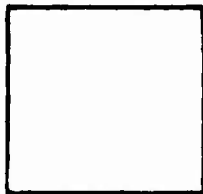


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REPORT 1805, AERO REPORT 1067

NAVY DEPARTMENT
THE DAVID W. TAYLOR, MODEL BASIN
AERODYNAMICS LABORATORY
WASHINGTON 7, D C

A WIND-TUNNEL AIR WAKE SURVEY OF A 1/144-SCALE MODEL AIRCRAFT
CARRIER WITH DECK AND ISLAND MODIFICATIONS

by

Martin L Cook

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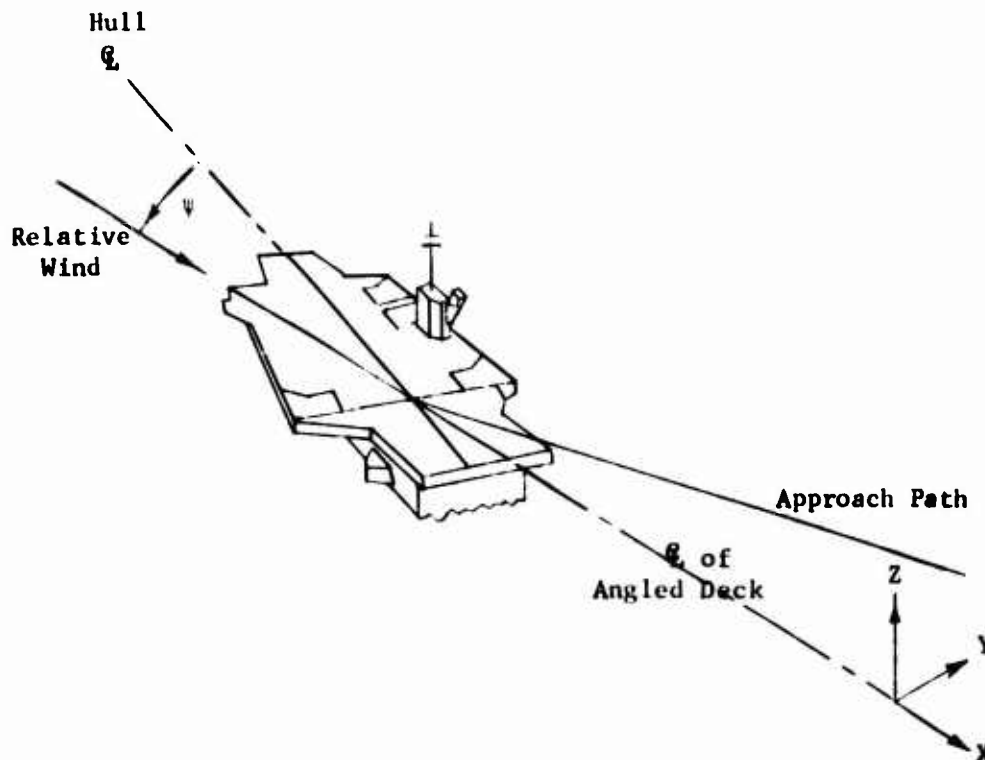
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NOTATION

Positive directions of axes and angular displacement are shown by arrows.



X - Origin is at the intersection of the center line of the angled deck and the aft edge of the deck, positive aft.

Y - Origin is on the center line of the angled deck.

Z - Origin is at the deck level, positive upward.

SYMBOLS

q	local dynamic pressure in pounds per square foot $\left(q = \frac{\rho V^2}{2}\right)$
q_0	free-stream dynamic pressure in pounds per square foot $\left(q = \frac{\rho V_0^2}{2}\right)$
q/q_0	dynamic pressure ratio
q_a	local dynamic pressure of airplane
q_{a_0}	airplane dynamic pressure at approach airspeed (free-stream conditions)
V	local airspeed at any point, in feet per second
V_0	tunnel free-stream airspeed or full-scale wind over deck in feet per second
R	Reynolds number $\left(\frac{\rho V_0 l}{\mu}\right)$
X, Y, Z	coordinates which define the survey position referred to full scale, in feet
ρ	mass density of air in slugs per cubic foot
l	length of flight deck in feet
μ	absolute coefficient of viscosity in pound-seconds per square foot
α	angle of yaw in degrees (angle between relative wind vector and the hull axial center line, positive when wind is off the port bow)
ϵ_z	angularity of local airflow, in degrees, positive in the Z direction (see notation sheet)
ϵ_y	angularity of local airflow, in degrees, positive in the -Y direction (see notation sheet)
ϵ	resultant direction of the local airflow in degrees $= \sqrt{\epsilon_y^2 + \epsilon_z^2}$

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Report 1805
Aero Report 1067

AERODYNAMICS LABORATORY
DAVID TAYLOR MODEL BASIN
UNITED STATES NAVY
WASHINGTON, D C.

A WIND-TUNNEL AIR WAKE SURVEY OF A 1/144-SCALE MODEL AIRCRAFT
CARRIER WITH DECK AND ISLAND MODIFICATIONS

by

Martin L. Cook

SUMMARY

The air wake behind a model of the proposed CVA 67 aircraft carrier was surveyed in the wind tunnel. This survey is a part of a general wake study to investigate the wake disturbances along the flight approach path for aircraft. Aerodynamic data were obtained in the wake of the carrier with several modifications to the deck and island.

The air wake in the approach was most favorably improved with a deck modification rather than an island modification.

Presented are local dynamic pressure variations and angularity of airflow.

INTRODUCTION

The aerodynamics of the wake of a proposed CVA 67 aircraft carrier (hereinafter referred to as the CVA 67) in the aircraft approach region was investigated. This investigation, a wind-tunnel survey of the wake behind a 1/144-scale model was authorized by the Bureau of Ships in Reference 1. These tests are a part of a general study of various configuration changes to improve the aerodynamic wake characteristics in the approach region.

The results of these wind-tunnel tests show variations in the local dynamic pressure and the angularity of airflow in the wake. Investigations were made of several modifications to the deck and island at two yaw attitudes.

The tests were made in the 8- by 10-Foot Subsonic Wind Tunnel during two periods: (1) from 12 March 1963 through 29 March 1963, and (2) from 23 April 1963 through 30 May 1963.

MODEL

The 1/144-scale waterline model aircraft carrier, the proposed CVA 67, was fitted with a mirror-image model with the attachment plane coincident with the plane of the waterline. The mirror-image mounting system simulates a water surface having no boundary layer because, according to current theory, there is no flow across the plane of symmetry. The carrier model (erect) was supported in the test section by the image model (inverted), which was supported from the floor.

Dynamic pressures and angularity of the local airstream were sensed at various positions in the wake by a 10-tube pitot-static directional probe rake mounted on a remote-controlled support system.

Two modifications to the deck were investigated. First, the deck edge was rounded to an equivalent full-scale radius of six feet with no overhanging structures or cutouts, such as catwalks and ladders. The second modification consisted of a fillet in the area, at deck level, between the front edge of the angled deck and the port deck edge.

The island configurations investigated included the following: a CVA 65 island positioned at the same location as the CVA 67 island, the CVA 67 island in both the conventional position and forward on the flight deck, and an island obtained by fairing in the CVA 67 island to an airfoil shape. The airfoil-shaped island is described by ordinates and stations presented in Table 1. A sketch of the carrier model and the principal dimensions are presented in Figure 1. Photographs showing the deck modifications and the three island configurations tested are shown in Figure 2. A sketch of the airfoil-shaped island is shown in Figure 3.

TESTS

Two types of quantitative data were obtained from the pitot-static angularity rake; a local dynamic pressure and a local airflow angularity.

Air wake survey data were obtained with the wind from either of two directions: parallel to the center line of the ship ($\psi = 0^\circ$); and parallel to the angled deck ($\psi = 11^\circ$).

The rounded-edge deck and deck fillet were tested separately and in combination. The island configurations were tested with the port elevator removed to simulate the porous condition of the elevator grating. The effect of removing all elevators was also investigated.

The test is summarized in Table 2. The full-scale positions of the probes with respect to the carrier deck are tabulated below. These positions represent points along a 3° approach path which ends 6 feet (full scale) above the deck at the intersection of the angled deck and the first pendant.

X	Z
-66	12
3	16
147	24
291	31
507	42

The lateral survey positions (Y-direction) were such that an aircraft with a wing span of 80 feet would always be in the survey region.

RESULTS

These results of the air wake survey show the effect of carrier configuration and relative wind on the local dynamic pressure referenced to the free-stream dynamic pressure (q/q_0) and local angularity of airflow as a function of X, Y, and Z. All data are taken along the aircraft approach path regardless of the carrier yaw attitude.

Figures 4 through 7 show dynamic pressure ratios along a 3° approach path for the model with various island and deck edge modifications. In a few cases, where a pressure probe was not located on the approach path, linear interpolations were made to obtain flight path data.

The local angularity of airflow presented in Figures 8 through 11 show the resultant of the two components of the angularity in degrees. Any particular arrow represents only the resultant direction (in degrees) of the velocity at that point. The term "vector" is purposely not used in this connection because the arrow does not necessarily indicate the

true magnitude of either the local velocity or of the local dynamic pressure. This direction of airflow, as presented here, is quite analogous to the flow pattern of an array of tufts, viewed from downstream, with the model upstream of the tufts.

The accuracy of the dynamic pressure ratios, based on repeatability, is approximately ± 3 percent in the turbulent region. This accuracy includes model installation error.

The data presented here define the more important wake effects obtained from the various configurations tested.

DISCUSSION

Analysis of the data shows no perceptible correlation between the dynamic pressure variation (q/q_0) and the angularity of airflow. The following analysis of the data from the carrier tests is based primarily on the dynamic pressure results with some additional commentary on the angularity of airflow results.

The discussion is divided into two parts according to whether the relative wind was aligned with the center line of the carrier ($\psi = 0^\circ$) or the angled deck ($\psi = 11^\circ$). Each configuration will be discussed in order of decreasing preference.

RELATIVE WIND PARALLEL TO THE CENTER LINE OF THE SHIP ($\psi = 0^\circ$)

The data from the island-off configuration, or flush deck, was studied (1) to show the basic flow condition due to the hull and the flight deck and (2) to evaluate the effect of any island configuration. This is the minimal configuration. (See Figures 4a and 5a.)

The data from the airfoil-shaped island rotated -11° appears to be quite similar to that from the flush deck, except for some local disturbances at the critical distances aft of the carrier (approximately 150 to 300 feet aft of the rear deck edge). (See Figures 4a(concl) and 5e.)

The CVA 67 island (basic configuration) shows a slightly greater depression of q/q_0 along the approach path ($Y = \pm 40$ feet) than the yawed airfoil-shaped island. This configuration also shows a much greater depression of q/q_0 to the starboard of the flight path than the airfoil-shaped island. (See Figures 4a(concl) and 5e.)

The results from the configurations with the yawed CVA 67 island, the rounded-deck edge with the CVA 67 island, and the CVA 67 island yawed and translated forward generally show the greater depression of the dynamic pressure ratio as shown in Figures 5b and 6. (Again, each configuration was mentioned in order of decreasing preference.)

From the data, in Figure 4a(concl), the q/q_0 depression is greatest for the CVA 65 Island.

RELATIVE WIND PARALLEL TO ANGLED DECK ($\psi = 11^\circ$)

At a relative wind parallel to the angled deck, there is a considerable change in the airflow pattern from that obtained at 0° , for all configurations (See Figure 5.) The results of the deck modifications show a greater potential for an improvement to the air wake than the island configurations.

At this yaw angle, the airflow wake from any island (in the conventional location) scarcely affects the flow along the approach path within one-half carrier length, because the island wake is practically parallel to the direction of the relative wind.

The configuration with the rounded-deck edge, with a fillet (with the CVA 67 island) gives a comparatively slight depression in the dynamic pressure ratio; therefore, this deck-island configuration is recommended at this yaw angle. This favorable contribution to the dynamic pressure ratio is due, principally, to the deck fillet, because the rounded-deck edge with the CVA 67 island without the deck fillet gives only a slight increase in q/q_0 . (Compare Figures 5b and 5c.)

The CVA 67 island yawed -11° (starboard edge of island is parallel to the angled deck) gives results which are substantially the same as those from the basic configuration, or unyawed island (Figure 4b). The results from the airfoil-shaped island, yawed -11° , and the CVA 65 island show slightly greater depressions in q/q_0 (Figure 4b(concl)). These islands are respectively somewhat less acceptable than the basic CVA 67 island.

GENERAL DISCUSSION

The wind angularity plots (Figures 8 through 11) show the vortex pattern, as well as the general wake. A strong downwash (generally observed throughout the data) at $X \geq 0$ and $Z \leq 0$ seems to be caused by a low pressure (base pressure) directly behind the hull. The effects

of this sink are seen over the entire survey plane at all values of X tested. Figure 12 shows this downwash component as a function of X for three island configurations.

Reynolds number has virtually no effect on the dynamic pressure variation. Figure 13 shows the Reynolds number effect.

The effect of removing all elevators (simulating grated elevators with no blockage), compared with solid-deck elevators in the up position, was found to be negligible.

Considerably more air wake data (angularity and dynamic pressure ratios) are available from the present survey, which define a much greater approach region than presented here. These data (not presented here) are available, and may be obtained upon request.

An equation, which defines the aircraft dynamic pressure ratio in terms of the pressure ratio from this survey (Reference 2), is presented, using a standard notation, in the appendix.

CONCLUSIONS

The deck fillet shows a considerable potential in regard to a solution to the air wake flow problem. This modification should be investigated further. Whereas q/q_0 is only slightly increased by the airfoil-shaped island (yawed -11°) at a relative wind parallel to the center of the ship and slightly decreased at a relative wind parallel to the angled deck, the present configuration of the CVA 67 island is a good compromise for use in the solution of the air wake problem.

As a corollary to the above conclusions, the adverse airflow conditions in the aircraft approach region is principally a result of the deck configuration and not of the island. From the data presented, the preceding statement applies to the air wake within one-half of a carrier length aft of the rounddown.

Aerodynamics Laboratory
David Taylor Model Basin
Washington, D. C.
January 1964

APPENDIX

RELATION BETWEEN q/q_o AND AIRPLANE DYNAMIC PRESSURE RATIO

It may be necessary to express the airplane dynamic pressure in terms of the measured carrier air wake dynamic pressure ratio as presented in Figures 4 through 7. The local velocity of the aircraft is the difference between the approach airspeed of the aircraft and the local differential velocity due to the carrier wake, or

$$V_a = V_{a_o} - \Delta V = V_{a_o} - V_o - V = V_{a_o} - V_o + V \quad [1]$$

Where

V_a local airspeed of airplane

V_{a_o} approach airspeed of aircraft (free-stream conditions)

Multiplying equation [1] by $\frac{1}{V_{a_o}}$

$$\frac{V_a}{V_{a_o}} = \left[1 - \frac{V_o}{V_{a_o}} \left(1 - \frac{V}{V_o} \right) \right] \quad [2]$$

But

$$\frac{V}{V_o} = \sqrt{\frac{q}{q_o}} \quad \text{and} \quad \frac{V_a}{V_{a_o}} = \sqrt{\frac{q_a}{q_{a_o}}}$$

Therefore

$$\sqrt{\frac{q_a}{q_{a_o}}} = \left[1 - \frac{V_o}{V_{a_o}} \left(1 - \sqrt{\frac{q}{q_o}} \right) \right] \quad [3]$$

or squaring, we have the required equation:

$$\frac{q_a}{q_{a_o}} = \left[1 - \frac{V_o}{V_{a_o}} \left(1 - \sqrt{\frac{q}{q_o}} \right) \right]^2$$

REFERENCES

1. BUSHIPS ltr F013 02 06 Ser 442-208 of 23 Nov 1962
2. White, Herbert E. Wind Tunnel Tests to Determine the Air-Flow Characteristics in the Wakes of Three Aircraft Carrier Models. Pt. 2: Tests of the Attack Carrier CVA 62. (Title Unclassified). Wash., Jun 1959. 19 l. incl. illus. (David Taylor Model Basin. Rpt. C-1073. Aero Rpt. 955, Pt 2) CONFIDENTIAL

Table 1

Ordinates and Stations of An Airfoil-Shaped Island

[Ordinates and stations in percent of chord.]

Station	Ordinates	
	Upper Surface	Lower Surface
0	0	0
10.0	8.42	6.49
20.0	11.10	7.02
21.7	11.30	7.02
30.0	11.60	7.02
40.0	11.37	6.93
50.0	11.30	6.75
60.0	10.60	6.23
70.0	9.34	5.44
75.0	7.94	5.09
80.0	6.84	4.39
90.0	3.60	2.54
100.0	0	0

Leading-edge radius: 3.84 percent chord.

Table 2

Test Summary

CVA 67 Configurations	Yaw Angle ψ , in deg	Island Information		
		Island Location ^a		Rotation Angle ^b in deg
		Distance Aft of Forward Perpendicular	Butt Line	
Basic	11	651	110	0
	0, 11	646	120	-11
Island Off	0, 11	--	--	--
Island Forward	0	334	103	-11
Rounded Deck Edge	0, 11	651	110	0
Rounded Deck Edge and Fillet	0, 11	651	110	0
CVA 65 Island	0, 11	618	115	0
Airfoil-Shaped Island	0, 11	676 Aft Point	125 Aft Point	-11

^aLocation of starboard aft corner of island in feet full scale.

^bIsland is rotated about its diametric center. Positive direction of rotation angle same as positive direction of ψ .

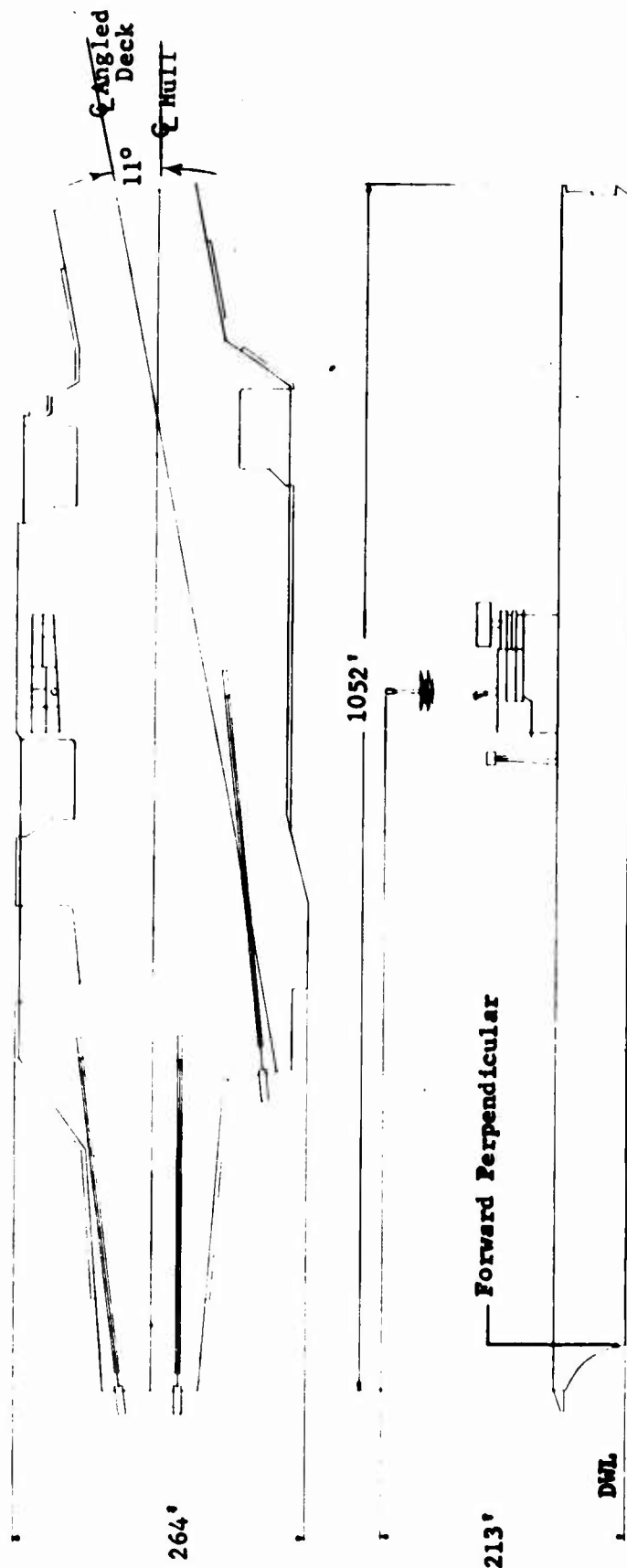


Figure 1 - General Arrangement of the 1/144-Scale Model Proposed CVA 67 Aircraft Carrier

10 July 1963



Islands: Airfoil-Shaped; CVA 67; CVA 65



Aircraft Carrier CVA 67



CVA 65 Island on CVA 67 Carrier



Airfoil-Shaped Island on CVA 67 Carrier

Figure 2 - Island Configurations Tested on 1/144-Scale Proposed
CVA 67 Carrier



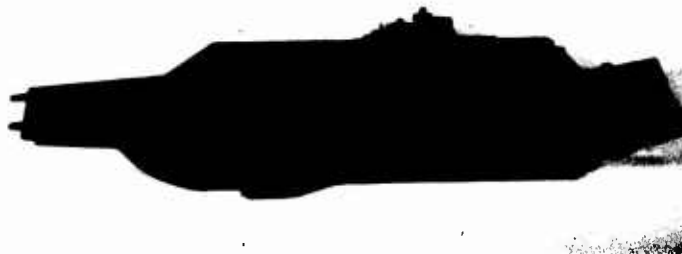
CVA 67 Island Yawed Parallel to Angled Deck



CVA 67 Island Forward and Yawed Parallel to Angled Deck



Elevation View of CVA 67 Carrier



Deck Fillet and Rounded-Deck Edge

Figure 2 (Concluded)

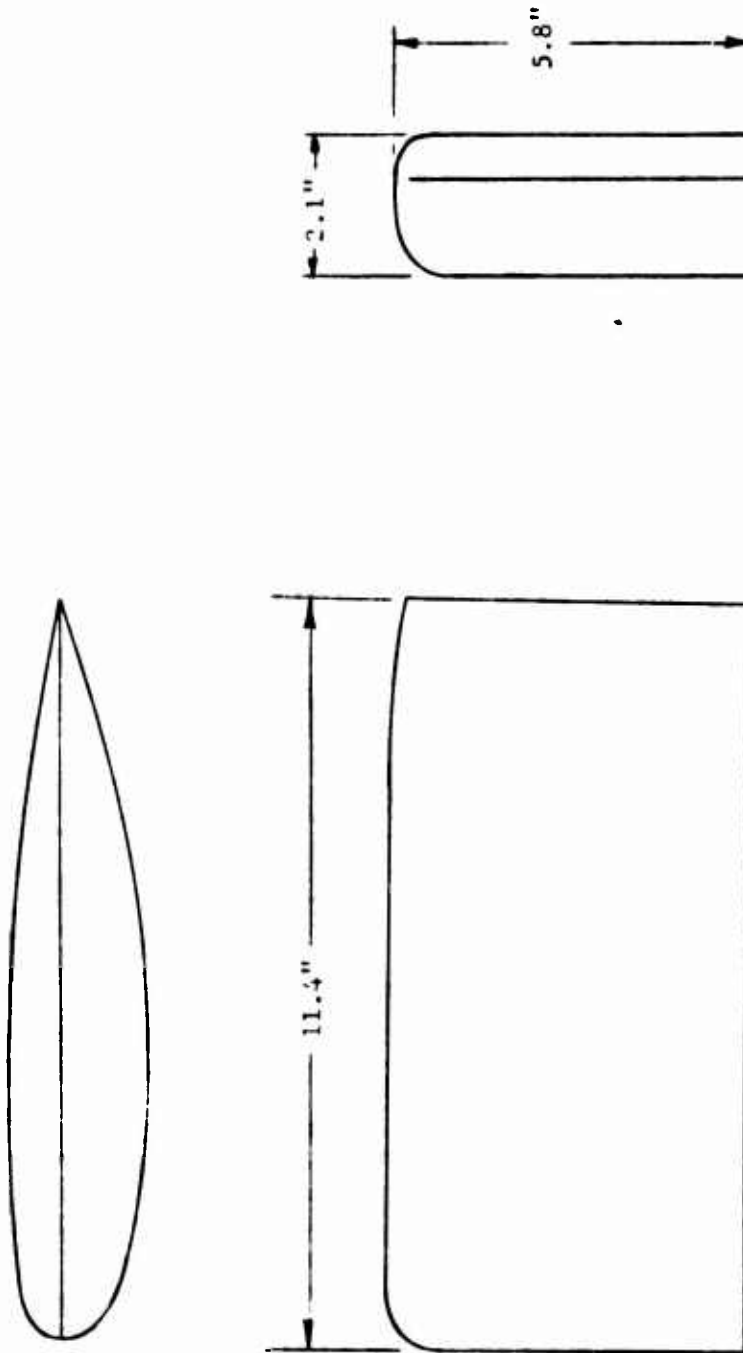


Figure 3 - Principal Dimensions of the Airfoil-Shaped Island Tested on the 1/144-Scale Model of a Proposed CVA 67 Aircraft Carrier

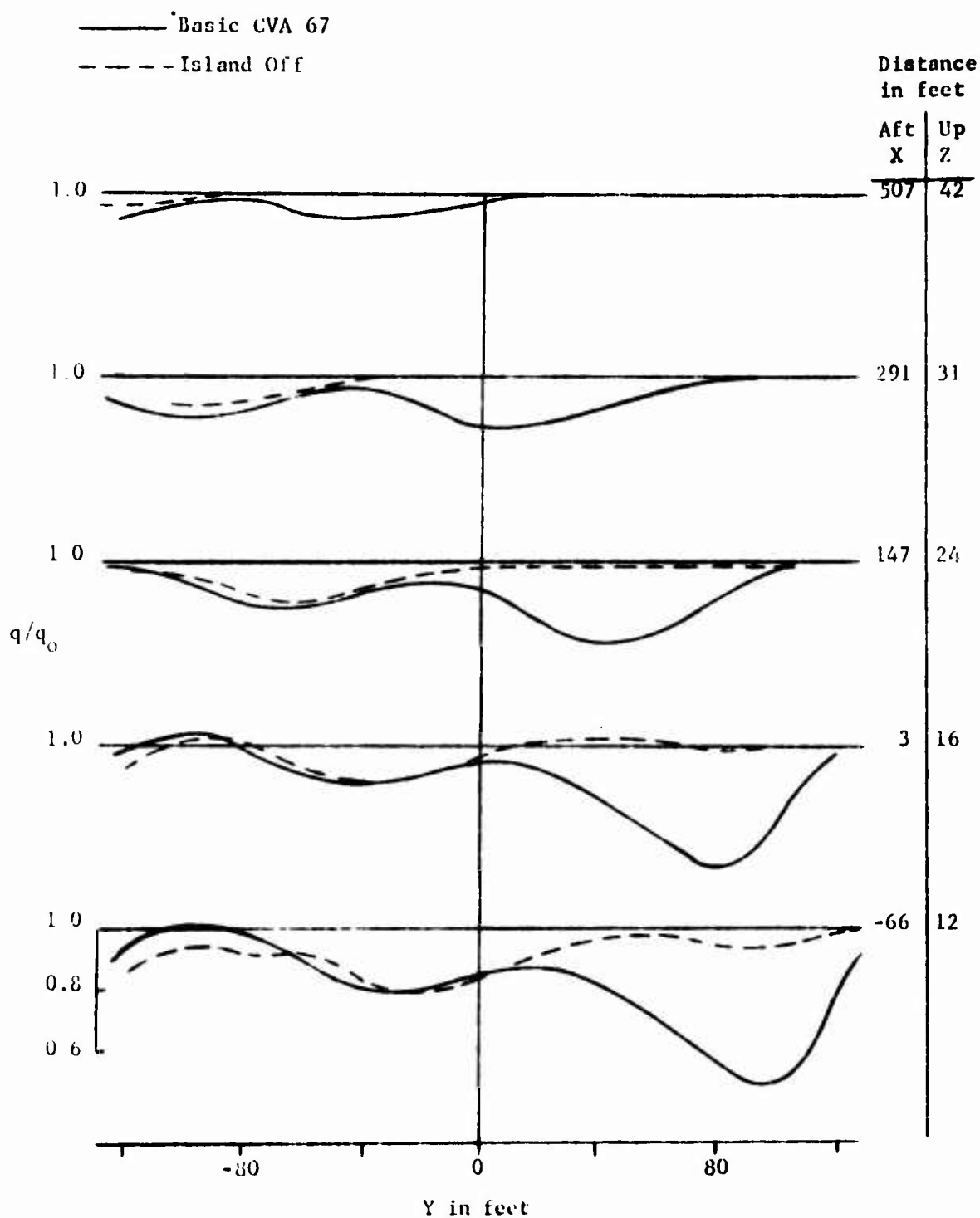


Figure 4 - Effect of Island Configurations on the Dynamic Pressure Variation Along a 3° Flight Path

(a) $\alpha = 0^\circ$

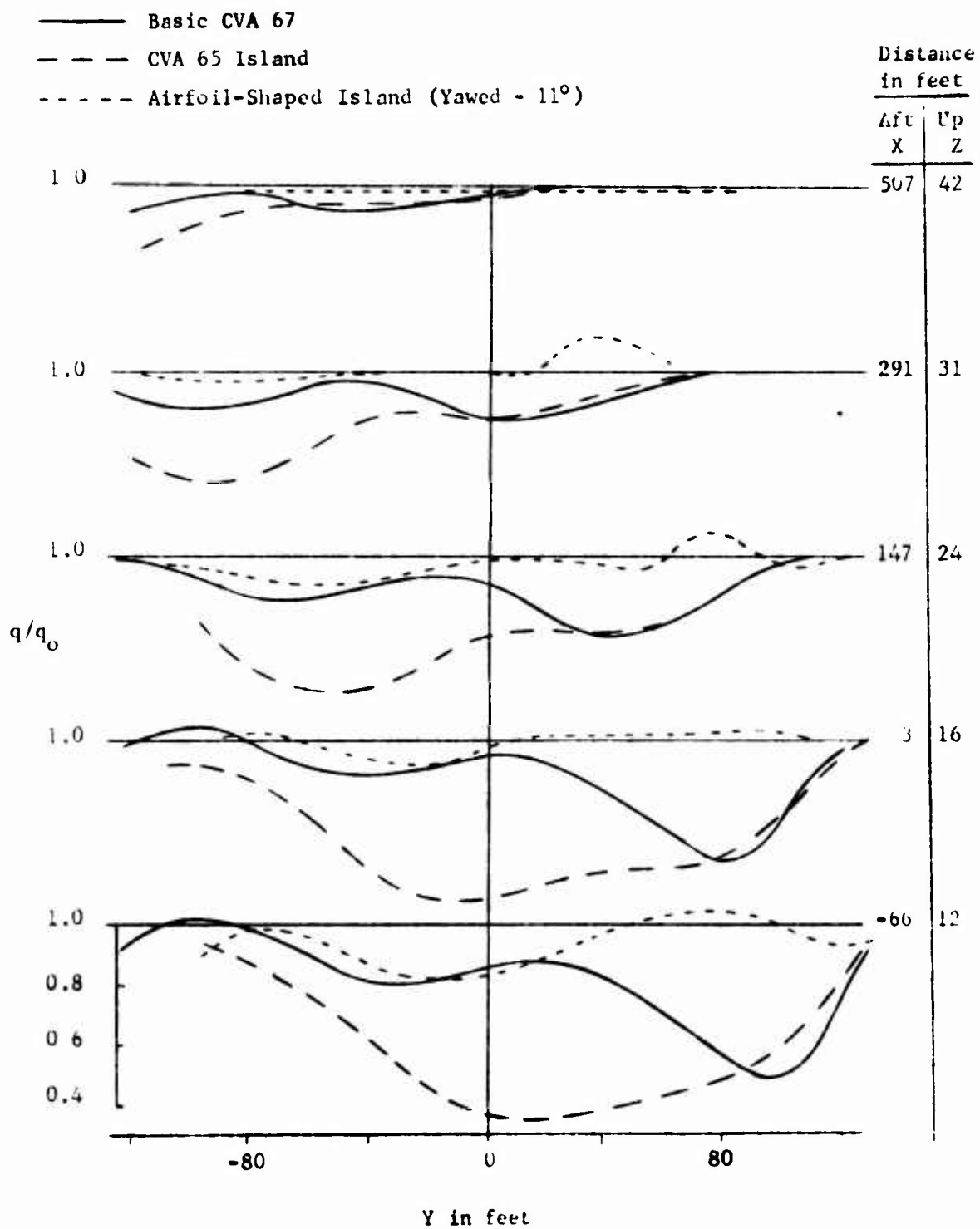


Figure 4 (Continued)

(a) Concluded

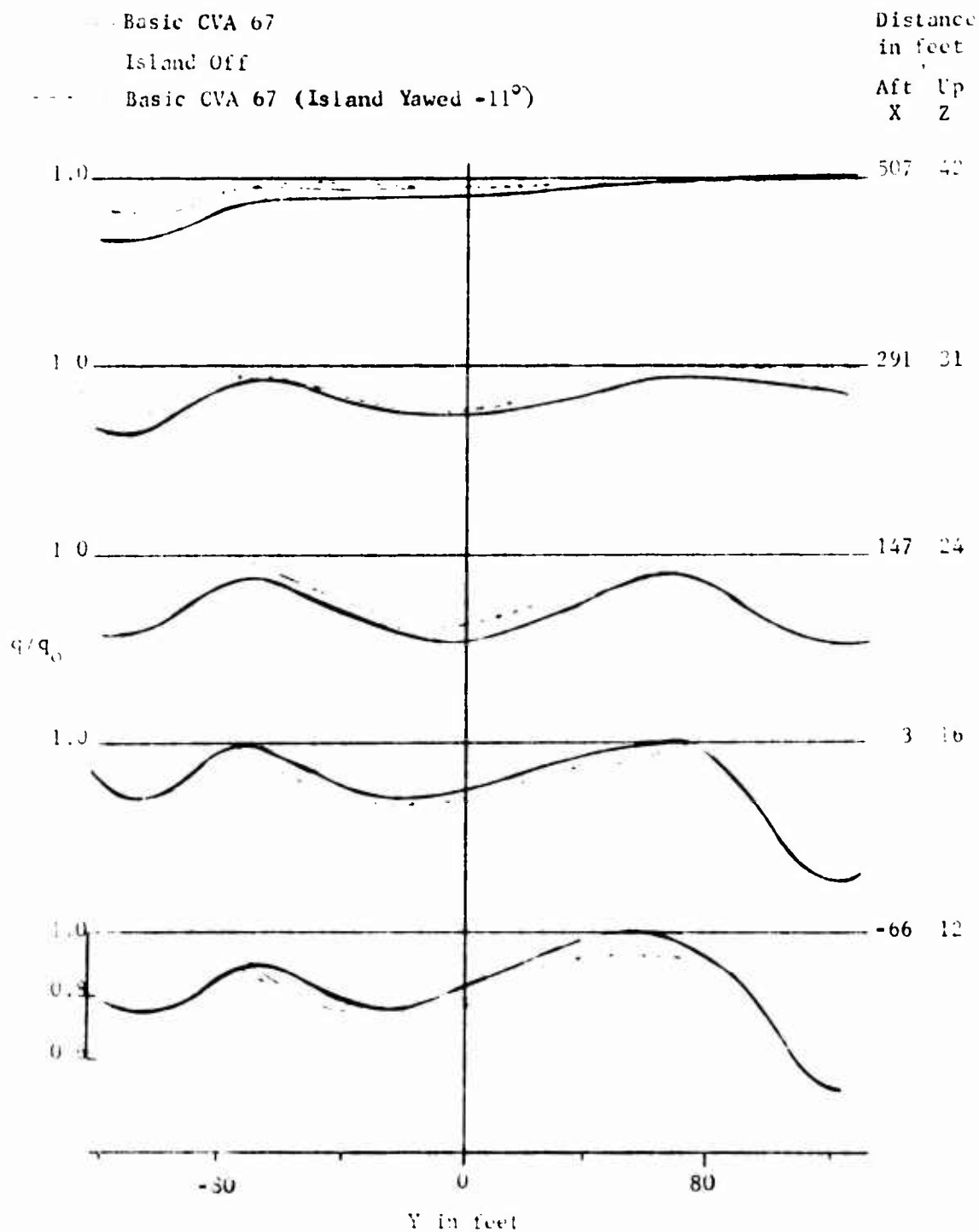


Figure 4 (Continued)

(b) $\alpha = 11^\circ$

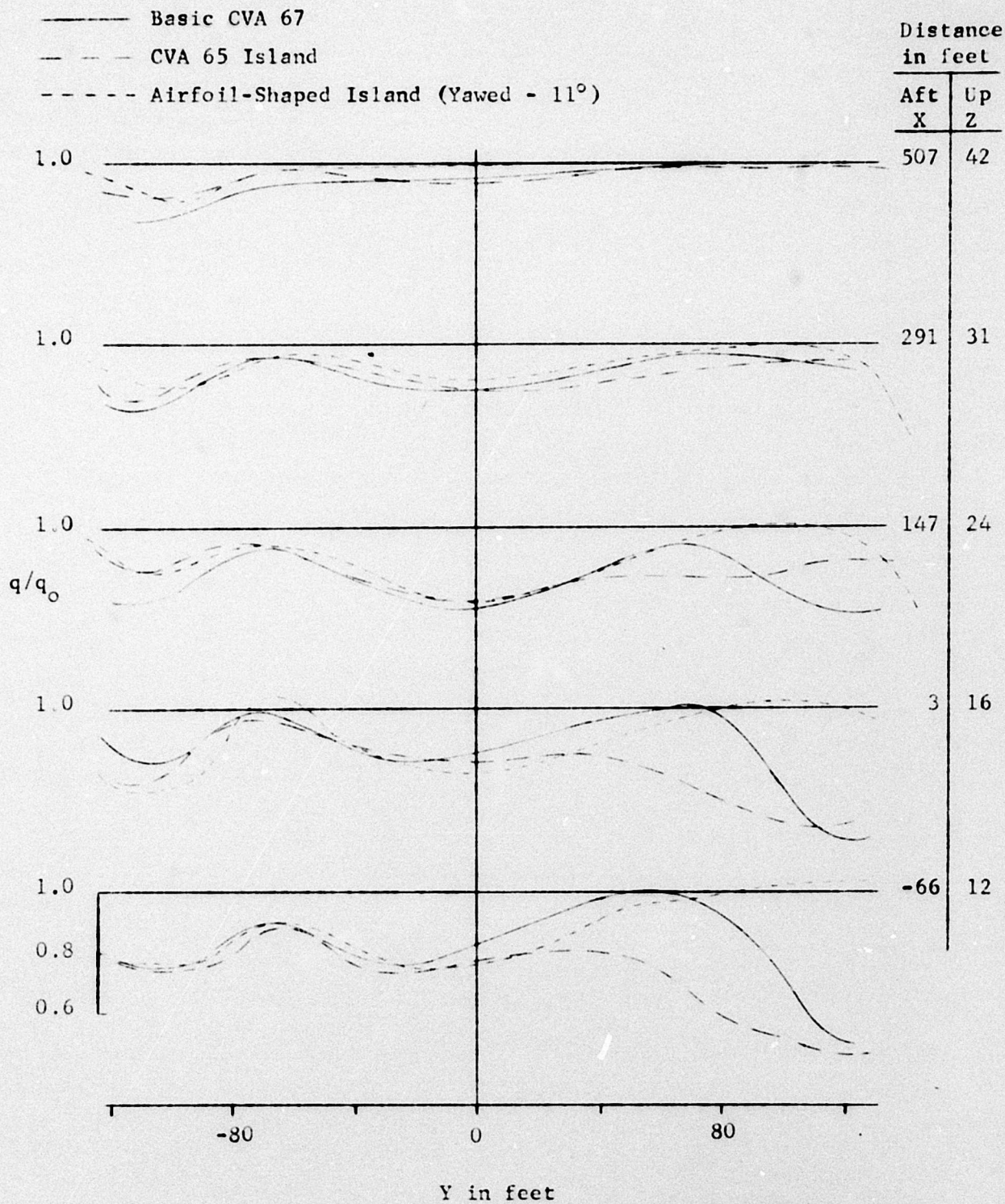


Figure 4 (Concluded)

(b) Concluded

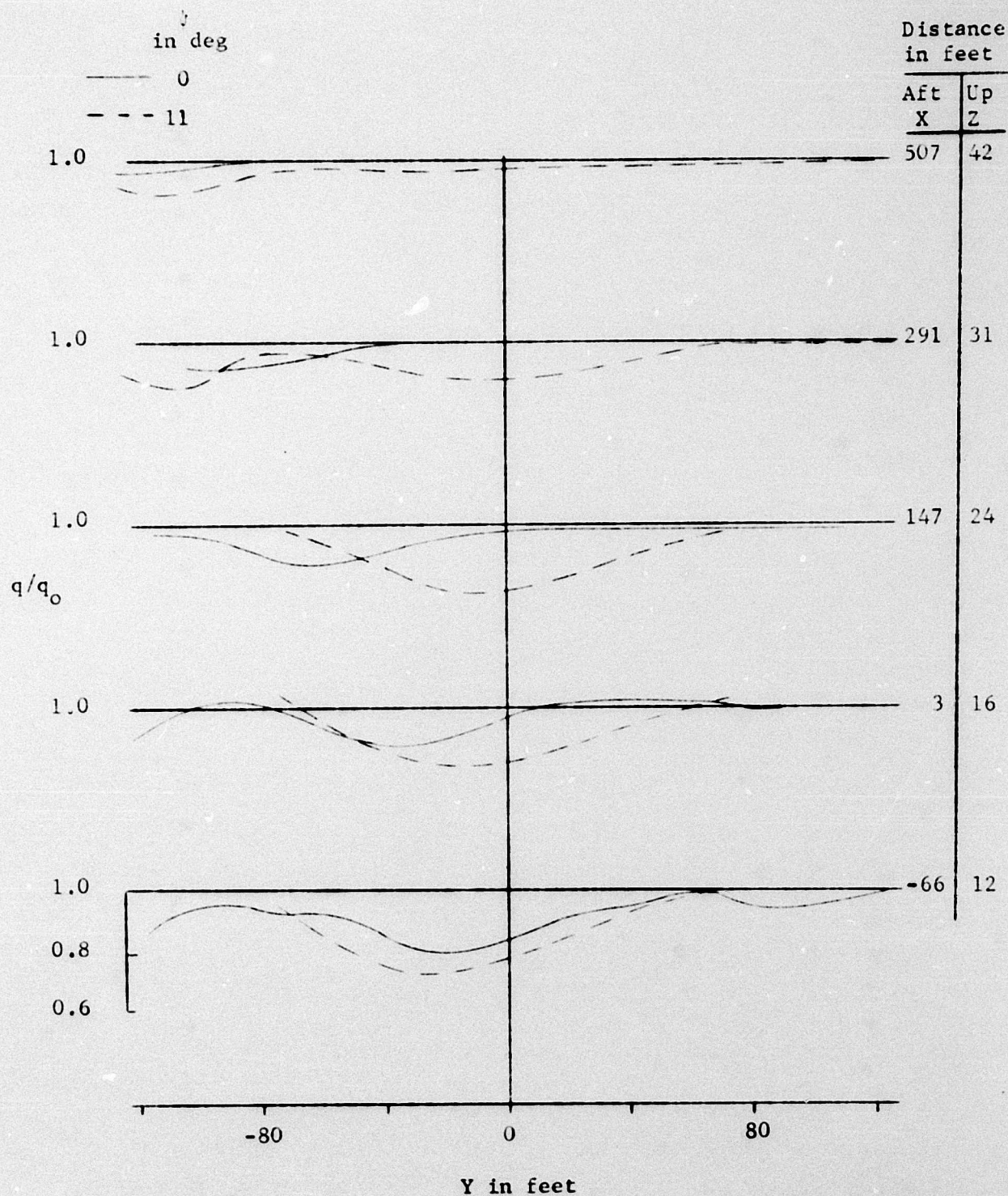


Figure 5 - Effect of Yaw Angle on the Dynamic Pressure
Variation Along a 3° Flight Path

(a) Basic Configuration: Island Off

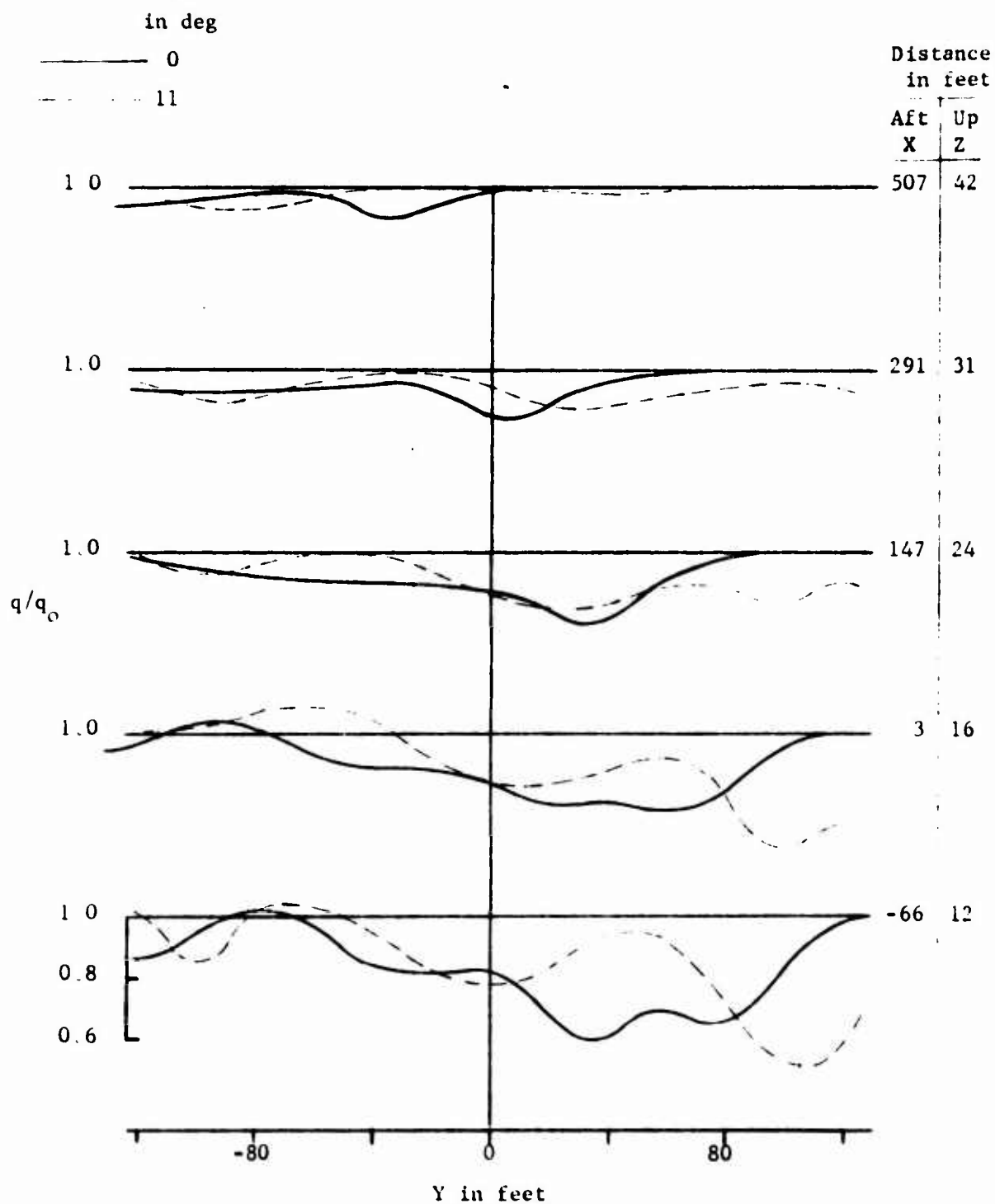


Figure 5 (Continued)

(b) Rounded Deck Edge and CVA 67 Island

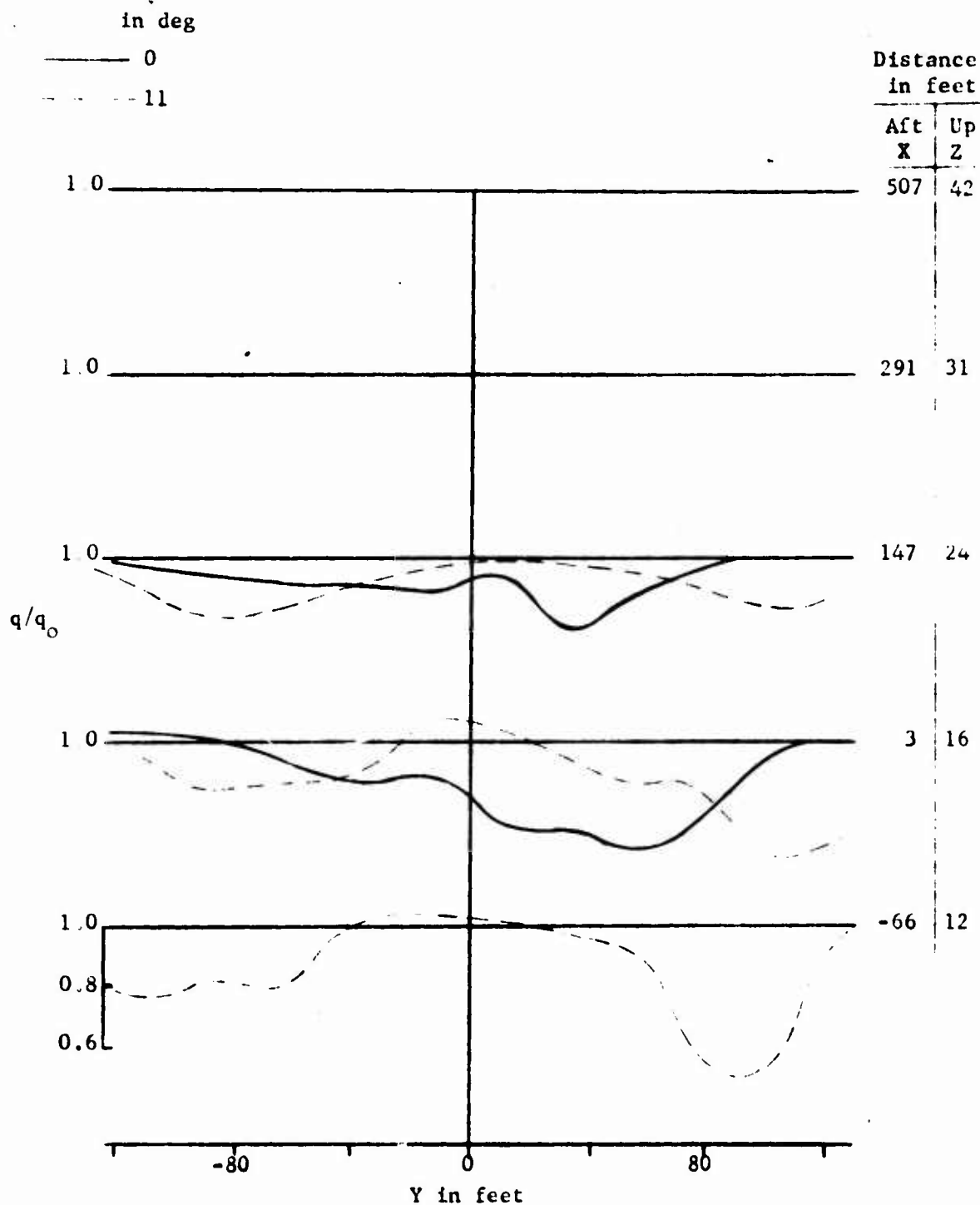


Figure 5 (Continued)

(c) Rounded Deck Edge With Fillet and CVA 67 Island

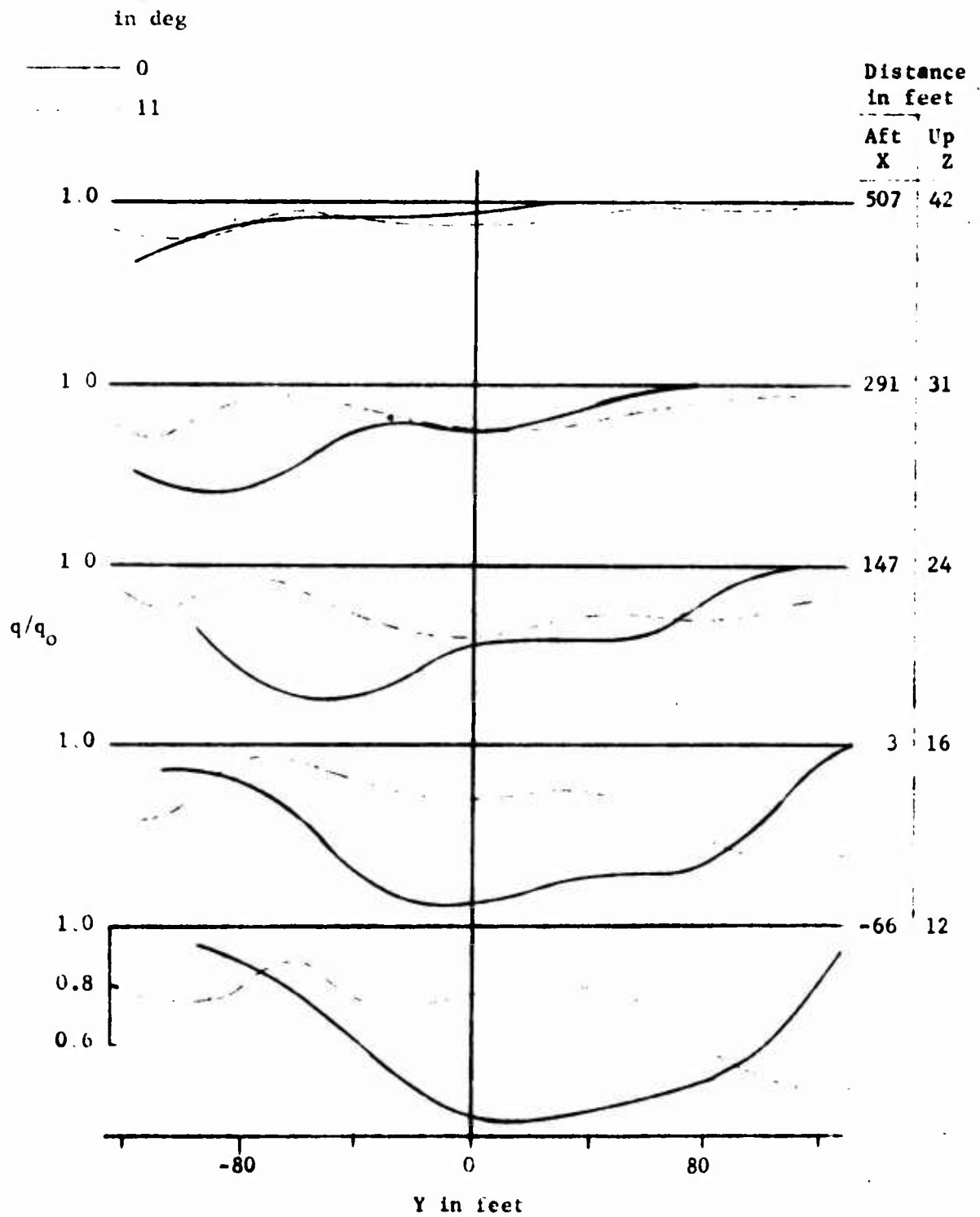


Figure 5 (Continued)
(d) CVA 65 Island

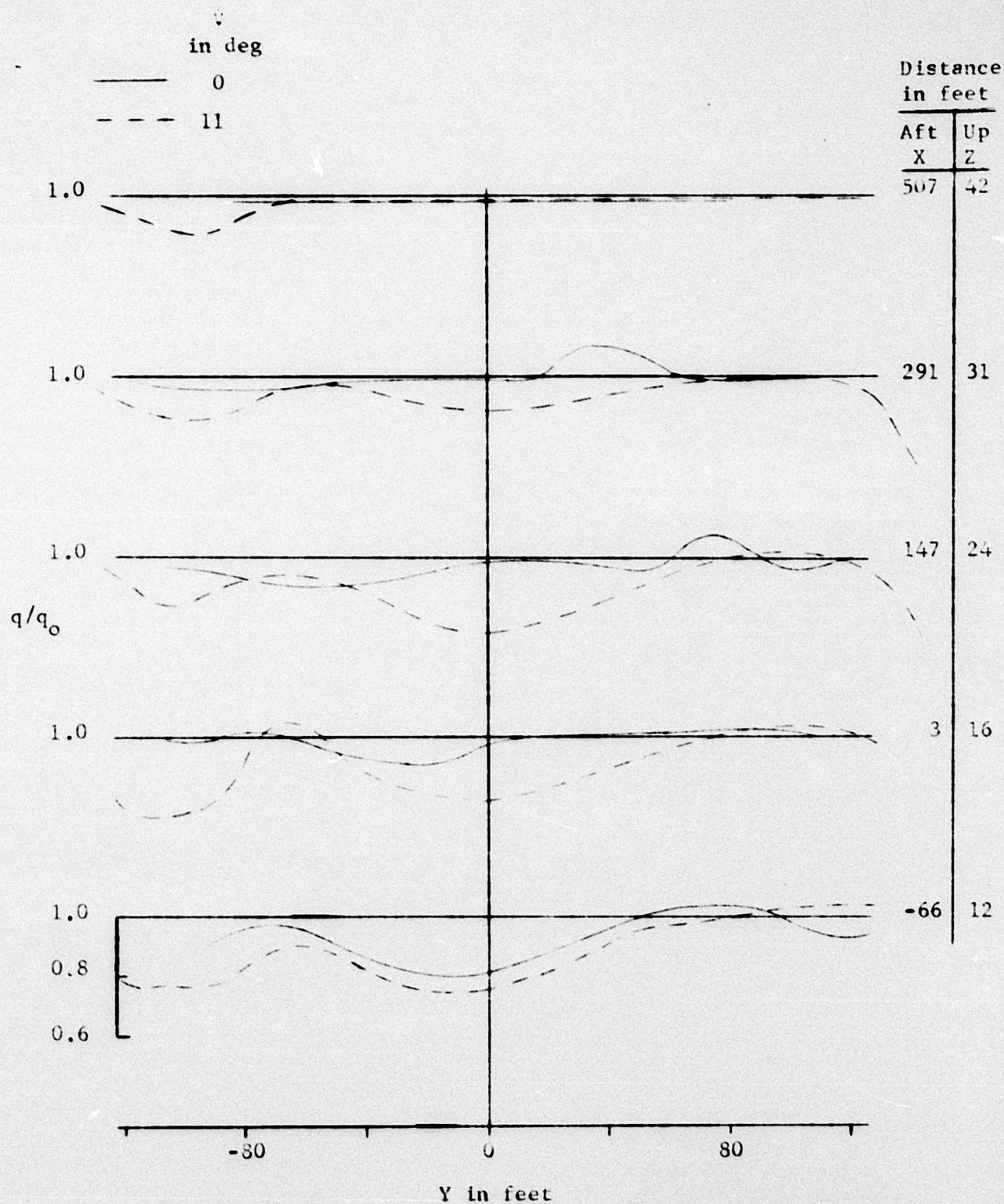


Figure 5 (Concluded)

(e) Airfoil-Shaped Island
(Yawed -11°)

Basic CVA 67 Island Configurations

— Unyawed
 - - - Yawed
 - - - - Island Forward and Yawed -11°

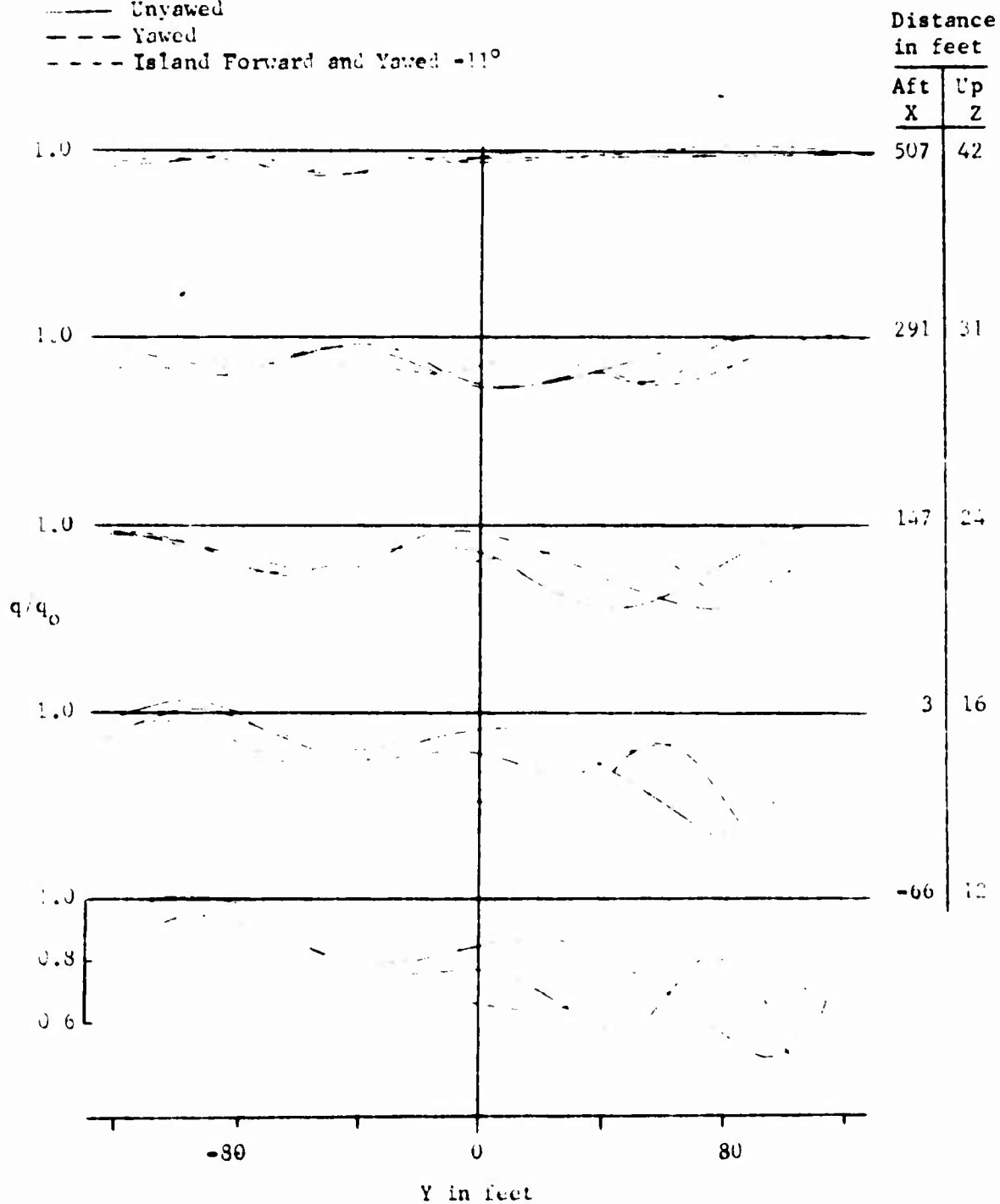


Figure 6 - Effect of Island Position and Attitude on the Dynamic Pressure Variation Along a 3° Flight Path

$\alpha = 0^\circ$

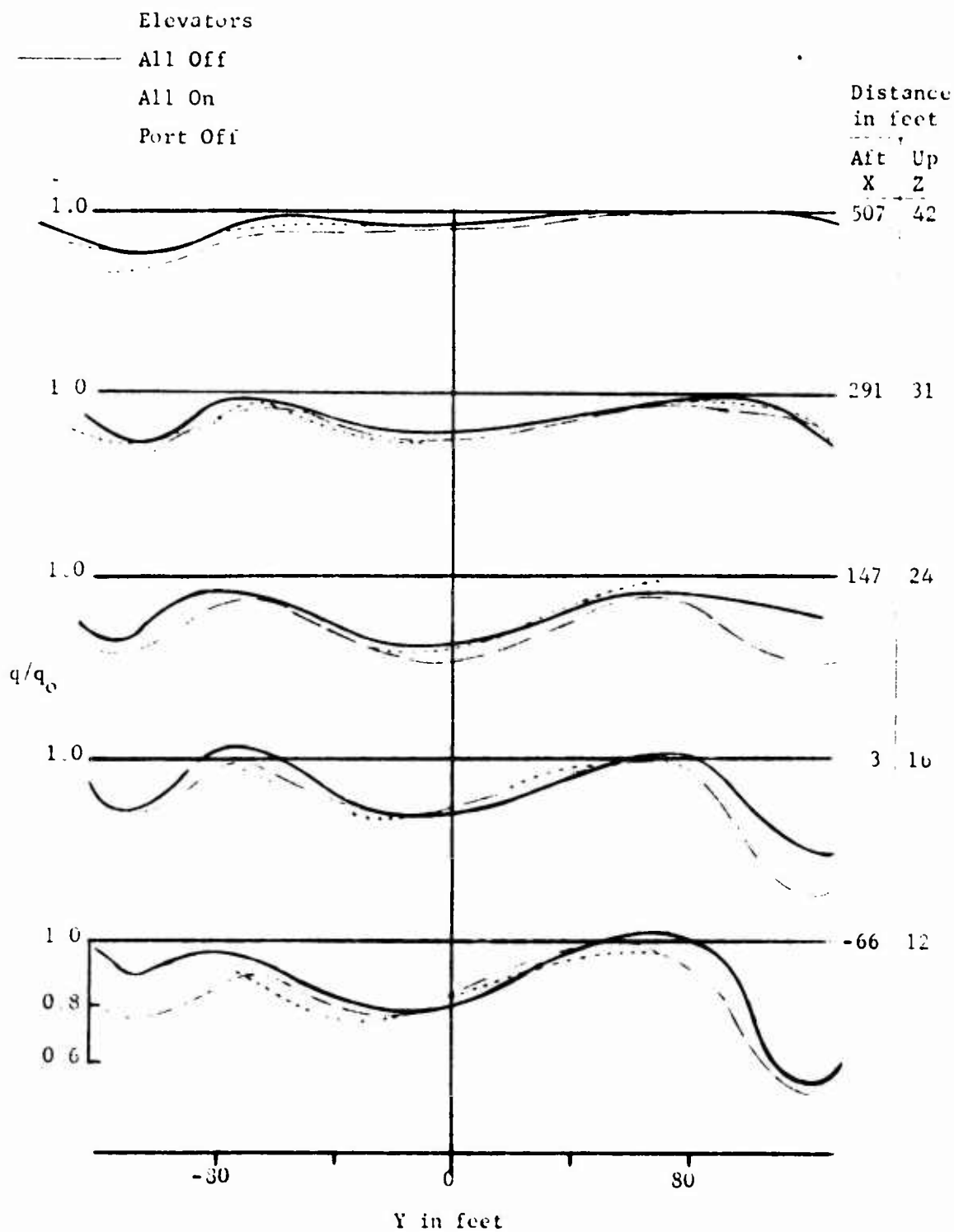


Figure 7 - Effect of Elevators on the Dynamic Pressure
 Variation Along a 3° Flight Path
 Basic CVA 67; $\alpha = 11^\circ$

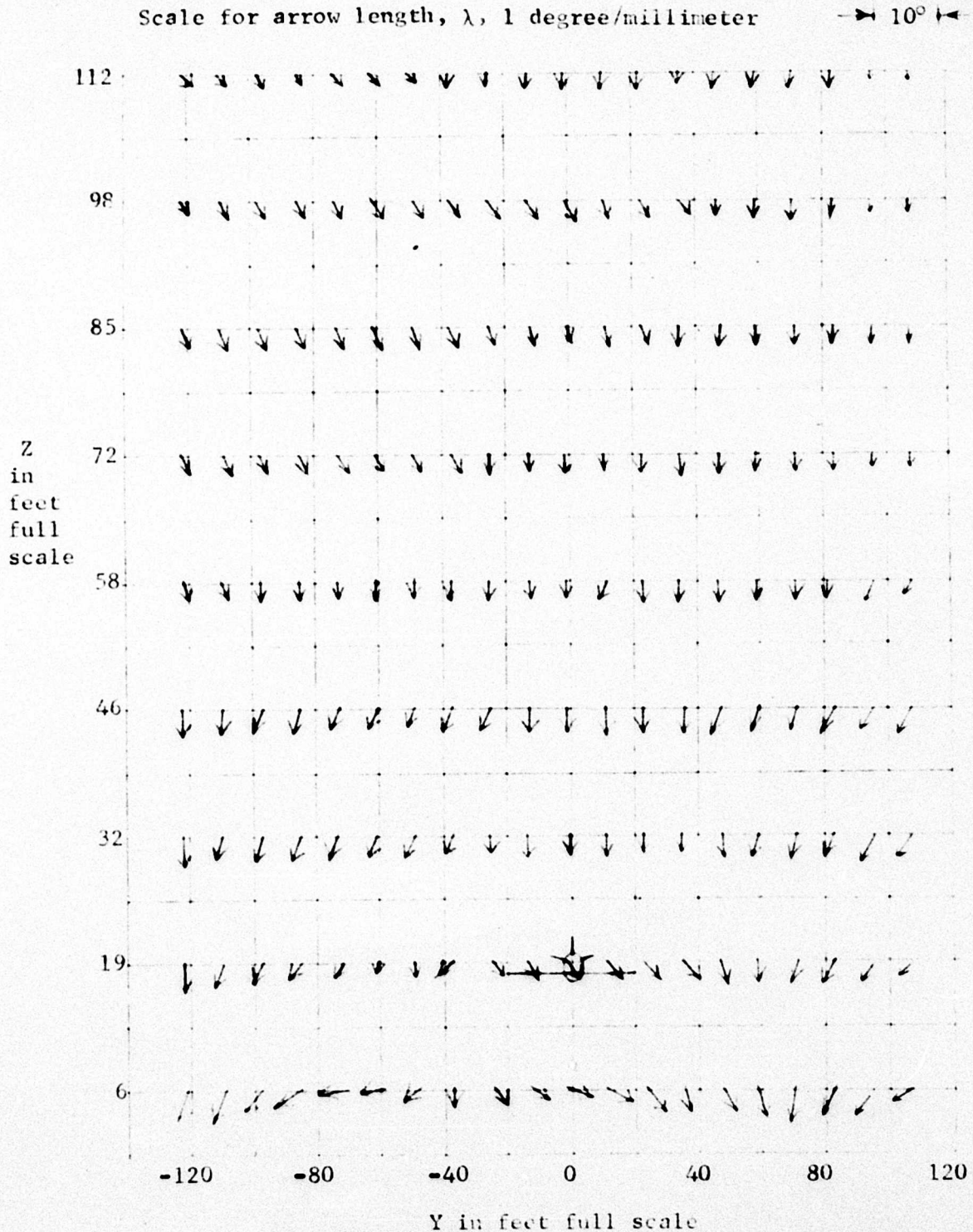


Figure 8 - Wind Angularity on the Y-Z Plane. $\psi = 0^\circ$; X = 3 Feet

(a) CVA 67 Deck; Island Off

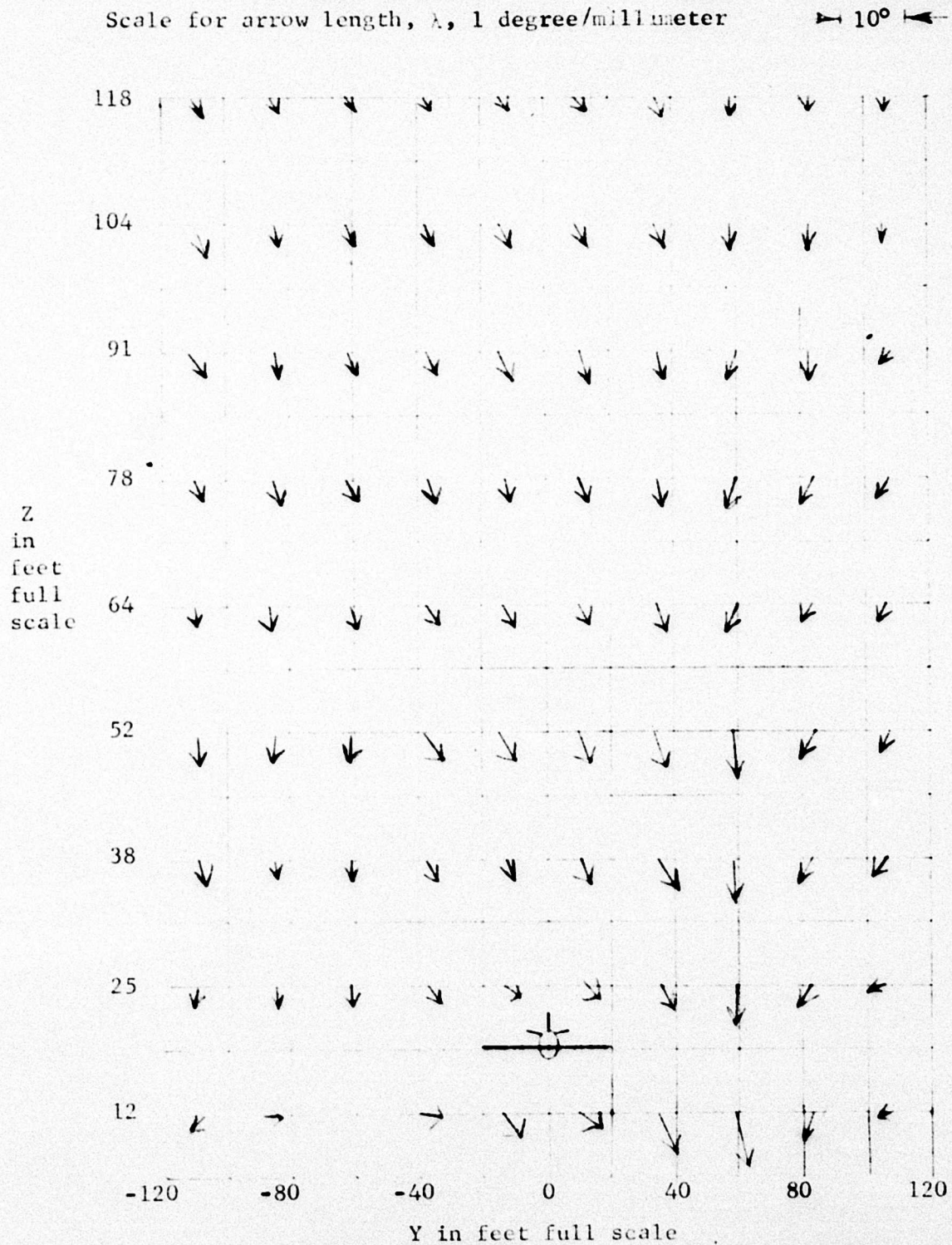


Figure 8 (Continued)

(b) Basic CVA 67

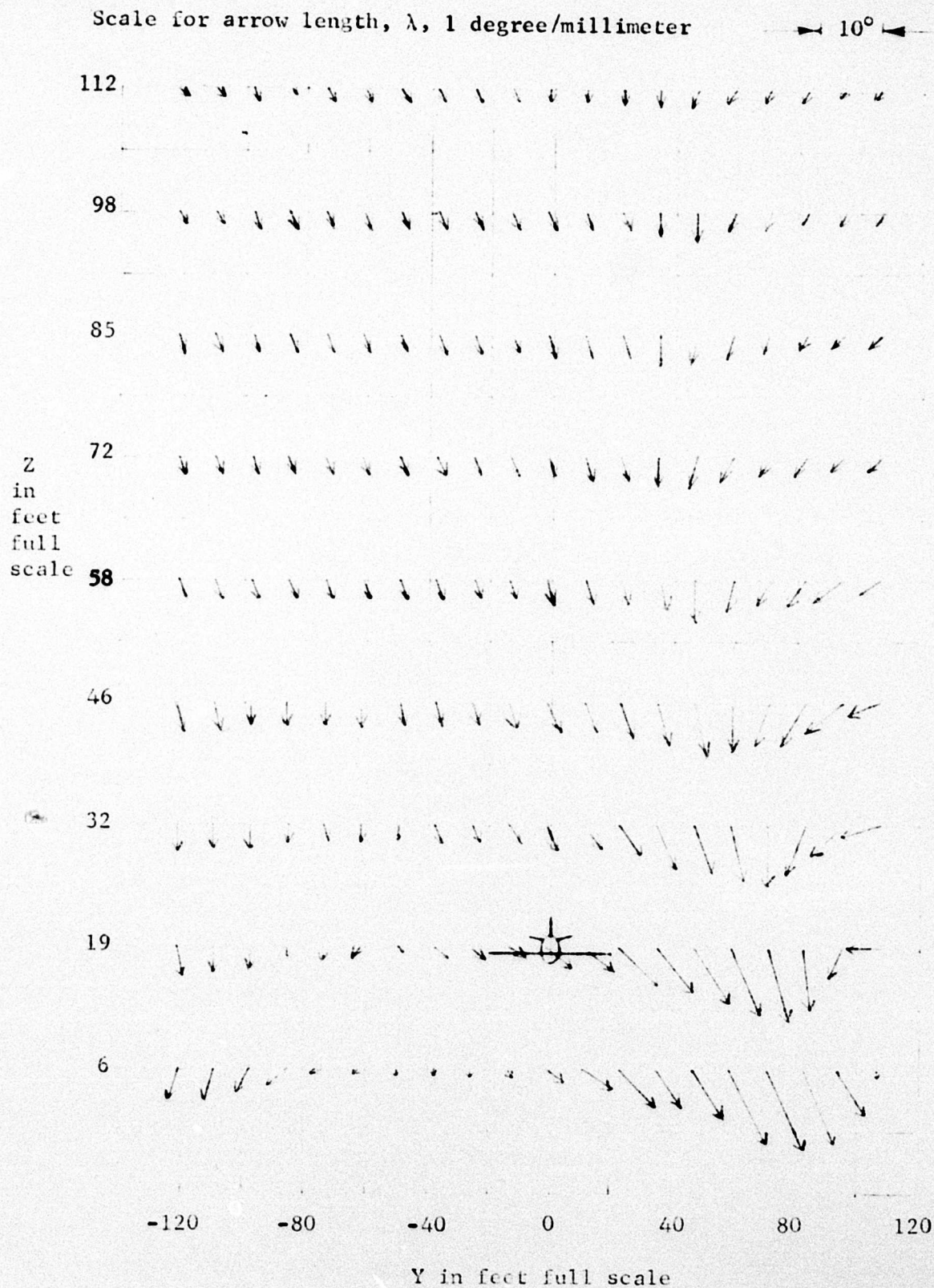


Figure 3 (Continued)

(c) Basic CVA 67; Island Yawed -11°

JGS 18 Oct 1963

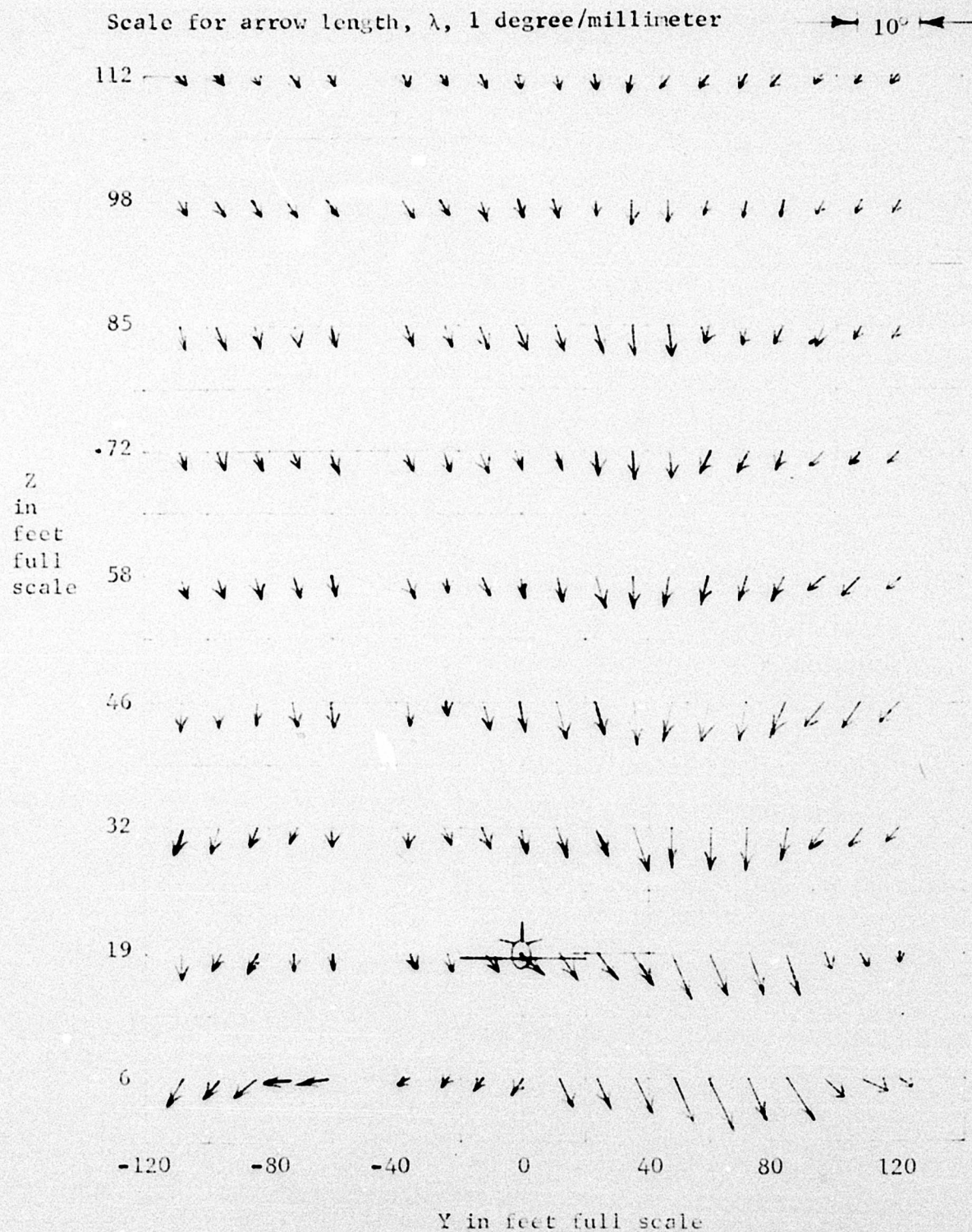


Figure 8 (Continued)

(d) Basic CVA 67; Island Forward and Yawed -11°

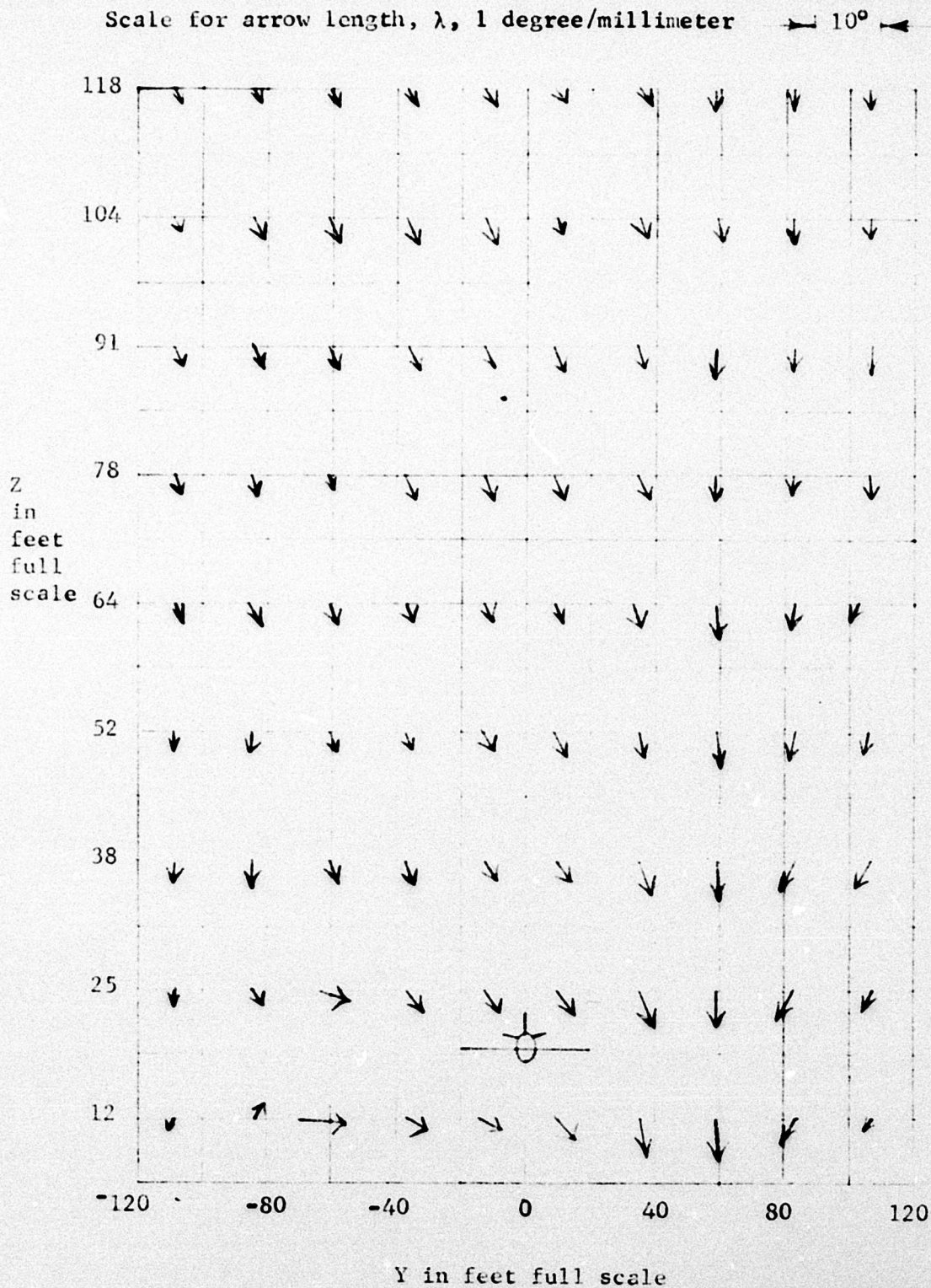


Figure 8 (Continued)
 (e) Basic CVA 67, With Rounded-Deck Edge

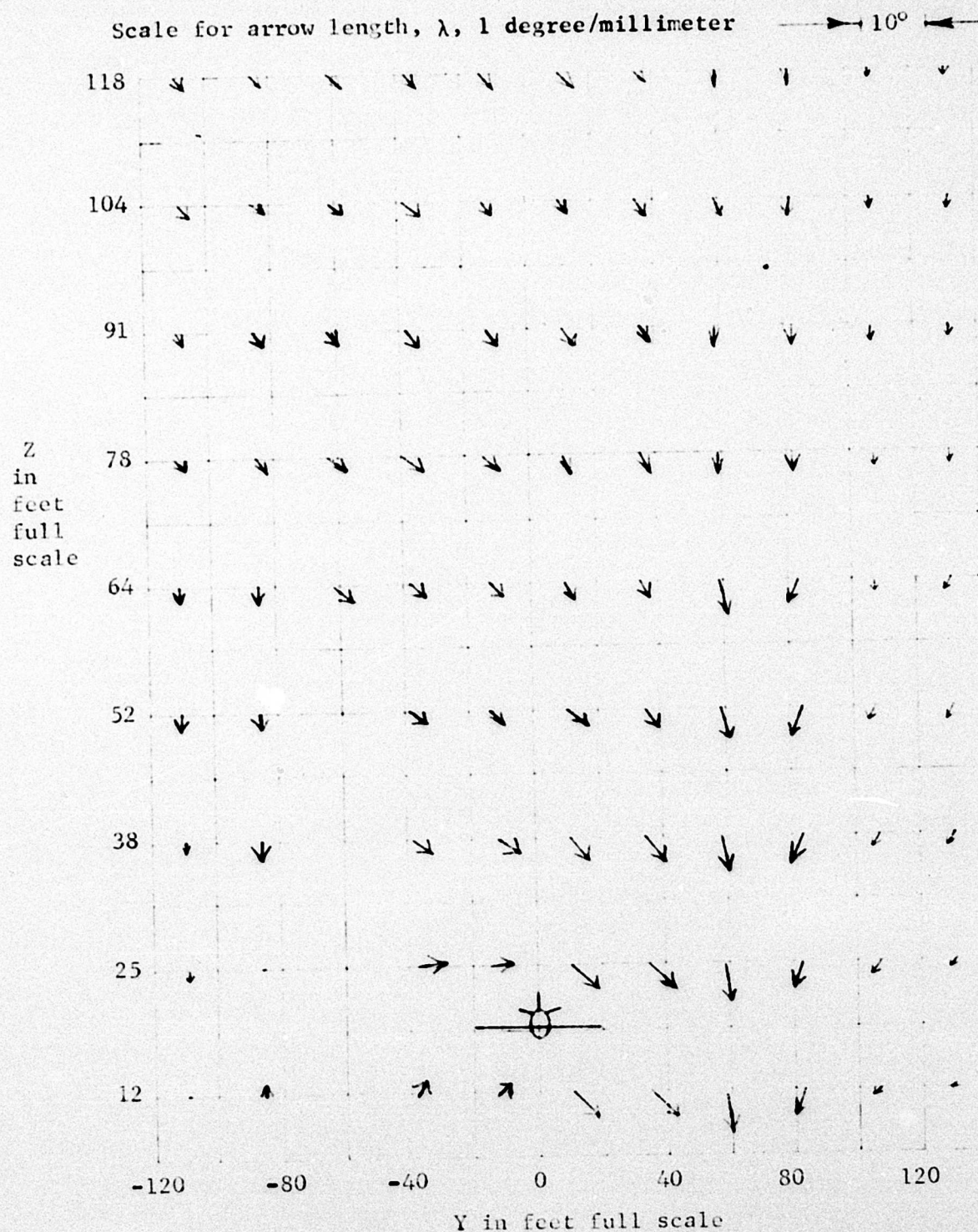


Figure 8 (Continued)

(f) Basic CVA 67, With Rounded-Deck Edge and Fillet

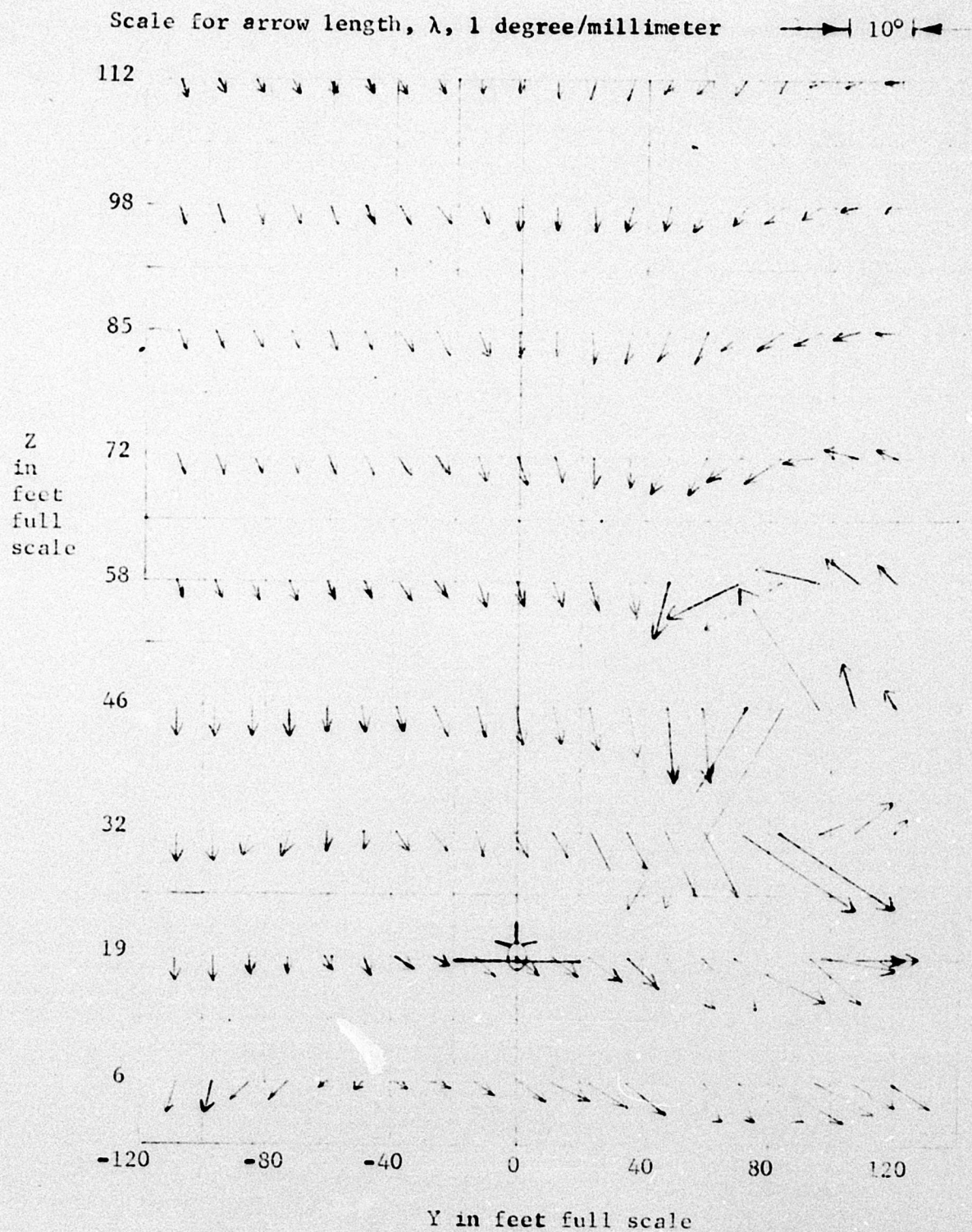


Figure 8 (Continued)
(g) Faired Island, Yawed -11°

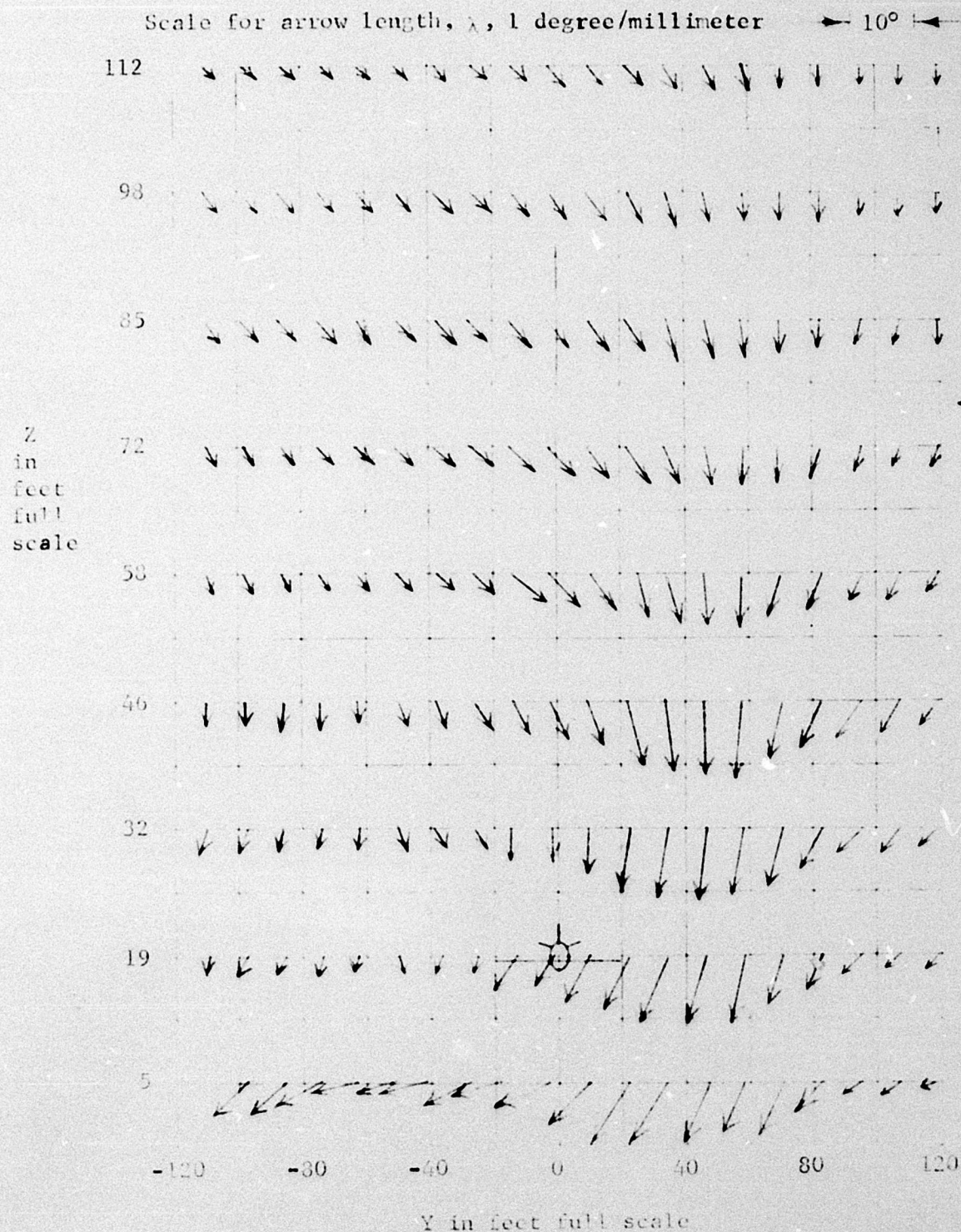


Figure 3 (Concluded)

(b) CVA 65 Island

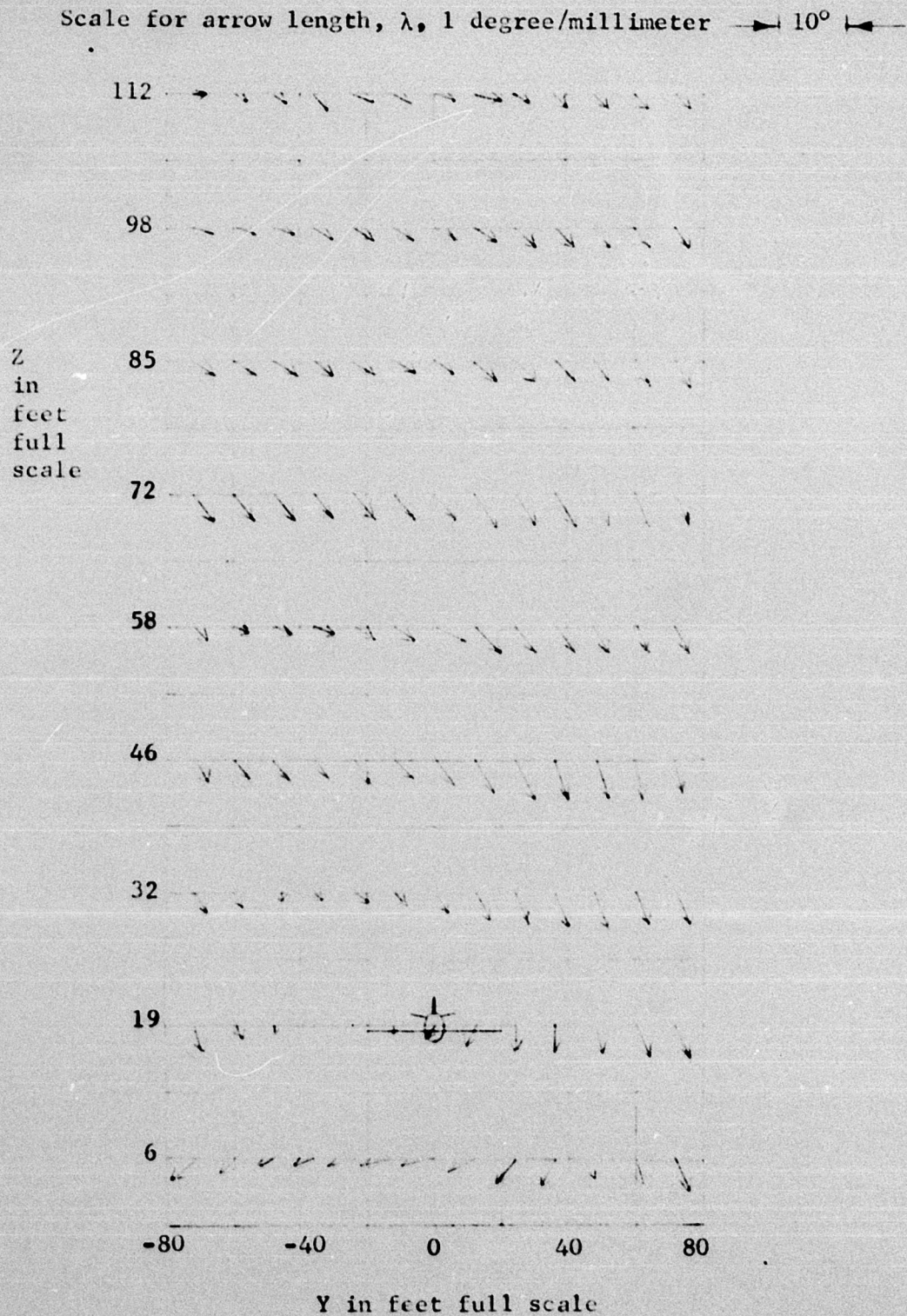


Figure 9 - Wind Angularity on the Y-Z Plane

 $\psi = 11^\circ$; $X = 3$ Feet

(a) Island Off

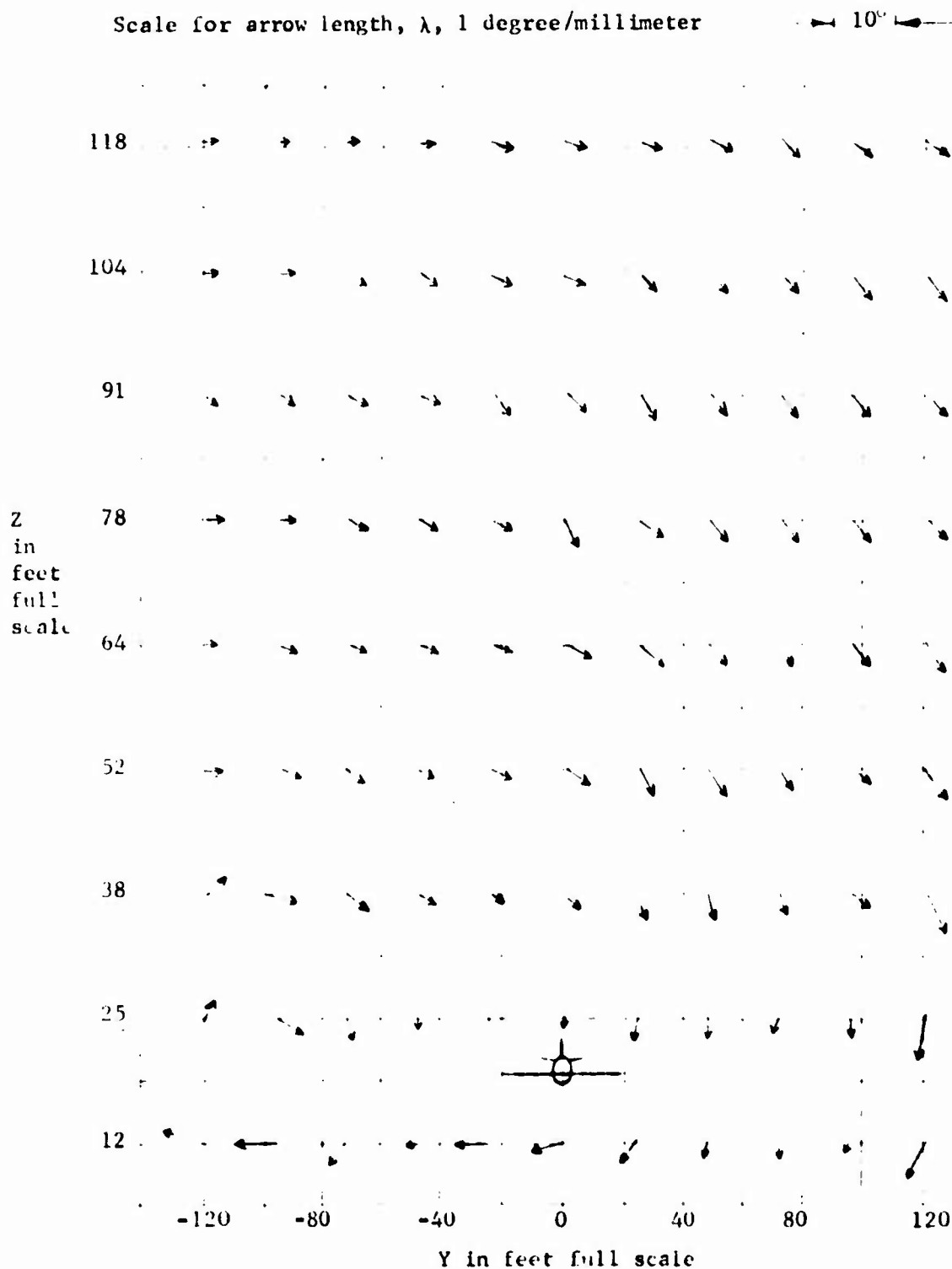


Figure 9 (Continued)

(b) Basic CVA 67

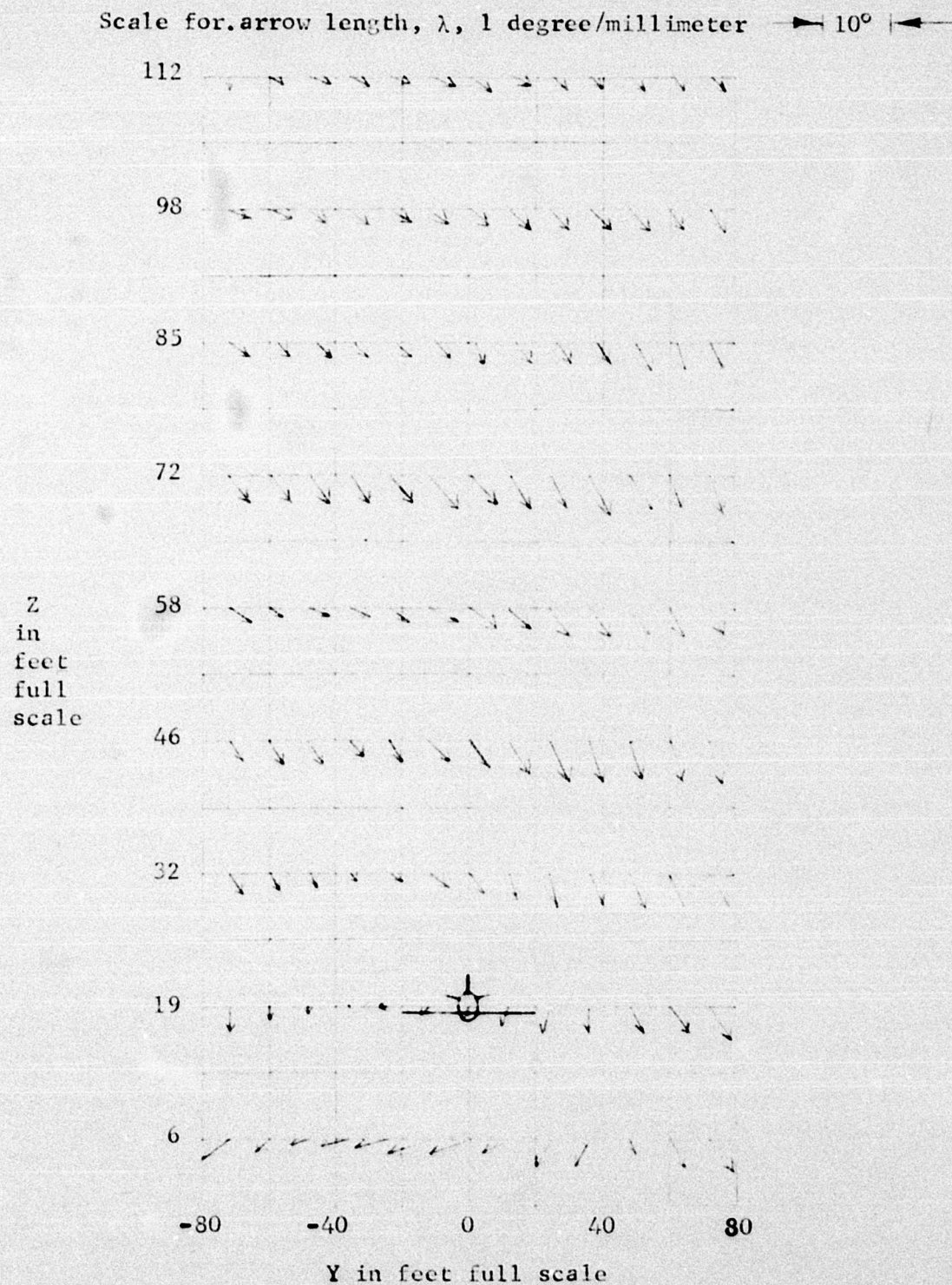


Figure 9 (Continued)

(c) Basic CVA 67; Island Yawed -11°

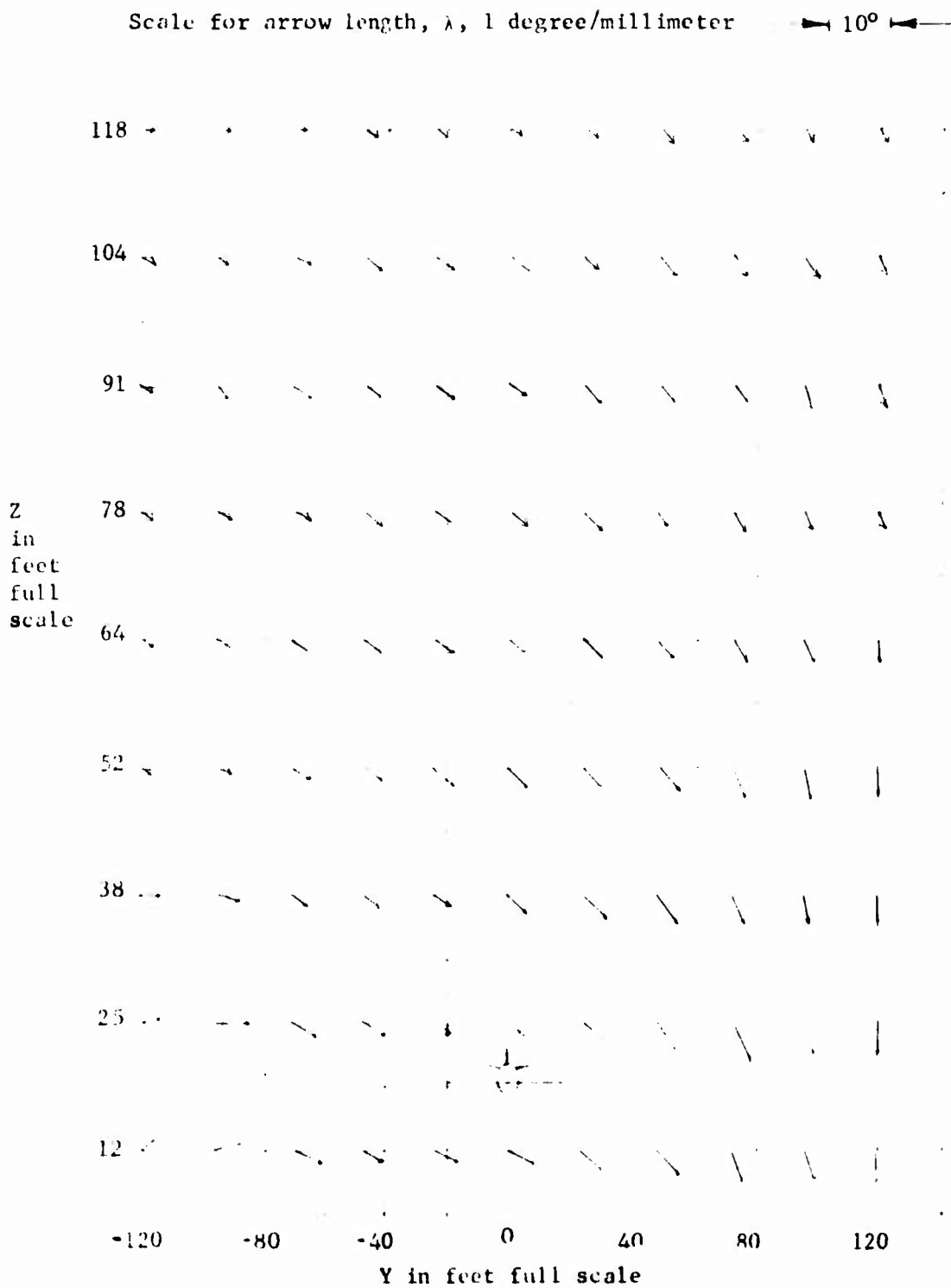


Figure 9 (Continued)

(d) Rounded-Deck Edge, Island Off

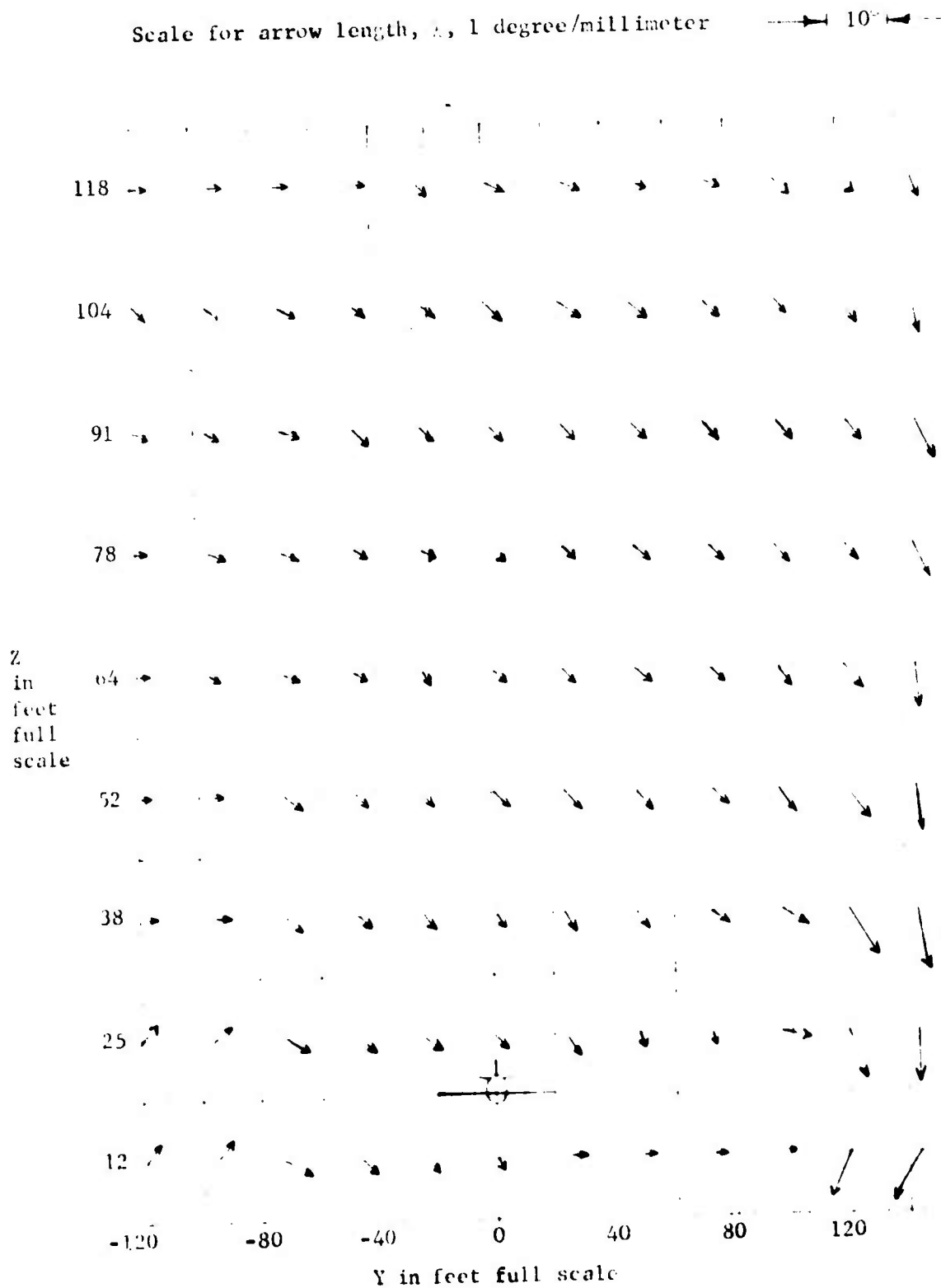


Figure 9 (Continued)

(e) Basic CVA 67, With Rounded-Deck Edge

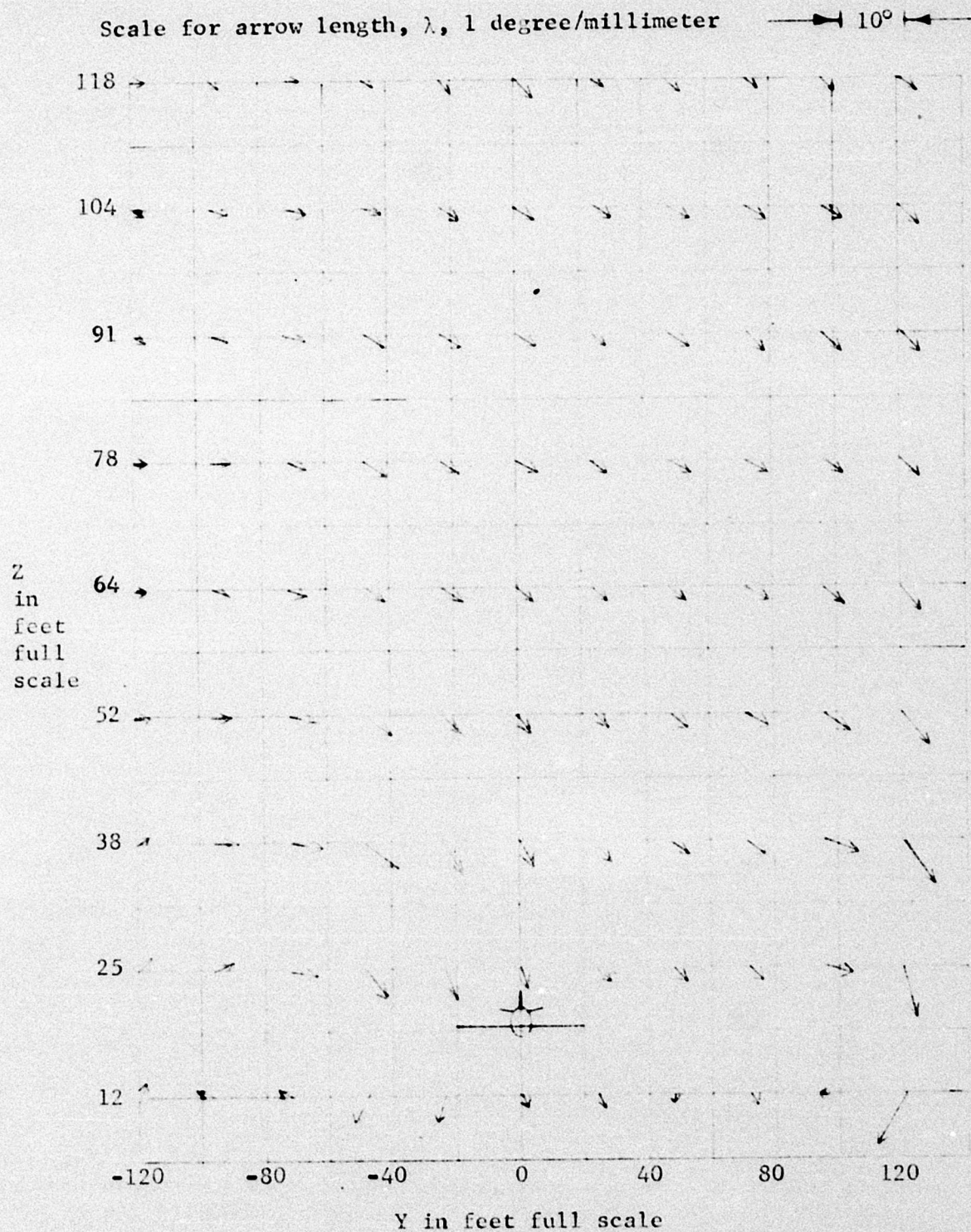


Figure 9 (Continued)

(f) Basic CVA 67, With Rounded-Deck Edge and Fillet

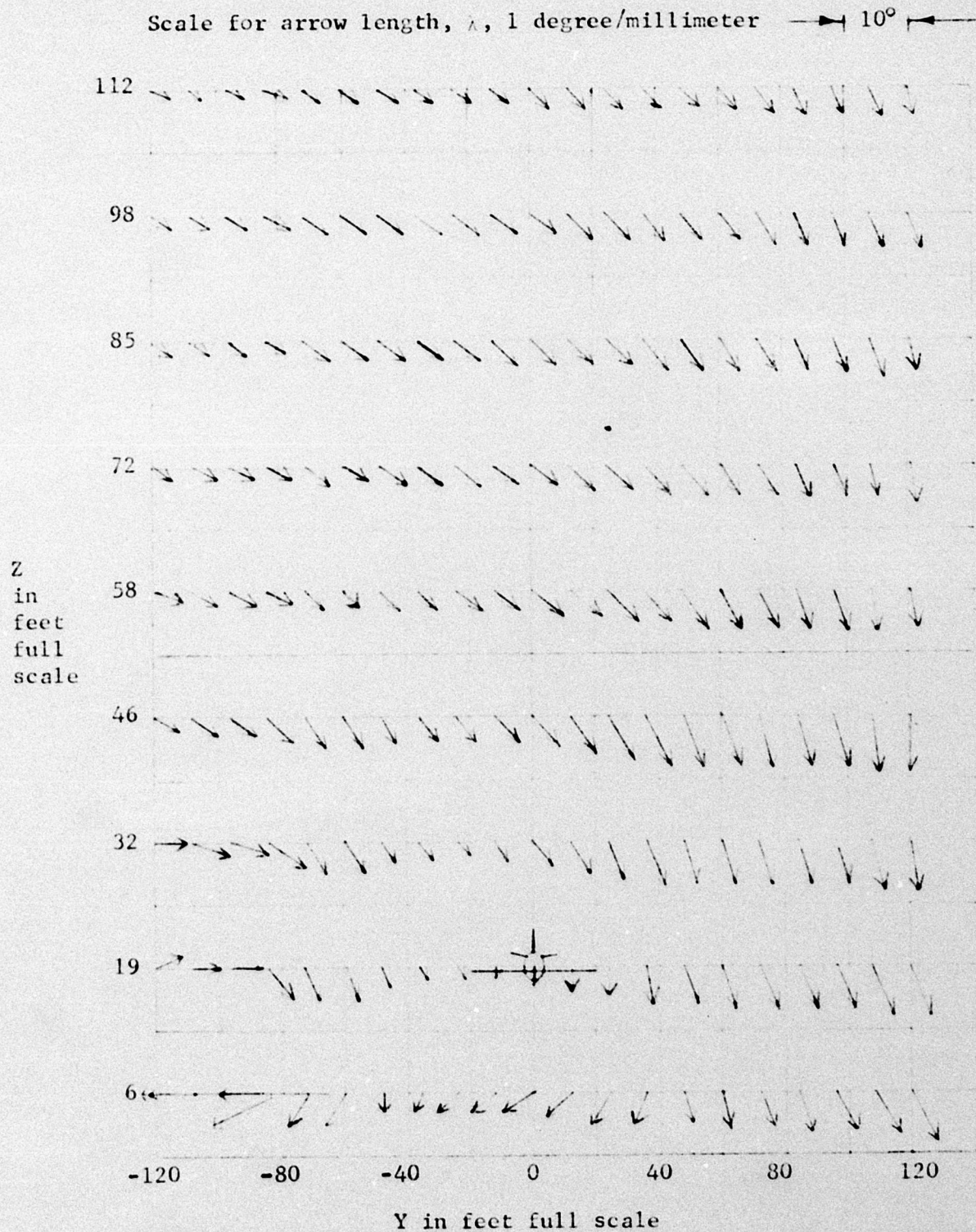


Figure 9 (Continued)
(g) Faired Island Yawed -11°

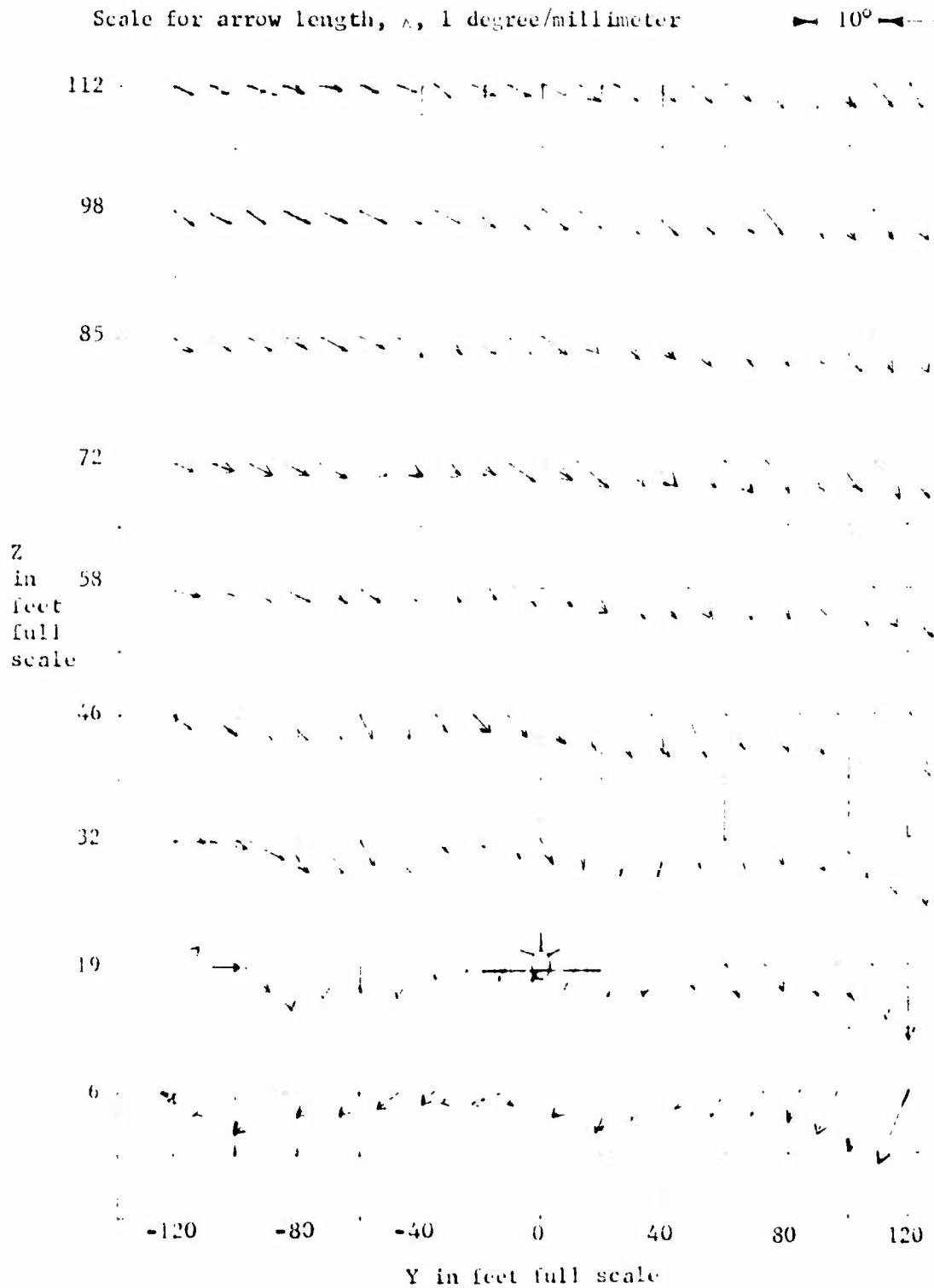


Figure 9 (Concluded)

(h) CVA 65 Island

JCS 18 Oct 1963

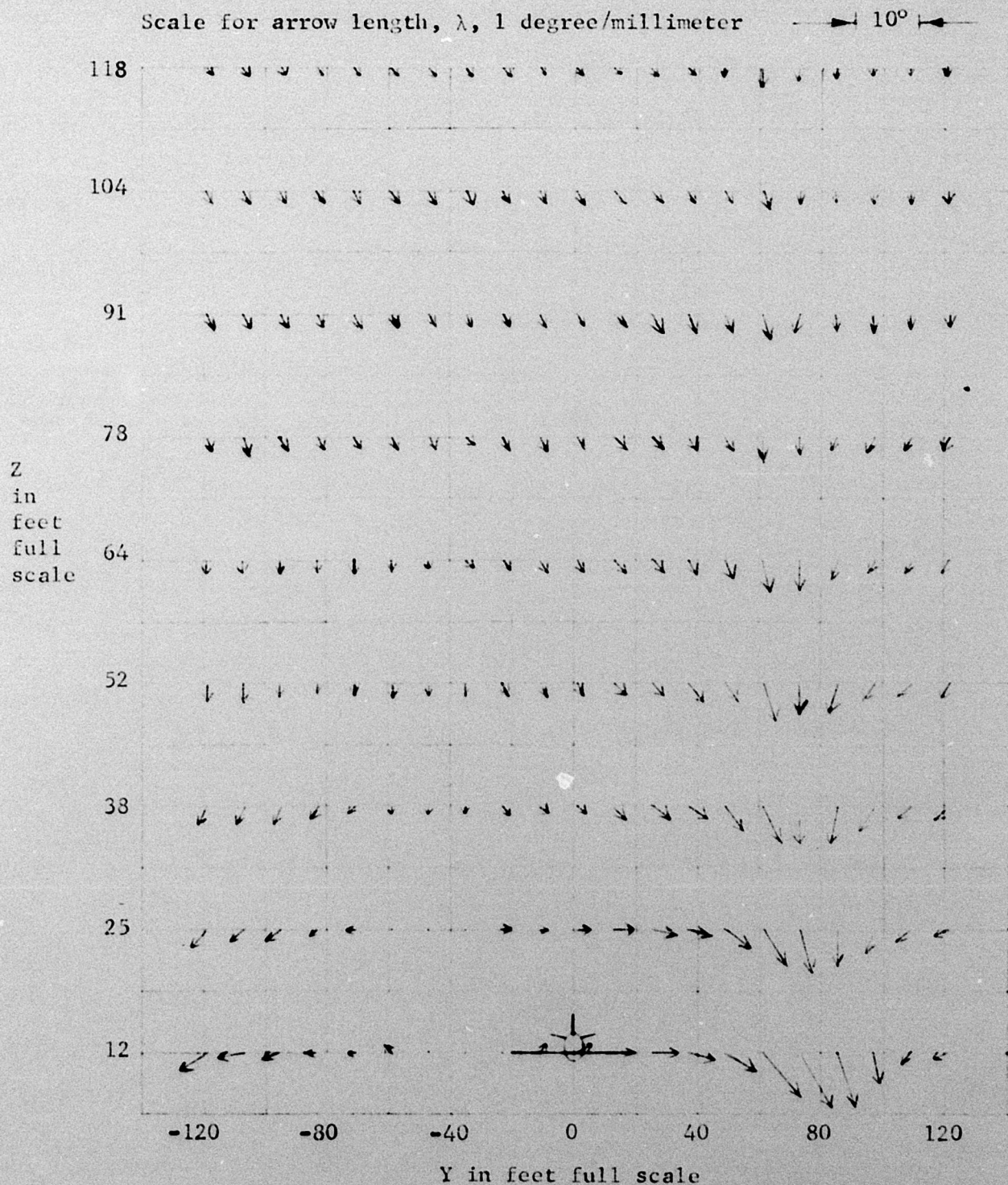


Figure 10 - Wind Angularity on the Y-Z Plane

Basic CVA 67; $\psi = 0^\circ$ (a) $X = -66$ Feet

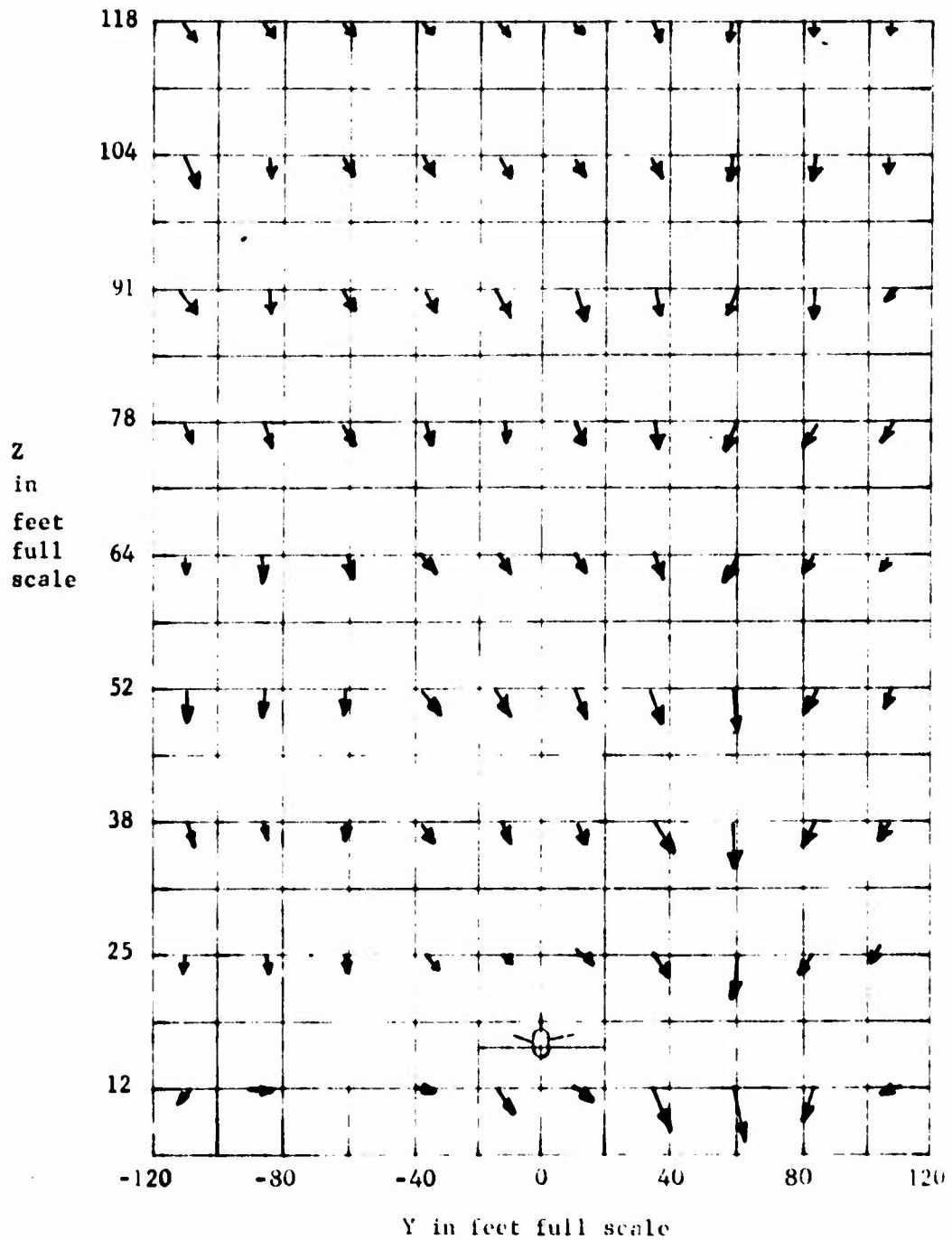
Scale for arrow length, λ , 1 degree/millimeter $\rightarrow 10^\circ$ 

Figure 10 (Continued)

(b) $X = 3$ Feet

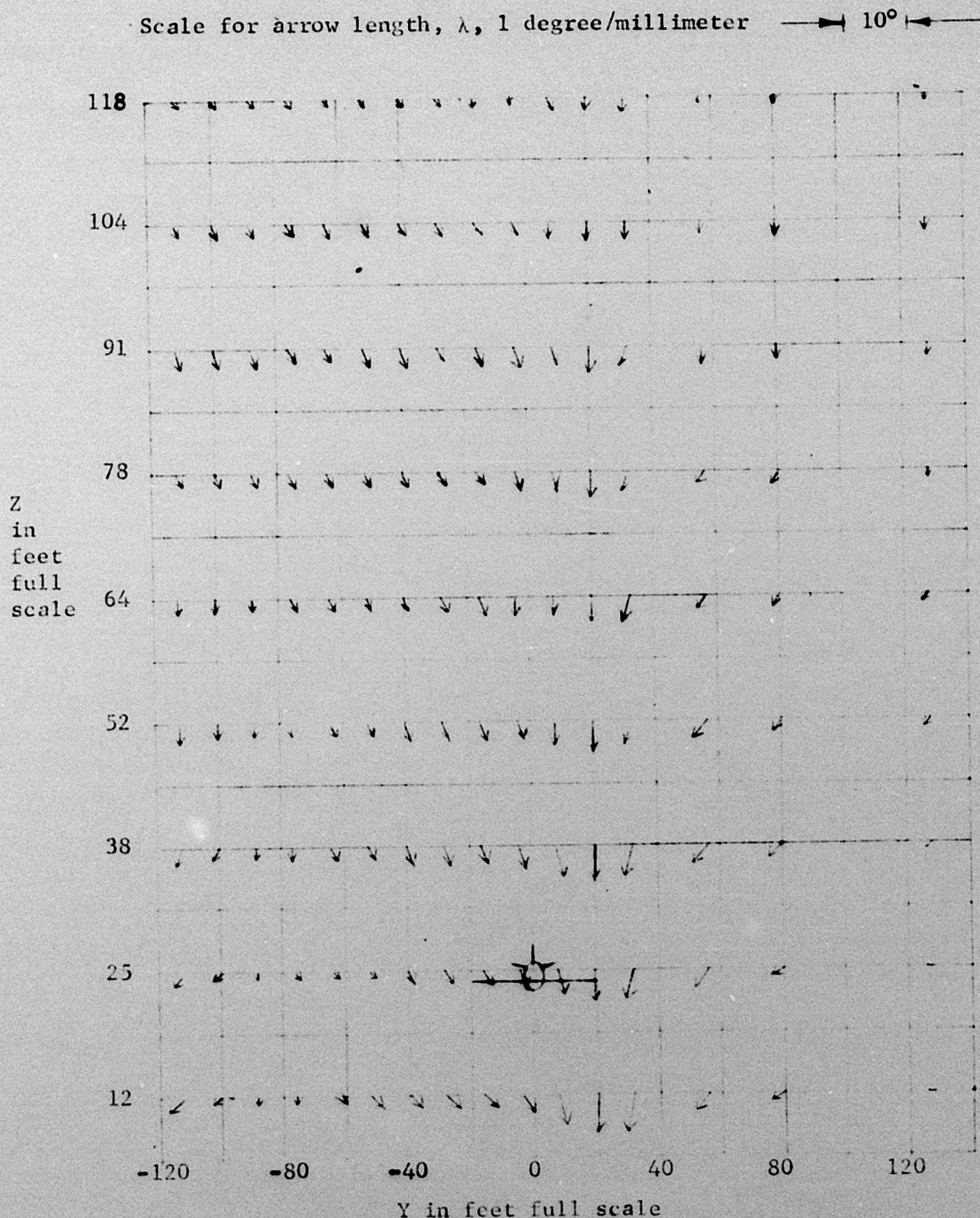


Figure 10 (Concluded)

(c) $X = 147$ Feet

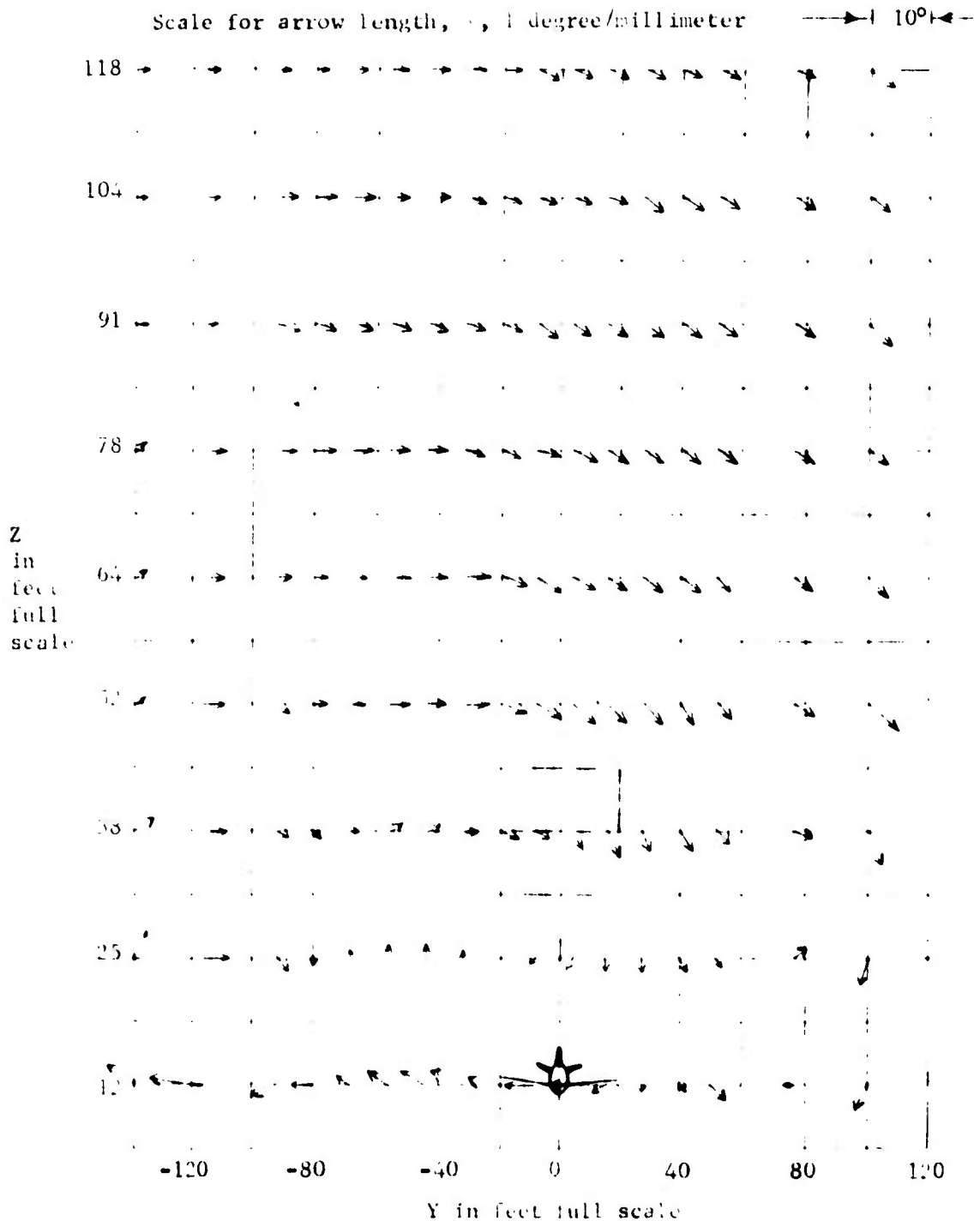
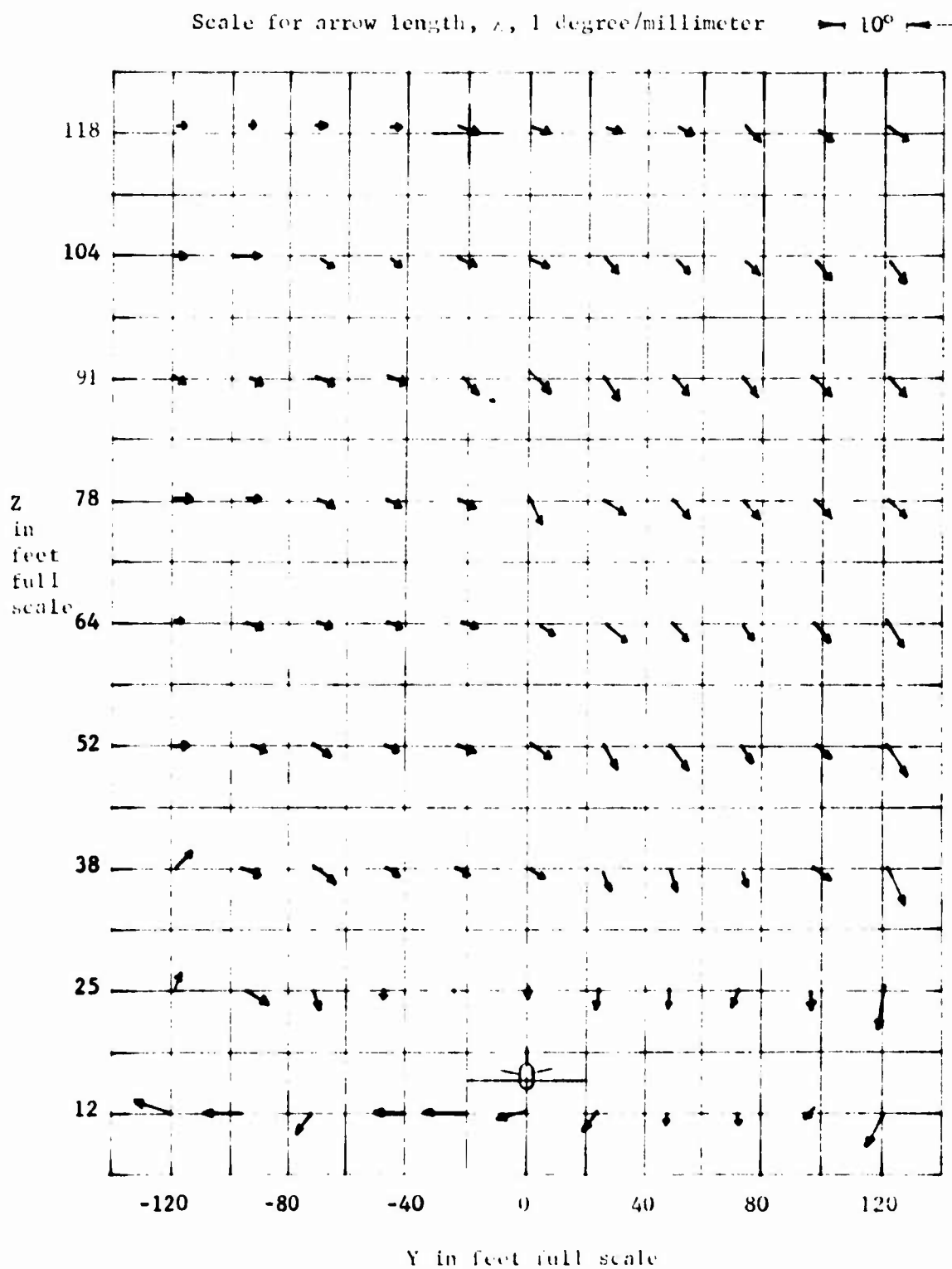


Figure 11 - Wind Angularity on the X-Z Plane.

Basic CVA 67; $\alpha = 11^\circ$

(a) X = -66 Feet



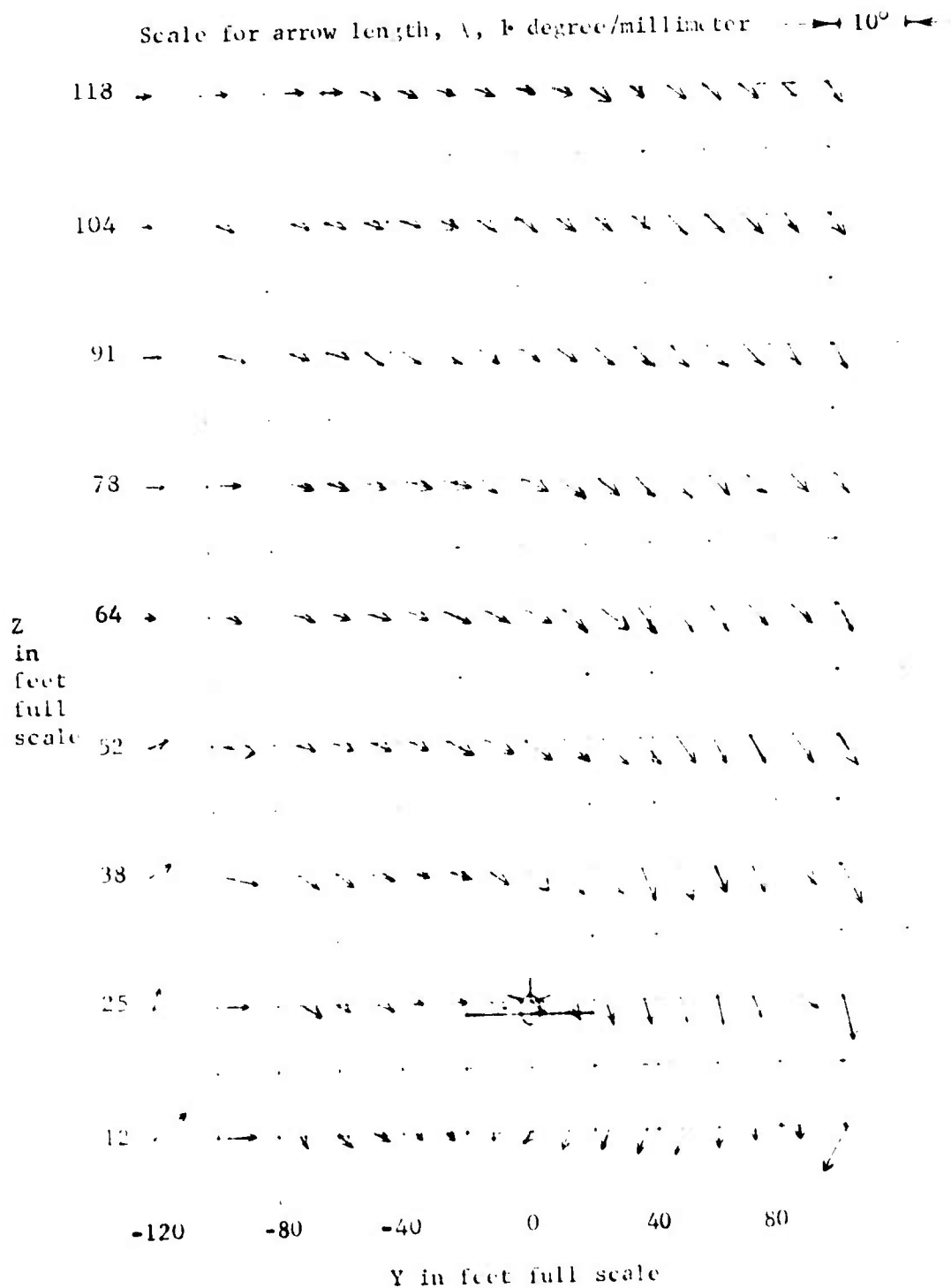


Figure 11 (Concluded)
(c) $X = 147$ Feet

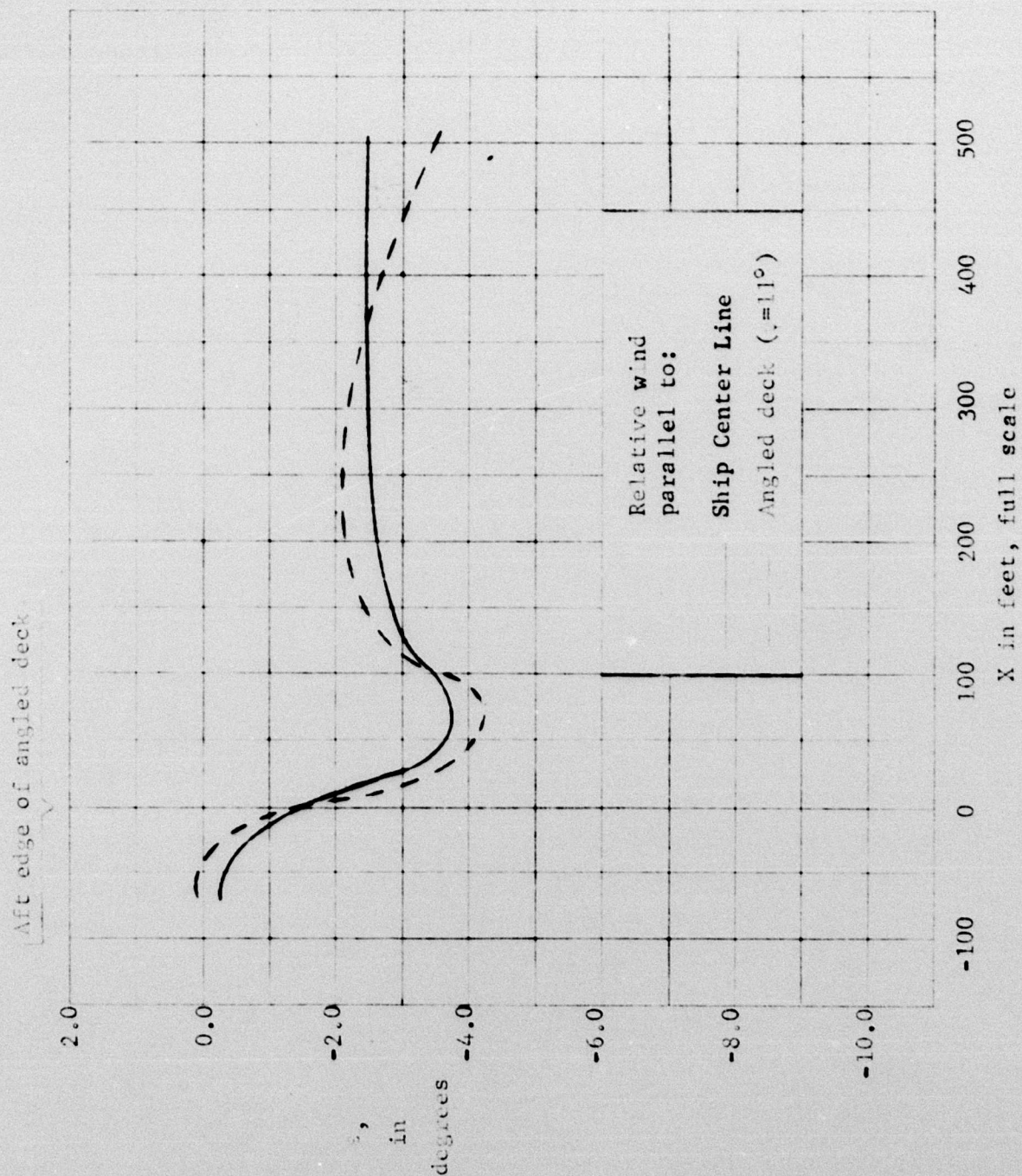


Figure 12 - Vertical Component of Wind Angularity on a 3° Approach Path

(a) Island Off; CVA 67 Deck

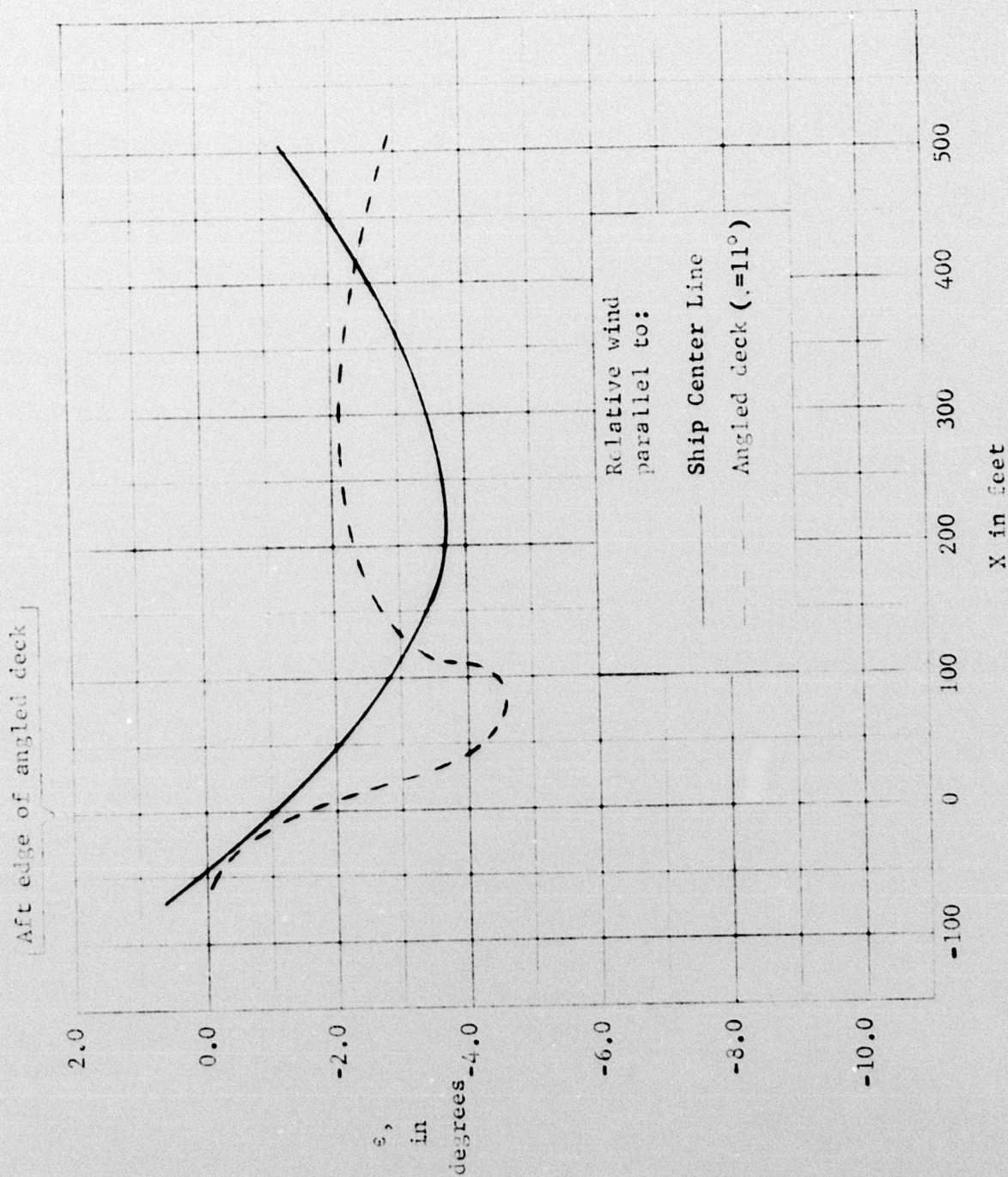


Figure 12 (Continued)

(b) Basic CVA 67

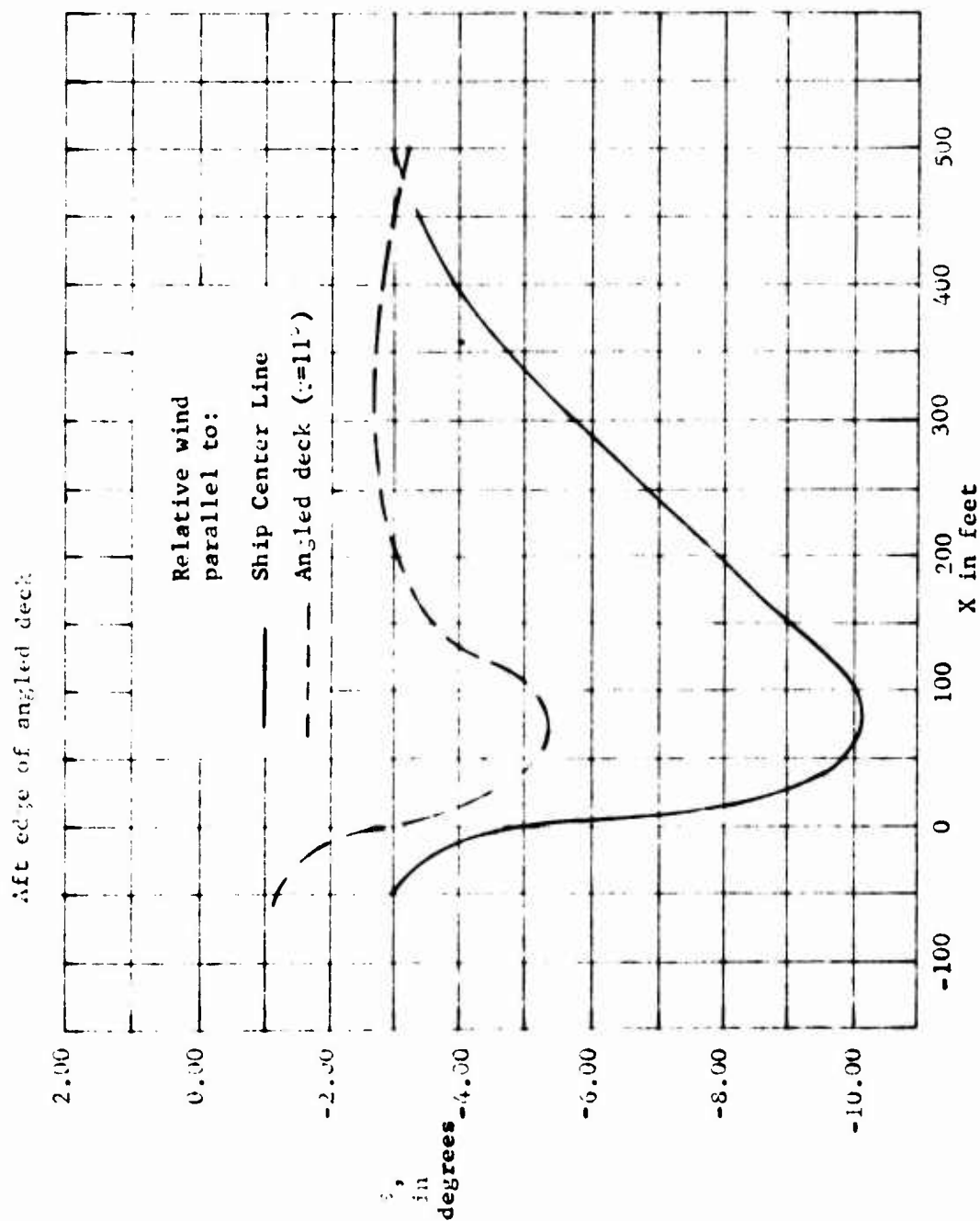


Figure 12 (Concluded)

(c) CVA 65 Island

Reynolds Number*

 $\times 10^{-6}$

○ 3.15

□ 5.05

◇ 6.38 Test Reynolds Number

*Based on a model carrier length of 7.33 feet.

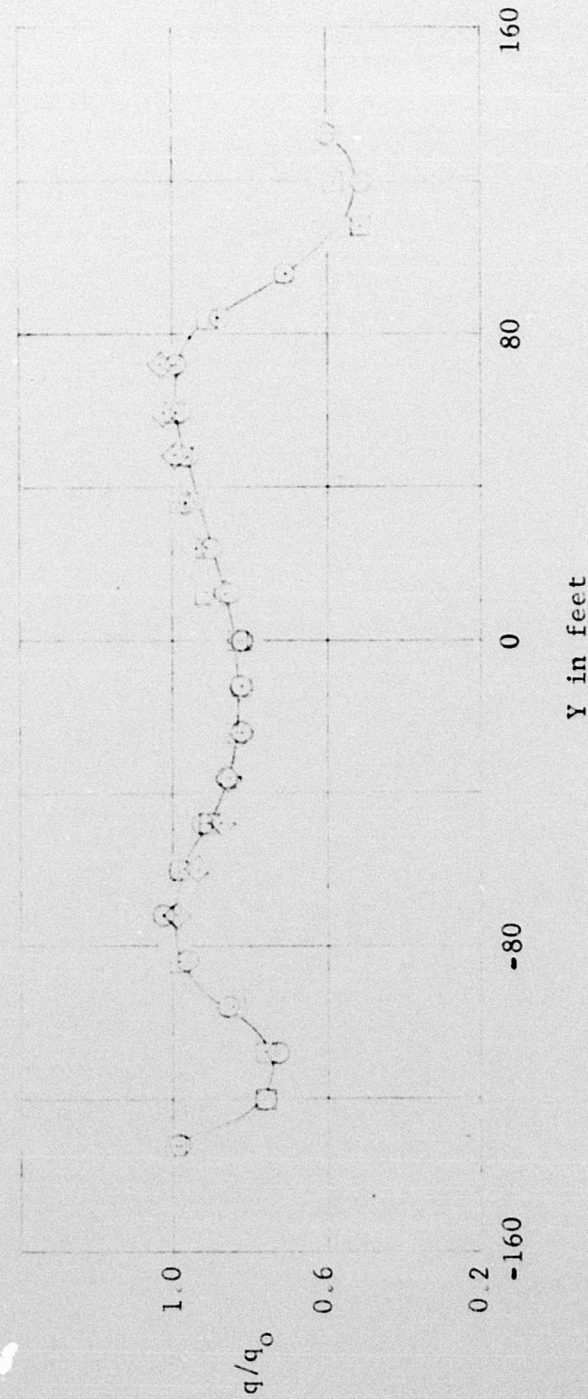


Figure 13 - Effect of Reynolds Number on the Dynamic Pressure Variation in the Wake of a Proposed 1/144-Scale CVA 67 Aircraft Carrier. $\psi = 11^\circ$

(a) $X = 6$ Feet

Reynolds Number *
 $\times 10^{-6}$

•	3.22
•	4.99
•	6.38

*Based on a carrier length of 7.33 feet.

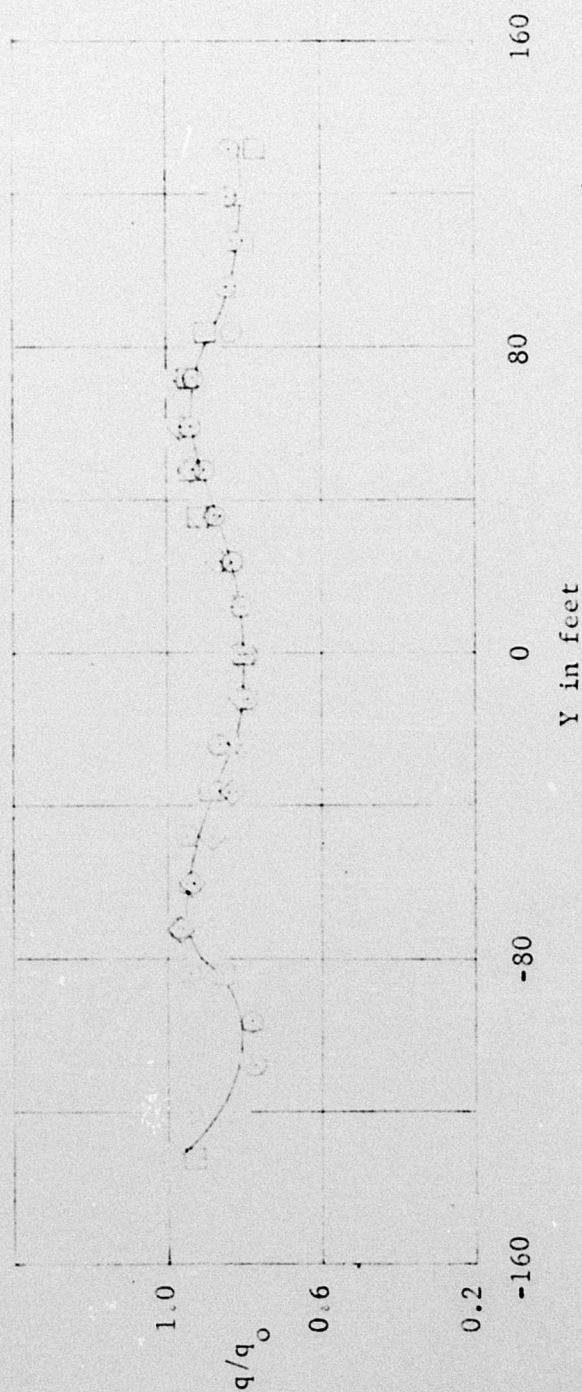


Figure 13 (Concluded)

(b) $X = 222$ Feet

/

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