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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

NOMENCLATURE

ET	External Tank
FPR	Flight Performance Reserves (propellant required to protect for inflight dispersions)
H_o	Reference height for SVWP
h	Altitude of vehicle
Ma	Mach number
MECO	Main Engine Cut-Off
N_z, N_y	Vehicle axial accelerations
p, q, r	Vehicle roll, pitch, yaw rates
Q	Aerodynamic heat load indicator
$\dot{Q}$	Aerodynamic heat rate
q_∞	Dynamic pressure
SRB	Solid Rocket Booster(s)
SD	Standard Deviation, a sample statistical parameter
SSV	Space Shuttle Vehicle
SSWP	Synthetic Scalar Wind Profile
STS-1	Space Transportation System (flight 1)
SVWP	Synthetic Vector Wind Profile
u	Zonal wind component (positive west to east)
V	Vehicle relative velocity
v	Meridional wind component (positive to north)
w	Wind speed (scalar wind) or modulus of wind

(u,v,w are defined in the standard meteorological coordinate system)

α	Angle of attack
β	Angle of sideslip
αq^∞	Aerodynamic load indicator in pitch plane
βq^∞	Aerodynamic load indicator in yaw plane

SENSITIVITY ANALYSIS OF THE SPACE SHUTTLE TO ASCENT WIND PROFILES

I. BACKGROUND

The synthetic scalar wind profile (SSWP) [1] widely used in preliminary design for aerospace vehicle ascent structural load and performance is defined by the locus versus altitude formed by subtracting the 99th percentile conditional scalar wind shears from the given wind speed at a reference height. The given wind speed is the envelope of the 95th percentile value of the wind speed over all months for a specified launch site. A table of conditional wind speed shears for given wind speeds is furnished [1]. A discrete wind gust model is also used with the SSWP. The discrete wind gust model widely used as design criteria has a quasi-square-wave shape with an amplitude of 9 m/s (30 ft/s) and a gust length that varies from 60 to 300 m (197 to 984 ft). In practice, this gust amplitude is reduced by a factor of 0.85 when used with the SSWP model. All of these statistical parameters have been derived using empirical statistical methods. Although the SSWP model has been used for aerospace vehicle design over the past 25 years, it was found to be inadequate for the Space Shuttle. This is because of the complexity of the Space Shuttle configuration, which has four main bodies (the ET, two SRB's, and the Orbiter), and the program requirements for a versatile Space Transportation System (STS). Some subsystems of the Space Shuttle Vehicle (SSV) are more sensitive to ascent wind loads in the yaw plane than in the pitch plane. To reduce the requirements for ascent wind loads, a load alleviation technique is used for the SSV. This is done by shaping the ascent trajectory (wind biasing) to the profile of monthly mean wind components (vector mean wind) in the pitch and yaw planes. The flight control system is programmed to perform the wind load relief function through the altitude region of maximum dynamic pressure. The concern now becomes that of determining the contribution of wind dispersions with respect to the monthly vector mean wind to structural loads and performance parameters. Reference design missions were established for STS flights from Kennedy Space Center (KSC) and from Vandenberg AFB. Hence, a new wind profile model was required to permit the statistical treatment of wind as a vector quantity on a monthly basis for the two sites. This led to the development of a vector wind profile model which is outlined in Section II.

II. WINDS FOR AEROSPACE VEHICLE FLIGHT

This section treats the following topics: (1) the development of the Synthetic Vector Wind Profile (SVWP) model, (2) the time conditional change in wind vectors which is used to construct the time conditional SVWP model, and (3) statistical data samples of detailed wind profiles as measured by the Jimsphere system. The limitations of wind models and the recognition for improvements in gust modelling are discussed.

A. The Synthetic Vector Wind Profile Model

The details of the SVWP model with several options treated by Smith [2] are lengthy; hence, only the fundamental principles of these models can be presented in this report. The SVWP model uses the properties of the quadravariate normal probability distribution function. The 14 statistical parameters required to define this probability distribution function are estimated from long periods (11 years) of steady state rawinsonde wind records for Cape Canaveral and Vandenberg AFB. These 14 sample statistics relate wind vectors at one altitude to those at another altitude through the quadravariate normal probability distribution. Because aerospace vehicle designers have historically been concerned with wind shear, the tabulations of the 14 parameters have been made in terms of the zonal and meridional wind components and the differences of the zonal and meridional wind components between two altitudes. The paired differences are repeated for all altitudes at 1-km intervals from 0 to 27 km. These 14 statistical parameters for wind vectors and vector wind shears have been tabulated by monthly reference periods for Cape Canaveral and Vandenberg AFB. The conventional statistical tabulations would be the complete variance-covariance matrix of these wind components as pairs over all altitudes. The end results for the SVWP model are the same because the sum and differences of normally distributed variates are normally distributed. Using the five component winds statistical parameters at a reference height, H_0, the practice is to compute the 95 percent probability ellipse. This ellipse contains 95 percent of the wind vectors at the reference height. Wind vectors on the 95 percent ellipse at the reference height are selected. The conditional distribution of vector wind shears is computed over successive altitudes for the given wind vector at H_0. In general functional notation, the conditional distribution is:

$$f(x_1,x_2 \mid x_3,x_4) = \frac{f(x_1,x_2,x_3,x_4)}{f(x_3,x_4)}$$

where x_1, x_2, x_3, and x_4 are quadravariate normally distributed variates. Here x_3 and x_4 are the components of the given wind at H_0, and x_1 and x_2 are the components of the wind shear. The joint conditional probability for wind shears is bivariate normally distributed. These conditional distributions are made bivariate circular normal to simplify the modelling. The locus of the envelope of conditional shear circles versus altitude in-plane with the given wind vector gives the largest shears. These conditional shears are subtracted from the given wind vector. The resulting locus gives one of several options for the SVWP model. Hence, the SVWP is formed as the distribution of wind shears which varies with (1) the given wind vector at a reference height, (2) altitude, (3) month, and (4) launch site. Because this model is based on the properties of the multivariate normal distribution, it can be made completely general for any probability level. By convention, the 99 percent conditional shears are used in the SVWP. The classical 9 m/s square gust, discussed in Section I, is reduced by a factor of 0.85 when used with the SVWP.

A statistical analysis of the SVWP for the design reference missions reveals that the February SVWP for Cape Canaveral and December SVWP for Vandenberg AFB would establish the range for design requirements. The design objective is to have not more than a 5 percent chance of launch delay due to ascent winds in any month for the design reference missions.

To illustrate the principles of the SVWP, an example for the December winds at Vandenberg AFB is given. The reference height, H_0, is 10 km (Fig. 1); the given wind vector has the direction from 330 degrees with a magnitude of 57.8 m/s which intercepts the 95 percent vector wind ellipse. This wind vector represents a right-to-left quartering wind for a mission flight azimuth of 195 degrees. (The flight azimuth is measured in degrees clockwise from true north.) The 99 percent conditional shear circles are computed for all altitudes for the given wind vector. A scale plot of the conditional shear circles subtracted from the given wind vector (Fig. 2) infers that 99 percent of the wind vectors are contained in these circles given the wind vector at 10 km is from 330 degrees with a magnitude of 58 m/s. The locus of the conditional circles in-plane with 330 degrees is called the SVWP. It is represented by the continuous line in Figure 2. The dashed line in Figure 2 that passes through the center of the circles is the conditional mean vector. Another illustration of this example is shown as Figure 3. In Figure 3 the curve labeled 1 is the SVWP, and the curve

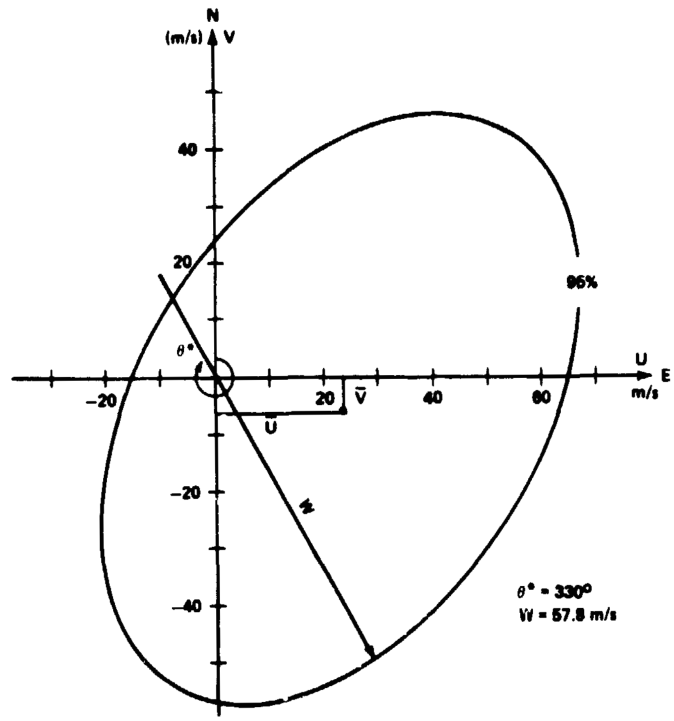

Figure 1. A 95 percent vector wind ellipse 10 km altitude, December, Vandenberg AFB.

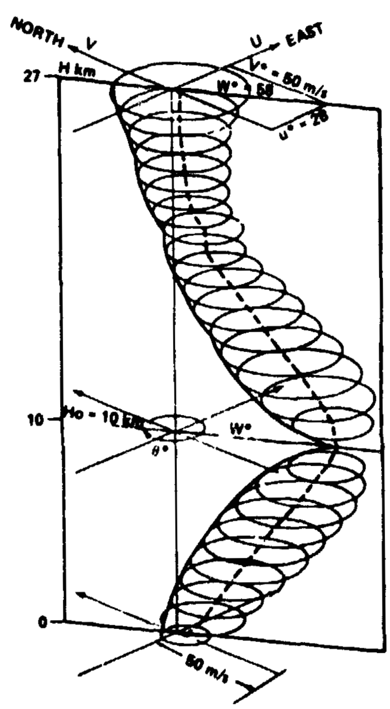

Figure 2. Conditional bivariate normal vector wind given the wind vector at H_O is 330 degrees at 58 m/s, Vandenberg AFB, December.

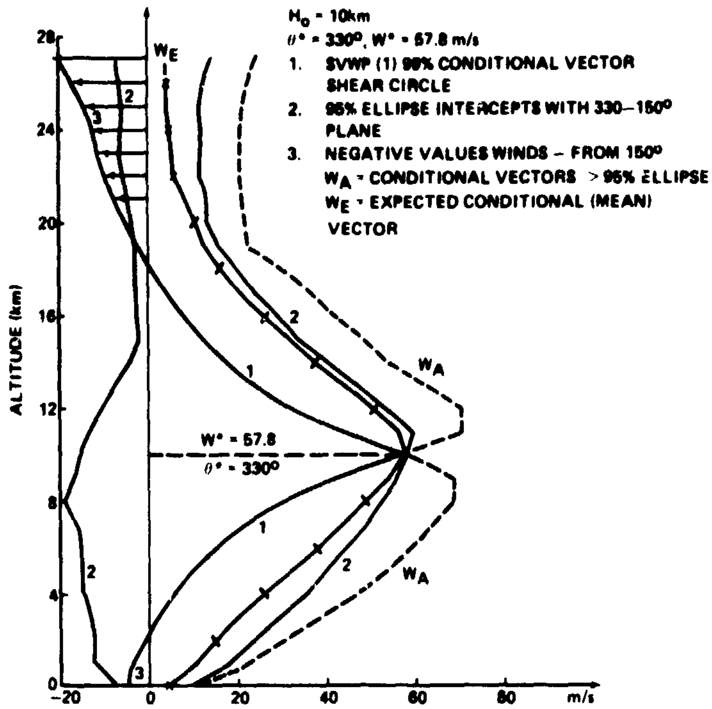

Figure 3. Synthetic vector wind profile for given wind vector at 10 km, Vandenberg AFB, December.

labeled W_E is the expected value (mean) of the conditional wind vectors. The curve labeled 2 has two branches: they are the two intercepts of the 330-150 degree plane with the 95 percent wind vector ellipses versus altitude. The curve labeled W_A is also a SVWP, but because it lies outside the envelope of the 95 percent ellipses it has not been adopted for use in the Space Shuttle program. Selections of several wind vectors at the reference height are used in the construction of SVWP, and several reference heights in the altitude region where the vehicle is most sensitive to winds are applied in the analysis. The vehicle system analysis may be made using the SVWP with or without gust.

B. Temporal Vector Wind Change and Time Conditional SVWP

For the launch operation of the Space Shuttle it has been proposed by Moote [3] to wind bias to the day-of-launch measured wind profile to further reduce the contribution of winds to the structural loads and performance requirements. To support such a procedure, a knowledge of not only the temporal variability of the wind is required, but also how much the ascent wind loads and performance parameters will vary with time. There is a requirement to make some allowance for wind loads and performance variation with respect to time during the countdown for key prelaunch operational decisions and also from the last time it is operationally feasible to perform a prelaunch flight simulation using a measured wind profile.

The statistical variation of winds with respect to time at discrete altitudes has been modelled using the properties of the quadravariate normal probability distribution. The 14 statistical parameters for this distribution have been tabulated [4] for each month at 1-km altitude intervals from 0 to 27 km for Cape Canaveral. The time conditional distribution of wind vectors for 12-hour change of time for a given wind vector is illustrated by the small ellipses in Figure 4 for five selected wind vectors. The given wind vectors I through IV are selected to be on the 95 percent April probability ellipse. The given wind vector labeled V is selected to coincide with the monthly vector mean wind. Note that all of the conditional ellipses (small ellipses) have the same size and orientation. The centroid of the small ellipses is the conditional mean. The size of the conditional ellipse decreases with decreasing time. The size of the 95 percent conditional ellipses approaches that of the monthly 95 percent ellipse as the time interval increases. Selected values on the 95 percent time conditional ellipses are used as given values at a reference height, and the SVWP is constructed as described in the previous section. In Section III performance parameters resulting from the time conditional SVWP and a sample of sequential wind profiles are compared.

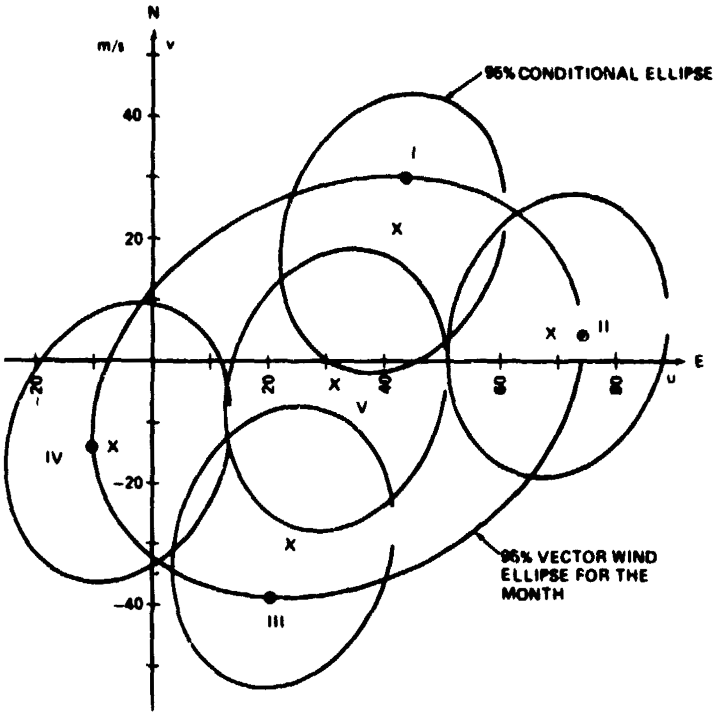

Figure 4. The 12-hour time conditional wind vectors for five given wind vectors, 12-km altitude, April, Cape Canaveral.

C. Samples of Jimsphere Wind Profiles

It was recognized early in the Space Shuttle program that all wind models have limitations. This is particularly true in depicting the structure of the wind profile as it occurs in nature. Detailed high-resolution wind profiles as measured by the Jimsphere system show many gust, shear, and wave-type oscillations that are not understood and hence are not subject to detailed modelling, nor are they predictable for aerospace vehicle launch operations. For these reasons a sample of 150 Jimsphere wind [5] profile measurements for each month was made available for Cape Canaveral for the Space Shuttle ascent design verification. These samples are also used for wind load and performance assessments for the scheduled launch month of the Shuttle.

To determine the wind loads and performance changes with respect to time for the purposes given in the previous section, a limited sample of sequential Jimsp! re wind profile measurements is available for Cape Canaveral. These measurements are at approximately 3-hour intervals. For Vandenberg AFB the available sequential data sample of Jimsphere wind profiles is even more limited.

D. Wind Gust Model

The 150 Jimsphere wind profiles have been used in the development of an improved gust model. A new concept of a vector wind gust model is reported by Smith and Adelfang [6] in which the gust amplitude and gust lengths for wind components are modelled using a bivariate gamma probability distribution function. The wind gust varies with the defining filter function, with altitude, and with season. The goal is to replace the 9 m/s design scalar wind gust (given in Section I), which is invariant with altitude and season, by this new gust model for ascent flight performance and load assessments that are done on a monthly basis.

III. ASCENT SYSTEMS ANALYSIS

In this section statistical comparisons are presented for the SSV performance parameters and ascent wind load indicators as derived from flight simulations using the SVWP model and a sample of 150 Jimsphere wind profile measurements. Also presented is a comparison of performance statistics derived from a time conditional SVWP and a sample of sequential Jimsphere wind profiles. These comparisons are illustrated from analyses for the STS-1 ascent flight using April wind models and samples of Jimsphere wind measurements for Cape Canaveral. These comparisons are summarized from more complete analyses (such as Austin [7]) to identify the contribution of winds to the ascent subsystem flight parameters.

Table 1 provides a descriptive summa. of the STS-1 ascent flight profile rence purposes. It is important to note that ascent winds during 30 to 85 s of flight time (9 to 60 tude) not only make significant contributions to the vehicle parameter variations in this flight period but also contribute to variations in the SRB staging conditions, aerodynamic heating, and flight performance reserves which occur later in flight.

TABLE 1. STS-1 ASCENT FLIGHT PROFILE

TIME SEC	ALTITUDE K FT	ALTITUDE KM	MACH NUMBER	DESCRIPTION
0	0	0	0	SRB IGNITION AND LIFT OFF
0–7	0.4	0.012	0.1	VERTICAL RISE
7–22	5	1.52	0.1–0.4	TILT MANEUVER AND ROLL TO FLIGHT AZIMUTH OF 60 DEGREES
30–85	9 TO 60	2.74 TO 18.29	0.6–2.5	PEAK WIND ENVIRONMENT; MAXIMUM DYNAMIC PRESSURE AND AERODYNAMIC LOADS REGION
90–100	80 TO 240	24.39 TO 73.17	2.5–5.0	MAXIMUM AERODYNAMIC HEATING
120–130	159 TO 170	48.48 TO 51.83	3.7–4.0	SRB TAIL–OFF AND STAGING
130–510	–	–	–	OPTIMUM GUID NCE TO MAXIMIZE PERFORMANCE AT SELECTED MECO TARGETS

A. Performance Parameters

The wind profile makes a significant contribution to the ascent flight performance parameters (Tables 2 and 3). The column heading "nominal ascent" in the tables gives the performance requirements for STS-1 wind biased to the April mean wind, and the last column is the dispersion of these parameters from all sources (i.e., the vehicle systems uncertainties combined with the wind contribution). The extreme range of performance parameters due to the wind profile as derived from the 95 percent SVWP with 99 percent conditional shears and gusts reduced by the 0.85 factor and the sample of 150 April wind profiles (Tables 2 and 3) not only illustrate the contribution of the wind profile to performance variation, but also show good agreement between the two methods. These performance parameters vary with the launch month due to different characteristics of the wind profile. Comparisons of flight parameters using the SVWP and the sample of 150 Jimsphere profiles for September and December have resulted in equally good agreement.

TABLE 2. STS-1 PERFORMANCE PARAMETER VARIATIONS FOR APRIL WINDS

PARAMETER	NOMINAL* ASCENT	EXTREME RANGE FROM		ALL DISPERSION SOURCES
		SVWP WITH GUST **	150 APRIL JIMSPHERE	
FPR (LBS)	13,465	+1750 −3080	+1215 −3145	−8700
MAX q_∞ (LB/FT^2)	575.9	+81 −36	+77 −46	+140
MAX $\dot{Q}$ (BTU/FT^2/SEC)	2.0	±0.5	±0.4	+1.1
Q SRB STAGING (BTU/FT^2)	84.5	±20	±15	+45

TABLE 3. STS-1 SRB STAGING PARAMETER VARIATIONS FOR APRIL WINDS

PARAMETER	NOMINAL * ASCENT	EXTREME RANGE FROM		FOR ALL DISPERSION SOURCES
		SVWP WITH GUST **	150 APRIL JIMSPHERE	
q_∞ (LB/FT^2)	16.4	±4	±4	+15
α (DEG)	0.62	±3	±1.5	±15
β (DEG)	−0.41	±3	±1.5	±15
h (FT)	167,266	±7000	±7000	±17000
V (FT/SEC)	4,196	±90	±100	±200
p,q,r (DEG/SEC)	−0.6, −0.1, −.16	±0.20	±0.25	±5, ±2, ±2

** SVWP

* NOMINAL TRAJECTORY WIND BIASED TO APRIL MEAN WIND

Another factor of significance with respect to these parameter variations is their reflection of the integrated effects of the wind profile during ascent. These integrated effects are representative of the steady state nature of the wind profile and, therefore, can be alleviated through the implementation of wind biasing techniques such as that discussed by Mooste [3] for day-of-launch operations. While the vehicle dynamic response as sensed by the angle of attack (α) and sideslip (β) excursions are somewhat alleviated by the use of a load relief scheme in the ascent flight control system (N_z and N_y feedback), the vehicle system response characteristics are such that large α and β dispersions still occur as a result of inflight wind shears and gusts. Unfortunately, these wind characteristics are random and not predictable by deterministic methods and, therefore, are not amenable to wind biasing techniques.

B. Ascent Wind Load Indicators

Aerodynamic load indicators are the product of angle-of-attack (α) and dynamic pressure (q_∞) and of sideslip angle (β) times dynamic pressure. For the purposes of trajectory design and mission assessments, these indicators have been found to be reliable representatives of the wind effects on the SSV structural loading in the maximum dynamic pressure flight regime. The load indicators, αq_∞ and βq_∞, for specific Mach numbers (Figs. 5 and 6) have been derived using the April 95 percent SVWP with and without the 9 m/s design gust. The solid line in these figures is the result from the April mean wind. The statistical mean values (denoted by the letter "M") obtained from 150 flight simulations using the April Jimsphere measured winds for Cape Canaveral are identical to those derived from the monthly mean wind. Also shown in Figures 5 and 6 is the 95 percent dispersion with respect to the sample mean for the Jimsphere data sample. The large differences between these load indicators for the 95 percent sample estimates and those derived from the 95 percent SVWP model are attributed to the differences in the two methods. The 9 m/s design gust is applied at each Mach number for the SVWP, whereas the data samples of Jimsphere wind profiles have gust amplitudes less than 9 m/s for gust lengths less than 300 m.

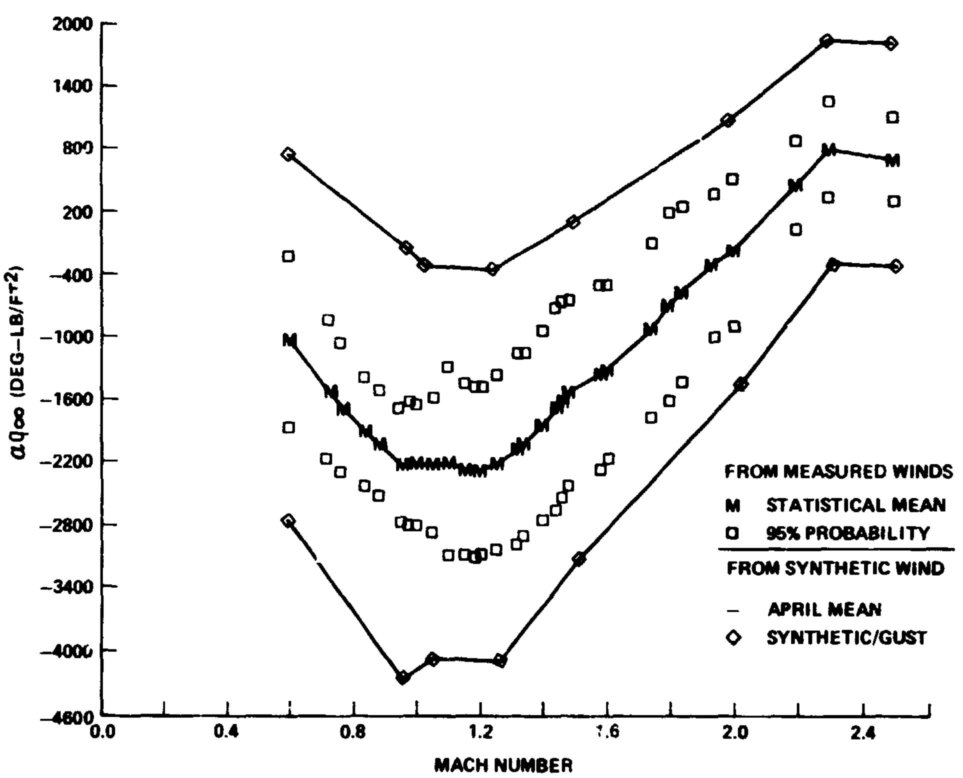

Figure 5. STS-1 wind load indicators in pitch plane from April winds, Cape Canaveral.

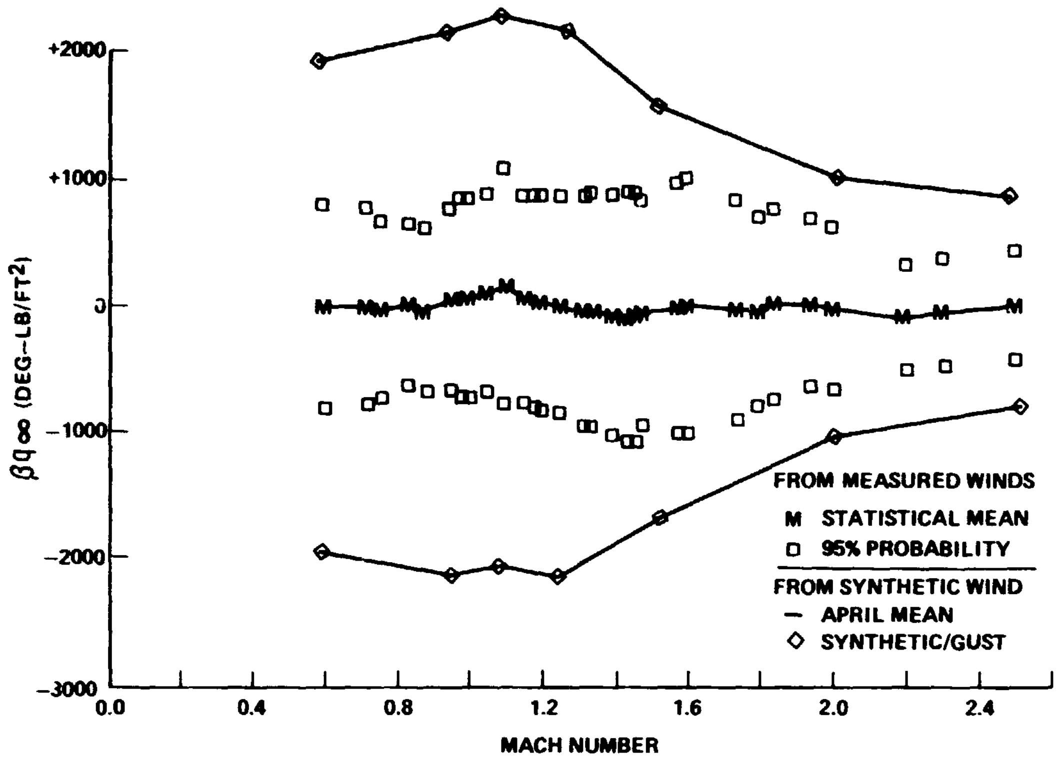

Figure 6. STS-1 wind load indicators in yaw-plane from April winds, Cape Canaveral.

The joint relationship between αq_∞ and βq_∞ serves as an important load indicator for the SSV subsystems analysis. Comparisons of the joint relationships for these load indicators for Mach numbers of 1.05 and 1.25 are shown in Figures 7 and 8, respectively. In these figures the dots represent the 150 pairs of αq_∞ and βq_∞ obtained from the April Jimsphere sample. The ellipse (heavy solid curve) is the 95 percent ellipse from this sample. This ellipse, indeed, contains 95 percent of the paired sample data points. The eight circled dots are the results from the 95 percent SVWP with the 99 percent shear without gust. The outermost values are for the 95 percent SVWP, 99 percent shear, and with the 9 m/s design gust reduced by the 0.85 factor. As shown, the 95 percent ellipse from the sample of wind measurements is very close to that given by the SVWP without gust. In addition, the significant impact of a wind gust on the SSV aerodynamic loads is seen by the approximately 850 deg-lb/ft^2 increase in the αq_∞ and βq_∞ resulting from the application of the design gust criteria. The gust contribution to the vehicle dynamic response envelope has been shown by other analyses to be approximately equal to that of all other sources of vehicle uncertainties.

The comparison of flight simulation results from wind models with those from a sample of detailed wind profiles as presented in this section is for discrete altitudes. The reader is cautioned not to conclude that the SSV is over-designed due to the use of the 9 m/s design gust criteria. These parametric analyses do not give the percentage of successful SSV flights when considering independent wind profile effects at all altitudes for the accumulation of all indicators. This subject is beyond the scope of this report.

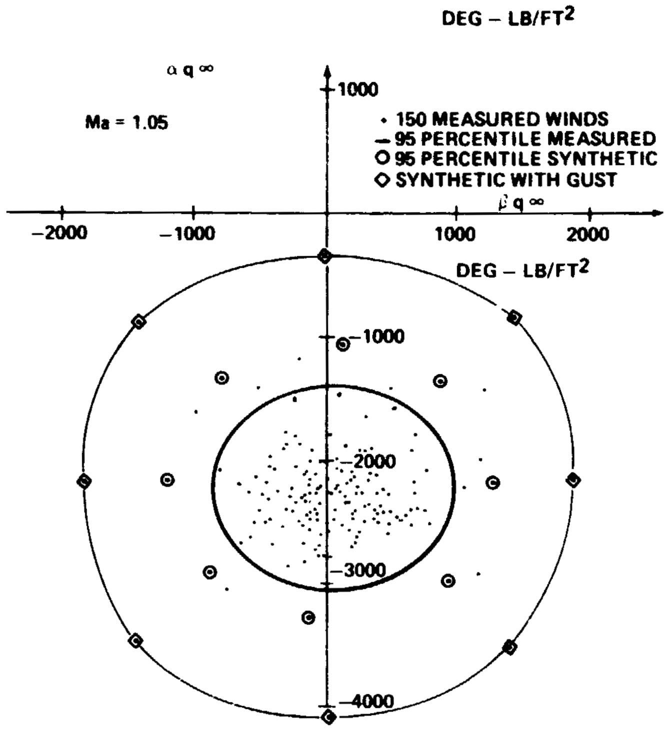

Figure 7. STS-1 pitch and yaw load indicators Ma = 1.05 from April winds, Cape Canaveral.

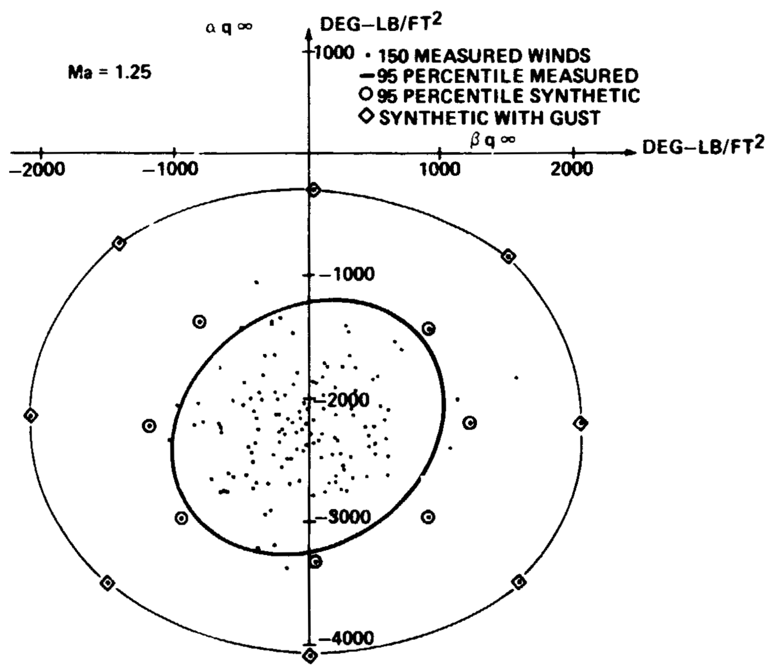

Figure 8. STS-1 pitch and yaw load indicators MA = 1.25 from April winds, Cape Canaveral.

C. Temporal Performance Variations

The sensitivity of the various ascent system indicators to inflight winds and the significant contribution of these winds to the SSV design requirements suggest a potential for increased subsystems performance margin through the implementation of a trajectory biasing concept based on a near-launch time wind environment. As a result of SSV response characteristics and the potential for a severe wind shear or gust to occur at any time during ascent, only those indicators which reflect the steady state nature of the wind will be significantly affected by a near-launch time trajectory design effort. However, the viability of such an effort depends upon the time frame required to accomplish the trajectory profile design, associated subsystem assessments, and software updates to the SSV prior to launch.

Table 4 summarizes the requirements levied on several STS-1 subsystem indicators as a result of ascent wind dispersions attendant with a trajectory profile design time frame. Current STS trajectory profiles are designed for a monthly wind dispersion since no software updates are planned near launch time. As a result, an STS-1 FPR of 1870 lb was required to protect against a launch hold for April wind uncertainties. Similarly, dynamic pressure and aerodynamic heating allowances had to be provided for the potential occurrence of near worst case April winds on launch day. However, analyses to identify the gains associated with reducing the impact of inflight wind dispersions on SSV and trajectory design requirements indicate only 335 lb of FPR required to protect for April wind uncertainties by designing the STS-1 trajectory profile for wind measurements taken 3 hours prior to launch.

TABLE 4. STS-1 TEMPORAL PERFORMANCE DISPERSIONS FOR APRIL WINDS

PARAMETER	3 STANDARD DEVIATIONS SYSTEMS DISPERSIONS	MONTHLY DISPERSION FROM 95% SVWP *	3 STANDARD DEVIATIONS CHANGES W.R.T. TIME			
			FROM SEQUENTIAL JIMSPHERE WINDS			FROM TIME CONDITIONAL SVWP *
			Δt = 3 HR	Δt = 6 HR	Δt = 9 HR	Δt = 24 HR
FPR (LBS)	6500	1870	335	500	924	1440
MAX q_∞ (LB/FT^2)	59	75	13.5	22.5	33	56
q_∞ SRB STAGING (LB/FT^2)	10	4	1	2	3	3
MAX $\dot{Q}$ (BTU/FT^2/SEC)	0.7	0.4	0.2	0.2	0.3	0.3
Q SRB STAGING (BTU/FT^2)	30	15	6	8	12	12

* SVWP – SYNTHETIC VECTOR WIND PROFILE WITHOUT GUST

As with the results presented in the previous section, the statistical analyses were made with a time conditional SVWP model and with a sample of Jimsphere wind profile measurements. The parameter variations for STS-1 presented in Table 4 were obtained from a statistical assessment of 144 Jimsphere wind profiles sequentially measured at 3-, 6-, and 9-hour intervals. The synthetic time conditional wind model has been used to identify parameter variations for various launch months (February, April, September, and December) and trajectory profile design time frames (6, 9, 12, 24, 48, and 72 hours). Figures 9 and 10 give

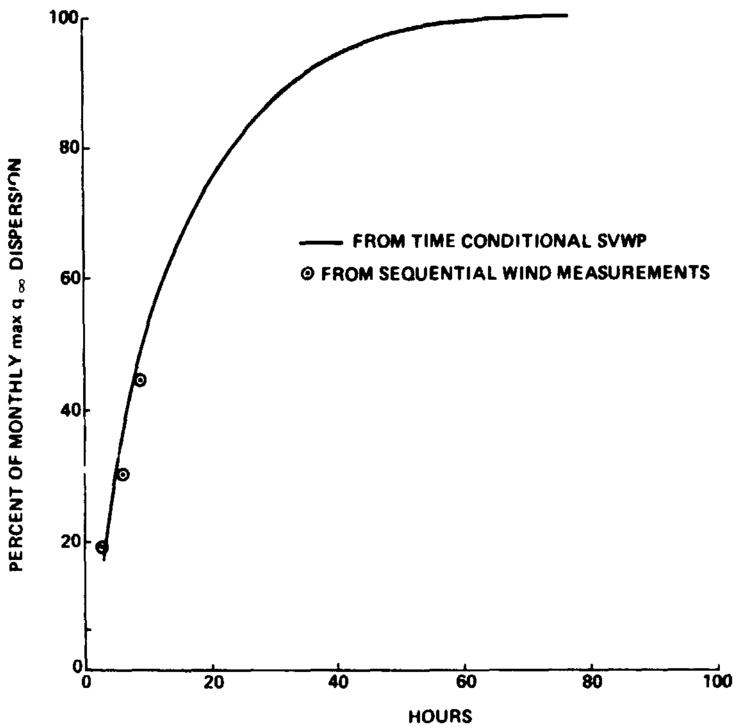

Figure 9. STS-1 three standard deviation change in max q_{∞} relative to monthly dispersion, April winds, Cape Canaveral.

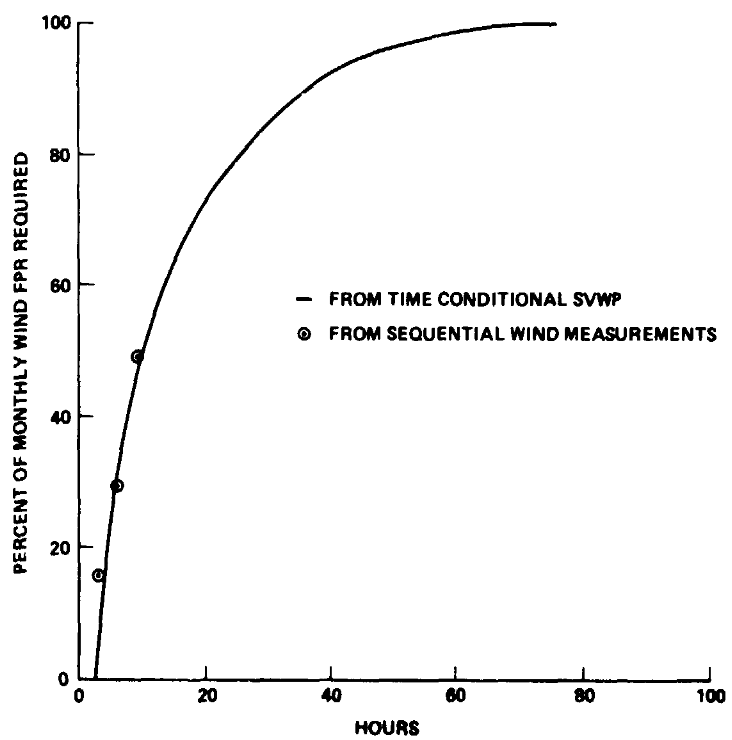

Figure 10. STS-1 three standard deviation change in FPR relative to monthly dispersion, April winds, Cape Canaveral.

the time variation for the SSV dynamic pressure dispersion and FPR. These parameters have been normalized to their monthly wind variation levels to provide a more generalized assessment of the impact of changes in these parameters due to temporal changes in the wind. While these results show the good agreement between the synthetic and measured winds, they also indicate a potential to reduce the wind dispersion allowance to 50 percent of the monthly requirement by shaping the ascent trajectory profile for a wind measured approximately 10 hours prior to launch.

IV. CONCLUSIONS

Using STS-1 as an example, the results presented herein indicate the significant role played by the ascent wind environment in the design and launch-commit criteria of the SSV. While the steady state and dynamic (discrete gusts) nature of the wind profile combine to contribute to the vehicle design requirements, some alleviation of the SSV launch-commit uncertainty is possible by biasing for steady state winds measured in the near-launch time frame. In addition, analysis results summarized in this report indicate extremely good agreement between the available synthetic wind profile models and Jimsphere measured winds. It is important to understand both the quality and applicability of the synthetic wind models so as to enhance our capability to provide detailed subsystem assessments when budget constraints and STS operational flight schedules do not permit the engineering support required by a measured wind data base.

REFERENCES

1. Daniels, Glenn E., Ed.: Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development, 1973 Revision. NASA TMX-64757, July 5, 1973.

2. Smith, O. E.: Vector Wind and Vector Wind Shear Models 0 to 27 km Altitude for Cape Kennedy, Florida, and Vandenberg AFB, California. NASA TMX-73319, July 1976.

3. Moote, Jack D.: Update of Space Shuttle Ascent Steering Parameters Using Day of Launch Winds. Rockwell Report, SD 78-SR-0018; presented at Conference on Atmospheric Environment of Aerospace Systems and Applied Meteorology, November 14-16, 1978.

4. Adelfang, S. I.: Analysis of Vector Wind Change with Respect to Time for Cape Kennedy, Florida. NASA CR-150779, August 1978.

5. Camp, Dennis W.: NASA/Marshall Space Flight Center's FPS16 Radar/Jimsphere Wind Profile Program. AMS Bulletin, 52, No. 4, April 1971, pp. 253-254.

6. Smith, O. E., and Adelfang, S. I.: A Gust Model Based on the Bivariate Gamma Probability Distribution Function, paper presented at the 19th AIAA Aerospace Sciences Meeting, St. Louis, Missouri, January 12-15, 1981; accepted for publication in Journal of Spacecraft and Rockets, 1982.

7. Austin, Lambert D.: OFT-1 Margin Assessment. NASA JSC Internal Note, JSC-13034, August 1, 1977.