ETSO-C117a

Date : 24.10.03

European Aviation Safety Agency

European Technical Standard Order

Subject: AIRBORNE WINDSHEAR WARNING AND ESCAPE GUIDANCE SYSTEMS (REACTIVE TYPE) FOR TRANSPORT AEROPLANES

1 - Applicability

This ETSO gives the requirements that airborne windshear warning and escape guidance systems (reactive type) for transport aeroplanes which are manufactured on or after the date of this ETSO, must meet in order to be identified with the applicable ETSO marking. It is not applicable to systems that look ahead to sense windshear conditions before the phenomenon is encountered nor to systems that use atmospheric and/or other data to predict the likelihood of a windshear alert.

2 - Procedures

2.1 - General

Applicable procedures are detailed in CS-ETSO Subpart A.

2.2 - Specific

None.

3 - Technical Conditions

3.1 - General

3.1.1 - Minimum Performance Standard

a. Purpose and Scope.

(1) Introduction. This ETSO prescribes the minimum performance standards for airborne windshear warning and escape guidance systems for transport category aeroplanes. This document defines performance, functions, and features for systems providing windshear warning and escape guidance commands based upon sensing the aeroplane's encounter of such phenomena. Airborne windshear warning and escape guidance systems that are to be identified with ETSO identification and that are manufactured on or after the date of this ETSO must meet the minimum performance standard specified herein.

(2) Scope. This ETSO applies only to windshear warning systems which identify windshear phenomenon by sensing the encounter of conditions exceeding the threshold values contained in this ETSO. In addition to windshear warning criteria, this ETSO provides criteria applicable to systems that provide optional windshear caution alert capability. Windshear escape guidance is provided to assist the pilot in obtaining the desired flight path during such an encounter.

(3) Applicable Documents. The following documents shall form a part of this ETSO to the extent specified herein. Should conflicting requirements exist, the contents of this ETSO shall be followed.

(i) EUROCAE/RTCA Document ED-14D/DO-160D, „Environmental Conditions and Test Procedures for Airborne Equipment“ change 3, dated December 2002 respectively subsequent revisions, see CS-ETSO Subpart A § 2.

(ii) EUROCAE/RTCA Document ED-12B/DO-178B, „Software Considerations in Airborne Systems and Equipment Certification,“ dated December 1992 respectively subsequent revisions, see CS-ETSO Subpart A § 2.

(iii) Society of Automotive Engineers, Inc. (SAE) Aerospace Recommended Practice (ARP) 4102/11, „Airborne Windshear Systems,“ dated July 1988.

(4) Definitions of Terms.

(i) Airborne Windshear Warning System. A device or system which uses various sensor inputs to identify the presence of windshear once the phenomena is encountered and provides the pilot with timely warning. The system may include both windshear warning and windshear caution alerts. A warning device of this type does not provide escape guidance information to the pilot to satisfy the criteria for warning and flight guidance systems.

(ii) Airborne Windshear Warning and Escape Guidance System. A device or system which uses various sensor inputs to identify the presence of windshear once the phenomenon is encountered and provides the pilot with timely warning and adequate flight guidance to improve the probability of recovery from the windshear encounter. This system may include both windshear warning and windshear caution alerts.

(iii) Airborne Windshear Auto Recovery System. A device or system which integrates or couples autopilot and/or autothrottle systems of the aircraft with an airborne windshear flight guidance system.

(iv) Airborne Windshear Escape Guidance System. A system which provides the crew with flight guidance information to improve the recovery probability once encountering a windshear phenomenon.

(v) Failure. The inability of a system, subsystem, unit, or part to perform within previously specified limits.

(vi) False Warning or Caution. A warning or caution which occurs when the design windshear warning or caution threshold of the system is not exceeded.

(vii) Nuisance Warning or Caution. A warning or caution which occurs when a phenomenon is encountered, such as turbulence, which does not, in fact, endanger the aircraft because of the duration of subsequent change of the windshear magnitude.

(viii) Recovery Procedure. A vertical flight path control technique used to maximize recovery potential from an inadvertent encounter with windshear.

(ix) Severe Windshear. A windshear of such intensity and duration which would exceed the performance capability of a particular aircraft type, and likely cause inadvertent loss of control or ground contact if the pilot did not have information available from an airborne windshear warning and escape guidance system which meets the criteria of this ETSO.

(x) Windshear Caution Alert. An alert triggered by increasing performance conditions which is set at a windshear level requiring immediate crew awareness and likely subsequent corrective action.

(xi) Windshear Warning Alert. An alert triggered by decreasing performance conditions which is set at a windshear level requiring immediate corrective action by the pilot.

b. General Standards. The following general requirements shall be met by all windshear warning and escape guidance systems:

(1) Airworthiness. Design and manufacture of the airborne equipment must provide for installation so as not to impair the airworthiness of the aircraft. Material shall be of a quality which experience and/or tests have demonstrated to be suitable and dependable for use in aircraft systems. Workmanship shall be consistent with high quality aircraft electromechanical and electronic component manufacturing practices.

(2) General Performance. The equipment must perform its intended function, as defined by the manufacturer.

(3) Fire Resistance. Except for small parts (such as knobs, fasteners, seals, grommets, and small electrical parts) that would not significantly contribute to the propagation of fire, all materials used must be self-extinguishing. One means for showing compliance with this requirement is contained in CS 25.853 and Appendix F.

(4) Operation of Controls. Controls intended for use during flight shall be designed to minimize errors, and when operated in all possible combinations and sequences, shall not result in a condition whose presence or continuation would be detrimental to the continued performance of the equipment.

(5) Accessibility of Controls. Controls that are not normally adjusted in flight shall not be readily accessible to the operator.

(6) Interfaces. The interfaces with other aircraft equipment must be designed such that normal or abnormal windshear warning and escape guidance equipment operation shall not adversely affect the operation of other equipment.

(7) Compatibility of Components. If a system component is individually acceptable but requires calibration adjustments or matching to other components in the aircraft for proper operation, it shall be identified in a manner that will ensure performance to the requirements specified in this ETSO.

(8) Interchangeability. System components which are identified with the same manufactured part number shall be completely interchangeable.

(9) Control/Display Capability. A suitable interface shall be provided to allow data input, data output, and control of equipment operation. The control/display shall be operable by one person with the use of only one hand.

(10) Control/Display Readability. The equipment shall be designed so that all displays and controls shall be readable under all cockpit ambient light conditions ranging from total darkness to reflected sunlight and arranged to facilitate equipment usage. Limitations on equipment installations to ensure display readability should be included in the installation instructions.

(11) Effects of Test. The design of the equipment shall be such that the application of the specified test procedures shall not produce a condition detrimental to the performance of the equipment except as specifically allowed.

(12) Equipment Computational Response Time. The equipment shall employ suitable update rates for computation and display of detection and guidance information.

(13) Supplemental Heating or Cooling. If supplemental heating or cooling is required by system components to ensures that the requirements of this ETSO are met, they shall be specified by the equipment manufacturer in the installation instructions.

(14) Self-Test Capability. The equipment shall employ a self-test capability to verify proper system operation.

(i) Any manually initiated self-test mode of operation shall automatically return the system to the normal operating mode upon completion of a successful test.

(ii) Any automatically activated self-test feature must annunciate this mode of operation to the pilot if this feature activates annunciation lights, aural messages, or displaces the guidance commands in any way.

(iii) Conduct of the system self-test feature must not adversely affect the performance of operation of other aircraft systems.

(iv) Failure of the system to successfully pass the self-test shall be annunciated.

(15) Independence of Warning and Escape Guidance Functions. Irrespective of whether the warning and escape guidance functions are in a combined system or are separate systems, they should be sufficiently independent such that a failure of either system does not necessarily preclude or inhibit the presentation of information from the other. A warning system failure shall not result in ambiguous or erroneous guidance system mode annunciation.

(16) System Reliability.

(i) The probability of a false warning being generated within the windshear warning system or the windshear warning and escape guidance system shall be 1×10^{-4} or less per flight hour.

(ii) The probability of an unannunciated failure of the windshear warning system or the windshear warning and escape guidance system shall be 1×10^{-5} or less per flight hour (reserved).

c. Equipment Functional Requirements - Standard Conditions. The equipment shall meet the following functional requirements.

(1) Mode Annunciation. The windshear escape guidance display mode of operation shall be annunciated to the pilot upon escape guidance activation during a windshear encounter and upon reversion to a different flight guidance mode.

(2) Malfunction/Failure Indications. The equipment shall indicate:

(i) Inadequate or absence of primary power.

(ii) Equipment failures.

(iii) Inadequate or invalid warning or guidance displays or output signals.

(iv) Inadequate or invalid sensor signals or sources.

These malfunction/failure indications shall occur independently of any operator action. The lack of adequate warning displays, escape guidance information, or sensor signals or sources shall be annunciated when compliance with the requirements of this ETSO cannot be assured.

(3) Windshear Caution Alert. If the equipment includes a windshear caution alert:

(i) It shall provide an annunciation of increasing performance shear (updraft, increasing headwind, or decreasing tailwind) in accordance with the shear intensity curve shown in figure 1.

(ii) This caution alert shall display or provide an appropriate output for display of an amber caution annunciation dedicated for this purpose. An aural alert may be provided as an option. The caution display (or output) should remain until the threshold windshear condition no longer exists (not less than a minimum of 3 seconds) or a windshear warning alert occurs.

(iii) Gust conditions shall not cause a nuisance caution alert. Turbulence shall not cause more than one nuisance caution alert per 250 hours (or 3,000 flight cycles based on 1 hour/flight cycle) of system operation.

(4) Windshear Warning Alert.

(i) A windshear warning alert shall provide an annunciation of decreasing performance shear (downdraft, decreasing headwind, or increasing tailwind) with a magnitude equal or greater than that shown in the shear intensity curve shown in figure 1.

(ii) This warning alert shall display or provide an appropriate output for display of a red warning annunciation labeled „windshear" dedicated for this purpose. The visual alert should remain at least until the threshold windshear condition no longer exists or a minimum of 3 seconds, whichever is greater. An aural alert shall be provided that annunciates „windshear" for three aural cycles. The aural alert need not be repeated for subsequent windshear warning alerts within the same mode of operation.

(iii) Gust conditions shall not cause a nuisance warning alert. Turbulence shall not cause more than one nuisance warning alert per 250 hours (or 3,000 flight cycles based on 1 hour/flight) of system operation.

(5) Operating Altitude Range. The system shall be designed to function from at least 50 feet above ground level (AGL) to at least 1000 feet AGL.

(6) Windshear Escape Guidance. Flight guidance algorithms shall incorporate the following design considerations:

(i) At the point of system warning threshold, the available energy of the aeroplane must be properly managed through a representative number of windfield conditions. These conditions must take into account significant shear components in both the horizontal and vertical axes, individually and in combination.

(ii) The flight path guidance commands must be suitable to the dynamic response of aircraft of the type on which the system is intended for installation.

(iii) If the magnitude of the shear components are such as to overcome the performance capability of the aeroplane, guidance commands must be such that ground impact will occur in the absence of ability to produce additional lift, absence of excessive kinetic energy, and without putting the aircraft into a stalled condition.

(iv) Flight guidance command information shall be provided for presentation on the primary flight display/attitude direction indicator (PFD/ADI) and any available Head Up Display (HUD).

(v) Flight guidance displays which command flight path and pitch attitude should be limited to an angle-of-attack equivalent to onset of stall warning or maximum pitch command of 27º, whichever is less.

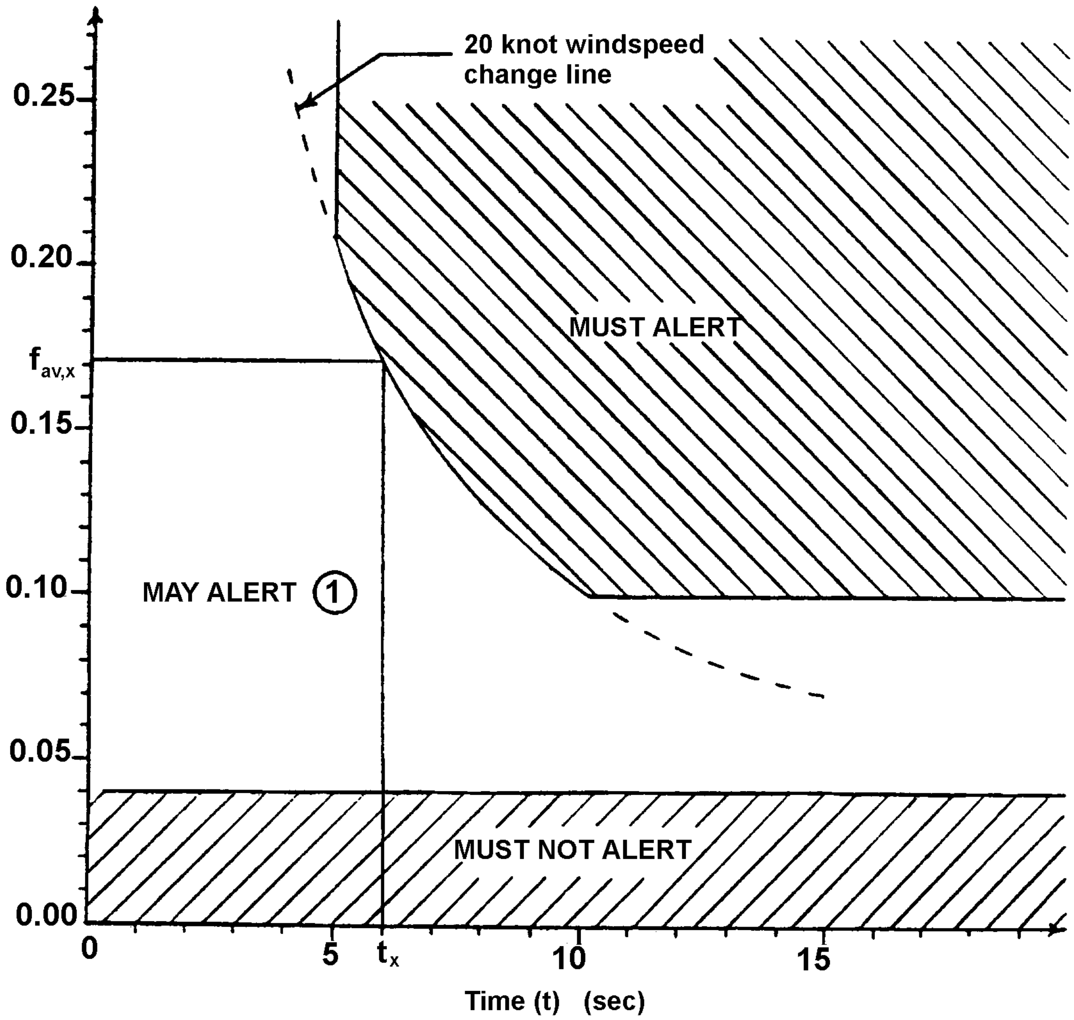
(vi) Flight guidance commands and any auto recovery mode (if included) may be automatically activated concurrent with or after the windshear warning alert occurs or may be manually selected. If manual selection is utilized, it shall only be via the takeoff-go around (TOGA) switch or equivalent means (i.e., a function of throttle position, other engine parameters, etc.).

(vii) Manual deselection of windshear flight guidance and any auto recovery mode (if included) shall be possible by means other than the TOGA switches.

(viii) Systems incorporating automatic reversion of flight guidance commands from windshear escape guidance to another flight guidance mode should provide a smooth transition between modes. Flight guidance commands shall not be removed from the flight guidance display until either manually deselected or until the aircraft, following exit of the warning conditions, has maintained a positive rate of climb and speed above 1.3 V_{s1} for at least 30 seconds.

FIGURE 1

SHEAR INTENSITY CURVE



$f_{av,x}$ = average shear intensity to cause a warning at time t_x (resulting in a 20 knot windspeed change, bounded as shown; applies to horizontal, vertical, and combination shear intensities)

$$= \frac{\int_0^{t_x} f(t)dt}{t_x}$$ whereby f(t) = instantaneous shear intensity at time t

(1) A nuisance warning test utilizing the Dryden turbulence model and discrete gust model are conducted independently from alert threshold tests to verify the acceptability of potential nuisance warnings due to turbulence or gusts.

d. Equipment Performance - Environmental Conditions. The environmental tests and performance requirements described in this subparagraph are intended to provide a laboratory means of determining the overall performance characteristics of the equipment under conditions representative of those that may be encountered in actual operations. Some of the environmental tests contained in this subparagraph need not be performed unless the manufacturer wishes to qualify the equipment for that particular environmental condition. These tests are identified by the phrase „When Required.“ If the manufacturer wishes to qualify the equipment to these additional environmental conditions, then these „When Required“ tests shall be performed.

Unless otherwise specified, the test procedures applicable to a determination of equipment performance under environmental test conditions are set forth in EUROCAE/RTCA Document ED-14D/DO-160D, „Environmental Conditions and Test Procedures for Airborne Equipment.“ Performance tests which must be made after subjection to test environments may be conducted after exposure to several environmental conditions.

(1) Temperature and Altitude Tests (ED-14D/DO-160D, Section 4.0). EUROCAE/RTCA Document ED-14D/DO-160D contains several temperature and altitude test procedures which are specified according to the category for which the equipment will be used. These categories are included in paragraph 4.2 of ED-14D/DO-160D. The following subparagraphs contain the applicable test conditions specified in Section 4.0 of ED-14D/DO-160D.

(i) Low Operating Temperature Test. The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraph 4.5.1, and the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(ii) High Short-Time Operating Temperature Test. The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraph 4.5.2, and the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(iii) High Operating Temperature Test. The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraph 4.5.3, and the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(iv) In-Flight Loss of Cooling Test (When Required). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraph 4.5.4, and the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(v) Altitude Test. The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraph 4.6.1, and the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(vi) Decompression Test (When Required). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraph 4.6.2, and the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(vii) Overpressure Test (When Required). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraph 4.6.3, and the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(2) Temperature Variation Test (ED-14D/DO-160D, Section 5.0). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, Section 5.0, and the following requirements of this standard shall be met:

(i) Section 3.1.1(c)(1) - Mode Annunciation
(ii) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(iii) Section 3.1.1(c)(3) - Windshear Caution Alert
(iv) Section 3.1.1(c)(4) - Windshear Warning Alert
(v) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(3) Humidity Test (ED-14D/DO-160D, Section 6.0). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, Section 6.0, and the following requirements of this standard shall be met:

(i) Section 3.1.1(c)(1) - Mode Annunciation
(ii) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(iii) Section 3.1.1(c)(3) - Windshear Caution Alert
(iv) Section 3.1.1(c)(4) - Windshear Warning Alert
(v) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(4) Shock tests (ED-14D/DO-160D, Section 7.0).

(i) Operational Shocks. The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraph 7.2, and the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(ii) Crash Safety Shocks. The application of the crash safety shock tests may result in damage to the equipment under test. Therefore, this test may be conducted after the other tests have been competed. In this case, paragraph 3.1.1 (b)(11), „Effects of Test," of this standard does not apply. The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraph 7.3, and shall meet the requirements specified therein.

(5) Vibration Test (ED-14D/DO-160D, Section 8.0). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, Section 8.0, and the following requirements of this standard shall be met:

(i) Section 3.1.1(c)(1) - Mode Annunciation
(ii) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(iii) Section 3.1.1(c)(3) - Windshear Caution Alert
(iv) Section 3.1.1(c)(4) - Windshear Warning Alert

(v) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(6) Explosion Proofness Test (ED-14D/DO-160D, Section 9.0) (When Required). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D , Section 9.0. During these tests, the equipment shall not cause detonation of the explosive mixture within the test chamber.

(7) Waterproofness Tests (ED-14D/DO-160D , Section 10.0).

(i) Drip Proof Test (When Required). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraph 10.3.1, and the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(ii) Spray Proof Test (When Required). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraph 10.3.2, and the following requirements of this standard shall be met:

NOTE: This test shall be conducted with the spray directed perpendicular to the most vulnerable area(s) as determined by the equipment manufacturer.

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(iii) Continuous Stream Proof Test (When Required). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraph 10.3.3, and the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(8) Fluids Susceptibility Tests (ED-14D/DO-160D, Section 11.0).

(i) Spray Test (When Required). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraph 11.4.1, and the following requirements of this standard shall be met:

At the end of the 24-hour exposure period, the equipment shall operate at a level of performance that indicates that no significant failures of components or circuitry have occurred. Following the two-hour operational period at ambient temperature, after the 160-hour exposure period at elevated temperature, the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(ii) Immersion Test (When Required). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraph 11.4.2, and the following requirements of this standard shall be met:

At the end of the 24-hour immersion period specified in ED-14D/DO-160D, paragraph 11.4.2, the equipment shall operate at a level of performance that indicates that no significant failures of components or circuitry have occurred. Following the two-hour operational period at ambient temperature, after the 160-hour exposure period at elevated temperature, the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(9) Sand and Dust Test (ED-14D/DO-160D, Section 12.0) (When Required). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, Section 12.0, and the following requirements of this standard shall be met:

(i) Section 3.1.1(c)(1) - Mode Annunciation
(ii) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(iii) Section 3.1.1(c)(3) - Windshear Caution Alert
(iv) Section 3.1.1(c)(4) - Windshear Warning Alert
(v) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(10) Fungus Resistance Test (ED-14D/DO-160D, Section 13.0) (When Required). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, Section 13.0, and the following requirements of this standard shall be met:

(i) Section 3.1.1(c)(1) - Mode Annunciation
(ii) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(iii) Section 3.1.1(c)(3) - Windshear Caution Alert
(iv) Section 3.1.1(c)(4) - Windshear Warning Alert
(v) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(11) Salt Spray Test (ED-14D/DO-160D, Section 14.0) (When Required). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, Section 14.0, and the following requirements of this standard shall be met:

(i) Section 3.1.1(c)(1) - Mode Annunciation
(ii) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(iii) Section 3.1.1(c)(3) - Windshear Caution Alert
(iv) Section 3.1.1(c)(4) - Windshear Warning Alert
(v) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(12) Magnetic Effect Test (ED-14D/DO-160D, Section 15.0). The equipment shall be subject to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, Section 15.0, and the equipment shall meet the requirements of the appropriate instrument or equipment class specified therein.

(13) Power Input Tests (ED-14D/DO-160D, Section 16.0).

(i) Normal Operating Conditions. The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraphs 16.5.1 and 16.5.2, as appropriate, and the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(ii) Abnormal Operating Conditions. The application of the low voltage conditions (DC) (Category B equipment) test may result in damage to the equipment under test. Therefore, this test may be conducted after the other tests have been completed. Section 3.1.1(b)(11), „Effects of Test,“ does not apply. The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, paragraphs 16.5.3 and 16.5.4, as appropriate, and the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(14) Voltage Spike Conducted Test (ED-14D/DO-160D, Section 17.0).
The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, Section 17.0, and the following requirements of this standard shall be met:

(a) Section 3.1.1(c)(1) - Mode Annunciation
(b) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(c) Section 3.1.1(c)(3) - Windshear Caution Alert
(d) Section 3.1.1(c)(4) - Windshear Warning Alert
(e) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(15) Audio Frequency Conducted Susceptibility Test (ED-14D/DO-160D, Section 18.0). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, Section 18.0, and the following requirements of this standard shall be met:

(i) Section 3.1.1(c)(1) - Mode Annunciation
(ii) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(iii) Section 3.1.1(c)(3) - Windshear Caution Alert
(iv) Section 3.1.1(c)(4) - Windshear Warning Alert
(v) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(16) Induced Signal Susceptibility Test (ED-14D/DO-160D, Section 19.0). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, Section 19.0, and the following requirements of this standard shall be met:

(i) Section 3.1.1(c)(1) - Mode Annunciation
(ii) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(iii) Section 3.1.1(c)(3) - Windshear Caution Alert

(iv) Section 3.1.1(c)(4) - Windshear Warning Alert
(v) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(17) Radio Frequency Susceptibility Test (Radiated and Conducted) (ED-14D/DO-160D, Section 20.0). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, Section 20.0, and the following requirements of this standard shall be met:

(i) Section 3.1.1(c)(1) - Mode Annunciation
(ii) Section 3.1.1(c)(2) - Malfunction/Failure Indications
(iii) Section 3.1.1(c)(3) - Windshear Caution Alert
(iv) Section 3.1.1(c)(4) - Windshear Warning Alert
(v) Section 3.1.1(c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(18) Emission of Radio Frequency Energy Test (ED-14D/DO-160D, Section 21.0). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, Section 21.0, and the requirements specified therein shall be met.

(19) Lightning Induced Transient Susceptibility (ED-14D/DO-160D, Section 22.0). The equipment shall be subjected to the test conditions as specified in EUROCAE/RTCA Document ED-14D/DO-160D, Section 22.0, and the requirements specified therein shall be met:

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

e. Equipment Test Procedures.

(1) Definitions of Terms and conditions of Tests. The following definitions of terms and conditions of tests are applicable to the equipment tests specified herein:

(i) Power Input Voltage. Unless otherwise specified, all tests shall be conducted with the power input voltage adjusted to design voltage ±2 percent. The input voltage shall be measured at the input terminals of the equipment under test.

(ii) Power Input Frequency.

(a) In the case of equipment designed for operation from an AC power source of essentially constant frequency (e.g., 400 Hz), the input frequency shall be adjusted to design frequency ±2 percent.

(b) In the case of equipment designed for operation from an AC power source of variable frequency (e.g., 300 to 1000 Hz), unless otherwise specified, test shall be conducted with the input frequency adjusted to within 5 percent of a selected frequency and within the range for which the equipment is designed.

(iii) Windfield Models. Unless otherwise specified, the windfield models used for tests shall be those specified in appendix 1 of this ETSO.

(iv) Adjustment of Equipment. The circuits of the equipment under test shall be aligned and adjusted in accordance with the manufacturer’s recommended practices prior to the application of the specified tests.

(v) Test Instrument Precautions. Due precautions shall be taken during the conduct of the tests to prevent the introduction of errors resulting from the connection of voltmeters, oscilloscopes, and other test instruments across the input and output impedances of the equipment under test.

(vi) Ambient Conditions. Unless otherwise specified, all tests shall be conducted under conditions of ambient room temperature, pressure, and humidity. However, the room temperature shall be not lower than 10° C.

(vii) Warm-up Period. Unless otherwise specified, all tests shall be conducted after the manufacturer's specified warm-up period.

(viii) Connected Loads. Unless otherwise specified, all tests shall be performed with the equipment connected to loads which have the impedance values for which it is designed.

(2) Test Procedures. The equipment shall be tested in all modes of operation that allow different combinations of sensor inputs to show that it meets both functional and accuracy criteria.

Dynamic testing provides quantitative data regarding windshear warning and escape guidance equipment performance using a simplified simulation of flight conditions. This testing, when properly performed and documented, may serve to minimize the flight test requirements.

It shall be the responsibility of the equipment manufacturer to determine that the sensor inputs, when presented to the windshear warning and escape guidance equipment, will produce performance commensurate with the requirements of this standard. Additional sensor inputs may be optionally provided to enhance equipment capability and/or performance.

The equipment required to perform these tests shall be defined by the equipment manufacturer as a function of the specific sensor configuration of his equipment. Since these tests may be accomplished more that one way, alternative test equipment setups may be used where equivalent test function can be accomplished. Combinations of tests may be used wherever appropriate.

The test equipment signal sources shall provide the appropriate signal format for input to the specific system under test without contributing to the error values being measured. Tests need only be done once unless otherwise indicated.

The scenarios established for testing windshear warning and escape guidance systems represent realistic operating environments to properly evaluate such systems. The windfield models contained in appendix 1 of this ETSO should be used to evaluate the performance of the windshear warning and escape guidance system. The manufacturer may propose different windfield models provided it is shown that they represent conditions at least as severe as those contained in this ETSO.

(3) Test Setup. Simulator tests shall be used to demonstrate the performance capability of the windshear warning and escape guidance equipment. A suitable equipment interface shall be provided for recording relevant parameters necessary to evaluate the particular system under test. The aircraft simulator shall be capable of appropriate dynamic modeling of a representative aircraft and of the windfield and turbulence conditions contained in appendices 1 and 2 of this ETSO or other windfield/turbulence models found acceptable by the Administrator.

(4) Functional Performance (paragraphs (c)(1) through (c)(6)). Each of the functional capabilities identified in paragraphs (c)(1) through (c)(6) shall be demonstrated with the windshear warning and escape guidance equipment powered. These capabilities shall be evaluated either by inspection or in conjunction with the tests described in paragraphs (e)(5) through (e)(11).

(5) Mode Annunciation (paragraph (c)(1)). With the equipment operating, verify the windshear escape guidance display mode of operation is annunciated to the pilot upon escape guidance activation and upon reversion to a different flight guidance mode.

(6) Malfunction/Failure Indications (paragraph (c)(2)). Configure the equipment for simulation tests as defined in paragraph (e)(3).

(i) With the system active (within the operating altitude range) and inactive (outside the operating altitude range), remove one at a time each required electrical power input to the equipment. There shall be a failure indication by the equipment of each simulated failure condition.

(ii) With the system active (within the operating altitude range) and inactive (outside the operating altitude range), cause each sensor or other signal input to become inadequate or invalid. There shall be a failure indication by the equipment of each simulated failure condition.

(7) Windshear Caution Alert (paragraph (c)(3)). For equipment incorporating a windshear caution alert function, accomplish the following tests:

(i) Configure the equipment for simulation test as defined in paragraph (e)(3). Subject the equipment to acceleration waveform values meeting the following conditions (reference figure 2). The system shall generate an appropriate caution alert (or no alert) within the time intervals specified when subjected to the following average shear intensity ($f_{av,x}$) values:

$f_{av,x}$ (1)	Time of Exposure (t) (sec)	Result
0.02	20	no alert
0.04	20	no alert
0.105	10	alert within 10 sec
1.049/t	t	alert within t sec (2)
0.21	5	alert within 5 sec
=0.270	5	alert within 5 sec

Notes: (1) The average shear intensity which must result in a caution alert after a time t_x or less meets the definition of $f_{av,x}$ in figure 1. The maximum instantaneous shear intensity of the test waveform is restricted to 0.075 or 100 percent of $f_{av,x}$ above the average shear value $f_{av,x}$, whichever is less. The minimum instantaneous shear intensity of the test waveform is zero. Test waveform rise and fall rates shall be limited to a maximum of 0.1 per second. The shear intensity before time 0 is zero for a sufficiently long time to allow the system to settle to stable conditions.

(2) t = 6, 7, 8, 9

The test conditions specified above shall be repeated 5 times. A different waveform for $f_{av,x}$ will be utilized for each of the 5 runs. An appropriate alert (or no alert) must be generated for each test condition.

Verify the system displays or provides an appropriate output for display of an amber caution annunciation dedicated for this purpose. Verify the visual caution display (or output) remains at least until the threshold windshear condition no longer exists or a minimum of 3 seconds (whichever is greater), or until a windshear warning occurs.

(ii) Subject the equipment to windspeeds defined by the Dryden turbulence model contained in appendix 2. The system shall be exposed to these conditions for a minimum of 50 hours (or 600 flight cycles) at each altitude specified in appendix 2 for a minimum total test duration of 250 hours (or 3,000 flight cycles based on 1 hour/flight cycle). No more than one nuisance caution shall be generated during this test.

(iii) Subject the equipment to windspeeds defined by the discrete gust rejection model contained in appendix 2. No alert shall be generated as a result of this test.

(8) Windshear Warning Alert (paragraph (c)(4)).

(i) Configure the equipment for simulation tests as defined in paragraph (e)(3). Subject the equipment to acceleration waveform values meeting the following conditions (reference figure 2). The system shall generate an appropriate warning alert (or no alert) within the time intervals specified when subjected to the following average shear intensity ($f_{av,x}$) values:

$f_{av,x}$ (1)	Time of Exposure (t) (sec)	Result
0.02	20	no alert
0.04	20	no alert
0.105	10	alert within 10 sec
1.049/t	t	alert within t sec (2)
0.21	5	alert within 5 sec
=0.270	5	alert within 5 sec

Notes: (1) The average shear intensity which must result in a warning alert after a time t_x or less meets the definition of $f_{av,x}$ in figure 1. The maximum instantaneous shear intensity of the test waveform is restricted to 0.075 or 100 percent of $f_{av,x}$ above the average shear value

$f_{av,x}$, whichever is less. The minimum instantaneous shear intensity of the test waveform is zero. Test waveform rise and fall rates shall be limited to a maximum of 0.1 per second. The shear intensity before time 0 is zero for a sufficiently long time to allow the system to settle to stable conditions.

(2) t = 6, 7, 8, 9

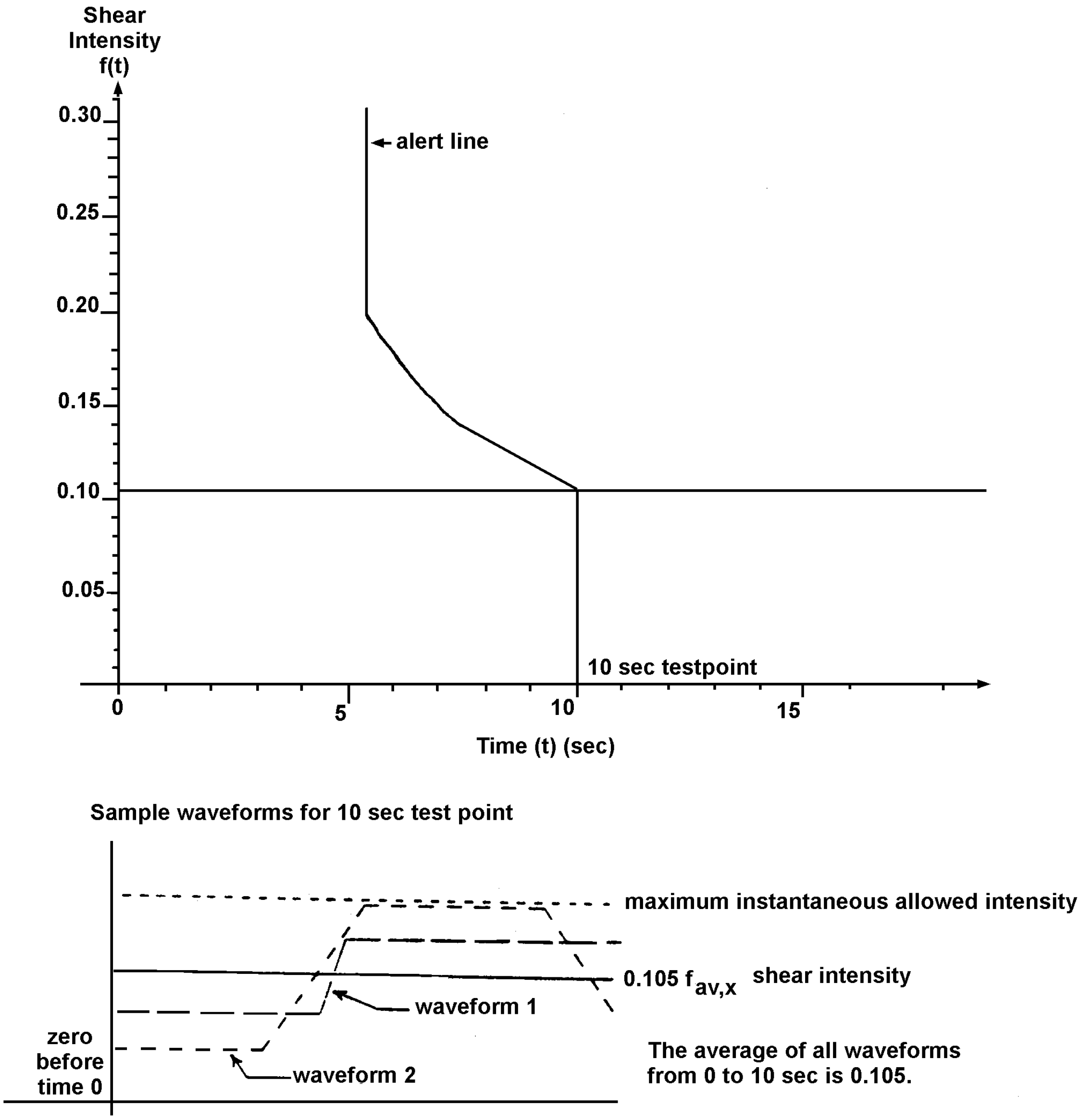
The test conditions specified above shall be repeated 5 times. A different waveform for $f_{av,x}$ will be utilized for each of the 5 runs. An appropriate alert (or no alert) must be generated for each test condition.

Verify the system displays or provides an appropriate output for display of a red warning annunciation labeled „windshear" dedicated for this purpose. Verify the visual warning display (or output) remains until the threshold windshear condition no longer exists or a minimum of 3 seconds, whichever is greater. Verify an aural alert is provided that annunciates „windshear" for three aural cycles.

(ii) Subject the equipment to windspeeds defined by the Dryden turbulence model contained in appendix 2. The system shall be exposed to these conditions for a minimum of 50 hours (or 600 flight cycles) at each altitude specified in appendix 2 for a minimum total test duration of 250 hours (or 3,000 flight cycles based on 1 hour/flight cycle). No more than one nuisance warning shall be generated during this test

FIGURE 2

WINDSHEAR ALERT TEST



(iii) Subject the equipment to windspeeds defined by the discrete gust rejection model contained in appendix 2. No alert shall be generated as a result of this test.

(9) Operating Altitude Range (paragraph (c)(5)). Configure the equipment for simulation tests as defined in paragraph (e)(3). Simulate a takeoff to an altitude of at least 1500 feet AGL. Verify the windshear warning and escape guidance system is operational from at least 50 feet AGL to at least 1000 feet AGL. Simulate an approach to landing from 1500 feet AGL to touchdown. Verify the windshear warning and escape guidance system is operational from at least 1000 feet AGL to at least 50 feet AGL.

(10) Windshear Escape Guidance (paragraph (c)(6)). Configure the equipment for simulation tests as defined in paragraph (e)(3). Subject the equipment to each of the windfield conditions contained in appendix 1 for each operating mode (takeoff, approach, landing, etc.) available. Each test condition shall be repeated 5 times. Recovery actions for the fixed pitch method comparison shall be initiated immediately upon entering the shear condition.

(i) Verify the flight path guidance commands manage the available energy of the aircraft to achieve the desired trajectory through the shear encounter. These tests shall be performed with vertical only, horizontal only, and combination vertical and horizontal shear conditions.

(a) For the takeoff case, verify the flight guidance commands produce a trajectory that provides a resultant flight path at least as good (when considered over the entire spectrum of test cases) as that obtained by establishing a 15° pitch attitude (at an approximate rate of 1.5° per second) until onset of stall warning and then reducing pitch attitude to remain at the onset of stall warning until exiting the shear condition. Evidence of a significant decrement (considered over the entire spectrum of test cases) below the flight path provided by the fixed pitch method that results from use of the guidance commands provided by the system must be adequately substantiated.

(b) For the approach/landing case, verify the flight guidance commands produce a trajectory that provides a resultant flight path at least as good (when considered over the entire spectrum of test cases) as that obtained by establishing maximum available thrust and a 15° pitch attitude (at an approximate rate of 1.5° per second) until onset of stall warning and then reducing pitch attitude to remain at the onset of stall warning until exiting the shear condition. Evidence of a significant decrement (considered over the entire spectrum of test cases) below the flight path provided by the fixed pitch method that results from use of the guidance commands provided by the system must be adequately substantiated.

(c) For shear conditions exceeding the available performance capability of the aircraft, verify the flight guidance commands result in ground impact in the absence of ability to produce additional lift, absence of excessive kinetic energy, and without putting the aircraft into a stalled condition.

(ii) Verify the flight guidance command outputs are capable of display on associated flight displays. Interface specifications shall be verified and determined to be appropriate for the systems identified in the equipment installation instructions.

(iii) Verify that pitch attitude commands do not result in an angle-of-attack exceeding the onset of stall warning or a maximum pitch command of 27°, whichever is less.

(iv) For systems incorporating manual activation of recovery flight guidance commands, verify the system is activated only by the TOGA switches (or equivalent means). For systems providing automatic activation of recovery guidance, verify the system is activated concurrent with the windshear warning alert.

(v) Verify that windshear recovery guidance commands and any automatic recovery mode can be deselected by a means other than the TOGA switches.

(vi) For systems incorporating automatic reversion of flight guidance commands from windshear escape guidance to another flight guidance mode, verify that the transition between flight guidance modes provides smooth guidance information.

(vii) Verify flight guidance commands are not removed from the flight guidance display until either manually deselected or until the aircraft, following exit of the warning conditions, has maintained a positive rate of climb and speed above 1.3 V_{s1} for at least 30 seconds.

3.1.2 - Environmental Standard

See CS-ETSO Subpart A paragraph 2.1

3.1.3 - Computer Software

See CS-ETSO Subpart A paragraph 2.2..In addition, the software for windshear warning and escape guidance functions must be verified and validated to at least Level C. An installation safety analysis for a particular aircraft installation should be accomplished to determine if software must be verified and validated to the more stringent Level B requirements.

4 - Marking

4.1 - General

Marking is detailed in CS-ETSO Subpart A paragraph 1.2.

4.2 - Specific

None.

5 - Availability of Referenced Document

See CS-ETSO Subpart A paragraph 3.

APPENDIX 1

This appendix contains data that defines the windfield models to be used in conducting the tests specified in paragraph (e)(10) of this TSO. This material was developed by the National Aeronautics And Space Administration (NASA), reference NASA Technical Memorandum 100632.

The downburst model parameters below provide the variables to be used to obtain the representative test conditions: (1)(2)

Radius of Downdraft (ft)	Maximum Outflow (ft/s)	Altitude of Max. Outflow (ft)	Distance From Starting Point (3) (ft)
920	37	98	20000 (-9000)
1180	47.6	98	15000 (-14000)
2070	58.4	131	25000 (-4000)
4430	68.9	164	30000 (1000)
9010	72.2	262	30000 (1000)
3450	88.2	197	25000 (-4000)
3180	53.1	262	30000 (1000)
1640	46	164	25000 (-4000)
5250	81.3	197	30000 (1000)
1250	67.6	100	25000 (-4000)

(1) From analytic microburst model documented in NASA TM-100632. These parameters are based on data from Proctor’s TASS model.

(2) For the takeoff case, the downburst center is positioned at the point the aircraft lifts off the runway for all test cases.

(3) For the approach/landing case, the downburst center is positioned as stated. The test is begun with the aircraft at an initial altitude of 1500 feet on a 3° glideslope (touchdown point approximately 29000 feet away). Distance from starting point indicates where the center of the downburst shaft is located relative to the starting point. The number in parenthesis next to it indicates the relative distance of the microburst center from the touchdown point (not the end of the runway). A negative number indicates that the microburst center is located before the touchdown point, positive indicates it is past the touchdown point.

SUMMARY

A simple downburst model has been developed for use in batch and real-time piloted simulation studies of guidance strategies for terminal area transport aircraft operations in wind shear conditions. The model represents an axisymmetric stagnation point flow, based on velocity profiles from the Terminal Area Simulation System (TASS) model developed by Proctor [ref. 3,4] and satisfies the mass continuity equation in cylindrical coordinates. Altitude dependence, including boundary layer effects near the ground, closely matches real-world measurements, as do the increase, peak, and decay of outflow and downflow with increasing distance form the downburst center. Equations for horizontal and vertical winds were derived, and found to be infinitely differentiable, with no singular points existent in the flow field. In addition, a simple relationship exists among the ratio of maximum horizontal to vertical velocities, the down draft radius, depth of outflow, and altitude of maximum outflow. In use, a microburst can be modeled by specifying four characteristic parameters. Velocity components in the x, y, and z directions, and the corresponding nine partial derivatives are obtained easily from the velocity equations.

INTRODUCTION

Terminal area operation of transport aircraft in a windshear environment has been recognized as a serious problem. Studies of aircraft trajectories through downbursts show that specific guidance strategies are needed for aircraft to survive inadvertent downburst encounters. In order for guidance strategies to perform in simulations as in actual encounters, a realistic set of conditions must be present during development of the strategies. Thus, aeroplane and wind models that closely simulate real-world conditions are essential in obtaining useful information from the studies.

Wind models for use on personal computers, or for simulators with limited memory space availability, have been difficult to obtain because variability of downburst characteristics makes analytical models unrealistic, and large memory requirements make use of numerical models impossible on any except very large capacity computers.

Bray [ref. 1] developed a method for analytic modeling of windshear conditions in flight simulators, and applied his method in modeling a multiple downburst scenario from Joint Airport Weather Studies (JAWS) data. However, the altitude dependence of his model is not consistent with observed data, and, although flexibility in sizing the downbursts is built into the model, it does not maintain the physical relationships which are seen in real-world data among the sizing parameters. In particular, boundary layer effects should cause radial velocity to decay vertically to zero at the ground, as does the vertical velocity.

In a study conducted at NASA Langley Research Center, three different guidance strategies for a Boeing 737-100 aeroplane encountering a microburst on takeoff were developed [ref. 2]. These strategies were first developed using a personal computer, and then implemented in a pilot-in-the-loop simulation using a very simple wind model in both efforts [fig. 1]. This model consisted of a constant outflow outside of the downburst radius and a constant slope headwind to tailwind shear across the diameter of the downburst. It was recognized that a more realistic wind model could significantly alter the outcome of the trajectory. For the subsequent part of this study, which involves altering the aeroplane model to simulate approach to landing and escape maneuvers and additional takeoff cases, a more realistic wind model was preferred. The simple analytical model outlined in this report was developed for this purpose.

SYMBOLS

JAWS	Joint Airport Weather Studies
NIMROD	Northern Illinois Meteorological Research on Downbursts
R	radius of downburst shaft (ft)
r	radial coordinate (distance from downburst center) (ft)
TASS	Terminal Area Simulation System
u	velocity in r-direction (or x-direction) (kts)
v	velocity in y-direction (kts)
w	velocity in z-direction (kts)
w_{max}	magnitude of maximum vertical velocity (kts)
u_{max}	magnitude of maximum horizontal velocity (kts)
x	horizontal (runway) distance, aeroplane to downburst center (ft)
y	horizontal (side) distance, aeroplane to downburst center (ft)
z	aeroplane altitude above ground level (ft)

z_h	depth of outflow (ft)
z_m	height of maximum U-velocity (ft)
z_{m2}	height of half maximum U-velocity (ft)
z^*	characteristic height, out of boundary layer (ft)
ϵ	characteristic height, in boundary layer (ft)
λ	scaling factor (s^{-1})

DEVELOPMENT OF VELOCITY EQUATIONS

Beginning with the full set of Euler and mass continuity equations, some simplifying assumptions about the down burst flow conditions were made. Effects of viscosity were parameterized explicitly, and the flow was assumed to be invariant with time. The downburst is axisymmetric in cylindrical coordinates, and characterized by a stagnation point at the ground along the axis of the downflow column. The flow is incompressible, with no external forces or moments acting on it.

The resulting mass conservation equation is

$$\nabla \cdot v = 0. \qquad (1)$$

Written out in full, equation 2 is

$$\frac{\partial u}{\partial r} + \frac{\partial w}{\partial z} + \frac{u}{r} = 0. \qquad (2)$$

This equation is satisfied by solutions of the form

$$w = g(r^2)q(z) \qquad (3a)$$

$$u = \frac{f(r^2)}{r} p(z) \qquad (3b)$$

provided that

$$f'(r^2) = \frac{\lambda}{2} g(r^2) \qquad (4a)$$

$$q'(z) = -\lambda p(z). \qquad (4b)$$

Note that $f'(r^2) = \frac{\partial f(r^2)}{\partial r^2}$. To solve this system of equations, solutions were assumed for two of the functions and the other two were obtained from equations 4a and 4b.

It was desired that the velocity profiles of this analytic model exhibit the altitude and radial dependence shown in the large-scale numerical weather model TASS (Terminal Area Simulation System) [ref. 3,4]. The TASS model is based on data from the Joint Airport Weather Studies (JAWS) [ref. 5], and provides a three-dimensional velocity field, frozen in time, for given locations of an aeroplane within the shear [ref. 6]. Figure 2 shows dimensionless vertical profiles of horizontal velocity, u, for TASS data, laboratory data obtained by impingement of a jet on a flat plate, and data from NIMROD (Northern Illinois Meteorological Research on Downbursts) [ref. 7]. Specific points of interest are the maximum horizontal velocity (located 100 - 200 meters above the ground), below which is a decay region due to boundary layer effects, zero velocity at the stagnation point on the ground, and an exponential decay with altitude above the maximum velocity altitude. Vertical velocity profiles from TASS data are shown in figure 3, also exhibiting a decay to zero at the stagnation point.

The radially varying characteristics desired for the horizontal wind were two peaks of equal magnitude and opposite direction located at a given radius, with a smooth, nearly linear transition between the two. Beyond the peaks, the velocity should show an exponential decay to zero. The vertical velocity was required to have a peak along the axis of symmetry (r = 0), and decay exponentially at increasing radius.

A pair of shaping functions that gave velocity profiles matching TASS data as required are given below.

$$g(r^2) = e^{-(r/R)^2}$$

$$p(z) = e^{-z/z*} - e^{-z/\varepsilon}$$

The remaining solutions were found by integrating equations 4a and 4b, yielding:

$$f\left(r^2\right) = \frac{\lambda R^2}{2}\left[1 - e^{-(r/R)^2}\right]$$

$$q(z) = -\lambda\left\{\varepsilon\left(e^{-z/\varepsilon} - 1\right) - z*\left(e^{-z/z*} - 1\right)\right\}.$$

Figures 4 and 5 show plots of these shaping functions.

Combining the functions as in equation 3, the horizontal and vertical velocities are expressed as

$$u = \frac{\lambda R^2}{2r}\left[1 - e^{-(r/R)^2}\right]\left(e^{-z/z*} - e^{-z/\varepsilon}\right) \tag{5}$$

$$w = -\lambda e^{-(r/R)^2}\left[\varepsilon\left(e^{-z/\varepsilon} - 1\right) - z*\left(e^{-z/z*} - 1\right)\right]. \tag{6}$$

By taking derivatives of equations 5 and 6 with respect to r and z, respectively, and substituting in equation 2, it can be shown that the velocity distributions satisfy continuity.

The parameters z* and ε were defined as characteristic scale lengths associated with „out of boundary layer“ and „in boundary layer“ behavior, respectively. Analysis of TASS data indicated that $z* = z_{m2}$, the altitude at which the magnitude of the horizontal velocity is half the maximum value.

It was also noted that the ratio

$$\frac{z_m}{z*} = 0.22$$

To determine the location of the maximum horizontal velocity, the partial derivatives of u with respect to r and z where set equal to zero. The resulting equation for the r– derivative is

$$2\left(\frac{r}{R}\right)^2 = e^{-(r/R)^2} - 1.$$

The resulting equation for the z-derivative is

$$\frac{z_m}{z*} = \frac{1}{(z*/\varepsilon) - 1} 1n\left(z*/\varepsilon\right).$$

Recalling that $z_m/z* = 0.22$, the values 1.1212 and 12.5 were obtained from iteration for the ratios r/R and z*/ε, respectively.

Using these values, the maximum horizontal velocity can be expressed as $u_{max} = 0.2357\,\lambda\, R$. The maximum vertical wind is located at r = 0 and z = z_h, by definition, and is given by $w_{max} = \lambda z*\left(e^{-(z_h/z*)} - 0.92\right)$.

A ratio of maximum outflow and downflow velocities can be formed

$$\frac{u_m}{w_m} = \frac{0.2357R}{z*\left(e^{-(z_h/z*)} - 0.92\right).}$$

The Scaling factor, λ, was determined by using either of equations 5 or 6 for horizontal or vertical velocity, and setting it equal to the maximum velocity, u_{max} or w_{max}, respectively. Solving for λ resulting in:

$$\lambda = \frac{w_m}{z*\left(e^{-(z_h/z*)} - 0.92\right)} = \frac{u_m}{0.2357R.}$$

The velocity equations were easily converted to rectangular coordinates, as shown in the Appendix. Partial derivatives with respect to x, y, and z were obtained by differentiating the velocity equations, and are also listed in the Appendix.

DISCUSSION AND RESULTS

Vertical and horizontal velocity profiles for u and w are shown in figures 6 and 7. Four profiles are shown for each component. The horizontal wind profiles in figure 6 were taken at the radios of peak outflow (r = 1.1212 R) and at about one-fourth that radius (r = 0.3 R), where the maximum outflow is approximately half the value at the peak outflow radius. The vertical wind profiles were taken at the radius of peak downflow (r = 0) and at r = 0.3 R. Horizontal wind and vertical wind profiles in figure 7 were taken at altitudes of h = z_m (maximum outflow), h = z* (half-maximum outflow), and h = z_h (depth of outflow).

This analytical model is compared with TASS, laboratory, and NIMROD data in figure 8. The figure shows that, when nondimensionalized by the altitude of half-maximum outflow (z*) and by the maximum outflow ($u = u_{max}$), the analytical model agrees closely with the other data.

Different shears can be modeled by specifying four parameters, and the location of downburst center relative to the aeroplane flying through it. The four parameters are: 1) a characteristic horizontal dimension; 2) maximum wind velocity; 3) altitude of maximum outflow; and 4) depth of outflow. The characteristic horizontal dimension specified is the radius of the downdraft column, noting that this is about 89 percent of the radius of peak outflow. The maximum wind velocity can be either horizontal or vertical.

CONCLUDING REMARKS

The analytic micorburst model developed for use in real-time and batch simulation studies was shown to agree well with real-world measurements for the cases studied. The functions chosen for the model showed boundary-layer effects near the ground, as well as the peak and decay of outflow at increasing altitudes, and increasing downflow with altitude. The exponential increase and decay of downflow and outflow (in the radial direction) are also characterized by the model. Equations for horizontal and vertical winds are simple and continuously differentiable, and partial derivatives in rectangular or cylindrical coordinates can be easily obtained by direct differentiation of the velocity equations. The governing equation for this system is the mass conservation law, and the analytic velocity functions developed here satisfied this condition. The model is sustained by a strong physical basis and yields high fidelity results, within the limitations of maintaining simplicity in the model, and variability of the microburst phenomenon. Parameterization of some of the characteristic dimensions allows flexibility in selecting the size and intensity of the microburst.

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APPENDIX

Define intermediate variables to simplify written equations:

$e_r = e^{-(r/R)^2}$

$e_e = e^{-(h/\varepsilon)}$

$e_z = e^{-(h/z^*)}$

$e_d = e_z - e_e$

$e_c = z^*(1 - e_z) - \varepsilon(1 - e_e)$

Horizontal and Vertical Velocities

$$W_X = \frac{\lambda R^2}{2r^2}(1 - e_r)e_d x_{ad}$$

$$W_y = \frac{\lambda R^2}{2r^2}(1 - e_r)e_d y_{ad}$$

$$W_h = -\lambda e_r e_c$$

Partial Derivatives

$$\frac{\partial w_x}{\partial x} = \frac{\lambda R^2 e_d}{2r^2}\left[e_r\left(\frac{2x_{ad}{}^2}{R^2} + \frac{2x_{ad}{}^2}{r^2} - 1\right) - \frac{2x_{ad}{}^2}{r^2} + 1\right]$$

$$\frac{\partial w_x}{\partial y} = \frac{\lambda R^2 x_{ad} y_{ad} e_d}{r^2}\left[e_r\left(\frac{1}{R^2} + \frac{1}{r^2}\right) - \frac{1}{r^2}\right]$$

$$\frac{\partial w_x}{\partial h} = \frac{\lambda R^2 x_{ad}}{2r^2}\left(1 - e_r\right)\left[\frac{e_e}{\varepsilon} - \frac{e_z}{z^*}\right]$$

$$\frac{\partial w_y}{\partial x} = \frac{\lambda R^2 x_{ad} y_{ad} e_d}{r^2}\left[e_r\left(\frac{1}{R^2} + \frac{1}{r^2}\right) - \frac{1}{r^2}\right]$$

$$\frac{\partial w_y}{\partial y} = \frac{\lambda R^2 e_d}{2r^2}\left[e_r\left(\frac{2y_{ad}{}^2}{R^2} + \frac{2y_{ad}{}^2}{r^2} - 1\right) - \frac{2y_{ad}{}^2}{r^2} + 1\right]$$

$$\frac{\partial w_y}{\partial h} = \frac{\lambda R^2 y_{ad}}{2r^2}\left(1 - e_r\right)\left[\frac{e_e}{\varepsilon} - \frac{e_z}{z^*}\right]$$

$$\frac{\partial w_h}{\partial x} = \frac{2\lambda x_{ad} e_r e_c}{R^2}$$

$$\frac{\partial w_h}{\partial y} = \frac{2\lambda y_{ad} e_r e_c}{R^2}$$

$$\frac{\partial w_h}{\partial h} = -\lambda e_r e_d$$

Other Relationships

From TASS $\quad \frac{z_m}{z^*} = 0.22 \quad \frac{z^*}{\varepsilon} = 12.5$

Maximums $\quad w_{x\,max} = 0.2357\lambda R$

$w_{y\,max} = w_{x\,max}$

$w_{h\,max} = \lambda z^*(e^{-(z_h/z^*)} - 0.92)$.

(λ is determined from the above relationships)

$$\frac{w_{x_{max}}}{w_{h_{max}}} = \frac{0.2357R}{z^*\left(e^{-z_h/z^*} - 0.92\right)}$$

Variable List

z^* = altitude where w_x is half the value of $w_{x\,max}$ (ft)
ε = characteristic height of boundary layer effects (ft)
z_h = depth of outflow (ft)
z_m = altitude of maximum outflow (ft)
λ = scaling parameter (s^{-1})
r = radial distance from aeroplane to downburst (ft)
h = altitude of aeroplane (ft)
R = radius of downdraft (ft)
x_{ad}, y_{ad} = x, y coordinates, aeroplane to microburst (ft)
$w_{x\,max}$, $w_{y\,max}$, $w_{h\,max}$ maximum winds, x, y, and h directions

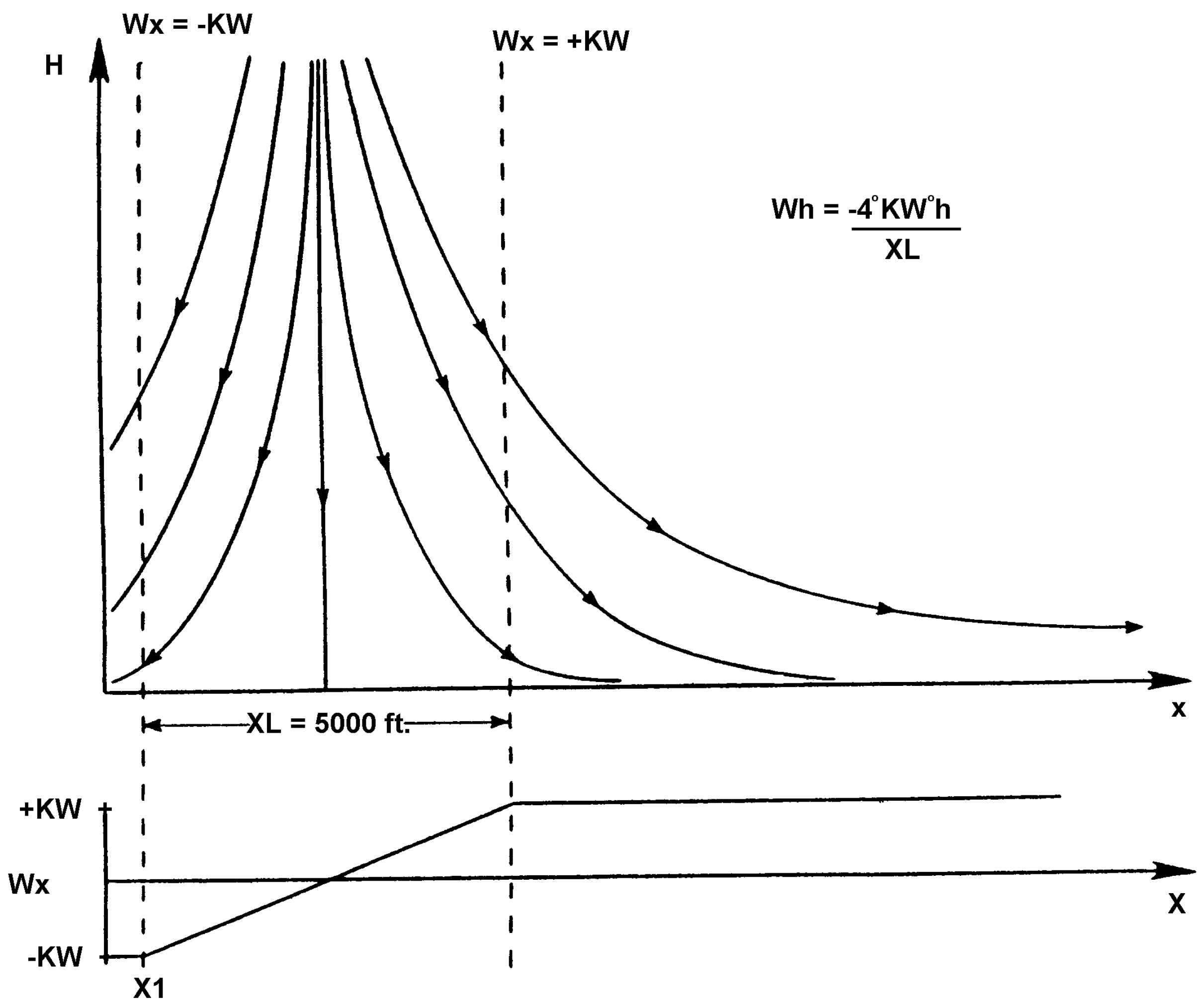

Figure 1 Wind Model Used In Guidance Studies

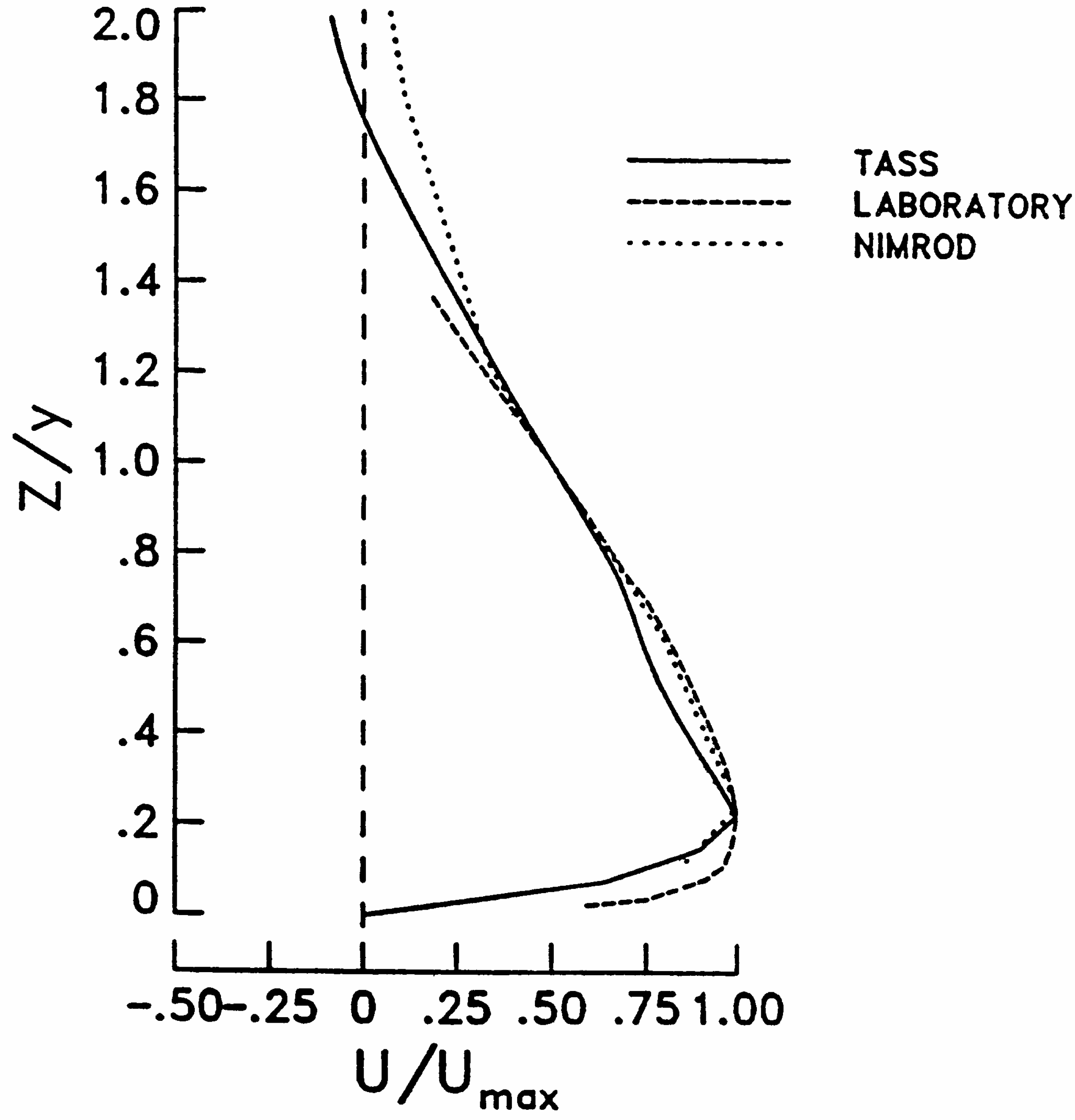

Figure 2 Vertical Profile of Microburst Outflow (Nondimensional)

VERTICAL PROFILES OF VERTICAL VELOCITY
FOR 30 JUN 82 CASE:
SENSITIVITY TO RADIUS OF PRECIPITATION SHAFT

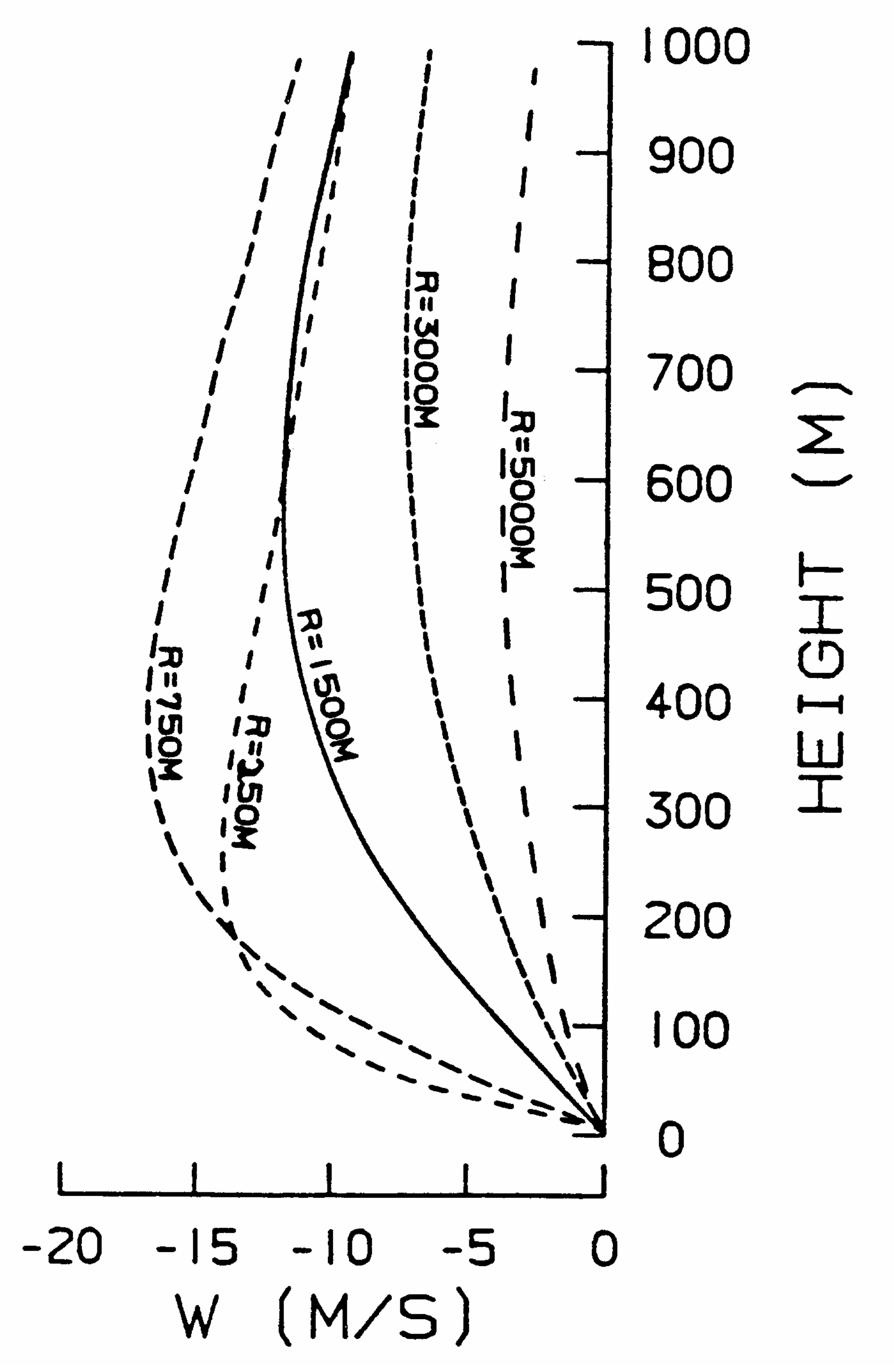

Figure 3 Vertical Profile of Microburst Downflow

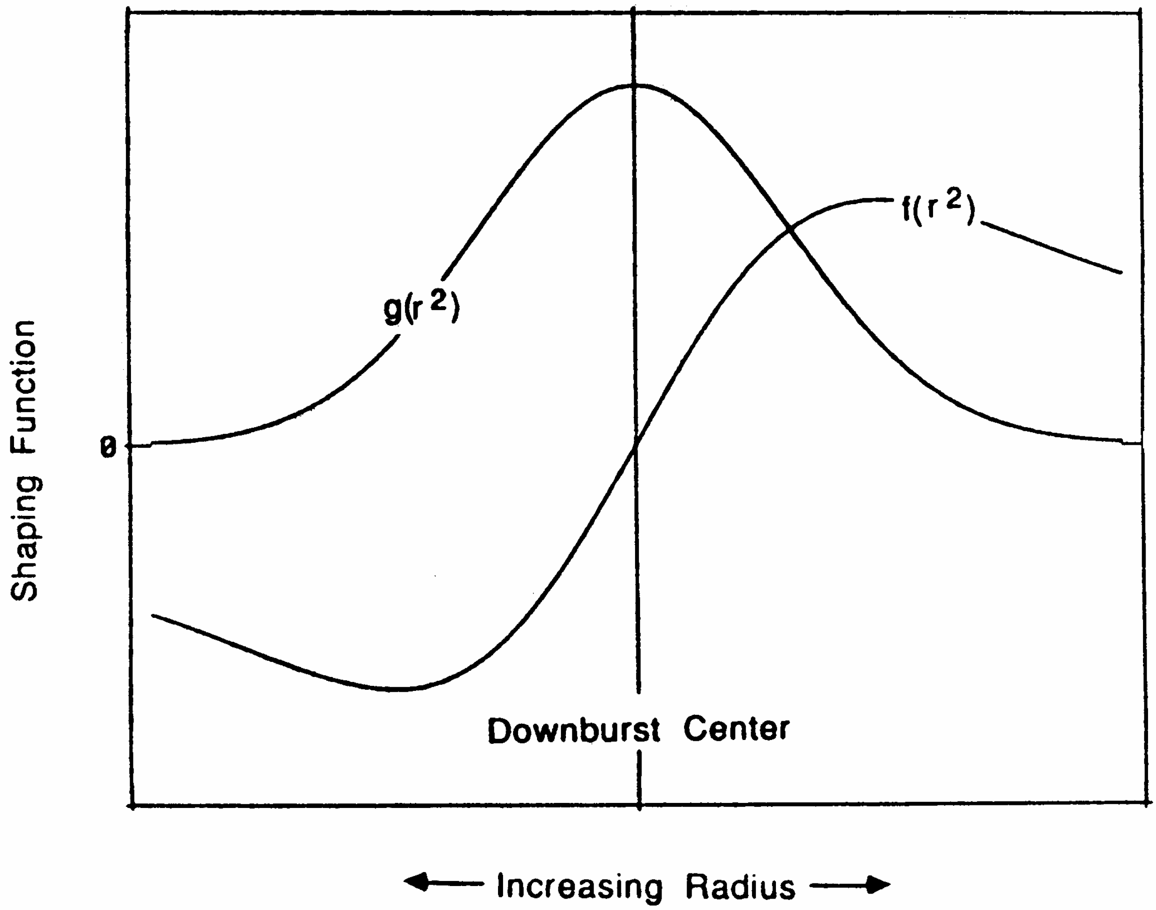

Figure 4 Characteristic Variation of Horizontal Shaping Functions

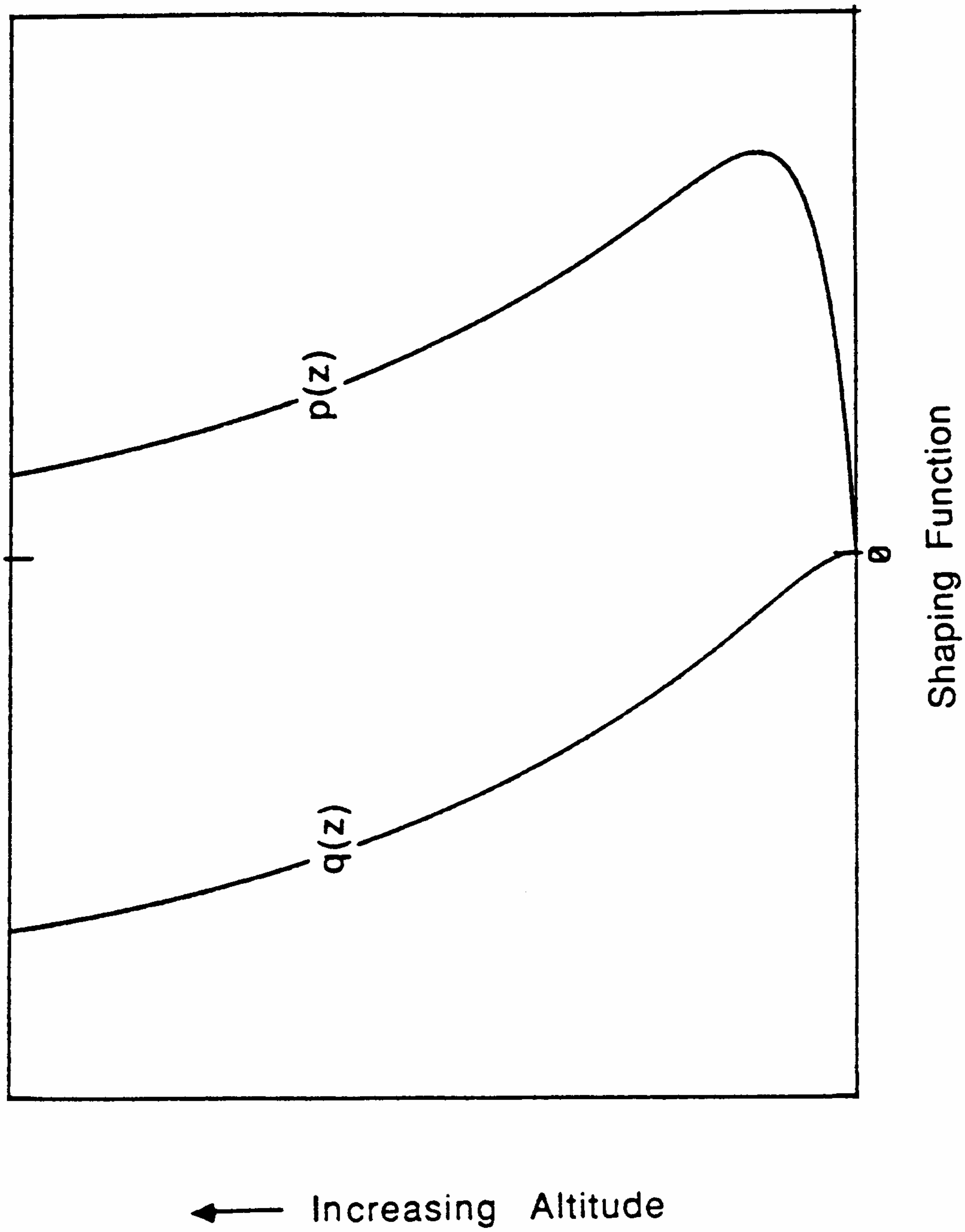

Figure 5 Characteristic Variation of Vertical Shaping Functions

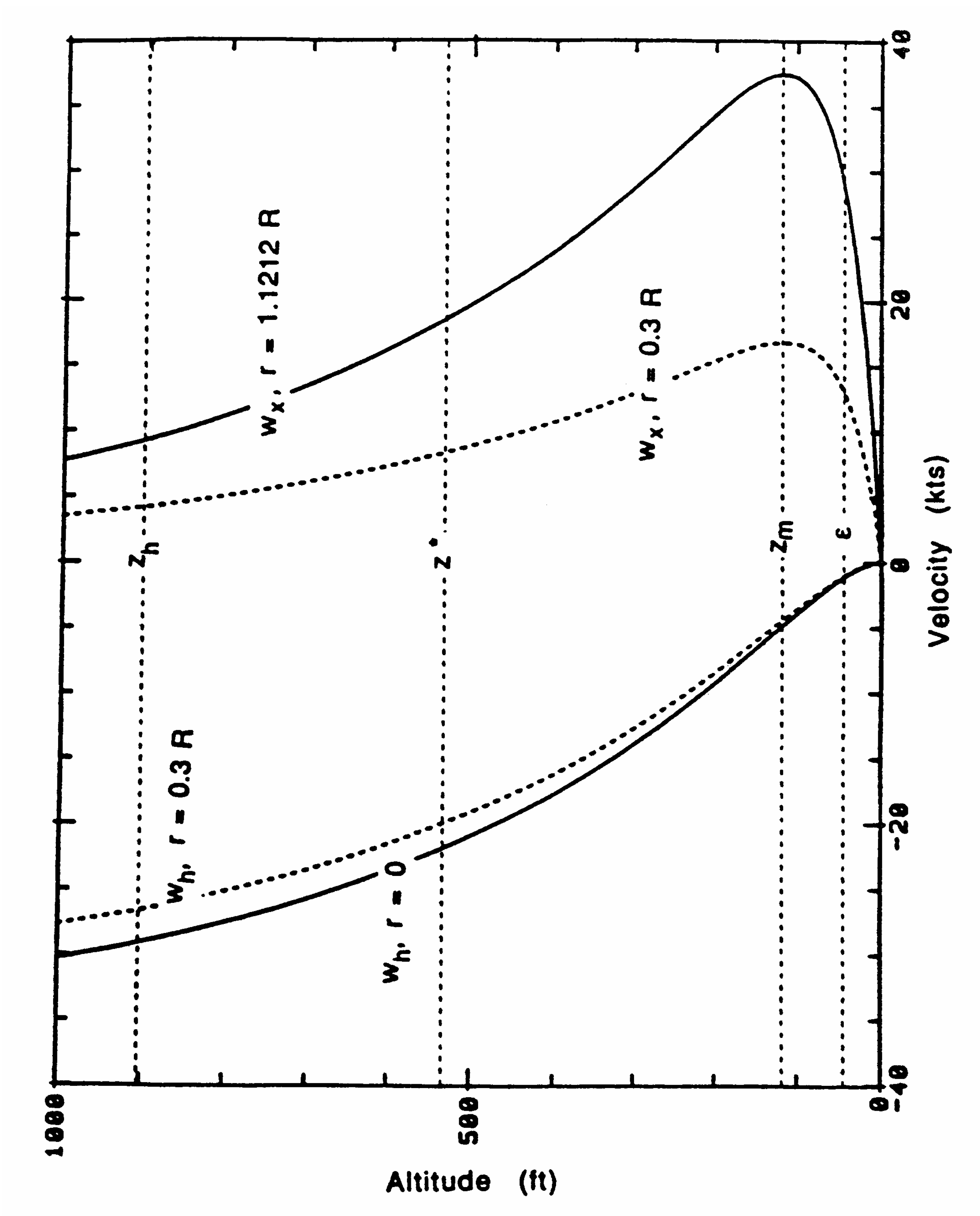

Figure 6 Vertical Velocity Profiles For Analytical Model

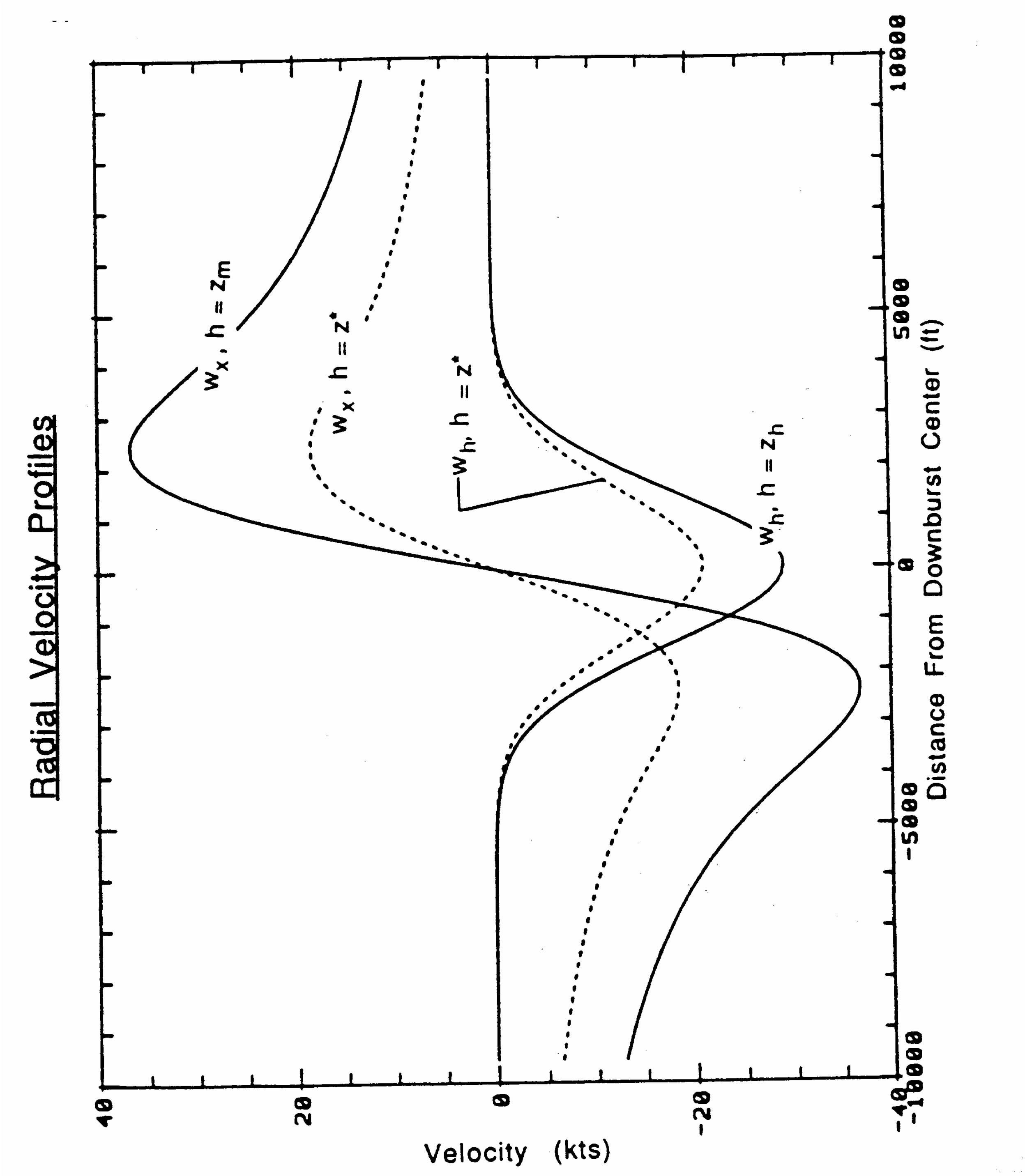

Figure 7 Radial Velocity Profiles For Analytical Model

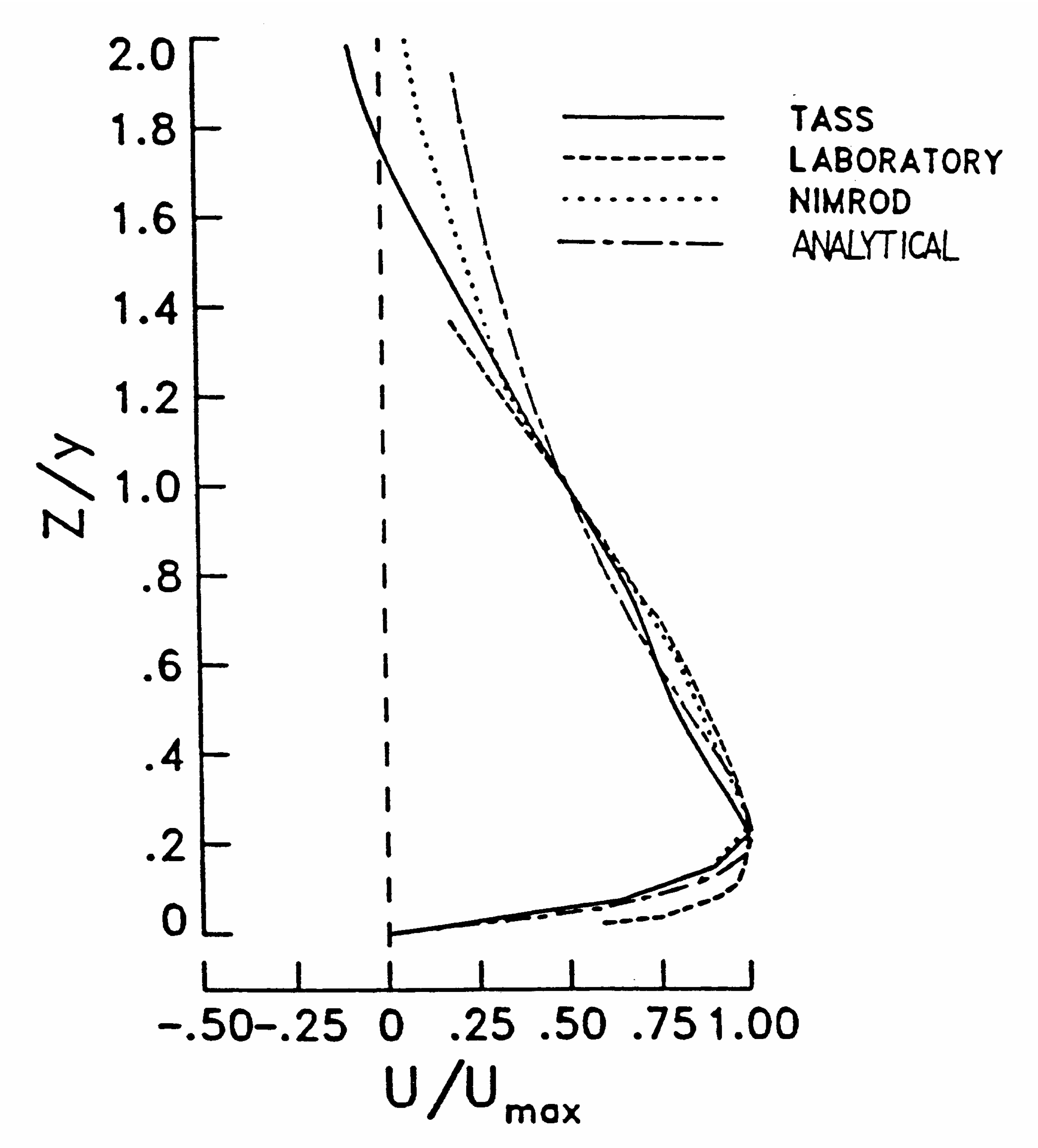

Figure 8 Comparison of Wind Model Vertical Profiles

APPENDIX 2

This appendix contains data that defines the Dryden turbulence model and discrete gust model to be used in conduction the tests specified in paragraphs (e)(7)(ii), (e)(7)(iii), (e)(8)(ii), and (e)(8)(iii) of this TSO.

Dryden Turbulence Model

$$Fu(S) = SIGMAu * SQRT\,(TAUu/PI) * 1/(1+TAUu*S)$$

$$Fv(S) = SIGMAv * SQRT\,(TAUv/PI2) * \frac{(1 + SQRT3*TAUv*S)}{(1 + TAUv*S)*(1 + TAUv*S)}$$

$$Fw(S) = SIGMAw * SQRT\,(TAUw/PI2) * \frac{(1 + SQRT3*TAUw*S)}{(1 + TAUw*S)*(1 + TAUw*S)}$$

where:

SIGMAu, SIGMAv, SIGMAw are the RMS intensities;
TAUu = Lu/VA;
TAUv = Lv/VA;
TAUw = Lw/VA;
Lu, Lv, Lw are the turbulence scale lengths;
VA is the aircraft's true airspeed (ft/sec);
PI = 3.1415926535;
PI2 = 6.2831853070 (2 times PI);
SQRT3 = 1.732050808 (square root of 3); and
S is the Laplace transform variable.

The following table lists SIGMAu, SIGMAv, SIGMAw, Lu, Lv, and Lw versus altitude. Extrapolation will not be used, and simulator altitudes outside the bounds of the turbulence list will use the data at the boundary.

Altitude	RMS Intensities (ft/sec)			Scale Lengths (feet)		
(feet)	Long	Lat	Vert	Long	Lat	Vert
100	5.6	5.6	3.5	260	260	100
300	5.15	5.15	3.85	540	540	300
700	5.0	5.0	4.3	950	950	700
900	5.0	5.0	4.45	1123	1123	900
1500	4.85	4.85	4.7	1579	1579	1500

The applicant must demonstrate that the variance of their turbulence implementation is adequate.

Discrete Gust Rejection

Discrete gusts (in the horizontal axis) with ranges of amplitude and frequency (A and OMEGA) of the form [A(1 − cos OMEGAt)] shall be used. The following table lists the values of A and OMEGA to be used (simulates an approximate15 knot gust condition):

A	OMEGA (rad/sec)	Approx. Gust Duration (sec)
7.5	2.10	3
7.5	1.26	5
7.5	0.78	8
7.5	0.63	10
7.5	0.52	12
7.5	0.42	15
7.5	0.31	20

APPENDIX 3

SHEAR INTENSITY

$$f(t) = \frac{\dot{w}_x}{g} - \frac{w_h}{V}$$

where

$\dot{w}_x$ = Horizontal component of the wind rate of change expressed in g units (1.91 kts/sec = 0.1 g) (positive for increasing headwind).

W_h = Vertical component of the wind vector w (ft/sec) (positive for downdraft).

V = True airspeed (ft/sec).

g = Gravitational acceleration (ft/sec^2).

APPENDIX 4

The following computer listing (written in QuickBasic) provides a simplified aircraft simulation model for evaluating the effectiveness of various guidance schemes. This simulation runs on a personal computer, and the results obtained using it have been found to be comparable to those obtained on a full six degree of freedom simulator. This model was developed by J. Rene Barrios of the Honeywell Company.

The Wind Shear Simulation Model (WSSM) is a point mass three-degree of freedom mathematical model which simulates the motion of an aircraft in a vertical plane. The equations of motion, which are described in the wind axes, include the wind components of velocity and acceleration so that the aircraft dynamics during a windshear encounter are accurately modeled. This model has been used by several investigators to study the behavior of an aircraft during windshear encounters.

(Copies of that listing may be may be purchased from the Superintendent of Documents, Government Printing Office, Washington, DC 20402-9325, USA.)