

Mod. 4

Location C

Hot Wire $\perp U_{\infty}$

$U_{\infty} = 44 \text{ ft/sec}$

Turbulence Intensity
 $\frac{\sqrt{u'^2}}{U_{\infty}} (\%)$

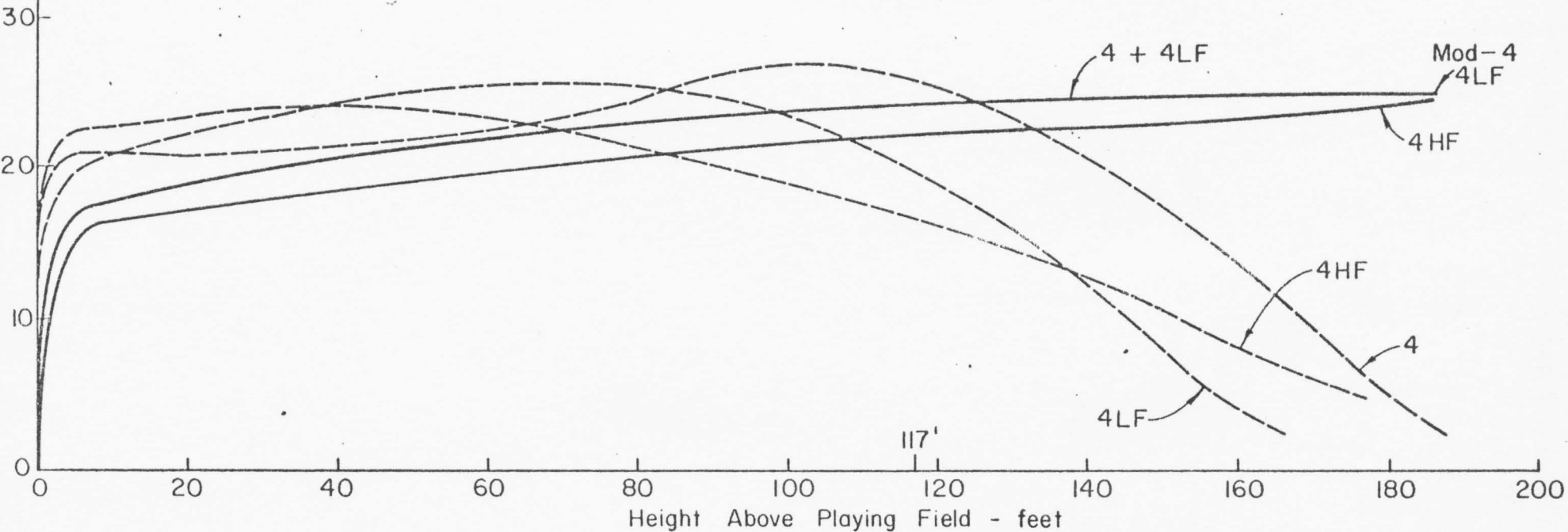


Fig. 75. Comparison of Turbulence for Modification 4 -- Wind at 239° & 255° -- Location C -- Hot Wire Perpendicular.

Velocity Profile
Wind — 255° N
 - - - 239° N
Mod. 4
Location C
Hot Wire $\perp U_{\infty}$
Wind Velocity at 800 ft. 30 mph (44 fps)

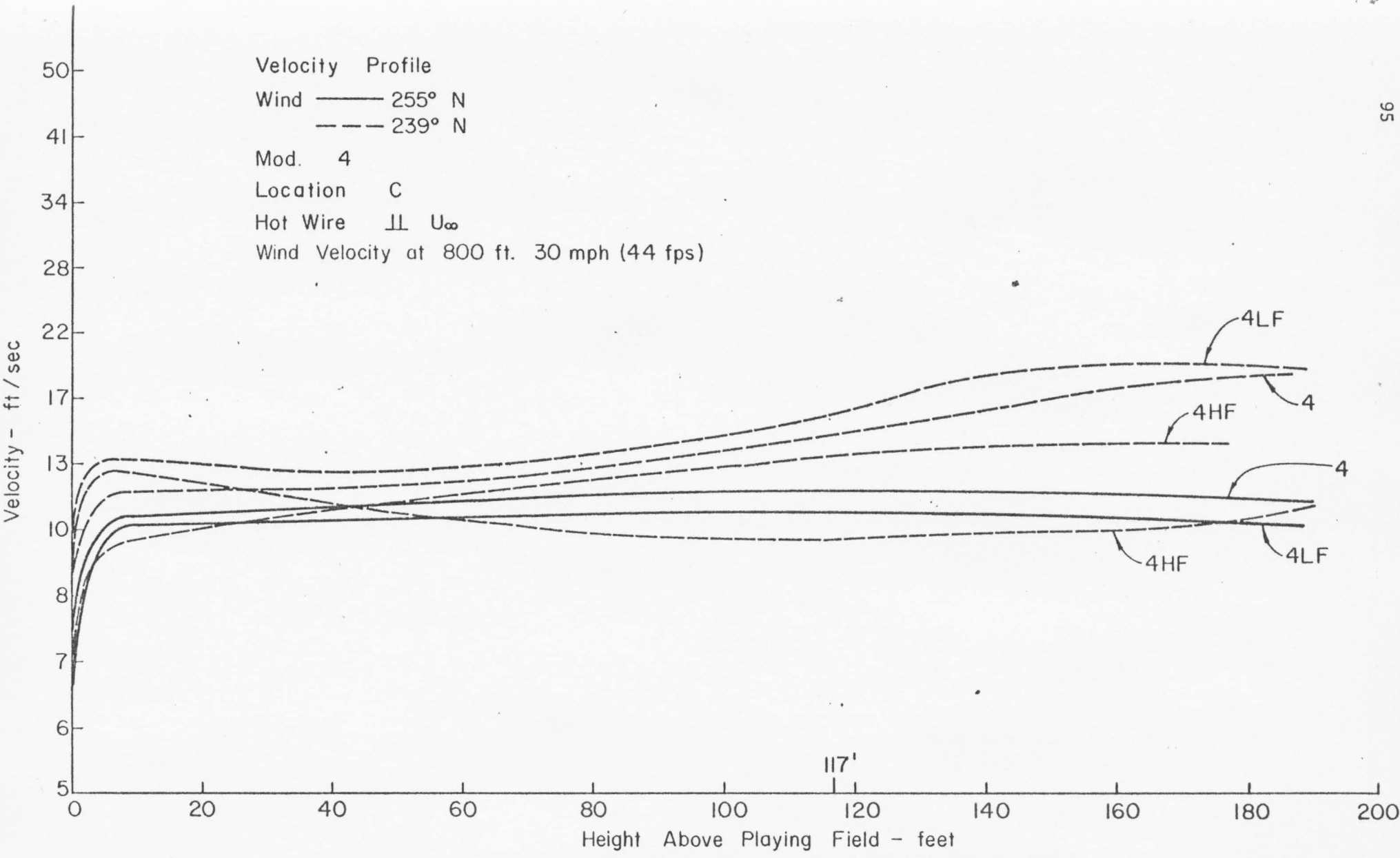


Fig. 76. Velocity Profiles for Modification 4 -- Wind at 239° & 255° -- Location C -- Hot Wire Parallel.

Comparison of Turbulence Levels

Wind ——— 255° N
----- 239° N

Mod. 4

Location C

Hot Wire $\perp U_{\infty}$

$U_{\infty} = 44$ ft / sec

Turbulence Intensity
 $\frac{\sqrt{u'^2}}{U_{\infty}}$ (%)

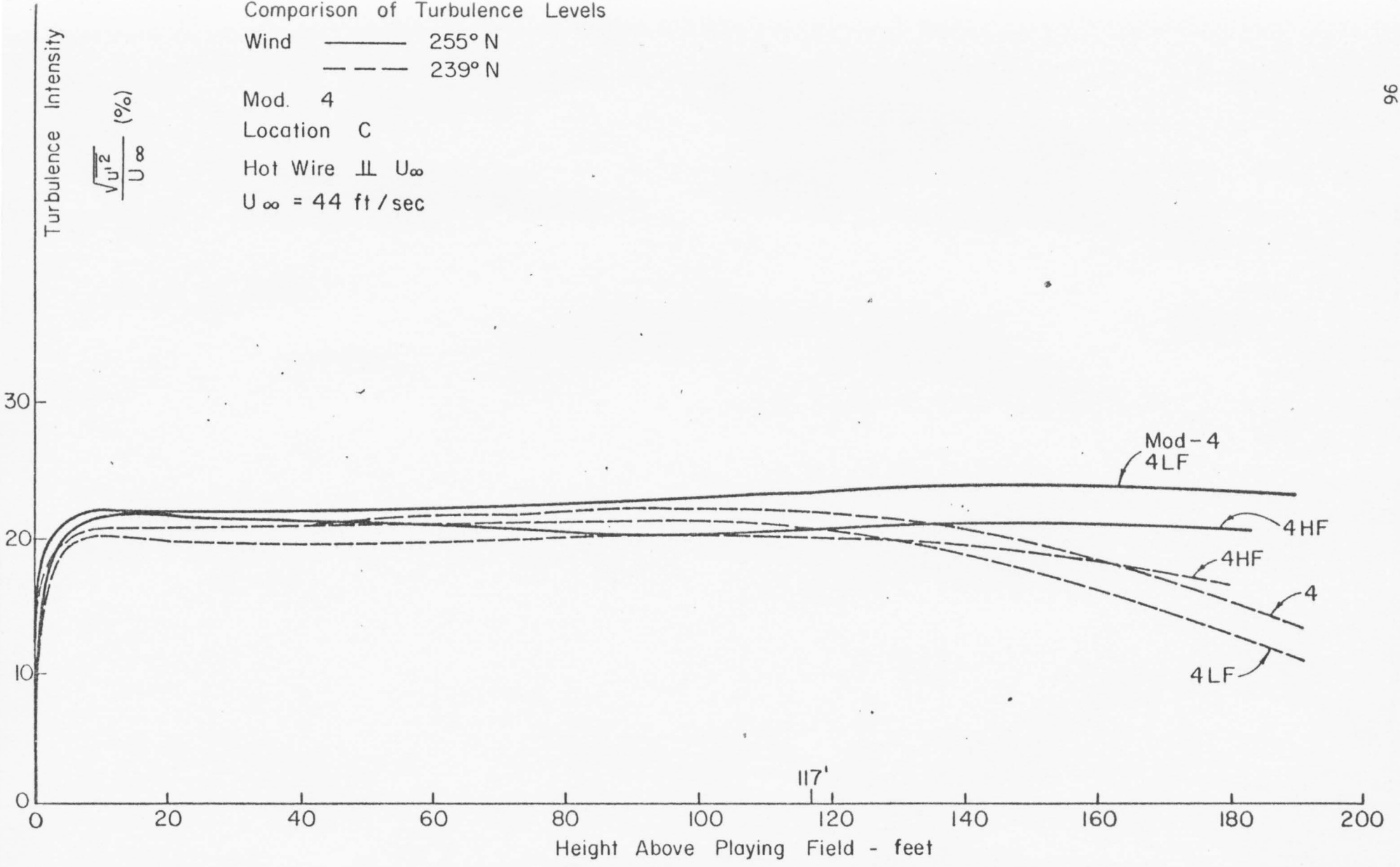


Fig. 77. Comparison of Turbulence for Modification 4 -- Wind at 239° & 255° -- Location C -- Hot Wire Parallel.

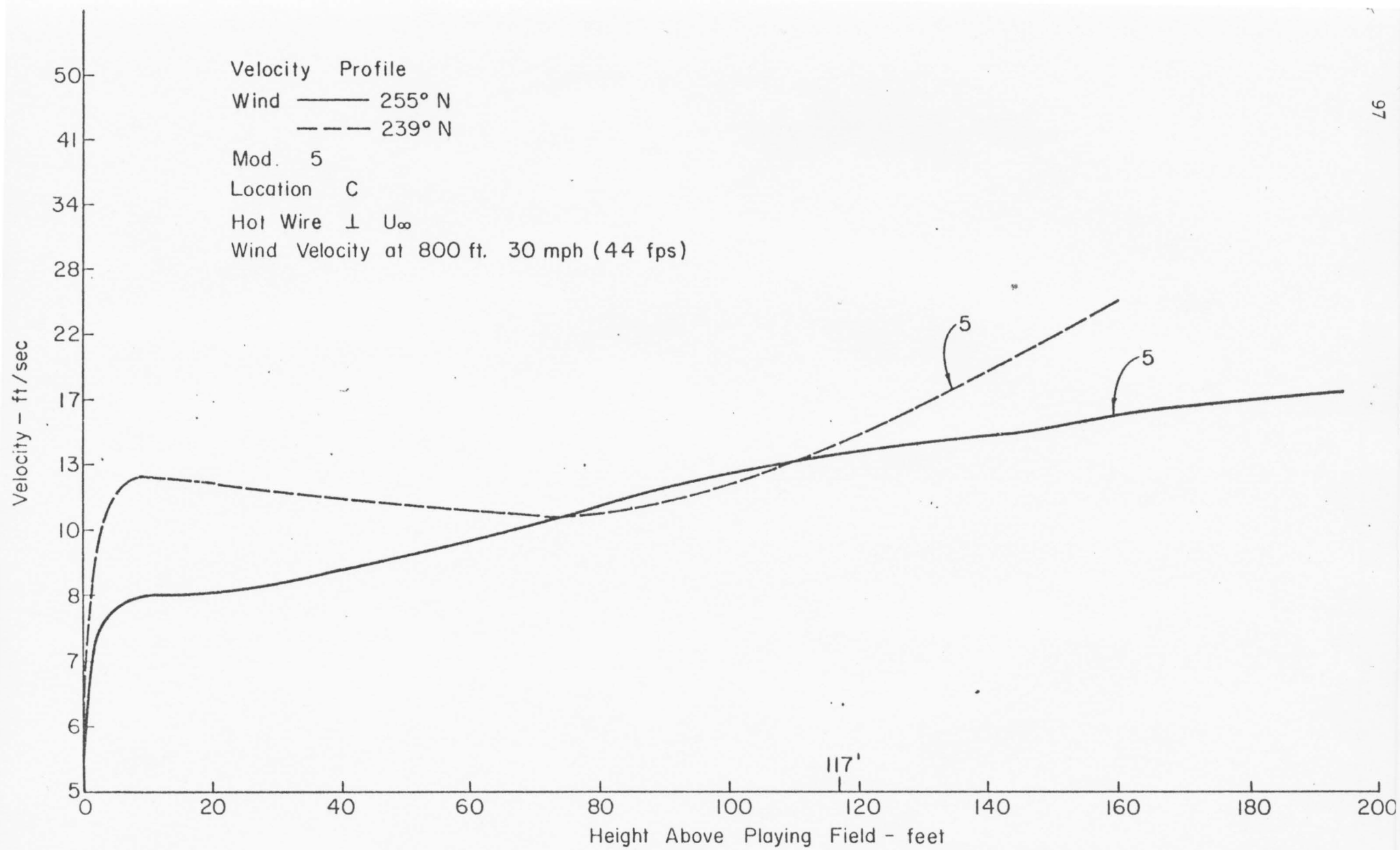


Fig. 78. Velocity Profiles for Modification 5 -- Wind at 239° & 255° -- Location C -- Hot Wire Perpendicular.

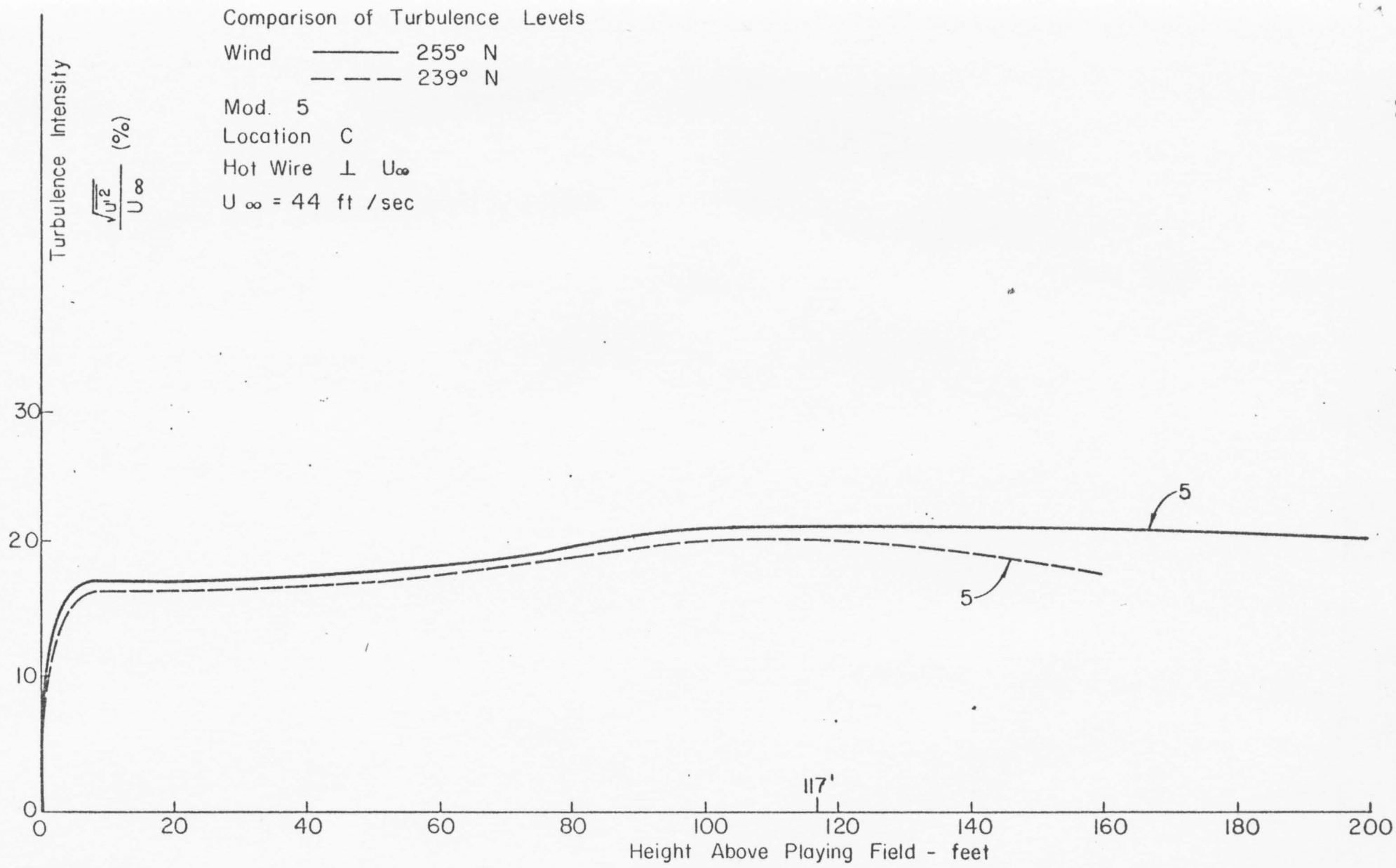


Fig. 79. Comparison of Turbulence for Modification 5 -- Wind at 239° & 255° -- Location C -- Hot Wire Perpendicular.

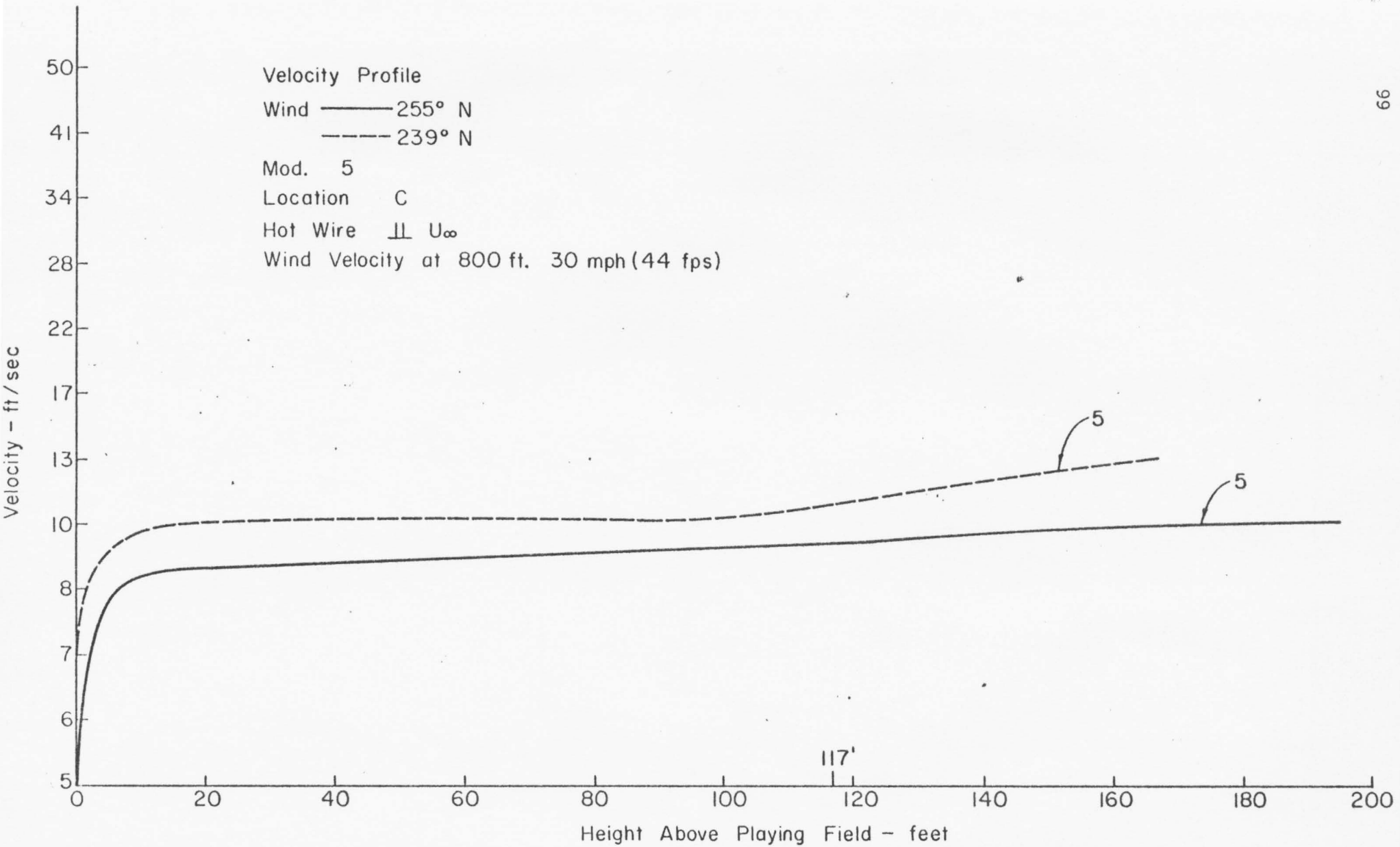


Fig. 80. Velocity Profiles for Modification 5 -- Wind at 239° & 255° -- Location C -- Hot Wire Parallel.

Comparison of Turbulence Levels

Wind ——— 255° N

----- 239° N

Mod. 5

Location C

Hot Wire \perp U_{∞}

$U_{\infty} = 44$ ft/sec

Turbulence Intensity
 $\frac{\sqrt{u'^2}}{U_{\infty}}$ (%)

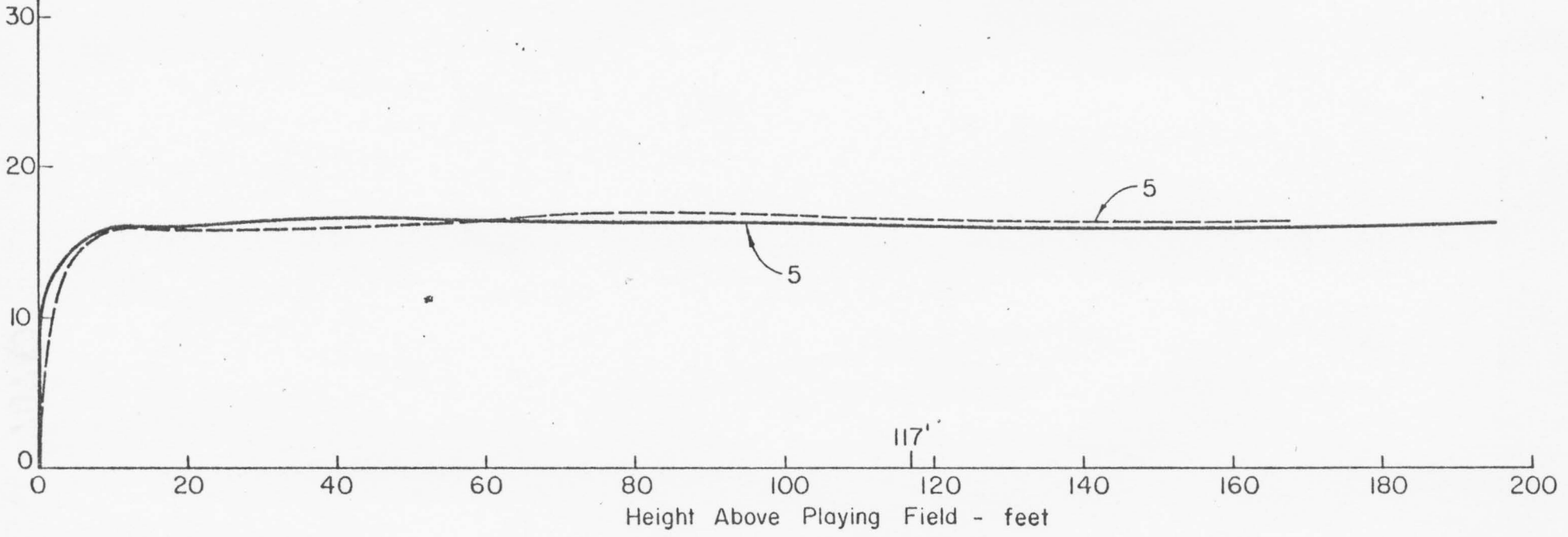


Fig. 81. Comparison of Turbulence for Modification 5 -- Wind at 239° & 255° -- Location C -- Hot Wire Parallel.