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12

DEVELOPMENT AND ANALYSIS OF A CVA AND A 1052 CLASS FAST FRIGATE AIR WAKE MODEL

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Two digital computer programs have been developed in subroutine form to simulate the ship airwake turbulence around a FF1052 Frigate and a CVA. This report documents and analyzes these two models.

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S U M M A R Y

This report documents two ship airwake turbulence models which have been developed to aid in the analysis and simulation of the shipboard launch and recovery dynamics of conventional and VSTOL aircraft. The two computer subroutines represent a large deck carrier and a FF 1052 frigate air wake. The carrier model has been used extensively for automatic carrier landing simulations. The frigate airwake model has been developed more recently and has not been widely tested. The FF 1052 airwake model has been installed as part of the NAVAIRDEVCEN VSTOL Launch and Recovery Program described in reference (a). The model has been analytically validated against wind tunnel data, but it has not been tested in a piloted simulator.

These two models are being documented in the hope that they may form the basis for a standardized method of simulating turbulence for shipboard launch and recovery analysis.

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INTRODUCTION

Two turbulence model algorithms have been developed for use in the design and analysis of conventional and vertical take-off aircraft. These are an attack carrier model (CVA) and a FF 1052 frigate model. The CVA model has been used since 1971 in the simulation of manual and automatic landings aboard large deck carriers. This model has been used at the NASA Ames Research Simulation Facility in piloted simulations of the F-14, A-7, and EA-6B aircraft. References (b) and (c) describe the data and equations used to develop the model. Free air turbulence, steady, and unsteady burble components are combined to produce the complete CVA model. To make the algorithm more suitable for VSTOL aircraft, several changes have been made from the form described in reference (c). These are as follows:

1. The ship airwake velocity components are programmed to exponentially decrease in magnitude beyond specified bounds of altitude and lateral position.

2. The vertical component of the steady air wake has been changed to include an upwash near the bow. This was inferred from time histories of AV8A launches aboard the U.S.S. Roosevelt. (See figure 1.)

3. An option to provide discrete gust sinusoids in place of the ship air wake model has been added. These inputs follow the form described in reference (f).

The model is limited to cases where the wind is aligned with the landing deck. Wind velocity is specified by setting the ship speed variable, VS.

The second model has been developed exclusively for VSTOL aircraft and is intended to represent wind conditions near an FF 1052 frigate.

The turbulence algorithm was developed from data derived from the wind tunnel test of a 1/50 scale FF 1052 ship model. These data are contained in reference (d). The structure for the algorithm was based on work performed by the Vought Corporation and described in reference (e). However, the model described herein has been modified from the original format as a result of additional analysis of the data contained in reference (d). The model described herein is a somewhat refined version of the Vought model.

This model was programmed on the NAVAIRDEVCEN CDC 6600 computer. The Fortran listings included in this report represent the present status of the two models.

The subroutines have been tested in batch mode runs and are considered to be reasonably accurate. However, the author takes responsibility for any deficiencies that may still remain in the code.

The FF 1052 air wake model was examined by computing time histories, power spectra, and probability distributions and then comparing these with the wind tunnel velocity time histories.

This report describes all work done to validate and adjust the FF1052 model to agree with wind tunnel data. Both the CVA model and the FF1052 model are offered for inspection, use, and criticism.

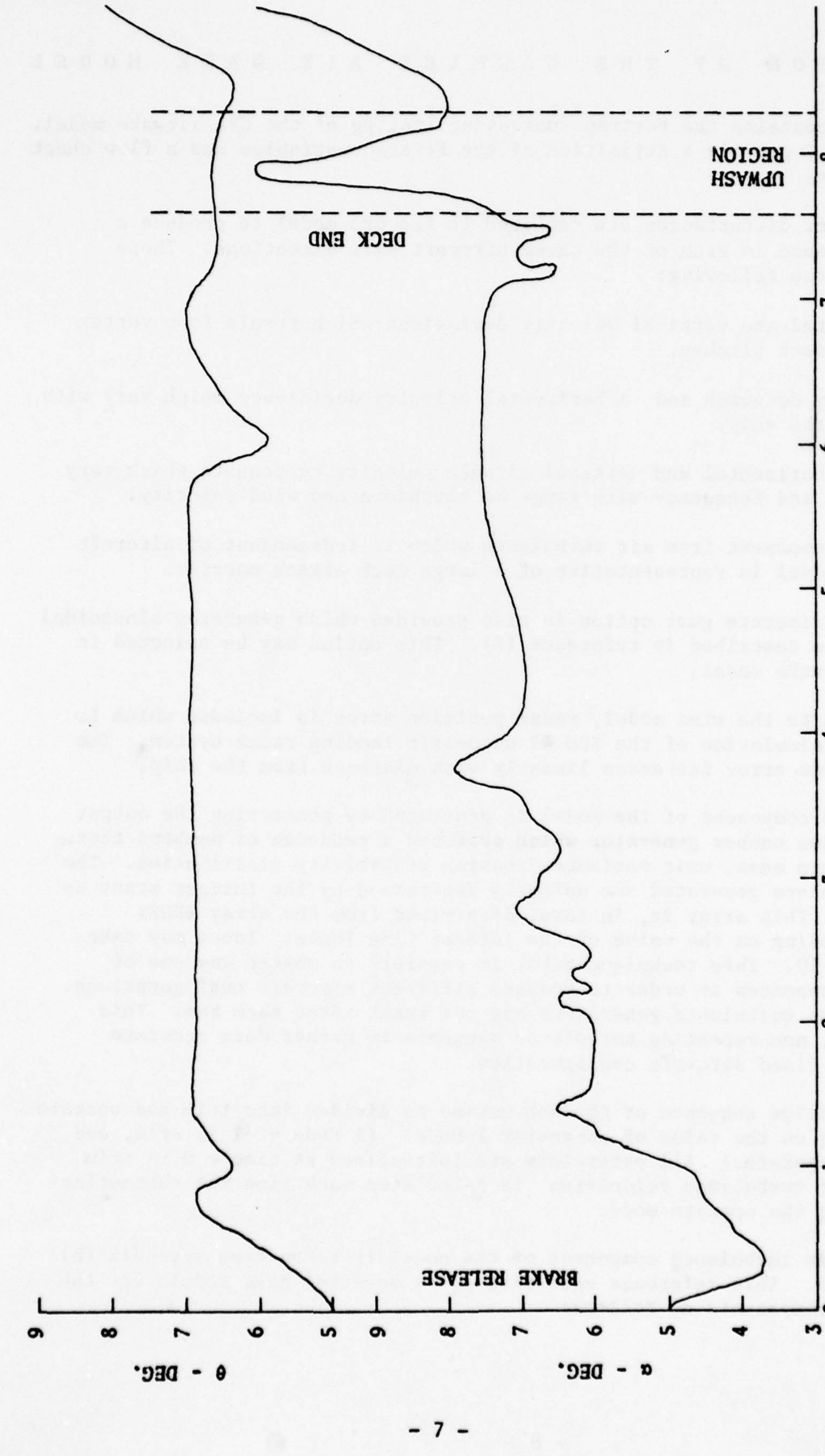


Figure 1 - Pitch Attitude and Angle of Attack During STO Launch

DESCRIPTION OF THE CARRIER AIR WAKE MODEL

Appendix A contains the Fortran subroutine listing of the CVA airwake model. Appendices B and C provide a definition of the Fortran variables and a flow chart of the subroutine.

Four distinct disturbances are combined in the CVA model to produce a velocity disturbance in each of the three aircraft axis directions. These sources include the following:

1. Horizontal and vertical velocity deviations which result from vortex shedding as the deck pitches.

2. A steady downwash and a horizontal velocity deficiency which vary with distance aft of the ship.

3. Random horizontal and vertical airwake velocity components which vary in RMS amplitude and frequency with range to touchdown and wind velocity.

4. Three-component free air turbulence which is independent of aircraft position. The model is representative of a large deck attack carrier.

A separate discrete gust option is also provided which generates sinusoidal gusts of the form described in reference (f). This option may be selected in place of the airwake model.

In addition to the wind model, radar position error is included which is appropriate for simulation of the SPN-42 automatic landing radar system. The simulated position error increases linearly with distance from the ship.

Each random component of the model is generated by processing the output of a pseudo-random number generator which produces a sequence of numbers that approximate a zero mean, unit variance Gaussian probability distribution. The sequences of numbers generated are uniquely determined by the integer start up array IRDST(I). This array is, in turn, determined from the array IRDSI (I, Ionce) depending on the value of the integer flag Ionce. Ionce may take values from 0 - 10. This technique makes it possible to repeat any one of 10 turbulence sequences in order to compare different aircraft configurations. If Ionce = 0, the turbulence generators are not reset after each run. This produces a long, non-repeating turbulence sequence to gather more accurate statistics on a fixed aircraft configuration.

The calculation sequence of the subroutine is divided into trim and operate modes depending on the value of parameter I Mode. (I Mode = -1 in trim, and I Mode = +1 in operate.) All parameters are initialized at time = 0 in trim and a new set of turbulence velocities is calculated each time the subroutine is called during the operate mode.

The free air turbulence component of the model is taken from appendix (b) of reference (h). This reference specifies power spectral gust models for the three velocity components as follows:

$$\phi\frac{\Delta u}{v_o} = \frac{200/v_o^3}{\left(\frac{S}{v_o/100}+1\right)\left(\frac{-S}{v_o/100}+1\right)} \quad \frac{(ft/sec)^2}{(rad/sec)}$$

$$\phi\frac{\Delta v}{v_o} = \frac{\left(\frac{5900}{v_o^3}\right)\left(\frac{S}{v_o/400}+1\right)\left(\frac{-S}{v_o/400}+1\right)}{\left(\frac{S}{v_o/1000}+1\right)\left(\frac{-S}{v_o/1000}+1\right)\left(\frac{S}{3v_o/400}+1\right)\left(\frac{-S}{3v_o/400}+1\right)} \quad \frac{(ft/sec)^2}{(rad/sec)}$$

$$\phi\frac{\Delta w}{v_o} = \frac{71.6/v_o^3}{\left(\frac{S}{v_o/100}+1\right)\left(\frac{-S}{v_o/100}+1\right)} \quad \frac{(ft/sec)^2}{(rad/sec)}$$

The corresponding root-mean-square gust amplitudes are:

u_G = .76 M./sec (2.5 ft/sec)

w_G = .457 M./sec (1.5 ft/sec)

v_G = .728 M./sec (2.39 ft/sec)

The frequency parameters of the free air turbulence filters are determined by the trim airspeed v_o. Since the algorithm was developed for conventional flight simulation, the equations do not permit the direct substitution of zero airspeed for a hover case. For low trim speeds, the parameter is arbitrarily set to 18.29 M./sec (60 ft/sec). This value was selected as a reasonable estimate of the maximum relative wind over a moving ship.

The turbulence routine options are determined by selecting integer flag parameters as either 0 or 1. The normal values of these flags are as follows:

Iwind = 1

ILburb = 1

ILturb = 1

IBfrz = 0

Idisct = 0

Iubt = 0

Ivbt = 0

Iwbt = 0

This produces a complete ship airwake model for approach simulation. The complementary values produce these effects:

Iwind = 0	Return all zero turbulence values.
ILburb = 0	Select alternate downwash function.
ILturb = 0	Set all free air turbulence components to zero.
IBfrz = 1	Fix turbulence range variable to xd = xfrz.
Iubt = 1	Set u component of airwake burble to zero.
Ivbt = 1	Set v component of airwake burble to zero.
Iwbt = 1	Set w component of airwake burble to zero.
Idisct = 1	Select discrete gust options in place of carrier airwake model.

The ship dependent portion of the airwake was developed primarily from water tunnel tests of CVA ship models. The steady components consist of tabulated values of horizontal and vertical velocity functions ($\Delta u/vs$ and $\Delta w/vs$) versus range. These functions are shown in figure 2. The downwash and reduction in relative wind is determined by multiplying the tabulated functions by ship speed vs. The model assumes that all the wind is generated by the ship and that the velocity is aligned with the landing deck.

Periodic wind components with magnitudes proportional to ship pitch are also included. These sinusoidal vertical and horizontal components propagate aft from the ship at 85 percent of the ship speed and decay in amplitude with range.

The apparent frequency at which the velocity varies is determined by the aircraft closing speed according to formula

$$\text{Magnitude} = \text{cosine}\left[\omega_p\left(1. + \frac{\Delta v}{0.85 \cdot v_s}\right)\cdot t + \frac{x_d}{0.85 \cdot v_s} + \phi - 1.57\right]$$

where ω_p = ship frequency, Δv = aircraft closing rate, v_s = ship speed, x_d = distance to ship cg, and ϕ = phase.

The magnitude of the sinusoid decreases linearly with distance aft of the ship. The burble is set to zero outside of established limits fore and aft of the ship. Additional limits on magnitude are established by altitude and lateral position of the aircraft. The magnitude is assumed to decrease exponentially at distances greater than 100 feet to the left or right of the ship and at altitudes greater than 50 feet above the deck. Reference (i) indicates that the burble is largely restricted to this region.

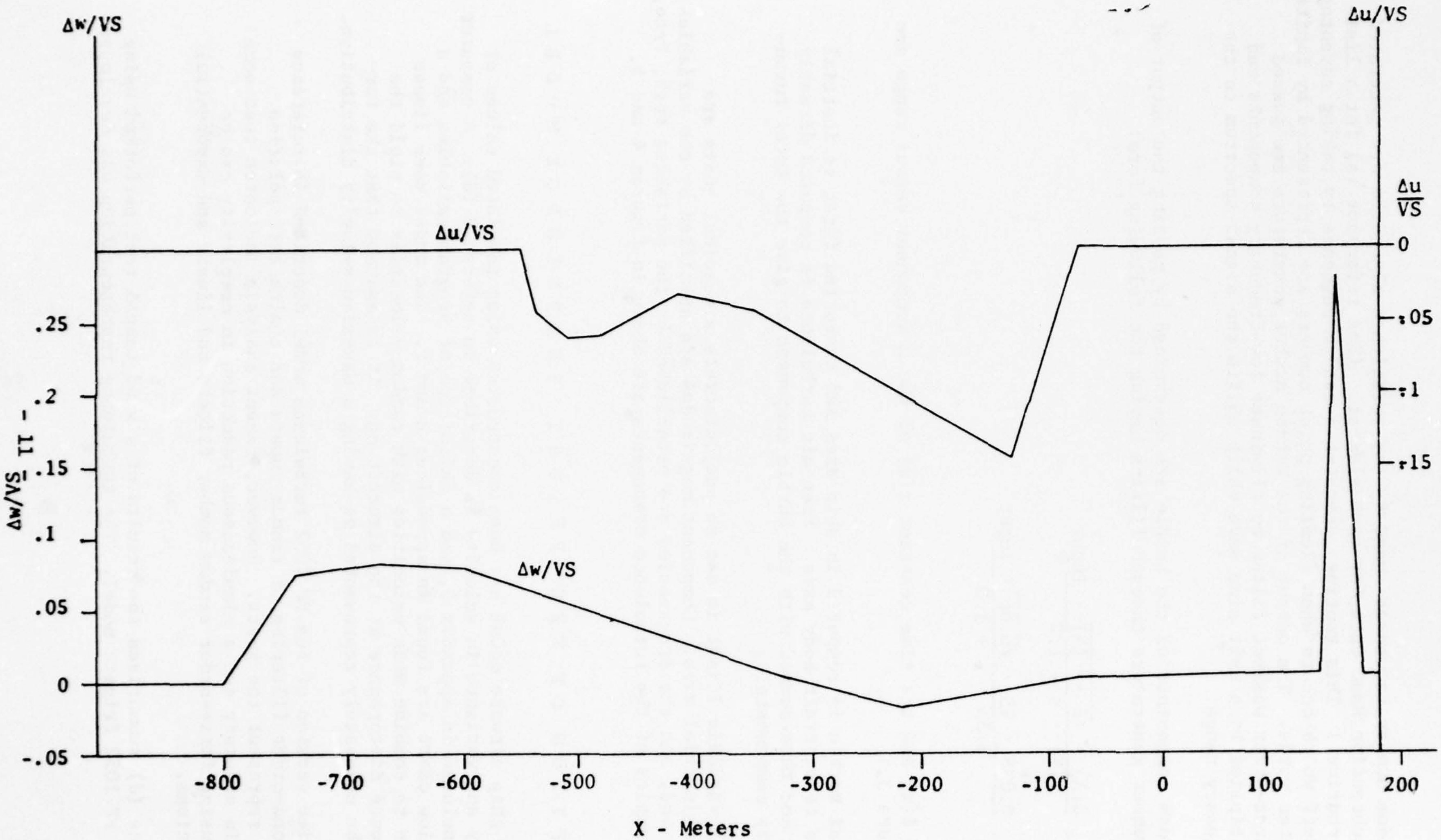


Figure 2 - CVA Ship Burble Steady Wind Ratios

The random number sequences used by the turbulence algorithm are generated by calling subroutine Rand once for each element. (See reference (a) for a listing of this routine.) This routine generates a random sequence by taking advantage of the roundoff which occurs when floating point numbers are represented by finite length computer words. The output of the random number generators are passed through a first-order washout filter to eliminate low-frequency components and are then multiplied by a unit sine wave which shifts the signal spectrum to the desired frequency range.

The random components of the burble are determined by passing the output of the random number generators through filters having the following form:

$$ub2(s) = \frac{\delta(X) \cdot \sqrt{2 \cdot \tau(X)} \cdot \text{Input}}{\tau(X) \cdot s + 1.0}$$

$$wb2(s) = \frac{0.035 \cdot VS \cdot \sqrt{6.66} \cdot \text{Input}}{3.33 \cdot s + 1.0}$$

The variance $\delta(x)$ and the time constant $\tau(x)$ of the u component versus range are shown on figure 3.

The total burble is computed in ship axes and converted first to inertial axes and then to aircraft body axes. Free air turbulence is computed directly in body axes and then summed with the burble component to give the total turbulence velocity components.

When the variable Idisct is set to one, discrete sinusoidal gusts are calculated in inertial axes. Component magnitudes are specified by the variables Vmn, Vme and Vmd, and the frequencies are established by the variables Frth, Frte, and Frtd. Samples of the turbulence components are shown in figures 4 and 5.

DESCRIPTION OF THE FF1052 TURBULENCE MODEL

A small ship airwake model has been constructed using tabulated values of mean velocity and variance in velocity as described in reference (d). A computer listing is included in appendix D, and a definition of program variables and a subroutine flow chart are found in appendices E and F. The model uses linear superposition to combine mean velocities with random velocities to yield the total turbulence disturbance at the aircraft cg. It is assumed that the turbulence may be adequately represented as having a Gaussian velocity distribution.

An earlier version of the FF 1052 turbulence model described in reference (e) used second-order filtering of random inputs and cosine extrapolation functions to represent the gusts. However, recent analysis indicates that some improvement in accuracy and a simultaneous reduction in complexity can be achieved by using first-order random number filters and linear and exponential shaping functions.

Reference (d) summarizes the results of a wind tunnel test performed using a 1/50 scale FF 1052 frigate model. The turbulence representation was developed

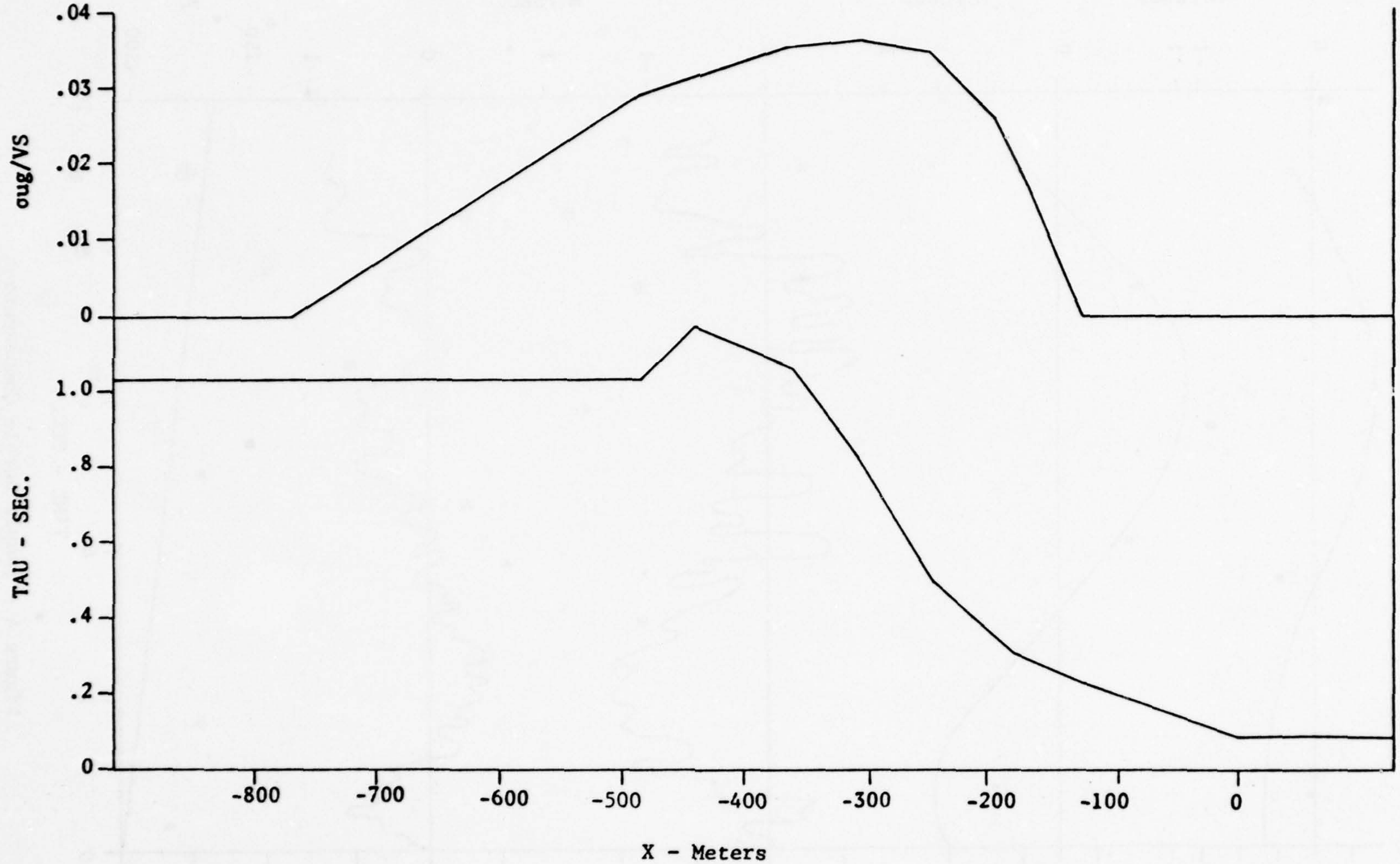


Figure 3 - U Component Burble Time Constant and Variance

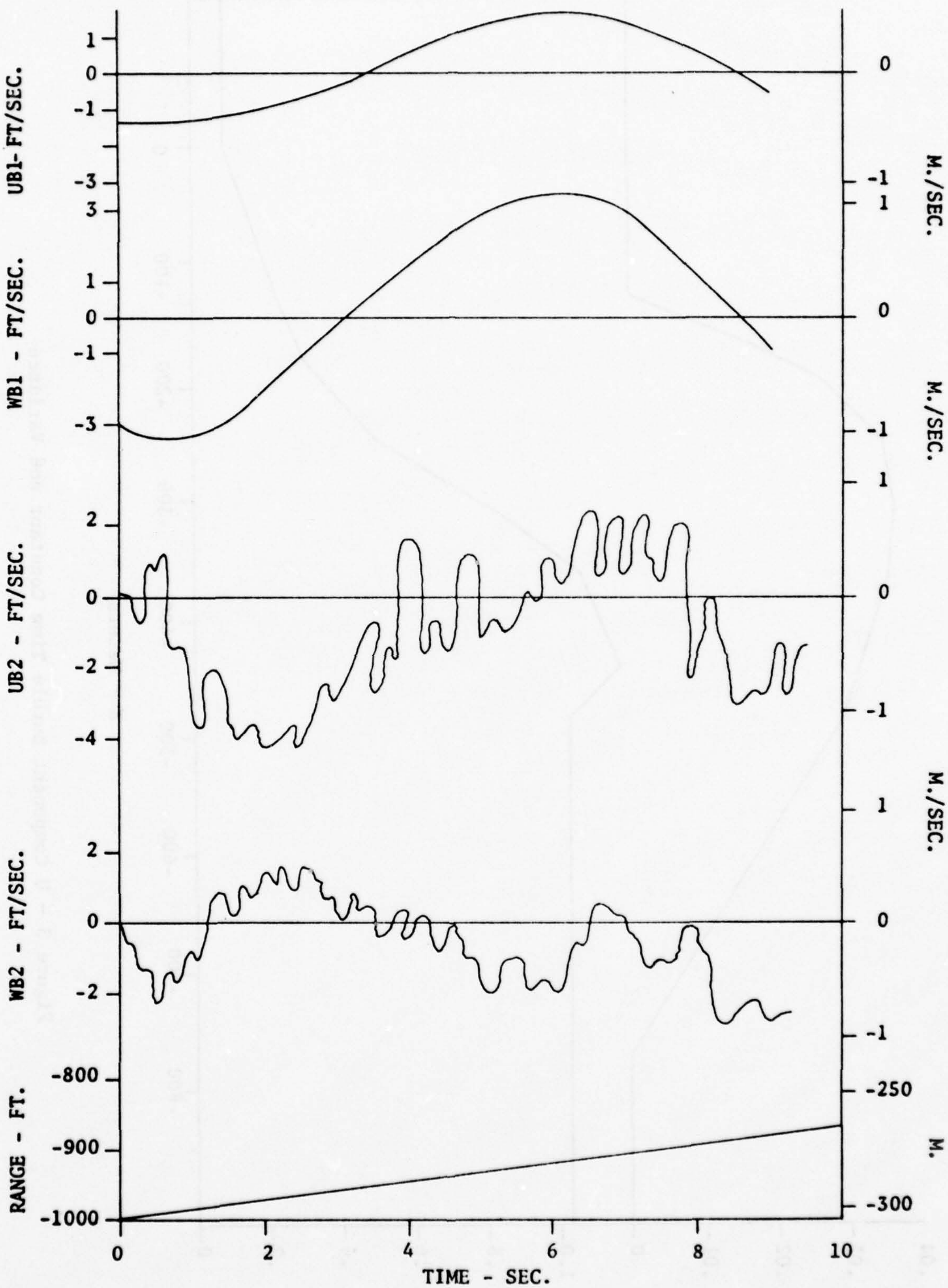


Figure 4 - Sample Burble Components
VO = VS = 18 M./Sec. (60 Ft./Sec.)

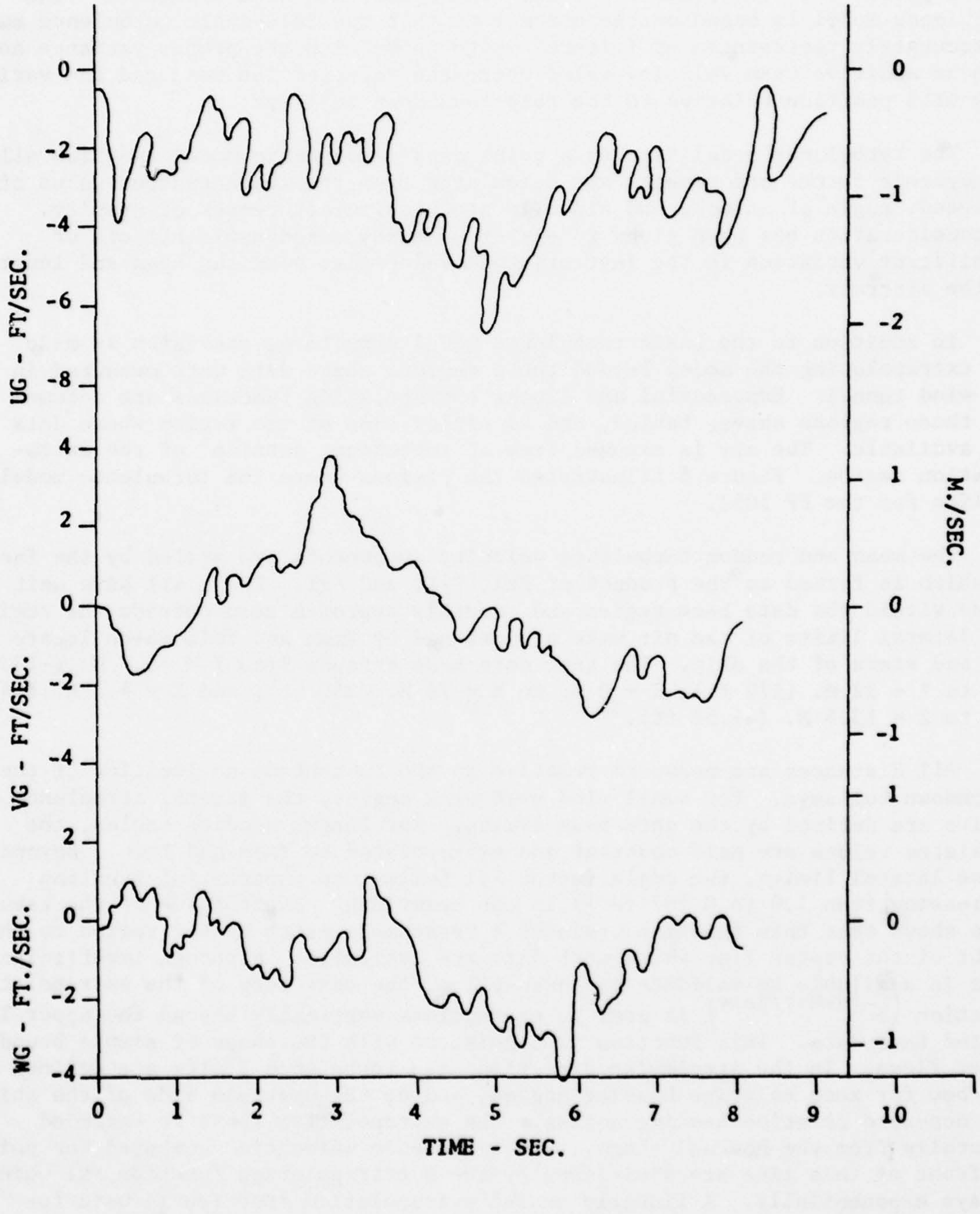


Figure 5 - Sample of CVA Simulated Free Air Turbulence

from statistical summaries of the measured turbulence velocities which define the mean and variance of the three velocity components recorded by an array of hot wire anenometer probes placed downstream of the ship model. The mean and variance were computed from a series of 262 measurements made over a 1.6-second period for each probe location, wind speed, and wind direction. The turbulence model is based on the assumption that the full-scale turbulence may be accurately represented as filtered white noise with the proper variance and with an additive mean velocity value where the value of the mean and the varian vary with position relative to the ship touchdown bullseye.

The turbulence model assumes a point mass aerodynamic model in which all aerodynamic forces and moments are calculated from the instantaneous value of airspeed, angle of attack, and sideslip at the aircraft center of gravity. No consideration has been given to either unsteady aerodynamic effects or significant variation in the instantaneous velocities over the span and length of the aircraft.

In addition to the basic turbulence model structure, provision is made for extrapolating the model beyond those regions where data were measured in the wind tunnel. Exponential and linear extrapolation functions are assumed for those regions above, behind, and to either side of the region where data are available. The air is assumed free of turbulence outside of the extra-polation region. Figure 6 illustrates the regions where the turbulence model applies for the FF 1052.

The mean and random turbulence velocity components are scaled by the factoı F1 which is formed as the product of Fx1, Fy1, and Fz1. These all have unit value within the data base region and smoothly approach zero outside the region. The lateral limits of the air wake are defined by Ymax and Ymin which locate the bow and stern of the ship. The test data base extends from Y = -5.7 M. (-18.75 ft) to Y = 52 M. (170 ft), X = 0 M. to X = 76 M. (250 ft), and Z = 4.4 M. (14.58 ft) to Z = 13.6 M. (44.58 ft).

All distances are measured relative to the instantaneous location of the touchdown bullseye. For small wind over deck angles, the lateral turbulence limits are defined by the data base limits. For larger heading angles, the tabulated values are held constant and extrapolated to Ymax and Ymin. Beyond these lateral limits, the scale factor Fy1 follows an exponential function decreasing from 1.0 to 0.367 (e^{-1}) in one beamwidth. Examination of the tabulat data shows that this function produces a reasonable match in the region to the right of the center line where most data are available. Although insufficient data is available to validate the assumption, the same form of the extrapolating function $\left(e^{-(H-Ho)/Beam}\right)$ is used to extrapolate vertically beyond the upper limi of the test data. This function is consistent with the shape of simple boundary layer flows. In the streamwise direction, the turbulence limits are defined by the bow for zero relative heading angles, and by the upstream side of the ship for non-zero relative heading angles. The extrapolation limit is extended laterally from the bow and stern. All turbulence velocities computed for points in front of this line are diminished by the X extrapolation function Fx1 which decays exponentially. A linearly scaled extrapolation function is used for Fx1 aft of the data base limit of 76 M. (250 feet).

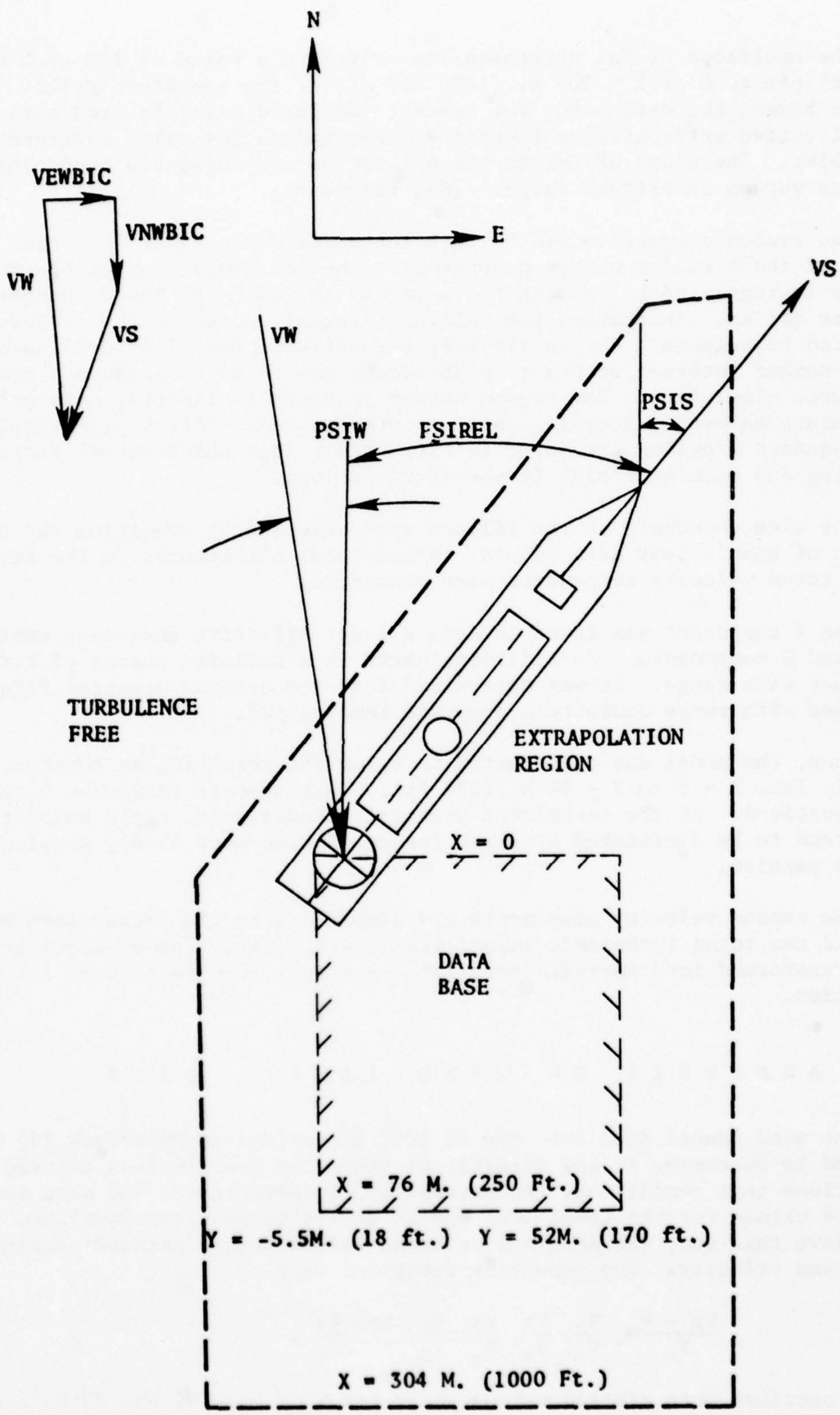


Figure 6 - FF 1052 Ship Airwake Model Geometry

The amplitude of Fx1 decreases linearly from a value of 1.0 at X = 76 M. (250 ft) aft to 0 at X = 305 M. (1000 ft) aft of the touchdown point. In the regions beyond the data base, the nearest tabulated value is used with the multiplicative extrapolation function F1 applied to the value returned from the tables. The slope of Fx1 in the aft region was suggested from plots of variance versus downstream range. (See figure 7.)

The random components of the turbulence are produced by filtering the output of these random number generators. The frequency content of the turbulence is regulated by varying the interval at which the random number generators are called. Increasing the calling interval decreases the frequency of the simulated turbulence. For an aircraft simulation interval of 0.05 second, a random number interval of 0.3 to 0.35 second was found to produce a reasonable turbulence simulation. The random number sequence is linearly interpolated for time values between succeeding calls to produce a smoothly varying number sequence. This sequence provides the input to first-order lags which effect additional filtering and eliminate high frequency variations.

The time constants of the filters were selected by examining the power spectra of sample test data points. Significant differences in the frequencies of the three velocity components were uncovered.

The X component was found to have a lower effective frequency content than the Y and Z components. In addition, there is a definite change of turbulence frequency with range. It was determined that the maximum spectral frequency decreased with range downstream from the landing pad.

Thus, the model was constructed to allow the three filter constants to vary linearly from X = 0 to X = 58 M. (190 ft). This appears realistic from physical considerations. As the turbulence propagates downstream, rapid velocity fluctuations tend to be diminished by shear forces whereas more slowly varying velocities tend to persist.

The random velocity components are combined with the steady mean components to yield the total turbulence velocities in wind axes. These velocities are then transformed into inertial axes for use by the main portion of the aircraft simulation.

ANALYSIS OF WIND TUNNEL DATA

The wind tunnel data for the FF 1052 summarized in reference (d) were analyzed to determine if any significant trends or correlations existed among the various test conditions. An attempt was made to reduce the mean and variance values for the three wind speeds tested to nondimensionalized functions. To achieve this end, the mean and variance values were nondimensionalized by the freestream velocity. The resulting functions were

$$\frac{Vx - V_\infty}{V_\infty},\ \frac{Vy}{V_\infty},\ \frac{Vz}{V_\infty},\ \frac{\delta x}{V_\infty},\ \frac{\delta y}{V_\infty},\ \text{and}\ \frac{\delta z}{V_\infty}.$$

These functions were plotted versus range for V_∞ = 10, 18, and 23 M./sec.

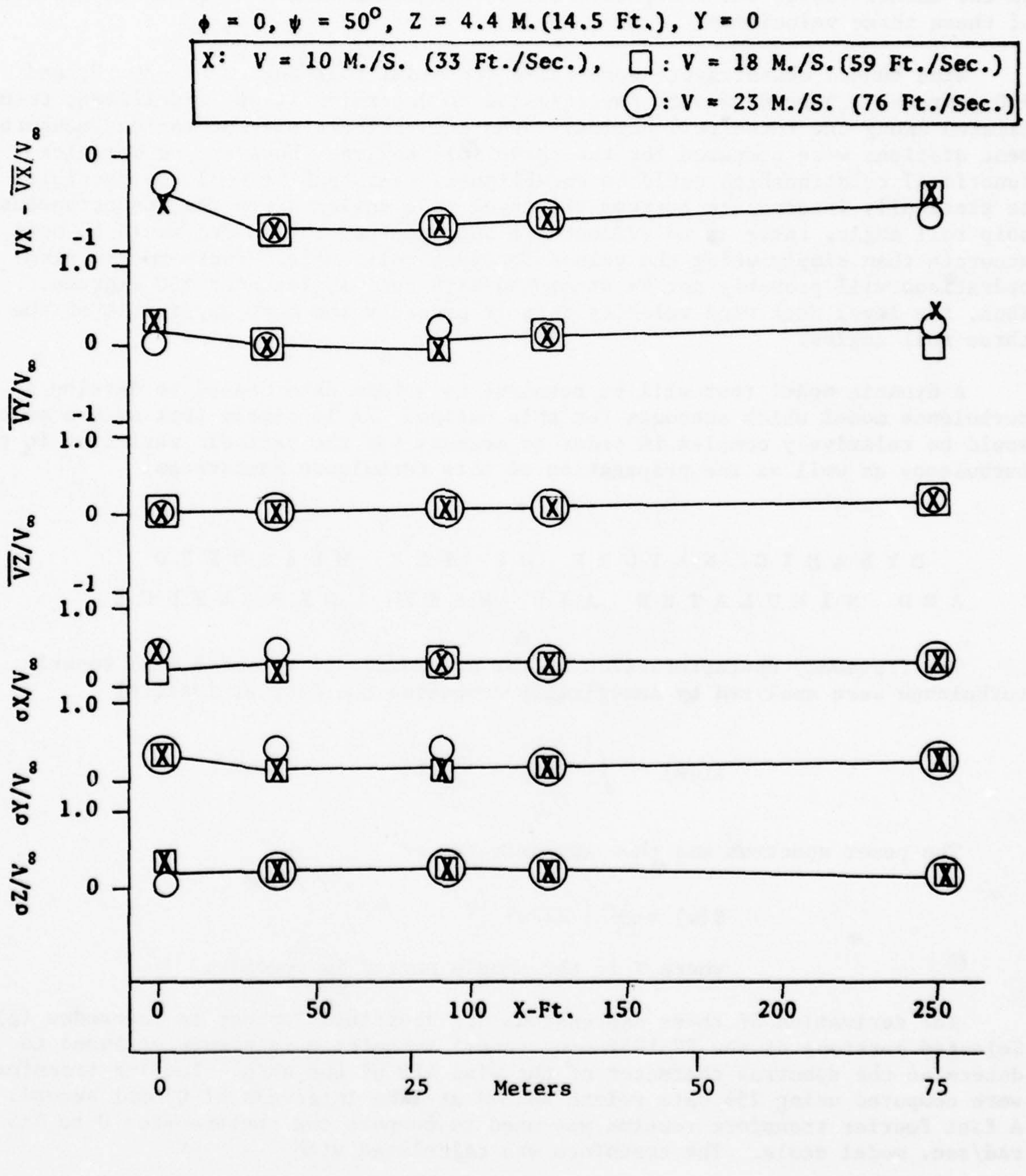


Figure 7 - Nondimensionalized Turbulence Parameters Versus Range

Figure 7 illustrates these functions. It can be seen that the nondimensionalized functions for the three velocities agree rather well. This suggests that a generalized model could be used which would be valid for all relative wind velocities. However, the present model is restricted to the three freestream velocities used in the tunnel tests, and a separate set of nonlinear tables is required for each of these three velocities.

Wind tunnel measurements were taken for model roll angles of -30, 0, and +30 degrees. These data were investigated to determine if any significant trends existed among the three roll angles. Mean and variance size at various measurement stations were compared for the three roll angles. However, no definite functional relationships could be established. Although it would be possible to statically interpolate between the three roll angles given the instantaneous ship roll angle, there is no evidence to suggest that this model would be more accurate than simply using the values for zero roll angle. Furthermore, air operations will probably not be attempted with roll angles near ±30 degrees. Thus, the level deck wind velocity data is probably the most applicable of the three roll angles.

A dynamic model test will be required to obtain data needed to develop a turbulence model which accounts for ship motion. It is likely that such a model would be relatively complex in order to account for the periodic variation in the turbulence as well as the propagation of this turbulence downstream.

DYNAMIC NATURE OF THE MEASURED AND SIMULATED AIR WAKE TURBULENCE

The frequency characteristics of the simulated and measured wind tunnel turbulence were analyzed by numerically computing the Fourier integral

$$X(J\omega) = \int_0^T X(t)\, e^{-J\omega t} dt.$$

The power spectrum was then approximated as

$$S(\omega) \simeq \frac{1}{2T} \mid X(J\omega) \mid^2$$

where T is the sample period in seconds.

The derivation of these expressions are described further in reference (g). Selected portions of the FF 1052 wind tunnel turbulence data were analyzed to determine the spectral character of the wind aft of the ship. Fourier transforms were computed using 256 data points spaced at time intervals of 0.0061 second. A fast Fourier transform routine was used to compute the spectra from 0 to 515 rad/sec. model scale. The transform was calculated with

$$\Delta\omega = \frac{2 \cdot PI}{Nsamples} \text{ rad./sec. and}$$

$$\text{maximum frequency} = \frac{PI}{\Delta T} = 515 \text{ rad./sec.}$$

TABLE I

Selected Wind Tunnel Test Points Used in Spectral Analysis

Yaw (deg.)	Roll (deg.)	Speed (M/S)	X (Meters)	Y (Meters)	Z (Meters)
30	0	9	0	0	4.2
50		9		0	4.2
50		9		0	7.6
0		16		5.5	4.2
0		16		0	4.2
0		16		0	7.6
30		16		5.5	4.2
30		16		0	4.2
30		16		0	7.6
50		16		0	4.2
50		16		0	7.6
0		22		5.5	4.2
30		22	0	0	4.2
30		9	11		4.2
30		9			7.6
50		9			4.2
50		9			7.6
30		16			7.6
30		23	11		4.2
30		10	27		4.2
30	0	18	27	0	4.2

TABLE II

Statistics of Frequency Value Corresponding to Maximum of Spectra Grouped by Velocity and Velocity Component

Freestream Velocity			Frequency - Rad/Sec.			
M./S.	(ft/sec)	Component	Average	Maximum	Minimum	RMS
9.1	30	X	60	110	30	30
9.1	30	Y	76	110	10	34
9.1	30	Z	90	150	30	43
16.46	54	X	95	190	10	52
16.46	54	Y	108	260	10	99
16.46	54	Z	140	290	30	90
21.9	72	X	90	170	30	58
21.9	72	Y	130	170	70	43
21.9	72	Z	290	410	150	107

TABLE III

Statistics of Peak Spectral Velocity Grouped by Velocity Only

Velocity		Peak Spectral Frequency - Rad/Sec.			
M./S.	(Ft./Sec.)	Average	Maximum	Minimum	RMS
9.1	(30)	75	150	30	45
16.46	(54)	114	290	15	80
21.9	(72)	170	410	30	114

Because the number of samples was relatively small, the power spectra were generally very erratic. The data were thus smoothed by averaging over groups of six succeeding frequency points. Figures 8 to 10 illustrate samples of the smoothed spectral data. The sample cases shown in table I were examined with regard to spectral content.

These data were analyzed to determine if any significant trends existed with respect to the spectral distributions. The frequency at which the spectrum attained its maximum value was computed for each case and the data were sorted according to freestream velocity and velocity component. The maximum, minimum, average, and RMS value of the frequency at which the peak of the spectrum occurs is tabulated in table II.

Grouping the data by freestream velocity only, the frequency statistics can be summarized as shown in table III.

Figure 11 summarizes the frequency trend as a function of test condition velocity. A least squares fit of the three gross averaged frequencies yields the relation

$$\omega_{\text{test}}^{\text{max}} = 3.837 + 2.2274 \cdot V - \text{rad/sec.}$$

Strouhal scaling based on model length is used to obtain the equivalent full-scale frequency as

$$\omega_{\text{full scale}}^{\text{max}} = 0.07674 + 0.04548 \cdot V - \text{rad/sec.}$$

For the test velocities, this becomes

TABLE IV

Turbulence Frequency Versus Airspeed

ω - Full Scale	V - Ft./Sec.
1.440	30
2.76	59
3.53	76

This differs from the second-order filter model frequency of 1.9 rad./sec. at V = 18 M./S. (59 ft./sec.) as described in reference (d). If additional wind tunnel data is unavailable, the FF 1052 model may be applied to larger or smaller ships having similar geometry or the same ship at different velocities by applying Strouhal scaling, where

$$SN = \frac{f \cdot h}{V}$$

SN = Strouhal number
f = Turbulence frequency
h = Ship beam
V = Flow velocity

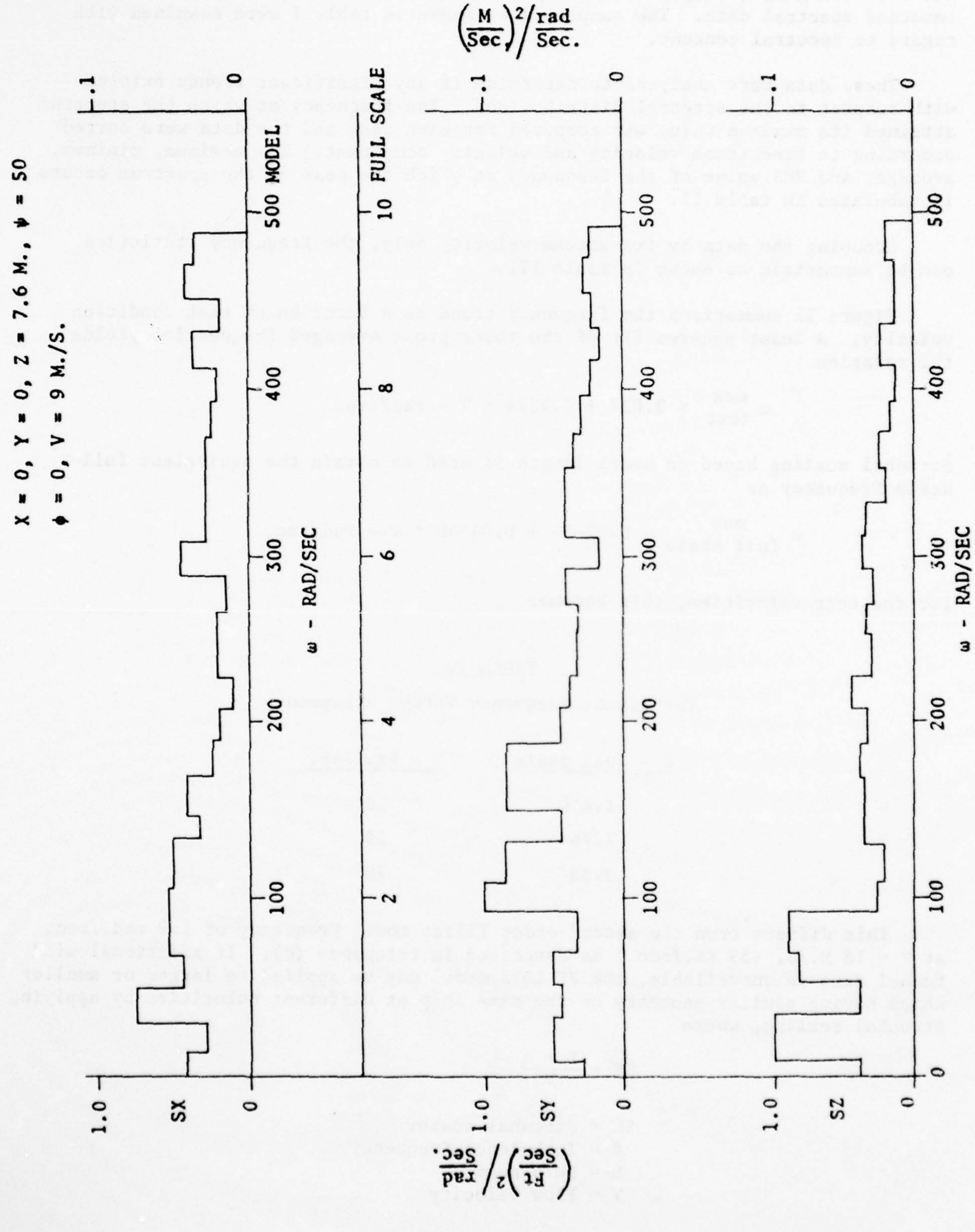


Figure 8 - Measured Gust Spectra, V = 9 M./Sec., X, Y, and Z Components

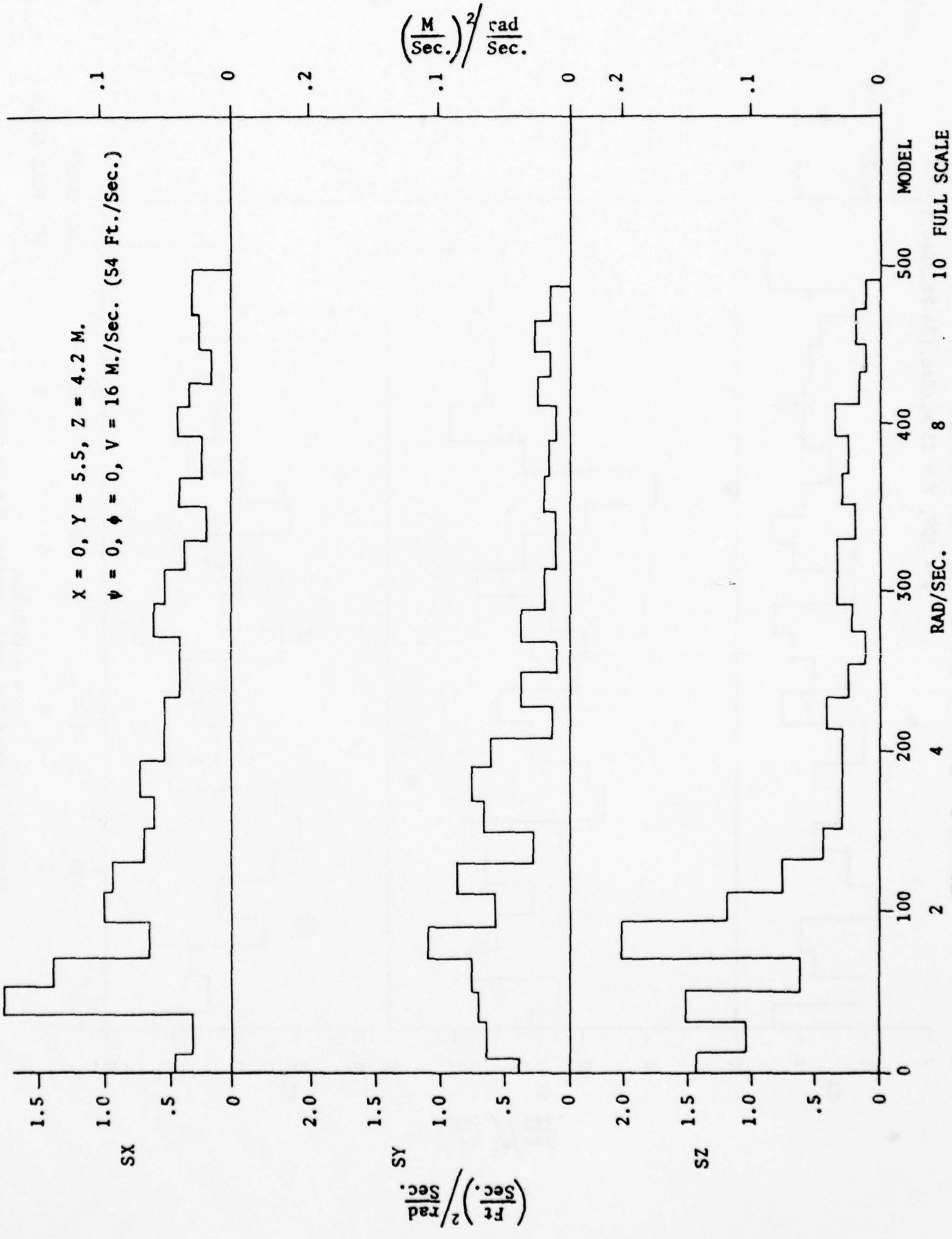


Figure 9 - Measured Gust Spectra, V = 16 M./Sec.,
X, Y, Z Components

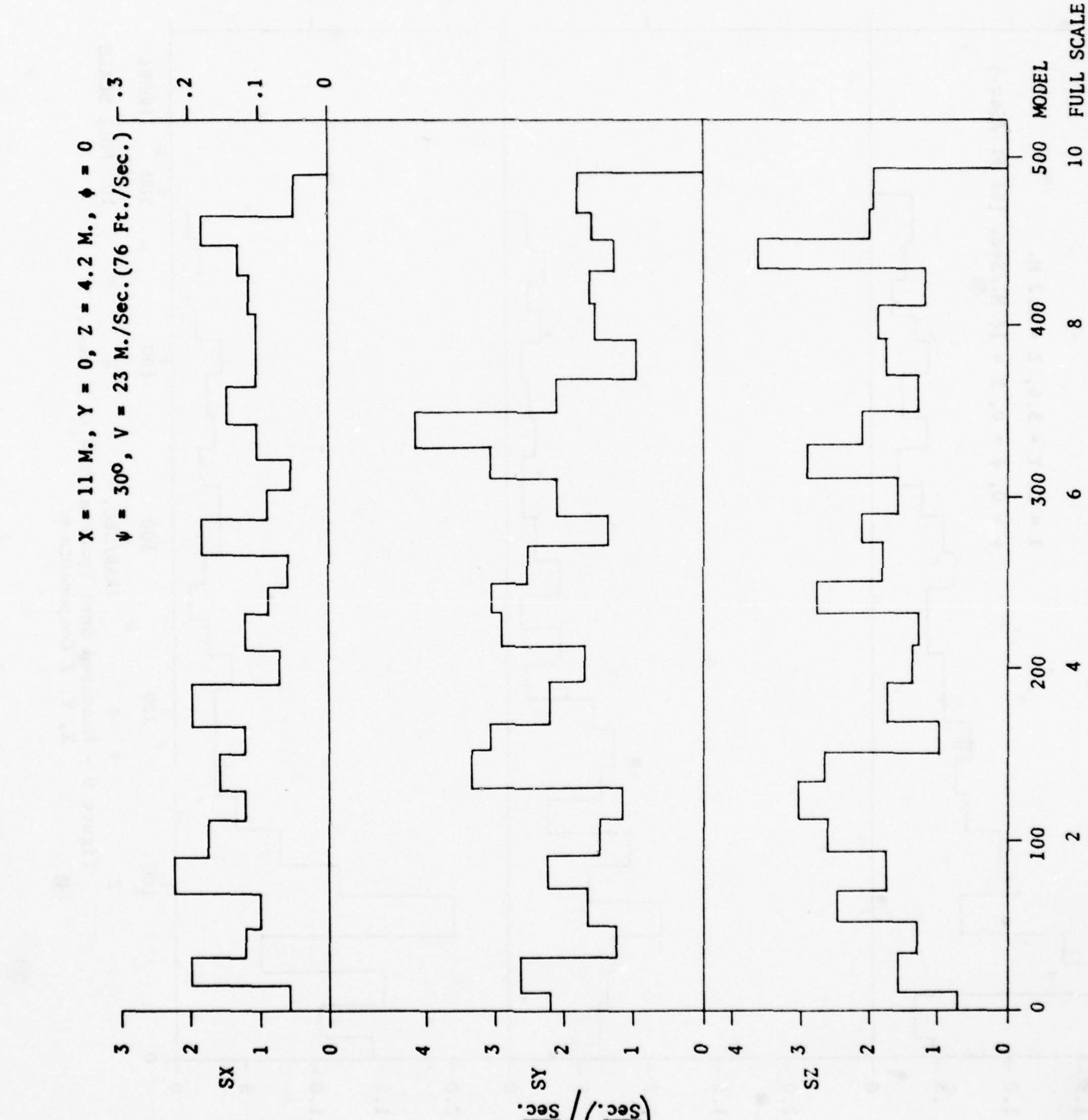


Figure 10 - Measured Gust Spectra, V = 23 M./Sec., X, Y, Z Components

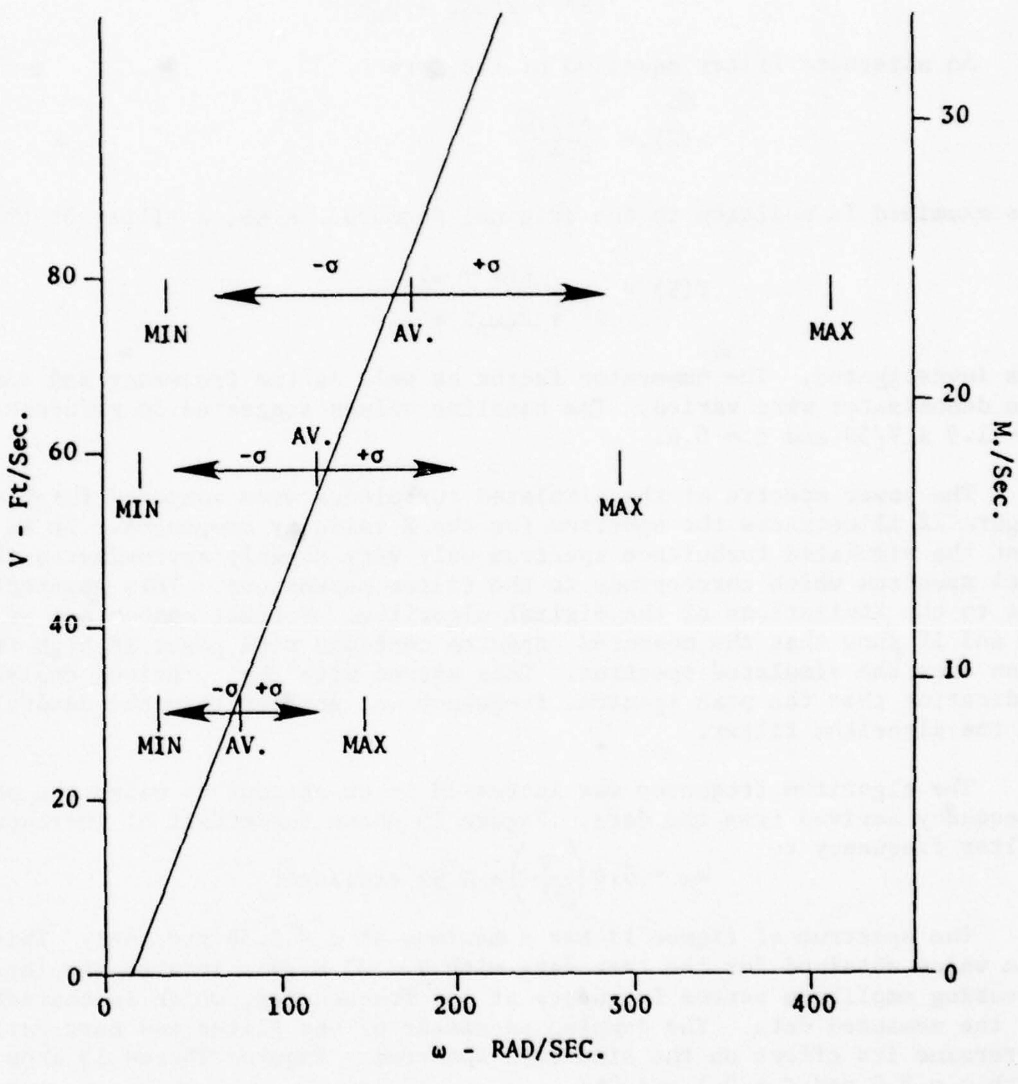


Figure 11 - Peak Spectral Frequency Versus Airspeed

The turbulence model was next examined to see how the properties of the simulated turbulence compared with the measured turbulence. The algorithm filter parameters were varied to determine if an improved match could be obtained between the simulated and test data turbulence. The basic filter equation proposed by reference (d) is

$$F(S) = \frac{\delta(x, y, z) \cdot \sqrt{4\zeta\omega_n{}^3}}{S^2 + 2\zeta\omega_n S + \omega_n{}^2}$$

An alternate filter equation of the form

$$F(S) = \frac{\delta \cdot / \sqrt{\omega}}{S + \omega}$$

was examined in addition to the original formula. Also, a filter of the form

$$F(S) = \frac{K(S + a)}{S^2 + 2\zeta\omega_n S + \omega_n{}^2}$$

was investigated. The numerator factor as well as the frequency and damping of the denominator were varied. The baseline values suggested in reference (d) were $\omega = 1.9 \times V/59$ and $\zeta = 0.4$.

The power spectra of the simulated turbulence were computed for V = 23 M./S. Figure 12 illustrates the spectrum for the X velocity component. It is apparent that the simulated turbulence spectrum only very roughly approximates the theoretical spectrum which corresponds to the filter parameters. This apparently occurs due to the limitations of the digital algorithm. Further comparison of figures 10 and 12 show that the measured spectra contains more power at high frequencies than does the simulated spectrum. This agreed with the previous analysis indicating that the peak spectral frequency was greater than the natural frequency of the algorithm filter.

The algorithm frequency was increased in an attempt to match the peak frequency derived from the data. Figure 13 shows the effect of increasing the filter frequency to

$$\omega_z = 4.6\left(\frac{V}{59}\right) = 5.93 \text{ rad./sec.}$$

The spectrum of figure 13 has a maximum at $\omega = 2.36$ rad./sec. This matches the value obtained for the test data with V = 23 M./S. It also displays an increasing amplitude versus frequency at low frequencies, which is characteristic of the measured data. The damping parameter of the filter was next varied to determine its effect on the simulated spectrum. Figures 14 and 15 show spectra with $\omega = 5.9$ and $\zeta = 0.1$ and 0.7.

Compared to the case with $\zeta = .4$, the configuration with $\zeta = 0.7$ had its peak amplitude at a lower frequency and lower amplitude at high frequencies. The $\zeta = 0.1$ case showed a large peak amplitude near the damped natural frequency and a rapid amplitude roll off at lower and higher frequencies. Thus, neither configuration appears to improve the correspondence with test data over that achieved with the original value of $\zeta = 0.4$.

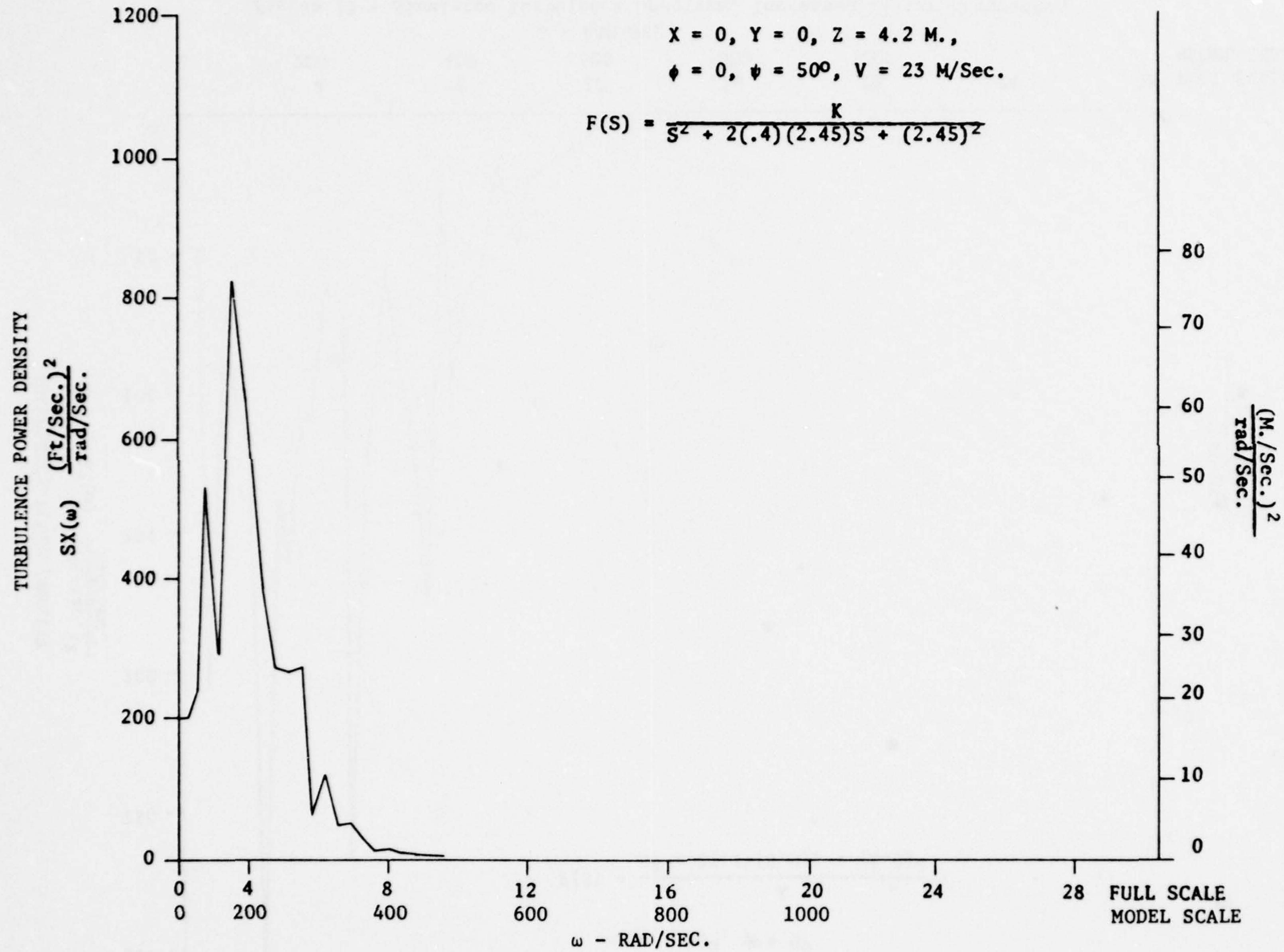


Figure 12 - Simulated Turbulence Spectrum, V = 23 M./Sec. (76 Ft/Sec.), X Velocity Component

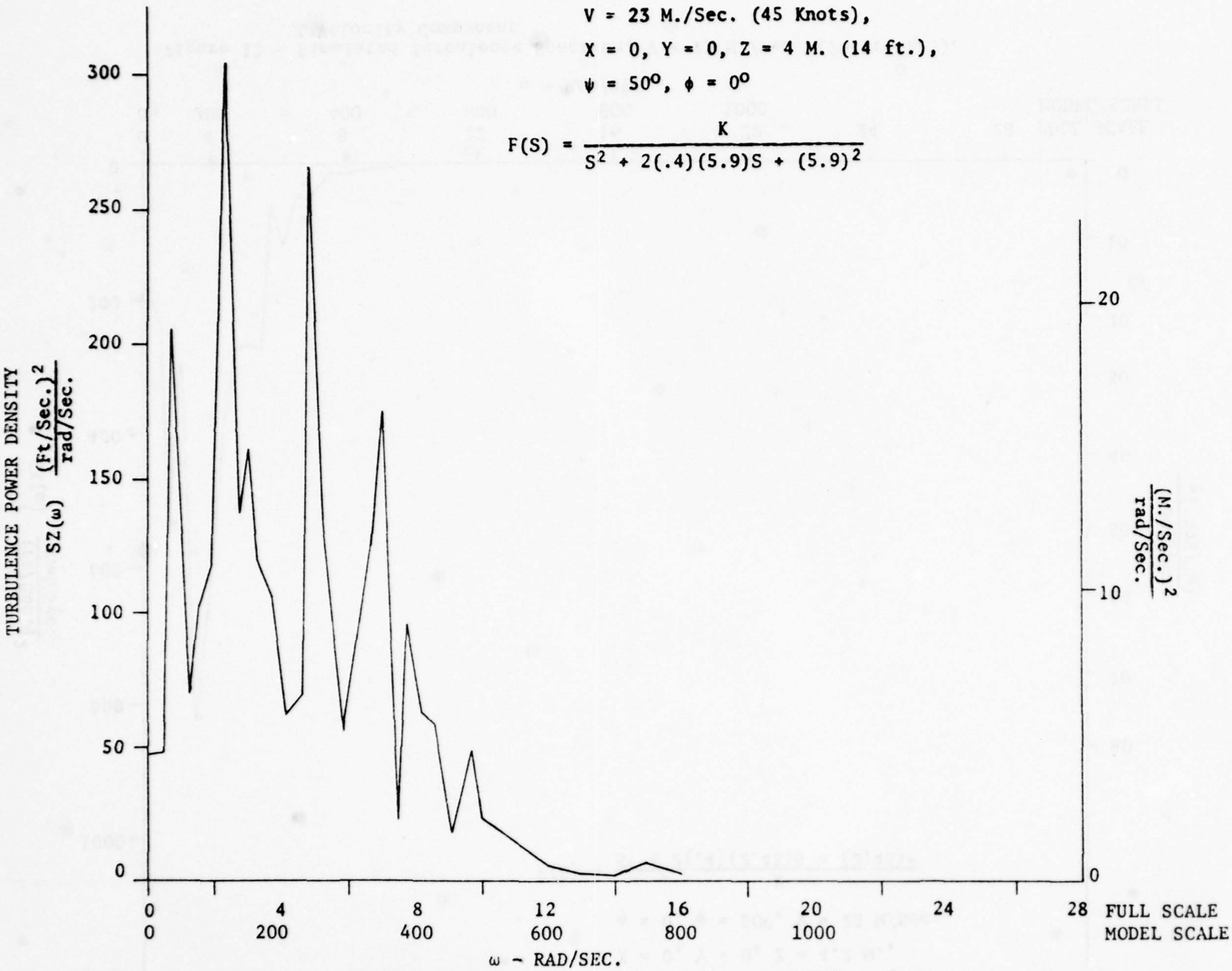


Figure 13 - Simulated Turbulence Spectrum, Increased Filter Frequency, Z Velocity Component

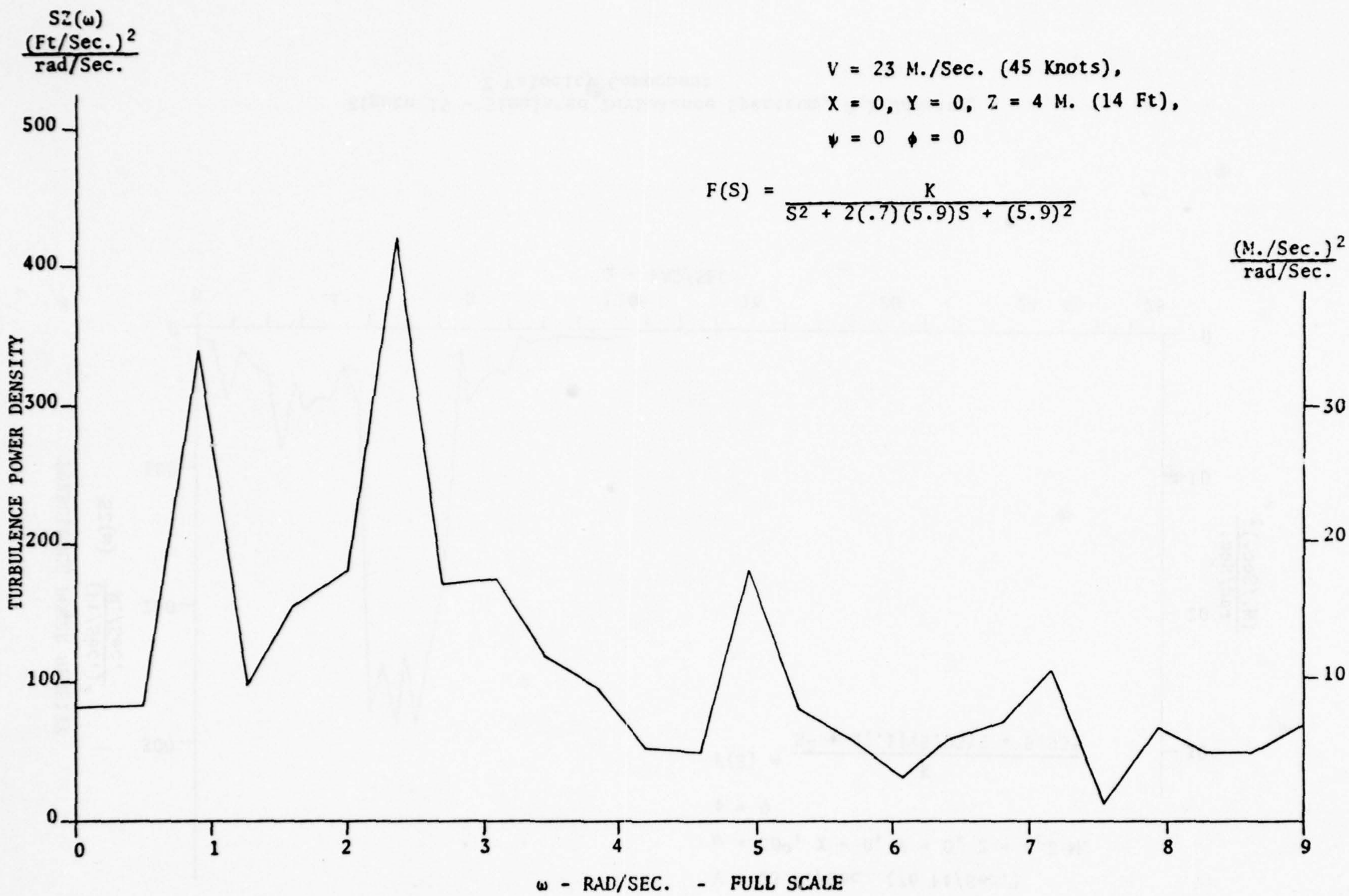


Figure 14 - Simulated Turbulence, 0.7 Damping, Z Velocity Component

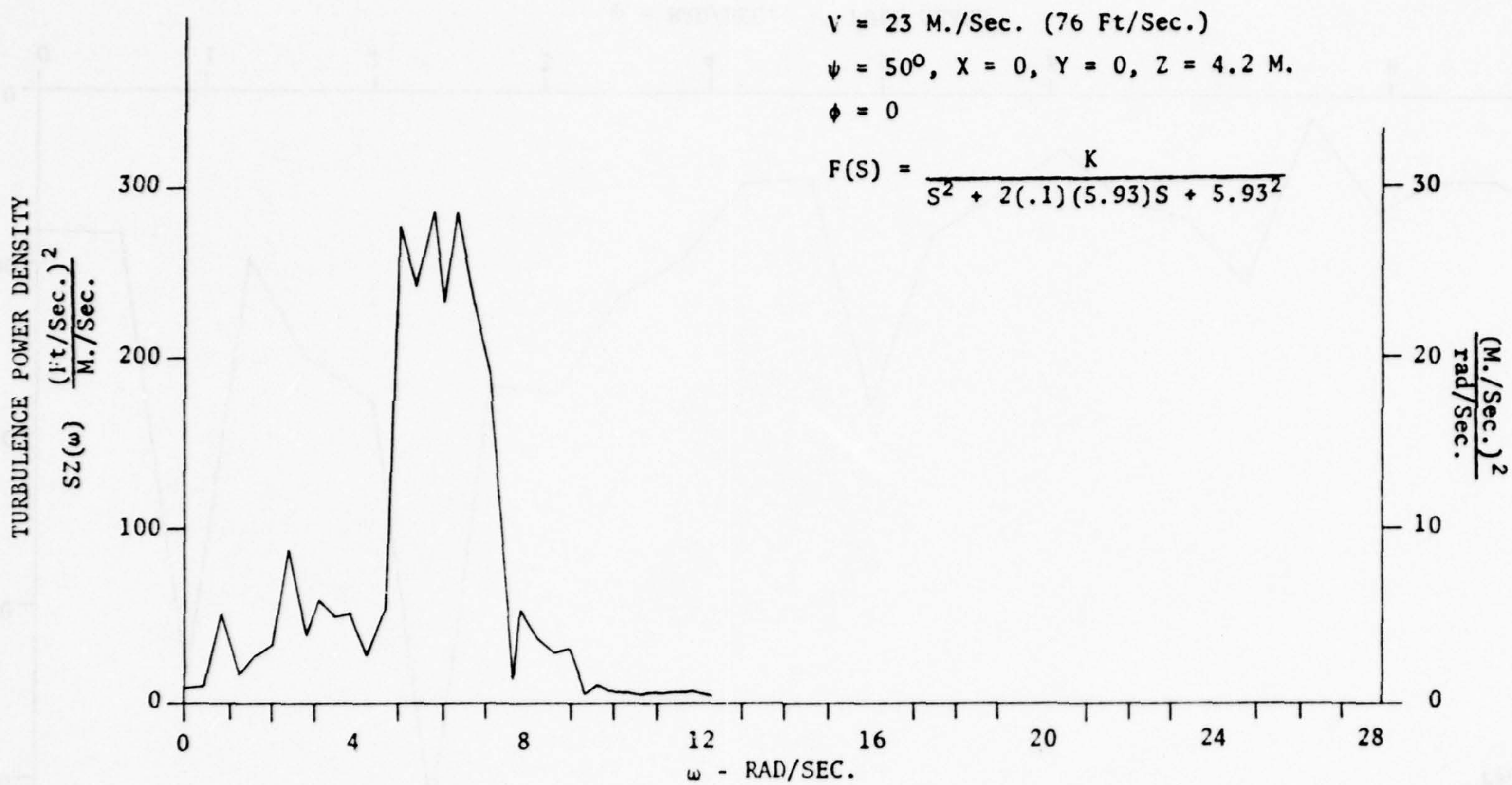


Figure 15 - Simulated Turbulence Spectrum, 0.1 Damping,
Z Velocity Component

One additional filter configuration was examined in which a first-order numerator term was introduced with a break point at the denominator natural frequency. The resultant filter had the form

$$F(S) = \frac{K\ (S + \omega)}{S^2 + 2\ (0.4)\ \omega S + \omega^2}$$

A representative spectrum for this configuration is shown on figure 16. This configuration shows a more pronounced peak and a less rapid dropoff at high frequency than does figure 12. However, it does not appear to match the measured data as well as the configuration shown on figure 13.

Comparison of the various power spectra is found to be a less than conclusive method of establishing the proper form for a turbulence simulation. The measured data was limited to 256 point samples. Because of the extremely random nature of the turbulence, the short data sample appears inadequate to exactly define the power spectra. Even the artificially generated turbulence is found to have rather irregular spectra although the equations used in the algorithm should theoretically produce a smooth spectra. This may be caused by either the finite samples examined or by the approximations of the digital algorithm.

Because of difficulty in defining an exact mathematical relation for the spectra of either the measured turbulence or the simulated turbulence, the modeling effort was limited to matching the mean value, the variance, the frequency at which the power spectra attained its maximum value, and the overall slope of the spectrum above and below the peak frequency. Only the mean and variance can be matched in an exact manner by adjusting the mean functions and the random filter gains. The remaining characteristics must be established on a trial basis.

All of the second-order simulation models showed a more pronounced peak and a more rapid high frequency dropoff than did the test data. As a result, it was concluded that a first-order model might be more appropriate. The principal disadvantage of the first-order filter is that the output velocities tend to be more jerky and less smooth than those produced with a second-order filter. The problem was recognized as being caused by the way in which the random number sequences were generated. When a random number sequence is generated at each aircraft integration interval (typically 0.05 second), the bandwidth of the random noise sequence is high. The magnitude of a purely random sequence is essentially uncorrelated from one point to the next. In fact, turbulent velocity variations occur over finite times, and real measured data shows correlation over a very short time duration.

The apparent solution to this problem was to generate the random number sequence less frequently than the aircraft equations of motion were integrated. By interpolating linearly between succeeding random numbers, a smoothed input was generated which had limited bandwidth. By specifying the ratio of aircraft equation update interval to random number update interval, the power spectral content of the simulated turbulence could be more readily adjusted to match the test data.

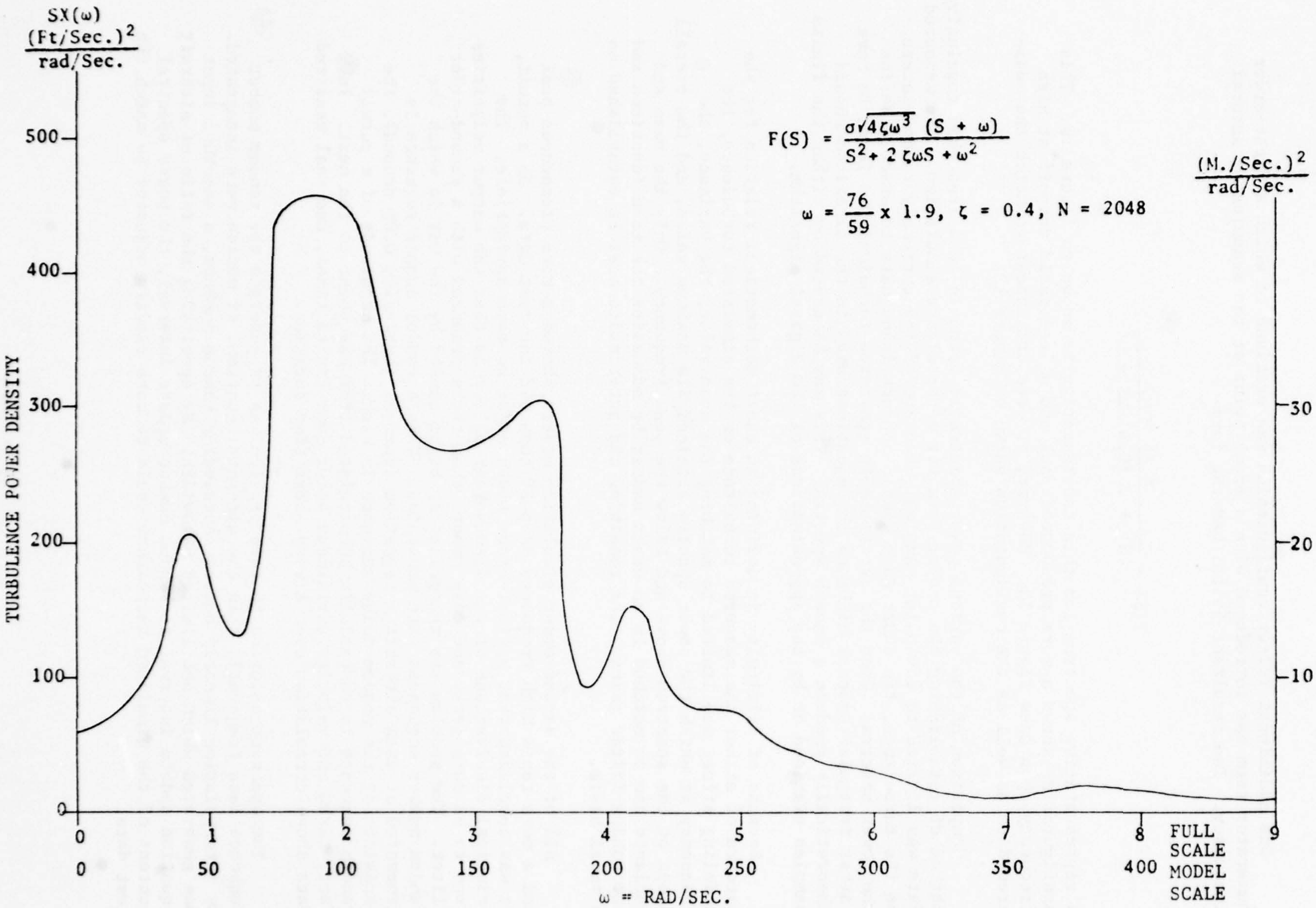


Figure 16 - Simulated Turbulence Spectrum, First Order Numerator

The smoothed random number sequence can be further processed to yield a reasonable simulation of the measured turbulence data by passing the number sequence through a properly designed first-order filter.

Because of the erratic nature of the measured data, it was decided to examine groups of points at various downstream ranges. Individual power spectra were normalized by dividing by their peak amplitudes. Then, these spectra were averaged on a component by component basis. The data selected included all cases for which $\phi = 0$, $\psi = 50$ deg, V = 23 M./Sec. The same process was performed for all data for which $\phi = 0$, $\psi = 50$ deg., and V = 9 M./Sec.

All points at a given downstream range were lumped together regardless of lateral position or height. Figures 17 to 20 show the effects of downstream station and freestream velocity on the character of the normalized spectra for the X, Y, and Z velocity components.

All four figures show a more pronounced dropoff of spectral amplitude with frequency for the X component than for the Y or Z components. Further, figures 17 and 18 show an overall lower frequency break point than do figures 19 and 20. This illustrates the fact that the turbulence frequency decreases as the distance downstream from the ship increases.

A least square straight line curve fit was first applied to the averaged test spectra. Then the break frequency of the first-order filter was assigned a value corresponding to the point at which the straight line reached a value of 0.5 times its value at zero frequency. This was chosen because the magnitude of

$$\left| \frac{1}{\frac{S}{\omega} + 1} \right|^2$$

reaches 0.5 at $S = \omega$. The curve fit analysis was applied to the cases for V = 23 M./Sec. (76 ft/Sec.).

Based on the assumption that Strouhal scaling could be applied, the filter frequency was made proportional to freestream velocity. The selected frequency was ratioed to the value obtained for the V = 23 M./S case by multiplying by V/76. The selected turbulence algorithm was then run repeatedly to obtain a good estimate of the spectral properties of the model. These spectra were averaged component by component and compared with the test spectra.

The filter break frequencies selected for V = 23 M./S., and X = 0 were as follows:

TABLE V

Filter Break Frequencies at X = 0

Component	Break Frequency (rad./sec.)
X	8.17
Y	10.41
Z	10.0

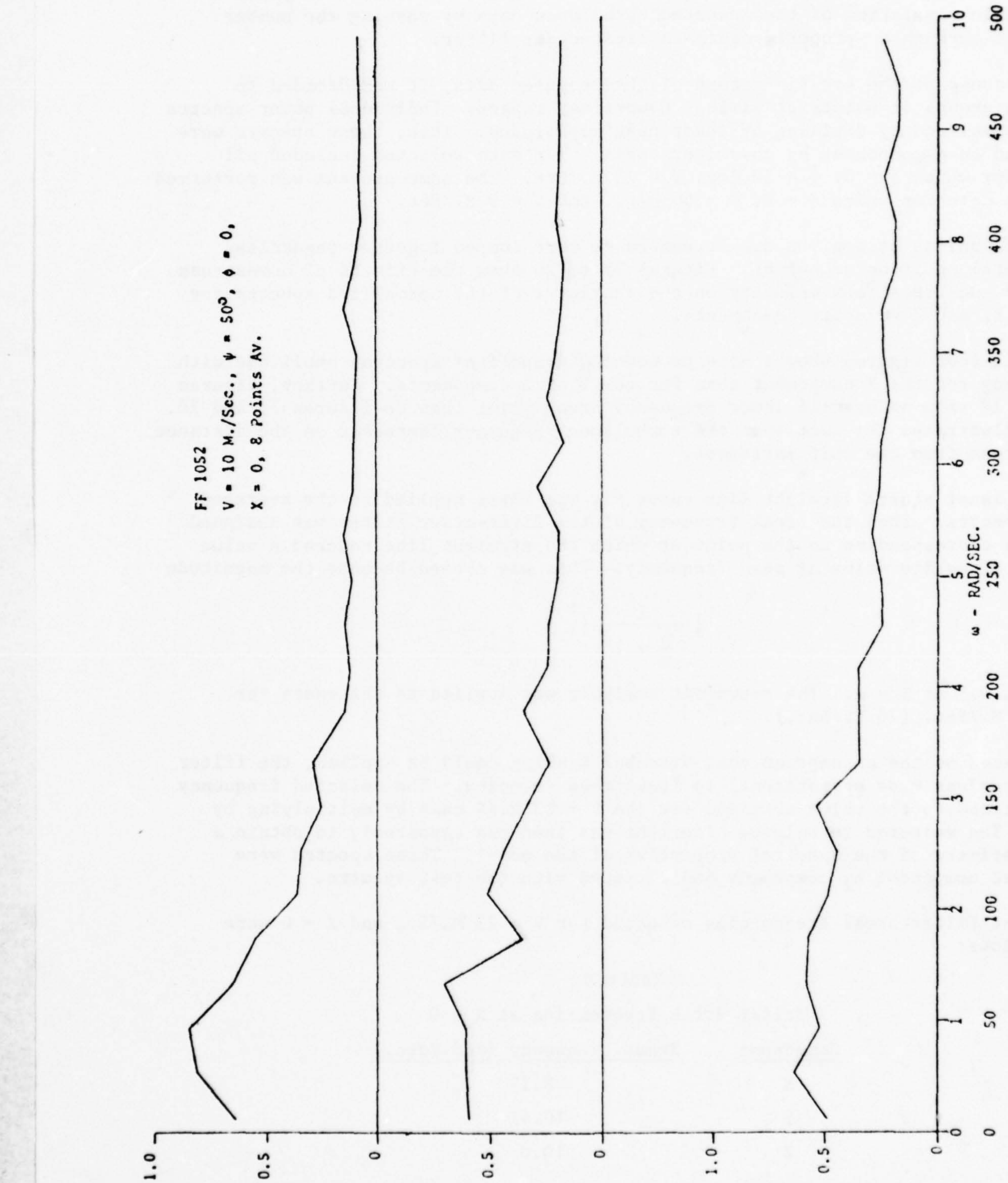


Figure 17 - Normalized Spectra for V = 10 M./Sec., X = 0 (Measured), X, Y, and Z Components

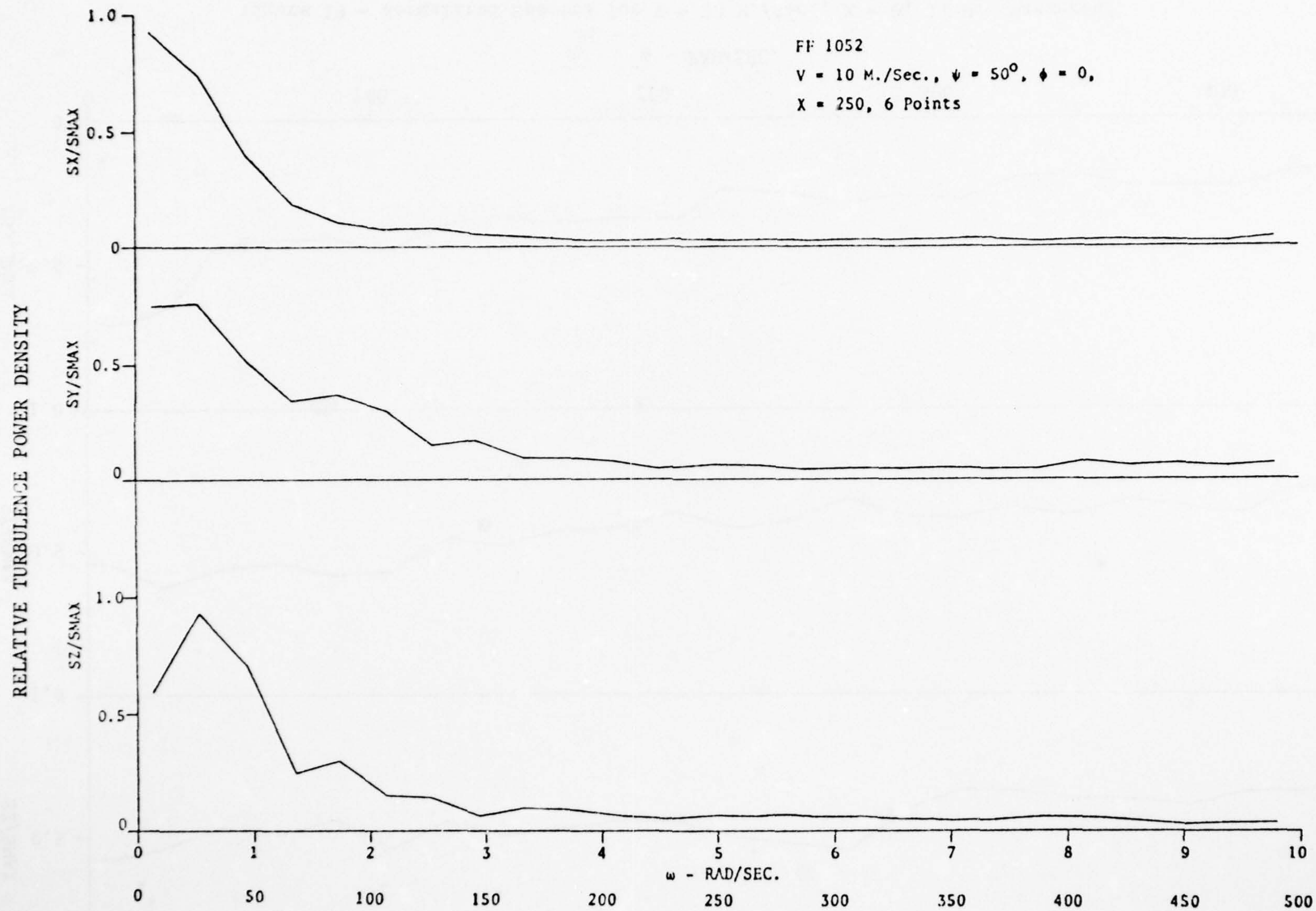


Figure 18 - Normalized Spectra for V = 10 M./Sec., X = 76 M. (Measured), X, Y, and Z Components

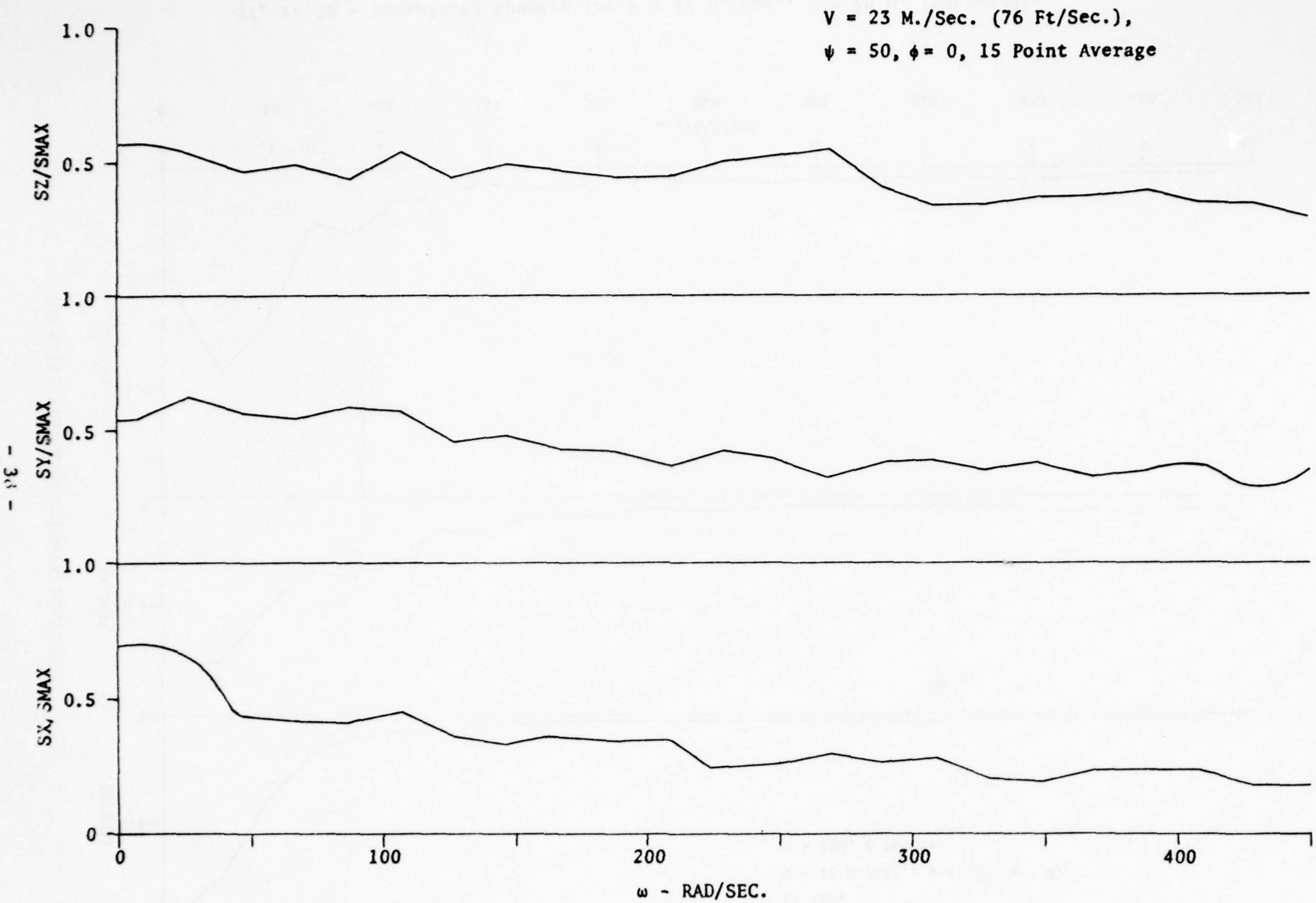


Figure 19 - Normalized Spectra for V = 23 M./Sec., X = 0, 11 M. (Measured), X, Y, and Z Components

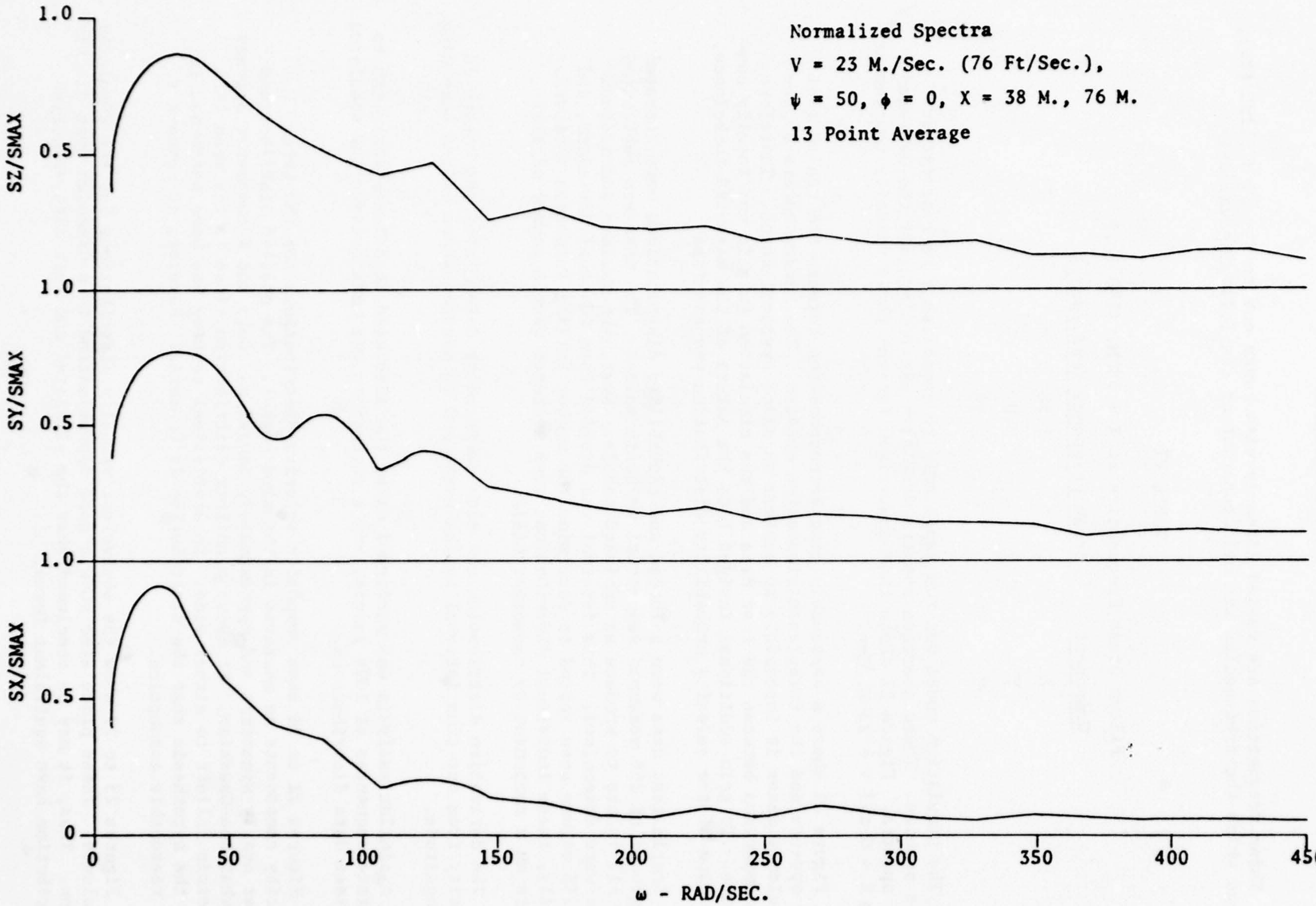


Figure 20 - Normalized Spectra for V = 23 M./Sec., X = 38 M., 76 M. (Measured), X, Y, and Z Components

These frequencies are varied linearly with range out to X = 58 M. (190 ft.), beyond which the frequencies are held constant at the following values:

TABLE VI

Filter Break Frequencies at X = 58 M. (190 ft.)

Component	Break Frequency (rad./sec.)
X	1.58
Y	3.0
Z	2.88

The simulation model was run repeatedly to establish a representative power spectra. These averaged spectra were then plotted against the averaged test spectra. Figure 21 shows this comparison for the three velocity components with X = 0 and V = 23 M./Sec.

Figure 21 shows a reasonably good correspondence between the scaled test data spectra and the turbulence simulation spectra. The random nature of the turbulence makes it impossible to achieve an exact spectral match. Therefore, the comparison between the test data and the simulation data is not totally conclusive. To gain additional insight into the nature of the measured turbulence, the shape of the velocity probability distribution was examined.

Sample test data were selected and probability distributions were computed for groups of 256 measured sequential velocity values. The mean was subtracted from all values to produce an unbiased sample. Next, the maximum and minimum value were determined. This interval was divided into 20 equal divisions, and the 256 values were sorted to determine the number falling into each interval. Finally, these individual distributions were averaged over a number of test points on a component by component basis.

The derivative distribution was also computed by determining the change in velocity from one time interval to the next, and by sorting these values according to magnitude.

A similar analysis was performed using the simulated turbulence algorithm to generate sequences of 1024 points, and a comparison was made between the simulated and test data distributions.

Figures 22 to 24 show composite velocity distributions for the three velocity components as measured in the wind tunnel. The plotted distributions appear nearly symmetric and approximately Gaussian. Only the X component appears somewhat non-Gaussian. It shows a uniform distribution close to the mean with symmetric falloff to either side. No statistical testing has been performed to test the hypothesis that the distribution is Gaussian. However, it appears to be a reasonable assumption.

Figures 25 to 27 show the equivalent velocity distributions for the simulated turbulence. These plots also show a good approximation to a Gaussian type distribution. Thus, it may be concluded that the simulated and test data velocity distribution have equivalent forms.

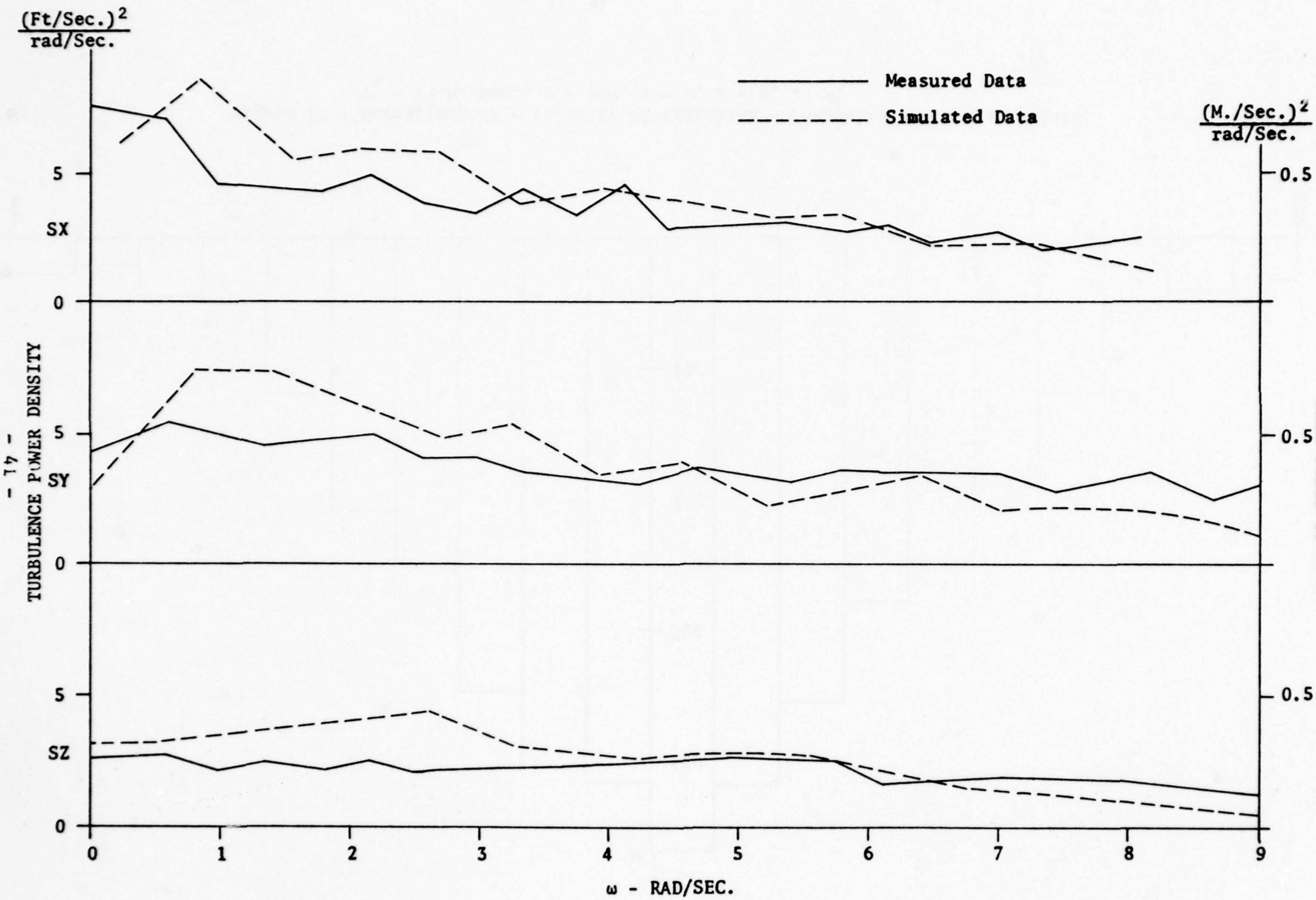


Figure 21 - Comparison of Test and Simulated Turbulence Spectra

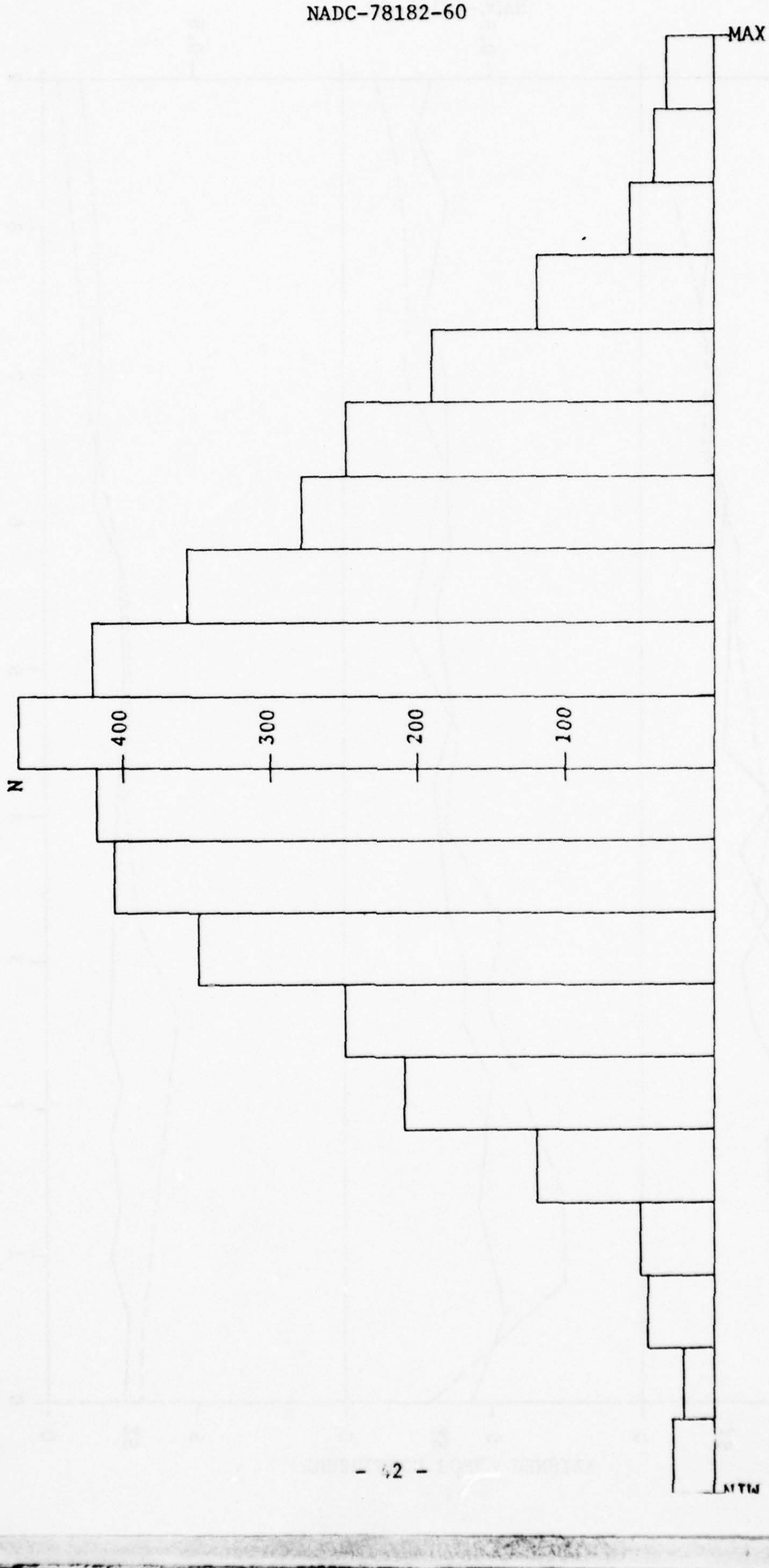


Figure 22 - Normalized VZ - Velocity Distribution - Composite of 16 Test Points, V_∞ = 23 M./Sec., ψ = 50°, ϕ = 0, X = 0, 27 M.

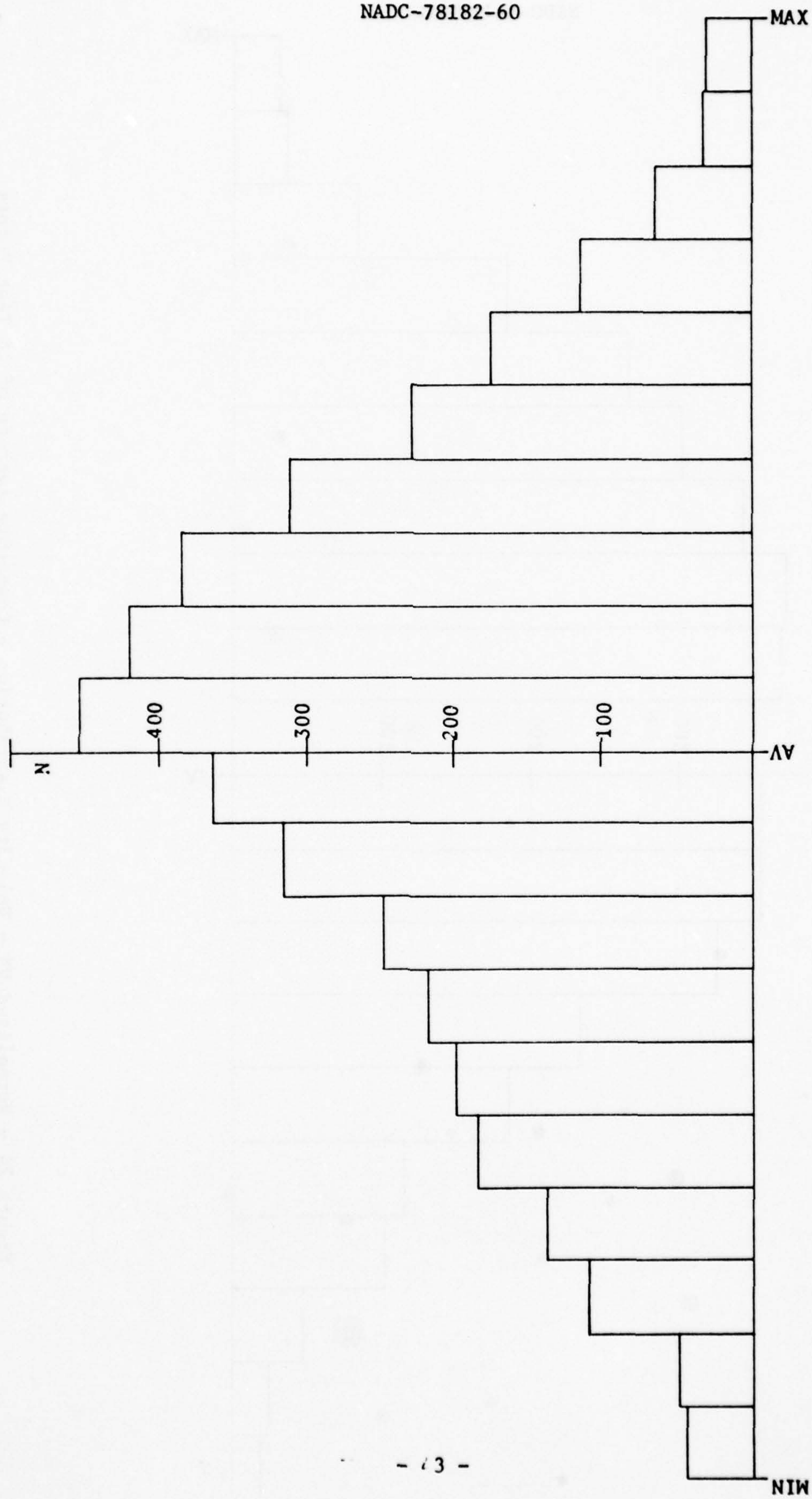


Figure 23 - Normalized VY - Velocity Distribution - Composite of 16 Test Points, $V_\infty = 23$ M./Sec., $\psi = 50^o$, $\phi = 0$, X = 0, 27 M.

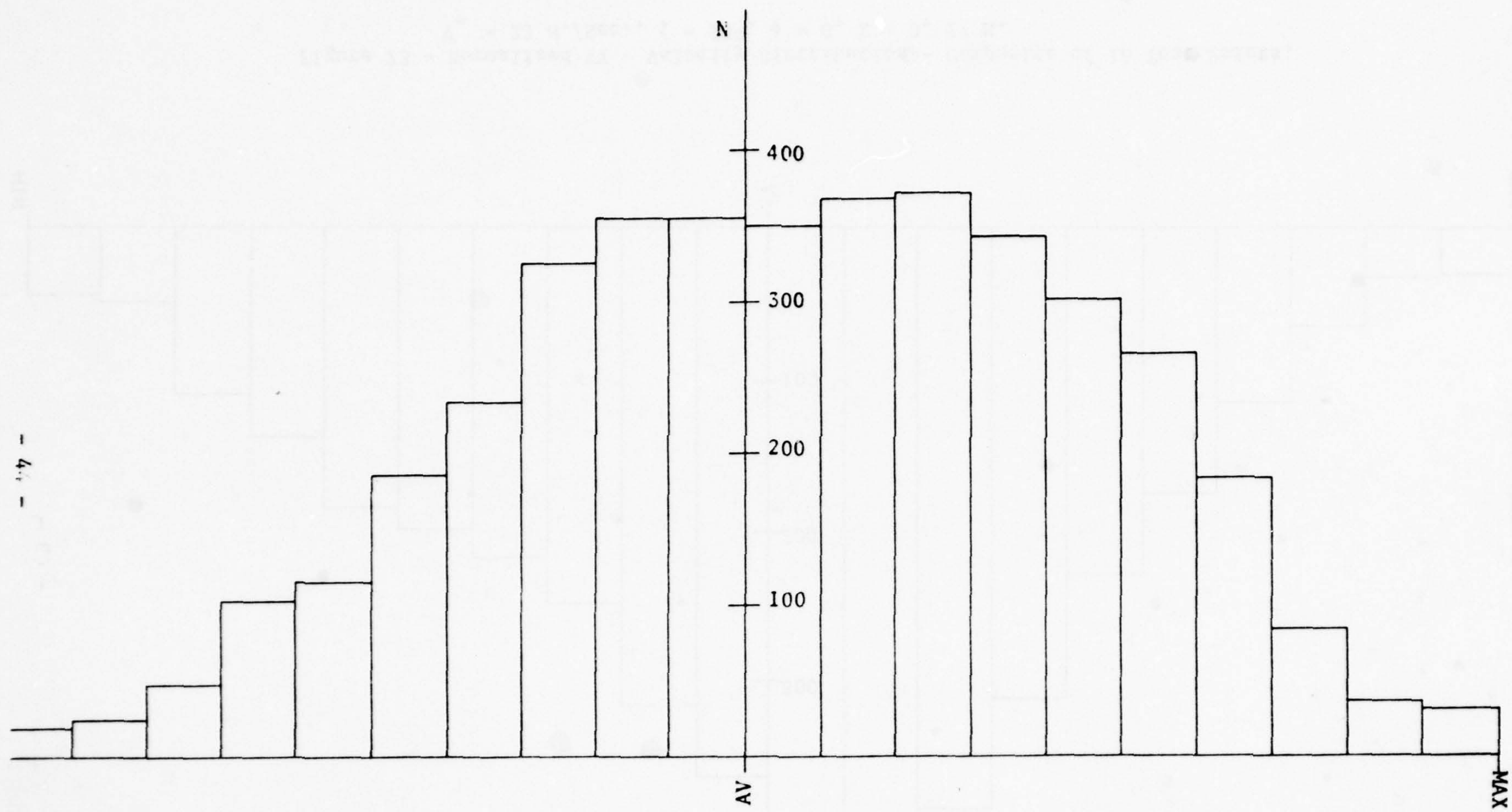


Figure 24 - Normalized VX - Velocity Distribution - Composite Average of 16 Test Points
V_∞ = 23 M./Sec., ψ = 50°, ϕ = 0, X = 0, 27 M.

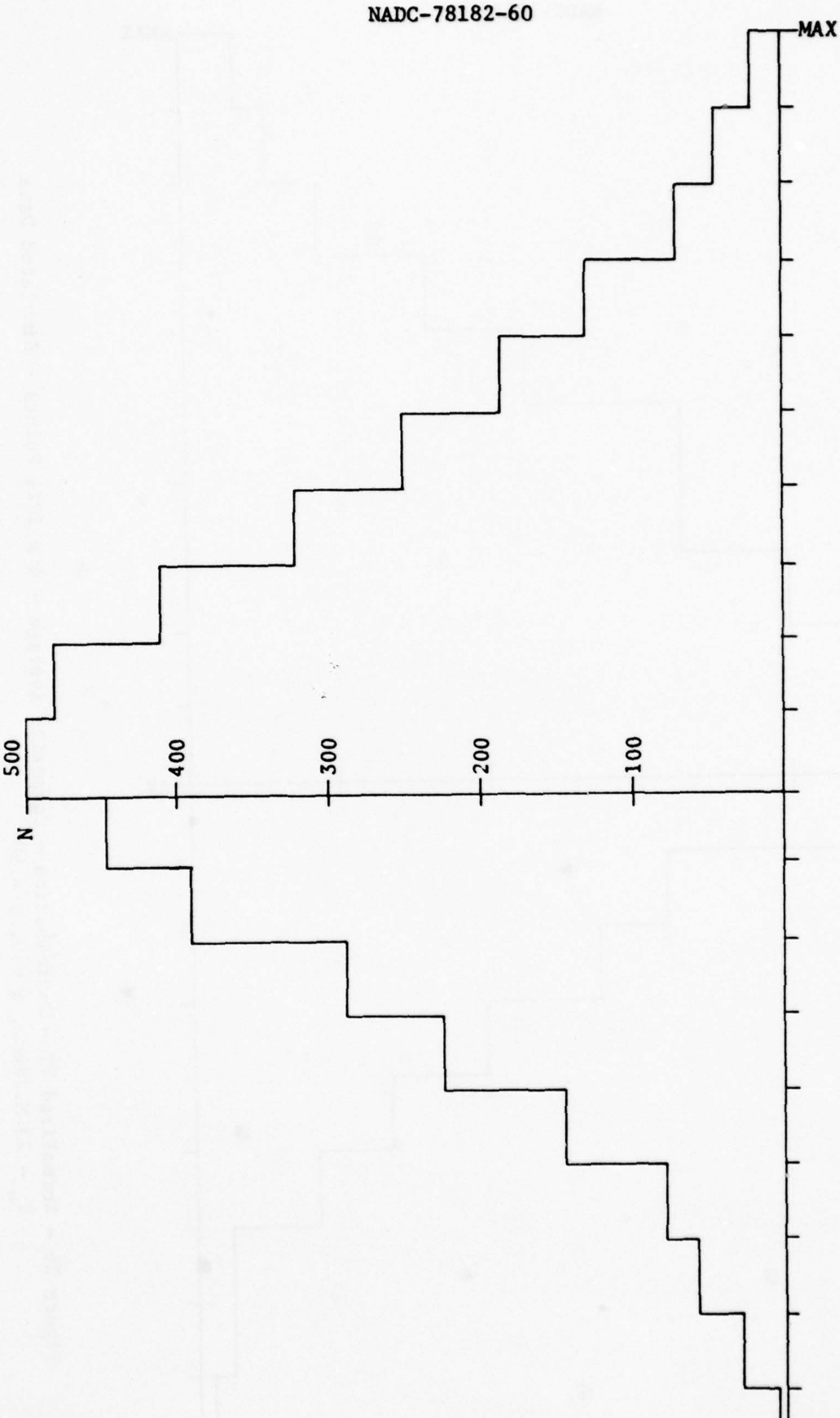


Figure 25 - Normalized VX - Distribution - Composite Average - 4 x 1024 Points - Simulated Data
V_∞ = 23 M./Sec., ϕ = 0, ψ = 50°

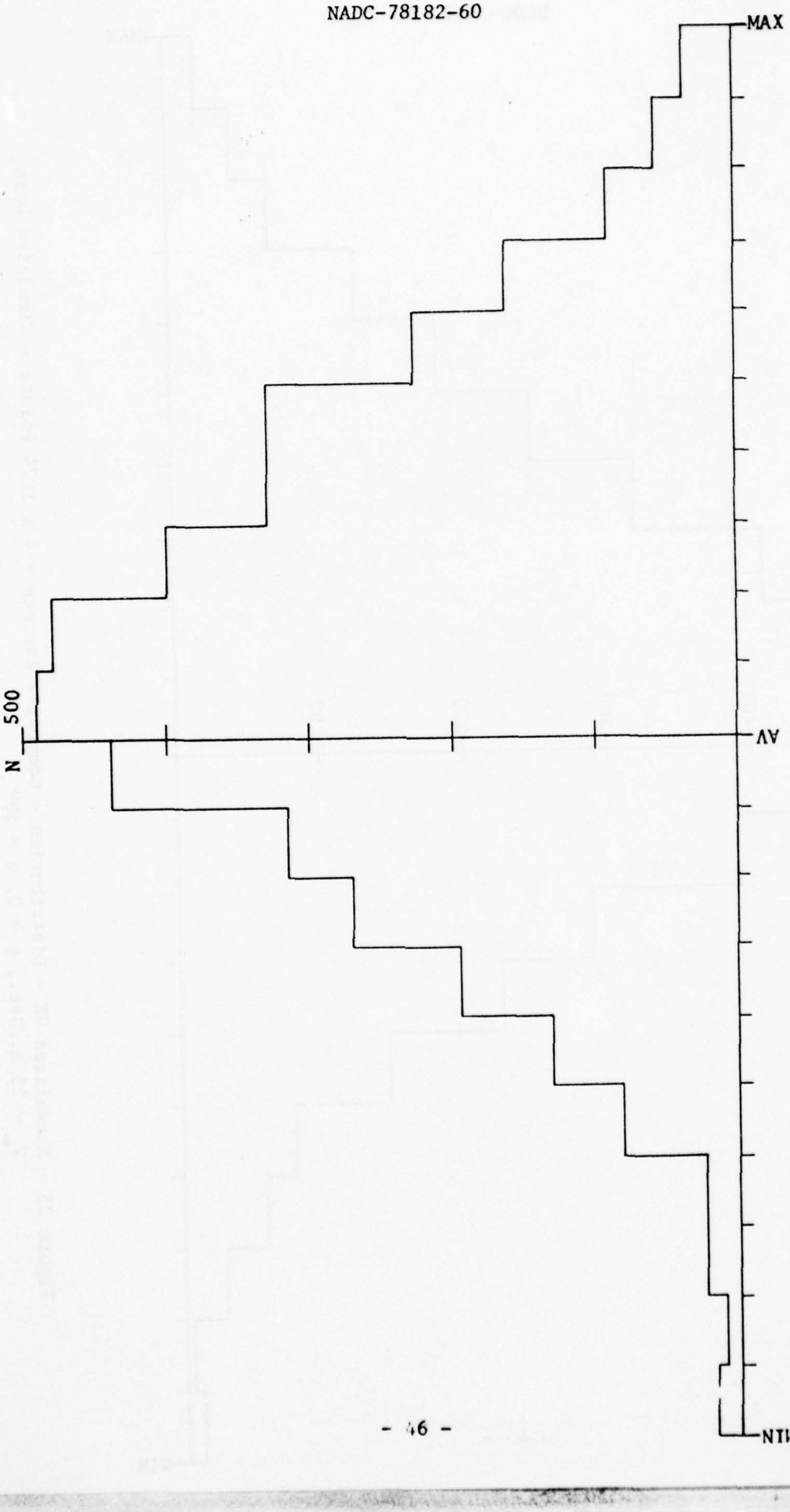


Figure 26 - Normalized VY - Distribution - Composite Average - 4 x 1024 Points - Simulated Data
V_∞ = 23 M./Sec., ϕ = 0, ψ = 50°

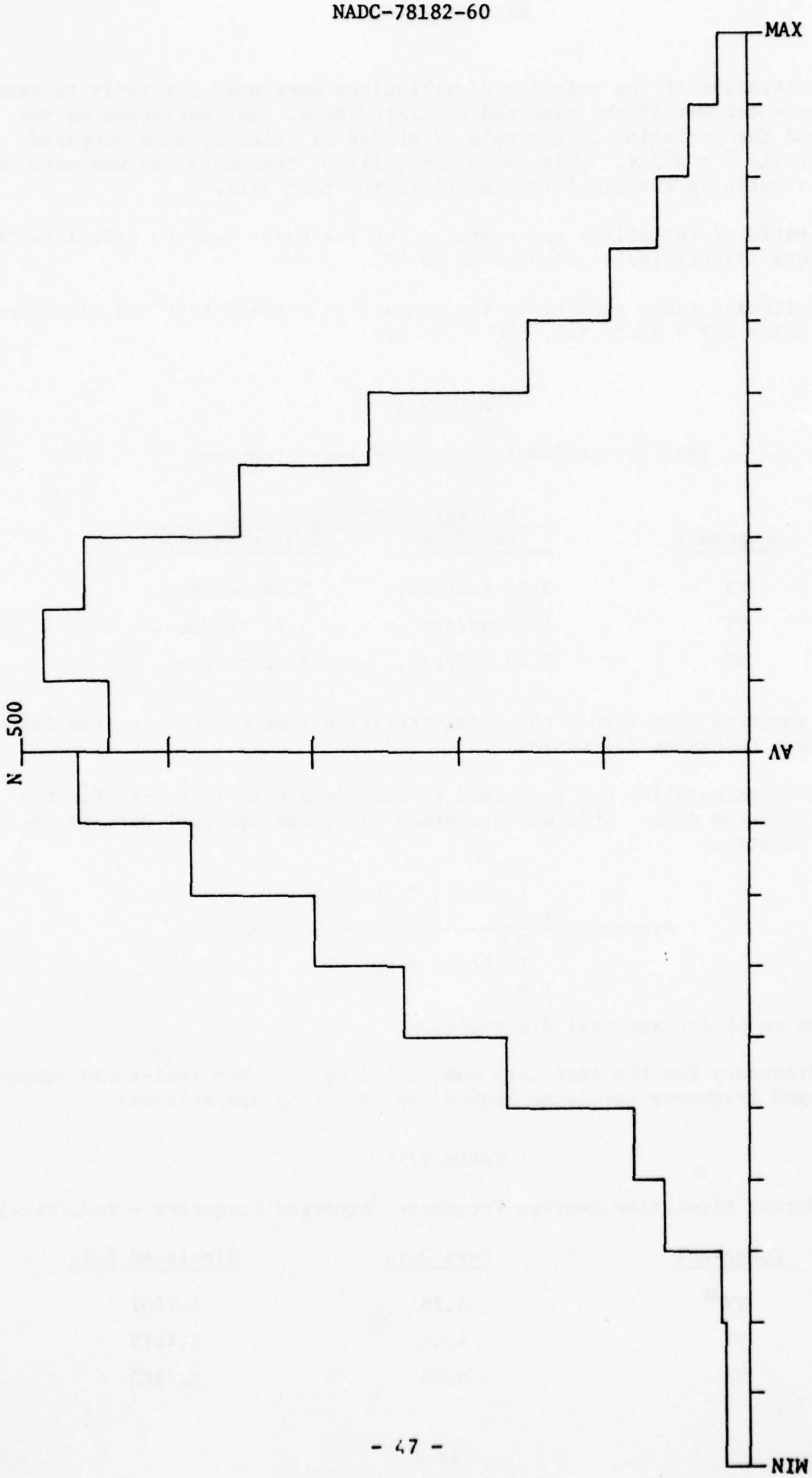


Figure 27 - Normalized VZ - Distribution - Composite Average - 4 x 1024 Points - Simulated Data
$V_\infty = 23$ M./Sec., $\phi = 0$, $\psi = 50^o$

The derivative of the velocity distributions were used primarily to examine the frequency content of the test and simulated data. The variation in the velocity and the variation in the rate of change of velocity were computed. Then, the ratio $\bar{\omega} = \delta\dot{V}/\delta V$. This ratio has units of frequency and was used as a basis for matching the simulation model to the test data.

This ratio of variations was computed for the cases used to calculate the distributions illustrated in figures 22 to 27.

The following table summarizes the comparison between test and simulated data with RNX = RNY = RNZ = 5.0, DTW = .05 sec.

TABLE VII

Test Versus Simulation Equivalent Frequency

Component	Equivalent Frequency - $\bar{\omega}$ Test Data	Simulation Model
VX	3.78 rad/sec.	5.38 rad/sec.
VY	4.2 rad/sec.	5.29 rad/sec.
VZ	4.23 rad/sec.	5.52 rad/sec.

This suggests that either the model iteration time constant or the filter time constant should be increased.

A second calculation was performed to compute a mean frequency for the test and simulated data. This was performed using the spectral data in the following equation:

$$\text{Average} = \frac{\sum_{i=1}^{N} S(\omega)i * \Delta\omega * \omega i}{\sum_{i=1}^{N} S(\omega)i * \Delta\omega} \text{ - rad/sec.}$$

This is the cg of the spectral distribution.

The frequency for the test data was scaled by 1/50 for full-scale comparison. This averaged frequency parameter showed the following comparisons:

TABLE VIII

Test Versus Simulation Average Frequency (Averaged Frequency - rad./sec.)

Component	Test Data	Simulated Data
VX	3.76	4.7707
VY	4.44	4.4115
VZ	4.54	4.7282

The fact that the equivalent frequency of all three components of the simulated turbulence is nearly identical in spite of differences in the filter constants suggests that the random number calling interval dominates the spectral distribution of the simulated turbulence. Therefore, the program scale factors RNX, RNY, and RNZ were adjusted from initial values of 5.0 to RNX = 7.12, RNY = 6.3, and RNZ = 6.52 based on the ratios of the equivalent frequency parameter. For these parameters, the equivalent and average frequencies compare as follows:

TABLE IX

Test Versus Adjusted Simulation Frequency

Component	Test		Simulation	
	ω	ωAv	ω	ωAv
VX	3.78	3.76	4.51	3.64
VY	4.2	4.44	4.63	3.68
VZ	4.23	4.54	4.65	3.79

Given the accuracy of the analysis and the limited sample size examined, this appears to represent a near optimum match. Figure 28 illustrates the resulting spectra for a single simulation run.

CORRELATION ANALYSIS

Certain test data points were selected for correlation analysis. The autocorrelation and cross-correlation functions were computed to determine if the gusts were purely random or if any time or space correlation existed. The equation used was

$$R_{XY}(N) = \frac{\displaystyle\sum_{i=N}^{M} \frac{(VX_i - \overline{VX})\cdot(VY_{i-N} - \overline{VY})}{(M-N)}}{\sqrt{\left(\displaystyle\sum_{i=N}^{M} \frac{(VX - \overline{VX})(VX - \overline{VX})}{M}\right)\cdot\left(\displaystyle\sum_{i=1}^{M} \frac{(VY - \overline{VY})(VY - \overline{VY})}{M}\right)}}$$

As expected, the autocorrelation functions were found to have unit values for zero time shift, but were close to zero for all non-zero time shift values. This means that no significant periodicity exists in the measured data. Most of the crosscorrelation functions were found to be essentially zero for all time shift values. The condition examined was X = 0, Y = 0, $\psi = 50^\circ$, $\phi = 0^\circ$, H = 4.2, 7.6 M. There was no space correlation between velocities at H = 4.2 M. and H = 7.6 M. above deck.

The only significant crosscorrelation uncovered was between the X and Y components at H = 4.2 M. (14 ft.) This can be interpreted as a vorticity in the wind velocity about the Z axis at this point. This corresponds to an aircraft

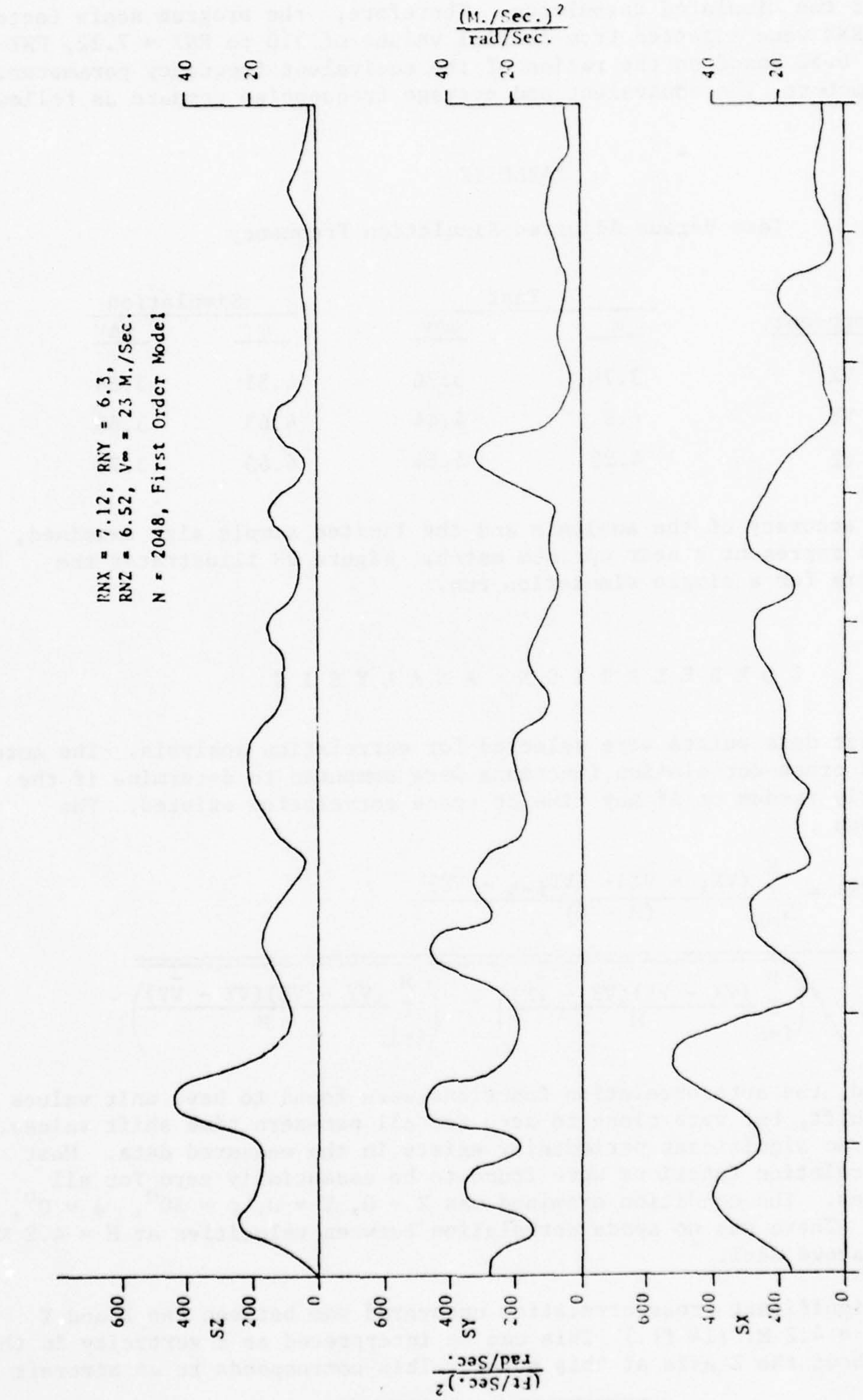


Figure 28 - Simulated Spectra With Adjusted Time Constants, X, Y, Z Components

TABLE X

Correlation Summary of Test Data V_∞ = 23 M./S., ψ = 50°, ϕ = 0

Point 1: X = 0, Y = 0, Z = 4.2 M.

Point 2: X = 0, Y = 0, Z = 7.6 M.

ΔT = 0.0061 second model scale

= 0.31 second full scale

Components		ΔT-Shift 0	1	2
X_1	X_1	1.0	0.288	-0.057
Y_1	Y_1	1.0	-0.08	-0.1
Z_1	Z_1	1.0	0.064	-0.014
X_1	Y_1	-0.544	-0.154	0.094
Y_1	Z_1	-0.05	-0.05	0.08
X_1	Z_1	-0.1	0.04	0.018
X_2	X_2	1.0	0.24	-0.01
Y_2	Y_2	1.0	-0.08	-0.002
Z_2	Z_2	0.998	-0.058	-0.206
X_2	Y_2	-0.303	-0.129	0.0409
Y_2	Z_2	0.0974	-0.081	-0.095
X_1	Z_2	-0.1	-0.001	0.08
X_1	X_2	0.237	0.16	-0.074
Y_1	Y_2	0.284	0.0107	-0.074
Z_1	Z_2	0.143	0.0446	0.0455
X_1	Y_2	-0.15	-0.076	-0.076
Y_1	Z_2	0.075	-0.174	-0.0216
X_1	Z_2	-0.096	0.121	0.171

yaw rate. It is not clear whether this has a significant effect on aircraft motion so that provision for including this effect should be added to the model. The effect does not appear strong enough to justify additional complexity in the model.

SENSITIVITY ANALYSIS OF THE EFFECTS OF THE ASSUMED FORM OF THE TURBULENCE SPECTRUM

Evaluation of the test data and the various model algorithms do not lead to an exact and definite conclusion regarding the values of the model parameters.

A question arises as to whether the exact turbulence spectrum must be duplicated by the model in order to yield a useful analytical tool. In an attempt to answer this question, the closed-loop pitch response to horizontal gusts was computed using the original second-order model format. RMS pitch response was computed for a range of spectral gust frequency model parameters. A closed-loop pitch transfer function was calculated for a representative VSTOL (AV8A) at a 62 M./S. (120 knot) transition condition. The pitch loop was closed with a simple gain pitch SAS and pilot model incorporating pitch attitude and pitch rate feedback through a delay.

The closed-loop pitch to horizontal gust transfer function was calculated and the RMS gust response was then determined using the equation:

$$\delta\theta^2 = \frac{1}{2\pi}\int_{-\infty}^{\infty} \left| \frac{N^{\theta}_{ug}}{D'} \right|^2 \Phi_{ugust}(jw) \cdot dw$$

where $\frac{N_{ug}}{D'}$ is the closed-loop transfer function

and Φ_{ugust} is the gust power spectrum.

The gust power spectrum is developed by squaring the magnitude of the gust transfer function as follows

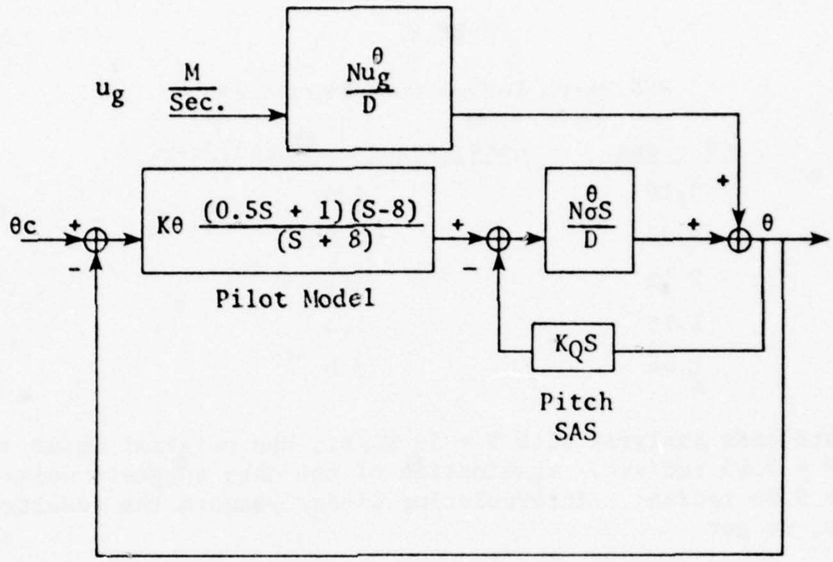
$$\frac{\text{Gust Velocity}}{\text{Random Input}}(S) = \frac{\delta \cdot 2 \cdot \sqrt{\zeta\omega^3}}{S^2 + 2\zeta\omega + \omega^2}$$

$$\Phi_{gust}(S) = \frac{\delta^2\ 4\ \zeta\omega^3}{(S^2 + 2\zeta\omega S + \omega^2)(S^2 - 2\zeta\omega S + \omega^2)}$$

The system block diagram is illustrated by figure 29.

The closed-loop gust transfer function then becomes

$$\frac{\theta}{ug}(S) = \frac{(3.28)(S + 8)(-0.002832S^2 + 0.0005604S + 0.0003527)}{(S^5 + 7.046S^4 + 17.9199S^3 + 27.827S^2 + 16.692S + 2.8202)}$$



$$N_{\sigma S}^{\theta} = -8.057\ S^2 - 5.218\ S - .823 \text{ Rad./rad.}$$

$$D = S^4 + 0.7382\ S^3 - 0.9896\ S^2 - 0.2859\ S + 0.006864$$

$$N_{u_g}^{\theta} = 3.28 \times \left(-0.002832\ S^2 + 0.0005604\ S + 0.0003527\right) \frac{\text{Rad}}{\text{M./Sec.}}$$

$$K\theta = 0.42 \text{ rad/rad.}$$

$$K_Q = -0.49 \text{ rad/rad/sec.}$$

Figure 29 - Closed-Loop Gust Response Transfer Function

RMS gust responses were calculated for the following parameters

σ_{ug} = 7.1 M./S. (23.3 ft/sec.), ζ = 0.4, ω = 1.4, 2, 3, 5, and 7 rad/sec.

The results follow:

TABLE XI

RMS Pitch Versus Gust Frequency

$\sigma\theta$ - deg.	Gust Frequency - rad./sec.
3.16	1.4
2.95	2.0
2.43	3.0
1.76	5.0
1.44	7.0

For the data case analyzed with V = 23 M./S., the original model uses $\omega_x = 1.9 \times V/59 = 2.45$ rad/sec. Examination of the data suggests using $\omega_x = 3 \times V/18 = 3.86$ rad/sec. Interpolating linearly among the results from the sample case, we get

$\sigma\theta$ - deg.	ω - rad./sec.
2.72	2.45
2.14	3.86

This corresponds to a 21-percent difference in sigma values for a 64-percent variation in frequency.

Thus, the frequency of the gust model does significantly affect the aircraft response for constant RMS gusts. However, a gust model which predicts gust response to within 10 percent would probably be a satisfactory tool. Thus, the assumed filter algorithm is not extremely critical. The sensitivity shown by the sample indicate that it would be sufficient to define the frequency parameter to within 25 percent of its true value. In contrast, the aircraft response varies directly with RMS gust amplitude. Thus, it is most important to accurately match the gust RMS amplitude.

TIME HISTORY COMPARISON

One final comparison of the simulated and measured turbulence was made by plotting the velocity time histories of the three velocity components. The case selected was

X = 0	V_∞ = 23 M./S.
Y = 0	$\psi = 50^o$
Z = 4.2 M.	$\phi = 0$

The experimental data was recorded at a time interval of 0.0061 second. This value was scaled up by a factor of 50 to yield a plot scale interval of 0.31 second. Simulated data points were calculated at a 0.05-second time interval. Because of the measurement interval, the bandwidth of the experimental data was limited to 10.13 rad./sec. Thus, higher frequency oscillations might have been present, but they could not be detected.

The simulated and test velocity sequences were compared on the basis of maximum, minimum, mean, and variance values as well as a qualitative comparison of the shapes of the plotted sequences. Figures 30 to 32 illustrate the relationships for the three velocity components. The mean and variance values compare well for all three components. The maximum and minimum values seem consistent in all cases with the magnitudes of the mean and variances.

A qualitative comparison of the number of local maxima and minima in a 10-second period show that the frequency content of the simulated and measured velocities compare satisfactorily.

RESULTS AND CONCLUSIONS

The CVA turbulence model contained herein remains basically unchanged from the version described in reference (c) as a result of analysis performed for this study. It is suitable for simulation of aft approaches and forward takeoffs of conventional and VSTOL aircraft.

The FF 1052 turbulence model is designed to permit VSTOL takeoff and landings from any angle. Wind conditions are currently limited to relative wind angles of 0, 30, and 50 degrees at total velocities of 10, 18, and 23 M./S. (20, 35, and 45 knots).

After considerable iteration, the FF1052 turbulence model structure was fixed with these features:

1. Exponential and linear extrapolation of tabulated mean and variance velocity values beyond the region of measured data.

2. First-order exponential filtering of random number inputs using inverse time constants that decrease linearly with range downstream.

3. The random number subroutine used to generate the three gust velocities are called less frequently than the basic simulation loop time, and the resultant random number sequences are linearly interpolated.

4. The random number update interval is selected to match test data spectral distributions.

5. The filter time constants vary inversely with freestream steady velocity.

6. The frequency content of the three velocity components display different characteristics with the horizontal component having a lower frequency spectrum than the Y and Z components.

	Simulation	Test Sample
$\overline{V}$	40.7	39.3 Ft/Sec.
σ	24.3	23.3 Ft/Sec.
VMAX	92.6	93.9 Ft/Sec.
VMIN	-30.4	-22.4 Ft/Sec.

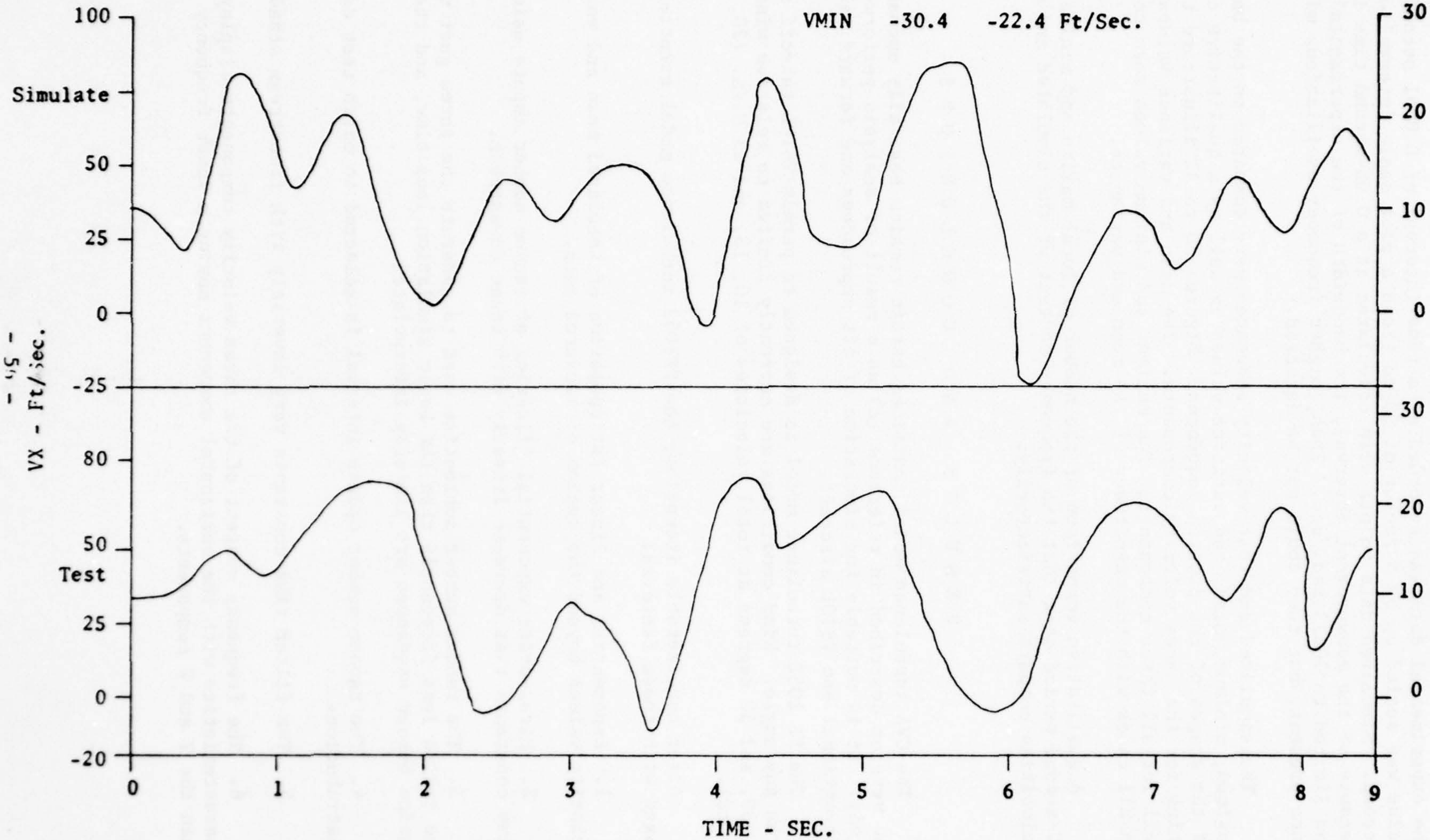


Figure 30 - X - Component Simulated and Measured Turbulence

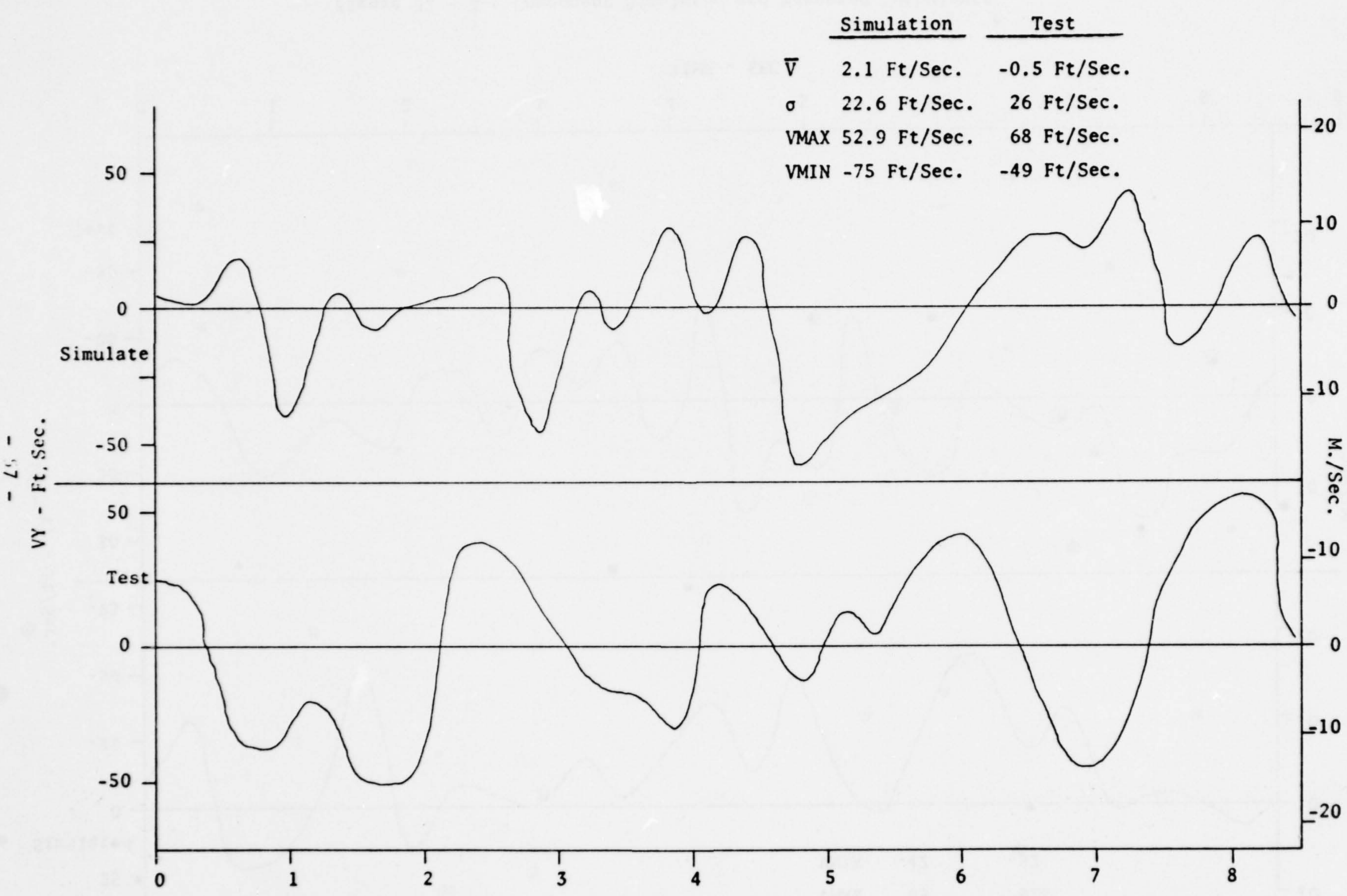


Figure 31 - Y - Component Simulated and Measured Turbulence

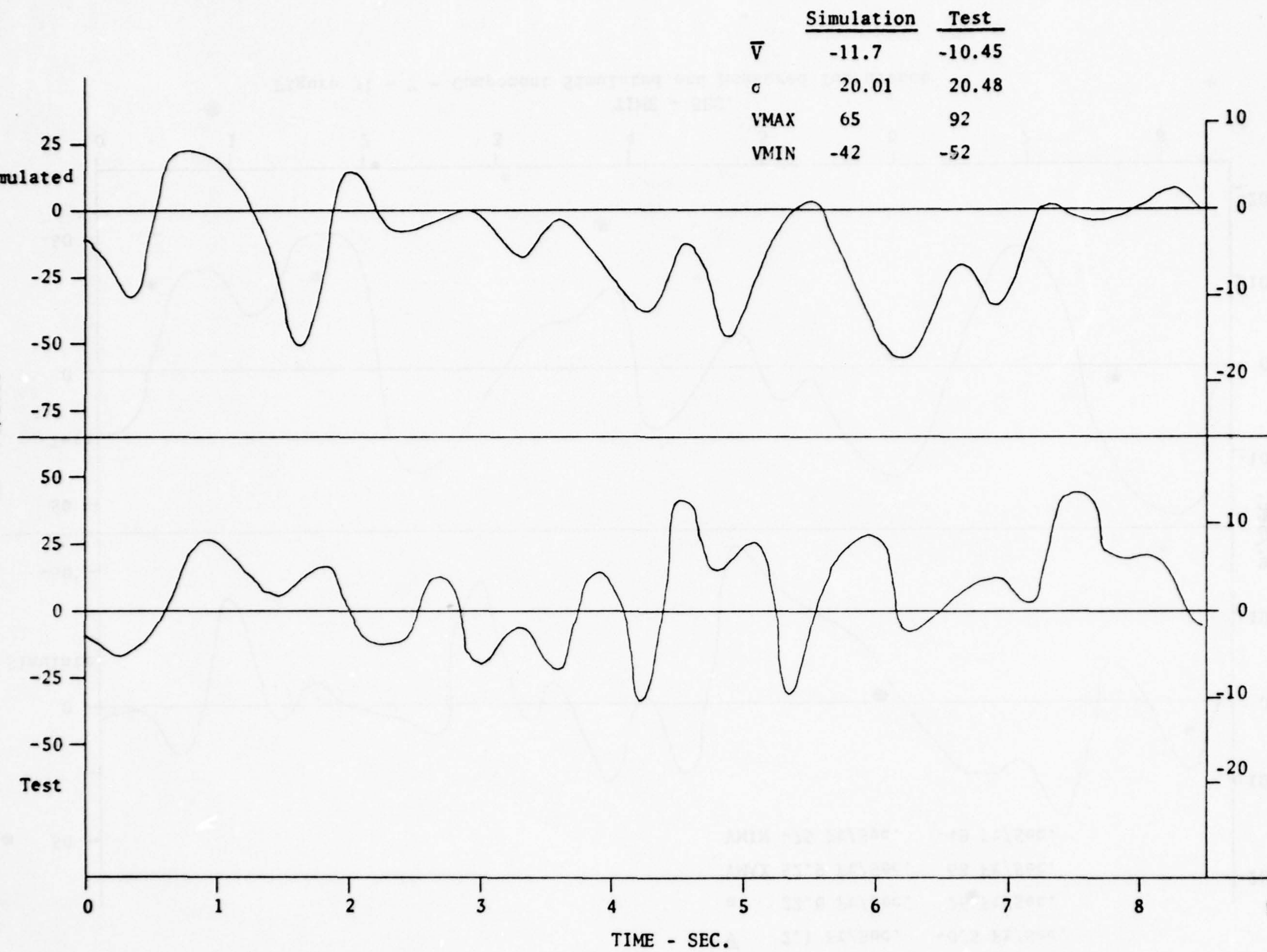


Figure 32 - Z - Component Simulated and Measured Turbulence

7. Although some cross-correlation between velocity components was observed in the measured data, it does not appear significant enough to include in the simulation model.

8. For 45-knot wind and the aircraft located over the deck, the filter frequency parameters were selected with the following values:

Component	Frequency - rad./sec.
X	8.17
Y	10.41
Z	10.00

9. These frequencies decrease linearly to X = 58 M. (190 ft.) where the filter frequencies become

Component	Frequency - rad./sec.
X	1.58
Y	3.0
Z	2.88

10. The test simulation was set up to update wind velocity intervals at 0.05 second intervals. The random number sequences were updated at the following multiple interval size:

Component	Update Interval - Sec.
X	0.05 x 7.12 = 0.356
Y	0.05 x 6.3 = 0.315
Z	0.05 x 6.52 = 0.326

11. Examination of the experimental data shows that the turbulence velocities reasonably approximated a Gaussian distribution. However, the distributions show some flattening and less peaking around the mean than do ideal theoretical distributions.

12. Analysis indicates that it is more important to exactly match the mean and variance of the turbulence velocities than to exactly match the spectral shape.

RECOMMENDATIONS

Because of differences in digital computers and particularly in random number generator subroutines, prospective users of these computer subroutines should follow the following precautions:

1. Run the model repeatedly for at least 100 seconds of simulation time at a fixed location in space.

2. Compare the mean and variance of the simulated data with that of the input tables corresponding to the selected point.

3. Compute the Fourier transform of the simulated turbulence and compare these with the spectral plots contained in this report.

4. Adjust the filter gains, time constants, and number update ratios RNX, RNY, RNZ if necessary.

5. The FF 1052 model should be tested on a moving base piloted simulation to get pilot confirmation of its validity.

LIST OF SYMBOLS

CVA	Attack Aircraft Carrier
PSIS	Ship Heading - Rad.
PSIREL	Wind Over Deck Relative Angle - Rad.
Rxy	Cross Correlation Function
S	Laplace Operator - 1/Sec.
Sx, y, z	Power Spectral Density
STO	Short Take Off
u	Longitudinal Wind Velocity - M./Sec.
ug	Longitudinal Gust Velocity - M./Sec.
V	Lateral Wind Velocity - M./Sec.
VG	Lateral Gust Velocity - M./Sec.
ν_o	Trim Aircraft Velocity - M./Sec.
VEWBIC	East Component of Natural Wind - M./Sec.
VNWBIC	North Component of Natural Wind - M./Sec.
VW	Total Wind Over Deck - M./Sec.
VS	Ship Speed - M./Sec.
VX	X Component of Wind Velocity - M./Sec.
VY	Y Component of Wind Velocity - M./Sec.
VZ	Z Component of Wind Velocity - M./Sec.
V_∞	Free Stream Wind Velocity - M./Sec.
W	Lateral Wind Velocity - M./Sec.
X	Aircraft Position Aft of Ship - M.
Y	Aircraft Position Left or Right of Ship Centerline - M.
Z	Aircraft Altitude Above Touchdown Point - M.
α	Aircraft Angle of Attack - Deg.
$\frac{\Delta u}{VS}$	Normalized Horizontal Velocity Increment
$\frac{\Delta w}{VS}$	Normalized Down Wash Velocity Increment
θ	Aircraft Pitch Attitude - Deg.
σ	Root - Mean Squared Value
τ	Gust Time Constant - Sec.
ϕ	Ship Roll Angle - Deg.

$\phi_{\frac{\Delta u}{Vo}}$ Horizontal Gust Power Spectrum - $(ft/sec.)^2/(rad/sec.)$

$\phi_{\frac{\Delta v}{Vo}}$ Lateral Gust Power Spectrum - $(ft/sec.)^2/(rad/sec.)$

$\phi_{\frac{\Delta w}{Vo}}$ Vertical Gust Power Spectrum - $(ft/sec.)^2/(rad/sec.)$

ψ Ship Heading Angle - Deg.

REFERENCES

a. A Computerized VSTOL/Small Platform Landing Dynamics Investigation Model, Ronald L. Nave, Report No. NADC-77024-30, Naval Air Development Center, Sept 1977.

b. Analysis and Comparison of Carrier Air Wakes, David H. Weir, Report No. TR-NO. 158-1, Systems Technology Inc., April 1966.

c. A Simulator Comparison of an Integrated, Direct-Lift-Control Automatic Carrier Landing System With a Conventional Carrier Landing System, Robert L. Fortenbaugh, Report No. NADC-72210 - VT, Naval Air Development Center, 3 April 1973.

d. Investigation to Study the Aerodynamic Ship Wake Turbulence Generated by a FF 1052 Frigate, Theodore S. Garnett, Jr., Contract No. N00019-75-C-0493 Boeing Vertol Company, December 1976.

e. A Math Model for the Air Wake of a DE-1052 Class Ship, R. L. Fortenbaugh, Report No. 2-53300/7R-3397, Vought Corporation, 13 May 1977.

f. MIL-F-8785 (ASG), Military Specification, Flying Qualities of Piloted Airplanes.

g. Introduction to the Statistical Dynamics of Automatic Control Systems, V. V. Solodovnikov, Dover Publishing.

h. MIL SPEC AR-40A, Automatic Carrier Landing System Airborne Subsystem, General Requirements for.

i. A Wind Tunnel Air Wake Survey of a 1/144 Scale Model Aircraft Carrier With Deck and Island Modifications, Martin L. Cook, Report No. 1805, Naval Ship Research and Development Center, March 1967.

A P P E N D I X A

Listing of CVA Turbulence Model

```
CWINDC
      SUBROUTINE WINDC
      COMMON/XFLOAT/A(500)/IFIXED/IA(200)
       COMMON/CHF/B(200)/ICBF/IB(50)
       COMMON/GAIN1/GA(100)
      EQUIVALENCE(T11,A(16)),(T21,A(17)),(T31,A(18))
     1  ,(T12,A(19)),(T22,A(20)),(T32,A(21))
     2  ,  (T13,A(22)),(T23,A(23)),(T33,A(24))
      EQUIVALENCE(VNTURB,A(419)),(VETURB,A(420)),(VDTURB,A(421))
      EQUIVALENCE   (A(61),UTURB)
      EQUIVALENCE(A(62),VTURB)
      EQUIVALENCE(A(63),WTURB)
      EQUIVALENCE(A(70),VRW)
      EQUIVALENCE(A(168),DT)
      EQUIVALENCE(A(238),VEQIC)
       EQUIVALENCE(XCG,A(174)),(YCG,A(175)),(STHETR,A(114)),(CTHETR,
     1  A(115))
       EQUIVALENCE(ALT,A(83))
      EQUIVALENCE(A(303),TIME)
      EQUIVALENCE(IA(1),IMODE)
       EQUIVALENCE(IONCE,IB(16))
       EQUIVALENCE(VS,B(30))
       EQUIVALENCE(PHIP,B(112))
       EQUIVALENCE(OMEGP,B(111))
       EQUIVALENCE(UGST,B(153)),(VGST,B(154)),(WGST,B(155))
       EQUIVALENCE(XFRZ,B(156)),(SWBSW,B(157)),(SUBSW,B(158))
       EQUIVALENCE(IB(18),IPITCH)
       EQUIVALENCE(PITCHM,B(110))
       EQUIVALENCE(NCHK,IB(22))
      EQUIVALENCE(B(95),X2S),(B(94),X1S)
       EQUIVALENCE(ILBURB,IB(25))
       EQUIVALENCE(IBFRZ,IB(24)),(IWIND,IB(20)),(ILTURB,IB(21))
       EQUIVALENCE(GA(30),GR(1))
      EQUIVALENCE(HIS,B(100))
      EQUIVALENCE(IDISCT,IA(50))
      EQUIVALENCE(FRTN,B(194)),(FRTE,B(195)),(FRTD,B(196)),(VMN,B(197))
      EQUIVALENCE(VME,B(198)),(VMD,B(199)),(TDTURB,B(200))
      DIMENSION RD(7),GR(7)
       DIMENSION RDY(7),RDYI(7),IRDST(7),IRDSI(7,10)
       DIMENSION RDX(7)
       DATA SWBSW/1./,SUBSW/1./
      DATA TIM3/0./
       DATA(GR(I),I=1,7)/6.,6.,125.,125.,25.,3.,3./
      DATA RUA/.1/
      DATA PI/3.141592/
      DATA FC/5./
       DATA (IRDST(I),  I=1,7)/1,3,5,7,9,11,13/
      DATA IUBT/0/,IVBT/0/,IWBT/0/
       DATA ZR1/.001/,ZR2/1.5/,YR1/.001/,YR2/1.5/
       DATA XFRZ/1500./
       DATA((IRDSI(I,J),I=1,7),J=1,10)/1,3,5,7,9,11,13,13,1,3,5,7,9,11,
     1  11,13,1,3,5,7,9,9,11,13,1,3,5,7,7,9,11,13,1,3,   5,5,7,9,11,
     1  13,1,3,3,  5,7,9,11,13,1,15,17,19,21,23,25,27,27,15,17,19,21,
     3  23,25,25,27,15,17,19,21,23/
      IF(IDISCT)7,7,30
```

```
      7 IF(IMODE)2,3,4
      2 CONTINUE
         URIS=0.
        WRIS=0.
        WRISS=0.
        URISS=0.
        PITCHM1=PITCHM/57.3
         DT2=DT
        VO=VEOIC*1.689
         IF(VO.LT.60)VO=60.
        RK10=SQRT(3.14159*5900.)*.003
         RK11=SQRT(5900.*3.14159)*3.*VO/400000.
        S110=-VO/1000.
        S210=-3.*VO/400.
        Z01=EXP(S110*DT)
        Z02=EXP(S210*DT)
        Z11=-1./(S110-S210)*RK10*(1.-Z01)
        Z12=1./(S110-S210)*RK10*(1.-Z02)
        Z13=-1./(S210-S110)*RK11*(1.-Z01)/S110
        Z14=1./(S210-S110)*RK11*(1.-Z02)/S210
        Z0111  =EXP(-VO/100.*DT2)
         Z1111=SQRT(71.63*3.14159)/100.*(1.-Z0111)
        Z0112=EXP(-VO/100.*DT2)
        Z1112=SQRT(200.*3.14159)/100.*(1.-Z0112)
          IX=2**24-3
        DO 10 I=1,7
        RDX(I)=0.
        RDYI(I)=0.
         IF(IONCE.GT.0)   IRDST(I)=IRDSI(I,IONCE)
  00010 CONTINUE
        RN1=.044*SQRT(PI)
        WC=2.*FC*PI
        IF(VEOIC.NE.VEOICP)   IZX=1
        VEOICP=VEOIC
      3 CONTINUE
        WRSS=0.
        URSS=0.
         UR2S=0.
         RDSP=0.
         RD4=0.
         RD3=0.
         UG=0.
         WG=0.
        WR2S=0.
        UR2SS=0.
         YRSA=0.
         ZRSA=0.
         UGSA=0.
         WGSA=0.
         WGSA=0.
         UR2TA=0.
         WR2TA=0.
        WR2SS=0.
        UGS=0.
         VG1=0.
```

```
            VG2=0.
            VG3=0.
             VG4=0.
            VGS=0.
            WGS=0.
            UGSS=0.
            VGSS=0.
            WGSS=0.
            ZRS=0.
            YRS=0.
            ZRSS=0.
            YRSS=0.
            FACY=EXP(-ABS(YCG)/100.)
            ALT1=HIS+50.-XCG*.1
            FACZ=1.
            IF(ALT.GT.ALT1) FACZ=EXP((ALT1-ALT)/50.)
            FACW=FACY*FACZ
            XD=XCG
            UTURB=-VS*SUBSW*FACW*TAB1(XD,0.,0.,68,1)
            WTURB=-VS*SWBSW*FACW*TAB1(XD,0.,0.,69,1)
            VTURB=0.
            TIM3=0.
            ZR=0.
            YR=0.
            RETURN
     4      CONTINUE
            IF(IWIND.EQ.0)RETURN
             IF(NCHK.GT.0) RETURN
            FACY=EXP(-ABS(YCG)/100.)
            ALT1=HIS+50.-XCG*.1
             FACZ=1.
            IF(ALT.GT.ALT1) FACZ=EXP((ALT1-ALT)/50.)
             FACW=FACY*FACZ
            XD=XCG
             IF(IHFRZ.EQ.1) XD=-XFRZ
             UBSS1=-VS*TAB1(XD,0.,0.,68,1)
             UBSS=UBSS1*SUBSW*FACW
             IF(ILAURB)21,21,20
 00021      WBSS1=-VS*TAB1(XD,0.,0.,69,1)
            WBSS=WBSS1*SWBSW*FACW
            GO TO 22
 00020      WBSS1=-VS*TAB1(XD,0.,0.,70,1)
             WBSS=WBSS1*SWBSW*FACW
 00022      CONTINUE
            VSD=1./(.85*VS)
             CTERM=COS(OMEGP*((1.+(VRW-VS)*VSD)*TIME+XD*VSD+PHIP-1.57))*IPITCH
            UB1K=2.22+.0009*XD
            IF(UB1K.LT.0.0) UB1K=0.0
            UB1=PITCHM1*VS*UB1K*CTERM*FACW
             IF(XCG.LT.-2236.) UB1=0.
            IF(XCG.GT.X2S) UB1=0.
            WB1K=4.98+.0018*XD
            IF(WB1K.LE.0.0) WB1K=0.0
            WB1=PITCHM1*VS*WB1K*CTERM*FACW
             IF(XCG.LT.-2536.) WB1=0.
```

```
      IF(XCG.GT.X2S) WB1=0.
      SINWCT=SIN(WC*TIME)
      DO 1 I=1,7
      CALL RAND(IRDST(I),IX,1,1,U)
      RDX(I)=U
      RDY(I)=RDX(I)-RDYI(I)
      RDYI(I)=RDYI(I)+RDA*RDY(I)*DT
      RD(I)=RDY(I)*SINWCT
    1 CONTINUE
      SUB2=TAB1(XD,0.,0.,71,1)
      TUB2=TAB1(XD,0.,0.,72,1)
      DTOT=DT/TUB2
      UB2=UB2P*(1.-DTOT)+VS*SUB2*1.414*SQRT(TUB2)*DTOT*RD(1)*GR(1)
      UB2P=UB2
      DTOTW=DT/3.33
      WB2=WB2P*(1.-DTOTW)+.035*VS*2.58*DTOTW*RD(2)*GR(2)
      IF(XD.LT.-2540.) WB2=0.
      IF(XD.GT.X1S) WB2=0.
      WB2P=WB2
      VYBR=WB2
      VXBR=UBSS+UB1+UB2
      VDBR=WBSS+WB1+WB2
      VNBR=VXBR*CTHETR-VYBR*STHETR
      VEBR=VYBR*CTHETR+VXBR*STHETR
      UBT=T11*VNBR+T12*VEBR+T13*VDBR
      VBT=T21*VNBR+T22*VEBR+T23*VDBR
      WBT=T31*VNBR+T32*VEBR+T33*VDBR
      IF(IUBT.EQ.1) UBT=0.
      IF(IVBT.EQ.1) VBT=0.
      IF(IWBT.EQ.1)WBT=0.
      WG=Z0111*WG+ZI111*RD3
      RD3=RD(3)*GR(3)
      UG=Z0112*UG+ZI112*RD4
      RD4=RD(4)*GR(4)
      VG1=Z01*VG1+ZI1*RD5P
      VG2=Z02*VG2+ZI2*RD5P
      VG3=Z01*VG3+ZI3*RD5P
      VG4=Z02*VG4+ZI4*RD5P
      RD5P=RD(5)*GR(5)
      VG=VG1+VG2+VG3+VG4
      IF(ILTURB.EQ.1) GO TO 5
      UG=0.0
      VG=0.
      WG=0.
    5 CONTINUE
      UTURB=UBT+UG
      VTURB=VBT+VG
      WTURB=WBT+WG
      ZR=RN1*RD(6)*GR(6)*(ZR1*ABS(XD)+ZR2)
      YR=RN1*RD(7)*GR(7)*(YR1*ABS(XD)+YR2)
      UB1S=UB1S+UB1
      WB1S=WB1S+WB1
      UB2S=UB2S+UB2
      WB2S=WB2S+WB2
      UB1SS=UB1SS+DT*UB1**2
```

```
SUBROUTINE  WINDC                    CDC 6600 FTN V3.0-P380 OPT=1   78/04/11. 16.03.42.        PAGE     5
                WB1SS=WB1SS+DT*WB1**2
                UB2SS=UB2SS+DT*UB2**2
                WB2SS=WB2SS+DT*WB2**2
                UGS=UGS+UG
                VGS=VGS+VG
                WGS=WGS+WG
                UGSS=UGSS+DT*UG**2
                VGSS=VGSS+DT*VG**2
                WGSS=WGSS+DT*WG**2
                ZRS=ZRS+ZR
                YRS=YRS+YR
                ZRSS=ZRSS+DT*ZR**2
                YRSS=YRSS+DT*YR**2
                 IF(TIME)  30,30,25
        00025    CONTINUE
                 RAV=TIME/DT
                UB1A=UB1S/RAV
                WB1A=WB1S/RAV
                 YRSA=YRS/RAV
                 ZRSA=ZRS/RAV
                 UGSA=UGS/RAV
                 VGSA=VGS/RAV
                 WGSA=WGS/RAV
                 UB2TA=UB2S/RAV
                 WB2TA=WB2S/RAV
                UB2ST=UB2SS/TIME
                WB2ST=WB2SS/TIME
                UGST=UGSS/TIME
                VGST=VGSS/TIME
                WGST=WGSS/TIME
                ZRST=ZRSS/TIME
                YRST=YRSS/TIME
                UB1ST=UB1SS/TIME
                WB1ST=WB1SS/TIME
        00030    CONTINUE
                IF(IDISCT)37,37,33
           33   CONTINUE
                FRT=AMAX1(FRTN,FRTE,FRTD)
                PHASE=FRT*(TIME-TDTURB)
                IF(PHASE-6.28)34,34,36
           34   IF(TIME-TDTURB)36,36,35
           35   VNTURB=.5*VMN*(1.-COS(FRTN*(TIME-TDTURB))     )
                VETURB=.5*VME*(1.-COS(FRTE*(TIME-TDTURB))    )
                VDTURB=.5*VMD*(1.-COS(FRTD*(TIME-TDTURB)) )
                GO TO 37
           36   VNTURB=0.
                VETURB=0.
                VDTURB=0.
           37   CONTINUE
                RETURN
                END
```

```
      SUBROUTINE  WINDC                                    CDC 6600 FTN V3.0-P380 OPT=1  78/04/11. 15.03.42.       PAGE     6

      SYMBOLIC REFERENCE MAP

ENTRY POINTS      DEF LINE      REFERENCES
    1  WINDC           2         135          137         138        270

VARIABLES      SN  TYPE              RELOCATION
     0  A          REAL        ARRAY     XFLOAT       REFS          3        9*6       3*9        10        11        12        13
                                                        14         15       4*16        18        19
   122  ALT        REAL                  XFLOAT       REFS         18      2*126     2*142
  1143  ALT1       REAL                               REFS      2*126      2*142   DEFINED       124       140
     0  B          REAL        ARRAY     CBF          REFS          4         22        23        24      3*25      3*26        28
                                                      2*30         34       4*36      3*37
  1154  CTERM      REAL                               REFS        159        164   DEFINED       156
   162  CTHETR     REAL                  XFLOAT       REFS         16        188       189
   247  DT         REAL                  XFLOAT       REFS         14         63        70        71       172       177       180
                                                       220        221        222       223       227       226       229       232
                                                       233        236
  1165  DTOT       REAL                               REFS      2*178    DEFINED       177
  1170  DTOTW      REAL                               REFS      2*181    DEFINED       180
  1055  DT2        REAL                               REFS         76         78   DEFINED        63
  1145  FACW       REAL                               REFS        129        130       147       150       153       159       164
                                                   DEFINED        127        143
  1142  FACY       REAL                               REFS        127        143   DEFINED       123       139
  1144  FACZ       REAL                               REFS        127        143   DEFINED       125       126       141       142
   761  FC         REAL                               REFS         87    DEFINED        46
  1216  FRT        REAL                               REFS        259    DEFINED       258
   303  FRTD       REAL                  CBF          REFS         36        258       264
   302  FRTE       REAL                  CBF          REFS         36        258       263
   301  FRTN       REAL                  CBF          REFS         36        258       262
     0  GA         REAL        ARRAY     GAIN1        REFS          5         33
    35  GP         REAL        ARRAY     GAIN1        REFS         33         38       178       181       197       199       204
                                                       214        215    DEFINED        43
   143  HIS        REAL                  CBF          REFS         34        124       140
  1076  I          INTEGER                            REFS         82         83      2*84       169       170     3*171     3*172
                                                     2*173    DEFINED         81       168
     0  IA         INTEGER     ARRAY     IFIXED       REFS          3         20        35
     0  IB         INTEGER     ARRAY     ICBF         REFS          4         21        27        29        31      3*32
    27  IHFRZ      INTEGER               ICBF         REFS         32        145
    51  IDISCT     INTEGER               IFIXED       REFS         35         55       256
    30  ILBURB     INTEGER               ICBF         REFS         31        148
    24  ILTURB     INTEGER               ICBF         REFS         32        206
     0  IMODF      INTEGER               IFIXED       REFS         20         56
    17  IONCE      INTEGER               ICBF         REFS         21       2*84
    21  IPITCH     INTEGER               ICBF         REFS         27        156
  1254  IRDSI      INTEGER     ARRAY                  REFS         39         84   DEFINED        51
  1245  IRDST      INTEGER     ARRAY                  REFS         39        169   DEFINED        47        84
   752  IUBT       INTEGER                            REFS        193    DEFINED        48
   753  IVBT       INTEGER                            REFS        194    DEFINED        48
   754  IWBT       INTEGER                            REFS        195    DEFINED        48
    23  IWIND      INTEGER               ICBF         REFS         32        137
  1075  IX         INTEGER                            REFS        169    DEFINED        80
  1102  IZX      * INTEGER                         DEFINED         88
    25  NCHK       INTEGER               ICBF         REFS         29        138
   156  OMEGP      REAL                  CBF          REFS         24        156
```

```
      SUBROUTINE  WINDC                                            CDC 6600 FTN V3.0-P380 OPT=1  78/04/11. 16.03.42.       PAGE     7

VARIABLES      SN   TYPE             RELOCATION
  1217  PHASE       REAL                             REFS        260    DEFINED    259
   157  PHIP        REAL                   CHF       REFS         23       156
   760  PI          REAL                             REFS         86        87    DEFINED      45
   155  PITCHM      REAL                   CBF       REFS         28        62
  1054  PITCHM1     REAL                             REFS        159       164    DEFINED      62
  1264  RAV         REAL                             REFS        237       238       239      240       241       242       243
                                                      244        245    DEFINED    236
  1220  RD          REAL        ARRAY                REFS         38       178       181      197       199       204       214
                                                      215    DEFINED       173
   757  RDA         REAL                             REFS        172    DEFINED     44
  1362  RDX         REAL        ARRAY                REFS         40       171    DEFINED      82       170
  1227  RDY         REAL        ARRAY                REFS         39       172       173    DEFINED     171
  1236  RDYI        REAL        ARRAY                REFS         39       171       172    DEFINED      83       172
  1110  RD3         REAL                             REFS        196    DEFINED     96       197
  1107  RD4         REAL                             REFS        198    DEFINED     95       199
  1106  RD5P        REAL                             REFS        200       201       202      203    DEFINED      94       204
  1057  RK10        REAL                             REFS         72        73    DEFINED      66
  1060  RK11        REAL                             REFS         74        75    DEFINED      67
  1077  RN1         REAL                             REFS        214       215    DEFINED      86
  1161  SINWCT      REAL                             REFS        173    DEFINED    167
   161  STHETR      REAL                   XFLOAT    REFS         16       188       189
   235  SUBSW       REAL                   CBF       REFS         26       129       147    DEFINED      41
  1163  SUB2        REAL                             REFS        178    DEFINED    175
   234  SWBSW       REAL                   CBF       REFS         26       130       150      153    DEFINED      41
  1061  S110        REAL                             REFS         70        72        73     2*74        75
                                                  DEFINED         68
  1062  S210        REAL                             REFS         71        72        73       74      2*75
                                                  DEFINED         69
   307  TDTURB      REAL                   CBF       REFS         37       259       261      262       263       264
   456  TIME        REAL                   XFLOAT    REFS         19       156       167      234       236       246       247
                                                      248        249       250       251      252       253       254       259
                                                      261        262       263       264
   746  TIM3        REAL                          DEFINED         42       132
  1164  TUB2        REAL                             REFS        177       178    DEFINED     176
    17  T11         REAL                   XFLOAT    REFS          6       190
    22  T12         REAL                   XFLOAT    REFS          6       190
    25  T13         REAL                   XFLOAT    REFS          6       190
    20  T21         REAL                   XFLOAT    REFS          6       191
    23  T22         REAL                   XFLOAT    REFS          6       191
    26  T23         REAL                   XFLOAT    REFS          6       191
    21  T31         REAL                   XFLOAT    REFS          6       192
    24  T32         REAL                   XFLOAT    REFS          6       192
    27  T33         REAL                   XFLOAT    REFS          6       192
  1152  U           REAL                             REFS        169       170
  1104  UBSS        REAL                             REFS        186    DEFINED     92       147
  1151  UBSS1       REAL                             REFS        147    DEFINED    146
  1200  UBT         REAL                             REFS        211    DEFINED    190      193
  1156  UB1         REAL                             REFS        186       216       220    DEFINED     159       160       161
  1205  UB1A     *  REAL                          DEFINED        237
  1155  UB1K        REAL                             REFS        158       159    DEFINED     157       158
  1050  UB1S        REAL                             REFS        216       237    DEFINED      58       216
  1053  UB1SS       REAL                             REFS        220       253    DEFINED      61       220
  1214  UB1ST    *  REAL                          DEFINED        253
  1166  UB2         REAL                             REFS        179       186       218      222    DEFINED     178
```

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SUBROUTINE  WINDC                                   CDC 6600 FTN V3.0-P380 OPT=1  78/04/11. 16.03.42.      PAGE     8

VARIABLES      SN  TYPE          RELOCATION
   1167  UB2P      REAL                          REFS      178   DEFINED     179
   1105  UB2S      REAL                          REFS      218       244   DEFINED      93       218
   1114  UB2SS     REAL                          REFS      222       246   DEFINED     100       222
   1210  UB2ST   * REAL                       DEFINED      246
   1121  UB2TA     REAL                       DEFINED      106       244
   1111  UG        REAL                          REFS      198       211       224     227   DEFINED      97      198
                                                  207
   1124  UGS       REAL                          REFS      224       241   DEFINED     109       224
   1117  UGSA      REAL                       DEFINED      103       241
   1133  UGSS      REAL                          REFS      227       248   DEFINED     116       227
    230  UGST      REAL          CBF             REFS       25   DEFINED     248
     74  UTURB     REAL          XFLOAT          REFS       10   DEFINED     129     211
   1201  VBT       REAL                          REFS      212   DEFINED     191     194
   1175  VDBR      REAL                          REFS      190       191       192   DEFINED     187
    644  VDTURB    REAL          XFLOAT          REFS        9   DEFINED     264     268
   1177  VEBP      REAL                          REFS      190       191       192   DEFINED     189
    355  VEQIC     REAL          XFLOAT          REFS       15        64        88      89
   1101  VEQICP    REAL                          REFS       88   DEFINED      89
    643  VETURB    REAL          XFLOAT          REFS        9   DEFINED     263     267
   1203  VG        REAL                          REFS      212       225       228   DEFINED     205      208
   1121  VGS       REAL                          REFS      225       242   DEFINED     114       225
   1207  VGSA    * REAL                       DEFINED      242
   1134  VGSS      REAL                          REFS      228       249   DEFINED     117       228
    231  VGST      REAL          CBF             REFS       25   DEFINED     249
   1125  VG1       REAL                          REFS      200       205   DEFINED     110       200
   1126  VG2       REAL                          REFS      201       205   DEFINED     111       201
   1127  VG3       REAL                          REFS      202       205   DEFINED     112       202
   1130  VG4       REAL                          REFS      203       205   DEFINED     113       203
    305  VMD       REAL          CBF             REFS       37       264
    305  VME       REAL          CBF             REFS       37       263
    304  VMN       REAL          CBF             REFS       36       262
   1176  VNBR      REAL                          REFS      190       191       192   DEFINED     188
    642  VNTURB    REAL          XFLOAT          REFS        9   DEFINED     262     266
   1056  VO        REAL                          REFS       65        67        68      69        76       78
                                              DEFINED       64        65
    105  VRW       REAL          XFLOAT          REFS       13       156
     35  VS        REAL          CBF             REFS       22       129       130     146       149      152      155
                                                  156      159       164       178     181
   1153  VSD       REAL                          REFS    2*156   DEFINED     155
     75  VTURB     REAL          XFLOAT          REFS       11   DEFINED     131     212
   1174  VXBR      REAL                          REFS      188       189   DEFINED     186
   1173  VYBR      REAL                          REFS      188       189   DEFINED     185
   1103  WBSS      REAL                          REFS      187   DEFINED      91     150       153
   1152  WBSS1     REAL                          REFS      150       153   DEFINED     149       152
   1202  WBT       REAL                          REFS      213   DEFINED     192     195
   1160  WB1       REAL                          REFS      187       217       221   DEFINED     164      165      166
   1206  WB1A    * REAL                       DEFINED      238
   1157  WB1K      REAL                          REFS      163       164   DEFINED     162       163
   1051  WB1S      REAL                          REFS      217       238   DEFINED      59       217
   1052  WB1SS     REAL                          REFS      221       254   DEFINED      60       221
   1215  WB1ST   * REAL                       DEFINED      254
   1171  WB2       REAL                          REFS      184       185       187     219       223
                                              DEFINED      181       182       183
   1172  WB2P      REAL                          REFS      181   DEFINED     184
```

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      SUBROUTINE  WINDC                                  CDC 6600 FTN V3.0-P380 OPT=1  78/04/11. 16.03.42.      PAGE      9

VARIABLES      SN   TYPE                 RELOCATION
   1113  WH2S       REAL                             REFS      219      245   DEFINED     99      219
   1123  WH2SS      REAL                             REFS      223      247   DEFINED    108      223
   1211  WH2ST   *  REAL                          DEFINED      247
   1122  WH2TA      REAL                          DEFINED      107      245
   1100  WC         REAL                             REFS      167  DEFINED        87
   1112  WG         REAL                             REFS      196      213       226    229  DEFINED      98      196
                                                      209
   1132  WGS        REAL                             REFS      226      243   DEFINED    115      226
   1120  WGSA       REAL                          DEFINED      104      105       243
   1135  WGSS       REAL                             REFS      229      250   DEFINED    118      229
    232  WGST       REAL          CBF                REFS       25  DEFINED       250
     76  WTURB      REAL          XFLOAT             REFS       12  DEFINED       130    213
    255  XCG        REAL          XFLOAT             REFS       16      124       128    140      144     160     161
                                                      165      166
   1146  XD         REAL                             REFS      129      130       146    149      152     156     157
                                                      162      175      176       182    183      214     215
                                                  DEFINED      128      144       145
    233  XFRZ       REAL          CBF                REFS       26      145   DEFINED     50
    135  X1S        REAL          CBF                REFS       30      183
    136  X2S        REAL          CBF                REFS       30      161       166
    255  YCG        REAL          XFLOAT             REFS       16      123       139
   1150  YR         REAL                             REFS      231      233   DEFINED    134      215
   1137  YRS        REAL                             REFS      231      239   DEFINED    120      231
   1115  YRSA       REAL                          DEFINED      101      239
   1141  YRSS       REAL                             REFS      233      252   DEFINED    122      233
   1213  YRST    *  REAL                          DEFINED      252
    767  YR1        REAL                             REFS      215  DEFINED        49
    770  YR2        REAL                             REFS      215  DEFINED        49
   1065  ZI1        REAL                             REFS      200  DEFINED        72
   1072  ZI111      REAL                             REFS      196  DEFINED        77
   1074  ZI112      REAL                             REFS      198  DEFINED        79
   1066  ZI2        REAL                             REFS      201  DEFINED        73
   1067  ZI3        REAL                             REFS      202  DEFINED        74
   1070  ZI4        REAL                             REFS      203  DEFINED        75
   1063  ZO1        REAL                             REFS       72       74       200    202  DEFINED      70
   1071  ZO111      REAL                             REFS       77      196   DEFINED     76
   1073  ZO112      REAL                             REFS       79      198   DEFINED     78
   1064  ZO2        REAL                             REFS       73       75       201    203  DEFINED      71
   1147  ZR         REAL                             REFS      230      232   DEFINED    133      214
   1136  ZRS        REAL                             REFS      230      240   DEFINED    119      230
   1116  ZRSA       REAL                          DEFINED      102      240
   1140  ZRSS       REAL                             REFS      232      251   DEFINED    121      232
   1212  ZRST    *  REAL                          DEFINED      251
    765  ZR1        REAL                             REFS      214  DEFINED        49
    765  ZR2        REAL                             REFS      214  DEFINED        49

EXTERNALS          TYPE    ARGS         REFERENCES
       COS         REAL     1 LIBRARY      156       262      263      264
       EXP         REAL     1 LIBRARY       70        71       76       78       123    126      139     142
       RAND                 5              169
       SIN         REAL     1 LIBRARY      167
       SQRT        REAL     1 LIBRARY       66        67       77       79        86    178
       TAB1        REAL     5              129       130      146      149       152    175      176
```

APPENDIX B

Definition of Variables Used in CVA Program

A	Common Array
alt	Aircraft Altitude Above Sea Level - Ft.
alt_1	Altitude Boundary on Turbulence - Ft.
B	Common Storage Array
CTERM	Periodic Amplitude of Sinusoidal Airwake Terms
DT	Time Increment - Sec.
DTOT	Nondimensionalized Time Increment of u Burble Component
DTOTW	Nondimensionalized Time Constant of W Burble Component
DT2	Time Increment - Second
FacW	Extrapolation Factor of Airwake Velocity
FacY	Extrapolation Function in Y Direction
FacZ	Extrapolation Function in Z Direction
FC	Shift Frequency - Cycle/Sec.
FRT	Maximum Gust Frequency - Rad./Sec.
FRTD	Frequency of Vertical Discrete Gust - Rad./Sec.
FRTE	Frequency of East Discrete Gust - Rad./Sec.
FRTN	Frequency of North Discrete Gust - Rad./Sec.
GA	Common Storage Array
GR	Array Containing Turbulence Gains
HIS	Steady Deck Height Above Sea Level - Ft.
I	Integer Counter
Ia	Integer Common Array
IB	Integer Common Array
IBFRZ	Constant Range Flag
IDISCT	Discrete Turbulence Flag
ILBURB	Downwash Selection Switch
ILTURB	Free Air Turbulence Switch
IMode	Operating Mode Switch
Ionce	Turbulence Initialization Option Switch
IPitch	Ship Pitch Flag
IRDSI	Start Up Array

IRDST	Start Up Array
IuBT	Switch for u Burble Component
IVBT	Switch for V Burble Component
IWBT	Switch for W Burble Component
Iwind	Turbulence Selection Switch
IX	Random Number Startup Parameter
OMEGP	Ship Pitch Frequency - Rad/Sec.
Phase	Discrete Turbulence Phase - Rad.
PHIP	Ship Pitch Phase - Rad.
PI	3.14159
PITCHM	Ship Pitch Magnitude - Deg.
PITCHMI	Ship Pitch Magnitude - Rad.
RAV	Averaging Parameter
RD	Filtered Output of Random Number Generator
RDA	Time Constant of Random Number Filter - 1/Sec.
RDX	Raw Output of Random Number Generator
RDY	Intermediate Random Number Value
RDYI	Intermediate Random Number Value
RD3	Intermediate Turbulence Variable
RD4	Intermediate Turbulence Variable
RD5P	Intermediate Turbulence Variable
RK10	Turbulence Filter Gain
RN1	Radar Noise Gain
SIN WCT	Frequency Shifting Function
STHETR	Sine of Ship Heading Angle
SuBSW	Steady u Burble Scale Factor
SuB2	Random u Burble RMS Magnitude
SwBSW	Steady w Burble Scale Factor
S110	Filter Parameter
S210	Filter Parameter
TDTURB	Discrete Turbulence Switch Time - Sec.
TIME	Simulation Running Time - Sec.
TuB2	Random u Burble Time Constant - Sec.
T11 - T33	Euler Angle Conversion Matrix Relating Aircraft Body Axes and Inertial Axes
u	Output of Random Number Generator

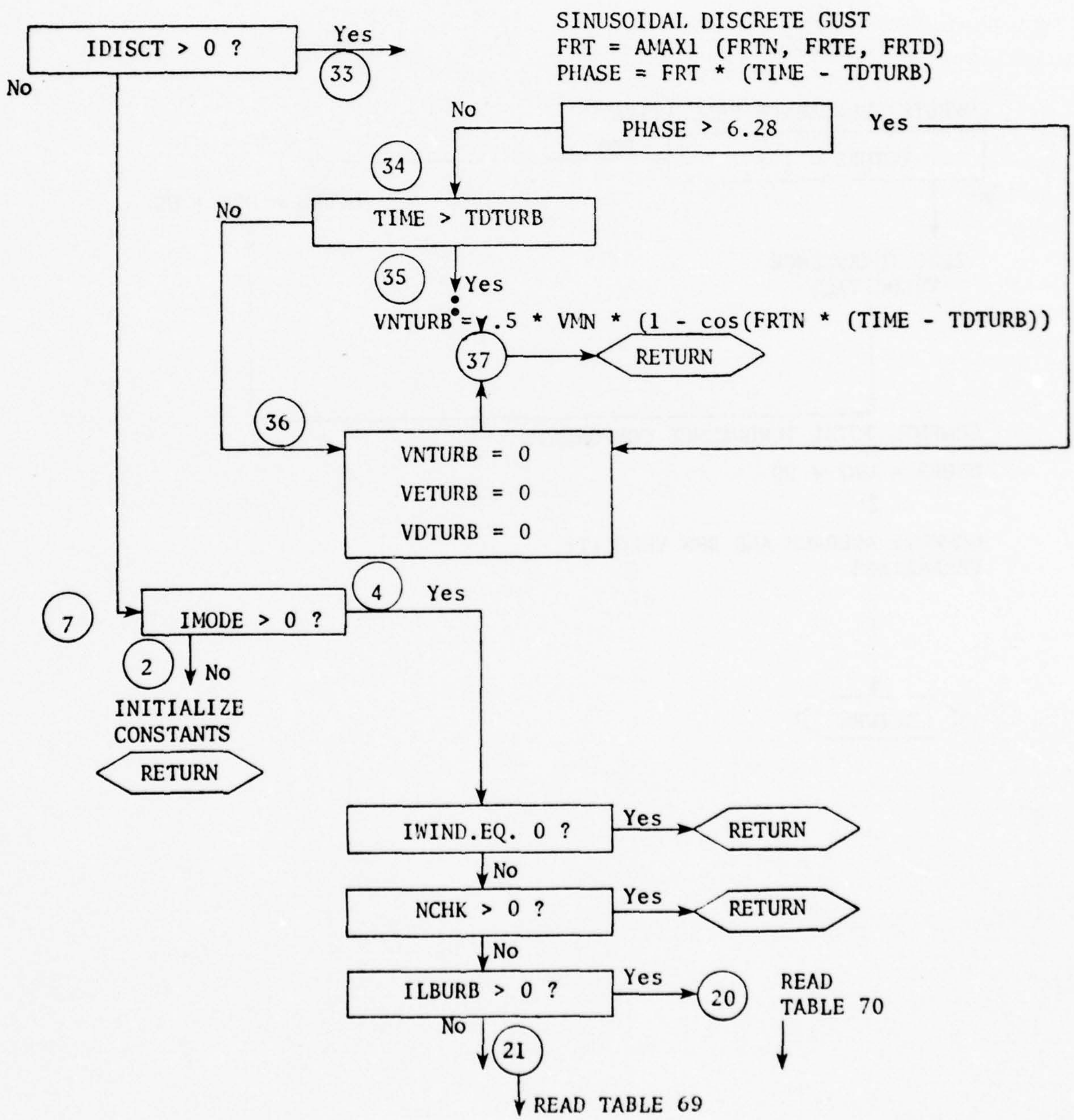
uBSS	Steady u Component of Burble - Ft./Sec.
UBSS1	Intermediate Turbulence Variable
UBT	u-Body Axis Burble Component - Ft./Sec.
uB1	X-Ship Axis Periodic Burble - Ft./Sec.
uB1A	Intermediate Variable
uB1K	Intermediate Variable
uB1S	Statistical Summary Variable
uB1SS	Statistical Summary Variable
uB1ST	Statistical Summary Variable
uB2	Ship X Axis Random Burble Component - Ft./Sec.
uB2P	Intermediate Variable
uB2S	Statistical Summary Variable
uB2SS	Statistical Summary Variable
uB2ST	Statistical Summary Variable
uB2TA	Statistical Summary Variable
uG	Aircraft X-Axis Free Air Turbulence Component - Ft./Sec.
uGS	Statistical Summary Variable
uGSA	Statistical Summary Variable
uGSS	Statistical Summary Variable
uGST	Statistical Summary Variable
uTURB	Total Aircraft X-Axis Turbulence - Ft./Sec.
VBT	Lateral Burble Velocity - Ft./Sec.
VDBR	Vertical Burble Component - Ft./Sec.
VDTURB	Vertical Turbulence Velocity - Ft./Sec.
VEBR	East Component of Burble - Ft./Sec.
VEQIC	Aircraft Trim Velocity - Knots
VEQICP	Previous Trim Velocity - Knots
VETURB	East Component of Turbulence - Ft./Sec.
VG	Aircraft Y-Axis Component of Free Air Turbulence - Ft./Sec.
VGS	Statistical Summary Variable
VGSA	Statistical Summary Variable
VGSS	Statistical Summary Variable
VGST	Statistical Summary Variable
VG1	Intermediate Variable
VG2	Intermediate Variable
VG3	Intermediate Variable

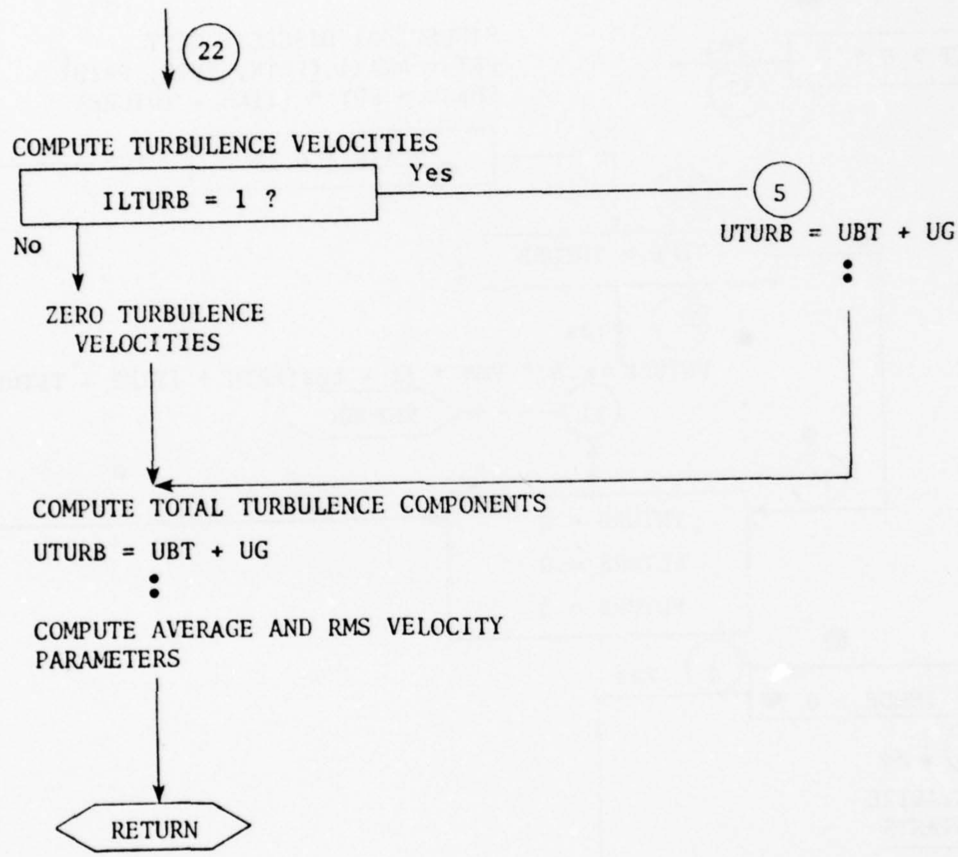
VG4	Intermediate Variable
VMD	Vertical Discrete Gust Magnitude - Ft./Sec.
VME	East Discrete Gust Magnitude - Ft./Sec.
VMN	North Discrete Gust Magnitude - Ft./Sec.
VNBR	North Burble Component - Ft./Sec.
VNTURB	North Turbulence Component - Ft./Sec.
VO	Trim Velocity - Ft./Sec.
VRW	Aircraft Airspeed - Ft./Sec.
VS	Relative Wind Over Deck Speed - Ft./Sec.
VSD	Burble Propagation Speed - Ft./Sec.
VTURB	Aircraft Y Axis Component of Total Turbulence - Ft./Sec.
VXBR	Ship X Axis Component of Burble - Ft./Sec.
VYBR	Ship Y Axis Component of Burble - Ft./Sec.
WBSS	Steady Downwash Velocity - Ft./Sec.
WBSS1	Intermediate Variable
WBT	Aircraft Z Axis Component of Burble - Ft./Sec.
WB1	Periodic Component of Ship Downwash - Ft./Sec.
WB1A	Statistical Summary Variable - Ft./Sec.
WB1K	Intermediate Variable
WB1S	Statistical Summary Variable
WB1SS	Statistical Summary Variable
WB1ST	Statistical Summary Variable
WB2	Vertical Random Burble Component - Ft./Sec.
WB2P	Intermediate Variable
WB2S	Statistical Summary Variable
WB2SS	Statistical Summary Variable
WB2ST	Statistical Summary Variable
WB2TA	Statistical Summary Variable
WC	Frequency Shift Parameter - Rad./Sec.
WG	Aircraft Z-Axis Free Air Turbulence
WGS	Statistical Summary Variable
WGSA	Statistical Summary Variable
WGSS	Statistical Summary Variable
WGST	Statistical Summary Variable
WTURB	Aircraft Z-Axis Turbulence Velocity - Ft./Sec.
XCG	Aircraft X Position Relative to Ship cg - Ft.

XD	X-Position Variable Used in Table Look Up - Ft.
XFRZ	Fixed Position Used in Table Look Up - Ft.
X1S	Forward Turbulence Limit - Ft.
X2S	Forward Turbulence Limit - Ft.
YCG	Aircraft Lateral Position Relative to Ship - Ft.
YR	Lateral Radar Error - Ft.
YRS	Statistical Summary Variable
YRSA	Statistical Summary Variable
YRSS	Statistical Summary Variable
YRST	Statistical Summary Variable
YR1	Scale Factor on Radar Noise Function
YR2	Scale Factor on Radar Noise Function
ZI1	Turbulence Filter Parameters
ZI111	Turbulence Filter Parameters
ZI112	Turbulence Filter Parameters
ZI2	Turbulence Filter Parameters
ZI3	Turbulence Filter Parameters
ZI4	Turbulence Filter Parameters
ZO1	Turbulence Filter Parameters
ZO111	Turbulence Filter Parameters
ZO112	Turbulence Filter Parameters
ZO2	Turbulence Filter Parameters
ZR	Vertical Radar Noise - Ft.
ZRS	Statistical Summary Parameter
ZRSA	Statistical Summary Parameter
ZRSS	Statistical Summary Parameter
ZRST	Statistical Summary Parameter
ZR1	Radar Noise Parameter
ZR2	Radar Noise Parameter

APPENDIX C

Flow Chart for CVA Model




22
COMPUTE TURBULENCE VELOCITIES
ILTURB = 1 ?
Yes
No
5
UTURB = UBT + UG
ZERO TURBULENCE VELOCITIES
COMPUTE TOTAL TURBULENCE COMPONENTS
UTURB = UBT + UG
COMPUTE AVERAGE AND RMS VELOCITY PARAMETERS
RETURN

APPENDIX D

Listing of FF 1052 Turbulence Subroutine

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```
SUBROUTINE WINDC       74/74    OPT=1                     FTN 4.5+428         79/01/15. 08.01.01        PAGE     1

              SUBROUTINE WINDC
              COMMON/XFLOAT/A(500)/IFIXED/IA(200)
              COMMON/CBF/B(200)/ICBF/IB(50)
              EQUIVALENCE(ALT,A(83)),(IA(1),IMODE),(VS,B(30)),(DT,A(168)),
             1(VNW,A(76)),(VEW,A(77)),(VDW,A(78)),(A(419),VNTURB),(A(420),VETURB
             2),(A(421),VDTURB),(VNWBIC,B(35)),(VEWBIC,B(36)),(PSIS,B(84))
              EQUIVALENCE(XF,B(141)),(YF,B(142))
              EQUIVALENCE(A(500),PSIW)
              EQUIVALENCE(HTD,B(103))
              EQUIVALENCE(IWIND,IB(20))
              EQUIVALENCE(TIME,A(303)),(IONCE,IB(16))
              DATA IONCE/1/
              DATA BEAM/46.75/,RLTD/351./,RLS/441./
              DATA IRDSTX/37/,IRDSTY/43/,IRDSTZ/53/,PI/3.14159/
              DATA IRDSTXI/37/,IRDSTYI/43/,IRDSTZI/53/
              DATA RNX/7.12/,RNY/5.3/,RNZ/6.52/
              DATA SLOPEX/.00133333/
              IF(IWIND)15,15,20
C              INITIALIZE VELOCITIES AND RANDOM NUMBER GENERATORS
   15         VNTURB=0.
              VETURB=0.
              VDTURB=0.
              RETURN
   20         IF(IMODE)1,1,2
    1         IX=2**24-3
              SLOPE1=0.
              VXT=0.
              VYT=0.
              VZT=0.
              VXTP=0.
              VYTP=0.
              VZTP=0.
              TCOUNTX=0.
              TCOUNTY=0.
              TCOUNTZ=0.
              RANDXP=0.
              RANDYP=0.
              RANDZP=0.
              IF(IONCE.LT.1) GO TO 21
              IRDSTXI=IRDSTX
              IRDSTYI=IRDSTY
              IRDSTZI=IRDSTZ
   21         CONTINUE
              TCOUNT=0.
C              SET DTW TO CONSTANT SO THAT TURBULENCE SEQUENCE REMAINS CONSTANT
C              REGARDLESS OF LOOP TIME USED  IN AIRCRAFT SIMULATION
              DTW=.05
              IF(DT.GT..05)DTW=DT
C              COMPUTE TIME INCREMENTS FOR RANDOM NUMBER GENERATORS
              DTX=DTW*RNX
              DTY=DTW*RNY
              DTZ=DTW*RNZ
              PSISR=PSIS/57.3
              SPSISR=SIN(PSISR)
              CPSISR=COS(PSISR)
              VEL=VEWBIC-VS*SPSISR
              VNL=VNWBIC-VS*CPSISR
```

```
      VW=SQRT(VEW**2+VNW**2)
      PSIW=ATAN2(VEW,VNW)-PI
      CPSIW=COS(PSIW)
      SPSIW=SIN(PSIW)
      PSIREL=PSIW-PSISH
      CPSIREL=COS(PSIREL)
      SPSIREL=SIN(PSIREL)
C      COMPUTE TURBULENCE EXTRAPOLATION BOUNDARIES
      YMAX=-RLTD*SPSIREL+BEAM/2.*CPSIREL
      YMAX1=YMAX-BEAM*CPSIREL
      YMIN=-BEAM/2.*CPSIREL+(RLS-RLTD)*SPSIREL
      YMIN1=YMIN
      XMIN1=-RLTD*CPSIREL-BEAM/2.*ABS(SPSIREL)
      XMIN2=(RLS-RLTD)*CPSIREL-BEAM/2.*ABS(SPSIREL)
      IF(YMIN.GT.-18.75) YMIN=-18.75
      IF(YMAX.LT.170.) YMAX=170.
      IF(PSIREL)50,49,50
   50 SLOPE1=(XMIN1-XMIN2)/(YMAX1-YMIN1)
   49 CONTINUE
      VW1=VW/76.
      VW1=VW/59.
    2  CONTINUE
      IF(TIME-TCOUNT)101,100,100
  100 TCOUNT=TCOUNT+DTW
      VETO=VETN
      VNTO=VNTN
      VDTO=VDTN
      XWIND=YE*SPSIW+XE*CPSIW
      YWIND=-XE*SPSIW+YE*CPSIW
C     GUST MODEL EXTRAPOLATIONS FUNCTIONS
C       XTAB,YTAB, ZTAB ARE INPUT TO TABLES
      XTAB=-XWIND
      YTAB=YWIND
      ZTAB=ALT-HTD
      FX1=1.
      FY1=1.
      FZ1=1.
      IF(ZTAB.LT.0) ZTAB=0.
      IF(ZTAB-44.95)31,31,30
   30 FZ1=EXP((44.95-ZTAB)/BEAM)
   31 CONTINUE
      IF(ZTAB.GT.44.95)ZTAB=44.95
      IF(YTAB-YMAX)3,5,4
    4 FY1=EXP((YMAX-YTAB)/BEAM)
      GO TO 5
    3 IF(YTAB-YMIN)6,5,5
    6 FY1=EXP((YTAB-YMIN)/BEAM)
    5 CONTINUE
      IF(PSIREL)7,8,7
    8 XMIN=XMIN1
      GO TO 13
    7 IF(YWIND-YMAX)9,10,10
   10 XMIN=XMIN1
      GO TO 13
    9 IF(YTAB-YMIN)11,12,12
   11 XMIN=XMIN2
      GO TO 13
```

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SUBROUTINE WINDC       74/74    OPT=1                    FTN 4.5+428        79/01/15. 08.01.01        PAGE     3

   12   XMIN=XMIN2+SLOPE1*(XMIN0-XMIN)
   13   CONTINUE
        IF(XTAR-XMIN)14,16,16
   14   FX1=EXP((XTAR-XMIN)/BEAM)
        GO TO 17
   16   CONTINUE
        IF(XTAR-250.)17,17,18
   18   CONTINUE
        FX1=1.-(XTAR-250.)*SLOPEX
        IF(FX1.LT.0.) FX1=0.
   17   CONTINUE
        IF(XTAR.LT.0.) XTAR=0.
        IF(XTAR.GT.250.) XTAR=250.
        IF(YTAR.LT.-18.75)YTAR=-18.75
        IF(YTAR.GT.170.) YTAR=170.
        F1=FX1*FY1*FZ1
C        VXMS,VYMS,VZMS ARE MEAN VALUES
        VXMS=TAB1(XTAR,YTAR,ZTAB,76,3)
        VYMS=TAB1(XTAR,YTAR,ZTAB,79,3)
        VZMS=TAB1(XTAR,YTAR,ZTAB,82,3)
C        SIGX,SIGY,SIGZ ARE VARIANCE VALUES
        SIGX=TAB1(XTAR,YTAR,ZTAB,85,3)
        SIGY=TAB1(XTAR,YTAR,ZTAB,88,3)
        SIGZ=TAB1(XTAR,YTAR,ZTAB,91,3)
        VXBAR=(VXMS-VW)*F1
        VYBAR=VYMS*F1
        VZBAR=VZMS*F1
        SIGVX=SIGX*F1
        SIGVY=SIGY*F1
        SIGVZ=SIGZ*F1
        RNOUE=(INOUE+1)/2
C    SPECIFY      PERIODICITY OF RANDOM NUMBER CALL TO REGULATE FREQUENCY
C       OF RANDOM TURBULENCE SIMULATION . INCREASE DTX,DTY,DTZ TO REDUCE
C        FREQUENCY OF TURBULENCE
C      LINEARLY INTERPOLATE RANDOM NUMBER INPUT BETWEEN CALLS.
        IF(TIME-TCOUNTX)202,200,200
  200   RANDXO=RANDXN
        CALL RAND(IPOSTXI,IX,1,1,RANDXN)
        TCOUNTX=TCOUNTX+DTX
  202   RANDX=RANDXO+(RANDXN-RANDXO)*(TIME+DTX-TCOUNTX)/DTX
        IF(TIME-TCOUNTY)302,300,300
  300   RANDYO=RANDYN
        CALL RAND(IPOSTYI,IX,1,1,RANDYN)
        TCOUNTY=TCOUNTY+DTY
  302   RANDY=RANDYO+(RANDYN-RANDYO)*(TIME+DTY-TCOUNTY)/DTY
        IF(TIME-TCOUNTZ)402,400,400
  400   RANDZO=RANDZN
        CALL RAND(IPOSTZI,IX,1,1,RANDZN)
        TCOUNTZ=TCOUNTZ+DTZ
  402   RANDZ=RANDZO+(RANDZN-RANDZO)*(TIME+DTZ-TCOUNTZ)/DTZ
C        TURBULENCE FREQUENCY VARIES WITH DOWNSTREAM RANGE
        OMEGAX=6.17*VW1
        OMEGY=10.41*VW1
        OMEGZ=10.*VW1
        IF(XTAR-16.)500,500,501
  500   FOMEGAX=1.
        FOMEGY=1.
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SUBROUTINE WINDC      74/74    OPT=1                       FTN 4.5+428        79/01/15. 08.01.01       PAGE     4

          GO TO 504
    501   IF(XTAR-190.)502,503,503
    502   FOMEGX=1.-.00424478*XTAR
          FOMEGY=1.-.0037463*XTAR
          GO TO 504
    503   FOMEGX=.1935
          FOMEGY=.2682
    504   CONTINUE
C     SCALE FILTER FREQUENCY WITH RANGE AND FREE STREAM VELOCITY
          OMEGX=OMEGX*FOMEGX
          OMEGY=OMEGY*FOMEGY
          OMEGZ=OMEGZ*FOMEGY
          EXPX=EXP(-DTW*OMEGX)
          EXPY=EXP(-DTW*OMEGY)
          EXPZ=EXP(-DTW*OMEGZ)
C      COMPUTED RANDOM TURBULENCE
          VXT=VXTP*EXPX+(1.-EXPX)*4.48*SIGVX/SQRT(OMEGX)*RANDX*RMODE
          VYT=VYTP*EXPY+(1.-EXPY)*4.48*SIGVY/SQRT(OMEGY)*RANDY*RMODE
          VZT=VZTP*EXPZ+(1.-EXPZ)*4.48*SIGVZ/SQRT(OMEGZ)*RANDZ*RMODE
          VXTP=VXT
          VYTP=VYT
          VZTP=VZT
C      TOTAL TURBULENCE IN WIND AXES
          VXTURB=VXBAR+VXT
          VYTURB=VYBAR+VYT
          VZTURB=VZBAR+VZT
C      TOTAL TURBULENCE IN INERTIAL AXES
          VNTN=VXTURB*CPSIW-VYTURB*SPSIW
          VETN=VYTURB*CPSIW+VXTURB*SPSIW
          VDTN=VZTURB
    101   CONTINUE
          IF(IMODE.EQ.-1) 102,103
    102   VNTO=VNTN
          VETO=VETN
          VDTO=VDTN
    103   CONTINUE
          TFAC=(TIME+DTW-TCOUNT)/DTW
C      UPDATE VALUE OF TURBULENCE IN INERTIAL AXES
          VNTURB=VNTO+TFAC*(VNTN-VNTO)
          VETURB=VETO+TFAC*(VETN-VETO)
          VDTURB=VDTO+TFAC*(VDTN-VDTO)
          IF(IMODE.EQ.-1) PRINT 104,VXWS,VYWS,VZWS,SIGX,SIGY,SIGZ,F1,
         1  XTAR,YTAR,ZTAR,PSIREL,SLOPE1
    104   FORMAT(10X,12F10.4)
          RETURN
          END

     SYMBOLIC REFERENCE MAP (R=3)

 ENTRY POINTS      DEF LINE      REFERENCES
    1  WINDC           1            23        214
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SUBROUTINE WINDC        74/74    OPT=1                       FTN 4.5+428        79/01/15. 08.01.01      PAGE     5

VARIABLES       SN   TYPE             RELOCATION
    0   A            REAL      ARRAY   XFLOAT     REFS       2       6*4                11
  122   ALT          REAL              XFLOAT     REFS       4       91
    0   B            REAL      ARRAY   CHF        REFS       3       4*4       2*7       9
  552   BEAM         REAL                         REFS      66       67        68       70       71       97      101
                                                   104     118    DEFINED      13
  715   CPSTHEL      REAL                         REFS      65       67        68       70       71
                                                DEFINED     63
  710   CPSISH       REAL                         REFS      57    DEFINED      55
  712   CPSIW        REAL                         REFS      85       86       194      200    DEFINED     60
  247   DT           REAL              XFLOAT     REFS       4      2*45
  702   DTW          REAL                         REFS      50       51        52       81      184      185      186
                                                  2*208  DEFINED    47        48
  703   DTX          REAL                         REFS     153     2*154   DEFINED      50
  704   DTY          REAL                         REFS     158     2*159   DEFINED      51
  705   DTZ          REAL                         REFS     163     2*164   DEFINED      52
  775   EXPX         REAL                         REFS    2*148   DEFINED     184
  777   EXPY         REAL                         REFS    2*149   DEFINED     185
 1000   EXPZ         REAL                         REFS    2*140   DEFINED     186
  774   FOMEGX       REAL                         REFS     181   DEFINED     170      174      177
  775   FOMEGY       REAL                         REFS     182      183   DEFINED     171      175      178
  741   FX1          REAL                         REFS     124      130   DEFINED      92      118      123      124
  742   FY1          REAL                         REFS     130   DEFINED      93      101      104
  743   FZ1          REAL                         REFS     130   DEFINED      94       97
  745   F1           REAL                         REFS     139      140       141      142      143      144      213
                                                DEFINED    130
  146   HTE          REAL              CHF        REFS       4       91
    0   IA           INTEGER   ARRAY   IFIXED     REFS       2        4
    0   IB           INTEGER   ARRAY   ICHF       REFS       3       10        11
    0   IMODE        INTEGER           IFIXED     REFS       4       24       145      203      213
   17   IORDE        INTEGER           ICHF       REFS      11       39   DEFINED      12
  555   IRDSTX       INTEGER                      REFS      40   DEFINED      14
  571   IRDSTXI      INTEGER                      REFS     152   DEFINED      15       40
  555   IRDSTY       INTEGER                      REFS      41   DEFINED      14
  572   IRDSTYI      INTEGER                      REFS     157   DEFINED      15       41
  567   IRDSTZ       INTEGER                      REFS      42   DEFINED      14
  573   IRDSTZI      INTEGER                      REFS     162   DEFINED      15       42
   23   IWIND        INTEGER           ICHF       REFS      10       18
  553   IX           INTEGER                      REFS     152      157       162   DEFINED     25
  771   OMEGX        REAL                         REFS     181      184       188   DEFINED    166      181
  772   OMEGY        REAL                         REFS     182      185       189   DEFINED    167      182
  773   OMEGZ        REAL                         REFS     183      186       190   DEFINED    168      183
  570   PI           REAL                         REFS      59   DEFINED      14
  714   PSIREL       REAL                         REFS      53       54        74      106      213
                                                DEFINED     62
  123   PSIS         REAL              CHF        REFS       4       53
  705   PSISP        REAL                         REFS      54       55        62   DEFINED     53
  763   PSIW         REAL              XFLOAT     REFS       8       60        61       62    DEFINED     59
  754   RANDX        REAL                         REFS     148   DEFINED     154
  676   RANDXN       REAL                         REFS     151      152       154   DEFINED     36
  753   RANDXO       REAL                         REFS    2*154   DEFINED     151
  765   RANDY        REAL                         REFS     149   DEFINED     159
  677   RANDYN       REAL                         REFS     155      157       159   DEFINED     37
  755   RANDYO       REAL                         REFS    2*159   DEFINED     155
  770   RANDZ        REAL                         REFS     140   DEFINED     164
  700   RANDZN       REAL                         REFS     161      162       164   DEFINED     38
  757   RANDZO       REAL                         REFS    2*164   DEFINED     161
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      SUBROUTINE WINDC        74/74    OPT=1                        FTN 4.5+428      79/01/15. 08.01.01        PAGE     6

VARIABLES        SN   TYPE               RELOCATION
   564   HLS          REAL                             REFS       68        71   DEFINED        13
   563   RLTD         REAL                             REFS       66        68        70        71   DEFINED        13
   702   RMODE        REAL                             REFS      188       189       190   DEFINED       145
   574   RNX          REAL                             REFS       50   DEFINED        16
   575   RNY          REAL                             REFS       51   DEFINED        16
   576   RNZ          REAL                             REFS       52   DEFINED        16
   757   SIGVX        REAL                             REFS      188   DEFINED       142
   760   SIGVY        REAL                             REFS      189   DEFINED       143
   761   SIGVZ        REAL                             REFS      190   DEFINED       144
   751   SIGX         REAL                             REFS      142       213   DEFINED       136
   752   SIGY         REAL                             REFS      143       213   DEFINED       137
   753   SIGZ         REAL                             REFS      144       213   DEFINED       138
   577   SLOPEX       REAL                             REFS      123   DEFINED        17
   654   SLOPE1       REAL                             REFS      115       213   DEFINED        26        75
   715   SPSIPEL      REAL                             REFS       66        68        70        71   DEFINED        64
   707   SPSISR       REAL                             REFS       55   DEFINED        54
   713   SPSIA        REAL                             REFS       85        86       199       200   DEFINED        61
   701   TCOUNT       REAL                             REFS       80        81       206   DEFINED        44        81
   673   TCOUNTX      REAL                             REFS      150       153       154   DEFINED        33       153
   674   TCOUNTY      REAL                             REFS      155       156       159   DEFINED        34       158
   675   TCOUNTZ      REAL                             REFS      160       163       164   DEFINED        35       163
  1004   TFAC         REAL                             REFS      210       211       212   DEFINED       208
   456   TIME         REAL          XFLOAT             REFS       11        80       150       154       155       159       160
                                                        164      204
   733   VDTN         REAL                             REFS       84       206       212   DEFINED       201
   732   VDTO         REAL                             REFS    2*212   DEFINED        84       206
   644   VDTOPH       REAL          XFLOAT             REFS        4   DEFINED        22       212
   115   VEW          REAL          XFLOAT             REFS        4
   727   VETN         REAL                             REFS       82       205       211   DEFINED       200
   726   VETO         REAL                             REFS    2*211   DEFINED        82       205
   643   VETOPH       REAL          XFLOAT             REFS        4   DEFINED        21       211
   114   VEX          REAL          XFLOAT             REFS        4        58        59   DEFINED        56
    43   VEXMIC       REAL          CHF                REFS        4        56
   731   VNTN         REAL                             REFS       83       204       210   DEFINED       199
   730   VNTO         REAL                             REFS    2*210   DEFINED        83       204
   642   VNTOPH       REAL          XFLOAT             REFS        4   DEFINED        20       210
   113   VNW          REAL          XFLOAT             REFS        4        58        59   DEFINED        57
    42   VNWMIC       REAL          CHF                REFS        4        57
    35   VS           REAL          CHF                REFS        4        56        57
   711   VW           REAL                             REFS       77        78       139   DEFINED        58
   725   VW1          REAL                             REFS      166       167       168   DEFINED        77        78
   754   VXBAR        REAL                             REFS      145   DEFINED       139
   665   VXT          REAL                             REFS      191       195   DEFINED        27       188
   670   VXTP         REAL                             REFS      188   DEFINED        30       191
  1001   VXTOPH       REAL                             REFS      199       200   DEFINED       195
   746   VXMS         REAL                             REFS      139       213   DEFINED       132
   755   VYBAR        REAL                             REFS      196   DEFINED       140
   665   VYT          REAL                             REFS      192       196   DEFINED        28       189
   671   VYTP         REAL                             REFS      189   DEFINED        31       192
  1002   VYTOPH       REAL                             REFS      199       200   DEFINED       196
   747   VYMS         REAL                             REFS      140       213   DEFINED       133
   756   VZBAR        REAL                             REFS      197   DEFINED       141
   667   VZT          REAL                             REFS      193       197   DEFINED        29       190
   672   VZTP         REAL                             REFS      190   DEFINED        32       193
  1003   VZTOPH       REAL                             REFS      201   DEFINED       197
   750   VZMS         REAL                             REFS      141       213   DEFINED       134
   214   XS           REAL          CHF                REFS        7        65        66
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SUBROUTINE WINDC        74/74    OPT=1                                    FTN 4.5+428        79/01/15. 08.01.01        PAGE      7

VARIABLES       SN  TYPE             RELOCATION
   744   XMIN       REAL                               REFS       117       118   DEFINED       107        110        113        115
   723   XMIN1      REAL                               REFS        75       107       110   DEFINED         70
   724   XMIN2      REAL                               REFS        75       113       115   DEFINED         71
   735   XTAB       REAL                               REFS       117       118       121       123        126        127        132
                                                        133       134       136       137       138        169        173        174
                                                        175       213   DEFINED        69       126        127
   734   XWIND      REAL                               REFS        49   DEFINED        85
   215   YE         REAL                    C#F        REFS         7        85        86
   717   YMAX       REAL                               REFS        67        73       100       101        109
                                                    DEFINED        66        73
   720   YMAX1      REAL                               REFS        75   DEFINED        67
   721   YMIN       REAL                               REFS        69        72       103       104        112        115
                                                    DEFINED        68        72
   722   YMIN1      REAL                               REFS        75   DEFINED        69
   737   YTAB       REAL                               REFS       100       101       103       104        112        128        129
                                                        132       133       134       136       137        138        213
                                                    DEFINED        90       128       129
   735   YWIND      REAL                               REFS        90       109       115   DEFINED         86
   740   ZTAB       REAL                               REFS        95        96        97        99        132        133        134
                                                        136       137       138       213   DEFINED         91         95         99

FILE NAMES          MODE
        OUTPUT      FMT                      WRITES     213

EXTERNALS            TYPE     ARGS          REFERENCES
        ATAN2        REAL      2 LIBRARY        59
        COS          REAL      1 LIBRARY        55         60        63
        EXP          REAL      1 LIBRARY        97        101       104       118       184       185       186
        RAND                   5               152        157       162
        SIN          REAL      1 LIBRARY        54         61        64
        SQRT         REAL      1 LIBRARY        58        188       189       190
        TABI         REAL      5               132        133       134       136       137       138

INLINE FUNCTIONS     TYPE     ARGS       DEF LINE   REFERENCES
        ABS          REAL      1 INTRIN                70        71

STATEMENT LABELS                    DEF LINE     REFERENCES
     0  1          INACTIVE            25         2*24
   121  2                              79          24
   155  3                             103         100
     0  4          INACTIVE           101         100
   173  5                             105         100        102       2*103
     0  6          INACTIVE           104         103
   176  7                             105        2*104
     0  8          INACTIVE           107         106
   202  9                             112         109
     0  10         INACTIVE           110        2*109
     0  11         INACTIVE           113         112
   205  12                            115        2*112
   212  13                            116         106        111        114
     0  14         INACTIVE           118         117
     0  15         INACTIVE            20        2*18
   217  16                            120        2*117
   225  17                            125         119       2*121
     0  18         INACTIVE           122         121
     5  20                             24          18
    27  21                             43          39
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      SUBROUTINE KINDC        74/74   OPT=1                                FTN 4.5+428          79/01/15. 08.01.01         PAGE     8

 STATEMENT LABELS                     DEF LINE    REFERENCES
       0   30          INACTIVE         67          96
     153   31                           96         2*96
     117   49                           76          74
       0   50          INACTIVE         75         2*74
       0  100          INACTIVE         81         2*80
     445  101                          202          80
       0  102          INACTIVE        204         203
     454  103                          207         203
     517  104      FMT                 215         213
       0  200          INACTIVE        151        2*150
     302  202                          154         150
       0  300          INACTIVE        156        2*155
     315  302                          159         155
       0  400          INACTIVE        161        2*160
     332  402                          164         160
       0  500          INACTIVE        170        2*169
     352  501                          173         169
       0  502          INACTIVE        174         173
     351  503                          177        2*173
     354  504                          179         172          176

 COMMON BLOCKS      LENGTH       MEMBERS - BIAS NAME(LENGTH)
          XFLOAT      500                  0 A      (500)
          IFIXED      200                  0 IA     (200)
          CHF         200                  0 B      (200)
          ICHF         50                  0 IB     (50)

 EQUIV CLASSES      LENGTH       MEMBERS - BIAS NAME(LENGTH)
 A        A           500                 75 VNW    (1)            76 VEW    (1)            77 VDW    (1)
                                          82 ALT    (1)           167 DT     (1)           302 TIME   (1)
                                         418 VNTURB (1)           419 VETURB (1)           420 VDTURB (1)
                                         499 PSIW   (1)
 IA       IA          200                  0 IMODE  (1)
 B        B           200                 29 VS     (1)            34 VNWBIC (1)            35 VEWBIC (1)
                                          93 PSIS   (1)           102 HTD    (1)           140 XE     (1)
                                         141 YE     (1)
 IB       IB           50                 15 IONCE  (1)            19 IWIND  (1)

 STATISTICS
   PROGRAM LENGTH                      1005B       517
   CM LABELED COMMON LENGTH            1666B       950
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```
 6.      12.                                                              1
  .86    -.974                                                            2
   672201111     PITCH TIME HISTORY FOR# 3A AV-8A
 0.      1.25    1.75    2.      6.      6.5     9.      9.25    9.5      1
 5.5     5.      6.5     7.      7.      6.5     7.      6.5     6.4      2
 9.75    10.     10.25   10.5    11.     11.5    12.     12.5    12.75    3
 7.5     8.7     9.25    9.5     9.5     9.7     10.     9.5     9.2      4
 13.     13.25   15.     16.                                              5
 9.5     10.     10.     10.                                              6
   661201111     STEADY UBUBBLE VERSUS RANGE
 -1834. -1800. -1700. -1600. -1400. -1200. -850.  -660.   -460.           1
  0.     -.04    -.06   -.056   -.03    -.04    -.097  -.12    -.14       2
 -300.   0.      100.                                                     3
                                                                          4
   6913 1111           STEADY WBUBBLE VS RANGE
 -2700. -2600. -2250. -2000. -1500. -1100. -1000. -400.   -300.           1
  0.     .055    .07     .065    .035    0.      -.005  -.0175  0.        2
 400.    434.    510.    550.                                             3
 0.      .256    0.      0.                                               4
   760901111     DOWN WASH WITH ILBUBB=1
 -2700. -2500. -2250. -2000. -1500. -1100. -1000. -600.   -600.           1
  0.     .065    .07     .065    .035    0.      -.005  -.0175  0.        2
   71 4 1111     SIGMA RANDOM BUBBLE
 -2540. -1600. -1200. -1100. -1000. -800.   -600.   -440.   0.            1
  0.     .024    .035    .0355   .036    .0335   .021   0.      0.        2
   72 9 1111          TAU RANDOM BUBBLE
 -2540. -1600. -1200. -1100. -1000. -800.   -600.   -440.   0.            1
 1.02    1.02    1.05    .95     .82     .5      .325   .25     .11       2
   73 7 5111     DCL 120 G. TANK MOD 4 ESTIMATE
 0.      .05     .1      .15     .2      .25     .3                       1
0.                                                                        2
30.   -.42    -.354   -.288   -.223   -.1355  -.108   -.05                3
50.   -.405   -.344   -.284   -.223   -.164   -.134   -.089               4
50.   -.4     -.341   -.282   -.223   -.175   -.167   -.14                5
98.   -.4     -.341   -.282   -.223   -.175   -.167   -.14                6
   743401111        STABILIZER VS TIME FOR#38
 0.      1.      1.25    1.5     1.75    2.      2.25    3.      4.       1
 5.5     6.5     6.5     7.      7.3     7.      6.5     6.5     6.1      2
 7.      7.05    7.2     7.4     7.6     7.75    9.      9.4     10.      3
 5.      6.5     5.      5.      6.5     6.      5.5     4.5     7.       4
 10.25   10.5    10.75   11.     11.5    11.75   12.     12.75   13.      5
 8.5     7.      6.7     7.1     7.      7.5     7.7     6.2     6.2      6
 14.     15.     16.     17.     18.     18.25   20.                      7
 5.5     7.      6.      5.7     5.7     5.      5.                       8
   751301111        STICK VS STABILIZER GEARING
 -10.    -8.     -6.     -4.     -2.     -.5     0.      2.      4.       1
 -7.5    -6.6    -5.55   -4.35   -3.1    -2.05   -1.7    -.5     .5       2
 6.      8.      10.     11.3                                             3
 1.5     2.5     3.3     3.7                                              4
   760500111     VX FAR VSS=45 KNOT.PSIS=50 DEG Z=14.58
14.58   0.      37.     90.     125.    250.                              1
-10.75  75.52   71.69   39.59   29.08   26.57                             2
0.      39.33   11.8    13.82   20.84   22.95                             3
16.75   -9.05   3.67    10.63   17.09   20.55                             4
 54.    19.08   14.04   14.65   12.53   21.55                             5
 104.   11.57   9.25    6.33    14.21   39.44                             6
 170.   39.34   42.13   40.59   45.66   65.27                             7
   770500111     VX-AF .VSS=45 KNOT.PSIS=50..Z=25.
25.     0.      37.     90.     125.    250.                              1
-18.75  77.64   60.95   56.43   41.51   36.76                             2
0.      65.59   32.61   25.38   38.5    30.51                             3
18.75   10.49   17.44   20.78   27.28   27.28   26.38                     4
54.     53.9    35.23   28.17   24.18   27.88                             5
104.    37.5    64.7    1 .67   21.71   40.96                             6
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 ...      ...      ...     ...     ...     ...
         780506111          VX77- VSS=45 KNOT.Z=14.5
44.58  0       37.     90.     125.    250.                 1
-18.75 7    7  82.79   77.67   69.34   57.35                2
0.     78.49   75.16   56.57   53.55   51.35                3
18.75  79.76   56.22   41.59   40.91   43.69                4
54.    55.52   65.19   71.63   61.04   55.71                5
104.   17.65   35.79   47.93   46.63   54.48                6
170.   73.88   77.63   59.18   67.5    74.94                7
         790506111          VYHAR VSS=45 KNOT PSIS=50 DEG Z=14.58
14.58  0.      37.     90.     125.    250.                 1
-18.75 -4.95   -11.73  .73     -2.59   3.65                 2
0.     5.18    -7.2    -.07    -.23    2.49                 3
18.75  -15.63  -15.71  -4.81   .6      .93                  4
54.    -1.15   -2.26   1.33    3.27    -1.58                5
104.   5.82    12.74   7.59    3.54    -9.16                6
170.   -6.264  -.535   3.109   6.385   9.02                 7
         800506111          VYEAR VSS=45 KNOT PSIS=50 Z=25
25.    0.      37.     90.     125.    250.                 1
-18.75 -.79    -3.53   -.71    1.23    9.9                  2
0.     -5.2    -1.3    -.93    -.07    6.83                 3
18.75  1.9     -7.26   -3.     4.42    5.7                  4
54.    -.87    3.1     9.11    9.      1.11                 5
104.   18.81   13.55   8.07    5.33    -5.58                6
170.   -13.06  -4.49   .575    4.61    8.47                 7
         810506111          VYHZR VSS=45 KNOT PSIS=50 DEG
44.58  0.      37.     90.     125.    250.                 1
-18.75 1.8     2.92    6.04    9.      14.94                2
0.     -5.24   2.19    4.77    3.67    8.56                 3
18.75  8.19    11.74   3.59    2.45    7.81                 4
54.    4.24    4.32    9.8     10.13   7.5                  5
104.   5.36    10.59   14.86   8.25    6.28                 6
170.   -19.78  -12.27  -4.33   -2.808  5.414                7
         820506111          VZHAR VSS=45 KNOT PSIS=50 DEG Z=14.58
14.58  0.      37.     90.     125.    250.                 1
-18.75 -24.54  -1.09   -.05    -2.22   -.77                 2
0.     -10.45  1.2     -5.47   -6.13   2.19                 3
18.75  -4.25   -5.27   -6.56   -4.14   5.81                 4
54.    -.23    -6.15   -6.4    -3.32   7.16                 5
104.   -12.95  -2.51   2.42    6.74    12.47                6
170.   -19.138 -26.31  -23.13  -24.49  -14.85               7
         830506111          VZHAR VSS=45 KNOTS PSIS=50 DEG Z=25
25.    0.      37.     90.     125.    250.                 1
-18.75 -21.37  -13.51  -3.29   -7.69   -2.59                2
0.     -22.44  -7.15   -5.21   -3.45   3.17                 3
18.75  -3.55   -6.19   -4.56   -3.03   5.13                 4
54.    -3.77   -3.55   -4.91   -.99    9.51                 5
104.   -13.57  -1.05   5.56    9.98    14.29                6
170.   -22.509 -28.5   -22.804 -2.301  -12.75               7
         840506111          VZHAF VSS=45 PSIS=50 DEG Z=44.58
44.58  0.      37.     90.     125.    250.                 1
-18.75 -17.25  -16.49  -15.28  -2.43                        2
0.     -23.42  -15.85  -4.85   -3.78   .51                  3
18.75  -18.37  -6.6    3.28    4.07    11.51                4
54.    -14.39  -9.78   -5.     1.12    10.49                5
104.   -9.7    -2.54   2.66    6.66    10.82                6
170.   -11.68  -17.22  -18.24  -17.92  -11.459              7
         850506111          SIGA VSS=45 PSIS=50 Z=14.58
14.58  0.      37.     90.     125.    250.                 1
-18.75 5.45    16.22   19.45   14.98   17.07                2
0.     24.31   20.14   14.50   15.6    16.15                3
18.75  12.84   14.31   12.63   12.32   14.17                4
54.    15.43   15.7    14.42   15.95   14.4                 5
104.   15.95   12.36   12.39   13.91   12.65                6
170.   17.72   13.846  13.49   12.55   6.52                 7
```

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           860506111      SIGZ VSS=45 45 TS PSIS=50 Z=25 FEET
25.     .       37.    90.    125.    250.                          1
-18.75  2.86    11.79 19.77   15.26   20.54                         2
0.      15.91   20.76 18.35   15.51   14.57                         3
18.75   20.61   18.79 17.     14.67   14.45                         4
54.     17.5    19.49 18.86   17.57   16.76                         5
104.    19.21   16.25  15.12  14.95   13.51                         6
170.    16.09   13.646 13.857 12.53   5.72                          7
           870506111     SIGY VSS=45 PSIS=50 Z=44.53
44.53   0.      37.    90.    125.    250.                          1
-18.75  1.05    3.72   12.02  15.17   16.4                          2
0.      2.56    13.73  19.33  17.11   15.11                         3
18.75   4.22    20.34  23.52  19.65   14.93                         4
54.     2.06    4.75   15.93  17.07   16.19                         5
104.    15.19   16.43  14.13   13.59  13.23                         6
170.     18.25  14.01  15.18  14.05   2.772                         7
           880506111      SIGY VSS=45 PSIS=50 Z=14.58
14.58   0.       37.   90.    125.    250.                          1
-18.75  7.1      20.67 22.41  15.59   17.69                         2
0.      26.1     20.57 17.02  15.61   15.73                         3
18.75   11.43    15.46 14.03  15.45   16.9                          4
54.     15.06    15.43 15.56  17.73   17.88                         5
104.    14.55    11.01 10.66  15.68   15.77                         6
170.    15.706 17.694 17.19 17.33  9.503                            7
           890506111     SIGY VSS=45 PSIS=50    Z=25
25.     0.       37.   90.    125.    250.                          1
-18.75  4.7      13.77 21.29  20.51   18.33                         2
0.      20.41    25.7  19.81  14.08   16.57                         3
18.75   21.24    23.84 13.56  14.31   16.44                         4
54.     17.2     17.05 18.84  15.68   13.31                         5
104.    19.5     13.98 14.47  17.16   17.68                         6
170.    22.64  14.89  18.242 17.62   7.05                           7
           900506111     SIGY VSS=45  PSIS=50 Z=44.58
44.58   0.      37.    90.    125.    250.                          1
-18.75  1.19     4.28 14.92   17.18   17.58                         2
0..     2.63    14.33  21.28  20.95   16.31                         3
18.75   3.5     21.63  27.21  24.25   19.59                         4
54.     2.50    5.82   18.01  20.32   16.61                         5
104.    15.77   19.74  19.43  18.45   15.37                         6
170.    15.38   16.32  18.52  17.23   3.366                         7
           910506111      SIGZ VSS=45 PSIS=50       Z=14.95
14.58   0.      37.    90.    125.    250.                          1
-18.75  5.11    17.01  17.54  17.6    15.57                         2
0.      20.48   19.33  16.38  15.74   14.31                         3
18.75   12.41  14.11   13.04  14.33   13.47                         4
54.     15.76   15.38  14.29  16.47   14.92                         5
104.    14.25   13.52  11.15  11.5    16.63                         6
170.    15.822  14.37  14.57  13.93   7.236                         7
         · 920506111      SIGZ VSS=45 PSIS=50  Z=25
25.     0.      37.    90.    125.    250.                          1
-18.75  5.09    12.43  19.53  15.46   16.7                          2
0.      18.46   19.58  17.42  15.4    14.12                         3
18.75   19.5    17.39  17.83  16.09   14.11                         4
54.     14.84   19.47  20.11  15.29   16.56                         5
104.    17.15   14.66  13.92  13.86   14.64                         6
170.    14.019  16.54  15.672 15.37   7.118                         7
           930506111      SIGZ VSS=45 PSIS=50 Z=44.53
44.53   0.      37.    90.    125.    250.                          1
-18.75  1.42    3.49   13.32  15.39   15.34                         2
0.      4.41    16.07  20.94  20.21   15.6                          3
18.75   5.49    20.17  25.03  21.22   18.23                         4
54.     2.21    5.9    15.09  17.49   14.31                         5
104.    16.39   19.33  17.83  16.77   12.77                         6
```

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APPENDIX E

Variable Definitions for FF 1052 Program

A	Common Array
ALT	Altitude of Aircraft cg Above Sea Level - Ft.
B	Common Array
Beam	Ship Beam - Ft.
CPSIREL	Cosine of Relative Wind Angle
CPSISR	Cosine of Ship Heading Angle
CPSIW	Cosine of Absolute Wind Direction
DT	Integration Frame Time - Sec.
DTW	Integration Frame Time of Turbulence Subroutine - Sec.
DTX	Update Time Increment of X-Random Number Generator - Sec.
DTY	Update Time Increment of Y Component Random Number Generator
DTZ	Update Increment of Z Component Random Number Generator
EXPX	X Component Difference Equation Parameter
EXPY	Y Component Difference Equation Parameter
EXPZ	Z Component Difference Equation Parameter
FOMEGX	X Frequency Extrapolation Function
FOMEGY	Y Frequency Extrapolation Function
FX1	X Direction Extrapolation Function
FY1	Y Direction Extrapolation Function
FZ1	Z Direction Extrapolation Function
F1	Total Extrapolation Function
HTD	Height of Touchdown Point Above Sea Level - Ft.
IA	Integer Common Array
IB	Integer Common Array
IMODE	Simulation Mode Switch
IONCE	Random Number Startup Option Switch
IRDSTX	Initial Value of X - Random Number Sequence
IRDSTXI	Current Value of X - Random Number Sequence
IRDSTY	Initial Value of Y - Random Number Sequence
IRDSTYI	Current Value of Y - Random Number Sequence
IRDSTZ	Initial Value of Z - Random Number Sequence

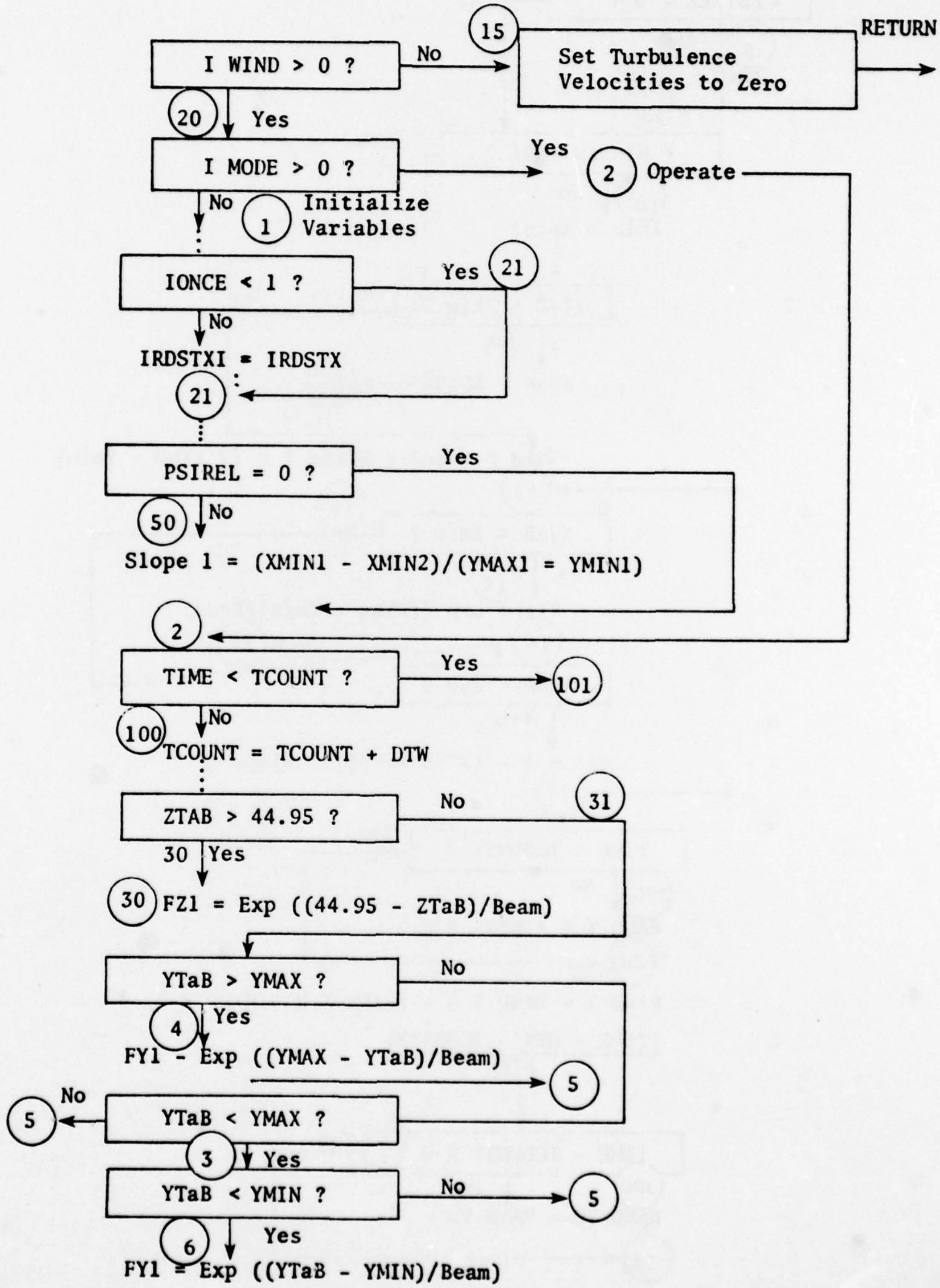
IRDSTZI	Current Value of Z - Random Number Sequence
IWIND	Turbulence on/off Flag
IX	Machine Dependent Random Number Generator Parameter
OMEGX	X - Component Filter Constant
OMEGY	Y - Component Filter Constant
OMEGZ	Z - Component Filter Constant
PI	3.14159
PSIREL	Angle of Relative Wind With Respect to Ship - Rad.
PSIS	Ship Heading - Deg.
PSISR	Ship Heading - Rad.
PSIW	Absolute Wind Direction - Rad.
RANDX	Interpolated Value of X - Component Random Number Generator
RANDXN	Current Output of X - Random Number Generator
RANDXO	Previous Output of Y - Component Random Number Generator
RANDY	Interpolated Value of Y Component Random Number Generator
RANDYN	Current Output of Y Random Number Generator
RANDYO	Previous Output of Y Random Number Generator
RANDZ	Interpolated Value of Z Component Random Number Generator
RANDZN	Current Output of Z Random Number Generator
RANDZO	Previous Output of Z Random Number Generator
RLS	Ship Length - Ft.
RLTD	Distance From Bow to Touchdown Point - Ft.
RMODE	Mode Parameter
RNX	X Component Time Increment Ratio
RNY	Y Component Time Increment Ratio
RNZ	Z Component Time Increment Ratio
SIGVX	X Velocity Variance - Ft./Sec.
SIGVY	Y Velocity Variance - Ft./Sec.
SIGVZ	Z Velocity Variance - Ft./Sec.
SIGX	Tabulated X Component Variance - Ft./Sec.
SIGY	Tabulated Y Component Variance - Ft./Sec.
SIGZ	Tabulated Z Component Variance - Ft./Sec.
SLOPEX	X Extrapolation Parameter
SLOPE1	X Boundary Definition Parameter
SPSIREL	Sine of Relative Heading Angle
SPSISR	Sine of Ship Heading

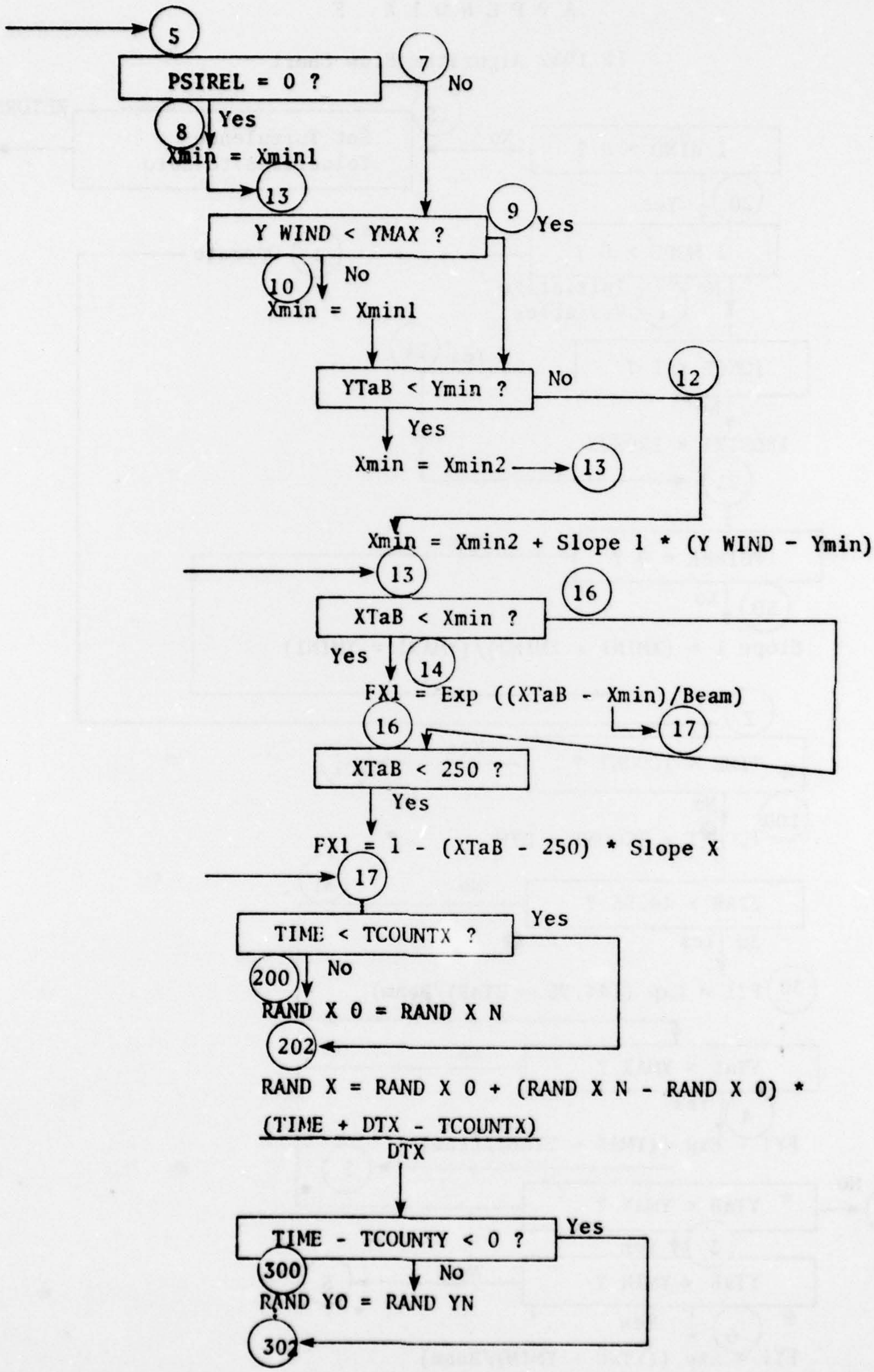
SPSIW	Sine of Wind Heading
TCOUNT	Update Time Counter - Sec.
TCOUNTX	X Update Time - Sec.
TCOUNTY	Y Update Time - Sec.
TCOUNTZ	Z Update Time - Sec.
TFAC	Turbulence Update Paramater
TIME	Simulation Time - Sec.
VDTN	Current Value of Vertical Turbulence Component - Ft./Sec.
VDTO	Previous Value of Vertical Turbulence Component - Ft./Sec.
VDTURB	Interpolated Value of Vertical Turbulence - Ft./Sec.
VDW	Total Vertical Wind Including Free Air Wind - Ft./Sec.
VETN	Current Value of Computed East Turbulence Component - Ft./Sec.
VETO	Previous Value of Vertical Turbulence Component - Ft./Sec.
VETURB	Interpolated Value of East Turbulence - Ft./Sec.
VEW	Total East Wind - Ft./Sec.
VEWBIC	Initial East Wind Component - Ft./Sec.
VNTN	Current North Turbulence Update - Ft./Sec.
VNTO	Previous North Turbulence Update - Ft./Sec.
VNTURB	Interpolated North Turbulence Component - Ft./Sec.
VNW	North Wind Component - Ft./Sec.
VNWBIC	Initial North Wind Component - Ft./Sec.
VS	Ship Speed - Ft./Sec.
VW	Total Steady Wind - Ft./Sec.
VW1	Velocity Ratio
VXBar	Mean X Turbulence Velocity - Ft./Sec.
VXT	Random X Component of Turbulence - Ft./Sec.
VXTP	Previous Value of VXT - Ft./Sec.
VXTURB	Total X Component of Turbulence - Ft./Sec.
VXWS	Tabulated Mean X Velocity Component - Ft./Sec.
VYBar	Mean Y Turbulence Velocity - Ft./Sec.
VYT	Random Y Component of Turbulence - Ft./Sec.
VYTP	Previous Value of VYT - Ft./Sec.
VYTURB	Total Y Component of Turbulence - Ft./Sec.
VYWS	Tabulated Mean Y Velocity Component - Ft./Sec.
VZBar	Z Component Mean Turbulence Velocity - Ft./Sec.
VZT	Z Component of Random Turbulence - Ft./Sec.
VZTP	Previous Value of VZT - Ft./Sec.

VZTURB	Total Z Component of Turbulence - Ft./Sec.
VZWS	Tabulated Mean Z Turbulence Velocity - Ft./Sec.
XE	North - South Distance From Aircraft cg to Touchdown Pt. - Ft.
XMIN	Forward Limit on Turbulence Region - Ft.
XMIN1	Intermediate Value of XMIN - Ft.
XMIN2	Intermediate Value of XMIN - Ft.
XTaB	X Table Lookup Parameter - Ft.
XWIND	Aircraft Position Measured Parallel to Relative Wind - Ft.
YE	Aircraft East - West Position Relative to Touchdown Point - Ft.
YMAX	Right Limit on Turbulence - Ft.
YMAX1	Intermediate Value of YMAX - Ft.
YMIN	Left Limit on Turbulence - Ft.
YMIN1	Intermediate Value of YMIN - Ft.
YTaB	Y Table Lookup Parameter
YWIND	Aircraft Position Relative to Touchdown Point Measured Transverse to Wind Direction - Ft.
ZTaB	Z Table Lookup Parameter - Ft.

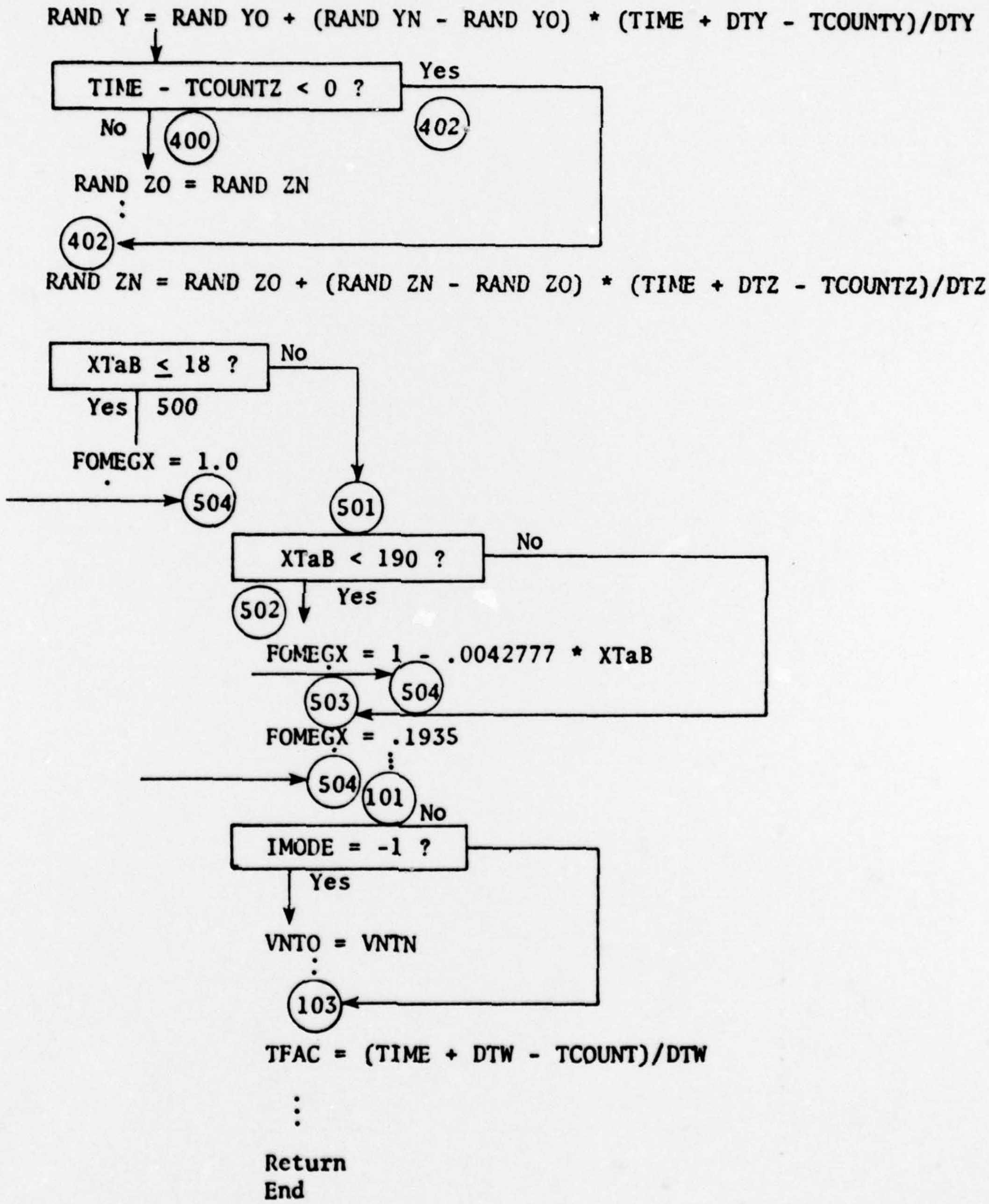
APPENDIX F

FF 1052 Algorithm Flow Chart





5
PSIREL = 0 ?
7
No
8
Yes
Xmin = Xmin1
13
Y WIND < YMAX ?
9
Yes
10
No
Xmin = Xmin1
YTaB < Ymin ?
No
12
Yes
Xmin = Xmin2
13
Xmin = Xmin2 + Slope 1 * (Y WIND - Ymin)
13
XTaB < Xmin ?
16
Yes
14
FX1 = Exp ((XTaB - Xmin)/Beam)
17
16
XTaB < 250 ?
Yes
FX1 = 1 - (XTaB - 250) * Slope X
17
TIME < TCOUNTX ?
Yes
200
No
RAND X 0 = RAND X N
202
RAND X = RAND X 0 + (RAND X N - RAND X 0) *
(TIME + DTX - TCOUNTX)
DTX
TIME - TCOUNTY < 0 ?
Yes
300
No
RAND YO = RAND YN
302


RAND Y = RAND YO + (RAND YN - RAND YO) * (TIME + DTY - TCOUNTY)/DTY
TIME - TCOUNTZ < 0 ?
Yes
No
400
402
RAND ZO = RAND ZN
402
RAND ZN = RAND ZO + (RAND ZN - RAND ZO) * (TIME + DTZ - TCOUNTZ)/DTZ
XTaB ≤ 18 ?
No
Yes
500
FOMEGX = 1.0
504
501
XTaB < 190 ?
No
502
Yes
FOMEGX = 1 - .0042777 * XTaB
504
503
FOMEGX = .1935
504
101
No
IMODE = -1 ?
Yes
VNTO = VNTN
103
TFAC = (TIME + DTW - TCOUNT)/DTW
Return
End

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