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THE STATUS OF MILITARY SPECIFICATIONS WITH REGARD TO ATMOSPHERIC TURBULENCE

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1. INTRODUCTION

Atmospheric turbulence models are included in a number of military specifications although there is no military specification devoted solely to atmospheric turbulence models, *per se*. Perhaps the closest example of one is Reference 1, a compilation of maximum gust values for design of ground equipment. Aircraft design specifications which contain gust or turbulence models do so for different purposes. One series addresses the vehicle structural design to ensure sufficient strength when penetrating gusts and turbulence in flight. The turbulence model is expressed in terms of probability of encountering certain levels of disturbance, and has not been revised since the 1960's. Reference 2 contains a turbulence model for use in flight control system design. Again this model has not changed in recent revisions of the specification. The main emphasis of study has been on the interaction of a pilot with his aircraft in various forms of disturbances. This is manifested in the flying qualities specification [3] which contains an extensive model of winds, wind shear, turbulence, and gusts for use in aircraft design and development. It is used in flight stability and control augmentation development and as a simulator model for aircraft design. The model was updated significantly in 1980 [3] and is being further refined in the change from a Specification to a Standard [4]. The remainder of this paper will concentrate on the development and application of the "flying qualities atmospheric disturbance model."

The evaluation of the effects of atmospheric disturbances on airplane flying qualities has been approached in a diverse number of ways. The large volume of literature is evidence of this. At the same time, we have little guidance for choosing among these alternatives when specifying or examining a given airplane design. It is far too easy to become bogged down in the ill-defined tradeoffs between Dryden and von Karman turbulence forms, the need for non-Gaussian or non-stationary charcteristics, the debate over how and when to model wind shear effects, or whether shorter turbulence scale lengths are more realistic than longer ones. Airplane designers and simulator researchers continually face such questions, and while they may find answers suitable for one situation, the same questions can re-appear on a subsequent occasion.

The paper will first discuss the features of atmospheric disturbances that are significant to aircraft flying qualities. Next follows a survey of proposed models. Lastly, there is a discussion of the content and application of the model contained in the current flying qualities specification and the forthcoming MIL-Standard.

2. FLYING QUALITIES NEEDS

It is appropriate first to define what is meant by flying qualities, in order to keep the whole discussion in perspective. One accepted definition is "those airplane characteristics which govern the ease or precision with which the pilot can accomplish the mission" [5]. Further, flying qualities are often "measured" by subjective pilot opinion according to the Cooper-Harper rating scale [5] wherein it is stated that flying qualities are tied to accomplishing a specific task. Due consideration of environmental conditions is, in turn, implied. An airplane can have characteristics that make the task of landing relatively easy in calm air. The same task becomes very demanding in strong turbulence or even impossible in a violent thunderstorm, even though the airplane characteristics may not have changed. Thus, due consideration of atmospheric disturbances is implicit in any analysis of flying qualities.

For the purposes of the Flying Qualities Specification, an engineering model of the atmosphere may be considered as the simplest or minimum acceptable model which correctly identifies the primary parameters of particular interest. This is in contrast to the objectives of basic research into meteorological phemonena or the physics of atmospheric dynamics. Reference 6 discusses this dichotomy in more detail, with some indication of how the model is built up of components. Each component either exercises a particular feature of the man/machine combination or adds a particular aspect of realism to the piloting task. Let us, therefore, devote a few paragraphs to an overview of atmospheric disturbance features which are involved in flying qualities matters.

3. ATMOSPHERIC DISTURBANCE FEATURES

Prior to discussing atmospheric disturbance modeling needs, let us quickly review some of the basic features of all such models realizing that each claims some kind of uniqueness with regard to the following features. We shall discuss the nature of the variations in properties, but in general they can be viewed in terms of their engineering convenience versus their physical correctness. For example, the well-known von Karman turbulence form yields more correct spectral characteristics, but it is not as easily realized computationally as the more approximate Dryden form. The same kind of tradeoff between convenience and correctness is a dominant theme in several other respects as we shall discuss under the following subheadings.

3.1 Determinism Versus Randomness

Atmospheric disturbance models first can be separated according to their degree of determinism or randomness. At some level, the dynamics of the earth's atmosphere must be deterministic, but at our degree of understanding they frequently appear random. While characteristics such as mean wind and wind shear are normally handled on a deterministic basis, turbulence is usually modeled as a randomly occurring phenomenon. Nevertheless, wind velocity or wind shear can be just as well described in strictly probabilistic terms, and turbulence, conversely, can be described in wholly deterministic terms (as with gusts composed of summed sinusoids). In addition, random and deterministic models are often combined to suit the needs of a particular application [7,8]. Deterministic features are usually quantified directly using analytic functions or tables (e.g., mean wind respect to time or space). Random components, on the other hand, involve random variable sources having their own particular statistical properties of probability distribution and correlation. The differences are probably academic to a pilot, since either or both approaches can give a realistic mode; however, appropriate partition of model determinism versus randomness figures greatly in the success of any given application as we shall discuss shortly.

3.2 Probability Distribution

The probability distribution of gusts describes their range of amplitudes and frequency of occurrence. This can be quantified in terms of probability density, cumulative probability distribution, or a varying number of central moments (mean, variance, skewness, kurtosis, etc.). While the Gaussian distribution is mathematically convenient, several turbulence models having more correct non-Gaussian distributions have been developed in order to address the characteristics of patchiness and intermittency. Patchiness is frequently considered as corresponding to a proportionately higher rate of occurrence of very large magnitude gusts than found in a Gaussian distribution and is reflected by the higher order even central moments (fourth, sixth, etc.) [9]. Intermittency is the counterpart to patchiness when applied to gust velocity differences over a given time or space interval [10]. But the usefulness of these model features depends upon whether the specific application can accommodate a characteristic such as patchiness on a probabilistic basis. Pilots comment on the noticeable symmetry of the Gaussian distribution. Given only Gaussian-distribution turbulence, a perturbation is invariably followed by a correction so that he can allow the aircraft to fly "hands off." One way to look at this is that the time-average of the mean is comparatively short, even for manned simulations, which involve a limited duration time frame and a limited number of sample runs. Mathematically, the frequency of occurrence of the larger magnitude gusts is more in real life than in the Gaussian distribution. Models have been proposed to correct this discrepancy but those have the undesirable effect of increasing the variability from run to run.

3.3 Correlation

Correlation is the measure of the predictability of a gust component at some future time or point in space based on the knowledge of a current gust. Since the modeling of a random process such as turbulence consists of developing techniques for predicting the behavior of that process, it can be seen that correct duplication of the correlation can be important since these are measures of predictability. There are at least two ways of presenting correlation information, in the time or space domain (correlation functions) or in the frequency domain (spectral density functions).

The correlation function can be converted to the frequency-domain via a Fourier transformation resulting in the power spectral density function. A frequency domain representation is often useful because it permits comparison of the aircraft's spectral features with the spectral content of the turbulence. It is thereby possible to judge the degree to which the turbulence will affect the aircraft's motion, as described in Reference 11.

The two most common ways of describing gust correlation are the Dryden and von Karman power spectral density forms [3]. The correctness advantage of the von Karman form is not an issue unless the significant spectral content is centered in the microscale range about one decade or more above the integral scale break frequency. The microscale of turbulence is an indication of the distance of time separation over which gusts remain highly correlated, i.e., the initial subrange [12]. The von Karman turbulence involves a non-zero microscale--Dryden does not. The integral scale of turbulence is equal to the area under the normalized autocorrelation function and much larger than the microscale. Correct measurement of the integral scale depends on stationarity.

3.4 Dimensionality of Gust Field

A gust field can be described using various orders of dimensionality. The simplest is a one-dimensional-field model which involves just the three orthogonal velocity components taken at a single point (usually the aircraft center of gravity). The Taylor hypothesis (frozen field) can be applied, however, in order to approximate gust gradients with respect to the x-axis of the aircraft without increasing dimensionality. A two-dimensional field model is used to define a gust field in the aircraft x-y plane and can account for the size of the aircraft relative to gust scales. (A large aircraft relative to the gust scale attenuates gust gradient spectral power at high frequencies.) A two-dimensional field can lead to greatly increased mathematical complexity over a one-dimensional field [13], but some turbulence models simply define one-dimensional uniform velocity components and then add two-dimensional forms for gust gradients which contain aircraft size effects (as in Reference 3). These additional components are typically the first term in a Taylor expansion. More recent work [14] indicates that the correctness of these terms may be no better than ignoring them. A third dimension can be introduced in the form of an altitude-dependent wind shear [7,8], independent of the remainder of the model. Because of the inordinate increase in computational complexity, Reference 6 suggests that the gust gradient terms should be considered only if required by a specific piloting task.

3.5 Stationarity

A random gust is stationary if, for a collection of gust samples, the corresponding probability and correlation properties describe any additional gust sample which may be taken. Thus, stationarity implies an atmospheric disturbance having an invariant mean, variance, and correlation length (or time). There is no restriction on whether the probability distribution is Gaussian or not. In piloting terms, the effects are similar to the discussion of predictability that results from the probability distribution.

4. EVALUATING ATMOSPHERIC DISTURBANCE MODEL NEEDS

Atmospheric modeling needs vary greatly with the specific application, even for a single given aircraft and flight condition. Some analysis procedures require only a simple one-dimensional turbulence model (e.g., Dryden) and a single gust component. At the other extreme, elaborate simulation can involve a fully defined two-dimensional, non-stationary turbulence field along with a spatially or time varying mean wind field (i.e., wind shear). It is the role of References 4 and 6 to offer guidance in evaluating such needs and selecting appropriate disturbance model options among the variety of modeling choices and identifying the appropriate method of demonstrating compliance.

Some ways of viewing the modeling needs of a user include:

1. How disturbance components enter the airframe force and moment equations.
2. Inner/outer loop structure hierarchy for mission/aircraft centered features.
3. The need for determinism versus randomness in the flying qualities application.

Based on our knowledge of the various stability derivatives and respective gust component intensities, we can estimate the relative effect of various gust terms in order to judge:

1. Axis cross coupling (e.g., longitudinal and lateral-directional forces and moments are likely to be fairly well decoupled).
2. Translation motion (e.g., force equations are mainly affected by gust velocity components alone).
3. Rotational motion (e.g., moment equations are affected by gust velocity, time derivative, and gradient components).

The loop structure hierarchy in mission/aircraft centered features provides us with another way of judging atmospheric disturbance model needs. Figure 1 shows a spectral comparison of mission/aircraft-centered features against atmospheric disturbance features. Although the spectral boundaries of each feature are admittedly more ill-defined than shown, we can nevertheless illustrate a point. That is, any mission/aircraft features which are to be analyzed require the significant atmospheric disturbance features acting within the same spectral range. Conversely, atmospheric disturbance features outside that spectral range are superfluous. Taking the argument to the extreme, navigation considerations are not likely to involve the microscale or even integral scale range of turbulence. Likewise, flexibility effects would not require inclusion of mean wind or wind shear features.

Continuing in a similar vein, the results obtained from exciting an airplane by atmospheric disturbances depend greatly upon how the airplane is

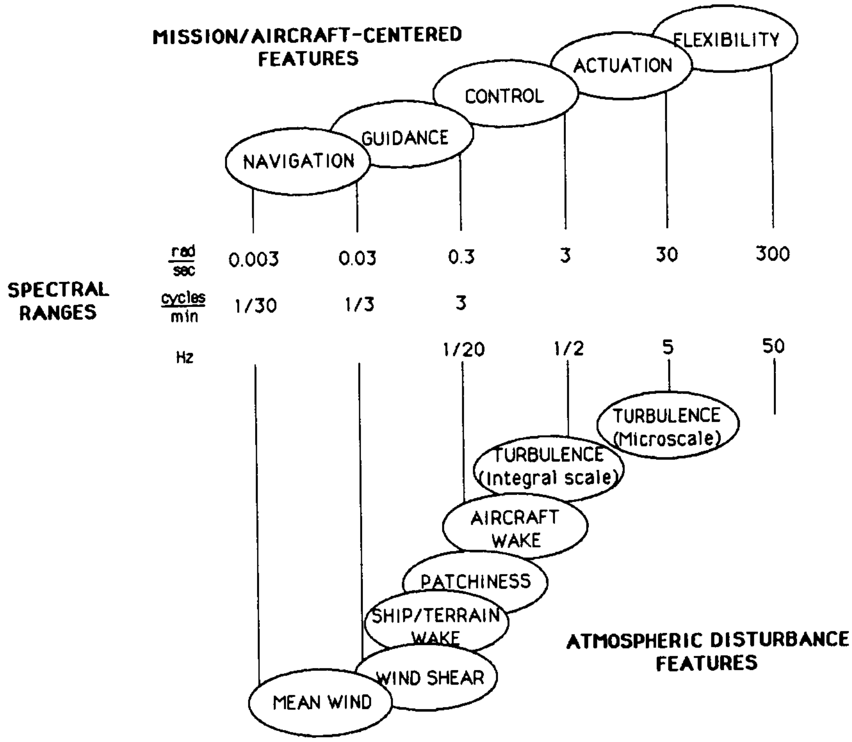

Figure 1. Spectral comparison of mission/aircraft-centered features against atmospheric disturbance features.

being operated, i.e., what the pilot is doing. The gust response can vary dramatically between hands-off operation and that involving tight regulation of attitudes and flight path. Frequently, the effects of wind shear are evaluated by measurement of the flight path excursion for a controls-fixed penetration of the shear. The phugoid is, of course, the dominant response mode in this case, and the result is a large-amplitude, undamped, roller-coaster-like flight path oscillation. But pilots do not characteristically operate hands-off in a wind shear environment. Rather, aircraft attitude is likely to be very well regulated by the pilot; hence, the flight path and airspeed modes would be exponentially decaying according to heave and speed damping stability derivatives (Z_w and X_u, respectively). Each of these two cases would lead one to vastly different conclusions regarding performance and identification of critical flying qualities parameters.

We need also to consider how determinism and randomness affect our choice of atmospheric disturbance models. Strict reliance upon a wholly random gust model for small-sample, short-term task evaluation is both impractical and improper. As investigators and evaluators, we desire to control disturbances well enough so that critical conditions and events can be staged especially in the case of manned simulation. This demands a fair degree of model determinism. On the other hand, pilot surprise and sensitivity to variation calls for a degree of randomness. Therefore, a compromise must be reached. This is an area which deserves to be addressed in a systematic way, but sometimes solutions must be based more upon experience than clear rationale.

5. PRACTICAL IMPLEMENTATION CONSIDERATIONS

The application of atmospheric disturbance models can involve a number of practical implementation problems--many associated with digital computer programming. One role of the Flying Qualities Handbook [4] will be to assist in answering some of the common implementation questions and to point out pitfalls frequently encountered. Some examples include:

1. Digital implementation of continuous spectral forms
2. Correct scaling of random noise sources
3. Evaluation of need for gradient components
4. Implementation of gust gradients, gust time derivatives, and gust transport lags.

Although these kinds of questions are based on fairly elementary mathematical or physical principles within the capacity of any practicing engineer, they are things which can nevertheless unnecessarily consume time and effort by flying qualities analysts. Table 1 illustrates some of the practical implementation matters addressed by the Flying Qualities Handbook [4].

TABLE 1. A List of Some Practical Implementation Topics from the Flying Qualities Handbook [4].

Implementation Item	Handbook Method	Comments
Digital implementation of continuous filter forms. Example: First-order Dryden form (applicable to u-gust or p-gust).	Spectral form: $$\Phi_{uu} = \sigma_{u_g}^2 \, 2L_u/\pi \cdot \frac{1}{1+(L_u\Omega)^2}$$ Discrete realization: $$u_g = c_1 u_g + c_2 \eta$$ where $$c_1 = \begin{cases} \text{either } \exp(-aT) & \text{(z-transform)} \\ \text{or } (1-aT) & \text{(Euler integration)} \\ \text{or } \frac{2-aT}{2+aT} & \text{(Tustin transform)} \end{cases}$$ $$a = V/L_u$$ and $$c_2 = \sqrt{1-c_1^2}\,\frac{\sigma_{u_g}}{\sigma_\eta}$$ where η is a normally distributed random number with variance σ_η^2.	This matter can be confusing because spectral forms are written in a number of ways (e. g., one-sided or two-sided, spatial or temporal frequency, or in terms of angular or cyclical frequency). Furthermore, white noise in the continuous domain must be converted to random numbers in the discrete domain.
Determination of p-gust level of importance.	Criterion: p-gust is significant relative to v-gust if: $$\sqrt{\frac{b}{L_w}} \cdot \lvert C_{l_p}\rvert > \lvert C_{l_\beta}\rvert$$ or $$\frac{2}{\sqrt{L_w b}} \cdot \lvert L_p \rvert > \lvert L_v \rvert$$ where b is span and L_w is gust scale length.	The p-gust can be an important disturbance component in the roll axis, expecially if effective dihedral is small.
Determination of p-gust intensity.	Holley-Bryson model: $$\sigma_{p_g} = \frac{2.15\,\sigma_{w_g}}{\sqrt{b\,L_w(1+b/L_w)}}$$ MIL-F-8785C model: $$\sigma_{p_g} = \frac{0.95\,\sigma_{w_g}}{\sqrt[3]{b^2 L_w}}$$ Approximate intensity averaged over several models: $$\sigma_{p_g} = \frac{1.9\,\sigma_{w_g}}{\sqrt{b\,L_w}}$$	If the p-gust component is considered important, one must determine the intensity in order to implement the gust filter. A specific easy-to-compute value for intensity is seldom available. also the various p-gust model forms all have different ways of expressing model parameters.

6. A SURVEY OF EXISTING MODELS

A major task in the development of the Military Standard and Handbook was the review of existing atmospheric disturbance models and model forms. The objective was to examine how various models make the tradeoff between convenience and correctness and to search for strengths or deficiencies which could be important to a flying qualities investigator. Rather than arriving at a single most universal model to serve as the basis for the Military Standard, a variety of model forms appropriate for various applications were suggested. Table 2 lists some of the models which have been surveyed and offer some potential in flying qualities applications. For each table entry a few summary remarks are given along with a list of basic references.

7. THE CURRENT MILITARY SPECIFICATIONS FOR FLYING QUALITIES

Since our goal is discussion of the Flying Qualities Military Specifications, we should try to understand their weaknesses as well a their strengths. Prior to the existing specification, MIL-F-8785B presented a basic disturbance model consisting of turbulence and discrete gusts, but the requirements for its use were few in number and qualitative in nature. For the current version, the MIL-F-8785B model was extended and more explicit requirements were formulated. It is instructive to understand the background of this existing array of model components and how they are used in defining flying qualities requirements.

The effect of increasing disturbance intensity is typically an increase in pilot workload and/or a degradation in task performance. The effect on pilot rating is similar to a degradation in flying qualities from other causes. This consideration led heuristically to the specification of three disturbance intensities, which are qualitatively linked to the three levels of flying qualities. In attempting to formulate requirements for use of the models, it was proposed originally to incorporate the effects of disturbances into the levels of flying qualities. In the final version, "qualitative degrees of suitability" are defined to parallel the levels of flying qualities. A new section of the specification now contains requirements for use of the disturbance model. These are presented as a matrix of failure versus disturbance intensities for the different flight envelopes.

Both the von Karman and Dryden forms of the turbulence spectra are retained with specified intensities corresponding to probabilities of occurrence of 10^{-1}, 10^{-3}, and 10^{-5}. The "versine" (or 1-cosine) shape is retained for the discrete gust, except that only half a period is specified. In this way it can be used singly (e.g., representing a wind shear) or in pairs (as in the familiar discrete gust application) yielding more flexibility in application.

A completely new model is specified for low altitudes, with a more realistic variation of turbulence intensities and scale lengths with height above the gound. A mean wind having a logarithmic variation with height (planetary boundary layer) is specified. In order to account for the severe but less probable phenomena that cause difficulties close to the ground, a

TABLE 2. A Survey of Atmospheric Disturbance Models.

Model	Key Features	Sources*
Dryden turbulence	A convenient spectral form based on an exponential autocorrelation function for the axial component.	15
von Karman turbulence	A spectral form for which the autocorrelation function includes a finite microscale, thus the relative proportion of spectral power at high frequencies exceeds that of the Dryden.	16,17
Ornstein-Uhlenbeck turbulence	A spectral form with first-order longitudinal and transverse components.	18
Etkin one dimensional turbulence power spectra	The local turbulent velocity field is approximated by a truncated Taylor series which yields uniform and gradient components. High frequency spectral components eliminated on the basis of aircraft size. Based on Dryden form, but gradient spectra are non-realizable unless simplified.	13,19,20
Versine gust	A discrete gust waveform.	3
Lappe low-altitude turbulence model	Experimentally-obtained data of vertical gust spectra, mean wind speed, and lapse rate were used to develop a low-level turbulence model. The turbulence spectra are presented for different types of terrain, height, and meteorological conditions.	21
Multiple point source turbulence	A two-dimensional gust field generated from two or more noise sources having prescribed correlation functions and located spanwise or lengthwise on the vehicle.	22,23,24
Holley-Bryson random turbulence shaping filters	A matrix differential equation formulation of uniform and gradient components including aircraft size effects. Filter equation coefficients determined from least square fit to multi-point-source-derived correlation functions.	23
University of Washington non-Gaussian atmospheric turbulence model	Non-Gaussian model using modified Bessel functions to simulate the patchy characteristic of real-world turbulence. Spectral properties are Dryden and include gust gradients.	9,25

*Source numbers refer to references cited at end of paper.

TABLE 2. (continued).

Model	Key Features	Sources
Delft University of Technology non-Gaussian structure of the simulated turbulent environment	Non-Gaussian model similar in form to the University of Washington model, but uses the Hilbert transform to model intermittency as well as patchiness. Includes University of Washington model features extended to approximate transverse turbulence velocities and gradients.	26
Royal Aeronautical Establishment model of non-Gaussian turbulence	Non-Gaussian turbulence model with a variable probability distribution function and a novel digital filtering technique to simulate intermittency. Spectral form approximately von Karman.	27,28,29
The Netherlands National Aerospace Laboratory model of non-Gaussian turbulence	Similar to the Royal Aeronautical Establishment model, but extended to include patchiness and gust gradient components and transverse velocities.	30, 31
University of Virginia turbulence model	Models patchiness by randomizing gust variance and integral scale length of basic Dryden turbulence.	32
Mil Standard turbulence model	First order difference equation implementation of turbulence filters based on 8785 Dryden turbulence and refitted rolling gust intensity.	4
Indian Institute of Science nonstationary turbulence model	Nonstationary turbulence is obtained over finite time-windows by modulating a Gaussian process with either a deterministic or random process. The result is patchy-like turbulence similar to the University of Washington model except the time-varying statistics of the turbulence are presented for the deterministic modulating functions.	18
FAA wind shear models	Three-dimensional wind profiles for several weather system types including fronts, thunderstorms, and boundary layer. The profiles are available in table form.	7,33
STI wind shear model	Time and space domain models of mean wind and wind shear (ramp wave forms) are combined with MIL-F-8785C Dryden turbulence to obtain the total atmospheric disturbance. The magnitudes of the mean wind and wind shear are evaluated in terms of the aircraft's acceleration capabilities.	8,34

TABLE 2. (continued).

Model	Key Features	Sources
Sinclair frontal surface wind shear model	A generic model of frontal surface wind shear derived from a reduced-order from of Navier-Stokes equations. Relatively simple to use and can match the overall characteristics of measured wind shears.	35,36
MIL-F-8785B atmospheric disturbance model	Intensities and scale lengths are functions of altitude and use either Dryden on von Karman spectral forms or a one minus cosine discrete gust. Also spectral descriptions of rotary gusts.	37,38
MIL-F-8785C atmospheric disturbance model	Same as 8785B with the addition of a logarithmic planetary boundary layer wind, a vector shear, and a Naval carrier airwake model.	3
ESDU atmospheric turbulence	Rather general, but contains comprehensive descriptive data for turbulence intensity, spectra, and probability density	39,40
Boeing atmospheric disturbance model turbulence	A comprehensive model of atmospheric disturbances that includes mean wind, wind shear, and random turbulence. Turbulence is Gaussian and uses linear filters that closely approximate the von Karman spectral form. Mean wind and turbulence intensity are functions of meteorological parameters.	41
Wasicko carrier airwake model	Includes mean wind profile, effect of ship motion, and turbulence.	42
Naval ship airwake model	Includes free air turbulence filters plus steady, periodic, and random components of airwake which are functions of time and space.	3, 43
Vought airwake model for DD-963 class ships	Combined random and deterministic wind components for free air and ship airwake regions. Based on wind tunnel flow measurements.	44
STI Wake vortex encounter model	A two-dimensional model of the flow-field due to the wake vortex of an aircraft is presented. The parameters of the flow-field model are weight, size, and speed of the vortex-generating aircraft, and distance and orientation of the vortex-encountering aircraft. Strip theory is used to model the aerodynamics of the vortex-encountering aircraft.	45

TABLE 2. (concluded).

Model	Key Features	Sources
Cambell and Stanborne wind shear and turbulence model	Spatial model based on joint airport weather studies (JAWS) microburst data. Permits calculation of aerodynamic loads over body of aircraft.	46
Zhu and Etkin microburst model	Generic spatial model of microburst velocity components based on potential flow singularity distribution involving only three adjustable parameters.	47

vector shear is specified--a change in wind direction over a certain change in height. This is used in lieu of a particular wind profile or set of profiles. It is believed that varying the orientation and height of the specified vector shear covers an adequate range of aircraft responses for the landing task.

The specification of vector shear has the appearance of an engineering artifact, i.e., a 90° change in wind direction over a given height. It is, however, based on the wind conditions that existed at the time of an actual aircraft accident [48]. The winds did not compromise aircraft performance and had no obvious indication of dangerous conditions--they formed an insidious contribution to the busy landing task. The use intended by MIL-F-8785C is to produce a complex but realistic task in piloted ground-based simulation. As the wind changes from crosswind to headwind, or vice versa, the pilot is continually controlling both longitudinal and lateral/directional axes. The six-degrees-of-freedom aspect of this control task is frequently missing in simulation.

Based on meetings with the Navy, it became apparent that their atmospheric disturbance requirements were driven by the carrier landing task. The carrier airwake represents a severe environment. The disturbance model of MIL-F-8785C was completed by adding a carrier airwake model supplied by Nave of NADC [43]. We know that a degradation in pilot rating is accepted relative to landing in calm air; however, we do not yet know how the severity compares with the other portions of the disturbance model.

It should be emphasized strongly that the intent is not to add a whole new dimension to all the existing requirements. In MIL-F-8785B, the guidance was to establish the flying qualities and probabilities associated with critical flight conditions and failures. For MIL-F-8785C, the intent is to limit the degradation in flying qualities due to atmospheric disturbances for the critical cases. With the requirements contained in separate sections, they can be easily modified, emphasized, or even deleted by the procuring activity according to the mission needs. Reference 6 supports the existing specification with more detail on the items discussed herein.

8. IMPLICATIONS FOR THE FORTHCOMING MILITARY STANDARD

The foregoing discussions have tended to dwell on practical aspects of atmospheric disturbance modeling in flying qualities applications. We have described the existing military specification, a variety of modeling topics, and a partial list of modeling alternatives. Regarding atmospheric disturbance models, again we should note that it would be difficult, if not unwise, to embody in a single model all of the features which have been addressed in the existing body of models. Furthermore, to the extent that this could be done, the resulting model would then become "overkill" for many applications. In addition, since the Standard is just that--a standard--it is not necessary to apply a high fidelity facsimile of the real-world environment (assuming that we could ever reach agreement on what the "real world" is). Rather, it is only necessary to apply something good enough to permit a judgment or comparison in each specific context addressed by the Standard. Our inclination is therefore to recommend individualized modeling approaches which would be stylized for a particular application and which would draw upon the rich variety of existing models or modeling forms. This would be accomplished by setting forth an unquantified checklist of atmospheric disturbance properties in the Military Standard document. Specific qualification would then be made by the procuring agency on the basis of the application, vehicle type, mission, and expected environment. This would be done from consultation of the accompanying Handbook and recommended sources listed within. The same procedure could also be followed by the disturbance model user performing analysis or simulation not necessarily connected with aircraft procurement.

Flying qualities requirements set by the Military Standard must necessarily recognize the key role which atmospheric disturbances play in the piloting of an airplane. Hence, prescription of performance (amplitude of response) or workload (pilot opinion or other workload-related metrics) requirements must be made with an understanding of the combined pilot-vehicle disturbance system. This implies that more is needed than guidelines between, say, gust components and airframe aerodynamics. Due consideration must also be given to the piloting tasks and the effect that it has on modifying airplane dynamics and their sensitivity to atmospheric disturbances.

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QUESTION: Walter Frost (FWG Associates). In your spectral rolling moment, is there a problem with transferring from coordinate systems? Generally those are developed for?

ANSWER: Generally, I think there can be but it's one of these things where at this stage using something is much better than the absence of a model, which is really the case right now.

FROST: How do you recommend calculating L_w.

HEFFLEY: That is up to the model user, although the value typically used for low altitude is height above ground.