U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: AIRWORTHINESS CRITERIA FOR THE APPROVAL OF AIRBORNE WINDSHEAR WARNING SYSTEMS IN TRANSPORT CATEGORY AIRPLANES

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1. PURPOSE. This advisory circular (AC) provides guidance for the airworthiness approval of airborne windshear warning systems in transport category airplanes. Like all advisory circular material, this advisory circular is not, in itself, mandatory and does not constitute a regulation. It is issued for guidance purposes and to outline a method of compliance with the rules. In lieu of following this method without deviation, the applicant may elect to follow an alternate method, provided the alternate method is also found by the Federal Aviation Administration (FAA) to be an acceptable means of complying with the requirements of Part 25 of the Federal Aviation Regulations (FAR). Because the method of compliance presented in this AC is not mandatory, the terms "shall" and "must" used in this AC apply only to an applicant who chooses to follow this particular method without deviation.

2. RELATED DOCUMENTS.

a. Related Federal Aviation Regulations (FAR). Portions of Part 25, as presently written, can be applied for the design, substantiation, and certification of airborne windshear warning systems for transport category airplanes. Sections which prescribe requirements for these types of systems include:

§ 25.207 Stall warning.
§ 25.1301 Function and installation.
§ 25.1303 Flight and navigation instruments.
§ 25.1305 Powerplant instruments.
§ 25.1309 Equipment, systems, and installation.
§ 25.1321 Arrangement and visibility.
§ 25.1322 Warning caution and advisory lights.
§ 25.1323 Airspeed indicating system.
§ 25.1335 Flight director systems.
§ 25.1351 Electrical systems and equipment.
§ 25.1353 Electrical equipment and installations.
§ 25.1355 Distribution system.
§ 25.1357 Circuit protective devices.
§ 25.1381 Instrument lights.
§ 25.1431 Electronic equipment.
§ 25.1581 Airplane flight manual.
§ 25.1585 Operating procedures.

b. Advisory Circulars.

AC 00-50A	Low Level Windshear
AC 20-57A	Automatic Landing Systems (ALS)
AC 25.1309-1	System Design Analysis
AC 25.1329-1A	Automatic Pilot Systems Approval
AC 25-11	Transport Category Airplane Electronic Display Systems.
AC 120-28C	Category III Landing Weather Minima
AC 120-29	Category I and II Landing Minima for FAR 121 Operations
AC 120-40	Airplane Simulator and Visual Systems Evaluation
AC 120-41	Criteria for Operational Approval of Airborne Windshear Alerting and Flight Guidance Systems

c. Industry Documents.

(1) RTCA DO-160B, Environmental Conditions and Test Procedures for Airborne Equipment; and RTCA DO-178A, Software Considerations in Airborne Systems and Equipment Certifications. These documents are available from the Radio Technical Commission for Aeronautics (RTCA), One McPherson Square, Suite 500, 1425 K Street NW, Washington, D.C. 20005.

(2) ARP 926A, Fault/Failure Analysis Procedure; and ARP 1834, Fault/Failure Analysis Guidelines for Digital Equipment (in work). These documents are available from the Society of Automotive Engineers, Inc. (SAE), 400 Commonwealth Drive, Warrendale, PA 15096.

d. Government Documents.

(1) Joint Airport Weather Studies (JAWS) Interim Report for Third Year's Effort (FY-84); and Recent Reports from the JAWS Project, JAWS NCAR Report No. 01-85. This document is available from the National Center for Atmospheric Research (NCAR), P.O. Box 3000, Boulder, Colorado 80307-3000.

(2) Wind Models for Flight Simulator Certification of Landing and Approach Guidance and Control Systems, Report No. FAA-RD-74-206. This FAA report is available from the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

(3) Windshear Training Aid Package. This multi-media package, which includes 90 color slides, 2 3/4-inch videocassettes, and 2 training guides, may be ordered from the National Audiovisual Center, Customer Services, 8700 Edgeworth Drive, Capitol Heights, Maryland 20743-3701.

(4) Terminal Area Simulation System. Volume I: Theoretical Formulation, NASA CR-4046 (DOT/FAA/PM-86/50,I); and Volume II: Verification Cases, NASA CR-4047 (DOT/FAA/PM-86/50,II). These documents are available from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

3. DEFINITIONS. The following definitions are applicable to this advisory circular.

a. Windshear Escape Maneuver. A pilot recovery technique used when an inadvertent windshear encounter is experienced. It is achieved by pitching toward an initial target attitude while using necessary thrust. The objective of the recovery technique is to keep the airplane flying as long as possible in hope of exiting the windshear. The maneuver is an operational technique to be used to escape from the encounter that was developed to be effective, simple, easily recalled, and to have general applicability.

b. Airborne Windshear Warning System. A device or system which identifies the presence of windshear once the phenomena is encountered. 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.

c. Airborne Windshear Warning and Escape Guidance System. A device or system which identifies the presence of a severe windshear phenomena and provides the pilot with timely warning and adequate flight guidance for the following:

(1) Approach/Missed Approach. To permit the aircraft to be flown using the maximum performance capability available without inadvertent loss of control, stall, and without ground contact.

(2) Takeoff and Climbout. To permit the aircraft to be flown during the initial or subsequent climb segments using the maximum performance capability available without inadvertent loss of control or ground contact with excess energy still available.

d. Airborne Windshear Detection and Avoidance System. A device or system which detects a potentially severe windshear phenomena far enough in advance of the encounter in both the takeoff/climbout profile and the approach/landing profile to allow the pilot to successfully avoid the phenomena and thereby alleviate a flight hazard.

e. Severe Windshear. A windshear of such intensity and duration which would exceed the performance capability of a particular aircraft type, and 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 paragraph 6d.

f. Proof-of-Concept Testing. Proof-of-concept testing is defined as a generic demonstration in a full operational environment of facilities, weather, crew complement, aircraft systems, environmental systems, and any other relevant parameters necessary to show concept validity in terms of performance, system reliability, repeatability, and typical pilot response to failure, as well as to demonstrate that an equivalent level of safety is provided. Proof-of-concept may be established by a combination of analysis, simulation, and/or flight demonstrations in an operational environment.

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

h. False Warning. A case where the windshear warning threshold is exceeded outside of the design limits as a result of a failure within the system.

4. SCOPE. The material provided in this advisory circular addresses system design aspects, functions, characteristics, and the criticality of system failure cases for both "warning only" and "warning with escape guidance" airborne windshear systems. Although not limited to a specific technology, the guidance criteria is directed toward systems which inherently depend upon the airplane to enter a windfield and experience some degree of performance degradation in order to detect and annunciate a windshear condition.

5. BACKGROUND.

a. Over the past 10 years, there have been three major air carrier accidents directly attributed to the windshear phenomena. In addition, five other air carrier incidents or accidents have been recorded during the same period where operation through low level windshear was identified as the cause. Prior to that, there were numerous other incidents and accidents where exposure to the phenomena during low level operation was suspected of being a causal factor. In 1971, the FAA initiated activity on the windshear subject by forming a task force and later a program office to coordinate various areas of activity. The major areas of investigation centered around ground based detection and alerting systems, airborne detection and warning systems, and the improvement of windshear forecasting and information reporting techniques. Improved forecasting and the reporting of information address the primary goal of avoidance, while individually or in combination, ground based and airborne systems can provide an increased level of safety during inadvertent terminal area operation in areas of low level windshear.

b. Technological advancement in all three areas has been an evolutionary process. In the forecasting area, the National Weather Service (NWS) was able to improve forecasts of windshears associated with frontal movement but was less successful with windshears due to gust fronts and downburst activity. Long-term NWS programs are being proposed to address the problem. Meanwhile, a great deal of valuable information has come out of the Joint Airport Weather Studies (JAWS) program on characterizing the formation, life, movement, and severity of microburst and downburst activity. The National Center for Atmospheric Research (NCAR) is continuing to evaluate the results. In 1984, the FAA, in conjunction with the NCAR, initiated an operational evaluation of microburst forecast detection and warning techniques known as Classify, Locate, and Avoid Windshear (CLAWS). This program produced, for the first time, operationally usable information by providing pilots with forecasts of microburst activity as well as information on actual microburst occurrences. Both programs used microwave Doppler radar as the means to measure and to collect windshear data in real time. Also, the evaluation of the effectiveness of Doppler radar in detecting and evaluating severe storms was made by the National Severe Storm Laboratory (NSSL). The program provided the information needed to define the Next Generation Weather Radar (NEXRAD) program. This program is being restructured to provide a national enroute network. Also, the FAA plans to install 17 terminal versions of NEXRAD where the radar parameters and operating modes are tailored to the detection of severe weather and windshear as they affect terminal area air traffic control (ATC) operations.

c. In the area of ground based systems, a number of sensors were tested and evaluated and wind measuring sensors, operating in conjunction with a computer, provided the most consistent detection of windshear conditions existing at the surface. The Low Level Windshear Alert System (LLWAS) was developed and installed at 90 airports and 20 more are being added. The system alerts the tower controller whenever the wind at any sensor, located at the perimeter of the airport, shows a vector difference of 15 knots or more with a centerfield sensor, and a windshear alert is transmitted to affected pilots by the tower controller. The JAWS program provided improved spacing criteria for the LLWAS wind sensors, and the FAA is enhancing the current system by augmenting the current ring of sensors with additional sensors to detect a smaller diameter windshear. In addition, the processing capability is being expanded. The LLWAS is limited to the detection of windshear conditions in the immediate airport area at or near ground level. Detection of windshear in the approach or departure areas must await the implementation of a remote sensing capability such as terminal Doppler weather radar.

d. In the airborne system area, the FAA and the National Aeronautics and Space Administration (NASA), supported by the Stanford Research Institute, investigated a number of airborne sensors and techniques for detecting windshear; and the results were subsequently published and made available to industry. Most techniques centered around airspeed/ground speed comparison or the computation of airplane acceleration margin. In 1981, industry presented the first operational windshear warning system to the FAA for certification. As the evolutionary period of airborne system-development and certification matured, the FAA formed an Airborne Windshear Warning System Airworthiness Committee in 1983 to develop certification guidance criteria for "annunciation-only" type systems. This activity was later expanded to include systems with full escape guidance provisions. Since then, numerous versions of windshear "annunciation only" systems and windshear "annunciation with guidance" systems have been certified on transport category airplanes. Up to this time, all airborne systems have depended, to some degree, upon the sensor derived comparison between air mass and inertial airplane acceleration, the difference being attributed to windshear. The application of this technology inherently requires the entry of the airplane into some level of windshear with a resulting loss or gain of potential climb gradient. Nevertheless, these systems provide a valuable service in the detection, timely annunciation, and confirmation of a potentially hazardous windshear condition generally in advance of human pilot recognition time. For systems that provide command guidance features, the available energy of the airplane is efficiently managed to enhance flight path control during the escape maneuver. Ideally, the development of a sensor located on a moving platform, capable of detecting the movement of clear air ahead of the airplane against the background of the earth's surface, would have all the advantages of a look-ahead system. The FAA has identified a requirement to define the systems requirements for these devices and requested NASA to take the technical leadership in this area as extensive research and testing are required.

e. The FAA contracted with a consortium of aviation specialists from The Boeing Company, United Airlines, McDonnell Douglas, Lockheed-California, Aviation Weather Associates, and Helliwell, Inc. to produce the Windshear Training Aid. The Training Aid presents an effective means of training flightcrews to minimize the windshear threat through avoidance and cockpit recognition and recovery techniques. The Windshear Training Program has two important parts: (1) TRAINING FOR RECOGNITION AND AVOIDANCE of weather phenomena that cause windshear, and (2) TRAINING IN COCKPIT RECOGNITION OF WINDSHEAR AND RECOVERY TECHNIQUES for the inadvertent encounter.

6. AIRWORTHINESS CONSIDERATIONS.

a. Certification Program. This advisory circular provides guidance for the airworthiness approval of both "annunciation only" and "annunciation with guidance" airborne windshear warning systems as many of the system design aspects, functions, and characteristics are common. In either case, the scope of the applicant's program should be directed toward airworthiness approval through the Type Certificate (TC) or Supplemental Type Certificate (STC) process. In the case of systems with flight guidance which will ultimately be used on aircraft in air carrier service, the applicant is encouraged to undertake a certification program which will satisfy both the criteria contained herein, as well as that contained in AC 120-41, Criteria for Operational Approval of Airborne Windshear Alerting and Flight Guidance Systems. Many of the criteria outlined below in paragraph 6(d)(2) can also be satisfied in finding compliance with § 25.1301 of the FAR, if the certification program satisfies both operational and airworthiness criteria. A statement will be placed in the approved Airplane Flight Manual indicating compliance with AC 120-41, thereby providing for a more streamlined operational approval process for an air carrier under Parts 121 or 135 of the FAR.

b. Certification Plan. A comprehensive certification plan should be developed by the applicant. It should include how the applicant plans to comply with the applicable regulations and should provide a listing of the substantiating data and necessary tests. Also, a comprehensive system description and an estimated time schedule should be included. A well developed plan will be of significant value both to the applicant and the FAA.

c. System Criticality. Certain types of failure cases must be addressed in consideration of the potential hazard they may induce during the course of normal system operation. Advisory Circular 25.1309-1, System Design Analysis, provides criteria to correlate the depth of analysis required with the type of function the system performs (nonessential, essential, or critical). Also, failure conditions which result from improper accomplishment or loss of function are addressed. The criticality of certain system failure cases for windshear warning and systems with escape guidance are outlined in paragraphs (1) and (2) below. In the case of systems which provide escape guidance, there may be a number of complex system integrations with existing airplane systems and sensors; and the treatment of all the combinations possible is beyond the scope of this AC. In this case, AC 25.1309-1 states that the flight test pilot should: (1) determine the detectability of a failure condition, (2) determine the required subsequent pilot actions, and (3) make a judgment if satisfactory intervention can be expected of a properly trained crew. In addition, failure of the windshear warning system should not degrade the integrity of other essential or critical systems installed in the airplane. This includes common shared sensors.

(1) Windshear Warning. The system should be designed so that false warnings have a probability of occurrence on the order of 10^{-4} or less. This includes the failure of the system to annunciate a windshear warning as a result of a latent failure.

(2) Systems with Escape Guidance. In addition to the criteria of paragraph (1) above, the following system failure cases should be improbable in

accordance with AC 25.1309-1. (Consideration for out-of-production airplanes with early versions of unmonitored flight director computers and mechanical flight instruments is warranted, and those systems may have a probability of failure on the order of 10^{-3} or less.)

(i) Unannunciated failure of the system to provide the escape guidance function when commanded. Removal of flight director command bars constitutes adequate annunciation.

(ii) The display of escape guidance other than that evaluated and approved in accordance with § 25.1301 of the FAR (see paragraph d, Intended Function, below).

NOTE: The loss of windshear warning annunciation should not preclude or inhibit the presentation of the escape guidance information, as long as the guidance mode change annunciation remains valid and the annunciation is provided in a clear and unambiguous manner.

(3) Software Based Systems. The software should be developed to a minimum of level 2. An acceptable means for obtaining approval for the development of the software based system is to follow the design methodology contained in RTCA Document DO-178A, Software Considerations in Airborne Systems and Equipment Certification.

(4) Probability Analysis. The applicant should provide a quantitative probability analysis to support an engineering evaluation of the system failure cases listed above. For this purpose, an exposure time of 0.1 hour has been found acceptable by the FAA in the past. This criteria assumes that internal system tests verify proper system status immediately prior to the system being enabled. The probability of the airplane encountering a severe windshear should be 1 (one) and the computed probabilities of occurrence should be expressed in failures per flight hour.

d. Intended Function. The major emphasis for showing compliance with § 25.1301 is centered around the aspects of establishing a windshear warning threshold that considers remaining airplane performance. For systems that include escape guidance provisions, a subjective evaluation of airplane performance is made to determine that the algorithms manage the available energy in such a manner as to enhance flight path control beyond that which would be normally expected without the use of the system. In addition, applicable system integration aspects are evaluated in order to determine that there are no adverse functional effects with the existing airplane systems and sensors that are integrated to the windshear warning system.

(1) Airborne Warning System. The applicant must demonstrate by analysis and simulation that the system warning threshold is appropriate for a given airplane/engine combination. Once this aspect has been demonstrated and approved by the FAA for a given windshear warning system, it need not be repeated for other airplane models if the applicant can show that the technology employed for this purpose is suitable. If applicable, system integration and the use of external airplane sensors on the same or new model types must be taken into account.

(i) Caution Threshold. Although not specifically required, the applicant should provide the system with the capability of detecting a rapidly increasing headwind or updraft and to display this condition with a caution annunciation. These conditions are routinely precursors of severe adverse windshear conditions.

(ii) Warning Threshold. The windshear alert threshold should be established considering the airplane's available performance and the propensity for nuisance alerts due to turbulence. The pilot has two sources of available airplane energy to help escape a windshear environment. The pilot may increase engine thrust and/or increase the nose up pitch attitude to prevent loss of altitude. Engine thrust energy is limited by thrust available, and nose-up pitch is limited by the reduction of airspeed to stall speed. Studies and analyses show that although pilots will readily apply maximum rated thrust to the engines, they may hesitate to reduce airspeed in order to prevent the loss of altitude. For this reason, if the alert value is dependent on airplane available energy alone, then only the energy from thrust should be considered. In establishing the threshold based upon available thrust, consideration should be given to establishing a limiting value, regardless of the thrust-to-weight ratio available; in severe windshear conditions, airplane controllability, stabilization, and pilot workload become increasingly more important.

NOTE: Experience has shown that warning threshold values in excess of 15% loss of climb gradient fall into this category. In addition, the success of a properly executed go-around maneuver from a windshear of fixed intensity requires that the altitude available exceed the altitude required for the maneuver. Consequently, at progressively lower altitudes, a windshear warning based upon a fixed threshold may not allow the flightcrew sufficient altitude to successfully execute a go-around maneuver. Accordingly, consideration should be given to the implementation of a variable warning threshold that is altitude programmable by the automatic system, which has increasing sensitivity to lowering altitudes.

(iii) Nuisance Warning. The applicant should show by analysis or other suitable means that the system threshold is above a point at which nuisance warnings would be objectionable under conditions of severe turbulence. If electronic techniques are used to reduce or remove turbulence, it must be shown that system response to windshear detection is acceptable.

(2) Windshear Warning and Escape Guidance System. The flight guidance algorithms should be evaluated with a simulator capable of representing the dynamic response of the airplane/engine combination with pilot-in-the-loop fixed or moving base simulation. An instrumentation and recording system should be provided to record the parameters necessary to evaluate the system. A suitable cross section of pilots may be used for this purpose. Advisory Circular 120-40, Airplane Simulator and Visual System Evaluation, provides performance standards for dynamic simulators.

(i) Caution and Warning Threshold. The criteria specified above in paragraphs d(1)(i) and (ii) for airborne warning systems is also appropriate for systems providing escape guidance.

(ii) Nuisance Warning. The criteria specified above in paragraph d(1)(iii) for airborne warning systems is also appropriate for systems providing escape guidance.

(iii) Design Considerations. The flight guidance algorithms must incorporate the following design considerations.

(A) At the point of system threshold, the available energy of the airplane must be properly managed through a representative number of windfield conditions. This must take into account significant shear components in both the horizontal axis and the vertical axis, individually and in combination.

(B) It must be shown that the flight path guidance commands are suited to the dynamic response of the airplane/engine combination from initiation to completion of the escape maneuver.

(C) It must be shown that if the magnitude of the shear components are such as to overcome the performance capability of the airplane, impact will occur in the absence of excessive kinetic energy. Guidance which commands flight path and pitch attitude and associated angle-of-attack margin of 2 degrees to stall warning has been found acceptable for this purpose.

(D) It must be shown analytically or by other means acceptable to the FAA that the performance characteristics and dynamic response of the airplane/engine combination are correctly represented.

(iv) System Integration. The installation should address the compatibility of other normally operating systems and sensors during periods of windshear system activation. Hazardous interactions are not acceptable.

(3) Simulation Program. The general airplane simulation test criteria outlined in paragraphs 8 thru 11 of AC 120-41 may also be used to demonstrate compliance with § 25.1301 for the flight guidance part of the system. Also, the demonstration should include system exposure to a representative number of the windfield models discussed below in paragraph e. For those applicants who plan to seek subsequent operational approval by following this method, the airplane simulator evaluation team should be comprised of a combination of flight operations and aircraft certification pilots. Currently, a number of Part 25 airplane model types do not have a dynamic simulator available for this purpose. In other cases, an applicant may not choose to follow the guidelines of AC 120-41 for subsequent operational approval and may elect to propose an alternate means to evaluate the escape guidance algorithms in order to demonstrate compliance with § 25.1301. Some of these alternate means may include individually, or in combination, the use of a generic simulator, computer modeling, or other analytical techniques found acceptable to the FAA.

(i) Approval by Similarity. The simulation program should be evaluated and approved on a fixed or moving base simulator of the same airplane model type for which approval is sought. If a previously approved system is proposed for escape guidance system evaluation on a simulator of a like or different airplane model type, certification credit may be extended if the applicant can account for the differences in airplane performance, dynamic response, and flightcrew procedures.

(ii) Autopilot/Autothrottle Operation. If system integration features are proposed that include autopilot/autothrottle functions that are activated at the windshear warning threshold, a proof-of-concept demonstration should be incorporated into the simulation program for the first of an airplane model type. Subsequent evaluation of the escape guidance algorithms should be made with the system operating in the proposed mode. If the proposed functions are flightcrew selectable, the simulation program should be evaluated with and without the systems in operation.

e. Windfield Models.

(1) The windfield models used for the purpose of finding compliance with § 25.1301, as described in paragraph 6d above, may be in addition to or in place of those models listed in Appendix I of AC 120-41. The windfield models utilized should contain the current understanding of the basic characteristics of the microburst phenomena. Examples of the basic characteristics are given in the 1984 JAWS Report No. 01-85. It is recognized that it is unlikely that any single guidance algorithm can be optimized for all the variables of a microburst encounter as there are theoretically an infinite number of penetration planes. Also, it is unlikely that any single windfield model will contain all the variations and combinations of vertical and horizontal shear components that may occur in nature. As a result, the evaluation of satisfactory guidance performance should be made over a suitable number of windfield models selected with the goal of providing the known characteristics of the windshear phenomena. This may be a combination of "analytically derived" windfield models or "real world" data sets available from field experiments such as the JAWS data. In either case, the windshear models should be selected to stress the performance characteristics of the airplane and systems being evaluated.

(2) Turbulence components should be added to both analytically derived models and, if applicable, the data sets from field experiments. One suitable means is to use the turbulence models in Report No. FAA-RD-74-206, Wind Models for Flight Simulator Certification of Landing and Approach Guidance and Control Systems. Although turbulence components are inherently part of the windshear components measured in the JAWS data, they are not readily identifiable as such because of the large difference in frequency between the two components. As a result, the airplane dynamic response in the simulation program is effectively masked from turbulence components known from service experience to exist in windshear.

f. Windshear Warning. Unless otherwise indicated, the following criteria apply to both "warning only" and "warning with escape guidance" systems.

(1) Guidance and Annunciation Enable. The system should be enabled from a minimum of 1,000 ft. above ground level (AGL) down to at least 50 ft. AGL for the approach to landing case, and from at least 50 ft. AGL to 1,000 ft. AGL for the takeoff case. Protection from the beginning of takeoff roll to 50 ft. AGL should be initiated as soon as technically feasible.

(2) Visual Annunciation. At system caution threshold, an amber annunciation should be displayed within each pilot's primary field of view. At system warning threshold, a red annunciation labeled "windshear" should be

displayed within each pilot's primary field of view. The characteristics of the warning display should denote immediate flightcrew action. The warning display should remain on at least until the alert drops below the warning threshold level.

(3) Aural Annunciation. At system warning threshold, "windshear" should be annunciated for a minimum of 3 aural cycles, unless the warning alert drops below the threshold level sooner. The prioritization of windshear warning over existing aural communications should be evaluated on a case-by-case basis as their interaction may vary from one airplane model to another.

(4) System Fail Annunciation. A system fail light or equivalent should be provided to annunciate all probable system failures.

g. Equipment Installation.

(1) Mechanization. The windshear warning system should be installed and integrated to the existing airplane systems in such a manner that upon system threshold, the warning and/or escape guidance functions will be activated regardless of any combination of airplane system configuration, flight director/command instrument switch positions and flight guidance, or other automatic system modes selected.

(2) Failure Modes and Effects Analysis (FMEA). An installation FMEA should be provided, the scope of which is dependent upon the extent of integration of the windshear warning system with existing airplane systems and sensors.

h. Test Requirements.

(1) Environmental Tests. The major components comprising the windshear warning system should be qualified to the appropriate sections of RTCA Document DO-160B, Environmental Conditions and Test Procedures for Airborne Equipment, or equivalent.

(2) Ground Tests. The applicant should provide a ground test plan that includes the tests necessary to verify that the windshear warning system provisions installed in the airplane perform their intended function and that there are no adverse effects to existing airplane systems and sensors.

(3) Flight Tests. The applicant should provide a flight test plan that includes tests to verify, to the extent possible, that the windshear warning system performs its intended function and that there are no adverse effects to existing airplane systems and sensors. This would include each airplane type and sensor combination, unless that combination has been previously demonstrated. These tests should include the following:

(i) Abrupt air maneuvers, including airplane entry into the onset of stall buffet, in order to detect windshear false warnings.

(ii) The airplane should be flown to stall warning or the limit defined by any flight envelope system using takeoff power in order to demonstrate that the fullest performance that may be required from the recommended escape maneuver can be readily accomplished by pilots of average skill, unless the applicant provides data to show that the condition was previously demonstrated.

(iii) Flight test evaluations should be made to determine that prior approvals of existing airplane systems have not been compromised. This aspect could require extensive re-evaluation if integration of the windshear warning system required changes to existing airplane systems or sensors having prior approval for automatic functions such as flight director takeoff, Category II or Category III landing modes.

i. Airplane Flight Manual Supplement (AFMS).

(1) Flight Procedures. From studies conducted by the FAA on the NASA Motion Base 727-200 Simulator during June 1985, it became apparent that the pilots were often unaware for relatively long periods of the occurrence of even severe windshear during takeoff. This was more evident with just the downburst model with no horizontal windshear. It was assumed that this lack of awareness to rapidly deteriorating climb performance was due to the pilot instrument scan which, after retracting the landing gear, concentrates on airspeed and pitch angle. This is in contrast to the approach in which flight path angle is known and in which changes are more quickly apparent. The "Windshear Training Aid" provides sufficient information. Considering that most commercial transports have comparable aerodynamic performance on approach, the only significant difference between airplanes is their available thrust-to-weight ratios. Given that a finite amount of time is required to reconfigure the airplane during a windshear encounter, retracting flaps and landing gear is not recommended unless a significant performance benefit can be realized. Application of maximum rated thrust and pitch management are the only remaining sources for conserving or minimizing the loss of potential energy. Increasing thrust during a severe windshear encounter is a normal pilot procedure. Reducing airspeed below reference minimum is contrary to normal piloting technique. Pilot training can establish that airspeed reduction is proper in this situation.

(i) Takeoff Flight Regime. During takeoff, the only options available to the pilot to cope with windshear, once it is encountered, are setting thrust and trading kinetic energy, as necessary, to maintain a positive climb gradient. The optimum strategy, for the most part, is to delay reducing airspeed until at least level flight is no longer possible at the existing pitch attitude and airspeed with maximum rated thrust applied. This procedure saves the available kinetic energy as long as possible in the event the windshear becomes more severe. The rate of airspeed reduction should not be greater than that needed to prevent a loss of altitude. This procedure also delays the loss of kinetic energy as long as possible in the hopes that the shear conditions can be exited, and reduces the exposure time to airspeeds at or near the airplane stall warning. Also, this delays flying the airplane at an increasingly adverse lift-to-drag ratio as long as possible.

(ii) Approach Flight Regime. During the approach, the options available to the pilot for coping with the windshear are the same as takeoff; that is, setting thrust and trading kinetic energy to minimize any negative gradient. For some airplanes, a configuration change during the encounter may improve climb gradient but may also reduce the available speed margin to stall warning. The strategy for dealing with severe windshear is the same as takeoff; that is, conserving or maintaining potential energy. The FAA has analyzed a number of severe windshear encounters and conducted studies to determine the criticality of flight variables like airspeed, altitude, thrust-to-weight ratio, etc. This effort has resulted in the identification of a number of items that should be considered when establishing alert threshold, flight procedures, and training requirements.

(2) Warning Only System. The procedure added to the AFMS should contain the following basic elements:

(i) Aggressively apply maximum rated thrust, disengaging autothrottle if necessary.

(ii) Rotate smoothly at a normal rate to the go-around/takeoff pitch attitude and allow the airspeed to decrease, if necessary.

(iii) If the airplane is descending, increase pitch attitude smoothly and in small increments, bleeding airspeed as necessary to stop the descent.

(iv) Use stall warning onset as the upper limit of pitch attitude.

(v) Engine overboost should be avoided unless the airplane continues to descend and airplane safety is in doubt. When airplane safety has been assured, adjust thrust to maintain engine parameters within approved limits.

NOTE: Overboosting engines while at angles of attack near airplane stall warning may cause engine stall, surge, or flameout.

(vi) Do not retract flaps or landing gear until safe climb-out is assured.

(3) Warning with Escape Guidance System. In addition to providing the information and procedures peculiar to the new system, a statement should be made in the AFMS that in all cases of windshear warning, the escape guidance should be followed until the maneuver has been safely completed.

LEROY A. KEITH
Manager, Aircraft Certification Division