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A NEW HANDBOOK FOR THE DEVELOPMENT OF SPACE VEHICLE TERRESTRIAL ENVIRONMENT DESIGN REQUIREMENTS

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Abstract

A new NASA document entitled "Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development (NASA-HDBK-1001A) has been developed. The Handbook provides terrestrial environment information, data bases, models, recommendations, etc. for use in the design, development, trade studies, testing, and mission analyses for space (or launch) vehicles. This document is organized into fourteen specific natural environment disciplines of which some are winds, atmospheric models, thermal radiation, precipitation-for-icing, cloud cover, atmospheric electricity, geologic hazards, toxic chemical release by propulsion systems, and sea state.

Atmospheric phenomena play a significant role in the design and flight of aerospace vehicles and in the integrity of the associated aerospace systems and structures. Environmental design criteria guidelines in this document are based on measurements and observations of atmospheric and climatic phenomena relative to various aerospace development, operational, and vehicle launch locations.

The natural environment criteria guidelines data presented in this Handbook were formulated based on discussions with and requests from engineers involved in aerospace vehicle development and operations. Therefore, they represent responses to actual engineering problems and are not just a general compilation of environmental data. The Handbook addresses the basis for the information presented, the interpretations of the terrestrial environment guideline given in the Handbook, and its application to the development of aerospace vehicle design requirements. Specific examples of the Handbook content and associated "lessons learned" are given in this paper.

Introduction

The NASA Standard "Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development"[3] (NASA-HDBK-1001) has been updated for release in early 2008. The current handbook was approved by the NASA Chief Engineer in 2000 as a 'NASA Preferred Technical Standard' (reference 3). However, its technical contents were based on natural environment statistics/models and criteria developed mostly in the early 1990's[6]. Therefore, a task was approved to completely update the handbook in order to reflect the current state-of-the-art in the various terrestrial environment climatic areas. This has now been accomplished. Copies may be obtained upon request to the Natural Environments Branch (EV44), NASA Marshall Space Flight Center, Huntsville, AL 35812. Or a copy can be downloaded from the NASA Technical Standards Program Website: http://standards.nasa.gov.

This handbook originally goes back to the early 1960's and has been periodically updated as a NASA Technical Memorandum (TM). The reader is also referred to the references 2, 8, 9, 12, 15 and 17 for a better insight into developing, modeling, and interpretation of terrestrial environment parameters for application to aerospace vehicle engineering problems. The SLaTS (Space Launch and Transportation Systems) document[11], along with the wind related documents [1, 13] are particularly useful in describing the various atmospheric and wind model applications.

The structure of the handbook, along with the fourteen technical sections, is given in Table 1. A few key examples of the contents of the handbook are presented in this paper. This handbook publication is prepared primarily for the aerospace community, program managers and design engineers as a source document for required natural terrestrial environment inputs for use in aerospace vehicle mission planning, design and trade studies.

Background

Atmospheric phenomena play a significant role in the design and operation of aerospace vehicles and in the integrity of the associated aerospace systems, elements and payloads. This handbook revision contains new and updated material in most sections. Specifically, aerospace vehicle design guidelines are provided and presented by sections as presented in Table 1. The last section in this handbook includes information on physical constants and English/Metric unit conversion factors.

In general, the handbook does not specify how the designer should use the data in regard to a specific aerospace vehicle design. Such specifications may be established only through analysis and study of a particular design problem. Although of operational significance, descriptions of some atmospheric conditions have been omitted since they are not of direct concern for an aerospace vehicle system's design, the primary emphasis of this document. Induced environments (vehicle caused) may be more critical than the natural environment for certain vehicle operational situations. In some cases the combination of natural and induced environments will be more severe than either environment alone. Induced environments are considered in other aerospace vehicle design criteria documents, which should be consulted for such information.

The natural environment criteria guidelines presented in the handbook were formulated based on discussions with and requests from engineers involved in aerospace vehicle development and operations and "lessons learned" since the original publication of the document in 1963. Therefore, they represent responses to actual engineering problems and are not just a general compilation of environmental data. The NASA Centers, various other Government agencies, and their associated contractors responsible for the design, mission planning, and operational studies use this document extensively. The Glossary of Climate and Meteorology, published by the American Meteorological Society, 45 Beacon Street, Boston, MA 02108, should be consulted for the definition of environment terms not otherwise defined in this document.

Engineering Importance

It is important to recognize the need to define the terrestrial environment design requirements very early in the design and development cycle of any aerospace vehicle[4]. This is especially true for a new configuration. Using the desired operational capabilities and flight profiles for the vehicle, specific definitions of the terrestrial environment can be provided which, if the aerospace vehicle is designed to accommodate, will ensure the desired operational capability within the defined design risk level. It is very important that those responsible for the terrestrial environment definitions for design of an aerospace vehicle have a close working relationship with program management and design engineers. This will ensure that the desired operational capabilities are reflected in the terrestrial environment requirements specified for design of the vehicle.

An aerospace vehicle's response to terrestrial environment design criteria must be carefully evaluated to ensure an acceptable design relative to desired operational requirements. The choice of criteria depends upon the specific launch and landing location(s), vehicle configuration, and the expected mission(s). Vehicle design, operation, and flight procedures can be separated into particular categories for proper assessment of environmental influences and impact upon the life history of each vehicle and all associated systems. These include categories such as:

(1) purpose and concept of the vehicle
(2) preliminary engineering design
(3) structural design
(4) control system design
(5) flight mechanics, orbital mechanics and performance (trajectory shaping)
(6) optimization of design limits regarding the various natural environmental factors
(7) final assessment of natural environmental capability for launch and flight operations

Another important requirement that must be recognized is the necessity for having a coordinated and consistent set of terrestrial environment requirements for use in a new aerospace vehicle's design and development. This is particularly important where diverse groups are involved in the development, and is of utmost importance for any international endeavor. A "central control point" focused on definition and interpretation of the terrestrial environment inputs is critical to the successful design and operation of any new aerospace vehicle. Without this control, different terrestrial environment values or models can be used with costly results, both in terms of money, time, and vehicle performance. This "central control point" should include responsibility for mission analysis, test support requirements, flight evaluation and operational support relative to terrestrial environment requirements.

During the early stages of a new aerospace vehicle's design and development, trade-off studies to establish sensitivities of various terrestrial environment-forcing functions are important. Feedback from these studies is key to establishing the necessary terrestrial environment inputs for the vehicle's final design requirements, including a single source (central control point) responsible for the preliminary design trade-off study terrestrial environment inputs and their interpretation is important. This will preclude a multitude of problems in the final design and development process. This will enable terrestrial environment requirements to be established with a minimum amount of communication problems and misunderstanding of design issues.

The close association between the design and test engineering groups and those responsible for the terrestrial environment inputs is key to the success of the vehicle's development process. This procedure has been followed in many NASA aerospace vehicle developments and is of particular importance for any new aerospace vehicle. Figure 1 illustrates the necessary interactions relative to terrestrial environment definition and engineering application. Feedback is critical to the process and ability to produce a viable vehicle design and operational capability.

Finally, although often not considered to be significant, it is of major importance that all new aerospace vehicle design review meetings include a representative from the terrestrial environment group (central control point) assigned to support the program. This will ensure good understanding of design requirements and timely opportunity to incorporate terrestrial environment inputs and interpretations, which are tailored to the desired operational objectives, into the design process. It is also necessary that any proposed deviations from the specified terrestrial environment requirements, including those used in preliminary design trade-off studies, be approved by the responsible terrestrial environment "central control point" to ensure that all program elements are using the same baseline inputs. This will help the program manager understand the operational impact of any change in terrestrial environment requirements before implementation into the design. Gross errors and deficiencies in design can result from use of different inputs selected from various diverse sources by those involved in design and other performance studies.

Terrestrial Environment Issues

For terrestrial environment extremes, there is no known physical upper or lower bound except for certain environmental conditions. For example, wind speed does have a strict physical lower bound of zero. Essentially all observed extreme conditions have a finite probability of being exceeded. Consequently, terrestrial environment extremes for design must be accepted with the knowledge that there is some risk of the values being exceeded. The measurement of many environmental parameters is not as accurate as desired. In some cases, the use of theoretical model estimates for design values are believed to be more representative for design use than those indicated by empirical distributions from short periods of record. Therefore, theoretical values have been given considerable weight in selecting extreme values for some parameters, i.e., the peak surface winds. Criteria guidelines are presented in the handbook for various percentiles based on available data samples. Caution should be exercised in the interpretation of these percentiles in aerospace vehicle studies to ensure consistency with physical reality, and the specific design and operational problems of concern.

Aerospace vehicles are not normally designed for launch and flight in severe weather conditions such as hurricanes, thunderstorms, ice storms, and squalls. Environmental parameters associated with severe weather that may be hazardous to aerospace vehicles include strong ground and in-flight winds, strong wind shears and gusts, turbulence, icing conditions, and electrical activity. Terrestrial environment guidelines usually provide information relative to severe weather characteristics that should be included in design requirements and specifications if required to meet the program mission requirements.

Knowledge of the terrestrial environment is also necessary for establishing test requirements for aerospace vehicles and designing associated support equipment. Such data are required to define the fabrication, storage, transportation, test, preflight design condition and should be considered for both the whole vehicle system and the components which make up the system. This is one of the uses of guideline data on terrestrial environment conditions for the various major geographic locations applicable to the design of a new vehicle and associated supporting equipment.

The group having the responsibility and authority "central control point" for terrestrial environment design requirement definition and interpretation must also be in a position to pursue applied research studies and engineering assessments relative to input updates. This is necessary to ensure accurate and timely terrestrial environment definitions that are tailored to the program's needs. Design engineers and program management that assume they can simply draw on the vast statistical data bases and numerous models of the terrestrial environment currently available in the literature, without interpretation and tailoring to specific vehicle design needs, will discover that this can prove to be a major deterrent to the successful development and operation of an aerospace vehicle.

Although a vehicle design should accommodate expected operational environment conditions, it is neither economically or technically feasible to design an aerospace vehicle to withstand all terrestrial environment extremes. For this reason, consideration should be given to the protection of vehicles from some extremes. This can be achieved by use of support equipment and specialized forecast personnel to advise on the expected occurrence of critical terrestrial environment conditions. The services of specialized forecast personnel and atmospheric measurements may be very economical in comparison with more expensive vehicle designs that would be necessary to cope with all terrestrial environment possibilities.

Although the terrestrial environment is the major environmental driver for an aerospace vehicle's design and is the focus of this document, the natural environment above 90 km must also be considered in the design of aerospace vehicles. The orbital phase of an aerospace vehicle includes exposure to space environment such as atomic oxygen, on-orbit atmospheric density, ionizing radiation, plasma, magnetic fields, meteoroids, etc., plus a few man made environments such as orbital debris. Specific aerospace vehicle space environments design requirements are normally also specified in the appropriate aerospace vehicle design criteria documentation.

Good engineering judgment must be exercised in the application of terrestrial environment inputs to an aerospace vehicle design analysis. Consideration must be given to the overall vehicle mission and system performance requirements. Knowledge is still lacking on the relationship between some of the terrestrial environment parameters that are required as inputs to the design of aerospace vehicles. Also, interrelationships between vehicle parameters and terrestrial environment variables cannot always be clearly defined. Therefore, a close working relationship and team philosophy must exist between the design and operational engineer and the respective organization's terrestrial environment specialists.

Vehicle and Environment Areas of Concern

As noted, it is important that the need for definition of the ground, ascent, on-orbit, and descent aerospace vehicle operational terrestrial environments be recognized early in the design and development phase of the vehicle program. Engineering technology is constantly changing. In some cases the current trends in engineering design have increased vehicle susceptibility to terrestrial environment factors. Based on past experience, the earlier the terrestrial environment specialists "central control point" become involved in the design process, the less the potential for negative environmental impacts on the program downstream, through redesign, operational work-around, etc.

Table 2 provides a reference guide for the terrestrial environment specialist, program management and design engineers on the development team for a new aerospace vehicle program. This information summarizes potential terrestrial environment areas of engineering concern when first surveying a vehicle program. As can be noted from this table, terrestrial environment phenomena may significantly affect multiple areas of an aerospace vehicle's design and thus operational capabilities, including areas involving structure, control, trajectory shaping (performance), heating, takeoff and landing capabilities, materials, etc. A breakout of typical terrestrial environment concerns with respect to both engineering systems and mission phase is shown in the matrix.

Selected Examples

Winds Aloft Example

The definition of ground winds and winds aloft plays a key role as inputs into the design and development of an aerospace vehicle or associated system(s). Although the value of the synthetic Vector Wind Profile (VWP) Model was presented in references 3 and 6, emphasis was also given to synthetic scalar wind profile models and their statistics. Since those publications, many VWP model improvements have been put in place [1, 13]. Detailed information on the VWP will be presented in the revised handbook as the recommended in-flight wind model A VWP example is presented in Figure 2 in which the 12 KSC, 0-27 km altitude VW profiles for February, with a reference altitude of 12 km, are used as inputs into an engineering vehicle trajectory simulation program which outputs the two aerodynamic load indicators ($Q\alpha$ and $Q\beta$) as a variable dispersion at 12 km altitude. As can be noted, the 12 resultant load indicators encompass all the 1800 measured wind input load results, as well as the 95% vector ellipse. Engineering design users do not need to input thousands of wind profiles, but only 12, if the synthetic VWP model is used.

Model Atmospheres – Earth GRAM Example

The initial development work relative to the NASA-MSFC Earth Global Reference Atmospheric Model (GRAM) occurred at Marshall Space Flight Center (MSFC) over 30 years ago as the 4-D Global Atmospheric Model. The GRAM has been improved periodically. Earth GRAM-07[10] updates the GRAM-99 version and provides complete geographical and altitude coverage (up to 2500 km) for each month of the year. Mean values of atmospheric temperature, pressure and density along with winds are available from the Earth GRAM-07 plus the variability (sigma's) about the monthly mean. An atmospheric vertical profile above any Global site or values along any inputted aerospace vehicle flight trajectory can be obtained. Figure 3 illustrates the various Earth GRAM-07 databases versus altitude that are used in the model.

The newest features that the Earth GRAM-07 model incorporates are: (1) It has the option of using either the 2006 revised Range Reference Atmosphere (RRA) data, or the earlier 1983 RRA data as a replacement for conventional Earth GRAM climatology. (2) An "auxiliary profile" feature has been implemented, allowing the user to input a data profile of pressure, density, temperature, and/or winds versus altitude to be used in place of conventional climatology values. (3) Various thermosphere improvements involving updates to the Marshall Engineering Thermosphere (MET-2007) model. (4) The Naval NRL MSIS E-00 thermosphere model, the associated Naval Harmonic Wind Model (HWM-93), along with the Jacchia-Bowman 2006 (JB2006) thermosphere model are all now included within Earth-GRAM-07 as optional features. (5) Various coordinate system changes and a revised earth reference ellipsoid. (6) Several changes/additions have been made in the perturbation model for Earth GRAM-07. These include: A new feature to update atmospheric mean values without updating perturbation values. The ability to simulate large-scale, partially-correlated perturbations as they progress over time for a few hours to a few days. A multiple-trajectory driver routine that allows multiple trajectories and perturbations to be simulated in one run. A multiple-profile driver routine that allows multiple profiles and perturbations to be simulated in one run, with small-scale correlations maintained between the profiles. Refer to reference 10 for complete details.

Figures 4 and 5 present an Earth GRAM-07 example involving a computation of mean and extreme atmospheric density values along a typical January re-entry trajectory into Edwards AFB. Figure 4 presents the X-37 ground-track, relative to the vehicle's trajectory, with associated time and altitude values. Figure 5 presents two resultant Earth GRAM-07 atmospheric density computations (as a ratio of the US76 Standard Atmosphere density). The left figure (5A) shows the trajectory path with average January density values (all versus height and longitude). The right figure (5B) presents the same trajectory verses density ratio (on ordinate) and longitude (on abscissa). Here the Earth GRAM-07 mean density is presented along with the plus and minus 2-sigma values. Also shown is one example of the monte-carlo realistic density profile along the trajectory that the Earth GRAM-07 produces.

Sea State Example

Knowledge of sea state characteristics and probabilities are important to aerospace vehicle water entry elements design and trade studies. This information is needed for use in the development of detailed design requirements and specifications, such as for entry, afloat, recovery, secure, tow back, and other operational analyses. Sea state is determined by the mean wind speed, the fetch (the distance over which it blows), and the duration of wind over open water.

The availability within the last decade of data from satellites such as GEOSAT, TOPEX/Poseidon, ERS-1, and ERS-2 coupled with computer model data has made possible the means to provide selected sea state characteristics and probabilities on essentially a global basis in a way that was previously impossible with only Land/Sea-based wind and wave measurements. Using 10 years of satellite altimeter observations of significant wave height and wind speed together with numerical model values for peak wave period, mean wave period, mean wave direction, and mean wind direction a global wind/wave atlas has been developed and recorded on CD ROM[18]. Using commercially available MATLAB software, the CD ROM can be utilized to calculate and plot historical sea state characteristics such as mean monthly wave height, mean monthly wind speed, wave height exceedance, wind speed exceedance, mean monthly spectral peak period, mean monthly spectral mean period, spectral peak period exceedance, spectral mean period exceedance, mean monthly wave duration, mean monthly wind direction, and extreme wave heights for nearly any designated latitude and longitude ocean location. It should be noted that this CD ROM uses longitudes measured East rather than West.

Figure 6 is a global contour plot example of mean monthly wave height in meters for the month of January. Figure 7 is another global plot example of mean wave direction for the month of August with arrows indicating wave direction of travel. These two figures are typical examples of the output available from the Sea State Atlas/CD ROM.[19]

Tornado Example

The SAT-3.0 tornado program from VorTek [7, 20] provided the update to the tornado statistics in the handbooks section 12. The SAT-3.0 period of record extended from 1950 through 2001 and was used in the update. Table 3 presents various tornado statistics for different sites of interest to NASA activities. The Annual Coverage Fraction (ACF) is an areal tornado statistic in which the total area encompassed by tornado tracks is calculated and used within any circular area of interest. Over this 52-year POR), Houston TX ranked number 2 in the nation behind Oklahoma City OK in total number of tornadoes per 1000 sq miles, for both a 20- and a 40-mile radius. Although Johnson Space Center (JSC) experienced far more tornadoes (310 total), within a circular radius (equivalent to a 1° latitude-longitude square) than did Marshall Space Flight Center (134 total). It turns out that the amount of ground area engulfed by the stronger and larger Marshall tornadoes (ACF = 8.1×10^{-4}) was much more than that experienced at Johnson (ACF = 3.1×10^{4}) by the weaker, mainly 'touch-down' type tornadoes that occurred at JSC. The 10 year tornado probabilities for a 1 square mile area at these locations are also given in Table 3.

Figure 8 presents as an example a map of all the tornado tracks and touchdowns (with dates and intensity) that have occurred within 20 miles of MSFC over the POR of 1950 through 2001. Figure 9 shows an example of a complete annual tornado probability map for the State of Florida with Kennedy Space Center (KSC) being close to the center of maximum tornado probability.

Summary Remarks

Given that all aerospace vehicles must operate within the terrestrial environment for some part, if not all, of their mission, the importance of having an adequate and controlled terrestrial environment definition and interpretation for design use is evident. The Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development (NASA–HDBK-1001A) is intended to serve this purpose as a source document from which terrestrial environment design requirements can be derived relative to the intended operational capability desired for a new aerospace vehicle. This handbook can be obtained and downloaded at: http://standards.nasa.gov.

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Table 1. Sectional Layout of Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development (NASA-HDBK-1001)

Section	Title
1	Introduction
2	Winds
3	Atmospheric Thermodynamic Properties and Models
4	Solar and Thermal Radiation
5	U.S. and World Surface Extremes
6	Humidity
7	Precipitation Fog and Icing
8	Cloud Phenomena and Cloud Cover Models
9	Atmospheric Electricity
10	Atmospheric Constituents
11	Aerospace Vehicle Exhaust and Toxic Chemical Release
12	Occurrence of Tornadoes and Hurricanes
13	Geologic Hazards
14	Sea State
15	Day of Launch/Flight Evaluation
16	Conversion Units
	Index

Table 2. Key Terrestrial Environment Parameters Needed versus Engineering Systems (X) and Mission Phase (P).

X	Terrestrial Environment Parameter											P
Launch Vehicle Systems (Sub-)	Winds & Gusts	Atmosphric Thermodyn	Atmosphr Constit	Solar/ Thermal Radiation	Atmosph Electricy	Clouds & Fog	Humidity	Precip or Hail	Sea State	Severe Weather	Geologic Hazzards	Mission Phase
System	X P	X P	X P	X P	X P	X P	X P	X P	X P	X P	X	Mission Analysis
Propulsion/Engine Sizing	X	X P	P		X		X P			X		Manufacturing
Structures/Airframe	X P	X P		X	X P		P	X P	X	X P	P	Testing
Performance/Trajectory G&N	X P	X P	P	P	X P	P	P	P	P	P	P	Transport & Ground Hdl
Aerodynamics	X P	X P	P	P	P		P	P	P	P		Rollout/Ch[illegible]
Thermal Loads/Aerodynamic Heat	X P	X P	P	X P	P	P	P	P	P	P		Pre-launch DOL [illegible]
Control	X P	X P	P	P	X P	P	P	P		X P		Lift Off/Ascent
Loads	X P	X P			P	P		P	X P	X P		Stages Recovery
Avionics	P	P	X	X	X P	P	X	P		X P		Flight
Materials	X	X P	X P	X P	X		X	X	X	X		Orbital
Electrical Power	P	P	X		X P	X		X P		P		Descent
[illegible]	P	X P	X P	X	P	X P	P	X P	P	P		Landing
Thermal Control	P	X P	P	X P	P		P	X P	P	P		Post-land
Telemetry, Tracking & Communication	P	X P	X P	P	X P	X P	P	X P	P	X P	P	Ferry/Transport
	P				P		P	P		P	P	[illegible]
	P	P	P		P		P	P			P	Refurbishment
Misc. Considerations	X P	X P	X P	X P	X P	X	X P	X P	X	X P	X P	Storage

Table 3. Tornado Statistics for Stations Specified, 1950-2001

Station:	Number of Tornadoes in Circular Region	Mean No./Year in Circular Region	Area* (A_2) of Circular Region km^2	(mi^2)	Radius of Circular Region km	(mi)	Annual Coverage Fraction (ACF) (yr^{-1})	Recurrence Interval 1/ACF (yr)	Average Tornado Size $\bar{A}_T$(mi^2)	10 year Tornado Prob for A=2.59km^2 or (1 mi^2)
Marshall Space Flight Center	134	2.58	10,179	(3,930)	56 89	(35.36)	**$8.069 \cdot 10^{-4}$**	**1,239**	**1.230**	**$6.54x10^{-2}$**
Kennedy Space Center	124	2.38	10,839	(4,185)	58.73	(36.50)	$7.498 \quad 10^{-5}$	13,337	0.132	$5.67x10^{-3}$
Vandenberg AFB	3	0.0577	10,179	(3,930)	56.89	(35.36)	$4.827 \cdot 10^{-10}$	$2.071 \cdot 10^{9}$	$3.29x10^{-5}$	$1.47x10^{-4}$
Edwards AFB	8	0.154	10,179	(3,930)	56 89	(35.36)	$1.851 \cdot 10^{-8}$	$5\,402 \cdot 10^{7}$	$4.73x10^{4}$	$3\,92x10^{-4}$
New Orleans	101	1 94	10,645	(4,110)	58 20	(36 17)	$3.627 \cdot 10^{5}$	27,571	$7.67x10^{-2}$	$4\,71x10^{-3}$
Stennis Sp Ctr	196	3.77	10,645	(4,110)	58.20	(36 17)	$7\,150 \cdot 10^{-4}$	1,399	0.780	$9.13x10^{-3}$
Johnson Space Center	**310**	**5.96**	10,736	(4,145)	58.44	(36 32)	$3.121 \cdot 10^{-4}$	3,204	0.217	$1.43x10^{2}$
White Sands	7	0 135	10,412	(4,020)	57.55	(35.77)	$1.017 \cdot 10^{-6}$	$9\,833 \cdot 10^{5}$	$3.04x10^{-2}$	$3.36x10^{-4}$

*** Area of circular region equal to area of 1° square.**

Note: Bold type indicates most extreme tornado statistics.

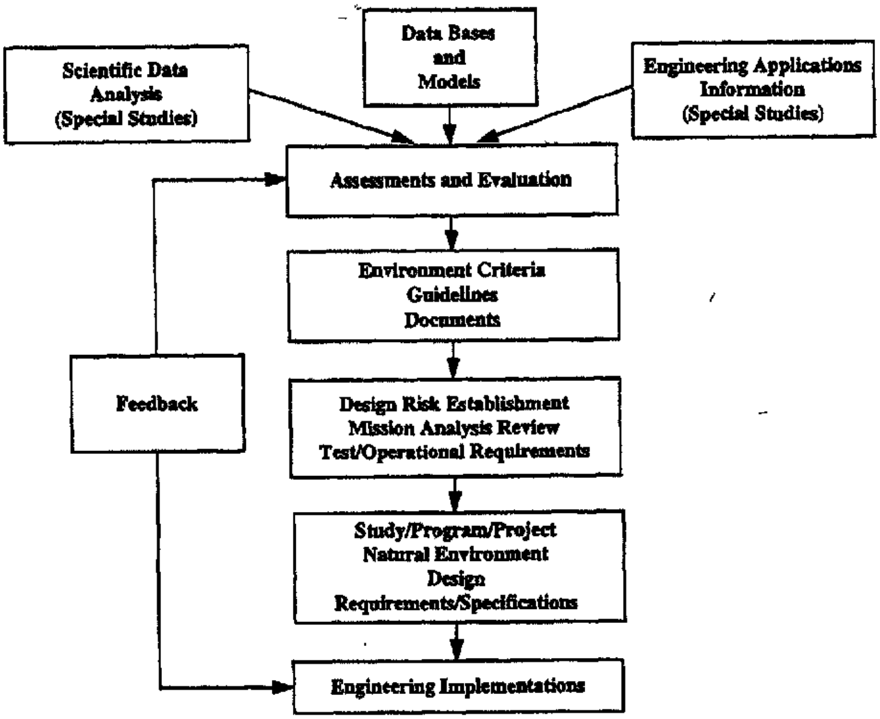


Figure 1. Natural Terrestrial Environment Definition and Analysis Process for Aerospace Vehicle Engineering Application

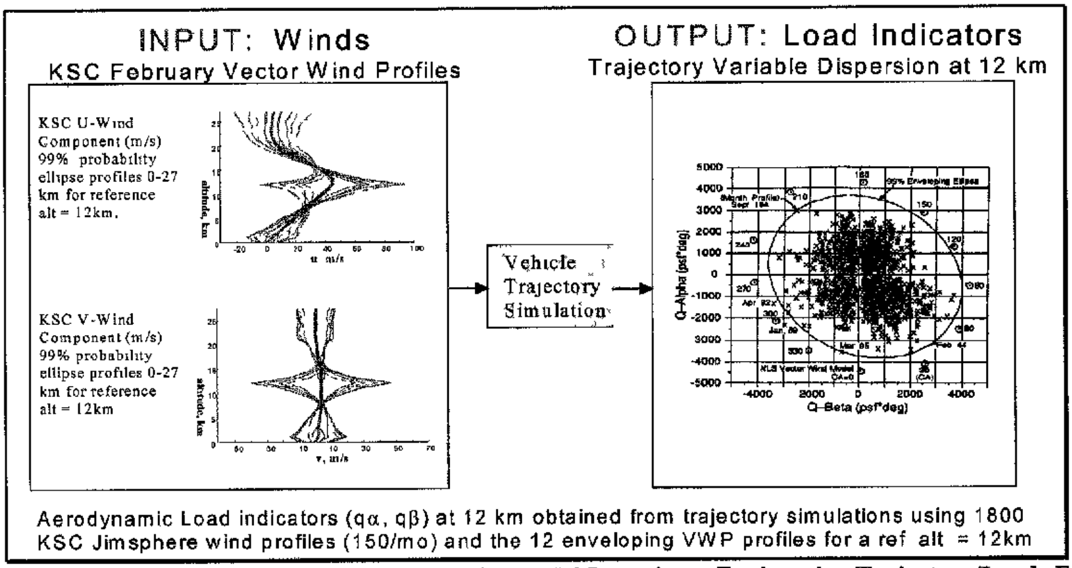


Figure 2. February KSC Vector Wind Profile Model Input in an Engineering Trajectory/Loads Example.

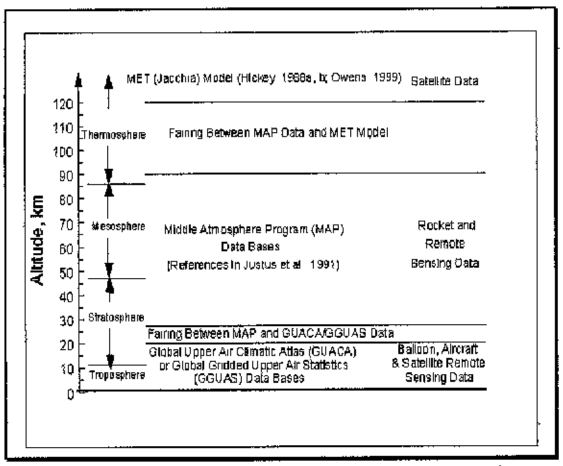
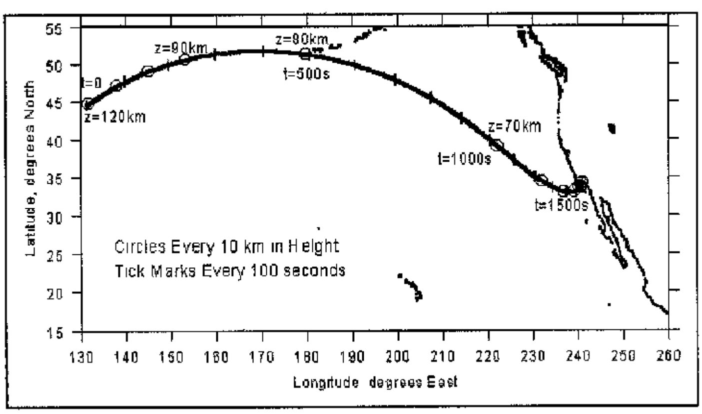


Figure 3. Schematic Summary of Atmospheric Regions and Data Sources Used in Earth GRAM-07.

Figure 4. Earth GRAM-07 Example of a Typical January Ground Track Re-entry Trajectory (57° Inclination Orbit) Landing at Edwards AFB.



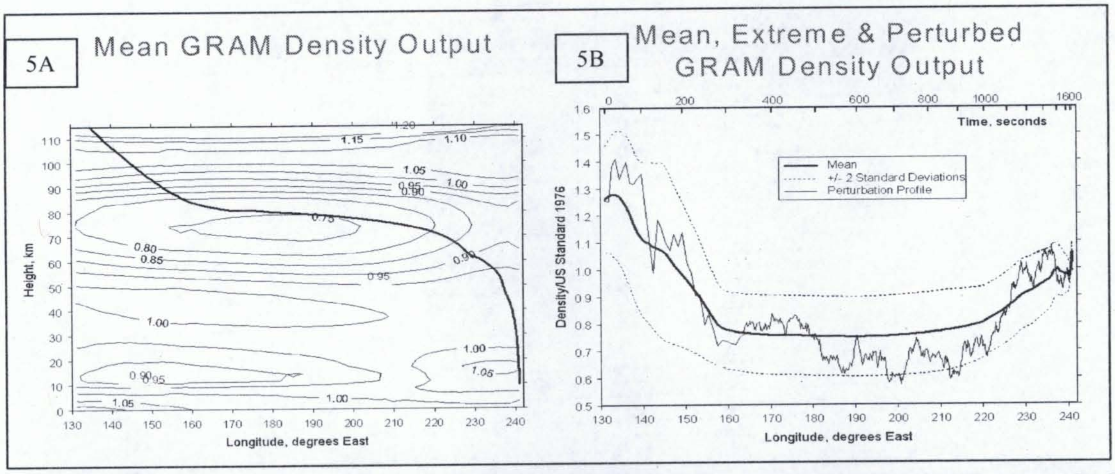


Figure 5. Resultant Earth GRAM-07 Mean and Extreme Density Values Computed Along the Example Mean January Trajectory. Figure 5A: Height vs. Longitude Cross Section of Density. Figure 5B: 2σ Density Envelopes, and One Monte-Carlo Density Perturbation Profile vs. Longitude. Density Expressed as a Ratio of US76 Standard Atmosphere Density.

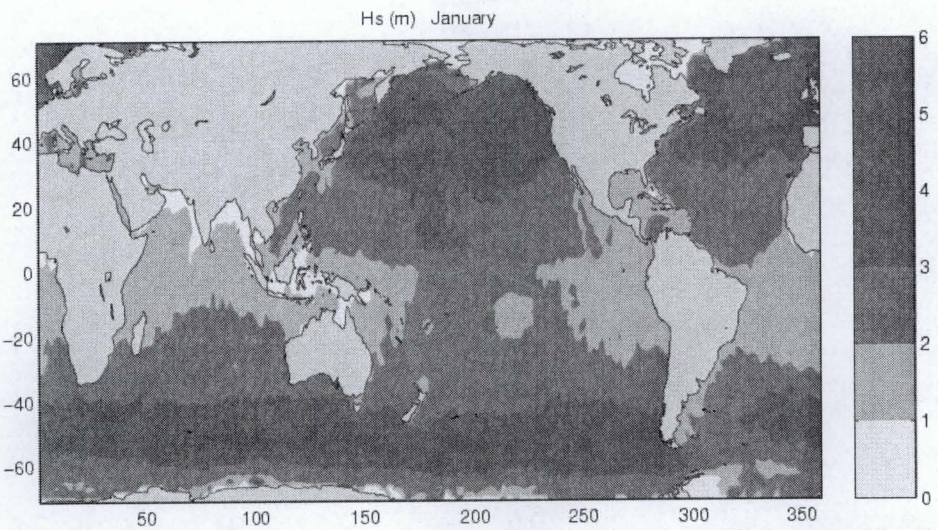


Figure 6. Global contour plot of mean significant wave height, Hs, in meters for the month of January. The darker (red) areas depict regions with wave height of greater than 5 m (16 ft.).

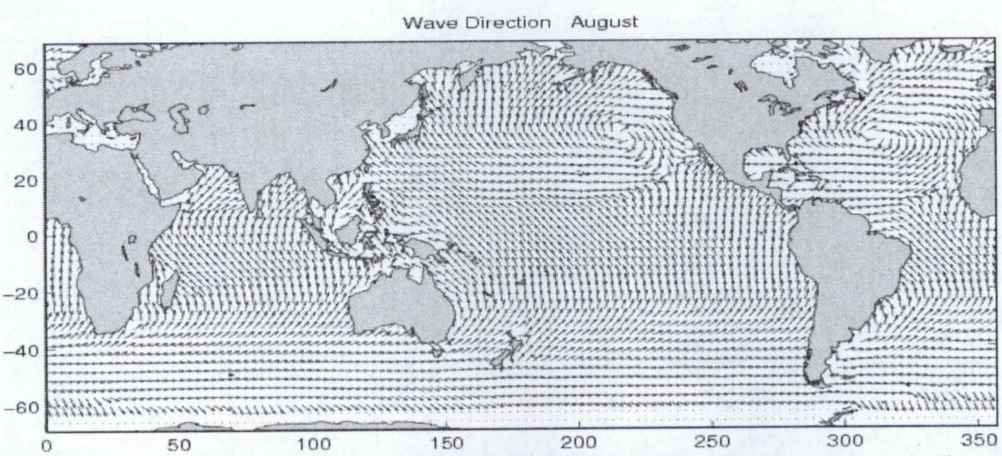


Figure 7. Global plot of mean wave direction for the month of August. Arrows indicate direction of wave travel. Note that longitudes are measured East rather than West.

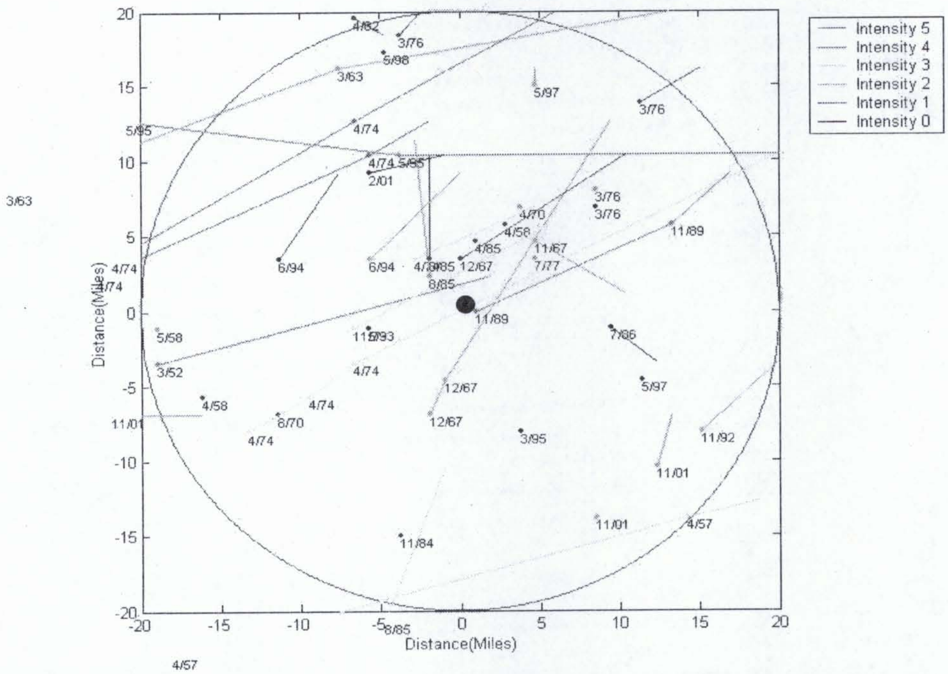


Figure 8. Tornado Tracks and Touchdowns within 20 miles of MSFC (1950-2001)

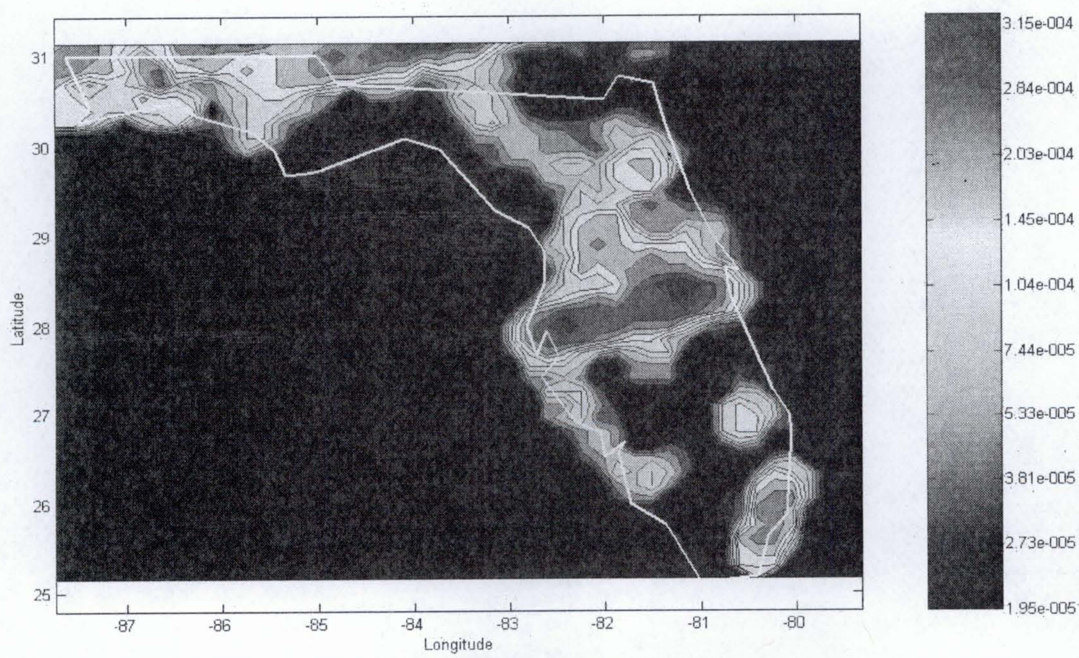


Figure 9. Tornado Probability Map for Florida (1950-2001)

MSFC - 611 - Presentation

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A New Handbook for the Development of Space Vehicle Terrestrial Environment Design Requirements

"Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development: NASA-HDBK-1001A"

Dale L. Johnson, NASA-MSFC

William W. Vaughan, UAH

(assistance from Vernon W. Keller)

AMS Conference on Aviation, Range, and Aerospace Meteorology

21-25 January 2008, New Orleans, LA

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Presentation Outline

- Introduction:
  - Terrestrial Handbook: Contents
  - Terrestrial Environment-Engineering: Philosophy
  - Terrestrial Environment-Engineering: Process
  - Key Terrestrial Environment Parameters to Consider
- Selected Examples:
  - Ground Winds - Peak
  - Winds Aloft (VWPM)
  - Ocean Waves (GOWM)
  - Tornado Statistics (SATT 3.0)
  - Mission Analysis Program (APRA)
  - Atmospheric Model (GRAM-99)
- Conclusions:

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NASA Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development: (NASA-HDBK-1001A)*

Section	Title
1	Introduction
2	Winds
3	Atmospheric Thermodynamic Properties and Models
4	Solar and Thermal Radiation
5	U.S. and World Surface Extreme
6	Humidity
7	Precipitation, Fog and Icing
8	Cloud Phenomena and Cloud Cover Models
9	Atmospheric Electricity
10	Atmospheric Constituents
11	Aerospace Vehicle Exhaust and Toxic Chemical Release
12	Occurrences of Tornadoes and Hurricanes
13	Geologic Hazards
14	Sea State
15	Day of Launch-Flight Evaluation
16	Conversion Units

* Can be electronically downloaded at: http://standards.nasa.gov in early 2008.

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Terrestrial Environment (TE) & Aerospace Vehicle (AV) Design Philosophy

- **Fact: "Terrestrial Environment parameters (also the space environment) pose a threat to the operational integrity of an AV and must be considered in engineering design" (be included in: structures, control systems, trajectory shaping, aero-heating, etc studies)**

- Now: The Project has a certain mission in mind, and wants certain desired operational capabilities & characteristics for the vehicle

- But: The TE forms a fundamental constraint to the vehicle's design and operability (applies to all phases of the mission plan from roll-out through launch to orbit and landing). Note: Ground Winds and Winds Aloft represent the largest TE constraints to AV design and development

- Therefore: The TE operability constraint is normally addressed and answered in terms of: (1) Robust Design, (2) Operational Mitigation, & (3) Mission Risk. So the influence of the TE exists, and must be managed and engineered into the vehicle's development cycle.

- NASA-HDBK-1001A Addresses & Presents Wind and Atmospheric Criteria & Models/Statistics previously used in the Design & Development of various aerospace/launch vehicle programs.

****

Terrestrial Environment Process – with Program Management & Engineering

1. Establish Project Office/Terrestrial Environment ("**Central Control Point**") Team Connection* early on.
2. Establish TE Team/Engineering Working Group*.
3. Determine (1) Vehicle - Mission Statement / Profile, & (2) Accepted Risk.
4. Initiate TE Model / Database selection process.
5. TE team to interact with Project Engineering (and Management) to define preliminary/generic TE Inputs for first concept cycle. To include TE models, parameters, & statistics tailored for vehicle/mission profile.
6. Continue TE interaction (**iteration**) with Engineering in developing program baseline TE definitions with the ultimate goal of finally arriving at a set of Final Terrestrial Environment Design Requirements that will complete the mission model and vehicle concept, given the proper **risk** analysis. The TE inputs will help drive the various engineering (system & sub-system) trade studies, and as the system design matures, the necessary TE can be supplied and **documented**. (All engineering systems should use a **common set** of Terrestrial Environment (central control point) inputs, and if a TE change is made - all systems should be aware and apply as needed.)

*** Note: The "TE/Program/Engineering" connection/working group should exist (beyond formulation) throughout the entire AV program - to launch and re-entry.**

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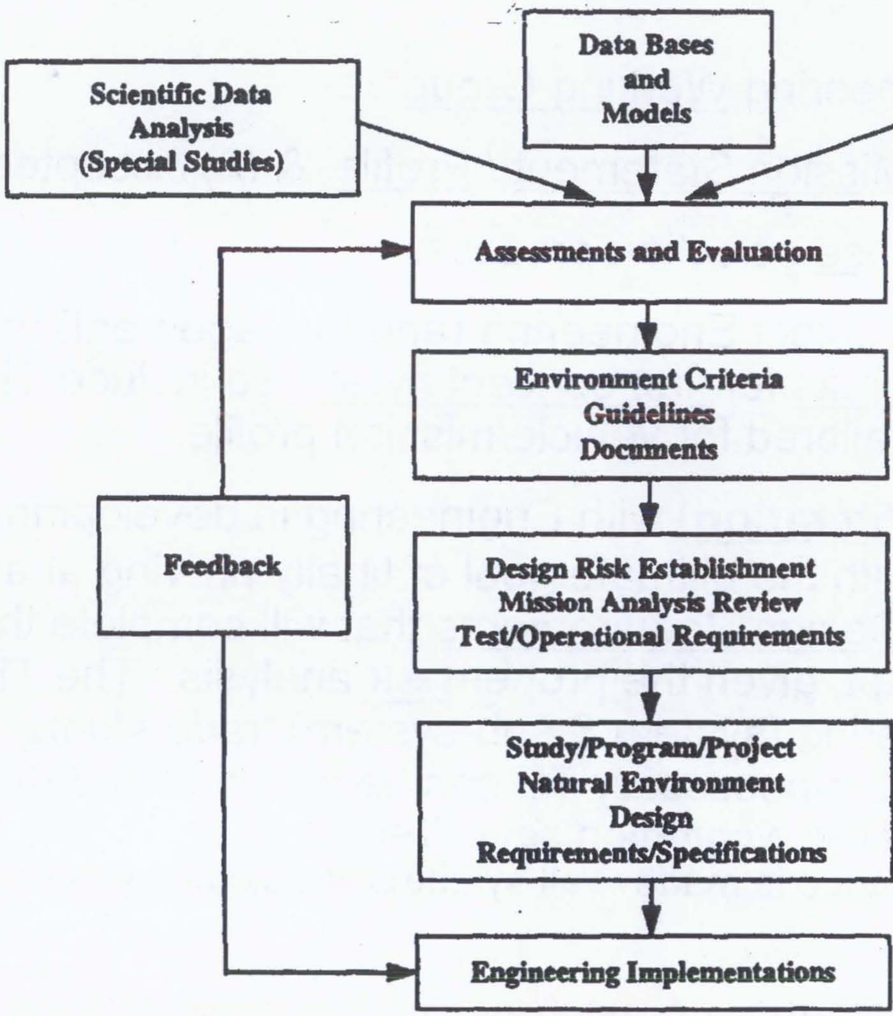
Terrestrial Environment Definition and Analysis 'Process' for Aerospace Vehicle Engineering Application



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Key Terrestrial Environment Parameters to Consider vs. Engineering Systems ("X") and Mission Phase ("P")

X	Terrestrial Environment Parameter											P
Launch Vehicle Systems (Sub-)	**Winds & Gusts**	**Atmosphric Thermodyn**	**Atmosph Constit**	**Solar/ Thermal Radiation**	**Atmosph Electricy**	**Clouds & Fog**	**Humidity**	**Precip or Hail**	**Sea State**	**Severe Weather**	**Geologic Hazzards**	**Mission Phase**
System	X P	X P	X P	X P	X P	X P	X P	X P	X P	X P	X	Mission Analysis
Propulsion/ Engine Sizing	X	X P	P		X		X P			X		Manufactur-ing
Structures/ Airframe	X P	X P		X	X P		P	X P	X	X P	P	Testing
Performance/ Trajectory/G&N	X P	X P	P	P	X P	P	P	P	P	P	P	Transport & Ground Hdl
Aerodynamics	X P	X P	P	P	P		P	P	P	P		Rollout/On-pad
Thermal Loads/ Aerodynamic Heat	X P	X P	P	X P	P	P	P	P	P	P		Pre-launch DOL cnt dn
Control	X P	X P	P	P	X P	P	P	P		X P		Liftoff/ Ascent
Loads	X P	X P			P	P		P	X P	X P		Stages Recvry
Avionics	P	P	X	X	X P	P	X	P		X P		Flight
Materials	X	X P	X P	X P	X		X	X	X	X		Orbital
Electrical Power	P	P	X		X P	X		X P		P		Descent
Optics	P	X P	X P	X	P	X P	P	X P	P	P		Landing
Thermal Control	P	X P	P	X P	P		P	X P	P	P		Post-land
Telemetry, Tracking & Communication	P	X P	X P	P	X P	X P	P	X P	P	X P	P	Ferry/ Transport
	P				P		P	P		P	P	Facil/spt Eq
	P	P	P		P		P	P			P	Refurbishmt
Mission Operations	X P	X P	X P	X P	X P	X	X P	X P	X	X P	X P	Storage

****

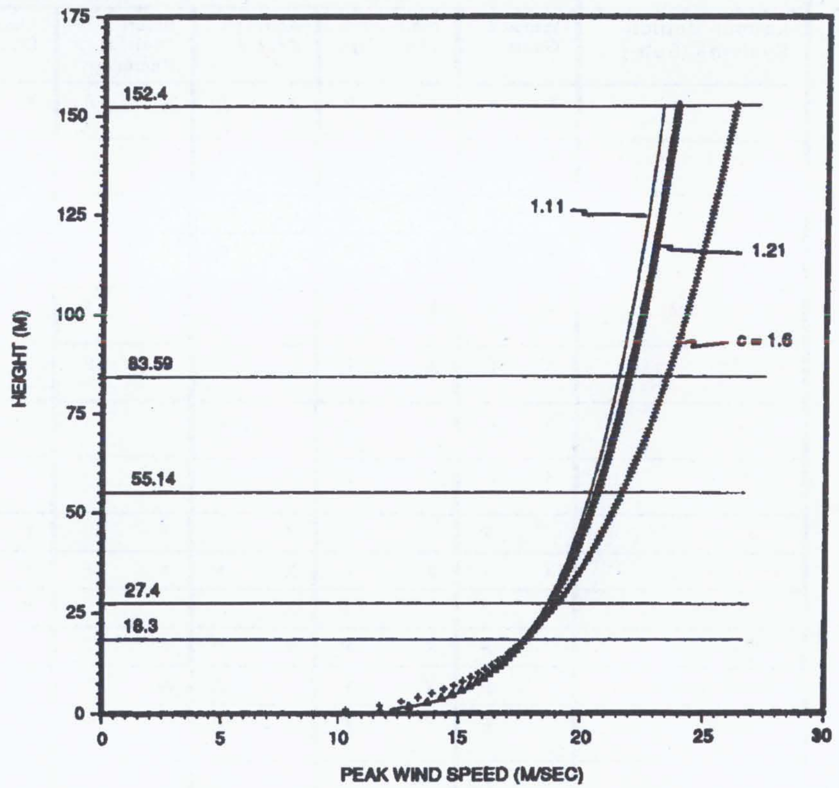
Design Peak Wind Profile Example – Ground Winds

Using a Power Law relationship one can determine the Peak Wind Speed Profile at any level between 0 and 150 m altitude, by just knowing the Peak wind at the KSC 18.3 m (60 ft) reference altitude:

$$U(h) = U_{18.3} (h/18.3)^{K}$$

$$\text{where: } K = C(U_{18.3})^{-0.75}$$

(and U is in m/s, and h in m.)



For a KSC Tower Clearance problem, with the windiest 1-hr exposure period and assuming a 5% risk, Tabular values of C give C = 1.60.

Therefore, given a known peak wind speed of 17.7 m/s at the 18.3 m level, the peak wind speed is calculated to be 26.2 m/s at 152.4 m (500 ft).

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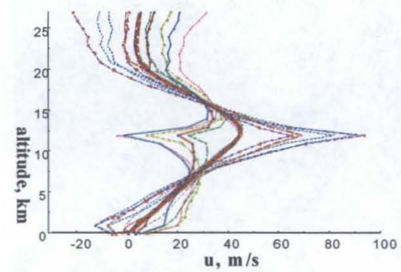
February KSC Vector Wind Profile Model Input in an Engineering Trajectory/Loads Example

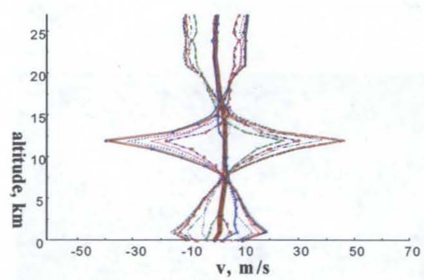
INPUT: Winds

KSC February Vector Wind Profiles

KSC U-Wind Component (m/s) 99% probability ellipse profiles 0-27 km for reference alt = 12km.



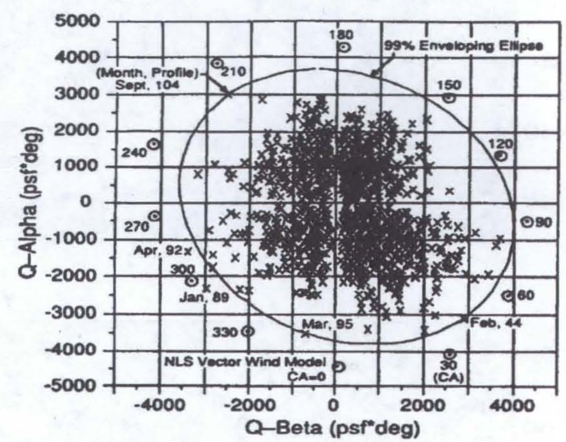
KSC V-Wind Component (m/s) 99% probability ellipse profiles 0-27 km for reference alt = 12km.



Vehicle Trajectory Simulation

OUTPUT: Load Indicators

Trajectory Variable Dispersion at 12 km



Aerodynamic Load indicators ($q\alpha$, $q\beta$) at 12 km obtained from trajectory simulations using 1800 KSC Jimsphere wind profiles (150/mo) and the 12 enveloping VWP profiles for a ref. alt. = 12km

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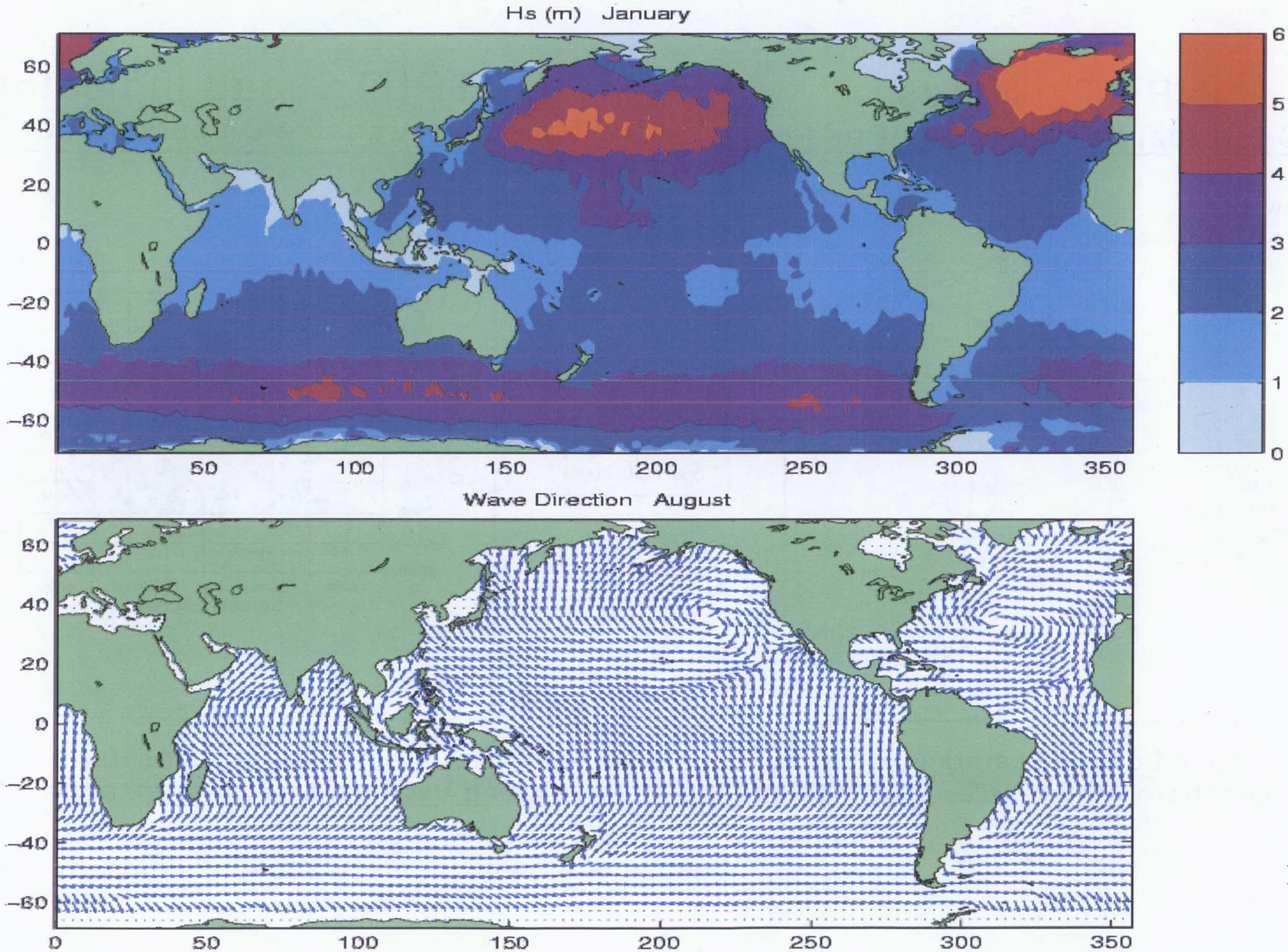
Global Plots of Mean Significant Wave Height (January-top) and Mean Wave Direction (August-bottom)

source: Young 2003 'Atlas of the Oceans: Wind and Wave Climate'



SATT* 3.0 Tornado Statistics for Stations Specified, 1950 -2001

Station:	Number of Tornadoes in Circular Region	Mean No./Year in Circular Region	Area** (A_2) of Circular Region km^2	(mi^2)	Radius of Circular Region km	(mi)	Annual Coverage Fraction (ACF) (yr^{-1})	Recurrence Interval 1/ACF (yr)	Average Tornado Size $\bar{A}_T$ (mi^2)	10 year Tornado Prob for A=2.59km^2 or (1 mi^2)
• Marshall Space Center	134	2.58	10,179	(3,930)	56.89	(35.36)	**$8.069 \cdot 10^{-4}$**	**1,239**	**1.230**	**6.54×10^{-2}**
• Kennedy Space Center	124	2.38	10,839	(4,185)	58.73	(36.50)	$7.498 \cdot 10^{-5}$	13,337	0.132	5.67×10^{-3}
• Vandenberg AFB	3	0.0577	10,179	(3,930)	56.89	(35.36)	$4.827 \cdot 10^{-10}$	$2.071 \cdot 10^{9}$	3.29×10^{-5}	1.47×10^{-4}
• Edwards AFB	8	0.154	10,179	(3,930)	56.89	(35.36)	$1.851 \cdot 10^{-8}$	$5.402 \cdot 10^{7}$	4.73×10^{-4}	3.92×10^{-4}
• New Orleans	101	1.94	10,645	(4,110)	58.20	(36.17)	$3.627 \cdot 10^{-5}$	27,571	7.67×10^{-2}	4.71×10^{-3}
• Stennis	196	3.77	10,645	(4,110)	58.20	(36.17)	$7.150 \cdot 10^{-4}$	1,399	0.780	9.13×10^{-3}
• Johnson Space Center	**310**	**5.96**	10,736	(4,145)	58.44	(36.32)	$3.121 \cdot 10^{-4}$	3,204	0.217	1.43×10^{-2}
• White Sands	7	0.135	10,412	(4,020)	57.55	(35.77)	$1.017 \cdot 10^{-6}$	$9.833 \cdot 10^{5}$	3.04×10^{-2}	3.36×10^{-4}

*** SATT = Site Assessment of Tornado Threat**

**** Area of circular region equal to area of 1° square.**

Note: Bold type indicates the most extreme tornado statistics.

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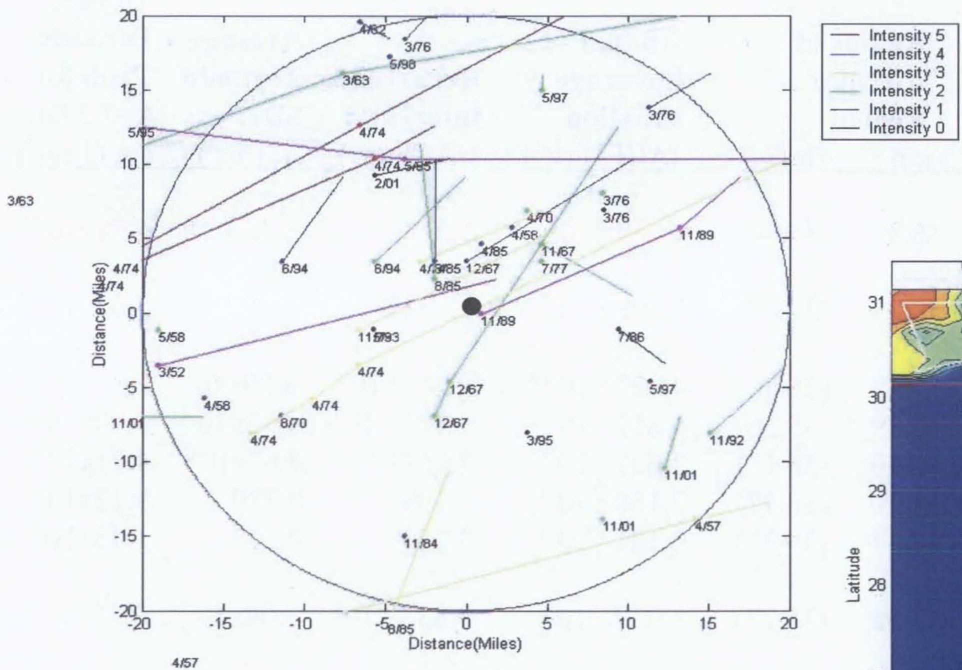
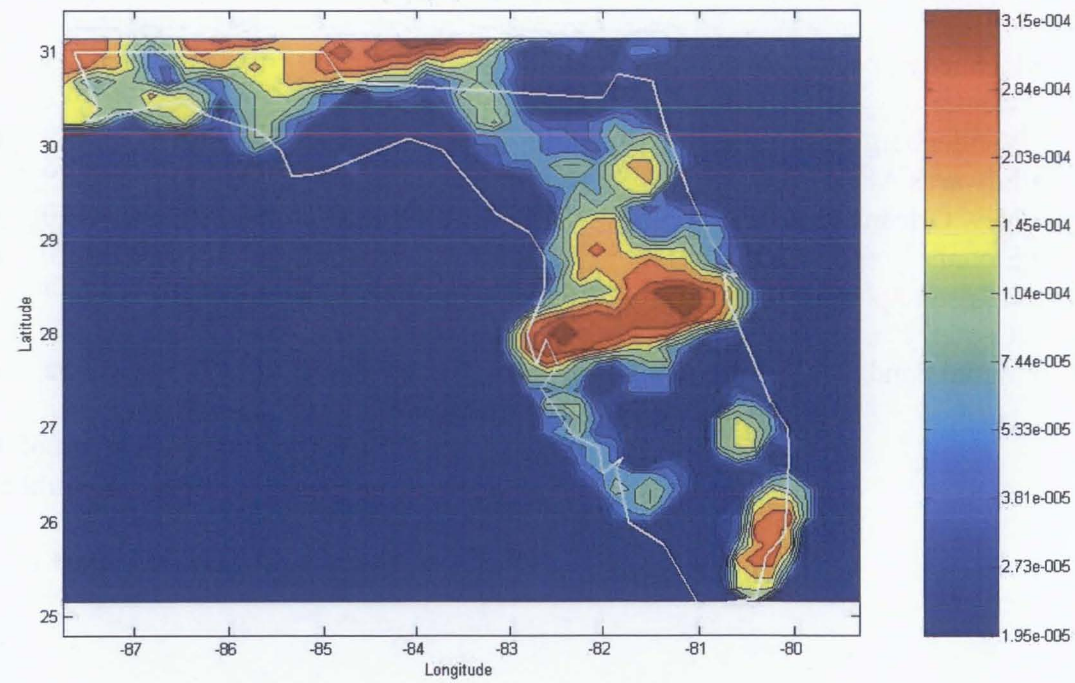
SATT 3.0 Tornado Program Output Examples (1950-2001)

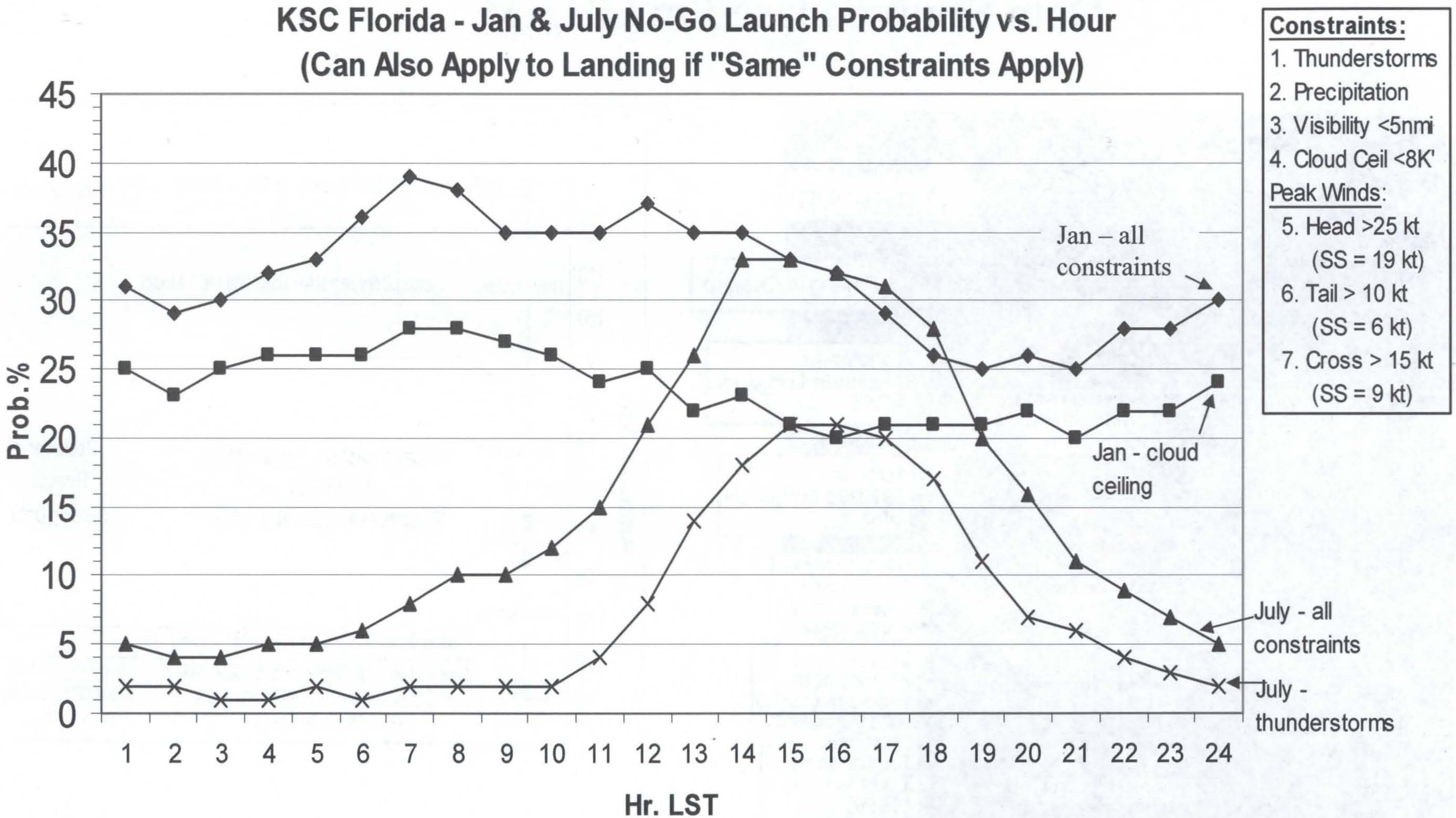


Tornado Tracks & Touchdowns Within 20 miles of MSFC

Tornado Probability Map for Florida



Mission Analysis (APRA* Program): KSC Launch Example



* APRA or 'Atmospheric Parametric Risk Analysis' program

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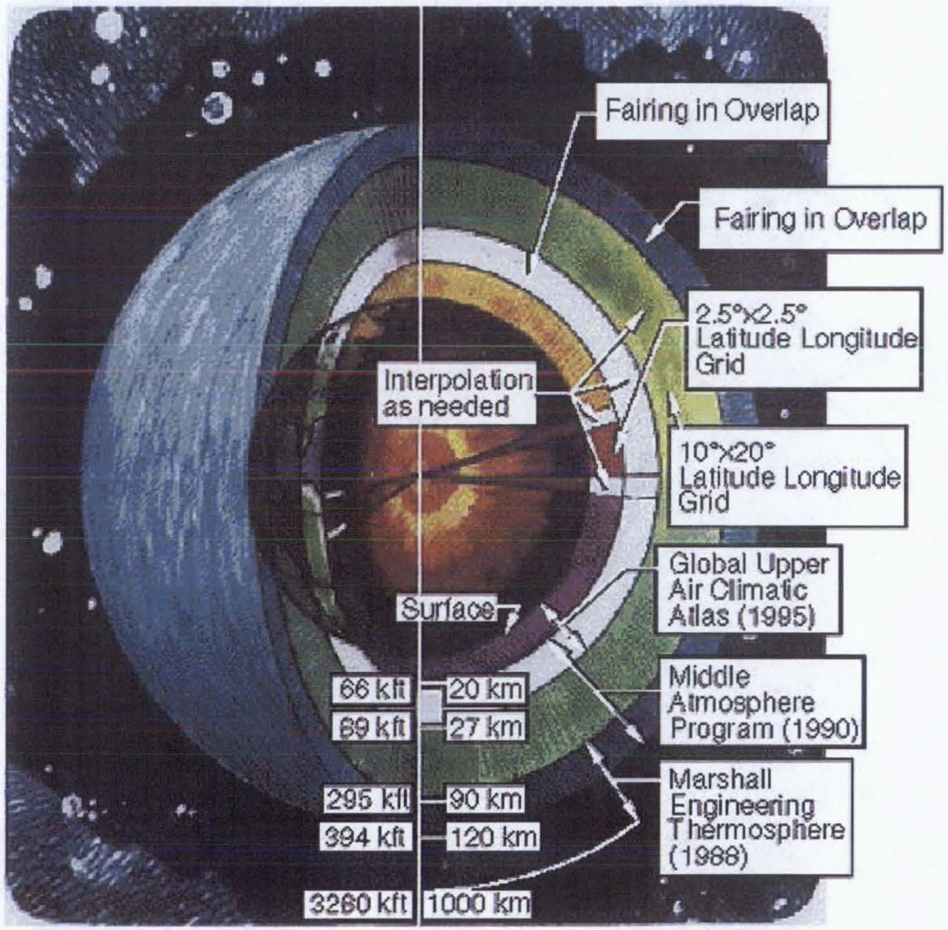
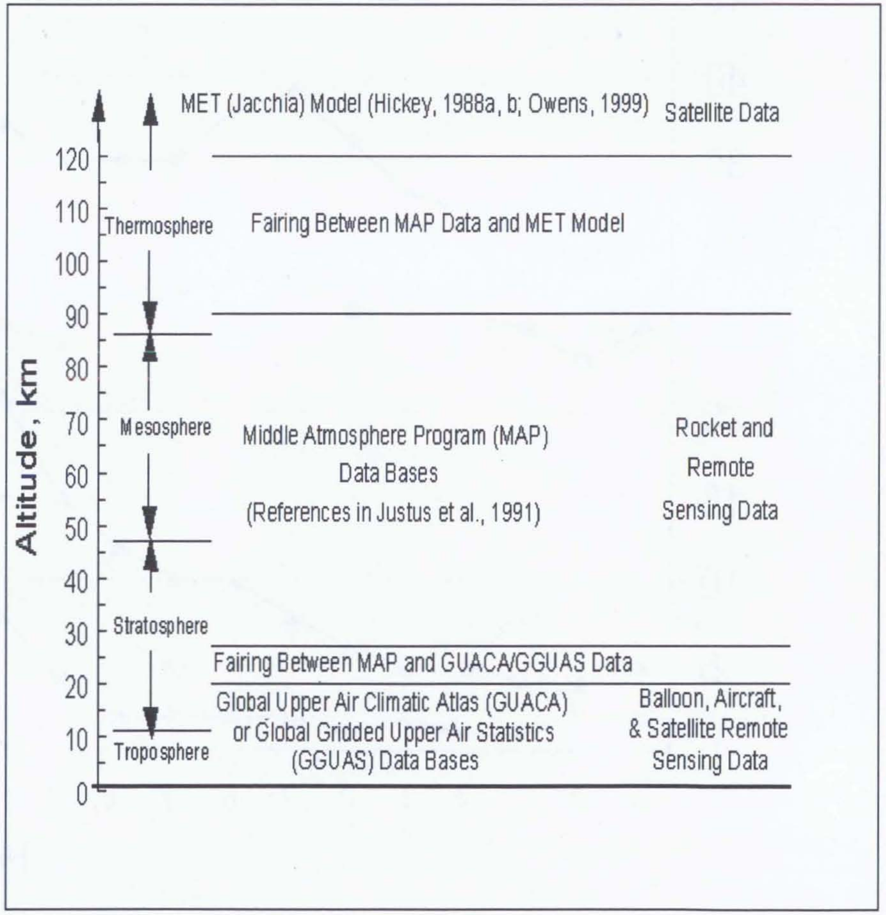
Earth-Global Reference Atmospheric Model 2007

Schematic Summary of Atmospheric Regions and Data Sources Used in GRAM





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Global Reference Atmospheric Model – 2007

- Space & Time Coverage etc.

  - ❑ Complete Seasonal Coverage (Monthly) of Mean & Sigmas.
  - ❑ Complete Global Coverage (all Latitudes & Longitudes).
  - ❑ Complete Altitude Coverage (Surface to 2500 km), or along any inputted trajectory.
  - ❑ GRAM does all necessary Interpolations to desired space & time resolution.
  - ❑ GRAM can generate perturbations: 1) small-scale (turbulence) 2) large-scale (tides) 3) numerous, realistic, Monte-Carlo-type atmospheric profile simulations.

- Geophysical Parameters (Output by GRAM)

Parameter	Monthly Means	Sigma Perturb. Values
Temperature	X	X
Density	X	X
Pressure	X	X
Horiz. Wind	X	X
Vertical Wind	X	X
Water Vapor	X	
11 Constituents	X	

(O_3, N_2O, CO, CH_4, CO_2, N_2, O_2, O, A, He and H)

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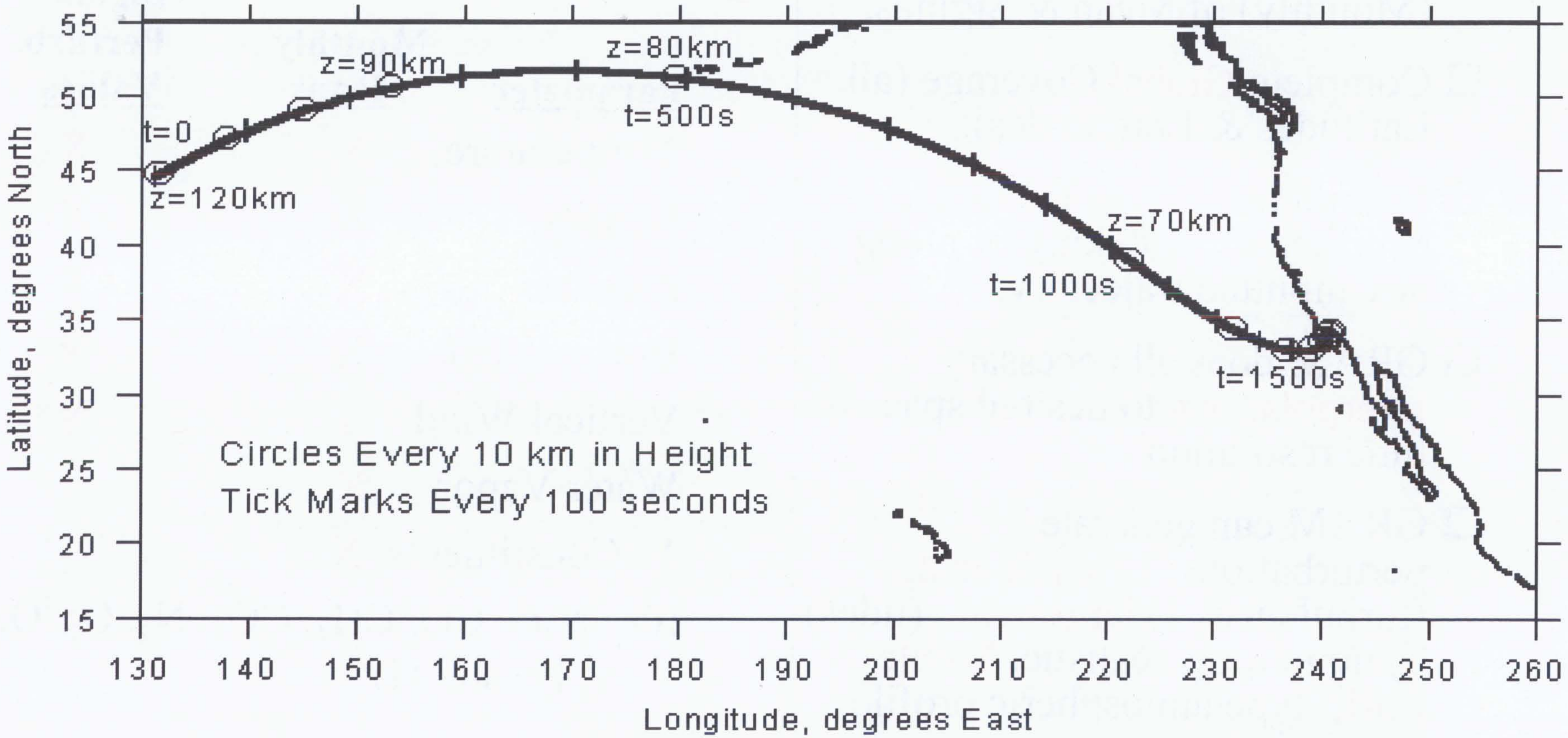
GRAM07 Typical January Ground Track Re-entry Trajectory (57° Inclination Orbit) Example into Edwards AFB



GRAM07 Typical Trajectory Atmospheric Density Examples

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Mean GRAM Density Output

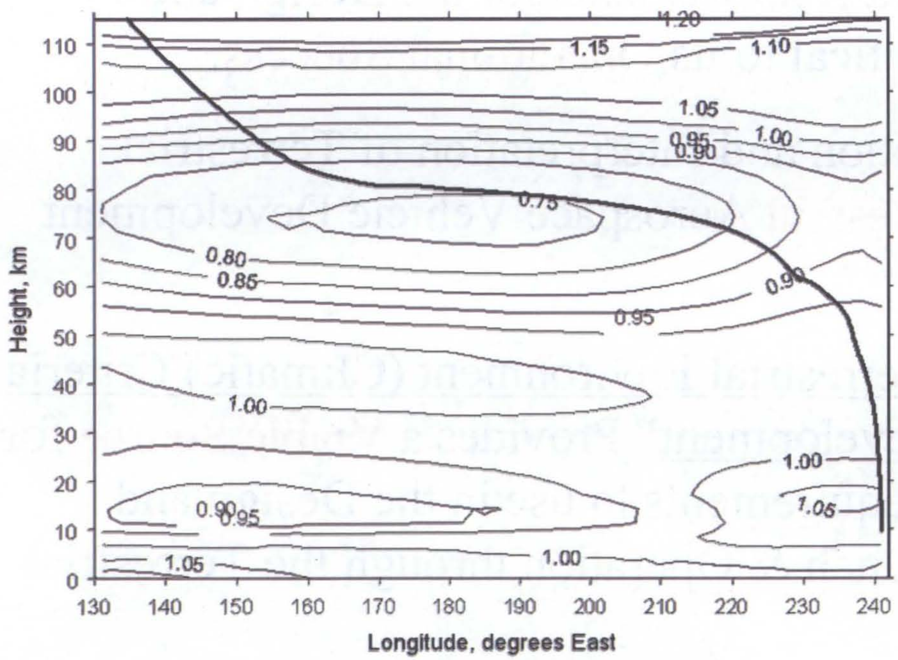

Fig A. Trajectory thru Mean January Height vs. Longitude Cross Section of Density (as Ratio of US76 Density).

Mean, Extreme & Perturbed GRAM Density Output

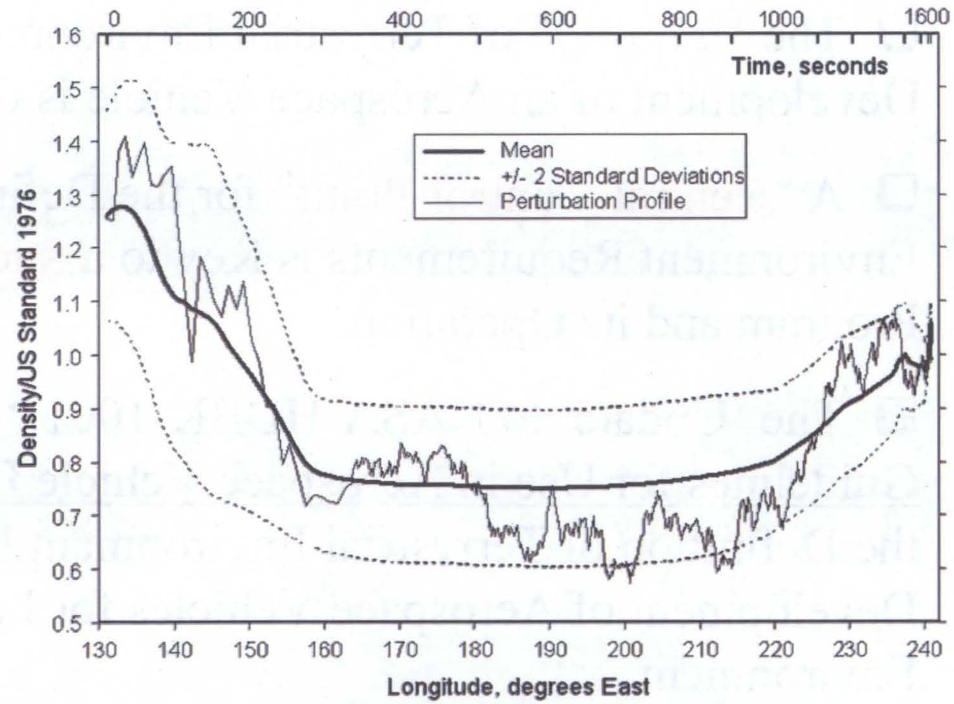

Fig B. Trajectory thru Mean January Atmospheric Density with 2σ Density Envelopes & one Monte-Carlo Density Perturbation Profile vs. Longitude (as Ratio of US76 Density).

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CONCLUSIONS

- ❑ The Terrestrial Environment (0 – 90 km altitude) has a Significant Influence on the Operational Capability of an Aerospace Vehicle.

- ❑ The Definition of Terrestrial Environment Requirements for the Design and Development of an Aerospace Vehicle is Critical to its Operational Success.

- ❑ A "Central-Control-Point" for the Definition and Interpretation of Terrestrial Environment Requirements is Key to a Successful Aerospace Vehicle Development Program and its Operation.

- ❑ The 'Update' to NASA-HDBK-1001 "Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development" Provides a Viable Source for the Definition of Terrestrial Environment Requirements to use in the Design and Development of Aerospace Vehicles for Launch & Operation through the Terrestrial Environment.

- ❑ The Handbook is currently under Revision and the Technical Updates should be Completed and ready for distribution within the early part of 2008.