Department of Transportation
Federal Aviation Administration
Aircraft Certification Service
Washington, DC

TSO-C117a

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Technical Standard Order

Subject: TSO-C117a, AIRBORNE WINDSHEAR WARNING AND ESCAPE GUIDANCE SYSTEMS FOR TRANSPORT AIRPLANES

a. Purpose and Scope.

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

(2) Scope. This TSO applies only to windshear warning systems which identify windshear phenomenon by sensing the encounter of conditions exceeding the threshold values contained in this TSO. In addition to windshear warning criteria, this TSO 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 TSO to the extent specified herein. Should conflicting requirements exist, the contents of this TSO shall be followed.

(i) RTCA Document No. DO-160B, "Environmental Conditions and Test Procedures for Airborne Equipment," dated July 1984.

(ii) RTCA Document No. DO-178B, "Software Considerations in Airborne Systems and Equipment Certification," dated December 1992.

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

DISTRIBUTION: ZVS-326; A-W(IR)-3; A-X(CD)-4; A-FFS-1, 2, 7, 8 (LTD); A-X(FS)-3; AVN-1 (2 cys); A-FAC-0 (MAX)

(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 TSO.

(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 Federal Aviation Regulations (FAR) Part 25, 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 TSO.

(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 TSO 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 (1×10^{-3} or less per flight hour for systems installed in out-of-production aircraft as defined in FAR 121.358).

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 TSO 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 airplane 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 airplane, 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 27°, whichever is less.

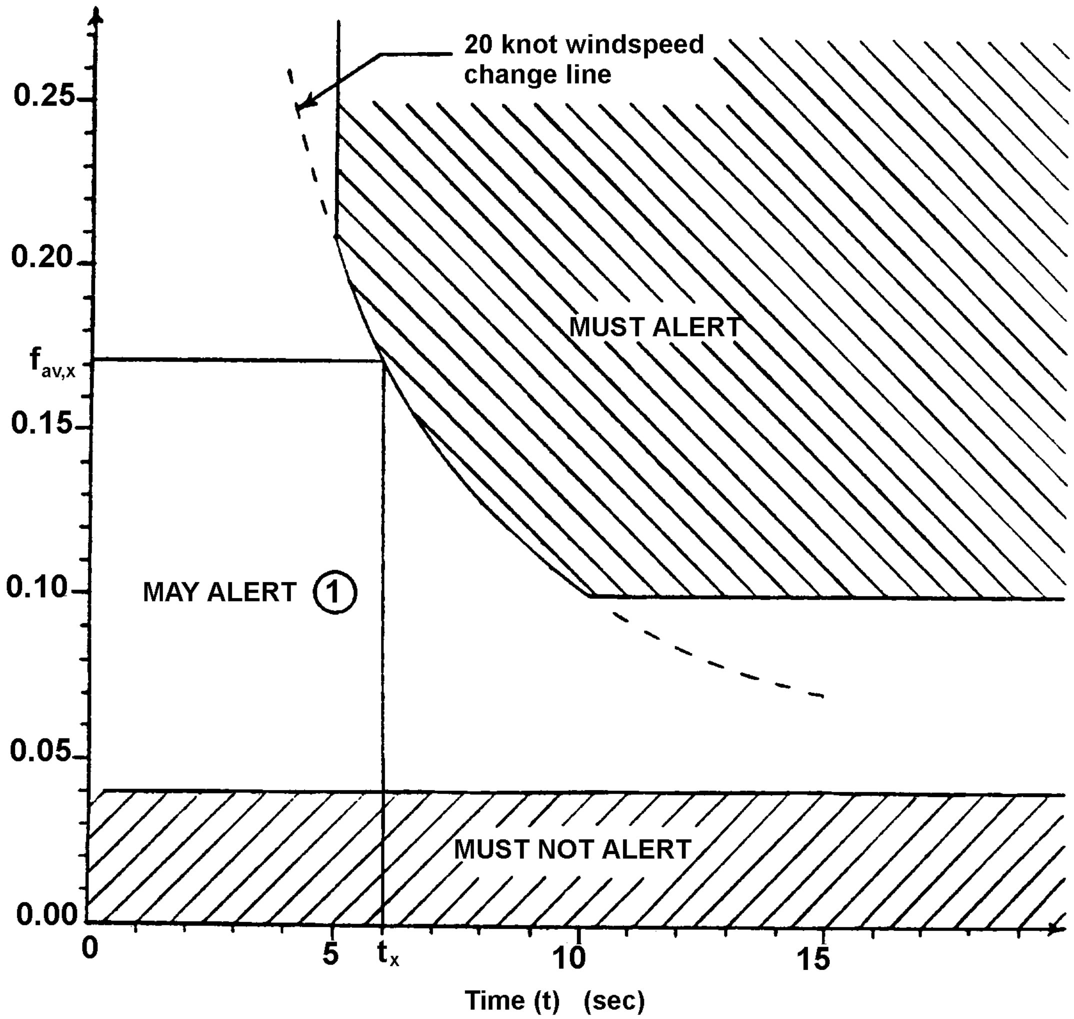
(vi) Flight guidance commands and any auto recovery mode (if included) may be automatically activated concurrent with or after the windshear warning alert occurs or may be manually selected. If manual selection is utilized, it shall only be via the takeoff-go around (TOGA) switch or equivalent means (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 subsection 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 subsection 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 RTCA Document DO-160B, "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 (DO-160B, Section 4.0). RTCA Document DO-160B 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 DO-160B. The following subsections contain the applicable test conditions specified in Section 4.0 of DO-160B.

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

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (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 RTCA Document DO-160B, paragraph 4.5.2, and the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (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 RTCA Document DO-160B, paragraph 4.5.3, and the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (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 RTCA Document DO-160B, paragraph 4.5.4, and the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (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 RTCA Document DO-160B, paragraph 4.6.1, and the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (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 RTCA Document DO-160B, paragraph 4.6.2, and the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (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 RTCA Document DO-160B, paragraph 4.6.3, and the following requirements of this standard shall be met:

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

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

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

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

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

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

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

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

(4) Shock tests (DO-160B, Section 7.0).

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

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (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, section (b)(11), "Effects of Test," of this standard does not apply. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 7.3, and shall meet the requirements specified therein.

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

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

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

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

(7) Waterproofness Tests (DO-160B, Section 10.0).

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

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert

(d) Section (c)(4) - Windshear Warning Alert
(e) Section (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 RTCA Document DO-160B, 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 (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (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 RTCA Document DO-160B, paragraph 10.3.3, and the following requirements of this standard shall be met:

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

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

(8) Fluids Susceptibility Tests (DO-160B, Section 11.0).

(i) Spray Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, 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 (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications

(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (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 RTCA Document DO-160B, 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 DO-160B, 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 (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (c)(6) - Windshear Escape Guidance

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

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

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

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

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

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

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

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

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

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

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

(13) Power Input Tests (DO-160B, Section 16.0).

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

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (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 (b)(11), “Effects of Test,” does not apply. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraphs 16.5.3 and 16.5.4, as appropriate, and the following requirements of this standard shall be met:

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

(e) Section (c)(6) - Windshear Escape Guidance

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

(14) Voltage Spike Conducted Test (DO-160B, Section 17.0).

(i) Category A Requirements (If Applicable). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 17.3, and the following requirements of this standard shall be met:

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

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

(ii) Category B Requirements (If Applicable). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraphs 17.4.1 and 17.4.2, and the following requirements of this standard shall be met:

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

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

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

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

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

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

(i) Section (c)(1) - Mode Annunciation
(ii) Section (c)(2) - Malfunction/Failure Indications
(iii) Section (c)(3) - Windshear Caution Alert
(iv) Section (c)(4) - Windshear Warning Alert
(v) Section (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) (DO-160B, Section 20.0). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 20.0, and the following requirements of this standard shall be met:

(i) Section (c)(1) - Mode Annunciation
(ii) Section (c)(2) - Malfunction/Failure Indications
(iii) Section (c)(3) - Windshear Caution Alert
(iv) Section (c)(4) - Windshear Warning Alert
(v) Section (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 (DO-160B, Section 21.0). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 21.0, and the requirements specified therein shall be met.

(19) Lighting Induced Transient Susceptibility (DO-160B, Section 22.0). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, 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 TSO.

(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 TSO 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 TSO.

(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 TSO 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

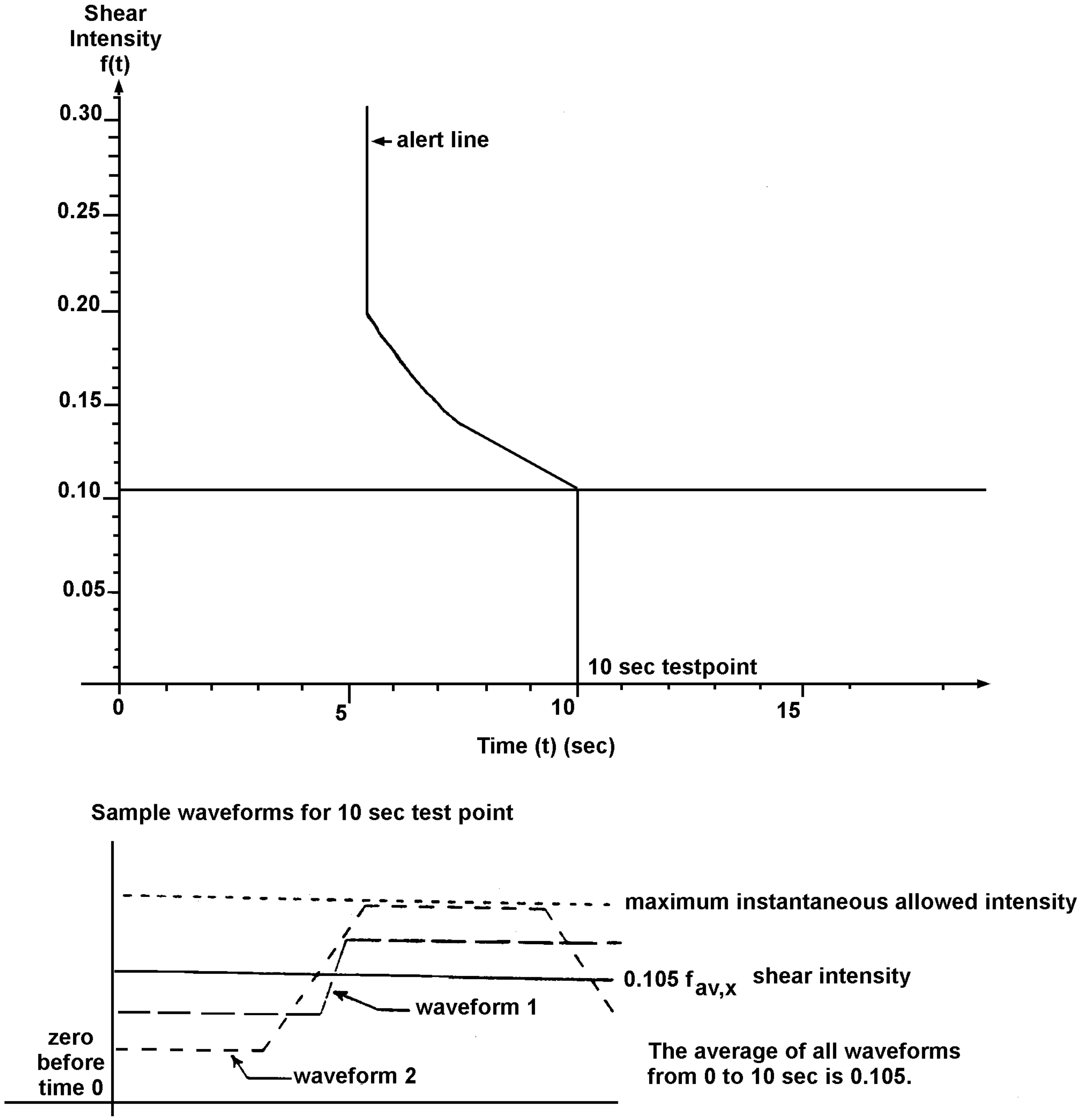
The test conditions specified above shall be repeated 5 times. A different waveform for $f_{av,x}$ will be utilized for each of the 5 runs. An appropriate alert (or no alert) must be generated for each test condition.

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.

f. Computer Software. If the equipment design implementation includes a digital computer, the computer software must be verified and validated in an acceptable manner. One acceptable means of compliance for the verification and validation of the computer software is outlined in RTCA Document No. DO-178A, "Software Considerations in Airborne Systems and Equipment Certification," dated March 1985. For those applicants who elect to use RTCA Document No. DO-178A to demonstrate compliance for the verification and validation of the computer software, the following requirements must be met:

(1) RTCA Document No. DO-178A defines three levels of software; Level 1, 2, and 3. The applicant must declare the level (or levels) to which the computer software has been verified and validated. If the equipment incorporates more than one software level, appropriate partitioning of different software levels is required. The software for windshear warning and escape guidance functions must be verified and validated to at least Level 2. 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 1 requirements.

(2) The applicant must submit a software verification and validation plan for review and approval.

NOTE: The FAA strongly recommends early discussion and agreement between the applicant and the FAA on the applicant's proposed software verification and validation plan, and the applicant's proposed software level or levels.

g. Marking. In addition to the marking specified in Federal Aviation Regulations (FAR) Section 21.607(d), the following information shall be legibly and permanently marked on the major equipment components:

(1) Each separate component of equipment that is manufactured under this TSO must be permanently and legibly marked with at least the name of the manufacturer and the TSO number.

(2) With regard to FAR Section 21.607(d)(2), the part number is to include hardware and software identification, or a separate part number may be utilized for hardware and software. Either approach must include a means for showing the modification status.

(3) The level(s) to which the computer software has been verified and validated.

h <u>Data Requirements</u>.

(1) In addition to FAR section 21.605, the manufacturer must furnish the Manager, Aircraft Certification Office (ACO), Federal Aviation Administration, having purview of the manufacturer's facilities, one copy each of the following technical data:

(i) Operating instructions.

(ii) Equipment limitations.

(iii) Installation procedures and limitations.

(iv) Schematic drawings as applicable to the installation procedures.

(v) Wiring diagrams as applicable to the installation procedures.

(vi) Specifications.

(vii) List of major components (by part number) that make up the equipment system complying with the standards prescribed in this TSO.

(viii) An environmental qualifications form as described in RTCA Document DO-160B for each component of the system.

(ix) Manufacturer’s TSO qualification test report.

(x) Nameplate drawing.

(xi) The appropriate documentation as defined in RTCA Document DO-178A, or equivalent, necessary to support the verification and validation of the computer software to Level 1 or 2. If the software is verified and validated to more than one level, the appropriate documentation for all such levels must be submitted.

(2) In addition to those data requirements that are to be furnished directly to the FAA, each manufacturer must have available for review by the Manager of the ACO having purview of the manufacturer's facilities, the following technical data:

(i) A drawing list, enumerating all of the drawings and processes that are necessary to define the article's design.

(ii) The functional test specification to be used to test each production article to ensure compliance with this TSO.

(iii) Equipment calibration procedures.

(iv) Corrective maintenance procedures (within 12 months after TSO authorization).

(v) Schematic drawings.

(vi) Wiring diagrams.

(vii) Documentation to support the computer software verification and validation plan for Level 1 or 2 software.

(viii) The appropriate documentation as defined in RTCA Document DO-178A, or equivalent, necessary to support the verification and validation of the computer software to Level 1 or 2. If the software is verified and validated to more than one level, the appropriate documentation for all such levels must be available for review.

(ix) The results of the environmental qualification tests conducted in accordance with RTCA Document DO-160B.

i. Data to be Furnished with Manufactured Units. One copy of the data and information specified in paragraphs i(l)(i) through (viii) of this TSO, and instructions for periodic maintenance and calibration which are necessary for continued airworthiness must go to each person receiving for use one or more articles manufactured under this TSO. In addition, a note with the following statement must be included:

> “The conditions and tests required for TSO approval of this article are minimum performance standards. It is the responsibility of those desiring to install this article either on or within a specific type of class of aircraft to determine that the aircraft installation conditions are within the TSO standards. The article may be installed only if further evaluation by the applicant documents an acceptable installation and is approved by the Administrator.”

j. Availability of Reference Documents.

(1) Copies of RTCA Documents Nos. DO-160B and DO-178A may be purchased form the RTCA, Inc., Washington, DC 20005.

(2) Federal Aviation Regulations Part 21, Subpart O; Advisory Circular (AC) 25-12, “Airworthiness Criteria for the Approval of Airborne Windshear Warning Systems in Transport Category Airplanes”; AC 20-1l0C, "Index of Aviation Technical Standard Orders";

and AC 120-41 “Criteria for Operational Approval of Airborne Windshear Alerting and Flight Guidance Systems”; may be reviewed at FAA Headquarters in the Aircraft Certification Service, Aircraft Engineering Division (AIR-100), and at all regional ACO’s.

/S/ John K. McGrath
Manger, Aircraft Engineering
Division, AIR-100

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, airplane 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 airplane 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 airplane 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, airplane to downburst center (ft)
y	horizontal (side) distance, airplane to downburst center (ft)
z	airplane 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)
e	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

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

Written out in full, equation 2 is

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

This equation is satisfied by solutions of the form

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

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

provided that

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

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

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 airplane 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 is 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

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

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

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 airplane 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:

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

$e_d = e_z - e_e$

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

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

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

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

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

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

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

(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 airplane to downburst (ft)
h = altitude of airplane (ft)
R = radius of downdraft (ft)
x_{ad}, y_{ad} = x, y coordinates, airplane to microburst (ft)
$w_{x\ max}$, $w_{y\ max}$, $w_{h\ max}$ maximum winds, x, y, and h directions

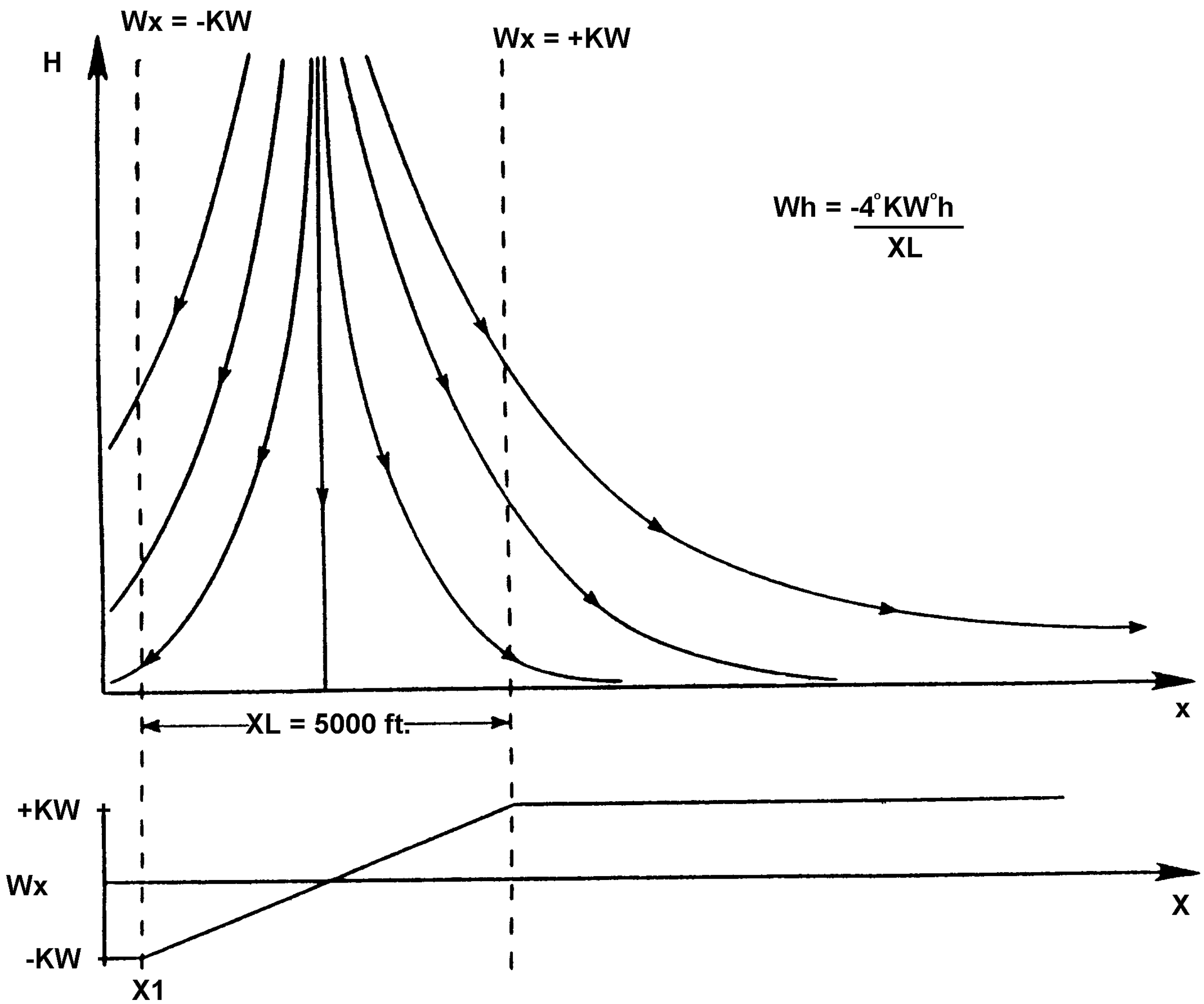

Figure 1 Wind Model Used In Guidance Studies

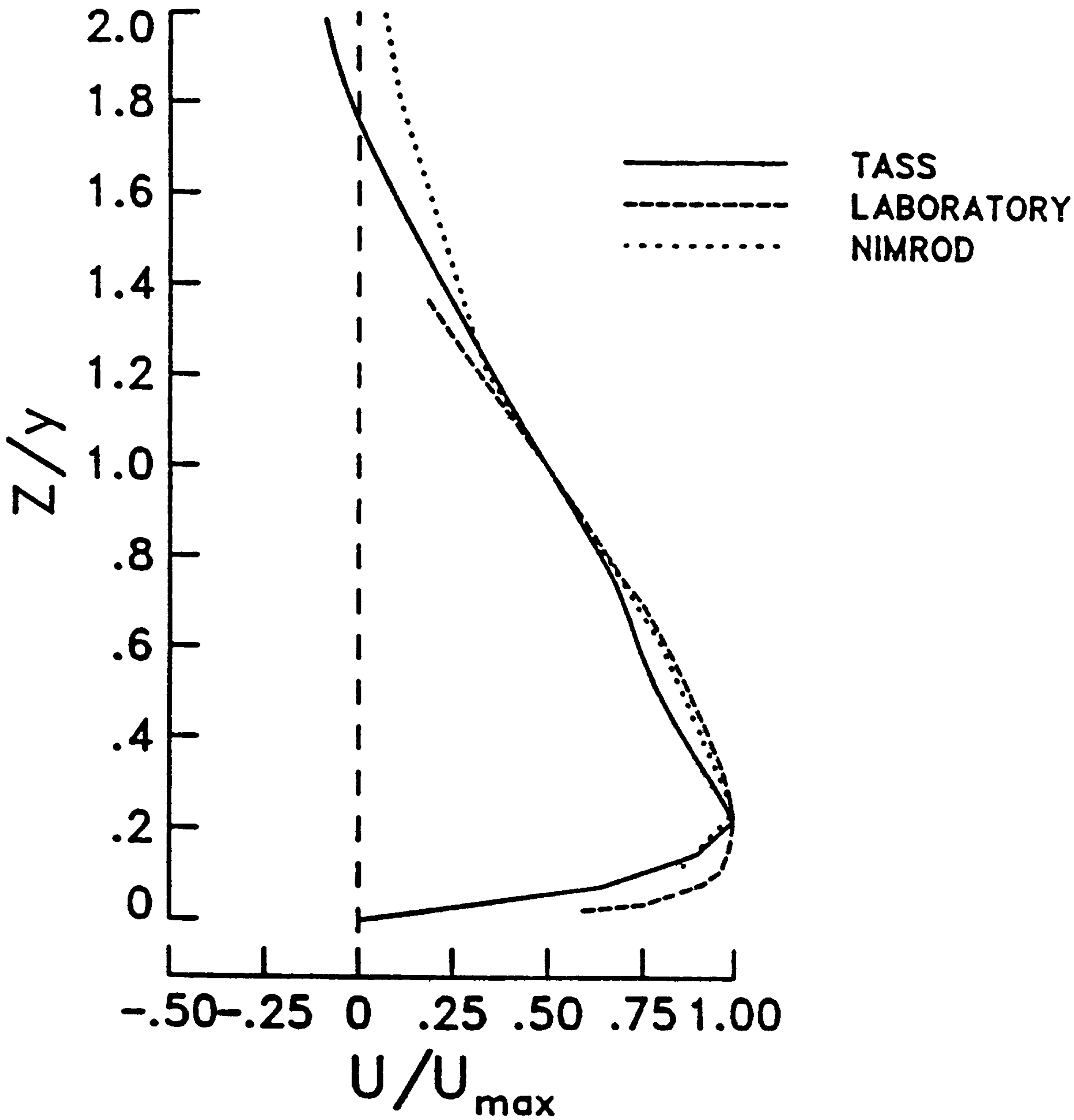

Figure 2 Vertical Profile of Microburst Outflow (Nondimensional)

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

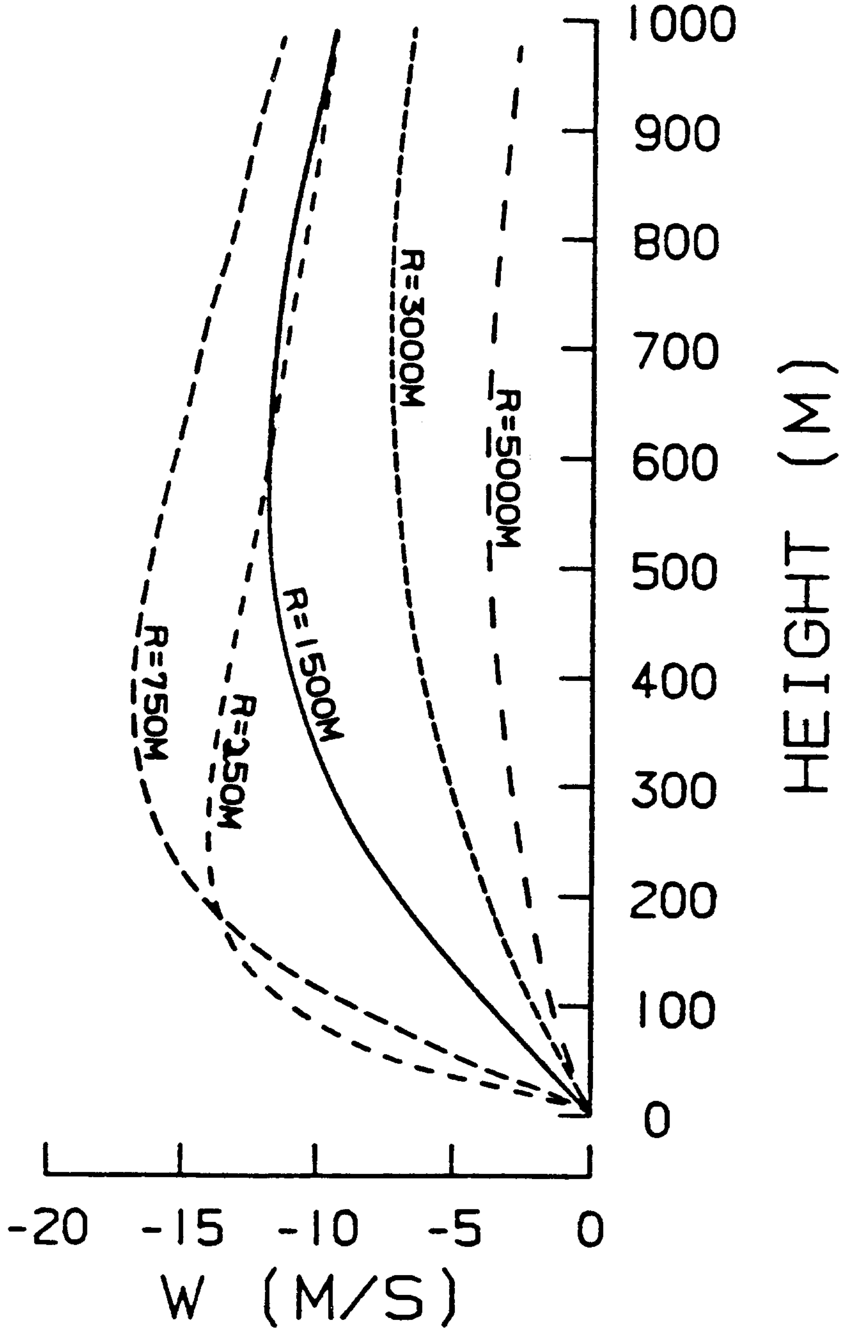

Figure 3 Vertical Profile of Microburst Downflow

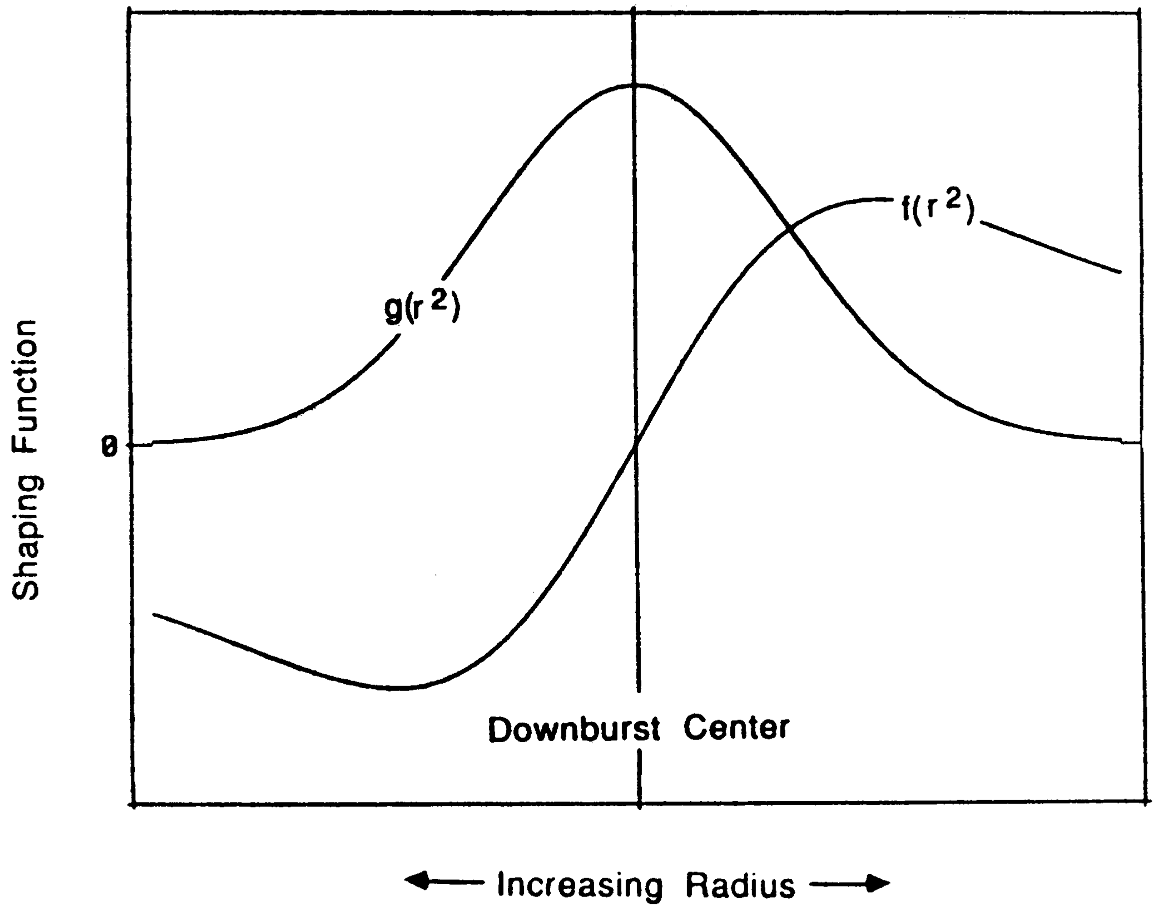

Figure 4 Characteristic Variation of Horizontal Shaping Functions

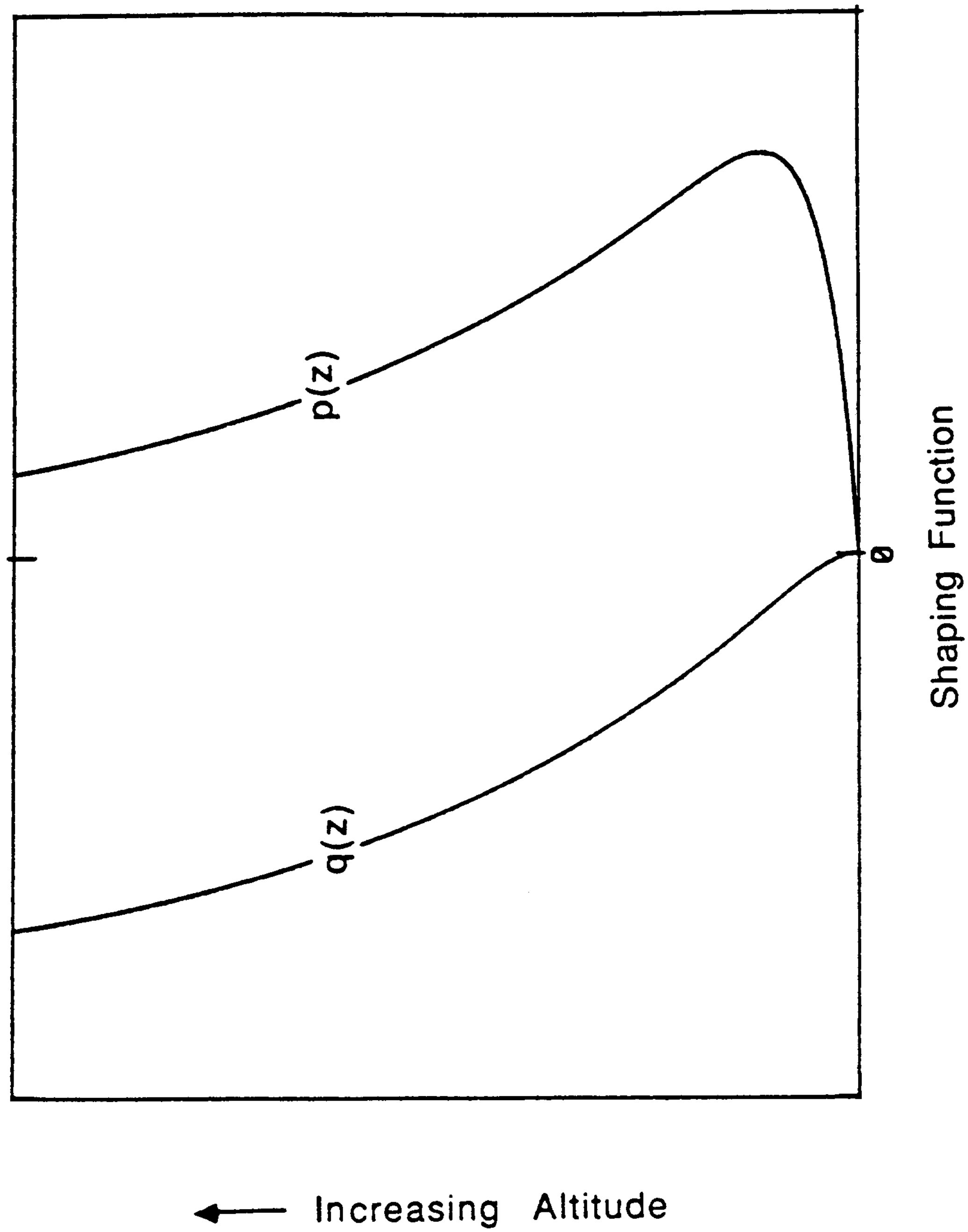

Figure 5 Characteristic Variation of Vertical Shaping Functions

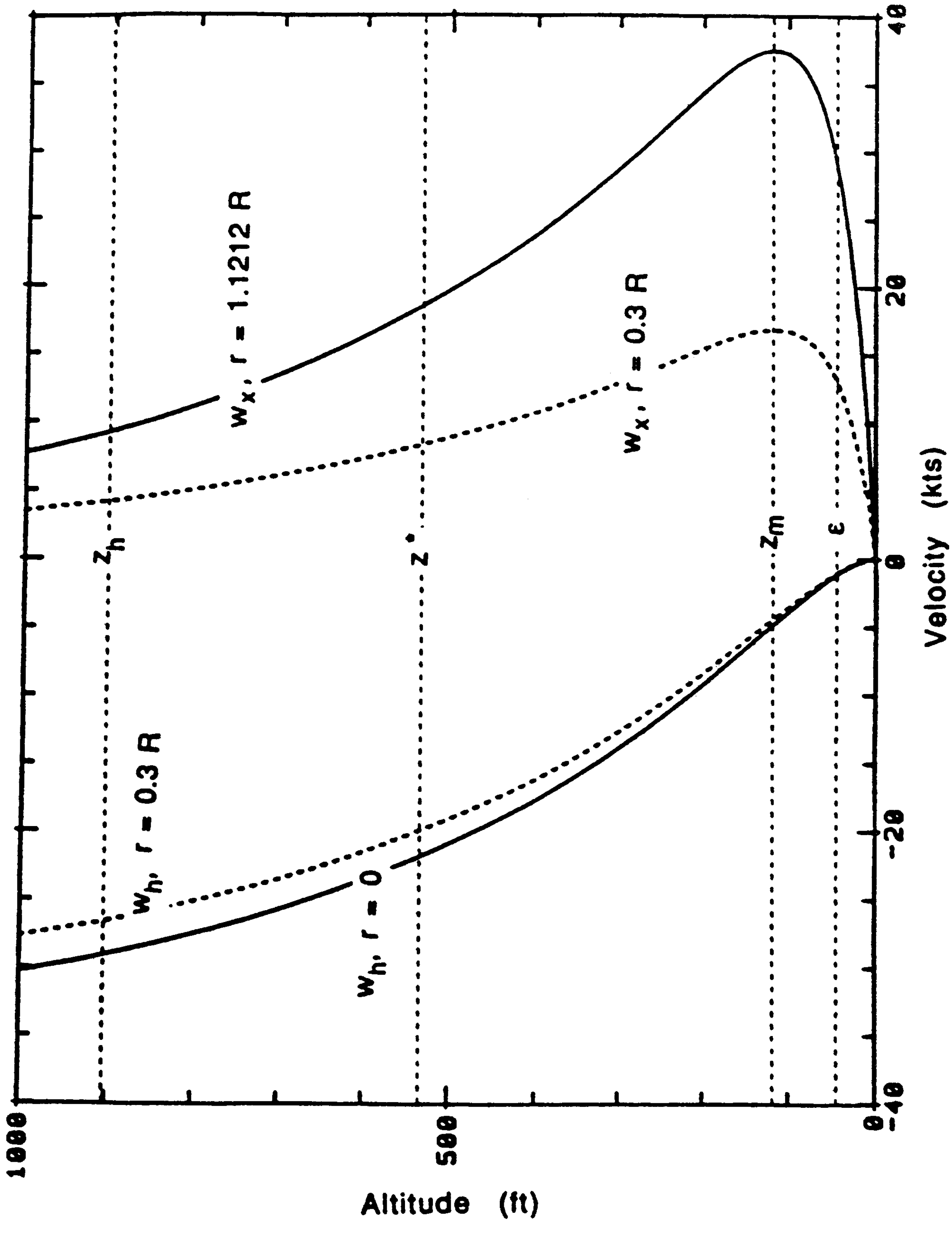

Figure 6 Vertical Velocity Profiles For Analytical Model

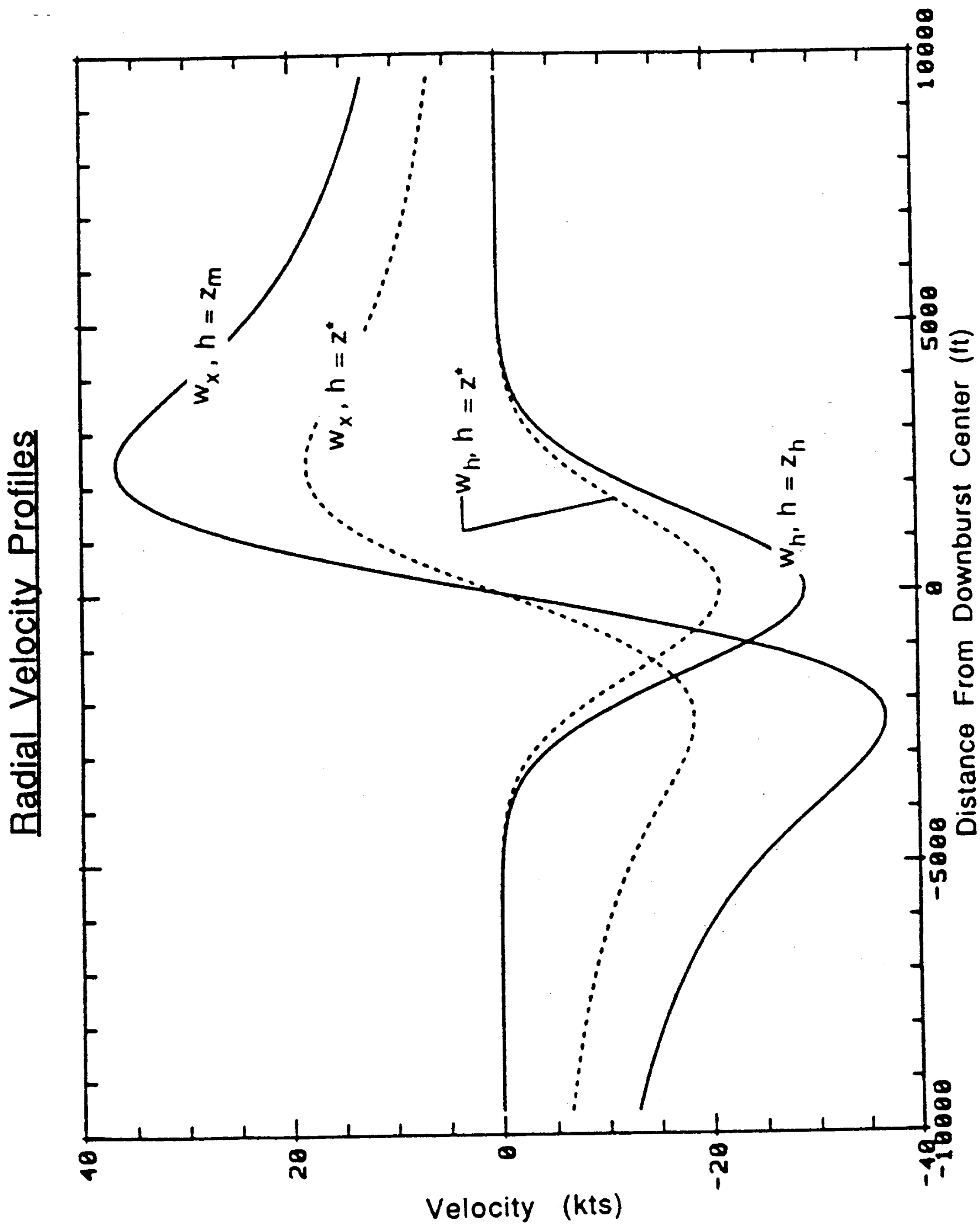

Figure 7 Radial Velocity Profiles For Analytical Model

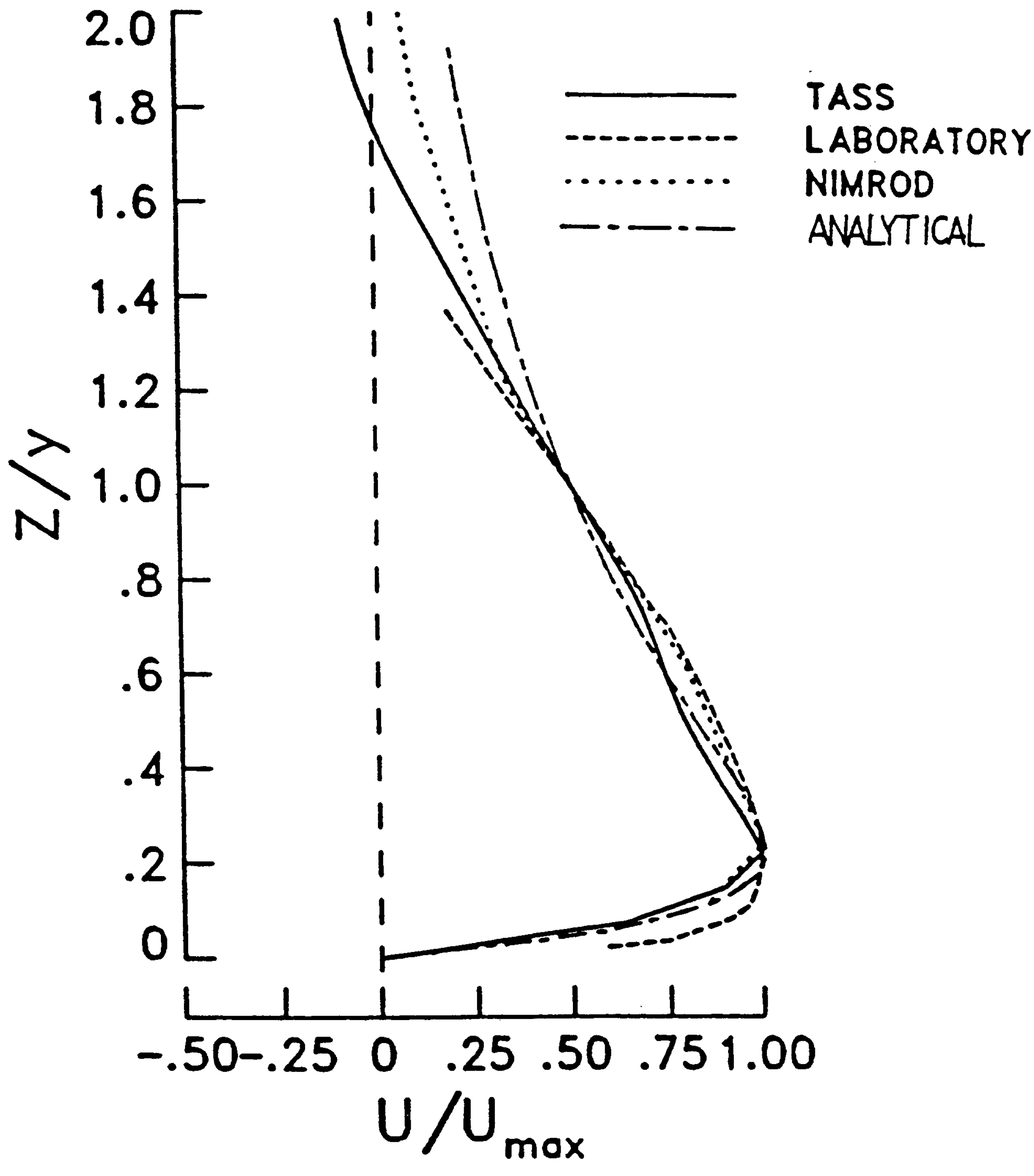

Figure 8 Comparison of Wind Model Vertical Profiles

APENDIX 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.

The Equations of Motion

The motion of a constant mass point in the vertical plane may be described by four equations of state and a control variable. For an aircraft it is convenient to use an orthogonal reference frame which is attached to the frame of the aircraft and its x-direction points in the direction of motion. Such a reference frame is the relative wind reference frame.

The following equations model the states of the aircraft in the wind axes:

$$\mathrm{Vdt} = g[(T.\mathrm{csalf}) - D)/W - \mathrm{sngam}] - \mathrm{Wxdt.csgam} - \mathrm{Wzdt.sngam} \quad (1)$$

$$\mathrm{Gdt} = \{g[(T.\mathrm{snalf} + L)/W - \mathrm{csgam}] + \mathrm{Wxdt.sngam} - \mathrm{Wzdt.csgam}\}/V \quad (2)$$

$$\mathrm{Hdt} = V.\mathrm{sngam} + \mathrm{Wz} \quad (3)$$

$$\mathrm{Xdt} = V.\mathrm{csgam} + \mathrm{Wx} \quad (4)$$

Where:

Vdt	=	Rate of change of true airspeed in knots/sec
g	=	Gravitational constant in knots/sec
T	=	Total engine thrust in lbs.
csalf	=	cos (alpha)
alpha	=	Angle of attack in radians
D	=	Total drag in lbs.
W	=	Gross weight in lbs.
sngam	=	sin (gamma)
gamma	=	Flight path angle in radians
Wxdt	=	Inertial windshear x-component in knots/sec
Gdt	=	Rate of change of gamma in rad/sec
snalf	=	sin (alpha)

L = Total lift in lbs.
V = True airspeed in knots
Hdt = Altitude rate in knots
Wz = Inertial wind z-component in knots
Xdt = Ground speed in knots

In the above equations, positive directions are upwards and forwards. This implies that tail winds and updrafts are positive while head winds and downdrafts are negative. All states can be determined from a given alpha; therefore, alpha is the control variable.

Since the model is that of a point mass, it is necessary to introduce the concept of alpha_command and actual alpha to account for the effect of the horizontal tail/elevator. This is done by introducing a lag between alpha_command and the actual alpha. Therefore, any command that is given to the elevator or stabilizer can be interpreted as an alpha_command which will cause a change in angle of attack.

From equations 1, 2, 3, and 4 it can be seen that any change in alpha will produce a change in the longitudinal and normal accelerations which in turn will change the states of the aircraft.

<u>The Path Control Function</u>

The different segments of the trajectory flown by the WSSM are described by a series of alpha_commands which are generated by the procedure explained below.

1. The aircraft is trimmed for the initial conditions specified by the user. Initial conditions are usually specified as altitude, gross weight, flaps, speed, flight path angle, and wind characteristics. The trimming operation consists in finding the angle of attack that satisfies the equations of state and will result in an unaccelerated motion.

2. After the initial trim, alpha_command must be specified for each segment of the trajectory, which usually consists of a climb or descent segment at constant speed of constant path angle, and guidance through wind disturbances. The wind disturbance is provided by wind models that can be selected at initialization time.

3. In order to specify an alpha_command the user must supply a subroutine where a quadratic function is defined in such a way that when minimized with respect to alpha, and constrained by the equations of state, the minimizing alpha will produce the desired path in an optimal manner. For example, if we want to fly initially at a constant path angle, say 8 degrees, then the quadratic function may be defined by the expression:

$$cst = (gamma + Gdt*dt - 8/57.3)^2 \quad (5)$$

where:

cst = Function to be minimized w/r/t alpha
dt = Time increment used in simulation in sec.

The term Gdt*dt is a predictive term which anticipates the change in gamma.

Other expressions follow:

$$cst = (V + Vdt*dt - V\_cmd)^2$$ Constant speed

$$cst = (alpha + gamma + Gdt*dt - pitch\_cmd)^2$$ Constant pitch

The minimization of the function cst is performed by a subroutine at each time frame and is totally transparent to the user, who has to supply only the objective function cst.

4. Each expression defining a different value of the objective function cst is called a "LAW". The user selects the guidance law to be used during the windshear encounter at menua time. This method allows the user to compare different guidance laws under the exact same conditions.

The Wind Models

The WSSM has two types of wind models: the Dallas-Ft Worth accident wind field simulated by a quad_vortex model, and the constant shear model which is user defined via the initial conditions menu.

Plotting Capabilities

The WSSM can plot up to 3 runs with 10 parameters per run. The length of each run should be kept under 60 seconds. This feature allows the user to compare different trajectories by overlaying the results.

The Program

The WSSM is written in Microsoft QuickBasic which is a highly structured language with a very friendly full page editor. QuickBasic is very convenient for development since it allows the user to stop execution, change the program and continue executing. It also interfaces with Microsoft FORTRAN, C, of assembly language.

The procedure suggested for this application is that the WSSM be complied without subroutines DETECT and GUIDE. DETECT and GUIDE can be separately complied and put in a library called WNDSHR.QLB. These external subroutines may be written in Microsoft FORTRAN, C, or assembly language.

```
'************     AIRCRAFT FLIGHT PROFILE SIMULAITON     **********
'
'

DECLARE SUB PLOT ( )
DECLARE SUB TAKEOFF ( )
DECLARE SUB EULER ( )
DECLARE SUB MCRBRST ( )
DECLARE SUB WINDS ( )
DECLARE SUB OPT ( )
DECLARE SUB MIN (DM, M2, C1, C2, C3, M)
DECLARE SUB BEGIN ( )
DECLARE SUB VSHAKER ( )
DECLARE SUB COST ( )
DECLARE SUB LIMIT ( )
DECLARE SUB RATES ( )
DECLARE SUB THRUST ( )
DECLARE SUB ATMOS ( )
DECLARE SUB PRINTS ( )
DECLARE SUB DRAGS ( )

COMMON SHARED FLPS%, GEAR%, GEAR$, CL, CD, LIFT, DRAG, ALPHA
COMMON SHARED SEC, ALT, DST, HDOT, ALF, GAM, GAMREF, GREF, G
COMMON SHARED WSALERT%, WXO, WL, WX, WXDT, WZ, WZDT, DFW%
COMMON SHARED WV, LC%, GM, GREFF, NOSAVE, GMO
COMMON SHARED DELTA, ISA, TO, SPDSND, VT, VC, MACH, AO, TAT, TAMF
COMMON SHARED THRST, EPR, TFCT, APPFLG%
COMMON SHARED SNGM, CSGM, CSAL, SNAL, VDOT, WG, GDOT, XDOT
COMMON SHARED AWX, AWZ, AU, AZ, VG, GRND, KF1, GMIN, KF2
COMMON SHARED ACMD, OLDALF, DT, HP, LP, ALFLIM
COMMON SHARED LAW%, GMR, ASS, CST, VTO, GCMD
COMMON SHARED OUTFILE$, DM, ALT1, PL$, TTT, WXDTO, TDX, TSH, WZO,
TDZ, TSV
COMMON SHARED GM1, VTP, THETA
COMMON SHARED ALFRTE, PLMFLG%

'******************************************
'              MAIN PROGRAM              *
'******************************************

START:  '< ----------------<<        RE-RUNS START HERE

CLOSE  :  CLEAR
COLOR  15,  1:  CLS  :  VIEW PRINT
LOCATE  8,  23:  PRINT  "          WINDSHEAR SIMULATION"
LOCATE  10,  23:  PRINT  "                    FOR                  "
LOCATE  12,  23:  PRINT  "               BOEING 737/200            "
```

```
        LOCATE  23,  25:  PRINT  "TYPE  "  +  CHR$(&H22)  +  "I"  +  CHR$(&H22)  +  "
FOR INFORMATION"
        DO  WHILE  a$  =  " "
        a$  =  INKEY$
    LOOP
    IF  a$  =  "I"  OR  a$  =  "i"  THEN
        a$  =  " ":  CLS
        '----------------------   INFORMATION PAGE
----------------------------------------
        LOCATE  2,  10:   PRINT  "                              BOEING  737/200
INFORMATON"
        LOCATE  3,  10:   PRINT  "                                     JT8D-17  ENGINES"
        LOCATE  5,  1:    PRINT
"------------------------------------------------------------------------------------------------------------------
-----------------------"
        LOCATE  7,  10:   PRINT  "ALLOWABLE  WEIGHT  RANGES.................................:
75,000 TO 120,000 POUNDS"
        LOCATE  9,  10:   PRINT  "ALLOWABLE  TAKEOFF  FLAP  SETTINGS................:
1,  2,  5,  15,  20,  25  DEGREES"
        LOCATE  11,  10:  PRINT  "ALLOWABLE  LANDING  FLAP  SETTINGS.................:
30,  40  DEGREES"
        LOCATE  13,  10:  PRINT  "TAKEOFF  EPR  AT  SEA  LEVEL,  STD.  DAY.............:
2.1    "
        LOCATE  15,  10:  PRINT  "REFERENCE WING  AREA.............................................:
980  SQUARE  FEET"
        LOCATE  17,  10:  PRINT  "REFERENCE  TAKEOFF  SPEED.....................................:
V2  +  10"
        LOCATE  19,  10:  PRINT  "REFERENCE  LANDING  SPEED.....................................:
1.3  Vs"
        LOCATE  23,  26:  PRINT  "Press Any Key to Continue..."
        DO:  LOOP WHILE INKEY$  =  " "
      END IF
      ANS$  =  "2"
      CLS
      WHILE  (ANS$  =  "2")
        LOCATE  10,  30:  PRINT  "fly    .....  1"
        LOCATE  12,  30:  PRINT  "plot  .....  2"
        LOCATE  14,  30:  PRINT  "exit  .....  3"
        LOCATE  18,  30:  INPUT  "Selection  .....";  ANS$
        IF ANS$  =  "2"  THEN
                              CALL PLOT
                              COLOR  15,  1
                              CLS
        END  IF
      WEND
      IF  ANS$  =  "3"  THEN END
      CALL  BEGIN            'GET  DATA/INITIALIZE  VARIABLES
      CALL  THRUST           'INITALIZE  THRUST
```

```
      CALL  TAKEOFF        'INITALIZE  TAKEOFF
      CALL  COST           'SUBROUTINE  COST
      CALL  PRINTS         'SUBROUTINE  PRINT

        FOR  ICL% = 1  TO  TTT'          TTT  IS  THE  RUN  TIME  IN  SECONDS

                CALL  THRUST        '  SUBROUTINE  EPR/THRUST
                CALL  WINDS         '  SUBROUTINE  WINDS
'                CALL  DETECT        '  SUBROUTINE  WINDSHEAR  DETECTION
                                    '  SUPPLIED  BY  USER
                                    '  MUST RESIDE IN LIBRARY WNDSHR.QLB
                CALL  OPT           '  SUBROUTINE  OPTIMIZE
                CALL  LIMIT         '  SUBROUTINE  ALPHA  RATE
                CALL  EULER         '  SUBROUTINE  INTEGRATE
                CALL  ATMOS         '  SUBROUTINE  ATMOSPHERE
                CALL  PRINTS        '  SUBROUTINE  PRINT
                IF  ALT  <  0  THEN  EXIT  FOR

        NEXT  ICL%

        PRINT  "                                          RUN IS COMPLETE"
        PRINT  "                                   TYPE  "  +  CHR$(&H22)  +  "D"  +
CHR$(&H22)  +  "  FOR RUN DATA"
        a$  =  " "

        DO  WHILE  a$  =  " "          ' Wait  for  key  to  be  pressed
                a$  =  INKEY$
        LOOP
        VIEW  PRINT:  COLOR  15,  4:  CLS
        IF      a$  =  "D"  OR a$  =  "d"  THEN
                a$  =  " "

                LOCATE  2,  30:  PRINT  "DATA  FROM  CURRENT  RUN"
                LOCATE  4,  1:  PRINT
"-------------------------------------------------------------------------------------------------------------------
---------------------------"
                LOCATE  6,  18:  PRINT  "GROSS  WEIGHT:                               ";
WG;  "  POUNDS"
                LOCATE  7,  18:  PRINT  "ISA  DEVIATION:                              ";
ISA;  "  DEG  C"
                LOCATE  8,  18:  PRINT  "FLAP  POSITION:                              ";
FLPS%;  "  DEGREES"
                LOCATE  9,  18:  PRINT  "GEAR  POSITION:                              ";
GEAR$
                LOCATE  11,  18:  PRINT  "CONTROL LAW:                                ";
LAW%
                LOCATE  12,  18:  PRINT  "GAMMA REFERENCE:                            ";
GAMREF
```

```
                LOCATE 13, 18: PRINT "PITCH LIMITING:                          ";
PL$
                IF PL$ = "YES" THEN LOCATE 13, 20: PRINT "MAXIMUM PITCH:
                        "; HP * 57.3; " DEGREES" : LOCATE 13, 20: PRINT
"MINIMUM PITCH:                       ";    LP * 57.3;  " DEGREES"
                LOCATE 15, 18: PRINT "TIME OF RUN:                             ";
TTT * DT; " SECONDS"
                IF DFW% = 1 THEN
                        LOCATE 17, 18: PRINT "                DALLAS/FW Wind Model"
                                        ELSE
                        LOCATE 17, 18: PRINT "HORIZ. WIND MAGNITUDE            ";
WXO; " KNOTS"
                        LOCATE 18, 18: PRINT "HORIZ. SHEAR MAGNITUDE:          ";
WXDTO; " KNOTS/SECOND"
                        LOCATE 19, 18: PRINT "HORIZ. SHEAR DURATION:           ";
TDX; " SECONDS"
                        LOCATE 20, 18: PRINT "VERT.   WIND MAGNITUDE:          ";
WZO  *   1.689;   "  FT/SECOND"
                        LOCATE 21, 18: PRINT "VERT.   WIND DURATION:           ";
TDZ: " SECONDS"
                        LOCATE 22, 1: PRINT
"--------------------------------------------------------------------------------------------------------------
------------------------------------"
                END IF
                IF LEN(OUTFILE$) = 0 THEN OUTFILE$ = "NONE"
                LOCATE 23, 18: PRINT "OUTPUT FILE:                             ";
OUTFILE$
                LOCATE 24, 26: PRINT "Press Any Key to Continue...."

                DO: LOOP WHILE INKEY$ = " "                'Wait for key to be
pressed

        END IF

        GOTO START
        END

SUB ATMOS STATIC
```

```
'****************************************************
'              SUBROUTINE  ATMOSPHERE               *
'****************************************************

    STATIC THETA

    L% = ALT > 36089!
    FISA = 1.8 * ISA

    IF ALT > 36089 THEN
                    TMP = .7519 * TO
                    DELTA = .2234 * EXP((36089! - ALT) / 20806)
            ELSE
                    TMP = TO - .0035662 * ALT
                    DELTA = (TMP / TO) ^ 5.256
    END IF

    TAMB = TMP + FISA              'TAMBient in deg.  R
    TAMF = TAMB - 459.7            '     "      "     F
    THETA = TAMB / TO
    SQRTH = AO * SQRTH

    IF VT > 0 THEN MACH = VT / SPDSND

    VC = A0 * SQR(5 * (((1 + MACH * MACH / 5) ^ 3.5 - 1) * DELTA + 1)
^ .28571 - 5)
    TAX = (TMP + FISA) * (1 + .2 * MACH * MACH) 'Deg. R
    TAT = 5 * (TAX - 459.7 - 32) / 9                'Deg. C

    IF INKEY$ <> " " THEN PRINT : INPUT "Press ENTER to continue....";  XXX

END SUB

SUB BEGIN STATIC
    CLS : VIEW PRINT

    '<--------------------------------  DATA_INPUT  ----------------------------->

    PRINT
    INPUT "OUTPUT FILE (DEFAULT IS NO FILE) "; OUTFILE$

    IF OUTFILE$ = " " THEN
                    NOSAVE = 1
              ELSE
                    NOSAVE = 0
    END IF
```

```
′ CONSTANTS USED IN CALCULATIONS:

AO = 661.478599#            ‘Speed of sound at sea level in knots
G = 19.07583                ‘Gravitational constant in knots/sec
TO = 518.67                 ‘Standard temperature at SL in deg Rankine
DT = .25                    ‘Simulation time step in seconds

‘ --------------------------------- INITIALIZATION OF VARIABLES
--------------------------

GMIN = 0
VDOT = 0
ALT1 = 0
INPUT “TAKEOFF OR APPROACH (T/A) (Default is T).....”; ANS$

IF ANS$ = “a” OR ANS$ = “A” THEN
                    INPUT “ENTER ALTITUDE IN FEET
    (Default is 1000’ . ”; ALT1
                    IF ALT1 = 0 THEN ALT1 = 1000
                    APPFLG% = 1
                    TFCT = 1
END IF
ALT = ALT1

′ ----------------------- CONFIGURTATION CONSTANTS
------------------------------------------

ASS = 16.5                  ‘Stick Shaker alpha in
degrees
ASS = ASS / 57.3            ‘ “ ″ ″ ″
radians

′ ------------------------------------------- GROSS WEIGHT ENTRY
------------------------------------------

PRINT : INPUT “ENTER GROSS WEIGHT IN POUNDS (Default is 110000) ”;
WG
IF WG = 0 THEN WG = 110000!         ‘ DEFAULT SETTING

FL% = 0

WHILE (NOT FL%)

    INPUT “ENTER FLAPS SETTING          (Default is 0).............”;
FLPS%

    SELECT CASE FLPS%
```

```
        CASE 0, 1, 2, 5, 15, 20, 25, 30, 40
            FL% = –1
        CASE ELSE
            FL% = 0
            PRINT "Invalid flaps setting"
            PRINT "Only 0, 1, 2, 5, 15, 20, 25, 30, & 40 are supported"
            PRINT
        END SELECT

    WEND


    IF FLPS% < 15 THEN GEAR% = 1
    IF FLPS% = 15 THEN INPUT "GEAR UP OR DOWN        (1/0)
(Default is Down).....”; GEAR%
    IF GEAR% = 1 THEN
                    GEAR$ = " UP"
                  ELSE
                    GEAR$ = " DOWN"

    END IF
    INPUT "ENTER ISA DEV. IN DEGREES C    (Default is 0)......"; ISA

    PRINT

    CALL VSHAKER          ' COMPUTE V2+10 FOR FLAPS<33 OR 1.3Vs FOR
FLAPS>32

    PRINT "                           CONTROL LAW SELECTION:"
    PRINT
    PRINT "                   Speed = 1.1* V_stall                  = 1"
    PRINT "                   Alpha = Stick Shaker Alpha            = 2"
    PRINT "                   Horizontal Acceleration = 0           = 3"
    PRINT "                   15_Degree Pitch                       = 4"
    PRINT "                   Theoretical HONEYWELL/SPERRY          = 5"
    PRINT "                   User Defined                          = 6"
    PRINT
    INPUT "                   SELECT CONTROL LAW ....................... "; LAW%

        IF LAW% = 0 THEN LAW% = 5

        PRINT : PRINT

        ' ------------------------------------   GAMMA REFERENCE INPUT
---------------------------------

        IF LAW% > 4 THEN
```

```
                    INPUT "ENTER GAMMA REFERENCE IN DEGREES (Default is
0).........";  GMR
                    PRINT
                    GAMREF = GMR
                    GMR = GMR / 57.3: GMIN = GMR
                END IF

                ' --------------------------------------- PITCH LIMITING SELECTION
---------------------------------------------

                INPUT "PITCH LIMITING DESIRED (Default is NO)...............";  PL$

                IF PL$ = "Y" OR PL$ = "y" THEN

                    PL$ = "YES"
                    INPUT "      MAXIMUM PITCH ALLOWED IN DEGREES ";  HP
                    INPUT "      MINIMUM PITCH ALLOWED IN DEGREES ";  LP
                    HP = HP / 57.3: LP = LP / 57.3: PL% = 1

                ELSE

                HP = 100
                LP = –100
                PL% = 0
                PL$ = "NO"

            END IF
            CLS
            ' ----------------------------------------------- TIME FOR RUN
-----------------------------------------------------------------
            PRINT
            INPUT "ENTER TIME OF RUN IN SECONDS (Default is 45)..............";  TTT
            TTT = TTT / DT
            IF TTT = 0 THEN TTT = 45 / DT                ‘  DEFAULT SETTING
            ' ------------------------------------- WINDSHEAR SET UP
-----------------------------------------------------
            INPUT "DALLAS/FW Wind Model........(Default is constant Shear).....";  ANS$

            IF ANS$ = "Y" OR ASN$ = "y" THEN
                DFW = 1
                                                ELSE
                DFW% = 0
                PRINT
                INPUT "MAGNITUED OF HORZ. WIND IN KNOTS......(Head wind <
0)......";  WXO
                INPUT "MAGNITUED OF HORZ. SHEAR IN KT/SEC. (Dec. Perf. > 0)......";
WXDTO
```

```
          INPUT "DURATION OF HORZ. SHEAR IN SEC.............(Default is 0)......";
TDX
          INPUT "TIME FOR SHEAR TO START IN SEC..............(Default is 0)......";
TSH
          PRINT

          INPUT "MAGNITUED OF VERT. WIND IN FT/SEC. (Down Draft < 0)......";
WZO
          WZO = WZO / 1.689                 'Convert to knots
          INPUT "DURATION  OF VERT. WIND IN SEC...........(Default is 0)........";
TDZ
          INPUT "TIME FOR SHEAR TO START IN SEC...........(Default is 0)......";
TSV
          PRINT
      END IF

      ' --------------------  OTHER SET UPS
-----------------------------------------------------
      VT = VTO
      WX = WXO

      CALL ATMOS              ' SUBROUTINE ATMOSPHERE

      ' ----------------------------------  HEADERS FOR SCREEN DISPLAY
-----------------------------------------------------
      CLS : PRINT
      PRINT "TIME  ALT  HDOT  VT  ALPHA  GAMMA  PITCH  GREF  WXDT
WZ  VDOT  ALRT"
      PRINT "(SEC)  (FT)  (FPM)  (KTS) (DEG)  (DEG)  (DEG)  (DEG) (KT/S)
(FPS) (KT/S)"
      PRINT STRING$(75, "–"): VIEW PRINT 5 TO 25
      '*************************************
      '   SUBROUTINE INIT_OUTPUT FILE  *
      '*************************************
      IF NOSAVE THEN    ' CREATE OUTPUT FILE
      ELSE
            OPEN "O", 2, OUTFILE$
            FMT$ = " ###.##  #####  #####  ####  ####  ##  ###.##  ###.##
###.##"
            FMT$ = FMT$ + " ###.##  ###.#  ###.#  ##.## "
      END IF

END SUB

SUB COST STATIC

      '**********************************************************
```

```
'                       SUBROUTINE COST                           *
'************************************************************

CALL DRAGS                          ' SUBROUTINE DRAG & LIFT

CALL RATES                          ' SUBROUTINE RATES


IF LC% = 0 THEN                     'Constant gamma segment

                    FCT = (GM + GDOT * DT – GMO) ^ 2
                    GREFF = 57.3 * GMO

            ELSE                    'All guidance laws


        SELECT CASE LAW%

            CASE 1   '----------------------------   1.1*Vstall
-----------------------------------

            CST = (VT + VDOT * DT – 1.1 * 135) ^ 2

            CASE 2   '----------------------------   Alpha = Ass
-----------------------------------

            CST = (ALPHA – ASS) ^ 2

            CASE 3   '----------------------------   Ax = 0
-----------------------------------

            CST = (VDOT – VT * GDOT * GM + WXDT) ^ 2

            CASE 4   '----------------------------   15 Degrees
-----------------------------------

            CST = (GM + 3 * GDOT * DT + ALPHA – 15 / 57.3) ^ 2

            CASE 5   '----------------------------   User Defined
-----------------------------------
                    PRINT "Not defined"
                    STOP

            CASE 6   '----------------------------   User Supplied
-----------------------------------

                'User must supply a subroutine called GUIDE
```

```
                'which must reside in the WNDSHR.QLB Library
                'GUIDE can have a list of arguments
                'As an example

                'ALF = 57.3*ALPHA
                "PTH = 57.3 * (ALPHA + GM)

                ' units :    ft    fpm   kt   deg   deg   g's  g's *

                'CALL GUIDE(ALT, HDOT, VC, ALF, PTH, AU, AZ, CST)

           END SELECT
      END IF

      '    CST is the Cost Function to be minimized

END SUB

      SUB DRAGS STATIC
           '****************************************************
           '     SUBROUTINE DRAG   FOR B737/200                *
           '****************************************************
           X = 57.3 * ALPHA + 1

           CF5 = 0: CF4 = 0: CF3 = 0: CF2 = 0

           SELECT CASE FLPS%

                  CASE 0
                       CF1 = .091
                       CF0 = .0156
                  CASE 1
                       CF3 = –1.164058E-04
                       CF2 = 2.48561E-03
                       CF1 = .0905781
                       CF0 = .062114

                  CASE 2
                       CF0 = .101198
                       CF1 = .110993
                       CF2 = –.0015162
                       CF3 = 1.8931E-04
                       CF4 = –7.1427E-06
                       CF5 = –4.2776E-09

                  CASE 5
                       CF0 = .192638
```

```
            CF1  =  .123509
            CF2  =  –.0051477
            CF3  =  6.4968E-04
            CF4  =  –3.0891E-05
            CF5  =  4.1291E-07

      CASE  10
            CF0  =  .249855
            CF1  =  .114005
            CF2  =  7.1207E-04
            CF3  =  –9.9541E-05
            CF4  =  7.0431E-06
            CF5  =  –2.3773E-07

      CASE  15
            CF0  =  .40149
            CF1  =  .118723
            CF2  =  –6.4877E-04
            CF3  =  6.6281E-05
            CF4  =  –1.6113E-07
            CF5  =  –1.4278E-07

      CASE  25
            CF0  =  .592655
            CF1  =  .122433
            CF2  =  –.0026365
            CF3  =  3.5963E-04
            CF4  =  –1.5579E-05
            CF5  =  1.0894E-07

      CASE  30
            IF  X  <  4  THEN
                                 CF1  =  .12
                                 CF0  =  .72
                         ELSE
                                 CF3  =  –1.651192E-04
                                 CF2  =  4.16461E-03
                                 CF1  =  8.337061E-02
                                 CF0  =  .8350316
            END  IF

      CASE  40
            IF  X  <  4  THEN
                                 CF1  =  .12
                                 CF0  =  1.08
                         ELSE
                                 CF3  =  –1.689903E-04
```

```
                                        CF2 = 3.733285E-03
                                        CF1 = 8.483822E-02
                                        CF0 = 1.201596
                              END IF

                    CASE ELSE
                              PRINT "Flaps "; FLPS%; " not available....."
                              END

     END SELECT                          'For CL computation

     CL = ((((CF5 * X + CF4) * X + CF3) * X + CF2) * X + CF1) * X + CF0


     SELECT CASE FLPS%              'Low Speed Drag Polars

                    CASE 0
                              D0 = .013285: D1 = .052868: D2 = –.07182: D3 =
.071561

                    CASE 1
                              D0 = .026143: D1 = .022358: D2 = –.00083: D3 =
.016338

                    CASE 2
                              D0 = .070346: D1 = –.0852: D2 =.097453: D3 = –.01207

                    CASE 5
                              D0 = .045214: D1 = –.0178: D2 =.04373: D3 = .002101

                    CASE 10
                              D0 = –.04266: D1 = .19643: D2 = –.1152: D3 = .03966

                    CASE 15

                              IF GEAR% = 0 THEN
                                                  D0 = .034954: D1 = .098892: D2
= –.04187: D3 = .020496
                                        ELSE
                                                  D0 = –.02822: D1 = .174631: D2
= –.0874: D3 = .029566
                              END IF
                    CASE 25
                              DO = –.10416: D1 = .327506: D2 = –.17059: D3 =
.043313
                    CASE 30
                              DO = .124697: D1 = –.03348: D2 =.055295: D3 =
```

```
–.00311
                    CASE 40
                         DO = .124925: D1 = .052537: D2 =.006912: D3 = .0058

                    CASE ELSE
                         PRINT "Flaps "; FLPS% " not available...."
                         END

     END SELECT
     CD = ((D3 * CL + D2) * CL + D1) * CL + DO
     Q = 1451770 * MACH * MACH * DELTA          'B737/200
     LIFT = Q * CL
     DRAG = Q * CD
     END SUB

SUB EULER STATIC

     '*****************************************************************
     '     SUBROUTINE EULER'S PREDICTOR/CORRECTOR                      *
     '          (INTEGRATION SUBROUTINE)                               *
     '*****************************************************************
     DTH = DT / 3600: DTM = DT / 60: SEC = SEC + DT: VTP = VT

     CALL RATES      ' SUBROUTINE RATES   <<PREDICTOR>>

     ALT1 = ALT: HDOT1 = HDOT: ALT = ALT + HDOT * DTM
     GM1 = GM: GDOT1 = GDOT: GM = GM + GDOT * DT
     DST1 = DST: XDOT1 = XDOT: DST = DST + XDOT * DTH
     VT1 = VT: VDOT1 = VDOT: VT = VT + VDOT * DT

     CALL RATES      ' SUBROUTINE RATES   <<CORRECTOR>>

     ALT = ALT1 + (HDOT1 + HDOT) * DTM / 2
     GM = GM1 + (GDOT1 + GDOT) * DT / 2
     DST = DST1 + (XDOT1 + XDOT) * DTH /2
     VT = VT1 + (VDOT1 + VDOT) * DT / 2

END SUB

SUB LIMIT STATIC



'***************************************************************************

     '          SUBROUTINE ALPHA DOT AND PITCH LIMIT
     *
```

```
'***************************************************************************

        ALPHA = OLDALF + .25 * (ACMD - OLDALF)     'Pitch dynamics

        CALL DRAGS          ' SUBROUTINE DRAG (REQ'D FOR RATE SUB CALL)

        IF PLMFLG% = 0 THEN EXIT SUB

        OLDGM = GM
        PLIM% = 0

        DO WHILE (PLIM% = 0)

        CALL RATES          ' SUBROUTINE RATES

        X = ALPHA + OLGM + GDOT * DT
        IF X > HP THEN ALPHA = .9 * ALPHA
        IF X < LP THEN ALPHA = 1.1 * ALPHA
        IF ALPHA > ALFLIM THEN
                              ALPHA = ALFLIM
                              PLIM% = 1
        END IF
        LOOP

END SUB

        SUB MCRBRST STATIC

        IF MU1 = 0 THEN
                        MU1 = -37141!
                        AV = 5500: H1 = 2500: G3 = 3: J1 = -700: J2 = 800: J3
= 6.5
                        MU2 = -20000
                        BV = 12000: H2 = 2000: N1 = 200: N2 = 2500: N3 = 4
                        WX = 5
                        IF ALT > 1000 THEN
                                        PRINT
                                        PRINT " DFW data not available above
1000'"
                                        PRINT " Please start at or below 1000'"
                                        END
                        END IF
        END IF

        X = 6078 * DST: Y = ALT: A1 = AV: A2 = BV
```

```
        NX1 = Y – H1: DENX1 = (Y – H1) ˆ 2 + (X – A1) ˆ 2
        NY1 = X + J2 – A1: DENY1 = (Y + J1 – H1) ˆ 2 + (X + J2 – A1) ˆ 2
        NX2 = Y – H2: DENX2 = (Y – H2) ˆ 2 + (X – A2) ˆ 2
        NY2 = X + N2 – A2: DENY2 = (Y + N1 – H2) ˆ 2 + (X + N2 – A2) ˆ 2
        NX3 = Y + H1: DENX3 = (Y + H1) ˆ 2 + (X – A1) ˆ 2
        NY3 = X + J2 – A1: DENY3 = (Y + J1 + H1) ˆ 2 + (X + J2 – A1) ˆ 2
        NX4 = Y + H2: DENX4 = (Y + H2) ˆ 2 + (X – A2) ˆ 2
        NY4 = X + N2 – A2: DENY4 = (Y + N1 + H2) ˆ 2 + (X + N2 – A2) ˆ 2
        XX = MU1 * (–NX1 / DENX1 + NX3 / DENX3) + MU2 * (NX2 / DENX2 –
NX4 / DENX4)
        WX = WX + .65 * (XX – WX) + 2 * G3

        IF DST = 0 THEN WXP = WX

        ZZ = MU1 * (NY1 / DENY1 – NY3 / DENY3) * J3 + MU2 * (–NY2 /
DENY2 + NY4 / DENY4) * N3
        WZ = WZ + .65 * (ZZ - WZ)

        IF DST = 0 THEN WZP = WZ

        WX5 = WX4: WX4 = WX3: WX3 = WX2: WX2 = WX1: WX1 = WX
        WZ5 = WZ4: WZ4 = WZ3: WZ3 = WZ2: WZ2 = WZ1: WZ1 = WZ

        IF WCNT% < 4 THEN WXDT = (WX – WXP) / DT: WXP = WX
        IF WCNT% < 4 THEN WZDT = (WZ – WZP) / DT: WZP = WZ
        IF WCNT% > 3 THEN WXDT = (26 * WX5 – 27 * WX4 – 40 * WX3 – 13
* WX2 + 54 * WX1) / (70 * DT)
        IF WCNT% > 3 THEN WZDT = (26 * WZ5 – 27 * WZ4 – 40 * WZ3 – 13 *
WZ2 + 54 * WZ1) / (70 * DT)
        IF ABS(WXDT) > 15 THEN WXDT = 15 * SGN(WXDT)
        IF ABS(WZDT) > 15 THEN WZDT = 15 * SGN(WZDT)
        WCNT% = WCNT% + 1


        END SUB

SUB MIN (DM, M2, C1, C2, C3, M) STATIC

        '*********************************************************
        'SUBROUTINE MIN_CST BY LEAST SQUARES PARABOLA     *
        '*********************************************************
        ALPHA = M2 + DM                'INCREMENT ALPHA

        CALL COST                               'SUBROUTINE COST

        IF DM < 0 THEN
                C4 = CST
```

```
        ELSE
                SWAP C1, C3
                C5 = CST
        END IF

        ALPHA = M2 – DM                 'DECREMENT ALPHA

        CALL COST                       'SUBROUTINE COST

        IF DM < 0 THEN
                C5 = CST
        ELSE
                C4 = CST
        END IF

        M = ABS(DM) * (14 * C1 + 7 * C4 – 7 * C5 – 14 * C3) / (20 * C1 – 10 *
C4 – 20 * C2 – 10 * C5 + 20 * C3)
END SUB

SUB OPT STATIS



'***************************************************************************
        'SUBROUTINE OPTALF - DETERMINES THE ALPHA REQD FOR CMD
GAMMA
*

'***************************************************************************

        OLDALF = ALPHA: GM1 = GM
        CALL ATOMS                      ' SUBROUTINE ATMOSPHERE

        CALL RATES                      ' SUBROUTINE RATES

        DM = 1 / 57.3                   ' SET ALPHA INCREMENT TO 1 DEGREE

        C1 = 1E+20
        C2 = 1E+20
        C3 = 1E+20

        OPTFLG% = 0

        WHILE (OPTFLG% = 0)

        CALL COST                 ' SUBROUTINE COST
```

```
        C3 = C2: C2 = C1: C1 = CST
        M3 = M2: M2 = M1: M1 = ALPHA

        LGC% = C1 > C2 AND C3 = 1E+20

        IF LGC% THEN
                        DM = –DM           ′ Reverse search direction
                        C1 = C2: C2 = CST: M1 = M2: M2 = ALPHA
                        ALPHA =ALPHA + 2 * DM
                ELSE
                        IF C1 < C2 THEN
                                L% = ABS(OLDALF – ALPHA) / DT
> ALFRTE OR ALPHA > ALFLIM OR ALPHA < –.08
                                IF L% THEN OPTFLG% = 1
                                ALPHA = ALPHA + DM
                        ELSE
                                DM = DM / 2
                                CALL MIN(DM, M2, C1, C2, C3,
M)′Fit parabola & find minimum
                                ALPHA = M2 + M ‘This is the
optimum alpha
                                OPTFLG% = 1       ‘Set flag to
terminate
                        END IF
        END IF
        WEND

        ALFLIM = ASS                ‘SET ALPHA LIMIT TO ALPHA STICK
SHAKER

        SELECT CASE LAW%

        CASE 4
                ALFLIM = ASS – .035 ‘LIMIT TO SS MINUS 2 DEG
        CASE 5, 6
                ALFLIM = ASS – KF2
        CASE ELSE
        END SELECT

        IF ALPHA < –.08 THEN ALPHA = -.08
        IF ALPHA > ALFLIM THEN ALPHA = ALFLIM

        ACMD = ALPHA                ‘SET ALPHA COMMAND TO COMPUTED
ALPHA

END SUB
```

```
SUB PLOT

'*******************************************************************************
********
    '*                    PLOT   ROUTINE
         *      *
'*******************************************************************************
*******

    REM $DYNAMIC

'                    TWO DIMENSIONAL PLOTTER

    DEFINT I-L, N

    DIM F$(3)                     ‘ file name array
    DIM DTA(3, 1000, 15)          ‘ data array
    DIM TY$(14)              ‘ title array (dependant variable)


    TITLE$ = “HONEYWELL WINDSHEAR SIMULATION”     ‘ main title
    TX$ = “Time (s)”                              ‘   X   title



    TY$(1) = “Altitude   ft     ”
    TY$(2) = “Alt Rate   fpm ”
    TY$(3) = “T A S     kts   ”
    TY$(4) = “Alpha      deg  ”
    TY$(5) = “Gamma    deg  ”
    TY$(6) = “Pitch        deg  ”
    TY$(7) = “G_ref      deg  ”
    TY$(8) = “Hz Shear kps ”
    TY$(9) = “Vt Wind   fps  ”
    TY$(10) = “Vt rate   kps  ”
    TY$(11) = “W/S Flag        ”

    NV = 12
    CLS

    LOCATE 3, 15: PRINT “Enter the names of the data files you wish to plot.”

    FOR NC = 1 TO 3
        LOCATE 6 + 2 * NC, 25                  ‘ input
        PRINT “FILENAME ”; NC; “ ”;            ‘ filenames
        INPUT ; F$(NC)                         ‘ containing
        IF F$(NC) = “ ” THEN EXIT FOR          ‘ data
```

```
        NEXT NC

        NC = NC – 1                               ‘ number of curves to plot

        LOCATE 20, 15: PRINT “Reading from disk.........”


        FOR I = 1 TO NC

                CLOSE

                OPEN “I”, #1, F$(I)           ‘ open file for input

                NP = 0

                DO
                        NP = NP + 1                   ‘ number of points

                        FOR J = 1 TO NV

                                INPUT #1, DTA(I, NP, J)    ‘ read data

                        NEXT J

                LOOP UNTIL EOF(1)

                CLOSE
        NEXT I


        DO ‘ display all selected parameters

        DO ‘ prompt user until a valid parameter is selected

100             CLS

                LOCATE 3, 20: PRINT “Select the parameter you wish to plot.”

                FOR I = 1 TO NV – 1

                LOCATE 4 + I, 30: PRINT TY$(I); “ = ”; I

        NEXT I

        LOCATE 21,  30: INPUT “parameter number (0 to exit)”; PARAM%

        IF PARAM% = 0 THEN
```

```
        CLS
        EXIT SUB                    ‘ return to calling program
    END IF

LOOP UNTIL 1 <= PARAM% AND PARAM% <= 14      ‘end of select loop

    PARAM% = PARAM% + 1



    DX = 5                  ‘ x axis grid increment

    GOSUB 400               ‘ find maximum x and y values

    IF PLTFLG% = 1 THEN
                            PRINT “No information to plot....”
                            PRINT “Press any key to continue...”
                            DO: LOOP WHILE INKEY$ = “ ”
                            GOTO 100

    END IF

    GOSUB 600           ‘ grid and titles

    FOR I = 1 TO NC
        GOSUB 1110          ‘ plot graph
    NEXT I


    DO
    LOOP WHILE INKEY$ = “ ”

    CLS : SCREEN 0

    LOOP

'*************************************************************************
*********
400 '*                              MAX SUBROUTINE
        *

'*************************************************************************
*********
    '
    MAXX = DTA(1, 1, 1)
    MAXY = DTA(1, 1, PARAM%)
    MINY = DTA(1, 1, PARAM%)
```

```
        FOR  I  =  1  TO  NC
               FOR  J  =  1  TO  NP
                      IF  DTA(I,  J,  1)  >  MAXX  THEN  MAXX  =   DTA(I,  J,  1)
                      IF  DTA(I,  J,  PARAM%)  >  MAXY  THEN  MAXY  =  DTA(I,  J,
PARAM%)

                      IF  DTA(I,  J,  PARAM%)  <  MINY  THEN MINY  =  DTA(I,  J,
PARAM%)

               NEXT  J
        NEXT  I

        PLTFLG%  =  0
        DY  =  (MAXY  –  MINY)  /  15
        IF  DY  =  0  THEN
                             PLTFLG%  =  1
                             DY  =  5

        END  IF
        MAG  =  10  ˆ  (INT(LOG(DY)  /  LOG(10))):  DY  =  DY  /  MAG

        IF  DY  <=  5  THEN
               DY  =  5
        ELSE
               DY  =  10
        END  IF

        DY  =  DY  *  MAG


        IF  INT(MAXX  /  DX)  < >  MAXX  /  DX  THEN  MAXX  =  INT(MAXX  /  DX  +
1)  *  DX

        IF  INT(MAXY  /  DY)  < >  MAXY  /  DY  THEN  MAXY  =  INT(MAXY  /  DY  +
1)  *  DY

        IF  INT(MINY  /  DY)  < >  MINY  /  DY  THEN  MINY  =  INT(MINY  /  DY)  *  DY


        NUMX  =  MAXX  /  DX
        NUMY  =  (MAXY  –  MINY)  /  DY
        RETURN


600
```

```
'*****************************************************************************
*********
    '*                    GRID AND TITLES
               *

'*****************************************************************************
**********
    '
    CLS
    SCREEN 2                    ' 640*200 monochrome graphics
    KEY OFF
    '
    FOR J = 0 TO NUMX
        Z = J * 580 / NUMX + 59
        LINE (Z, 10) – (Z, 170)         ' vertical grid line
        Z = J * 71 / NUMX + 7

        a = DX * J

        IF a <> 0 THEN                              ' adjustment for
            D = INT(LOG(a) / LOG(10)) + 1           ' large numbers
            IF D > 1 THEN Z = Z – D + 1
        END IF

        LOCATE 23, Z
        PRINT a;
    NEXT J

    FOR J = 0 TO NUMY
    Z = J * 160 / NUMY + 10
    LINE (60, Z) – (640, Z)                     ' horizontal grid line
    Z = 22 – J * 20 / NUMY

    LOCATE Z, 2

    Z = DY * J + MINY

    AZ = ABS(Z)

    IF INT(Z) = Z THEN
                            G$ = "######"
    ELSEIF AZ < .1 THEN
                            G$ = "#.####"
    ELSEIF AZ >= .1 AND AZ < 1 THEN
                            G$ = "##.###"
    ELSEIF AZ >= 1 AND AZ < 10 THEN
                            G$ = "###.##"
```

```
ELSEIF AZ >= 10 AND AZ < 100 THEN
                                          G$ = "####.#"
ELSE
                                          G$ = "######"
END IF

PRINT USING G$; Z;

NEXT J

Z = (80 - LEN(TITLE$)) / 2 + 2
LOCATE 1, Z: PRINT TITLE$ ' print main title

LOCATE 24, 36: PRINT TX$; ' X axis title

LOCATE 8, 1                                       ' Y

FOR J = 1 TO LEN(TY$(PARAM% - 1))                 ' axis
     PRINT MID$(TY$(PARAM% - 1), J, 1)            ' title
NEXT J

LOCATE 25, 10: PRINT "1";                         ' curve
LINE (90, 195) - (130, 195)
LOCATE 25, 20: PRINT "2";                         ' labels
     FOR J = 0 TO 40 STEP 8
          XX = 170 + J
          PSET (XX, 195)
          CIRCLE (XX, + 80, 195) , 2
NEXT J
LOCATE 25, 30: PRINT "3";
RETURN


'*******************************************************************************
************
     '*                              PLOTTING ROUTINE
          *

'*******************************************************************************
************
     '
1110 FOR J = 1 TO NP
          XX = 580 * DTA(I, J, 1) / MAXX + 60' calculate pixel X position
          YY = 170 - 160 * (DTA(I, J, PARAM%) - MINY) / (MAXY - MINY)


          IF J = 1 OR J = NP THEN GOTO 1170
```

```
            IF I = 1 THEN LINE (XXOLD, YYOLD) – (XX, YY) ‘ line 1170
            XXOLD = XX

            YYOLD = YY

            IF I = 2 THEN PSET (XX, YY)                    ‘ point
            IF I = 3 THEN CIRCLE (XX, YY), 2               ‘ circle
        NEXT J
        ‘
        RETURN

        END SUB

REM $STATIC
DEFSNG I-L, N
        SUB PRINTS

        '******************************************************************
        '              SUBROUTINE PRINT TO SCREEN AND FILE               *
        '******************************************************************
        ACMDG = 57.3 * ACMD
        ALF = 57.3 * ALPHA
        GAM = 57.3 * GM
        PITCH = ALF + GAM
        WZX = 1.689 * WZ
        IF NOSAVE = 0 THEN PRINT #2, SEC, ALT, HDOT, VT, ALF, GAM,
PITCH, GREFF, WXDT, WZX, VDOT, WSALERT%
        FMT1$ = “###.## #### ##### ### ###.# ###.# ###.# ##.# ###.# ###.#
###.#  #”
        PRINT USING FMT1$; SEC, ALT, HDOT, VT, ALF, GAM, PITCH, GREFF,
WXDT, WZX, VDOT, WSALERT%

        END SUB

SUB RATES STATIC

        '******************************************************************
        '                     SUBROUTINE RATES                           *
        '******************************************************************
        SNGM = SIN(GM): CSGM = COS(GM): SNAL = SIN(ALPHA): CSAL =
COS(ALPHA)
        VDOT = G * ((THRST * CSAL – DRAG) / WG – SNGM) – WXDT * CSGM
– WZDT * SNGM
        GDOT = G * ((LIFT + THRST * SNAL) / WG – CSGM) + WXDT * SNGM
– WZDT * CSGM
        GDOT = GDOT / VT
        HDOT = 101.28 * (VT * SNGM + WZ)
```

```
        XDOT = VT * CSGM + WX

        AWX = VDOT + WXDT * CSGM + WZDT * SNGM                    'Inertial
Acc. along Wind_x axis
        AWZ = VT * GDOT – WXDT * SNGM + WZDT * CSGN 'Inertial Acc. along
Wind_z axis

        AU = (AWX * CSAL + AWZ * SNAL) / G                 'LONG. ACCEL.
–>=+
        AZ = (AWX * SNGM + AWZ * CSGM) / G                 'VERT. ACCEL.
UP=+

        VG = XDOT
        GRND = (VT * GM + WZ) / (VT + WX)                  'Gamma w/r ground
        KF1 = 1
        GHAT = GMIN * (1 + WX / VT)
        IF WZ > -30 AND WZ < -20 THEN KF1 = 1 + .025 * (WZ + 20)
        IF WZ <= -30 THEN KF1 = .75
        DGAM = 57.3 * (20 * GDOT – (GHAT – GRND + (1 – KF1) * WZ / 152 +
20 * GDOT))

        IF DGAM < 0 THEN
              KF2 = (2 + .4 * DGAM)
        ELSE
              KF2 = 2
        END IF

        IF KF2 < 0 THEN KF2 = 0
        KF2 = KF2 / 57.3

END SUB

SUB TAKEOFF STATIC

        '*****************************************************************
        '           SUBROUTINE INTIALIZE TAKEOFF                          *
        '*****************************************************************
        IF APPFLG% = 0 THEN
                        ALPHA = .12
                        WHILE (LIFT <= WG)
                              CALL DRAGS
                              ALPHA = ALPHA + .01
                        WEND
                        GM = (THRST – DRAG) / WG      'COMPUTE
POTENTIAL GAMMA
                  ELSE
                        GM = –3 / 57.3
```

```
                    ALPHA = 2 / 57.3
                    CALL DRAGS
                    TFCT = 1
                    CALL THRUST
                    T = DRAG – .052 * WG
                    IF T < 0 THEN T = .2 * THRST
                    TFCT = T / THRST
                    THRST = T
    END IF
    GMO = GM
    CALL RATES
END SUB

SUB THRUST STATIC

    '******************************************************************
    '           SUBROUTINE EPR/THRUST                                 *
    '******************************************************************
    '       TAKE-OFF THRUST FOR JT8D-17 ENGINES
    VE = 1.668 * VT

    R00 = 14688.74: R01 = –.65187546#: R02 = 6.7371E-05
    R10 = –13.9295: R11 = .000751143#: R12 = –1.5405E-07
    R20 = .014643: R21 = 5.3444E-07: R22 = –4.8907E-10

    AA0 = (R02 * ALT + R01) * ALT + R00
    AA1 = (R12 * ALT + R11) * ALT + R10
    AA2 = (R22 * ALT + R21) * ALT + R20

    THRST = 2 * ((AA2 * VT + AA1) * VT + AA0)        'Temp. = 100 F

    IF APPFLG% = 1 THEN
                    IF LC% = 1 AND TFCT < 1 THEN
                                        GMO = .136
                                        TSPL = 5.5
'Engine Spool Up Time
                                        TFCT =
TFCT + DT / TSPL
                    END IF
                    IF TFCT > 1 THEN TFCT = 1
                ELSE
                    TFCT = 1
    END IF
    THRST = TFCT * THRST
''          THRST = 2 * (((2.64159E-05 * VT + 5.110896E-03) * VT – 12.56476) *
VT + 15550)
END SUB
```

```
SUB VSHAKER STATIC

    '----------------------------------- COMPUTATION OF Vss AND V2
------------------------
    V2 = 145
    VTO = V2 + 10'                 SETS INITAL SPEED EQUAL TO V2 + 10

    SELECT CASE FLPS%

    CASE 10
        IF VTO < 150 THEN VTO = 150          ‘ TAKEOFF
    CASE 18
        IF VTO < 148 THEN VTO = 148          ‘ FLAP
    CASE 22
        IF VTO < 147 THEN VTO = 147          ‘ SETTINGS

    CASE 33
        VTO = 63.11225 + .222468 * WG / 1000        ‘ APPROACH
    CASE 42                                         ‘ FLAP
        VTO = 62.67386 + .21744 * WG / 1000         ‘ SETTINGS

    CASE ELSE

    END SELECT

END SUB

SUB WINDS STATIC

    '****************************************************************
    '                    SUBROUTINE WINDS                           *
    '****************************************************************
    '
    IF TDX > 0 THEN
                    T1 = 4
                    T2 = TSH
                    T3 = T1 + T2
                    T4 = –4
                    T5 = T3 + TDX
                    T6 = T5 – T4

                    B1 = 3 * WXDTO / T1 ˆ 2
                    A1 = –2 * B1 / (3 * T1)
                    B2 = 3 * WXDTO / T4 ˆ 2
                    A2 = –2 * B2 / (3 * T4)
```

```
                IF SEC > T2 AND SEC < = T3 THEN
                              X = SEC –
T2

                              WXDT =
(A1 * X + B1) * X * X
                END IF

                IF SEC > T5 AND SEC < = T6 THEN
                              X = SEC - T6

                              WXDT = (A2
* X + B2) * X * X

                END IF

                IF SEC > T6 THEN WXDT = 0

                WX = WX + WXDT * DT
    END IF
    IF TDZ > 0 THEN
            T1 = 4
            T2 = TSV
            T3 = T1 + T2
            T4 = – 4
            T5 = T3 + TDZ
            T6 = T5 – T4

            B1 = 3 * WZO / T1 ^ 2
            A1 = –2 * B1 / (3 * T1)
            B2 = 3 * WZO / T4 ^ 2
            A2 = –2 * B2 / (3 * T4)

            IF SEC > T2 AND SEC <= T3 THEN
                          X = SEC – T2
                          WZ = (A1 * X +
B1) * X * X

                          WZC = WZ

            END IF

            IF SEC > T5 AND SEC <= T6 THEN
                          X = SEC – T6
                          WZ = (A2 * X +
B2) * X * X

                          WZC = WZ
            END IF
```

```
                KALT = (–.0000011 * ALT + .00212) * ALT – .0251

                IF KALT < 0 OR ALT <= 0 THEN KALT = 0
                KALT = 1
                WZ = KALT * WZC

                IF SEC > T6 THEN WZ = 0

                WZDT = (WZ – WZ1) / DT
                WZ1 = WZ
    END IF

    IF DFW% = 1 THEN CALL MCRBRST              'DALLAS Model

END SUB
```

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