Natural Environment Considerations for Space Shuttle System Development Support

William W. Vaughan* and S. Clark Brown†
NASA Marshall Space Flight Center, Huntsville, Alabama

The natural environment criteria required for the design, development, and testing of the Space Shuttle were developed and documented early in the STS program. The design criteria document specifies environments for all phases of STS activity from prelaunch through launch, ascent, on-orbit, descent, orbiter landing, ferry flight, and Solid Rocket Booster water impact. About three-fourths of the document is devoted to winds, which include ground winds, winds aloft and turbulence. Other specifications apply to lightning and thermodynamic values for ascent and descent; radiation, gas properties, meteoroids and thermal environment for on-orbit; and sea state conditions for Solid Rocket Booster impact. At its present stage of maturity, the STS still requires important natural environment support from the empirical statistics and atmospheric models used to develop the design criteria for performance assessments, system improvements, and mission analyses.

Introduction

NATURAL environment phenomena play a significant role in the design and flight of aerospace vehicles and in associated systems. Assessment of the natural environment in the early phases of an aerospace vehicle development program is very important for the development of a vehicle with a minimum operational sensitivity to the environment. For those areas of the environment that need to be monitored prior to, and during, tests and operations, this early planning will permit development of the required measuring and communication systems for accurate and timely monitoring of the environment.

An aerospace vehicle's response to environmental disturbances, especially wind, must be carefully evaluated to ensure an acceptable design relative to operational requirements. The choice of criteria depends upon the specific launch location(s), vehicle configuration, and mission. Vehicle design, operation, and flight procedures can be separated into particular categories for proper assessment of environmental influences and impacts upon the life history of each vehicle and all associated systems. These include such topics as 1) initial purpose and concept of the vehicle, 2) preliminary engineering design for flight, 3) structural design, 4) vehicle guidance and flight control design, 5) optimizations of design limits regarding the various environmental factors, and 6) final assessment of environmental capability for launch and flight operations. The proper selection, analyses, and interpretation of environmental information are essential duties of the atmospheric scientists responsible for establishing the environmental criteria to support aerospace programs and missions.

The environmental criteria for the Space Transportation System (STS) program were developed from data based on atmospheric and climatic phenomena applicable to the operating locations.[1-3] For some parameters, theoretical estimates were judged more representative than empirical values; for example, peak ground winds.[4] Because the STS was not designed for launch or flight in severe weather conditions such as hurricanes, thunderstorms, and squalls, the wind observations associated with those events were removed when possible from the inflight criteria data base.

With respect to the STS, a review of the primary mission phases provides an excellent frame of reference from which the natural environment considerations may be developed. The STS is a vehicle which reflects the environmental concerns of a rocket and an airplane. Figure 1 provides an overview of the STS mission phases.

The phases and some principal environmental considerations may be identified as follows: 1) Mission Planning—time and frequency of environmentally unfavorable events for all mission phases, development of operational delay risks and key environmental factors for operational decisions and design inputs; 2) Prelaunch—evaluation of launch preparations and on-pad stay time—winds, lightning, precipitation, and temperature are of particular concern; 3) Launch/Ascent—structural and control system plus tower clearance are important elements, ground and inflight winds along with lightning are of major concern; 4) Booster Recovery—sea state and winds are main concern; 5) On-Orbit—system and crew performance under expected radiation (flares, etc.) is the principal item, ambient environment gas properties and meteroid flux must be considered; and 6) Descent and Landing—thermal heating and performance due to density environment and wind structure are important for this phase,

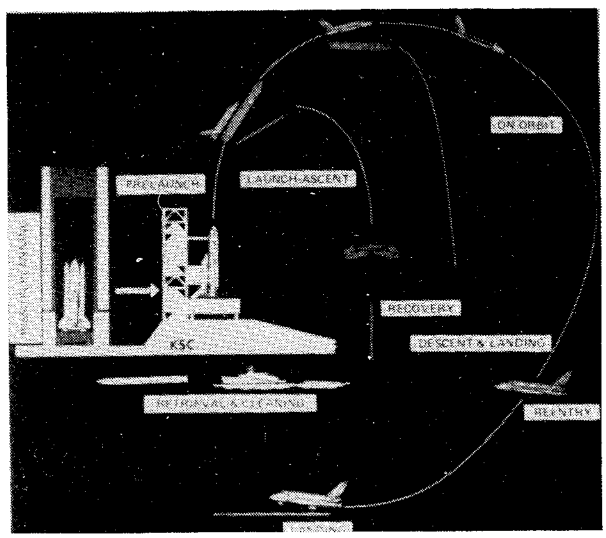

Fig. 1 Mission phases.

Submitted Aug. 16, 1983; presented as Paper 83-2663 at the AIAA Shuttle Environment and Operations Meeting, Washington, D.C., Oct. 31-Nov. 2, 1983; revision received May 30, 1984.

*Chief, Atmospheric Sciences Division. Associate Fellow AIAA.

†Aerospace Engineer.

avoidance of severe storms and their associated wind shears and lightning phenomena necessitate careful monitoring of primary and alternate landing site conditions prior to de-orbit command.

Environmental Considerations and Responses

This section is devoted to an examination of the natural environment effects on the Space Transportation System development and the response required by those effects. The effects and responses are categorized under four broad areas as follows.

Effects	Responses
A. Systems	Design philosophy development relative to natural environment input/interpretation/control
	Environment criteria and development
B. Structures and Control	Vector wind and wind shear model
	Jimsphere detail wind profile data set development
	Lift-off wind model
	Turbulence model and gust model
	Prelaunch loads monitoring—wind input definition
	Reference atmosphere models
C. Flight Operations	Mission analysis relative to atmospheric constraints—model development and analysis
	Critical operational constraint assessments
D. Thermal Protection	Reference atmosphere models

A. Systems

Design Philosophy Development

Because the wind environment, more than any other, affects the structural and control system design and performance of aerospace vehicles, it is especially important to use good technical judgment and apply sound engineering principles in preparing wind criteria that are descriptive and concise. Therefore, wind inputs have been used as the principal example for this paper.

The synthetic ground and inflight wind criteria concept has its major value and contribution to the design during the initial and intermediate phases of the development cycles of aerospace vehicles. Although a certain overall vehicle performance capability in terms of probability may be stated as a guideline, it is not realistic to expect a design to be developed that will meet this specified performance capability precisely because of the many unknowns in the vehicle characteristics and design criteria. Many advancements have been achieved regarding aerospace vehicle design, operations, and flight, but it is still not possible in these early phases to make exact statements on the overall design risks or operational capabilities of a vehicle. Therefore, it makes good engineering sense to establish a set of idealized or synthetic ground and inflight wind models which characterize such features as wind magnitude vs height, gust factors, turbulence spectra, and wind shear phenomena, and vector properties of winds.

During the later phase of a vehicle development program, when adequate vehicle response data are available, it is highly desirable, if not mandatory, to simulate the vehicle ascent flight and response to actual wind velocity profiles. However, these wind profiles should contain an adequate frequency content (gusts, turbulence, embedded jets, extreme shears, etc.) to encompass the significant frequencies of response of the vehicle to winds (control mode frequencies, first bending mode frequency, liquid propellant slosh modes, etc.). Anything short of this suggested approach would correspond to the use of only another preliminary design approximation of the natural environment. The current acceptable practice is to use a selection of detailed inflight wind profiles (resolution to about one cycle per 100 m) obtained by the FPS-16 Radar/Jimsphere technique for the launch sites of concern.

Environment Criteria and Development

Experience gained in developing design criteria for previous aerospace vehicle programs proved that to be most effective, the natural environment design criteria should be 1) available at the inception of any new program and based on the desired operational performance for the system, and 2) issued under the signature of the program manager to become part of the controlled program definition and requirements documentation.

The design criteria document specifies environments for all phases of STS activity from prelaunch through launch, ascent, on-orbit, descent, orbiter landing, ferry flight, and Solid Rocket Booster (SRB) water impact and receovery.[5] About three-fourths of the document is devoted to winds, which include ground winds, winds aloft, and turbulence. Other specifications apply to lightning and thermodynamic values for ascent and descent; radiation, gas properties, meteroids, and thermal environment for on-orbit, and sea state conditions for SRB impact.

B. Structures and Control

Wind and Turbulence Models for Space Shuttle—A Brief Summary

Reference 5 contains the appropriate Space Shuttle design wind and turbulence criteria. These wind criteria are based on avoidance of inflight thunderstorm penetrations by the Space Shuttle during tests and operations. (This restriction also provides for the avoidance of inlight lightning encounters). Wind and turbulence criteria enter into the Space Shuttle structural and control design during its stay on pad prior to launch, during launch and ascent, and during descent and landing.

Ground winds, those winds in the lowest 150 m of the atmosphere, are characterized by very complicated three-dimensional flow patterns with rapid variations in speed and direction in space and time. The forces generated by von Karman vortex shedding are an example of the ground wind effect on space vehicles. These forces can result in base bending moments while the vehicle is on the launch pad and in pitch and yaw plane angular accelerations during lift-off.

Peak wind statistics have three advantages over mean wind statistics. First, peak wind statistics do not depend upon an averaging operation as do mean wind statistics. Second, to construct a mean wind sample, a chart reader or weather observer must perform an "eyeball" average of the wind data, causing the averaging process to vary from day to day according to the mood of the observer, and from observer to observer. (Hourly peak wind speed readings avoid this subjective averaging process). Third, to monitor winds during the countdown phase of an aerospace vehicle launch, it is easier to monitor the peak wind speed than the mean wind speed. Also, it has been estimated from wind tunnel tests that only a few seconds are required for the wind to produce near steady-state drag loads on a vehicle such as the Space Shuttle in an exposed condition on the launch pad. For these reasons, the peak wind speed has been adopted as the fundamental measurement of wind for STS design and operation. The clearly defined peak wind speed shown in Fig. 2 illustrates some of the advantages described above.

By determining the distribution functions of peak wind speeds for various periods of exposure (hour, day, month, year, etc.), it is possible to determine the probability of occurrence of a certain peak wind speed magnitude during a prescribed period of exposure of an aerospace vehicle to the natural environment. Thus, if an operation requires, for example, one hour to complete, and if the critical wind loads on the vehicle can be defined in terms of the peak wind speed, then it is the probability of occurrence of the peak wind speed during a 1-h period that gives a measure of the risk of the occurrence of structural failure. Similarly, if an operation requires one day to complete, then it is the probability of occurrence of the peak wind speed during a 1-day period that gives a measure of the risk of structural failure. See Table 1 for basic STS ground winds design criteria.

All probability statements concerning the capabilities of the STS are prescribed in terms of peak wind speed exposure statistics.[1] These peak wind statistics are usually transformed to the 18.3-m (60-ft) reference level for design purposes (or higher levels for operational applications). However, to perform loading and response calculations resulting from steady-state and random turbulence drag loads and von Karman vortex shedding loads, the engineer requires information about the vertical variation of the wind and the structure of turbulence in the atmospheric boundary layer. The philosophy is to extrapolate the peak wind statistics up into the atmosphere via a peak profile. The associated steady-state or mean wind profile is obtained by applying a gust factor that is a function of wind speed and height.

The variation of the peak wind speed in the vertical, below 150 m, for engineering purposes, can be described with a power law relationship given by

$$u(z) = u_{18.3}\left(\frac{z}{18.3}\right)^k \tag{1}$$

where $u(z)$ is the peak wind speed at height z in meters above natural grade and $u_{18.3}$ is a known peak eind speed at $z = 18.3$ m, the design reference level.

A statistical analysis of the peak wind speed profile data revealed that for engineering purposes, k is distributed normally for any particular value of the peak wind speed at the 18.3-m level. Thus, for a given percentile level of occurrence, k is approximately equal to a constant for $u_{18.3} \leq 2$ m/s. For $u_{18.3} > 2$ m/s,

$$k = c(u_{18.3})^{-3/4} \tag{2}$$

where $u_{18.3}$ has the units of meter per second. The parameter c, for engineering purposes, is distributed normally with mean value 0.52 and standard deviation 0.36 and has units of $m^{3/4}$ $s^{-3/4}$.

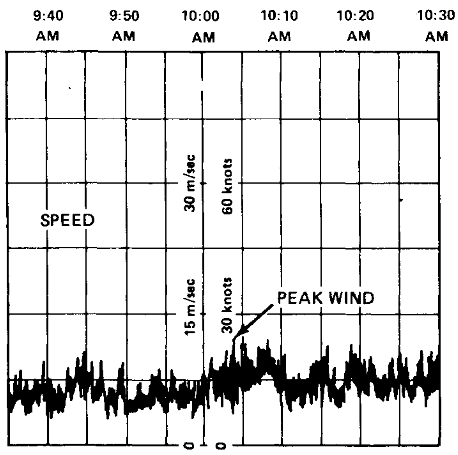

Fig. 2 Example of wind speed records.

Table 1 STS Design peak ground wind speeds

Vehicle condition	Exposure period	Risk,%	Peak Wu, m/s
Unfueled	14 days	1	31.3
Fueled	1 day	1	24.2
Launch	1 hour	5	17.7

Note: All peak wind speed profiles are calculated from Eq. (1) with $k = \bar{k} + 3\sigma$ and referenced to the 18.3-m (60-ft) reference level.

The ascent or boost phase wind environment criteria includes the vector wind and wind shears, discrete gust, and turbulence spectra.[6-9] They were formulated to produce an acceptable operational capability relative to structural and control system for the Kennedy Space Center (KSC) and Vandenberg Air Force Base (VAFB) design reference missions. (A maximum 5% launch delay risk reference criteria was selected for the windiest monthly reference period based on the steady-state vector wind profile criteria with a 1% design risk criteria relative to the associated vector wind shear, discrete gust, and turbulence spectra tuned in such a manner as to produce the maximum vehicle response for structural and control system design capability). This involved the application of the criteria for each reference mission and various azimuths and shear/gust/turbulence criteria to produce the required design characteristics for the Space Shuttle and its components. Monthly vector mean winds are included as a design wind bias, and prelaunch wind monitorship and vehicle structural and control simulation are included to minimize ascent risks relative to wind loads. Vehicle design capability was demonstrated by a detailed flight simulation for each design reference mission by use of a selection of 150 Jimsphere Vector Wind Profiles[10-12] representative of each month for each launch site. These Jimsphere Vector Wind Profiles provide the best available representation of the combined steady-state winds, shears, discrete gusts, and turbulence characteristics up to about 18 km altitude for the KSC and VAFB launch sites.

For Orbiter entry and landing, a set of wind criteria was developed to include steady-state wind profiles, wind shears, discrete gusts, and turbulence spectra with a similar rationale as for the ascent, except the steady-state wind profile values for descent were based on a 1% delay risk (rather than 5% risk for ascent) for the windiest monthly reference period. The discrete gust and turbulence spectra criteria were developed with a 1% design risk of exceedance during the specified 50-h design flight lifetime. The discrete gust and turbulence spectra criteria were developed using military and commercial aircraft design criteria data and design philosophy as a base.

The Space Shuttle natural environment requirements for design are not based on the indiscriminate operational commitment of the vehicle. Rather, they are based on the discriminate commitment of the vehicle to flight through careful advance mission planning and scheduling plus employing of a dedicated monitoring and watch of conditions, thereby minimizing potential problems and, thus, risks due to natural enviroment conditions.

All natural environment design requirements involve risk of exceedance relative to a stated reference period and represent an average risk over the period of years used as the data base. Therefore, for any given year the design value may or may not be exceeded by the stated design criteria risk value. There is no way to predict these conditions accurately in advance. Every opportunity was taken during the test phase to establish the actual natural environmental operational capabilities for the Space Shuttle since it would be a unique occurrence if the vehicle operational capability exactly matched the design requirements.

Prelaunch Loads Monitoring

The most important environmental consideration for the ascent is the wind profile, especially from about 20,000 to

50,000 ft.[13] STS ascent steering is programmed to expect the monthly mean wind in both pitch and yaw planes; thus, the ascent load problems are minimized when the mean occurs. Monthly mean wind statistics from serially complete rawinsonde observations at Cape Canaveral AFS and Vandenberg AFB[14] are used for ascent steering.

To evaluate ascent capability, frequent calculations of control, performance, and structural load values are made by simulating flight through a current Jimsphere measured detailed wind profile. These measurements are made during the prelaunch wind loads monitoring activity.

Structural Load

Beginning about 12 hours before STS launch, an intensive wind monitoring activity is begun. During this prelaunch period, load calculations are made at about 3-h intervals for all critical vehicle structures, by means of ascent simulations, using an updated Jimsphere wind profile for each simulation. The last simulation is made using a wind profile measured 3.5 h before launch. To account for uncertainties such as system dispersions and wind load changes that may occur during those last 3.5 hours, the "knockdown" load concept was adopted. "Knockdown" refers to the amount the allowable load or red line value should be reduced to account for the system uncertainties. The wind change contribution to the knockdown load is calculated from a sample of Jimsphere wind profile pairs measured 3.5 h apart. The pairs were extracted from a data base of sequential profiles[11] illustrated in Fig. 3.

Figure 4 shows the relative importance of the several system uncertainties in the knockdown load calculation for a selected load indicator as an example. The relative contribution of the 3.5 h wind change[15-17] varies depending upon the load indicator of concern.

C. Flight Operations

A set of natural environment guidelines, frequently referred to as constraints, have been developed from various sources such as design criteria, crew desires, and performance tests. These guidelines are provided in JSC-16007, "Shuttle Launch Commit Criteria and Background," and JSC-12820, "STS Operational Flight Rules," which are currently updated for each flight. Many of these values are in a state of flux, changing with the evolution of system capability, and are not hard constraints. A mission planner needs an evaluation of these constraints to answer several pertinent questions relative to environmental considerations. For example: 1) What are the optimum launch and landing times? 2) What is the probability of launch/landing delay at the scheduled time? 3) If adverse conditions occur at launch/landing time, what is the probability that they will continue for subsequent opportunities? 4) What is the probability that the landing site and alternate will both be unsatisfactory? 5) What is the contribution of each constraint to the overall probability of delay?

To respond to these questions, a mission analysis model was developed that calculates the frequency of occurrence of each "constraint" and of any "constraint" by hour for monthly reference periods.[18] The results are broken down to show the effects on prelaunch, launch, abort once around, any of the above, and for landing. An additional analysis-or-runs subroutine operates on the unfavorable cases to answer question 3 above. The principal atmospheric data bases used in these programs include surface and winds aloft observations for Cape Canaveral AFS, Vandenberg AFB, Edwards AFB, and Holloman AFB (White Sands Northrup Strip). Separate data bases of external tank ice amounts for Cape Canaveral and Vandenberg AFB are also available for use in the mission analysis programs. An example of the overall probability of landing delay and the contribution of each constraint is shown in Table 2. (This table is for model illustrative purposes only. The assigned "constraints" may not represent real landing concerns). For this example, the probability of landing delay at 0700 local standard time in January at KSC is 62%. The ceiling/visibility constraint makes the largest contribution (54%) followed by peak crosswinds (16%). The percent frequency of the individual constraints cannot be added to give the overall probability (last line) because the constraints sometimes occur at the same hour.

D. Thermal Protection

Model Atmospheres

Design requirements specify the use of specific reference model atmospheres for required engineering analyses.

Surface to Orbit Insertion

Patrick Reference Atmosphere PRA-63[1]	Nominal criteria
Vandenberg AFB Reference Atmosphere VRA-71[1]	Nominal criteria
Cape Kennedy Hot and Cold Atmospheres[1]	Extreme profiles
Vandenberg Hot and Cold Atmospheres[1]	Extreme profiles
U. S. Standard Atmosphere 1962	Engine ratings

On-Orbit

MSFC Modified-Smithsonian Model Atmosphere (MSFC/J70)—Nominal and variations in orbital altitude gas properties.[2]

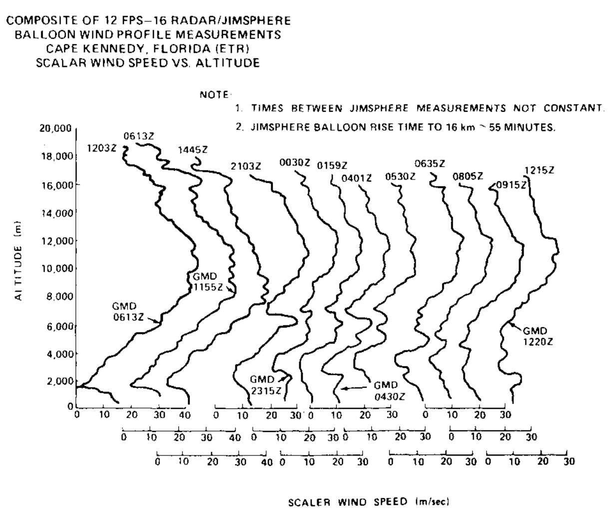

Fig. 3 Sequential Jimsphere wind profiles

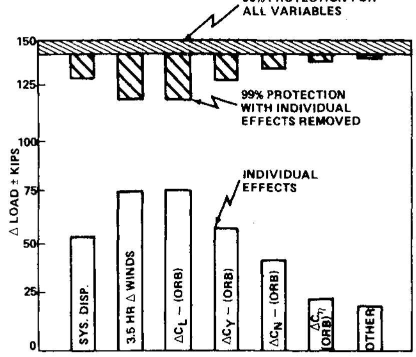

Fig. 4 Knockdown load effects example.

Table 2 Probability of atmospheric constraints from EOM landing at KSC, January

Period of record 1957-1970
Data sources:
  Deck 144
  Serially complete
  Thunderstorm
  Peak winds
Runaway angle 155.0 and 335.0 deg

Constraint/requirement	HR 00	HR 01	HR 02	HR 03	HR 04	HR 05	HR 06	HR 07	HR 08	HR 09	HR 10	HR 11	HR 12	HR 13	HR 14	HR 15	HR 16	HR 17	HR 18	HR 19	HR 20	HR 21	HR 22	HR 23
	Probabilities, %																							
Thunderstorm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Precipitation	6	4	7	6	7	9	7	8	7	9	7	7	7	7	6	4	6	5	6	6	7	6	7	6
Cloud ceiling < or = 2000 ft and/or visibility <8.n. miles	40	45	42	45	48	50	49	54	52	45	45	41	38	36	37	36	34	35	35	33	36	35	37	36
Visibility <O.n. miles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cloud cover >9.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peak winds Head wind > 25 knots Tail wind > 10 knots	1	1	1	1	1	1	2	1	1	2	3	2	3	3	3	2	4	2	1	1	1	1	0	0
Surface crosswind >99 knots –	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peak crosswind, >10 knots –	17	16	17	15	15	16	15	16	16	23	29	32	32	35	33	30	30	22	17	15	16	19	19	18
Any of the above	47	53	50	51	54	57	56	62	59	59	61	62	58	59	57	54	55	48	44	41	45	44	46	45

Descent and Entry

The atmospheric model used for all reentry analysis down to 20 km altitude is the Global Reference Atmosphere Model (GRAM).[19] This model generates realistic profiles of atmospheric variable—wind, pressure, temperature, and density—along any vehicle trajectory from orbital altitudes to sea level on a worldwide basis. The model has been computerized and is available to give these variables and their structure as a function of the three spatial coordinates, latitude, longitude, and altitude, and of the time domain (month). The GRAM is a composite of other atmospheric models together with new techniques to join models and simulate perturbations. From 30 km to the Earth's surface, the ascent range reference atmospheres are used.

New Range Reference Atmospheres (RRA) for Cape Canaveral and Vandenberg AFB[20,21] are being utilized in the STS program. These new and revised RRA's present not only the mean values of the thermodynamic quantities (pressure, temperature, virtual temperature, and density), but also include statistical measures for the dispersion (i.e., standard deviations and skewness coefficients). New quantities presented are water vapor pressure and dewpoint temperature. The statistical modeling for the wind is entirely new. The new approach uses the properties of the bivariate normal probability distribution function.

External Tank Icing

Certain atmospheric conditions—precipitation, low temperature, low wind speed—are more favorable for ice formation on the External Tank (ET) during and after tank loading. ET ice predictions using current atmospheric measurements are made hourly from tank loading until launch. Also, an atmospheric database representative of the South Vandenberg launch site has been developed. These data were used in evaluating the VAFB ET ice problem and in developing an ice suppression technique.

Summary

Natural environment phenomena played a significant role in the design and development of the STS and in the integrity of the associated control systems and structures. Coordinated and controlled environmental design criteria are an important input and major building block for any aerospace vehicle development. They are based on statistics and models of environmental phenomena relative to various aerospace industrial, test, and vehicle operational launch locations. The design parameters are scaled to show the probability of reaching or exceeding certain limits determined by an analysis of the mission requirements and desired operational lifetime for the aerospace system of concern.

Careful assessment of the natural environment design requirements in the early phases of an aerospace vehicle development program is critical in developing a vehicle with a minimum of mission operational constraints. For those areas of the environment that require monitoring prior to and during tests and operations, this early planning will permit development of the required measuring and communication systems.

Good engineeing judgment must be exercised in the application of any environmental data to aerospace vehicle design analysis. Consideration must be given to the overall vehicle mission and performance requirements. Knowledge still is lacking on the relationships between some of the environmental variates which are required as inputs to the design of aerospace vehicles. Also, interrelationships between aerospace vehicle parameters and natural environment variables cannot always be clearly defined. Therefore a close working relationship and team philosophy should exist between the design/operational engineer and the respective organization's aerospace atmospheric and space technologists.

Although ideally an aerospace vehicle design should accommodate all expected operational environmental conditions, it is neither economically nor technically feasible to design an aerospace vehicle to withstand all environmental extremes. For this reason, consideration should be given to protection of aerospace vehicles from some extremes by use of support equipment and by using specialized environment monitoring personnel to advise on the expected occurrence of critical environmental conditions. The services of specialized and dedicated monitoring personnel may be very economical in comparison with more expensive designing which would be necessary to cope with all environmental possibilities. At its present stage of maturity, the STS still requires important natural environment support for performance assessments, system improvements and mission analyses.

References

[1] Turner, R.E. and Hill, C.K., "Terrestrial Environment (Climatic) Guidelines for Use in Aerospace Vehicle Development, 1982 Revision," NASA TM 82473, June 1982.

[2] Smith, R.E. and West, G., "Space and Planetary Criteria Guidelines for Use in Space Vehicle Development, 1982 Revision (Vol. 1)," NASA TM-82478, Jan. 1983.

[3] Smith, R. E. and West, G, "Space and Planetary Environment Criteria Guidelines for Use in Space Vehicle Development, 1982 Revision (Vol. II)," NASA TM-82501, June 1983.

[4] Smith, O. E., Adelfang, S. I., and Tubbs, J. D., "A Bivariate Gamma Probability Distribution with Application to Gust Modeling," NASA TM-82483, July 1982.

[5] "STS Natural Environment Design Requirements," Appendix 10.10, Vol. X, Space Shuttle Level II Program Definition and Requirements, Document JSC 07700, NASA Johnson Space Center, 1970-1983 Revision.

[6] 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.

[7] Adelfang, S. I., and Evans, B., "Vector Wind Profile Gust Model," NASA CR-161475, April 1980.

[8] Adelfang, S. I., and Smith, O. E., "Vector Wind Profile Gust Model," NASA TM-82441, Aug. 1981.

[9] Fichtl, G., "A Technique for Simulating Turbulence for Aerospace Vehicle Flight Simulation Studies," NASA TM-78141, Nov. 1977.

[10] Brown, S.C., "150 Per Month Jimsphere Wind Speed Profiles for Aerospace Vehicle Design Capability Studies, Kennedy Space Center, Florida and Vandenberg AFB, California," Internal Document 82-2, Atmospheric Science Division, NASA-Marshall Space Flight Center, Feb. 1981.

[11] Johnson, D.L. and Vaughan, W.W., "Sequential High Resolution Wind Profile Measurements," NASA TP-1354, Dec. 1978.

[12] Camp, D.W., "Development of a Procedure to Model High-Resolution Wind Profiles from Smoothed or Low-Frequency Data," NASA TP-1071, Nov. 1977.

[13] Smith, O. E. and Austin, L. D., "Sensitivity Analysis of the Space Shuttle to Ascent Wind Profiles," NASA TP-1988, March 1982.

[14] Johnson, D. L. and Brown, S. C., "Surface to 90 km Winds for Kennedy Space Center, Florida and Vandenberg AFB, California," ANSA TM-78233, July 1979.

[15] Adelfang, S. I., "Analysis of Vector Wind Change with Respect to Time for Cape Kennedy, Florida," NASA CR-150779, Aug. 1978.

[16] Adelfang, S. I., "Analysis of Vector Wind Change with Respect to Time for Vandenberg Air Force Base, California," NASA CR-150776, Aug. 1978.

[17] Adelfang, S. I., "Analysis of Wind Bias Change with Respect to Time at Cape Kennedy, Florida, and Vandenberg, AFB, California," NASA CR-15077, Aug. 1978.

[18] Smith, O. E., Batts, G. W., and Willet, J. A., "Atmospheric Constraint Statistics for the Space Shuttle Mission Planning," NASA TP-2069, Aug. 1982.

[19] Justus, C.G, Fletcher, G.R., Gramling, F.E., and Pace, W.B., "The NASA/MSFC Global Reference Atmosphere Model—Mode 3 (with Spherical Harmonic Wind Model)," NASA CR-3256, March 1980.

[20] Anon.: "Cape Canaveral, Florida, Range Reference Atmosphere 0-70 KM Altitude," Document DOC-361-83, Meteorology Group, Range Commanders Council, Feb. 1983.

[21] Anon., "Vandenberg AFB, California, Range Reference Atmosphere 0-70 KM Atitude," Document No. DOC-361-83, Meteorology Group, Range Commanders Council, April 1983.