



Number: CTSO-C117b  
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Approved by: Xu Chaoqun

## China Civil Aviation Technical Standard Order

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This China Civil Aviation Technical Standard Order (CTSO) is issued according to Part 37 of the China Civil Aviation Regulations (CCAR-37). Each CTSO is a criterion which the concerned aeronautical materials, parts or appliances used on civil aircraft must comply with when it is presented for airworthiness certification.

### Airborne Windshear Warning And Escape Guidance Systems For Transport Airplanes

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#### **1. Purpose.**

This technical standard order (CTSO) is for manufacturers applying for a CTSO authorization (CTSOA). In it, we tell you what minimum performance standards (MPS) your airborne windshear warning and escape guidance systems for transport category airplanes must first meet for approval and identification with the applicable CTSO marking. This CTSO 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 encountering the phenomenon nor to systems using atmospheric and/or other data to predict the likelihood of a windshear alert.

Appendix 1 of this CTSO describes the MPS for the airborne

windshear warning and escape guidance systems for transport category airplanes. Appendix 2 of this CTSO describes the wind field models used to evaluate the performance of the windshear warning and escape guidance system. Appendix 3 of this CTSO describes the conversion of the velocity equations in Appendix 2 to rectangular coordinates. Appendix 4 of this CTSO contains data defining the Dryden turbulence model and discrete gust model used in conducting the windshear alert tests. Appendix 5 of this CTSO describes shear intensity. Appendix 6 of this CTSO provides a sample computer listing for a simplified aircraft simulation model for evaluating the effectiveness of various guidance schemes.

## **2. Applicability.**

This CTSO affects new applications submitted after its effective date.

a. From the effective date of this CTSO, applicants wishing to obtain Airborne windshear warning and escape guidance system CTSOA for transport aircraft shall submit their applications in accordance with this CTSO. However, if within six months from the date of entry into force of this CTSO, the applicant can indicate to the authorities that the new version has been developed in accordance with the minimum performance standards of the previous version before its entry into force,

an application can be submitted in accordance with the previous version of CTSO.

b. Since the effective date of this CTSO, CTSOA equipment obtained according to previous versions of CTSO can continue to be manufactured according to the requirements at the time of approval.

c. According to the equipment approved by CTSO, the major design changes shall be re-applied for CTSOA in accordance with CCAR-21-R4 § 21.353.

### **3. Requirements.**

New models of airborne windshear warning and escape guidance systems identified and manufactured on or after the effective date of this CTSO must meet the MPS qualification and documentation requirements set forth in appendix 1.

a. **Functionality.** This CTSO's standards apply to equipment intended to identify the presence of windshear once the phenomenon is encountered and provide the pilot with timely warning and adequate flight guidance to improve the probability of recovery from the windshear encounter.

b. **Failure Condition Classifications.**

(1) Failure of the function defined in paragraph 3.a resulting in unannounced malfunction or missed windshear detection is a major

failure condition.

(2) Loss of the function defined in paragraph 3.a is a minor failure condition.

(3) Design the system to at least these failure condition classifications.

c. Functional Qualification. Demonstrate the required functional performance under the test conditions in appendix 1 of this CTSO.

d. Environmental Qualification. Demonstrate the required performance under the test conditions in appendix 1, paragraph 4.c of this CTSO using standard environmental conditions and test procedures appropriate for airborne equipment. You may use different standard environmental conditions and test procedures than specified in RTCA/DO-160G provided the standard is appropriate for the airborne windshear warning and escape guidance system.

**Note:** The use of RTCA/DO-160D (with Changes 1 and 2 only, without Change 3 incorporated) or earlier versions is generally not considered appropriate and will require substantiation via the deviation process as discussed in paragraph 3.g of this CTSO.

e. Software Qualification. If the article includes software, develop the software according to RTCA, Inc., document, RTCA/DO-178C, Software Considerations in Airborne Systems and Equipment

Certification, dated December 13, 2011, including referenced supplements as applicable, to at least the software level consistent with the failure condition classification defined in paragraph 3.b of this CTSO. You may also develop the software according to RTCA, Inc., document RTCA/DO-178B, dated December 1, 1992, if you follow the guidance in FAA AC 20-115D, Airborne Software Development Assurance Using EUROCAE ED-12() and RTCA DO-178(), dated July 21, 2017, or latest revision.

f. Electronic Hardware Qualification. If the article includes complex custom airborne electronic hardware, then develop the component according to RTCA, Inc., Document RTCA/DO-254, Design Assurance Guidance for Airborne Electronic Hardware, dated April 19, 2000, to at least the design assurance level consistent with the failure condition classification defined in paragraph 3.b of this CTSO. For custom airborne electronic hardware determined to be simple, DO-254, paragraph 1.6 applies.

g. Deviations. We have provisions for using alternate or equivalent means of compliance with the criteria in the MPS of this TSO. If you invoke these provisions, you must show that your equipment maintains an equivalent level of safety. Apply for a deviation pursuant to CCAR-21-R4 § 21.618(1).

#### **4. Marking.**

a. Mark at least one major component permanently and legibly with all of the information in CCAR-21-R4 § 21.618(2).

b. If the article includes software and/or airborne electronic hardware, then the article part numbering scheme must identify the software and airborne electronic hardware configuration. The part numbering scheme can use separate, unique part numbers for software, hardware, and airborne electronic hardware.

c. You may use electronic part marking to identify software or airborne electronic hardware components by embedding the identification within the hardware component itself (using software) rather than marking it on the equipment nameplate. If electronic marking is used, it must be readily accessible without the use of special tools or equipment.

#### **5. Application Data Requirements.**

You must give the manager responsible for your facility a statement of conformance, as specified in CCAR-21-R4 § 21.353(1) and one copy each of the following technical data to support your design and production approval.

a. Manuals containing the following:

(1) Operating instructions and article limitations sufficient to describe the equipment's operational capability.

(2) Detailed description of any deviations.

(3) Installation procedures and limitations sufficient to ensure that the airborne windshear warning and escape guidance system, when installed according to the installation or operational procedures, still meets this CTSO's requirements. Limitations must identify any unique aspects of the installation. The limitations must also include a note with the following statement:

**“ This article meets the minimum requirements of CTSO-C117b. Installation of this article requires separate approval.”**

(4) For each unique configuration of software and airborne electronic hardware, reference the following:

(i) Software part number, including revision and design assurance level,

(ii) Airborne electronic hardware part number including revision and design assurance level,

(iii) Functional description.

(5) A summary of the test conditions used for environmental qualifications for each component of the article. For example, a form as described in RTCA/DO-160G, Environmental Conditions and Test Procedures for Airborne Equipment, Appendix A.

(6) Schematic drawings, wiring diagrams, and any other documentation necessary for installation of the airborne windshear

warning and escape guidance system.

(7) By part number list of replaceable components that make up the airborne windshear warning and escape guidance system. Include vendor part number cross-references, when applicable.

b. Instructions covering periodic maintenance, calibration, and repair, to ensure that the airborne windshear warning and escape guidance system continues to meet the CTSO approved design. Include recommended inspection intervals and service life, as appropriate.

c. If the article includes software: a plan for software aspects of certification (PSAC) software configuration index, and a software accomplishment summary.

d. If the article includes simple or complex custom airborne electronic hardware: a plan for hardware aspects of certification (PHAC), a hardware verification plan, top-level drawing, and hardware accomplishment summary (or similar document, as applicable).

e. A drawing depicting how the article will be marked with the information required by paragraph 4 of this CTSO.

f. Identify functionality contained in the article not evaluated under paragraph 3 of this CTSO (defined as non-CTSO functions). Non-CTSO functions can be accepted in parallel with the CTSOA. For those non-CTSO functions to be accepted, you must declare these functions and include the following information with your CTSO application:



(1) Description of the non-CTSO function(s), such as performance specifications, failure condition classifications, software, hardware, and environmental qualification levels. Include a statement confirming that the non-CTSO function(s) do not interfere with the article's compliance with the requirements of paragraph 3.

(2) Installation procedures and limitations sufficient to ensure that the non-CTSO function(s) meets the declared functions and performance specification(s) described in paragraph 5.f.(1).

(3) Instructions for continued performance applicable to the non-CTSO function(s) described in paragraph 5.f.(1).

(4) Interface requirements and applicable installation test procedures to ensure compliance with the non-CTSO function(s) performance data defined in paragraph 5.f.(1).

(5) Test plans and analysis, as appropriate, to verify that the performance of the hosting CTSO article is not affected by the non-CTSO function(s).

(6) Test plans and analysis, as appropriate, to verify that the function and performance of the non-CTSO function(s) as described in paragraph 5.f.(1).

g. The quality manual required by CCAR-21-R4 § 21.358, including functional test specifications. The quality system must ensure that you will detect any change to the approved design that could adversely affect

compliance with the CTSO MPS and reject the article accordingly. Applicants who currently hold CTSOAs must submit revisions to the existing quality manual as necessary.

- h. Material and process specifications list.
- i. A list of all drawings and processes (including revision level) that define the article's design.
- j. Manufacturer's CTSO qualification report showing results of testing accomplished according to paragraph 3.c of this CTSO.

## **6. Manufacturer Data Requirements.**

Besides the data given directly to the authorities, have the following technical data available for review by the authorities:

- a. Functional qualification specifications for qualifying each production article to ensure compliance with this CTSO.
- b. Article calibration procedures.
- c. Schematic drawings.
- d. Wiring diagrams.
- e. Material and process specifications.
- f. The results of the environmental qualification tests conducted according to paragraph 3.d of this CTSO.
- g. If the article includes software, the appropriate documentation defined in RTCA/DO-178B or RTCA/DO-178C specified in paragraph

3.e of this TSO, including all data supporting the applicable objectives in Annex A, Process Objectives and Outputs by Software Level of DO-178B or DO-178C.

h. If the article includes complex custom airborne electronic hardware, the appropriate hardware life-cycle data in combination with the design assurance level, as defined in RTCA/DO-254, Appendix A, Table A-1. For simple custom airborne electronic hardware, the following data are required: test cases or procedures, test results, test coverage analysis, tool assessment and qualification data, and configuration management records, including problem reports.

i. If the article contains non-CTSO function(s), you must also make items 6.a through 6.h available as they pertain to the non-CTSO function(s).

## **7. Furnished Data Requirements.**

a. When furnishing one or more articles manufactured under this CTSO to one entity (such as an operator or repair station), provide one copy or online access to the data in paragraphs 5.a and 5.b of this CTSO. Add any other data needed for the proper installation, certification, use, or continued compliance with the CTSO, of the airborne windshear warning and escape guidance system.

b. If the article contains declared non-CTSO function(s), include one

copy of the data in paragraphs 5.f.(1) through 5.f.(4).

c. If the article contains software, include one copy of the Open Problem Report (OPR) summary to type certification, supplemental type certification, or amended type certification design approval holders.

**8. Availability of Referenced Documents.**

Order RTCA documents from:

Radio Technical Commission for Aeronautics, Inc.

1150 18th Street NW, Suite 910, Washington D.C. 20036

You may also order them online from the RTCA Internet website at:

[www.rtca.org](http://www.rtca.org).

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Appendix 1 Federal Aviation Administration Minimum Performance  
Standard For Airborne Windshear Warning And Escape Guidance  
Systems For Transport Airplanes

**1. Purpose.**

This appendix establishes the Minimum Performance Standards (MPS) for the airborne windshear warning and escape guidance systems for transport category airplanes.

**2. Scope.**

The scope of this appendix is to provide minimum performance standards for your airborne windshear warning and escape guidance systems for transport category airplanes. All paragraph references cited herein are in reference to this appendix only.

This CTSO applies only to windshear warning systems which identify windshear phenomenon by sensing the encounter of conditions exceeding the threshold values contained in this CTSO. In addition to windshear warning criteria, this CTSO 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. Definition Of Terms.**

- a. 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.

b. 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.

c. 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.

d. 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.

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

f. False Warning or Caution. A warning or caution which occurs when the windshear warning or caution threshold of the system is not

exceeded.

g. 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.

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

i. Severe Windshear. A windshear of sufficient intensity and duration that exceeds the performance capability of a particular aircraft type. This would 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 CTSO.

j. 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.

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

#### **4. General Requirements.**

In addition to the performance requirements set forth in the main text of this CTSO, the following general requirements and equipment characteristics are defined below:

a. General Standards. The following general requirements must 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 must be of a quality which experience and/or tests have demonstrated to be suitable and dependable for use in aircraft systems. Workmanship must 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.

(4) Operation of Controls. Controls intended for use during flight must be designed to minimize errors, and when operated in all possible



combinations and sequences, must 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 must 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 must 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 must be identified in a manner that will ensure performance to the requirements specified in this CTSO.

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

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

(10) Control/Display Readability. The equipment must be

designed so that all displays and controls must 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 must be such that the application of the specified test procedures must not produce a condition detrimental to the performance of the equipment except as specifically allowed.

(12) Equipment Computational Response Time. The equipment must 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 ensure that the requirements of this CTSO are met, they must be specified by the equipment manufacturer in the installation instructions.

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

(i) Any manually initiated self-test mode of operation must 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 must 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 must 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 must be  $1 \times 10^{-4}$  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 must be  $1 \times 10^{-5}$  or less per flight hour .

b. Equipment Functional Requirements - Standard Conditions. The

equipment must meet the following functional requirements.

(1) Mode Annunciation. The windshear escape guidance display mode of operation must 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 must 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 must occur independently of any operator action. The lack of adequate warning displays, escape guidance information, or sensor signals or sources must be annunciated when compliance with the requirements of this CTSO cannot be assured.

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

(i) It must 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 must 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 3 seconds) or a windshear warning alert occurs.

(iii) Gust conditions must not cause a nuisance caution alert. Turbulence must 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 must 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 must 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 for a minimum of 3 seconds, whichever is greater. An aural alert must 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 must not cause a nuisance warning alert.

Turbulence must 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) Windshear Alert with Increased Approach Sensitivity and Reduced Takeoff Sensitivity Modes.

(i) Increased Approach Sensitivity Mode. If your system separates approach and takeoff scenarios, you may reduce the shear intensity level in the approach mode to increase the probability of providing timely windshear alerts. You may lower the floor of the shear intensity curve must alert curve in Figure 1 from 0.105 to 0.090. If you lower the floor, you may also modify the turbulence rejection tests in paragraph 4.d.(7).(ii) such that an alert in this region is not a failure of the turbulence rejection test.

(ii) Reduced Takeoff Sensitivity Mode. If your system separates approach and takeoff scenarios, you may desensitize the takeoff mode to reduce the probability of unwanted alerts. You may raise the floor of the shear intensity must alert curve in Figure 1 from 0.105 to 0.120.

(iii) Additional Reduced Takeoff Sensitivity Mode. Some high performance jet aircraft receive unwanted windshear alerts after takeoff when climbing at high rates through atmospheric wind gradients. If these unwanted alerts risk desensitizing pilots to windshear alerting, you may tailor the floor of the shear intensity must alert curve in Figure 1 to reduce these unwanted alerts under the following conditions:

(a) The airborne windshear warning and escape guidance system can determine the aircraft is in the takeoff versus approach phase.

(b) The aircraft is climbing at a high rate of climb, the aircraft continues to climb at a high rate, and the rate of climb is known to create unwanted windshear alerts.

(c) The aircraft power setting is at or near a level representative of the maximum for the segment of the takeoff, for example maximum takeoff thrust.

(d) The Figure 1 shear intensity must alert curve must be complied with after takeoff.

(6) Alerting Prioritization. Where alerting is prioritized in presentation for Windshear Warning and Escape Guidance System (Reactive Windshear), Forward Looking Windshear System, Terrain Awareness and Warning System, Ground Proximity Warning System, Traffic Collision Avoidance System, or where simultaneous aural annunciation could occur, sequencing must be implemented assuring reactive windshear warning alerts are presented or annunciated first. Reactive windshear alerts that are cautions have lower priority than all Terrain Awareness and Warning or Ground Proximity Warning System alerts.

(7) The reactive windshear systems caution alert should be disabled if a forward-looking windshear system is in operation. It is

acceptable to issue reactive windshear caution alerts if the forward-looking windshear system is inoperative.

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

(9) Windshear Escape Guidance. Flight guidance algorithms must 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 wind field 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. You must demonstrate the flight guidance commands during a dynamic windshear encounter can be followed without resulting in pilot-induced oscillations.

(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 must be provided for presentation on the primary flight display/attitude direction indicator (PFD/ADI) and any available Head Up Display (HUD).

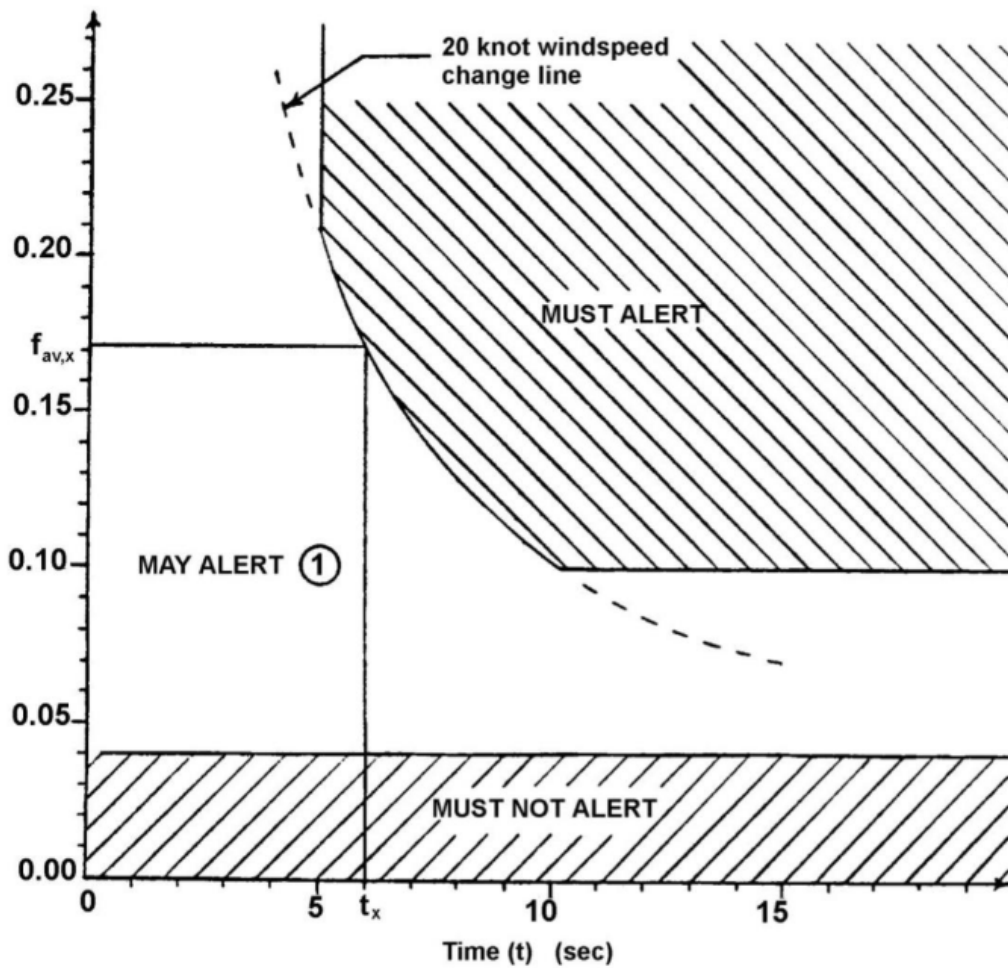
(v) Flight guidance displays which command flight path and pitch attitude should be limited to an angle-of-attack equivalent to onset of stall warning or maximum pitch command of  $27^{\circ}$ , whichever is less.

(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 must 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) must 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 must 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 wind speed 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.

c. Equipment Performance - Environmental Conditions.

(1) 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. Table 1 defines the environmental tests required for the equipment. It shows the section numbers in DO-160G that describe the individual environmental tests. 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” in Table 1. If the manufacturer wishes to qualify the equipment to these additional environmental conditions, then these “When Required” tests must be performed.

(2) Environmental Requirements. The following subset of performance requirements must be met under environmental conditions. Additionally, all system controls, displays, inputs, and outputs must perform their intended functions when subjected to the DO-160G environmental conditions.

(i) Section 4.(b)(1) - Mode Annunciation

(ii) Section 4.(b)(2) - Malfunction/Failure Indications

- (iii) Section 4.(b)(3) - Windshear Caution Alert, except § 4.(b)(3)(iii)
- (iv) Section 4.(b)(4) - Windshear Warning Alert, except § 4.(b)(4)(iii)
- (v) Section 4.(b)(5) - Windshear Alert with Increased Approach Sensitivity and Reduced Takeoff Sensitivity Modes
- (vi) Section 4.(b)(9) - Windshear Escape Guidance

Conduct environmental qualification test for the following shear intensity ( $f_{av,x}$ ) and exposure time (sec) in figure 1: 0.1050, 10; 0.1748, 6; and 0.2100, 5. Ensure the system generates and displays alerts when required. You may use a single representative windshear waveform for all environmental tests, if your system design is such that different waveforms will not affect performance under environmental conditions. Gust and turbulence rejection tests are not required under environmental conditions.

**Table 1  
Required DO-160G Testing By Category**

<b>Environmental Test</b>	<b>DO-160G Section</b>	<b>Required Test</b>
Temperature and Altitude	4	
Ground Survival Low Temperature and Short-Time Operating Low Temperature		✓
Low Operating Temperature		✓
Ground Survival High Temperature and Short-Time Operating High Temperature		✓
High Operating Temperature		✓
In-Flight Loss of Cooling		When Required
Altitude		✓
Decompression		When Required
Overpressure		When Required
Temperature Variation	5	✓
Humidity	6	✓
Operational Shocks and Crash Safety	7	
Operational Shocks		✓
Crash Safety		✓
Vibration	8	✓
Explosion proofness	9	When Required
Waterproofness	10	
Condensing Water Proof		When Required
Drip Proof		When Required
Spray Proof		When Required
Continuous Stream Proof		When Required
Fluids susceptibility	11	
Spray		When Required
Immersion		When Required
Sand and dust	12	When Required
Fungus resistance	13	When Required
Salt spray	14	When Required
Magnetic effect	15	✓
Power input	16	
Normal Operating Conditions (ac and dc)		✓
Abnormal Operating Conditions (ac and dc)		✓
Load Equipment Influence on Aircraft Electrical Power System (ac and dc)		When Required
Voltage spike	17	
Category A Requirements (If Applicable)		✓

*English Translation Version for Reference Only*

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<b>Environmental Test</b>	<b>DO-160G Section</b>	<b>Required Test</b>
Category B Requirements (If Applicable)		✓
Audio frequency conducted susceptibility	18	✓
Induced signal susceptibility	19	✓
RF susceptibility	20	✓
Emission of RF energy	21	✓
Lightning induced transient susceptibility	22	✓
Lightning Direct Effects	23	When Required
Icing	24	When Required
Electrostatic Discharge	25	When Required
Fire, Flammability	26	✓

d. 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 must be conducted with the power input voltage adjusted to design voltage  $\pm 2$  percent. The input voltage must 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 must be adjusted to design frequency  $\pm 2$  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, the test must 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) Wind Field Models. Unless otherwise specified, the wind field models used for tests must be those specified in appendix 2 of this CTSO.

(iv) Adjustment of Equipment. The circuits of the equipment under test must 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 must 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 must be made within the following ambient conditions:

- Temperature: +15 to +35 degrees C (+59 to +95 degrees F).
- Relative Humidity: Not greater than 85%.
- Ambient Pressure: 84 - 107 kPa (equivalent to +5,000 to - 1,500 ft.) (+1,525 to - 460m).

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

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

(2) Test Procedures. The equipment must 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 must 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 must be defined by the equipment manufacturer as a function of the specific sensor configuration of the equipment. Since these tests may be accomplished more than 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 must 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 wind field models contained in appendix 2 of this TSO should be used to evaluate the performance of the windshear warning and escape guidance system. The manufacturer may propose different wind field models provided it is shown that they represent conditions at least as severe as those contained in this TSO.

**Note:** The test waveform parameters provided in the TSO are sufficiently broad to cover the wind field parameters observed in known accident cases. However, the manufacturer is encouraged to verify that the detection systems will actually detect these windshears by subjecting them to the wind field conditions specified for use in evaluating guidance commands.

(3) Test Setup. Simulator tests must be used to demonstrate the performance capability of the windshear warning and escape guidance equipment. A suitable equipment interface must be provided for recording relevant parameters necessary to evaluate the particular system under test. The aircraft simulator must be capable of appropriate dynamic modeling

of a representative aircraft and of the wind field and turbulence conditions contained in appendices 2 and 3 of this CTSO or other wind field/turbulence models found acceptable by the Administrator.

**Note:** This section requires testing in a single representative aircraft simulator. Installation approval will require system testing in an aircraft simulator representative of the aircraft. Thus, we recommend you accomplish the section 4.d (3) simulator testing in as many representative simulators as necessary to cover all intended installations.

(4) Functional Performance (paragraphs (b)(1) through (b)(5), (b)(8), and (b)(9)). Each of the functional capabilities identified in paragraphs (b)(1) through (b)(5), (b)(7), and (b)(8) must be demonstrated with the windshear warning and escape guidance equipment powered. These capabilities must be evaluated either by inspection or in conjunction with the tests described in paragraphs (d)(5) through (d)(10).

(5) Mode Annunciation (paragraph (b)(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 (b)(2)). Configure the equipment for simulation tests as defined in paragraph (d)(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 must 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 must be a failure indication by the equipment of each simulated failure condition.

(7) Windshear Caution Alert (paragraphs (b)(3) and (b)(5)(i)). For equipment incorporating a windshear caution alert function, accomplish the following tests:

(i) Configure the equipment for simulation test as defined in paragraph (d)(3). Subject the equipment to acceleration waveform values meeting the following conditions (reference figure 2). The system must 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)	Alert Within
<hr style="width: 100%;"/>	<hr style="width: 100%;"/>	<hr style="width: 100%;"/>
	(sec)	(sec)(3)
0.0200	20	no alert
0.0400	20	no alert
0.1050	10	10
0.1166	9	9
0.1311	8	8
0.1499	7	7
0.1748	6	6.2
0.2100	5	5.7
0.2700 (2)	5	5

**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 must 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) In order to achieve the test condition with the shear intensity  $f_{av,x}$  equal to or greater than 0.270, it is necessary to have an initial rise of sufficient rate to achieve a shear intensity  $f$  value that will allow subsequent rise and fall rates limited to 0.1 per second to achieve the required  $f_{av,x}$  value.

(3) Account for latency due to the alert calculation and alert annunciation display functionality when measuring the alert time.

The test conditions specified above must be repeated 5 times for each axis (horizontal and vertical). A total of 90 runs are required for detection verification (9 conditions x 5 for each axis) for both performances increasing and decreasing windshears. 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 4. The system must be exposed to these conditions for a minimum of 50 hours (or 600 flight cycles) at each altitude specified in appendix 4 for minimum total test duration of 250 hours (or 3,000 flight cycles based on 1 hour/flight cycle). No more than one nuisance caution must be generated during this test.

(iii) Subject the equipment to windspeeds defined by the discrete gust rejection model contained in appendix 4. No alert must be generated as a result of this test.

(8) Windshear Warning Alert (paragraphs (b)(4) and (b)(5)(ii)).

(i) Configure the equipment for simulation tests as defined in paragraph (d)(3). Subject the equipment to acceleration waveform values meeting the following conditions (reference figure 2). The system must 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:

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$f_{av,x}$ (1)	Time of Exposure (t) (sec)	Alert Within (sec)(3)
0.0200	20	no alert
0.0400	20	no alert
0.1050	10	10
0.1166	9	9
0.1311	8	8
0.1499	7	7
0.1748	6	6.6
0.2100	5	6.2
0.2700 (2)	5	5.7

**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 must 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) In order to achieve the test condition with the shear intensity  $f_{av,x}$  equal to or greater than 0.270, it is necessary to have an initial rise of sufficient rate to achieve a shear intensity  $f$  value that will allow subsequent rise and fall rates limited to 0.1 per second to achieve the required  $f_{av,x}$  value.

(3) Account for latency due to the alert calculation and alert annunciation display functionality when measuring the alert time.

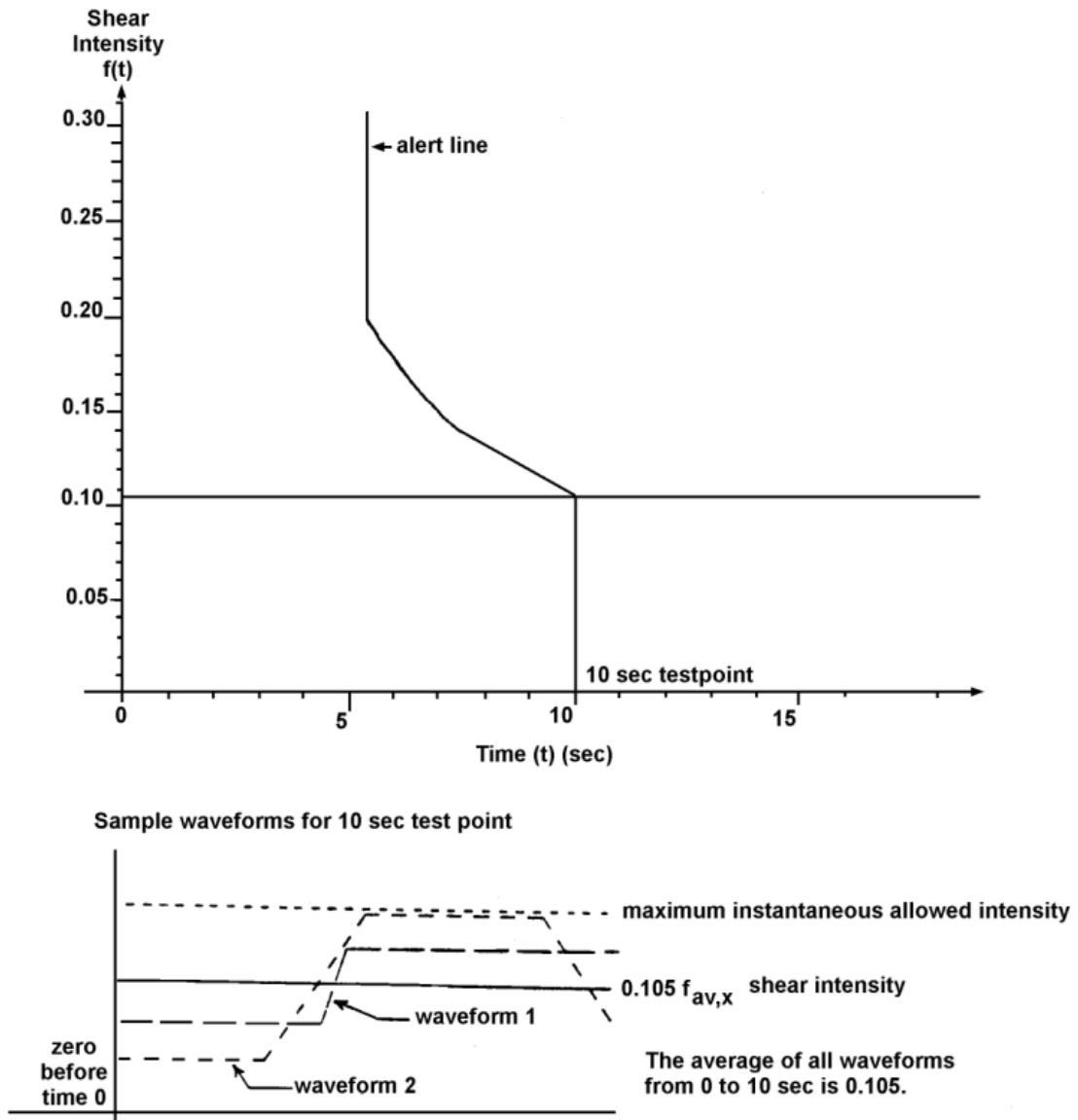
The test conditions specified above must be repeated 5 times for each axis (horizontal and vertical). A total of 90 runs are required for detection verification (9 conditions x 5 for each axis) for both performances increasing and decreasing windshears. A different waveform for  $f_{av,x}$  will be utilized for each of the 5 runs. An appropriate alert (or no alert) must be generated for each test condition.

Verify that the system displays or provides an appropriate output for display of a red warning annunciation labeled “windshear” dedicated for this purpose. Verify that 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 that 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 4. The system must be exposed to these conditions for a minimum of 50 hours (or 600 flight cycles) at each altitude specified in appendix 4 for minimum total test duration of 250 hours (or 3,000 flight cycles based on 1 hour/flight cycle). No more than one nuisance warning must be generated during this test.

(iii) Subject the equipment to windspeeds defined by the discrete gust rejection model contained in appendix 4. No alert must be generated as a result of this test.

FIGURE 2.  
WINDSHEAR ALERT TEST



(9) Operating Altitude Range (paragraph (b)(8)). Configure the equipment for simulation tests as defined in paragraph (d)(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 (b)(9)). Configure the equipment for simulation tests as defined in paragraph (d)(3). Subject the equipment to each of the wind field conditions contained in appendix 2 for each operating mode (takeoff, approach, landing, etc.) available. Each test condition must be repeated 5 times. Recovery actions for the fixed pitch method comparison must be initiated immediately upon entering the shear condition.

**Notes:**

(1) Evaluate windshear escape guidance commands using a simulation that incorporates necessary dynamic modeling of representative aircraft (more than 1 representative aircraft model may be necessary) in which installation is intended. Dynamic modeling of the representative aircraft should include consideration of all relevant effects, including, but not limited to, pitch and roll rates, control authority, delays between control inputs and aircraft responses, display system lead and lag, etc.

(2) The simulator should provide for a pilot in the loop evaluation of guidance flyability during simulated windshear encounters. Guidance command gains should be consistent with those incorporated in the flight guidance system. While “fine tuning” of guidance commands to obtain optimum performance for specific airplane may be accomplished, use of

unique tailoring for specific airplane may not be necessary. Evaluation through means of a suitable engineering simulation may be acceptable to demonstrate suitability of guidance commands for a representative airplane. However, the equipment manufacturer should demonstrate that the flight guidance commands during a dynamic windshear encounter can be followed without resulting in pilot-induced oscillations.

(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 must be performed with vertical only, horizontal only, and combination vertical and horizontal shear conditions. You may reduce the number of times you repeat each of these tests conditions below five. To reduce the number of repetitions below five you must have gathered sufficient data to demonstrate the flight path guidance commands meet these requirements. You should also include aircraft weight and center of gravity variations if applicable.

(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 that 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.

**Note:** There is no requirement to perform the tests described in § 4(d)(10)(ii) through (vii) with horizontal only, vertical only, and combination vertical and horizontal shear conditions. You may perform

the tests described in § 4(d)(10)(ii) through (vii) with only the combination vertical and horizontal shear conditions.

(ii) Verify that the flight guidance command outputs are capable of display on associated flight displays. Interface specifications must 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  $27^{\circ}$ , 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 that flight guidance commands are not removed

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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  $1.3 V_{st}$  for at least 30 seconds.

## Appendix 2

This appendix contains data that defines the wind field models to be used in conducting the tests specified in paragraph 4(d)(10) of appendix 1 of this CTSO. This material was developed by the National Aeronautics and Space Administration (NASA), reference NASA Technical Memorandum 100632 [ref. 1].

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 Terminal Area Simulation System (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.

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## 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 TASS model developed by Proctor [ref. 6-9] 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 from 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 have been difficult to obtain because variability of downburst characteristics makes analytical models unrealistic.

Bray [ref. 2] 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. 3-4]. 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)

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$z$	airplane altitude above ground level (ft)
$zh$	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)
$\lambda$	scaling facto (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

$$\nabla \cdot \mathbf{v} = 0 \quad (1)$$

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

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

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

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. 6-9]. The TASS model is based on data from the Joint Airport Weather Studies (JAWS) [ref. 10], and provides a three-dimensional velocity field, frozen in time, for given locations of an airplane within the shear [ref. 11-12]. Figure 2 of Appendix 3 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. 13-21]. 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 of Appendix 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:

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

Figures 4 and 5 of Appendix 3 show plots of these shaping functions.

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

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

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

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  $\varepsilon$  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  $z$  were 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

$$\frac{z_m}{z^*} = \frac{1}{(z^*/\varepsilon) - 1} \ln(z^*/\varepsilon)$$

Recalling that  $\frac{z_m}{z^*} = 0.22$ , the values 1.1212 and 12.5 were obtained from iteration for the ratios  $r/R$  and  $z^*/\varepsilon$ , 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

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

A ratio of maximum outflow and downflow velocities can be formed

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

The Scaling factor,  $\lambda$ , 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  $\lambda$  resulting in:

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

The velocity equations were easily converted to rectangular coordinates, as shown in this Appendix 3. Partial derivatives with respect

to  $x$ ,  $y$ , and  $z$  were obtained by differentiating the velocity equations, and are also listed in this Appendix 2.

## DISCUSSION AND RESULTS

Vertical and horizontal velocity profiles for  $u$  and  $w$  are shown in figures 6 and 7 of Appendix 3. Four profiles are shown for each component. The horizontal wind profiles in figure 6 of Appendix 3 were taken at the radius 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 of Appendix 3 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 of Appendix 3. 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 microburst 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 3

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

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

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

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

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

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

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

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

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

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

Other Relationships

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

Maximums

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

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

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

( $\lambda$  is determined from the above relationships)

$$\frac{w_{x \max}}{w_{h \max}} = \frac{0.2357R}{\lambda z^* (e^{-(z_h/z^*)} - 0.92)}$$

Variable List

$z^*$  = altitude where  $w_x$  is half the value of  $w_x \max$  (ft)

$\varepsilon$  = characteristic height of boundary layer effects (ft)

$z_h$  = depth of outflow (ft)

$z_m$  = altitude of maximum outflow (ft)

$\lambda$  = 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)

$W_{xmax}, W_{ymax}, W_{hmax}$  maximum winds,  $x, y,$  and  $h$  directions

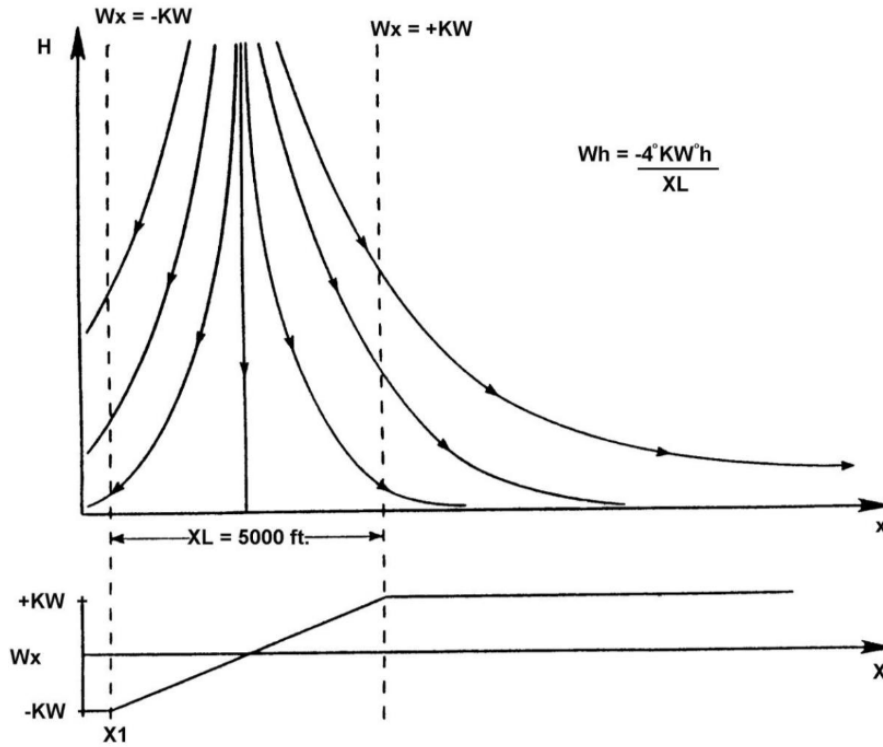


Figure 1. Wind Model Used In Guidance Studies

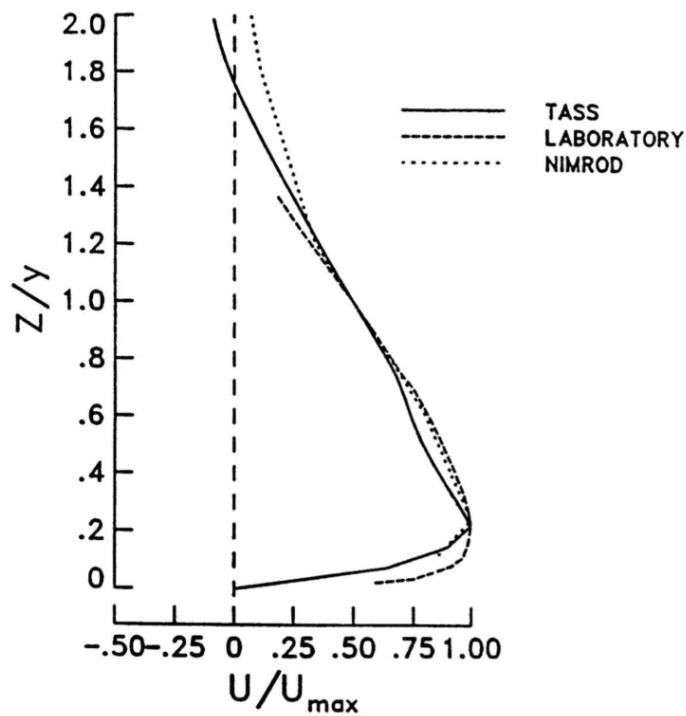


Figure 2. Vertical Profile of Microburst Outflow (Nondimensional)

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

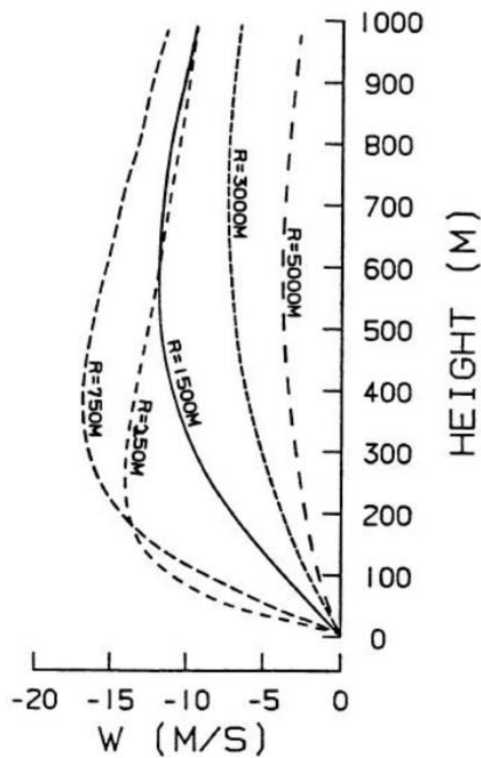


Figure 3. Vertical Profile of Microburst Downflow



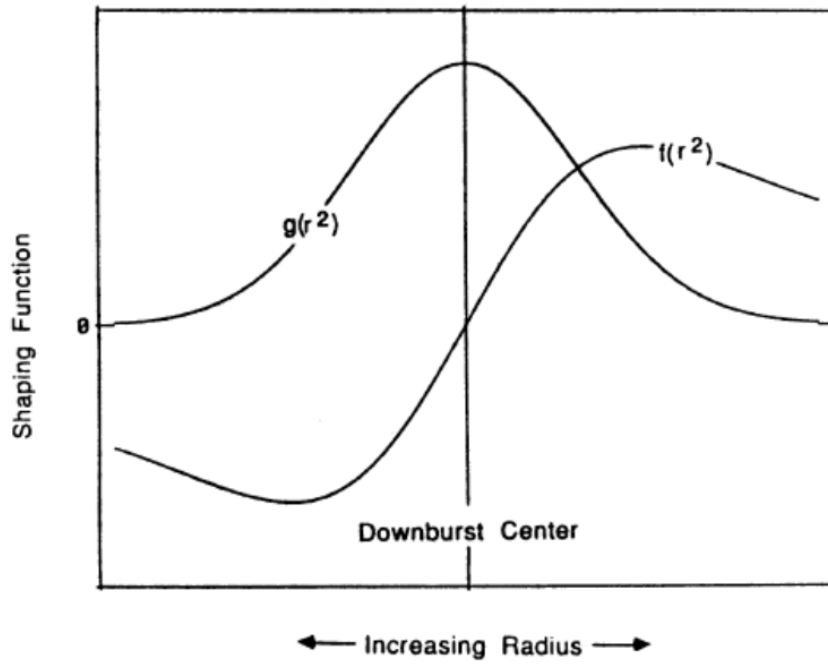


Figure 4. Characteristic Variation of Horizontal Shaping Function

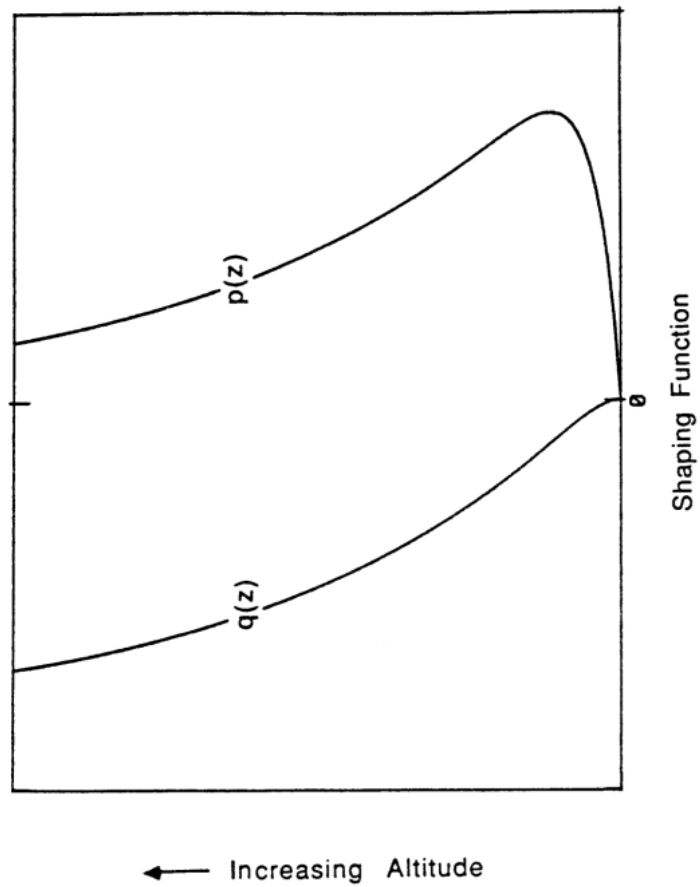


Figure 5. Characteristic Variation of Vertical Shaping Functions

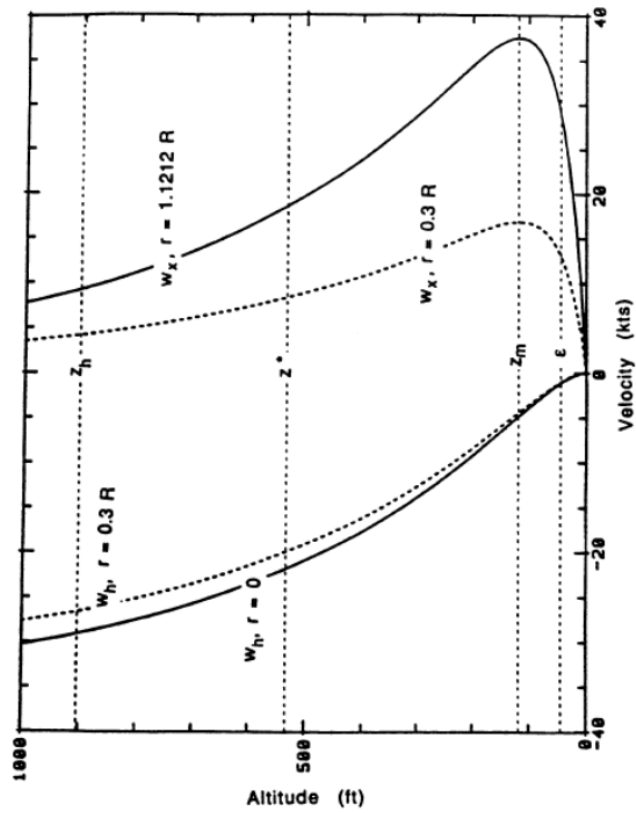


Figure 6. Vertical Velocity Profiles For Analytical Model

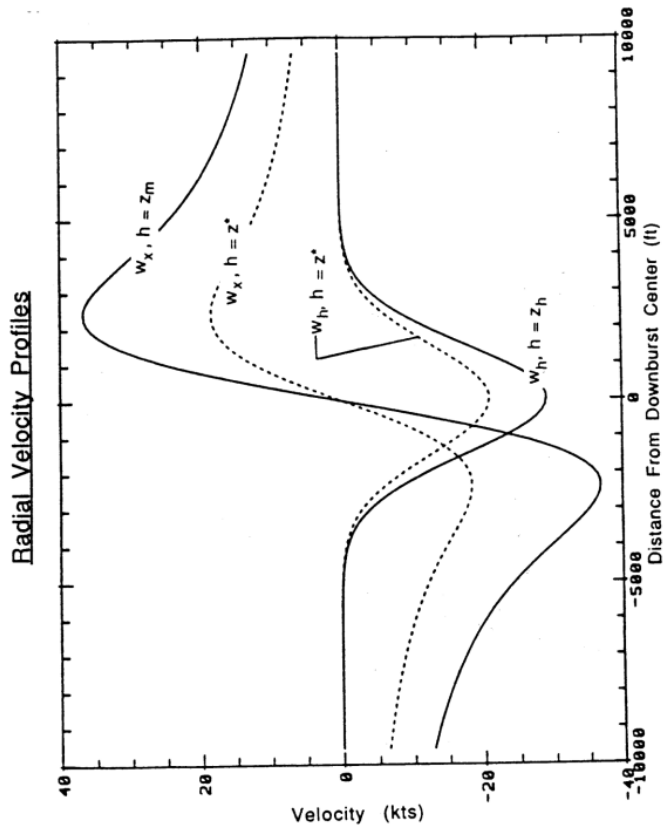


Figure 7. Radial Velocity Profiles For Analytical Model

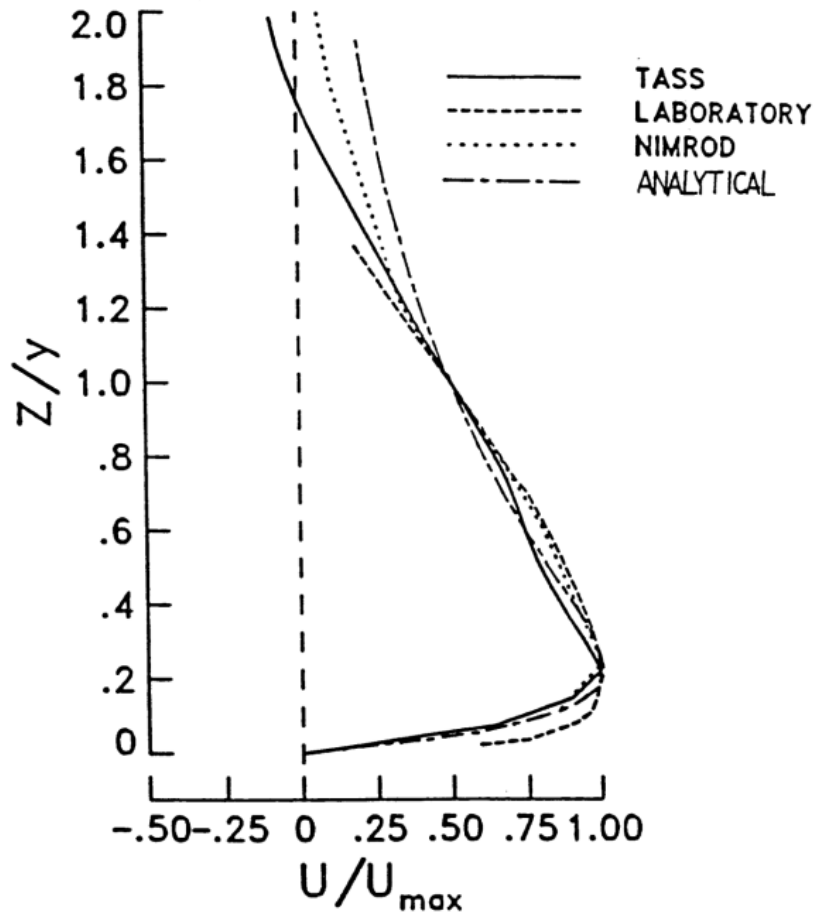


Figure 8. Comparison of Wind Model Vertical Profiles

Appendix 4

This appendix contains data that defines the Dryden turbulence model and discrete gust model to be used in conduction the tests specified in paragraphs (d)(7)(ii), (d)(7)(iii), (d)(8)(ii), and (d)(8)(iii) of appendix 1 of this CTSO.

Dryden Turbulence Model

$$F_u(S) = \text{SIGMA}_u * \text{SQRT}(\text{TAU}_u / \text{PI}) * 1 / (1 + \text{TAU}_u * S)$$

$$F_v(S) = \text{SIGMA}_v * \text{SQRT}(\text{TAU}_v / \text{PI}^2) * \frac{(1 + \text{SQRT}3 * \text{TAU}_v * S)}{(1 + \text{TAU}_v * S) * (1 + \text{TAU}_v * S)}$$

$$F_w(S) = \text{SIGMA}_w * \text{SQRT}(\text{TAU}_w / \text{PI}^3) * \frac{(1 + \text{SQRT}3 * \text{TAU}_w * S)}{(1 + \text{TAU}_w * S) * (1 + \text{TAU}_w * S)}$$

where:

SIGMA<sub>u</sub>, SIGMA<sub>v</sub>, SIGMA<sub>w</sub> are the RMS intensities;

TAU<sub>u</sub> = L<sub>u</sub>/VA;

TAU<sub>v</sub> = L<sub>v</sub>/VA;

TAU<sub>w</sub> = L<sub>w</sub>/VA;

L<sub>u</sub>, L<sub>v</sub>, L<sub>w</sub> are the turbulence scale lengths;

VA is the aircraft' s true airspeed (ft/sec);

PI = 3.1415926535;

PI<sup>2</sup> = 6.2831853070 (2 times PI);

SQRT3 = 1.732050808 (square root of 3); and

S is the Laplace transform variable.

The following table lists SIGMA<sub>u</sub>, SIGMA<sub>v</sub>, SIGMA<sub>w</sub>, L<sub>u</sub>, L<sub>v</sub>, and

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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 (feet)	RMS Intensities (ft/sec)			Scale Lengths (feet)		
	<u>Long</u>	<u>Lat</u>	<u>Vert</u>	<u>Long</u>	<u>Lat</u>	<u>Vert</u>
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  $[A(1 - \cos \text{OMEGA}t)]$  must be used. The following table lists the values of A and OMEGA to be used (simulates an approximate 15 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 5 Shear Intensity

$$f(t) = \frac{w_x}{g} - \frac{w_h}{V}$$

Where

$w_x$ =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<sup>2</sup>).

## Appendix 6

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.

**Note:** The Wind Shear Simulation Model provided at the end of this Appendix 6 is an example written in Microsoft QuickBasic. Other programming languages such as Microsoft FORTRAN, C, or assembly language are also acceptable.

### 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:

$$V_{dt} = g[(T \cdot \text{csalf}) - D]/W - \text{sngam}] - W_{xdt} \cdot \text{csgam} - W_{zdt} \cdot \text{sngam} \quad (1)$$

$$G_{dt} = \{g[(T \cdot \text{snalf} + L)/W - \text{csgam}] + W_{xdt} \cdot \text{sngam} - W_{zdt} \cdot \text{csgam}\} / V \quad (2)$$

$$H_{dt} = V \cdot \text{sngam} + W_z \quad (3)$$

$$X_{dt} = V \cdot \text{csgam} + W_x \quad (4)$$

Where:

$V_{dt}$  = Rate of change of true airspeed in knots/sec

$g$  = Gravitational constant in knots/sec

$T$  = Total engine thrust in lbs.

$\text{csalf}$  =  $\cos(\alpha)$

$\alpha$  = Angle of attack in radians

$D$  = Total drag in lbs.

$W$  = Gross weight in lbs.

$\text{sngam}$  =  $\sin(\gamma)$

$\gamma$  = Flight path angle in radians

$W_{xdt}$  = Inertial windshear x-component in knots/sec

$G_{dt}$  = Rate of change of  $\gamma$  in rad/sec



$$\text{snalf} = \sin(\alpha)$$

$$L = \text{Total lift in lbs.}$$

$$V = \text{True airspeed in knots}$$

$$\text{Hdt} = \text{Altitude rate in knots}$$

$$W_z = \text{Inertial wind z-component in knots}$$

$$\text{Xdt} = \text{Ground speed in knots}$$

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.

#### The Path Control Function

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:

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

where:

`cst` = Function to be minimized w/r/t `alpha`

`dt` = ime increment used in simulation in sec.

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

gamma.

Other expressions follow:

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

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

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, or assembly language.

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

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\*\*\*\*\* 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$, CL, CD, LIFT, DRAG, ALPHA
COMMON SHARED SEC, ALT, DST, HDOT, ALF, GAM, GAMREF, GREFF, G
COMMON SHARED WSALERT%, WXO, WL, WX, WXDT, WZ, WZDT, DFW%
COMMON SHARED WV, LC%, GM, GREFF, NOSAVE, GMO
COMMON SHARED DELTA, ISA, TO, SPDSND, VT, VC, MACH, AO, TAT,
TAMF
COMMON SHARED THRST, EPR, TFCT, APPFLG%
COMMON SHARED SNGM, CSGM, CSAL, SNAL, VDOT, WG, GDOT, XDOT
COMMON SHARED AWX, AWZ, AU, AZ, VG, GRND, KF1, GMIN, KF2
COMMON SHARED ACMD, OLDALF, DT, HP, LP, ALFLIM
COMMON SHARED LAW%, GMR, ASS, CST, VTO, GCMD
COMMON SHARED OUTFILE$, DM, ALT1, PL$, TTT, WXDTO, TDX, TSH,
WZO, TDZ, TSV
COMMON SHARED GM1, VTP, THETA
COMMON SHARED ALFRTE, PLMFLG%
*****
' MAIN PROGRAM *
*****
      START: '< -----<< RE-RUNS START HERE
COLOR 15, 1: CLS : VIEW PRINT
LOCATE 8, 23: PRINT " WINDSHEAR SIMULATION"
LOCATE 10, 23: PRINT " FOR "
LOCATE 12, 23: PRINT " BOEING 737/200 "
LOCATE 23, 25: PRINT "TYPE " + CHR$(&H22) + "I" + CHR$(&H22) + " FOR
INFORMATION"
```

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```
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 ....."; ANSS  
IF ANSS = "2" THEN  
CALL PLOT  
COLOR 15, 1  
CLS  
END IF  
WEND  
IF ANSS = "3" THEN END  
CALL BEGIN 'GET DATA/INITIALIZE VARIABLES
```

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```
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: "; GEARS$
LOCATE 11, 18: PRINT "CONTROL LAW: "; LAW%
LOCATE 12, 18: PRINT "GAMMA REFERENCE: ";
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"
```

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```
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
```

```
2*****
```

```
' 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)
```



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```
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) "; OUTFILES$
IF OUTFILES$ = " " THEN
NOSAVE = 1
ELSE
NOSAVE = 0
END IF
2 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
' ----- CONFIGURATION 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
```

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```
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
GEARS$ = " UP"
ELSE
GEARS$ = " 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
```

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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)....."; ANSS

IF ANSS = "Y" OR ANS\$ = "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

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```
' ----- 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$(75, "-"): VIEW PRINT 5 TO 25
'*****
' SUBROUTINE INIT_OUTPUT FILE *
'*****
IF NOSAVE THEN ' CREATE OUTPUT FILE
ELSE
OPEN "O", 2, OUTFILES
FMT$ = "###.## ##### ##### ##### ## ###.## ###.## ###.##"
FMT$ = FMT$ + " ###.## ###.## ###.## ##.## "
END IF
END SUB
SUB COST STATIC
'*****
2 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
```

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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

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```
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 用于CL计算
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
```

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```
*****
' 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
*2*****
*****
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 + OLGGM + 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
```



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```
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) ^ 2 + (X - A1) ^ 2
NY1 = X + J2 - A1: DENY1 = (Y + J1 - H1) ^ 2 + (X + J2 - A1) ^ 2
NX2 = Y - H2: DENX2 = (Y - H2) ^ 2 + (X - A2) ^ 2
NY2 = X + N2 - A2: DENY2 = (Y + N1 - H2) ^ 2 + (X + N2 - A2) ^ 2
NX3 = Y + H1: DENX3 = (Y + H1) ^ 2 + (X - A1) ^ 2
NY3 = X + J2 - A1: DENY3 = (Y + J1 + H1) ^ 2 + (X + J2 - A1) ^ 2
NX4 = Y + H2: DENX4 = (Y + H2) ^ 2 + (X - A2) ^ 2
NY4 = X + N2 - A2: DENY4 = (Y + N1 + H2) ^ 2 + (X + N2 - A2) ^ 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
```

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```
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 "
```

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```
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
```

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```
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 ^ (INT(LOG(DY) / LOG(10))): DY = DY / MAG
IF DY <= 5 THEN
```

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```
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
2*****
*****
/* 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
```

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```
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)
```

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```
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 * CSGM 'Inertial Acc. along
```



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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 INITIALIZE 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

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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

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```
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 ^ 2
A1 = -2 * B1 / (3 * T1)
B2 = 3 * WXDTO / T4 ^ 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
```

