U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: PILOT WINDSHEAR GUIDE
Date: 11/25/88
Initiated by: AFS-200
AC No: 00-54
Change:

1. PURPOSE. This advisory circular communicates key windshear information relevant to flightcrews. Appendix 1 of this advisory circular is the Pilot Windshear Guide, which is only one section of the two-volume Windshear Training Aid.

2. RELATED READING MATERIAL. The other components of the Windshear Training Aid are the Windshear Overview for Management, Windshear Substantiating Data, Example Windshear Training Program, and two training videos. These additional publications may be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, telephone (703) 487-4650. A multimedia package, including video tapes, slides, and the Windshear Training Aid, may be purchased from the National Audiovisual Center, 8700 Edgeworth Drive, Capitol Heights, MD 20743-3701, telephone (301) 763-1896.

3. BACKGROUND. In 1985, the Federal Aviation Administration (FAA) contracted with a consortium of aviation specialists from the Boeing Company, United Air Lines, McDonnell Douglas, Lockheed California, Aviation Weather Associates, and Heliwell, Inc., to study windshear. As a result, the Windshear Training Aid was developed. The Windshear Training Aid presents an effective means of training flightcrews to minimize the windshear threat through avoidance, cockpit recognition, and recovery techniques. In order to make the Pilot Windshear Guide section of the Windshear Training Aid available to a wide aviation audience, the guide is reprinted as appendix 1 to this advisory circular.

4. UPDATING PROCEDURE. In order to ensure that the Pilot Windshear Guide is kept up-to-date, the FAA will host meetings for the purpose of reviewing new information on the subject of windshear. These meetings will be held approximately every 18 months and will be announced in the Federal Register. Technical assistance will be solicited from representatives of the original contract team, as well as from other qualified industry sources, in proposing and evaluating changes. As improvements and changes to the Pilot Windshear Guide occur, they will be distributed as a change to this advisory circular.

D C Beaudette

D. C. Beaudette
Acting Director, Flight Standards Service

APPENDIX 1. PILOT WINDSHEAR GUIDE

Pilot Windshear Guide-- Disclaimer and Indemity Notice

The following disclaimer is required by virtue of the contract between the Federal Aviation Administration and the Boeing Commercial Airplane Company.

DISCLAIMER AND INDEMNITY NOTICE

This document, Pilot Windshear Guide, and its companion documents, Windshear Overview For Management, Example Windshear Training Program, Windshear Substantiating Data, and video presentations "A Windshear Avoided" and "Windshear What the Crew Can Do" were prepared pursuant to Federal Aviation Administration Prime Contract DFTA01-86-C-00005 with The Boeing Company as a training aid for flight in windshear conditions. The information contained herein and in the companion materials was derived from information originally developed for the Boeing 727, and provides a base-line training program with additional recommendations, developed and approved by Boeing, Douglas or Lockheed for their respective aircraft, regarding how that program might be adapted for use in specific commercial transport aircraft manufactured by Boeing [727, 737, 747, 757, and 767], Douglas [DC-9, MD-80, and DC-10] and Lockheed [L-1011]. ANY USE OF THIS PILOT WINDSHEAR GUIDE AND ITS COMPANION VIDEO PRESENTATIONS "A WINDSHEAR AVOIDED" AND "WINDSHEAR - WHAT THE CREW CAN DO" FOR ANY PURPOSE RELATED TO AIRCRAFT OR CONDITIONS OTHER THAN THOSE SPECIFIED ABOVE IS NOT AUTHORIZED AND MAY RESULT IN IMPROPER AIRCRAFT OPERATION, LOSS OF AIRCRAFT CONTROL, INJURY AND LOSS OF AIRCRAFT AND LIFE. ANY USE, ADAPTATION AND/OR USE AFTER ADAPTATION OF THE MATERIAL IN THIS PILOT WINDSHEAR GUIDE AND ITS COMPANION VIDEO PRESENTATIONS "A WINDSHEAR AVOIDED" AND "WINDSHEAR - WHAT THE CREW CAN DO" BY ANY ENTITY FOR ANY PURPOSE RELATED TO AIRCRAFT, CONDITIONS OR TO TRAINING PROGRAMS OTHER THAN THOSE SPECIFIED ABOVE SHALL BE COMPLETELY AT THE RISK OF THE ENTITY RESPONSIBLE FOR USING, ADAPTING AND/OR USING THE ADAPTATION OF THIS PILOT WINDSHEAR GUIDE AND ITS COMPANION VIDEO PRESENTATIONS "A WINDSHEAR AVOIDED" AND "WINDSHEAR - WHAT THE CREW CAN DO", AND SUCH ENTITY BY SUCH USE, ADAPTATION AND/OR USE AFTER ADAPTATION ASSUMES SUCH RISK AND WAIVES AND RELEASES ALL CLAIMS IT MAY HAVE AGAINST THE BOEING COMPANY, McDONNELL DOUGLAS CORPORATION, LOCKHEED CORPORATION, UNITED AIRLINES, AVIATION WEATHER ASSOCIATES, HELLIWELL, INC., THEIR DIVISIONS, SUBSIDIARIES, AFFILIATES AND THEIR OFFICERS, DIRECTORS, SUBCONTRACTORS AND EMPLOYEES FROM ANY LIABILITY WHATSOEVER, WHETHER BASED ON CONTRACT (INCLUDING BUT NOT LIMITED TO EXPRESS AND IMPLIED WARRANTY CLAIMS), TORT (INCLUDING BUT NOT LIMITED TO NEGLIGENCE AND STRICT LIABILITY CLAIMS) OR OTHERWISE, ARISING FROM SUCH USE, ADAPTATION AND/OR USE OF SUCH ADAPTATION. ANY SUCH ENTITY (INCLUDING WITHOUT LIMITATION ANY MANUFACTURER OF OTHER AIRCRAFT OR OPERATOR WITH ANOTHER TRAINING PROGRAM BUT NOT THE UNITED STATES GOVERNMENT) WHICH USES THIS PILOT WINDSHEAR GUIDE AND ITS COMPANION VIDEO PRESENTATIONS "A WINDSHEAR AVOIDED" AND "WINDSHEAR - WHAT THE CREW CAN DO" OR ADAPTS AND/OR USES AN ADAPTATION THEREOF WITH RESPECT TO SUCH OTHER AIRCRAFT, CONDITIONS OR TRAINING PROGRAM THEREBY AGREES TO INDEMNIFY AND HOLD HARMLESS THE BOEING COMPANY, McDONNELL DOUGLAS CORPORATION, LOCKHEED CORPORATION, UNITED AIRLINES, AVIATION WEATHER ASSOCIATES, HELLIWELL, INC., THEIR DIVISIONS, SUBSIDIARIES AND AFFILIATES AND THEIR OFFICERS, DIRECTORS, AGENTS, SUBCONTRACTORS AND EMPLOYEES FROM ANY LIABILITY WHATSOEVER, WHETHER BASED ON CONTRACT, (INCLUDING BUT NOT LIMITED TO EXPRESS AND IMPLIED WARRANTY CLAIMS), TORT (INCLUDING BUT NOT LIMITED TO NEGLIGENCE AND STRICT LIABILITY CLAIMS) OR OTHERWISE, ARISING FROM SUCH USE, ADAPTATION AND/OR USE OF SUCH ADAPTATION.

Notwithstanding any other provision of this contract to the contrary, the FAA shall accept the items delivered hereunder with the disclaimer affixed by Contractor and agrees not to remove such disclaimer for any reason whatsoever.

PILOT WINDSHEAR GUIDE

TABLE OF CONTENTS

2.0 INTRODUCTION

During the period from 1964 to 1986, at least 32 accidents and incidents have occurred in which windshear was identified as a contributing factor. These accidents and incidents resulted in over 600 fatalities and nearly 250 injuries. There is evidence to suggest that if undocumented "close calls" and general aviation statistics were included, these figures would be much higher.

Due to the serious nature of this problem, the National Research Council was commissioned to study the windshear issue. One finding of the Council was a general lack of effective pilot training programs for windshear. The Council made recommendations regarding further efforts needed to improve the training of pilots to recognize, avoid, and cope with inadvertent windshear encounters. As a result of these recommendations, the Federal Aviation Administration sponsored development of a comprehensive Windshear Training Aid.

The Pilot Windshear Guide is one of several parts of the Windshear Training Aid. The other components are the Windshear Overview for Management, Windshear Substantiating Data, Example Windshear Training Program, and two Training Videos.

The educational material and training recommendations provided in the Windshear Training Aid were developed through an extensive review process to achieve a wide air transport industry consensus. The goal of the Training Aid is to reduce windshear related accidents and incidents by modifying flight crew behavior through education and training.

2.1 OBJECTIVES

The objective of the Pilot Windshear Guide is to summarize and communicate key windshear information relevant to flight crews. It is intended to be provided to pilots during windshear ground training and to be retained as a windshear information reference for future use.

Avoidance is emphasized as the best defense against the hazards of low altitude windshear. Information to assist in recognizing and avoiding windshear is provided. However, precautions and techniques for improving chances of surviving an inadvertent windshear encounter are also discussed. Specifically, the Pilot Windshear Guide presents key findings regarding:

1) Windshear weather, particularly microbursts, and clues which may indicate its presence,

2) Effects of windshear on airplanes,

3) Windshear recognition from the cockpit, and avoidance,

4) Precautions to take when windshear is suspected,

5) Standard operating techniques related to windshear, and

6) Recovery techniques to be used in an inadvertent windshear encounter.

2.2 WINDSHEAR WEATHER

Wind variations at low-altitude have long been recognized as a serious hazard to airplanes during takeoff and approach. These wind variations can result from a large variety of meteorological conditions such as: topographical conditions, temperature inversions, sea breezes, frontal systems, strong surface winds, and the most violent forms of wind change--the thunderstorm and rain shower.

Throughout this document several terms are used when discussing low altitude wind variations. These terms are defined as follows:

Windshear - Any rapid change in wind direction or velocity.

Severe Windshear - A rapid change in wind direction or velocity causing airspeed changes greater than 15 knots or vertical speed changes greater than 500 feet per minute.

Increasing Headwind Shear - Windshear in which headwind increases causing an airspeed increase.

Decreasing Headwind Shear - Windshear in which headwind decreases causing an airspeed loss.

Decreasing Tailwind Shear - Windshear in which tailwind decreases causing an airspeed increase.

Increasing Tailwind Shear - Windshear in which tailwind increases causing an airspeed loss.

Examination of airplane accident and incident reports from 1959 - 1983 identified 51 windshear-related events. These events are summarized in Figure 1.

In order to avoid further windshear encounters, pilots must learn to recognize conditions producing windshear. As Figure 1 indicates, 2 out of every 3 windshear events were related to convective storms. For this reason, the primary focus of the Pilot Windshear Guide is directed toward windshear associated with convective weather conditions: thunderstorms, and in particular the most hazardous form of windshear, the microburst.

Weather System	Number of Windshear Events*
Convective Storms (Thunderstorms, Rain/ Snow Showers)	33
Front	7
Strong Surface Winds	2
Unstable (Turbulent) Air	2
Strong Winds on Top of Temperature Inversion	1
Sea Breeze Front	0
Mountain Wave	0
Unknown	6
Total	51

*Event - accident or incident

Figure 1. Windshear events by weather system (1959 to 1983).

o The Thunderstorm

There are two basic types of thunderstorms: airmass and frontal. Airmass thunderstorms appear to be randomly distributed in unstable air and develop from localized heating at the earth's surface (Figure 2). The heated air rises and cools to form cumulus clouds. As the cumulus stage continues to develop, precipitation forms in higher portions of the cloud and falls. Precipitation signals the beginning of the mature stage and presence of a downdraft. After approximately an hour, the heated updraft creating the thunderstorm is cut off by rainfall. Heat is removed and the thunderstorm dissipates. Many thunderstorms produce an associated cold air gust front as a result of the downflow and outrush of rain-cooled air. These gust fronts are usually very turbulent and can create a serious threat to airplanes during takeoff and approach.

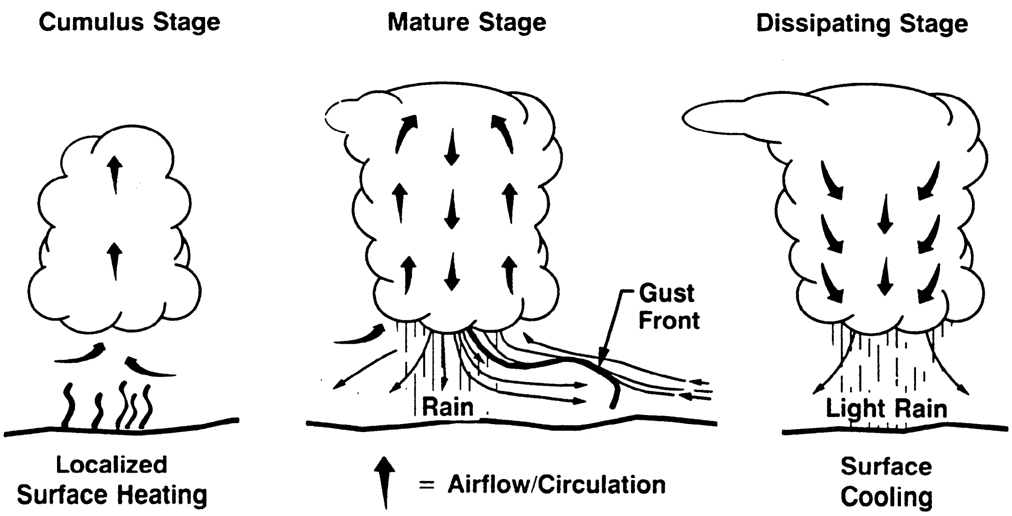

Figure 2. Airmass thunderstorm life cycle.

Frontal thunderstorms are usually associated with weather systems like fronts, converging winds, and troughs aloft. Frontal thunderstorms form in squall lines, last several hours, generate heavy rain and possibly hail, and produce strong gusty winds and possibly tornadoes. The principal distinction in formation of these more severe thunderstorms is the presence of large horizontal wind changes (speed and direction) at different altitudes in the thunderstorm. This causes the severe thunderstorm to be vertically tilted (Figure 3). Precipitation falls away from the heated updraft permitting a much longer storm development period. Resulting airflows within the storm accelerate to much higher vertical velocities which ultimately result in higher horizontal wind velocities at the surface.

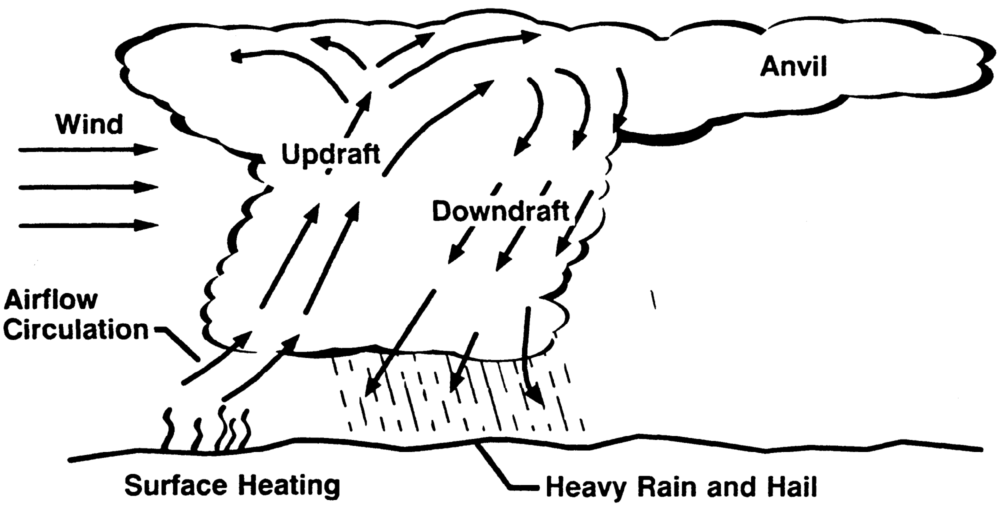

Figure 3. Severe frontal thunderstorm anatomy.

The downward moving column of air, or downdraft, of a typical thunderstorm is fairly large, about 1 to 5 miles in diameter. Resultant outflows may produce large changes in wind speed.

Though wind changes near the surface occur across an area sufficiently large to lessen the effect, thunderstorms always present a potential hazard to airplanes. Regardless of whether a thunderstorm contains windshear however, the possibility of heavy rain, hail, extreme turbulence, and tornadoes make it critical that pilots avoid thunderstorms. Figure 4 shows average annual worldwide thunderstorm days.

Certain areas can readily be seen to have a high potential for windshear because of the high level of convective activity. Due to the lower frequency of air traffic in the highest threat areas (the tropics), fewer accidents have been reported in these regions.

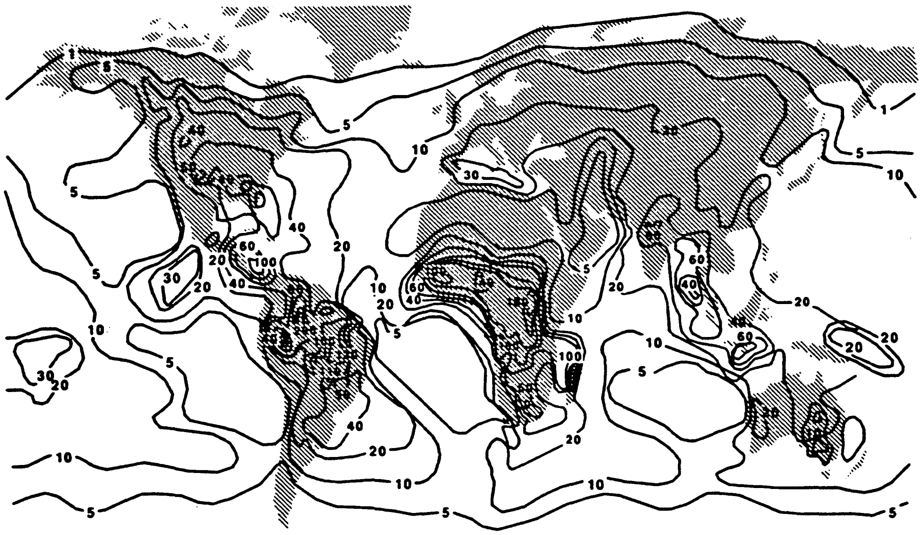

Figure 4. Average annual worldwide thunderstorm days. Note that the highest windshear threat occurs in the tropics.

Examination of the worldwide windshear-associated accidents and incidents in Figure 5 shows that the majority of these have occurred in the United States. The greater number of accidents results from the combination of high convective activity and high air traffic density. Many more windshear-associated accidents and incidents have probably occurred worldwide but have not been recorded as such.

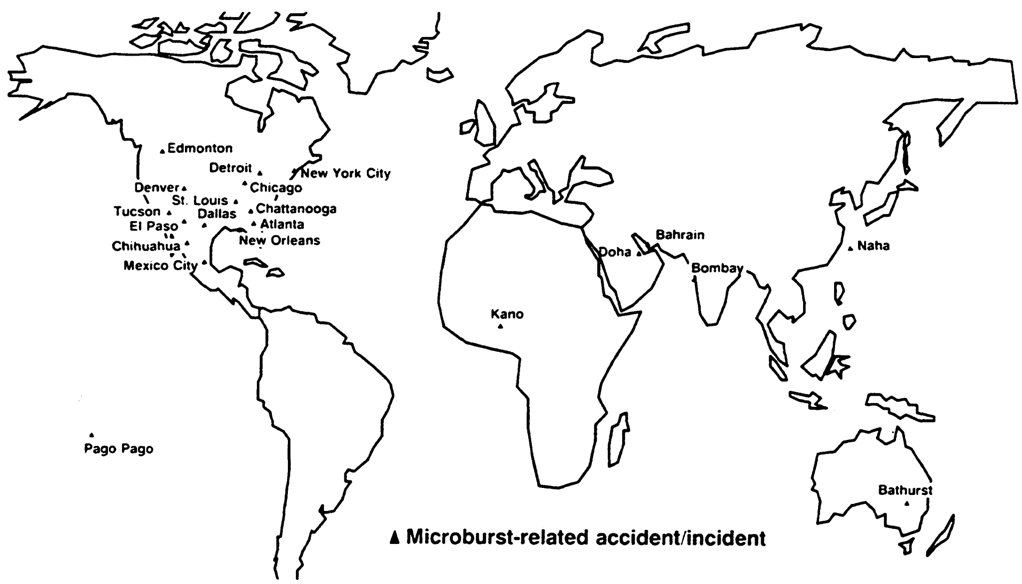

Figure 5. Worldwide microburst-related airplane accidents/incidents. High frequency of air traffic in North America combined with a high number of thunderstorm days leads to concentration of windshear-related accidents/incidents in United States.

In fact, closer examination of the United States (Figure 6) shows a correlation between areas of high thunderstorm activity and a number of accidents.

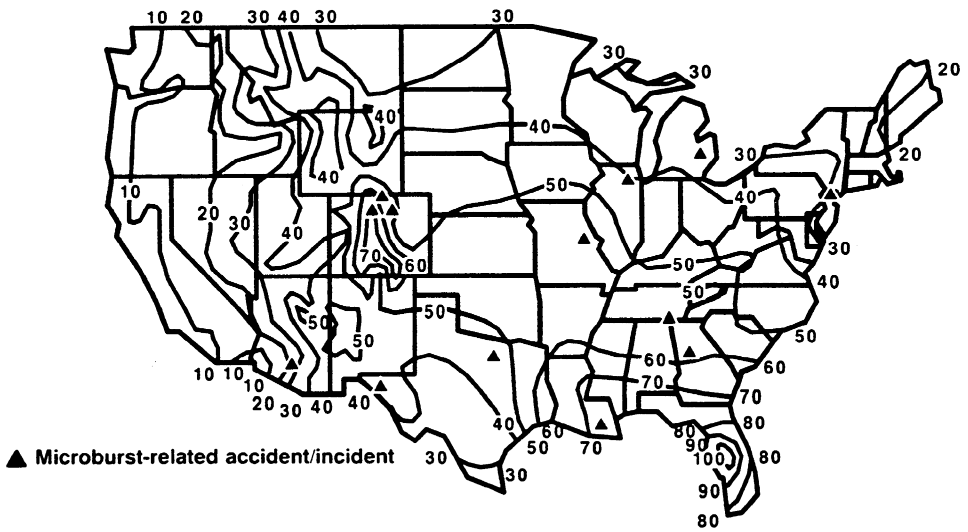

Figure 6. Average annual continental U.S. thunderstorm days. Correlation exists between regions of higher thunderstorm activity and windshear-related accidents incidents.

o The Microburst as a Windshear Threat

Identification of concentrated, more powerful downdrafts--known as microbursts--has resulted from the investigation of windshear accidents and from meteorological research. Microbursts can occur anywhere convective weather conditions (thunderstorms, rain showers, virga) occur. Observations suggest that approximately five percent of all thunderstorms produce a microburst.

Downdrafts associated with microbursts are typically only a few hundred to 3,000 feet across. When the downdraft reaches the ground, it spreads out horizontally and may form one or more horizontal vortex rings around the downdraft (Figure 7). The outflow region is typically 6,000 to 12,000 feet across. The horizontal vortices may extend to over 2,000 feet AGL.

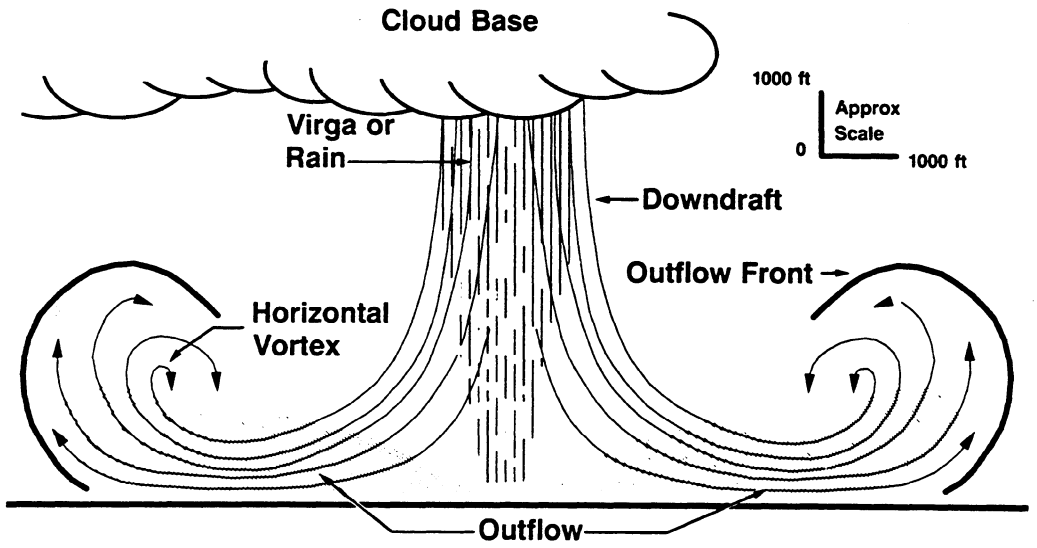

Figure 7. Symmetric microburst. An airplane transiting the microburst would experience equal headwinds and tailwinds.

Microburst outflows are not always symmetric (Figure 8). Therefore, a significant airspeed increase may not occur upon entering the outflow, or may be much less than the subsequent airspeed loss experienced when exiting the microburst.

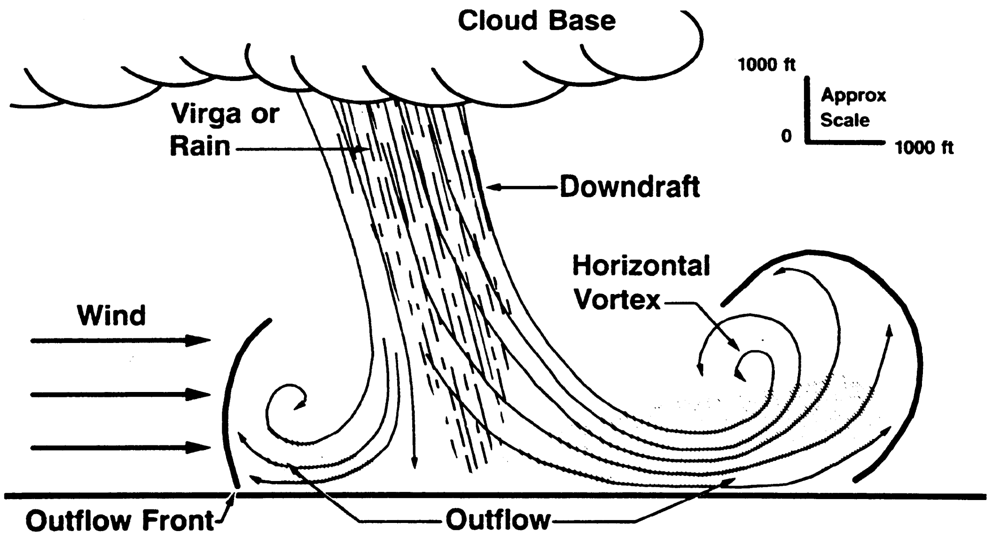

Figure 8. Asymmetric microburst. An airplane transiting the microburst from left to right would experience a small headwind followed by a large tailwind.

More than one microburst can occur in the same weather system. Pilots are therefore cautioned to be alert for additional microbursts if one has already been encountered or observed. If several microbursts are present, a series of horizontal vortices can form near the ground due to several microbursts being embedded in one another (Figure 9). Conditions associated with these vortices may produce very powerful updrafts and roll forces in addition to downdrafts.

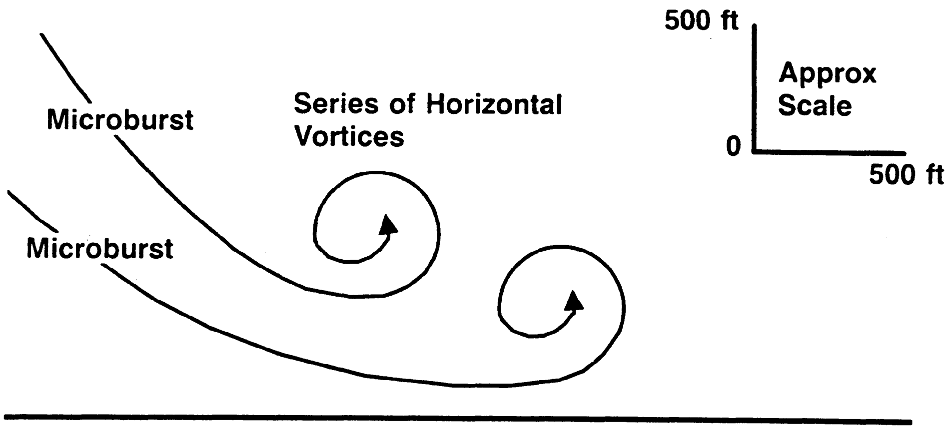

Figure 9. Horizontal Vortices. A series of horizontal vortices can form near the ground due to microbursts imbedded in one another.

Wind speeds intensify for about 5 minutes after a microburst initially contacts the ground (Figure 10). An encounter during the initial stage of microburst development may not be considered significant, but an airplane following may experience an airspeed change two to three times greater! Microbursts typically dissipate within 10 to 20 minutes after ground contact.

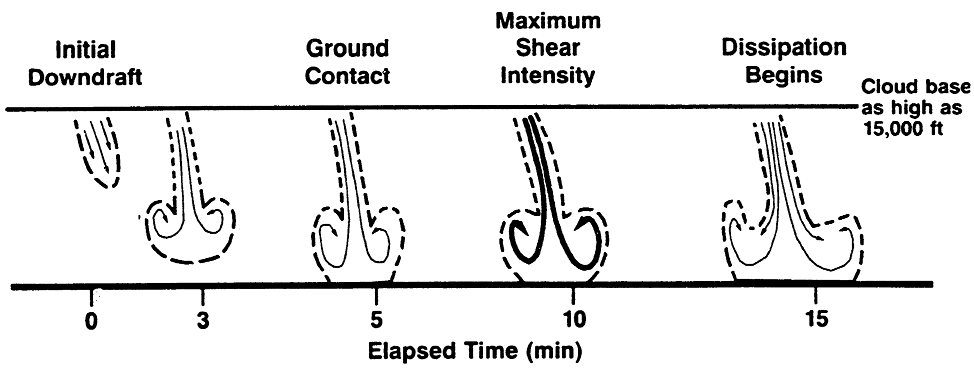

Figure 10. Evolution of a microburst. Microburst winds intensify for about 5 min after ground contact and typically dissipate about 10 to 20 min after ground contact.

Doppler radar wind measurements indicate that the wind speed change a pilot might expect when flying through the average microburst at its point of peak intensity is about 45 knots (Figure 11). However, microburst windspeed differences of almost 100 knots have been measured. In fact, a severe event at Andrews Air Force Base (Camp Spring, Maryland) on August 1, 1983 indicated headwind/tailwind differential velocities near 200 knots.

IT IS VITAL TO RECOGNIZE THAT SOME MICROBURSTS CANNOT BE SUCCESSFULLY ESCAPED WITH ANY KNOWN TECHNIQUES! Note that even windshears which were within the performance capability of the airplane have caused accidents.

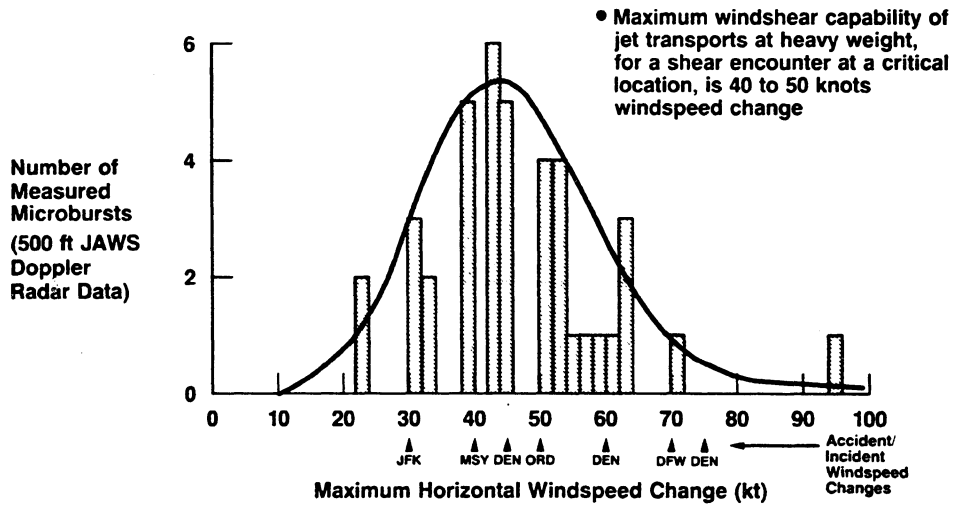

Figure 11. Microburst frequency versus intensity. Accidents have occurred in windshears within performance capability of airplane. Some windshears cannot be escaped successfully!

Microbursts can be associated with both heavy rain, as in thunderstorm conditions, and much lighter precipitation associated with convective clouds. Microbursts have occurred in relatively dry conditions of light rain or virga (precipitation that evaporates before reaching the earth's surface). The formation of a dry microburst is illustrated in Figure 12.

In this example, air below a cloud base (up to approximately 15,000 feet AGL) is very dry. Precipitation from higher convective clouds falls into low humidity air and evaporates. This evaporative cooling causes the air to plunge downward. As the evaporative cooling process continues, the downdraft accelerates. Pilots are therefore cautioned not to fly beneath convective clouds producing virga conditions.

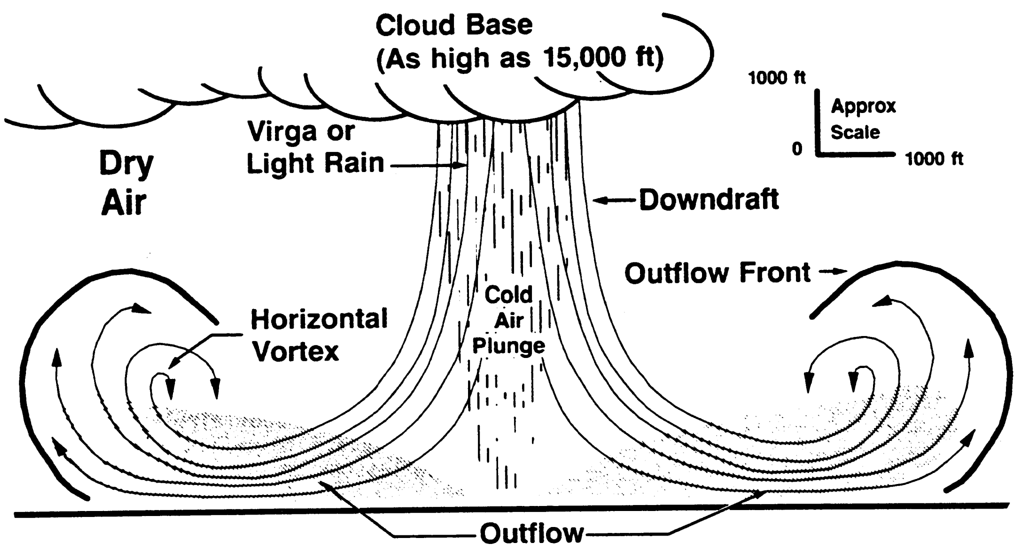

Figure 12. Dry microburst formation. Evaporation of rain below cloud base (virga) causes intense cooling of rainshaft air and subsequent cold air plunge.

2.3 LESSONS LEARNED FROM WINDSHEAR ENCOUNTERS

Analysis of past windshear accidents and incidents has taught valuable lessons regarding windshear recognition and flight path control. Engineering studies and flight simulator evaluations have been conducted as well to gather additional information. The resulting lessons learned form a basis for the recommended precautions and techniques in this document.

The primary lesson learned is that the best defense against windshear is to avoid it altogether. This is especially important because shears will exist which are beyond the capability of any pilot or airplane. In most windshear accidents, several clues--LLWAS alerts, weather reports, visual signs--were present that would have alerted the flight crew to the presence of a windshear threat. In all instances, however, these clues were either not recognized or not acted upon. Flight crews must seek and heed signs alerting them to the need for avoidance.

Other lessons were also learned regarding windshear recognition and pilot technique should the avoidance process fail. These lessons are summarized as follows:

Windshear Recognition

- o Recognition of windshear encounter is difficult and is usually complicated by marginal weather
- o Time available for recognition and recovery is short (as little as 5 seconds)
- o Flight crew coordination is essential for prompt windshear recognition and recovery

Pilot Technique

- o Flight path must be controlled with pitch attitude (unusual stick forces may be required as a result)
- o Lower than normal airspeed may have to be accepted to counter lift loss

In reaching these conclusions, three types of windshear encounters which have resulted in an accident or incident were examined: an encounter during takeoff after liftoff, an encounter during takeoff on the runway, and an encounter during approach. Details of these encounters and the lessons learned are described in Sections 2.3.1 through 2.3.3. Following this, Section 2.3.4 presents the lessons learned regarding effects of windshear on airplanes and airplane systems. Section 2.3.5 describes the impact of these lessons on simulator training.

2.3.1 ENCOUNTER DURING TAKEOFF - AFTER LIFTOFF

In a typical accident studied, the airplane encountered an increasing tailwind shear shortly after lifting off the runway (Figure 13). For the first 5 seconds after liftoff the takeoff appeared normal, but the airplane crashed off the end of the runway about 20 seconds after liftoff.

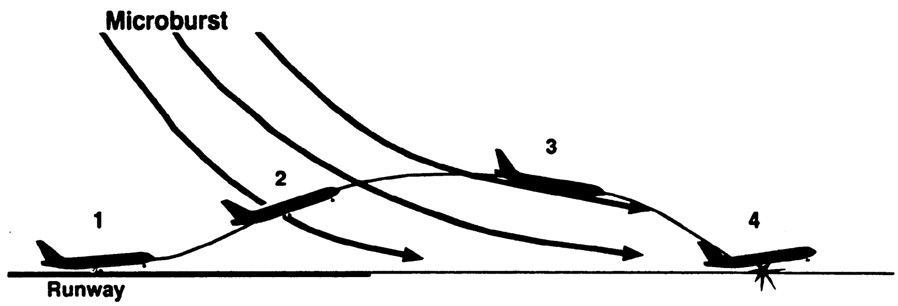

Figure 13. Windshear encounter during takeoff after liftoff. (1) Takeoff initially appeared normal. (2) Windshear encountered just after liftoff. (3) Airspeed decrease resulted in pitch attitude reduction. (4) Aircraft crashed off departure end of runway 20 sec after liftoff.

In many events involving after-liftoff windshear encounters, early trends in airspeed, pitch attitude, vertical speed and altitude appeared normal. In this example, the airplane encountered windshear before stabilized climb was established which caused difficulty in detecting onset of shear. As the airspeed decreased, pitch attitude was reduced to regain trim airspeed (Figure 14). By reducing pitch attitude, available performance capability was not utilized and the airplane lost altitude. As terrain became a factor, recovery to initial pitch attitude was initiated. This required unusually high stick force (up to 30 pounds of pull may be required on some airplanes). Corrective action, however, was too late to prevent ground contact since the downward flight path was well established.

Reducing pitch attitude to regain lost airspeed, or allowing attitude to decrease in response to lost airspeed, is the result of past training emphasis on airspeed control. Successful recovery from an inadvertent windshear encounter requires maintaining or increasing pitch attitude and accepting lower than usual airspeed. Unusual and unexpected stick forces may be required to counter natural airplane pitching tendencies due to airspeed and lift loss.

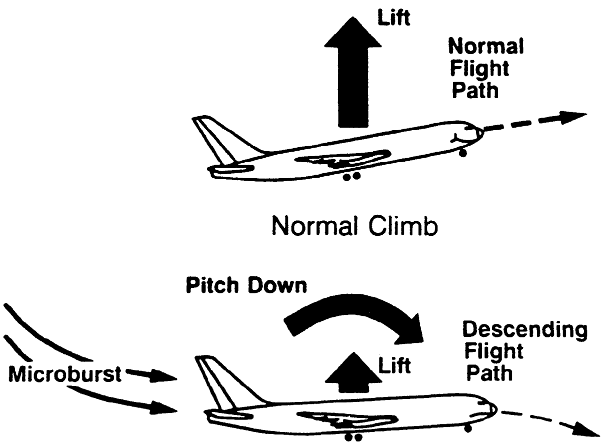

Figure 14. Windshear effects on flight path. Microburst reduces airspeed and lift at normal attitude which results in pitch down tendency to regain airspeed.

To counter the loss of airspeed and lift resulting from windshear, pitch attitude must not be allowed to fall below the normal range. Only by properly controlling pitch attitude and accepting reduced airspeed can flight path degradation be prevented (Figure 15). Once the airplane begins to deviate from the intended flight path and high descent rates develop, it takes additional time and altitude to change flight path direction.

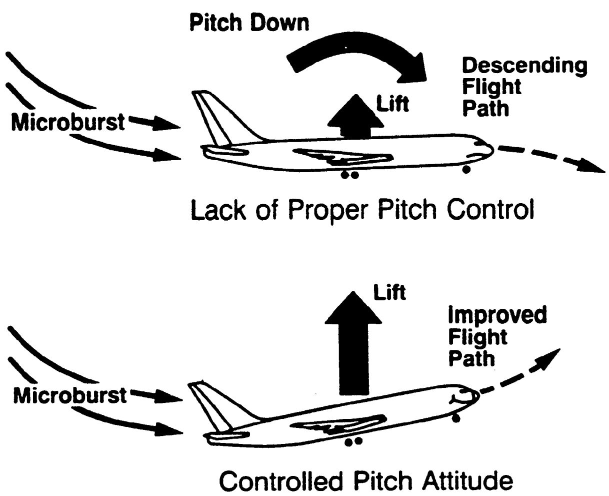

Figure 15. Pitch control effects on flight path. Control of pitch attitude and acceptance of reduced airspeed results in improved flight path.

In the windshear encounter cited earlier, available airplane performance capability may not have been used because of two factors: lack of timely recognition and inappropriate or inadequate response. Rapidly deteriorating climb performance may not be apparent to the crew unless all appropriate vertical flight path instruments are closely monitored.

Only 5 to 15 seconds may be available to recognize and respond to a windshear encounter (Figure 16). It is therefore of great importance that a windshear encounter be recognized as soon as possible. Timely recognition of windshear requires effective crew coordination and appropriate callouts by the pilot not flying.

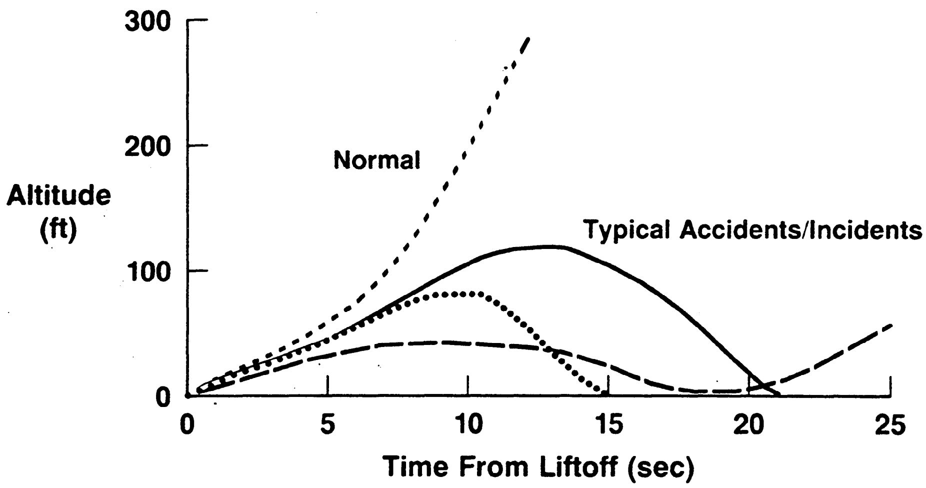

Figure 16. Time available to respond to windshear encounter. Takeoff initially appeared normal. Additional time is required to arrest descent. Result: only 5 to 15 sec may be available for recognition and recovery.

2.3.2 ENCOUNTER DURING TAKEOFF - ON RUNWAY

Analysis of a typical accident where an increasing tailwind shear was encountered during takeoff ground roll showed that initial indications appeared normal (Figure 17). Due to the increasing tailwind shear however, the airplane did not reach V_R until nearing the end of the runway. As the airplane lifted off, the tailwind continued increasing, preventing any further airspeed increase. The airplane contacted an obstacle off the departure end of the runway.

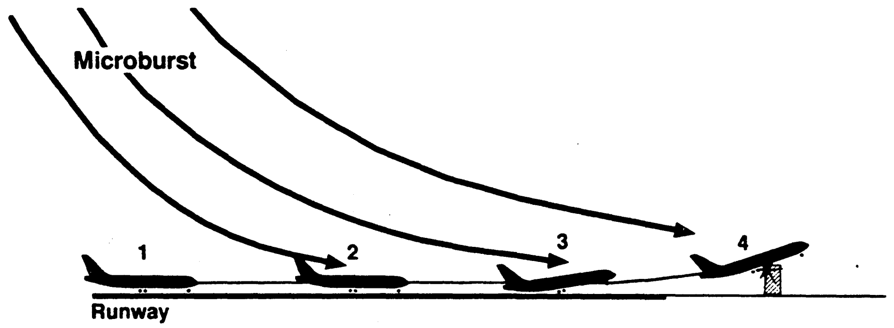

Figure 17. Windshear encounter during takeoff on runway. (1) Takeoff initially appeared normal. (2) Airspeed buildup slowed due to windshear. (3) Airplane reached V_R near end of runway, lifted off but failed to climb. (4) Airplane contacted obstacle off departure end of runway.

Less-than-normal airspeed, due to windshear encounter, resulted in reduced available lift at normal takeoff attitude (Figure 18). In turn, inability to lift off soon enough to clear obstacles resulted.

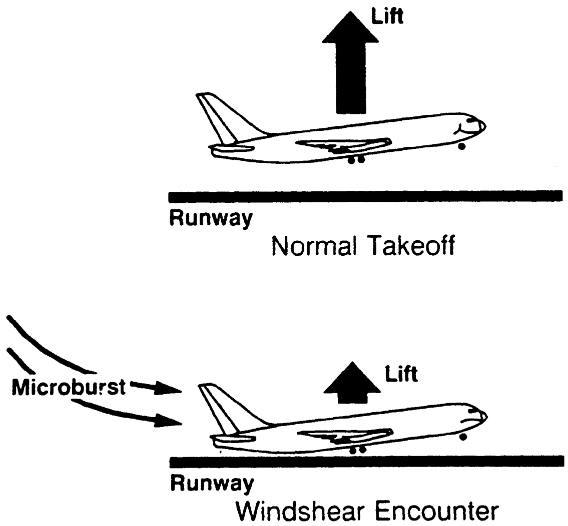

Figure 18. Windshear effects on liftoff. Microburst reduces airspeed and lift at normal attitude that results in inability to lift off.

An additional factor is the difficulty of recognizing deteriorating airplane performance. Timely recognition of a windshear encounter on the runway may be difficult since the only indication may be a slower than normal airspeed increase. The presence of gusts may mask abnormal airspeed build-up. Time available to respond effectively to a windshear may be as little as 5 seconds from the initial encounter. Effective crew coordination, particularly standard callouts, is essential in routine operations to develop habit patterns required to ensure timely recognition of degrading performance.

Full thrust may be required to provide additional performance, particularly if reduced thrust takeoff procedures have been used.

If there is insufficient runway left to accelerate to normal takeoff speed, and inadequate runway to stop, liftoff and safe climb may require rotation at speeds less than normal rotation speed (V_R). In this case, additional pitch attitude may be required to achieve sufficient lift (Figure 19). In traditional training, crews are frequently cautioned not to rotate at speeds less than V_R to avoid high pitch attitudes that could result in aft body contact. In a windshear encounter, rotation toward normal takeoff pitch attitude at lower than normal airspeed may be required to lift off in the remaining runway. This may result in aft body contact. To deal with an inadvertent windshear encounter, the pilot must be prepared to apply techniques which differ from those ordinarily used.

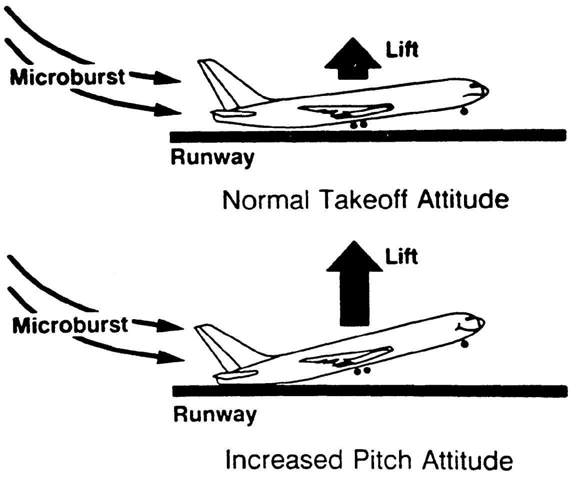

Figure 19. Pitch attitude effects on liftoff. Increased pitch attitude generates lift required for liftoff.

2.3.3 ENCOUNTER ON APPROACH

Analysis of a typical windshear encounter on approach provided evidence of an increasing downdraft and tailwind along the approach flight path (Figure 20). The airplane lost airspeed, dropped below the target glidepath, and contacted the ground short of the runway threshold.

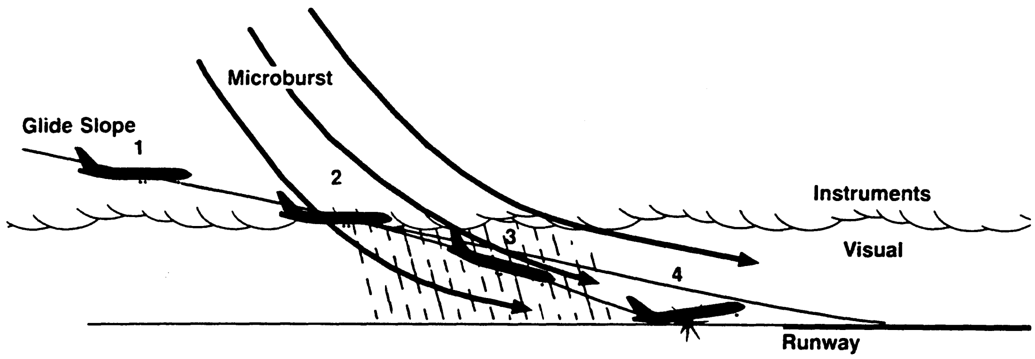

Figure 20. Windshear encounter during approach. (1) Approach initially appeared normal. (2) Increasing downdraft and tailwind encountered at transition. (3) Airspeed decrease combined with reduced visual cues resulted in pitch attitude reduction. (4) Airplane crashed short of approach end of runway.

Reduced airspeed, as the airplane encountered the windshear, resulted in decreased lift. This loss of lift increased the descent rate (Figure 21). The natural nose-down pitch response of the airplane to low airspeed caused additional altitude loss. Pitch attitude increase and recovery initiation were not used soon enough to prevent ground contact.

Lack of timely and appropriate response--affected by weather conditions, inadequate crew coordination and limited recognition time--was a significant factor in delaying recovery initiation. Gradual application of thrust during approach may have masked the initial decreasing airspeed trend. Poor weather conditions caused increased workload and complicated the approach. Transition from instruments to exterior visual references may have detracted from instrument scan. Inadequate crew coordination may have resulted in failure to be aware of flight path degradation. A stabilized approach with clearly defined callouts is essential to aid in recognition of unacceptable flight path trends and the need to initiate recovery.

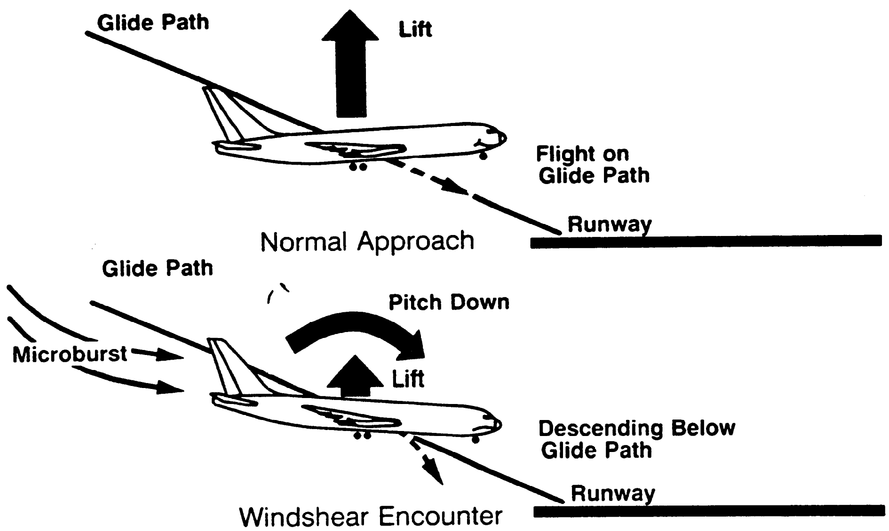

Figure 21. Windshear effects on flight path on approach. Microburst reduces airspeed and lift at normal attitude which results in pitch down tendency to regain airspeed.

2.3.4 WINDSHEAR EFFECTS ON AIRPLANES AND SYSTEMS

Windshear Effects on Airplanes

o Headwind/Tailwind Shear Response

The various components of windshear have unique effects on airplane performance. In addition, the magnitude of the shear depends on the flight path through the microburst.

An increasing headwind (or decreasing tailwind) shear increases indicated airspeed and thus increases performance. The airplane will tend to pitch up to regain trim airspeed. An additional consideration is that this type of shear may reduce normal deceleration during flare which could cause overrun.

Any rapid or large airspeed increase, particularly near convective weather conditions, should be viewed as a possible indication of a forthcoming airspeed decrease. Thus a large airspeed increase may be reason for discontinuing the approach. However, since microbursts are often asymmetric and the headwind may not always be present, headwind shears must not be relied upon to provide early indications of subsequent tailwind shears. Be prepared!

In contrast to shears which increase airspeed, an increasing tailwind (or decreasing headwind) shear will decrease indicated airspeed and performance capability. Due to airspeed loss, the airplane may tend to pitch down to regain trim speed.

o Vertical Windshear Response

Vertical winds exist in every microburst and increase in intensity with altitude. Such winds usually reach peak intensity at heights greater than 500 feet above the ground. Downdrafts with speeds greater than 3,000 feet per minute can exist in the center of a strong microburst. The severity of the downdraft the airplane encounters depends on both the altitude and lateral proximity to the center of the microburst.

Perhaps more critical than sustained downdrafts, short duration reversals in vertical winds can exist due to the horizontal vortices associated with microbursts. This is shown in Figure 22.

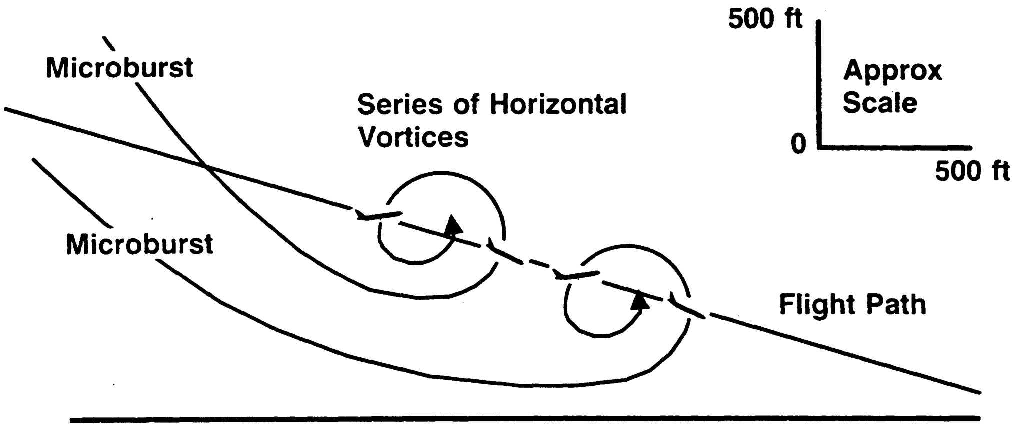

Figure 22. Encounter with microburst horizontal vortices. Rapid updraft downdraft variations due to horizontal vortices can cause uncommanded pitch changes and may result in momentary stick shaker activation well above normal stick shaker speeds.

An airplane flying through horizontal vortices as shown on the previous page experiences alternating updrafts and downdrafts causing pitch changes without pilot input. These vertical winds result in airplane angle-of-attack fluctuations which, if severe enough, may result in momentary stick shaker actuation or airframe shudder at speeds well above normal.

Vertical winds, like those associated with horizontal vortices, were considered in development of the recovery procedure. The most significant impact of rapidly changing vertical winds is to increase pilot workload during the recovery. The higher workload results from attention to momentary stick shaker actuation and uncommanded pitch attitude changes from rapid changes in vertical wind.

o Crosswind Shear Response

A crosswind shear tends to cause the airplane to roll and/or yaw. Large crosswind shears may require large or rapid control wheel inputs. These shears may result in significantly increased workload and distraction. In addition, if an aircraft encounters a horizontal vortex, severe roll forces may require up to full control wheel input to counteract the roll and maintain aircraft control.

o Turbulence Effects

Turbulence may be quite intense in weather conditions associated with windshear. Effects of turbulence can mask changing airspeed trends and delay recognition of severe windshear. Turbulence may also tend to discourage use of available airplane pitch attitude during a recovery by causing random stick shaker activity. These effects can significantly increase pilot workload and distraction.

o Rain Effects

Accident investigations and the study of windshear have shown that some forms of windshear are accompanied by high rates of rainfall. NASA research is underway to determine if high rainfall rates contribute to a loss of airplane performance. The results available to date are inconclusive. However, because rain may serve as a warning of severe windshear, areas of heavy rain should be avoided. High rates of rainfall also cause significant increases in cockpit noise levels, making crew coordination and pilot concentration more difficult.

o Basic Aerodynamics

The pilot has direct control over airplane pitch attitude which in turn acts to change the flight path. The angle-of-attack will change with pitch attitude resulting in a modified flight path angle. These three angles are related as follows:

Pitch Attitude = Angle of Attack + Flight Path Angle

o Airplane Performance

Transport category airplanes have considerable climb capability at speeds below normal reference values. As seen in Figure 23 for typical takeoff climb performance, a rate-of-climb of 1500 FPM is possible even at stick shaker speeds.

o Airplane Stability

As mentioned earlier, typical longitudinal stability characteristics tend to pitch the airplane up with increasing airspeed and down with decreasing airspeed. Thrust changes in response to these airspeed variations may also affect stability. In airplanes with underwing-mounted engines, there is an additional tendency to pitch up as thrust increases, and pitch down as thrust decreases. This tendency may become more pronounced at low speeds.

o Stall and Stall Warning

Airplane stall occurs when further increases in angle-of-attack produce no further increase in lift. In order to prevent inadvertent entry into this flight region, stall warning devices (stick shakers, stick pushers, stall warning horns) are installed on airplanes. In addition, having clean, smooth wing leading edges will help prevent both early onset of stall buffet as well as rolloff tendency prior to stall.

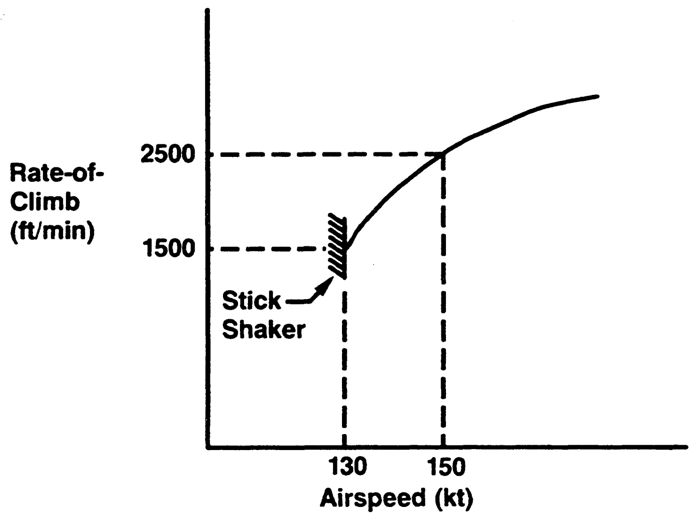

Figure 23. Typical takeoff rate-of-climb capability. Significant climb capability exists even at stick shaker airspeeds.

Windshear Effects on Systems

o Altimeters

During callouts and instrument scan in a windshear, use of radio and/or barometric altimeters must be tempered by the characteristics of each. Since radio altitude is subject to terrain contours, the indicator may show a climb or descent due to falling or rising terrain, respectively. The barometric altimeter may also provide distorted indications due to pressure variations within the microburst.

o Vertical Speed Indicators

The vertical speed indicator (VSI) should not be solely relied upon to provide accurate vertical speed information. Due to instrument lags, indications may be several seconds behind actual airplane rate of climb/descent and, in some situations, may indicate a climb after the airplane has started descending (Figure 24). Vertical speed indicators driven by an Inertial Reference Unit (IRU) show significant improvement over other type instruments but still have some lag.

In addition, gust-induced pitot static pressure variations within the microburst may introduce further VSI inaccuracies. Due to such lags and errors, all vertical flight path instruments should be crosschecked to verify climb/descent trends.

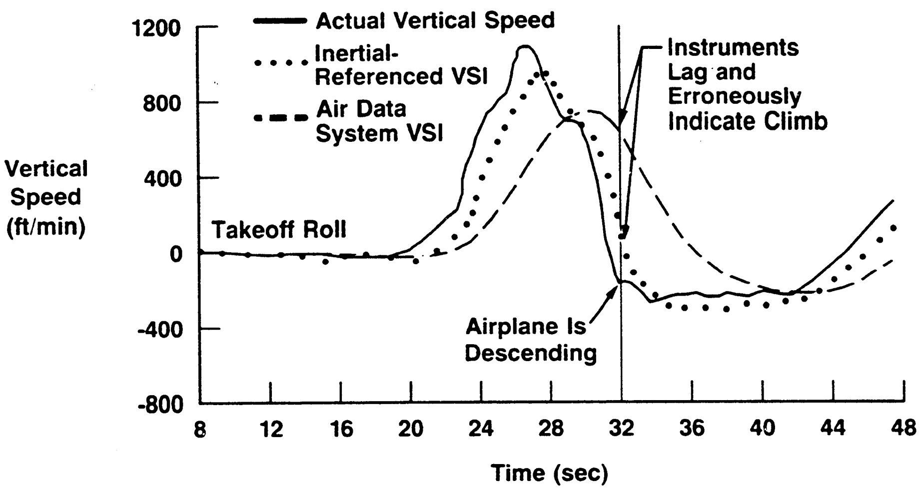

Figure 24. VSI error during takeoff windshear encounter. VSI may lag actual flight path changes.

o Stick Shaker

Stick shaker is activated by angle of attack. Consequently, rapidly changing vertical winds or maneuvering will vary the attitude and airspeed at which stick shaker occurs. With a properly functioning stall warning system and undamaged alpha vanes, stick shaker will normally activate below the stall angle of attack, thus providing a warning prior to stall.

o Cockpit Angle of Attack Indicators

Angle of attack indicators do provide useful indications of margin to stick shaker; however, they may not provide effective guidance in a windshear environment since angle of attack is controlled indirectly through pitch attitude adjustments. In an actual windshear encounter where rapidly changing vertical winds cause rapid angle of attack fluctuations independent of pilot input, the lack of direct control over angle of attack limits its usefulness as a guiding parameter.

2.3.5 DEVELOPMENT OF WIND MODELS

The lessons learned from windshear accident investigations, engineering analyses, and flight simulator studies have provided insight for development of simulator windshear models for pilot training. Through these efforts, it was determined that the essential elements which must be taught include:

1) Recognition of windshear encounter,

2) Flight at speeds significantly less than those speeds typically exposed to in training, and

3) Use of pitch attitude rather than airspeed control to recover.

A simple model presenting a significant windshear threat requiring use of prompt corrective attitude control is sufficient to teach these elements. Once the basics of recognition and recovery are understood, more complex models may be useful.

2.4 MODEL OF FLIGHT CREW ACTIONS

Due to the serious threat imposed by infrequent windshear encounters, an orderly set of actions is necessary to increase flight crew awareness of weather conditions that produce windshear (Figure 25). Additionally, certain operating practices have been developed that improve the chances of surviving a windshear encounter. In past windshear accidents, certain of these actions were frequently missing, thereby reducing crew effectiveness in dealing with the situation. The model of flight crew actions must be incorporated into day-to-day operations to ensure such actions are available and easily recalled when needed.

The recommended procedures in this section have been developed for Boeing, Douglas, and Lockheed jet transport airplanes. Use of these procedures for other types of airplanes is not appropriate until verified with the respective airframe manufacturer.

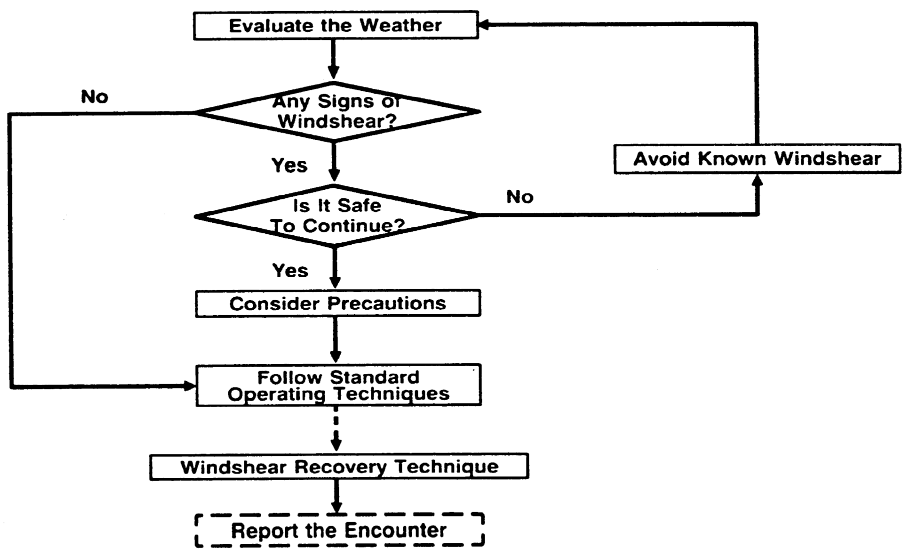

Figure 25. Model of flight crew actions.

2.4.1 EVALUATE THE WEATHER

The weather evaluation process that follows was developed after careful analyses of several windshear-related accidents. In each accident that occurred, several potential windshear indicators were present, but a clear, definitive choice to divert or delay was not made. The windshear indicators are meant to be cumulative. The more indicators present, the more crews should consider delaying departure or approach. Only through an increased awareness of potential windshear indicators and a proper weather evaluation routine will flight crews be best prepared to avoid microburst windshear.

Every windshear accident has occurred on a typical day, to a typical crew, on a typical takeoff or approach. Too many times a number of clues were present, acknowledged by the crew, but not accepted as potential indicators of windshear. The weather evaluation process must continue during the takeoff and climbout and throughout the approach and landing. If some of the indicators are present, this continual searching may lead to early recognition of the potential for a windshear encounter.

If convective cloud conditions are present and/or if thunderstorms appear likely, the potential for windshear and microburst activity exists. Even if there are only subtle signs of convective weather, such as weak cumulus cloud forms, suspect the possibility of microbursts, particularly if the air is hot and dry.

The following weather information should be examined for any potential windshear conditions affecting the flight:

1) Terminal Forecasts

An examination of terminal forecasts is recommended. Study o. the following two terminal forecasts demonstrates what to look for:

YNG FT AMD 1 101815 1820Z C45 BKN 80 OVC 2018G35 LLWS OCNL C20 OVC 3RW-/TRW-. 08Z C25 OVC 3214G25 OCNL C10 OVC 2RW-/TRW-. 09Z IFR CIG RW TRW WND.

HUF FT AMD 2 COR 101815 1745Z C30 BKN 2020G35 OCNL C12 OVC 3TRW CHC C4 X 1/2T+RW+AG55. 22Z C18 OVC 4TRW- 2420G30 SLGT CHC C4 X1/2TRW+G50. 01Z C16 OVC 2918G28 CHC 4RW-. 04Z C18 BKN 3016 BKN OCNL SCT. 09Z VFR..

Note that for Youngstown, Ohio the forecast is calling for LLWS--low level (altitude) windshear. While thunderstorms exist in the forecast, pilots are given an additional "LLWS" clue.

In the terminal forecast for Terre Haute, Indiana, LLWS does not appear. However, the chance of severe thunderstorm, heavy rain showers, hail, and wind gusts to 55 knots, suggest the potential for microbursts if actual thunderstorm conditions are encountered.

Dry microbursts are somewhat more difficult to recognize. When flying in regions of low humidity near the surface, any convective cloud is a likely microburst producer. Examination of the terminal forecast for convective activity--rain, thunderstorms, etc.--is good practice.

2) Hourly Sequence Reports

Hourly sequence reports should be inspected for windshear clues--thunderstorms, rainshowers, or blowing dust. The temperature and dew point spread should be examined for large differences, i.e. 30 to 50 degrees Fahrenheit, indicating low humidity. Additional signs such as warming trends, gusty winds, cumulonimbus clouds, etc., should be noted.

In the example shown below, evidence of blowing dust, large temperature/dewpoint spread, gusting winds, and thunderstorms (without rain) is present. These signs provide a strong indication that windshear may be present.

MSO SA 2152 50BKN 80OVC 12TBD 007/83/45/1715G30/974 VSBY W3 S1/2

3) Severe Weather Watch Reports

A check for issuance of an aviation severe weather watch should be made. In the following example, a line of thunderstorms approaching severe limits are forecast. Severe convective weather is a prime source for microbursts.

TSTMS FCST TO APCH SVR LIMITS THIS AFTN AND ERY EVE TO THE RT OF A LN FM YUM IPL RIV BUR 15 W SDB BFL IYK EED YUM.

4) LLWAS Reports

LLWAS (Low Level Windshear Alert System) - Presently installed at 110 airports in the U.S., this system is designed to detect wind shifts between outlying stations and a reference centerfield station (Figure 26). If an LLWAS alert (triggered by wind speed and/or direction differential) occurs, it indicates the presence of something shear-like, though not necessarily indicative of magnitude or location. However, the absence of an alert does not necessarily indicate that it is safe to proceed!

LLWAS information is available by request anytime, but will be provided by controllers whenever an LLWAS alert is in progress.

WINDSHEAR ALERTS. 2 QUADRANTS. CENTERFIELD WIND 210 AT 14. WEST BOUNDARY WIND 140 AT 22. NORTHEAST BOUNDARY WIND 270 AT 24.

LLWAS in its present form has some limitations:

A) shear magnitude may be seriously underestimated,
B) trees, buildings and other surface obstructions may disrupt or limit the flow of air near the sensors,
C) location and spacing of sensors may allow microburst development to go entirely undetected--particularly in the early stages (Figure 26),
D) because the sensors are on the ground, microburst development which has not yet reached the surface will not be detected, and
E) LLWAS coverage only exists near the runways and typically does not extend beyond the middle marker.

Even with these limitations, LLWAS can provide useful information about winds around the airport.

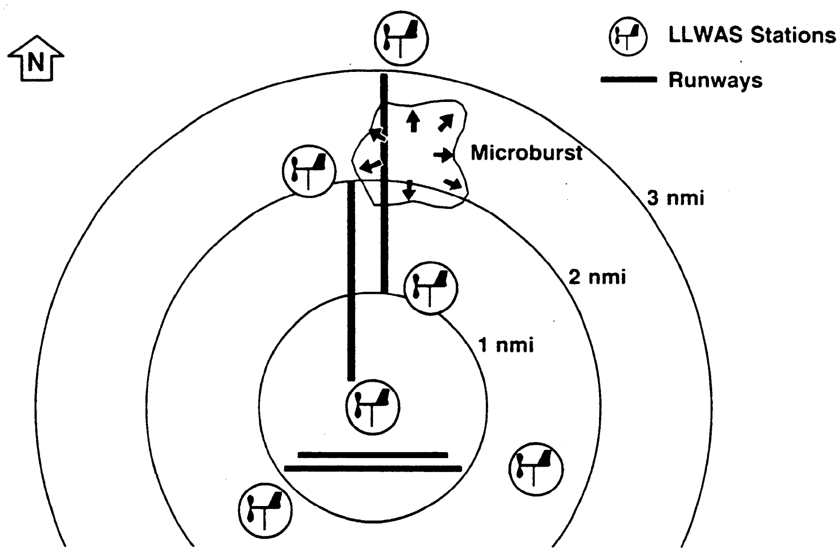

Figure 26. Undetected microburst due to wide LLWAS station spacing.

5) SIGMETS

SIGMETS, particularly CONVECTIVE SIGMETS, may provide essential clues. In the example, the CONVECTIVE SIGMET warns of scattered embedded thunderstorms, some reaching level 5 intensity, indicating a potential for windshear.

ATTENTION ALL AIRCRAFT, CONVECTIVE SIGMET CHARLIE ONE FROM THE VICINITY OF ELMIRA TO PHILLIPSBURG. SCATTERED EMBEDDED THUNDERSTORMS MOVING EAST AT ONE ZERO KNOTS. A FEW INTENSE LEVEL FIVE CELLS, MAXIMUM TOPS FLIGHT LEVEL FOUR FIVE ZERO.

6) Visual Clues from the Cockpit

The value of recognizing microbursts by visual clues from the cockpit cannot be overemphasized. Pilots must remember that microbursts occur only in the presence of convective weather indicated by cumulus-type clouds, thunderstorms, rain showers, and virga. (Note that other types of windshear can occur in the absence of convective weather.)

Microburst windshear can often be identified by some obvious visual clues such as heavy rain (in a dry or moist environment). This is particularly true if the rain is accompanied by curling outflow, a ring of blowing dust or localized dust in general, flying debris, virga, a rain core with rain diverging away horizontally from the rain core, or tornadic features (funnel clouds, tornados). At night, lightning may be the only visual clue. Pilots must become aware that these visual clues are often the only means to identify the presence of severe windshear.

7) PIREPS

PIREPS are extremely important indicators in microburst windshear situations. Reports of sudden airspeed changes in the airport approach or landing corridors provide indication of the presence of windshear.

"Miami Tower, PIREP, Flight 126 encountered windshear on final, loss of 20 knots at 300 feet approaching middle marker runway 27 right, Douglas MD-80."

In international weather reports, windshear observations or reports from pilots may be included at the end of routine and special weather reports.

"...WS WRNG B727 REPORTED MOD WS ON APCH RWY 34 AT 1610"

In the above example, a Boeing 727 on approach to Runway 34 reported moderate windshear at 1610 hours.

8) Airborne Weather Radar

The use of airborne weather radar to detect convective cells should be considered a matter of routine. Weather radar provides extremely useful information for the avoidance of thunderstorms in the airport terminal area, but cannot directly detect windshear. Pilots have become adept at avoiding thunderstorms while enroute and at altitude. However, relatively little emphasis has been placed on their use near the terminal area. Most heavy rain thunderstorms near the airport can be detected with conventional weather radar by a careful use of tilt control to scan above the intended flight altitude (15,000 to 20,000 feet). The subject of the proper use of tilt control for this purpose should be studied in available radar manuals and bulletins.

Pilots should understand that heavy precipitation, as seen on their radar and associated with convective clouds, indicates the possibility of microbursts; however, the absence of strong returns must not be depended upon to indicate a safe situation. Potentially hazardous dry microburst conditions may only produce weak radar returns.

Another significant aspect of weather radar use is attenuation. Attenuation is caused by heavy rainfall reducing the ability of the radar signal to penetrate, causing the radar to present an incomplete picture of the weather area. In the terminal area, comparison of ground returns to weather echoes is a useful technique to identify when attenuation is occurring. Tilt the antenna down and observe ground returns around the radar echo. With very heavy intervening rain, ground returns behind the echo will not be present. This area lacking ground returns is referred to as a shadow and may indicate a larger area of precipitation than is shown on the indicator. Areas of shadowing should be avoided.

Turbulence Doppler radars starting to become available to flight crews provide an additional clue to the presence of microbursts. If, in the departure/arrival segment of the airport vicinity, turbulence indications are present in mid-levels of convective cloud systems (e.g., 15,000 to 20,000 feet) and low humidity conditions exist (large temperature/dewpoint spread), the situation is prime for microburst formation. Pilots should be particularly cautious when they observe this indication.

2.4.2 AVOID KNOWN WINDSHEAR

The importance of avoiding severe windshear and microbursts cannot be over-emphasized. Microburst windshears have been measured which are beyond the capability of transport category airplanes and the most highly skilled pilots. Recall from Figure 11 that even windshears which were within the performance capability of the airplane have caused accidents. Avoidance may only involve delaying departure or approach for 10 to 20 minutes since this is the typical time required for microburst dissipation.

Even though significant emphasis on simulator training is recommended in pilot training curriculums, avoidance must be the first line of defense. Simulators are valuable for teaching windshear recognition and recovery. However, pilots are cautioned not to develop the impression that real-world windshear encounters can be successfully negotiated simply because they have received simulator training. In an airplane, complicating factors (i.e. turbulence, precipitation noise, instrument errors, etc.) may make shears much more difficult than in a simulator. In addition, simulator motion systems are limited in their capability to reproduce all the dynamics of an actual windshear encounter. Remember, some windshears cannot be escaped using any known techniques. Therefore, above all, AVOID, AVOID, AVOID!

Unfortunately, there are no universal quantitative windshear avoidance criteria that provide unambiguous go/no-go decision guidelines. There is no assured detection and warning system in operation which can measure windshear intensity along a specific flight path. However, a summary of the weather evaluation factors which can be helpful in avoiding windshear is shown in Table 1 on the following page.

TABLE 1

MICROBURST WINDSHEAR PROBABILITY GUIDELINES

OBSERVATION	PROBABILITY OF WINDSHEAR
PRESENCE OF CONVECTIVE WEATHER NEAR INTENDED FLIGHT PATH:	
- With localized strong winds (Tower reports or observed blowing dust, rings of dust, tornado-like features, etc.)	HIGH
- With heavy precipitation (Observed or radar indications of contour, red or attenuation shadow)	HIGH
- With rainshower	MEDIUM
- With lightning	MEDIUM
- With virga	MEDIUM
- With moderate or greater turbulence (reported or radar indications)	MEDIUM
- With temperature/dew point spread between 30 and 50 degrees fahrenheit	MEDIUM
ONBOARD WINDSHEAR DETECTION SYSTEM ALERT (Reported or observed)	HIGH
PIREP OF AIRSPEED LOSS OR GAIN:	
- 15 knots or greater	HIGH
- Less than 15 knots	MEDIUM
LLWAS ALERT/WIND VELOCITY CHANGE	
- 20 knots or greater	HIGH
- Less than 20 knots	MEDIUM
FORECAST OF CONVECTIVE WEATHER	LOW

NOTE: These guidelines apply to operations in the airport vicinity (within 3 miles of the point of takeoff or landing along the intended flight path and below 1000 feet AGL). The clues should be considered cumulative. If more than one is observed the probability weighting should be increased. The hazard increases with proximity to the convective weather. Weather assessment should be made continuously.

CAUTION: CURRENTLY NO QUANTITATIVE MEANS EXISTS FOR DETERMINING THE PRESENCE OR INTENSITY OF MICROBURST WINDSHEAR. PILOTS ARE URGED TO EXERCISE CAUTION IN DETERMINING A COURSE OF ACTION.

Table 1, designed specifically for convective weather (thunderstorm, rainshower, virga), provides a subjective evaluation of various observational clues to aid in making appropriate real time avoidance decisions. The observation weighting is categorized according to the following scale:

HIGH PROBABILITY:

Critical attention need be given to this observation. A decision to avoid (e.g. divert or delay) is appropriate.

MEDIUM PROBABILITY:

Consideration should be given to avoiding. Precautions are appropriate.

LOW PROBABILITY:

Consideration should be given to this observation, but a decision to avoid is not generally indicated.

The guidelines in Table 1 apply to operations in the airport vicinity (within 3 miles of takeoff or landing along the intended flight path below 1000 feet AGL). Although encountering weather conditions described in Table 1 above 1000 feet may be less critical in terms of flight path, such encounters may present other significant weather related risks. Pilots are therefore urged to exercise caution when determining a course of action. Use of Table 1 should not replace sound judgement in making avoidance decisions.

Windshear clues should be considered cumulative. The probability for each single observation is given. However, if more than one windshear clue is observed, the total probability rating may be increased to reflect the total set of observations.

Example:

Nearing destination, VIRGA is seen descending from high based clouds over the airfield (MEDIUM PROBABILITY). Commencing approach, a PIREP is received indicating that another flight just experienced a 10 knot airspeed loss on final approach to the same airport (MEDIUM PROBABILITY). Therefore, it would be appropriate to raise the total avoidance decision weighting to HIGH PROBABILITY (indicating a decision to avoid is appropriate).

2.4.3 CONSIDER PRECAUTIONS

Avoidance is the best precaution. However, there are situations when windshear clues do not clearly dictate delaying, but can be interpreted to mean that conditions are right for windshear activity. In these instances, pilots should consider the next step of flight crew actions, the use of precautions.

A number of precautionary techniques have been developed which crews can take to lessen the effect of windshear should an unsuspected severe windshear be encountered on takeoff or approach. These precautions include consideration of thrust setting, runway selection, flap selection, airspeed, use of autopilot, autothrottle and flight director. They were developed by detailed analysis and piloted simulation of several microburst windshear encounters. In many cases, tradeoffs were involved and no "best" recommendation for all conditions could be developed.

Use of precautions along with even the best recovery piloting skills cannot guarantee a successful escape from many microburst windshears. It is important to realize that the recommended precautions each have a relatively small effect on the outcome of an inadvertent windshear encounter. Therefore, use of precautions should not replace sound pilot judgment in deciding whether or not it is safe to proceed. Use of precautions should not bias a go/no-go decision in the go direction.

2.4.3.1 TAKEOFF PRECAUTIONS

o Thrust Setting

Maximum rated takeoff thrust should be used for takeoff. This shortens the takeoff roll and reduces overrun exposure. Full thrust also provides the best rate of climb, thus increasing altitude available for recovery if required. Lastly, full thrust takeoffs may eliminate resetting thrust in a recovery, thereby maximizing acceleration capability and reducing crew workload.

o Runway Selection

Use the longest suitable runway that avoids suspected areas of windshear. The choice of a suitable runway involves consideration of exposure to obstacles after liftoff and crosswind and tailwind limitations. This assures maximum runway available to accelerate to rotation speed and may result in more ground clearance at the end of the runway and during the climb profile. Should the decision be made to reject the takeoff, more runway is available on which to stop the airplane.

o Takeoff Flap Selection

The choice of takeoff flap setting is dependent on the airplane type. The following flap settings should be considered unless limited by obstacle clearance and/or climb gradient:

Airplane Type	Takeoff Flap Setting
B727	15
B737	5 to 15
B747	20
B757	20
B767	20
DC-9-10	10 or 20
DC-9-20,-30,-40,-50	5 or 15
MD-80	5 to 15
DC-10	5 to 20
L-1011	10 to 22

Studies of available takeoff flap settings showed that the greater flap setting provided best performance for windshear encounters on the runway. However, lesser flap settings showed the best performance for in-air windshear encounters. The takeoff flap settings in the table offered somewhat better performance over a wide range of conditions; however, it must be pointed out that the performance difference between flap settings is small.

o Increased airspeed

Increased airspeed at rotation improves the ability of the airplane to negotiate a windshear encountered after liftoff. Increased airspeed improves the flight path, reduces potential exposure to flight near stick shaker speeds, and reduces pilot workload.

Delaying rotation to a higher airspeed may appear to increase the risk of overrunning available runway. However, because of the manner in which increased rotation speed is calculated, it is simply using the runway as if the aircraft was loaded to the field length limit weight for that runway. If the takeoff is at field length limit conditions, the risk of overrunning the available runway is increased because there is no extra runway available. The overrun exposure is also increased if the windshear reduces the airspeed below the minimum airspeed required for liftoff at the maximum available (body contact) attitude. However, initiating rotation no later than 2000 feet from the end of the usable runway surface reduces the probability of overrun and maximizes the available energy after liftoff.

If increased V_R is to be used, the technique for scheduling and using increased rotation airspeed is:

1) Determine V_1, V_R and V_2 speeds for actual airplane gross weight and flap setting. Set airspeed bugs to these values in the normal manner.

2) Determine field length limit maximum weight and corresponding V_R for selected runway.

3) If field length limit V_R is greater than actual gross weight V_R, use the higher V_R (up to 20 knots in excess of actual gross weight V_R) for takeoff. Airspeed bugs should <u>not</u> be reset to the higher speeds.

4) Rotate to normal initial climb attitude at the increased V_R and maintain this attitude. This technique produces a higher initial climb speed which slowly bleeds off to the normal initial climb speed.

<u>WARNING</u>: If windshear is encountered at or beyond the actual gross weight (bug) V_R, do <u>not</u> attempt to accelerate to <u>the</u> increased V_R, but rotate without hesitation. In no case should rotation be delayed beyond 2,000 feet from the end of the usable runway surface. (See Section 2.4.5 Recovery Techniques)

If increased airspeed was not used prior to liftoff, accelerating to higher than normal airspeed after liftoff is not recommended. Reducing pitch attitude at low altitude to accelerate might produce a hazard if windshear is encountered.

o Flight Director

Do not use speed-referenced flight directors unless they are equipped with windshear recovery guidance.

WARNING: A speed-referenced flight director which does not have windshear recovery guidance may command a pitch attitude change to follow target airspeeds regardless of flight path degradation. This guidance may be in conflict with the proper procedures for windshear recovery. Such flight directors must be disregarded if a recovery is required and, time permitting, switched off by the Pilot Not Flying (PNF).

Some flight directors are equipped with a selectable pitch attitude mode. If normal procedures utilize this feature, the selectable pitch attitude mode may be effectively used in a windshear encounter provided the selected attitude is within the acceptable range. However, if an attitude other then the selected attitude becomes necessary, the flight director should be disregarded, and time permitting, switched off by the PNF.

Takeoff Precautions

- **Use maximum rated takeoff thrust**
- **Use longest suitable runway**
- **Consider using recommended flap setting**
- **Consider using increased rotation airspeed**
- **Do not use speed referenced flight director**

2.4.3.2 APPROACH PRECAUTIONS

o Stabilized Approach

During some normal operations, stabilized approaches are not achieved prior to 500 feet AGL. However, in a potential windshear environment, a stabilized approach should be established no later than 1,000 feet AGL to improve windshear recognition capability.

o Thrust Management

Minimize thrust reductions. Rather than immediately compensating for an airspeed increase by reducing thrust, a brief pause to evaluate speed trends is prudent. If a tailwind shear occurs and recovery is initiated, the additional airspeed and earlier availability of thrust (due to engines accelerating from a higher RPM) will be advantageous. If autothrottles are engaged, assure inappropriate thrust reductions do not occur. In the absence of a tailwind shear, this procedure may result in a higher than normal approach speed which may have to be accounted for on landing.

o Runway Selection

Use the most suitable runway that avoids the area of suspected windshear and is compatible with crosswind and tailwind limitations. A longer runway provides the greatest margin for increased ground roll due to unanticipated winds and possible resulting high ground speed at touchdown. A precision (instrument) approach and other aids to glide path monitoring (VASI, etc.) are also desirable as they can enhance windshear recognition by providing timely, accurate flight path deviation information.

o Landing Flap Selection

The choice of landing flap setting is dependent on airplane type. The following flap settings should be considered:

Airplane Type	Landing Flap Setting
B727	30
B737	30
B747	25 or 30
B757	30
B767	30
DC-9	*
MD-80	28
DC-10	35
L-1011	33

* Minimum flap setting authorized for particular model.

Studies of windshear encounters using all available landing flap settings showed that the flap settings recommended above provided the best overall recovery performance for a wide range of windshears.

o Increased Airspeed

Increased airspeed on approach improves climb performance capability and reduces the potential for flight at stick shaker during recovery from an inadvertent windshear encounter.

If available landing field length permits, airspeed may be increased up to a maximum of 20 knots. This increased speed should be maintained to flare. Touchdown must occur within the normal touchdown zone--do not allow the airplane to float down the runway.

As many variables are involved, it is not practical to provide exact guidance on the effect of 20 knots extra speed on actual stopping distance. Wind can be a major factor since stopping distance is affected by groundspeed rather than airspeed. If increased airspeed is used and an increasing performance shear is encountered, a go-around may be necessary due to insufficient landing field length for the higher approach speed. Furthermore, if a pilot can be reasonably certain that wind changes (due to topography or unique local conditions) will not result in decreasing performance, it may be inappropriate to use increased approach speed.

Other factors affecting stopping distance such as availability and effectiveness of thrust reversers, tire and brake condition, runway surface conditions, etc., must also be taken into consideration. On a dry runway with no adverse factors present, landing field length may accommodate 20 knots extra speed at touchdown In other cases greater field length may be required. If in doubt, use the longest suitable runway which does not expose the airplane to greater hazard from possible shear.

WARNING: Increased touchdown speeds increase stopping distance. An additional 20 knots at touchdown can increase stopping distance by as much as 25 percent and in some cases may exceed brake energy limits.

o Flight Director and/or Autopilot and Autothrottles

During approach it is desirable to utilize the flight director, autopilot and autothrottles to the maximum extent practical. These systems may relieve pilot workload, allowing the crew more time to monitor instruments and weather conditions. However, use of autoflight systems, and in particular the autothrottle, only provide benefits if properly monitored. In the absence of proper monitoring, these systems may mask onset of shear through lack of pilot awareness of control inputs being made.

Furthermore, not all autoflight systems perform well in gusty or turbulent conditions. The autopilot and/or the autothrottle should be disconnected when continued use appears counter-productive.

Approach Precautions

- Stabilize approach no later than 1000 ft AGL
- Minimize thrust reductions
- Use most suitable runway
- Consider using recommended flap setting
- Consider using increased approach speed
- Use autoflight systems during approach

2.4.4 FOLLOW ESTABLISHED STANDARD OPERATING TECHNIQUES

In an effort to aid crews with the early recognition of a windshear encounter, a series of recommendations were formulated under the general heading of Standard Operating Techniques (SOT's). These SOT's fall into two general headings of crew awareness and crew coordination.

The need for emphasis on SOT's came from recognition that in most takeoff windshear accidents, the airplane pitch attitude was reduced below the attitude that would maintain level flight. This was done when the airplane was already descending toward the ground and indicates lack of flight path awareness on the part of the crews involved. This lack of awareness was also observed during piloted simulator studies of windshear encounters. Traditional training programs and routine flying may not have reinforced proper flight path control and concern for altitude loss. However, flight path control should be the primary focus when dealing with windshear. TECHNIQUES SUCH AS STRICT ADHERENCE TO AIRSPEED MUST BE MODIFIED IN FAVOR OF MAINTAINING FLIGHT PATH BY CONTROLLING PITCH ATTITUDE.

The SOT's that follow emphasize flight path and pitch attitude for operations near the ground. Following SOT's results in better crew performance during day-to-day operations, as well as during windshear encounters. In both takeoff and approach to landing, crew awareness and coordination are vital for timely windshear recognition, particularly at night or in marginal weather conditions.

o Crew Awareness

It is important for crews to remain alert for any change in conditions, remembering that windshear can be quick to form and to dissipate. The shears that proved to be most deadly are those which caught crews by surprise.

Crews should be aware of normal vertical flight path indications so that windshear induced deviations are more readily recognized. On takeoff, this would include attitude, climb rate, and airspeed buildup. On approach, airspeed, attitude, descent rate and throttle position provide valuable information. Awareness of these indications assures that flight path degradation is recognized as soon as possible.

During takeoff and approach, be alert for airspeed fluctuations. Such fluctuations may be the first indication of windshear. Control column forces significantly different than those expected during a normal takeoff or go-around may result if airspeed is below target or airspeed buildup is low during rotation and liftoff. Vertical flight path displays should be used to crosscheck flight director commands.

During takeoff while at relatively low altitude (below 1000 feet), the SOT's require awareness and use of normal climbout pitch attitude and <u>less emphasis</u> on strict airspeed <u>control</u>. <u>Know</u> the all-engine initial climb pitch attitude. Rotate at the normal rotation rate to this attitude for all takeoffs. Minimize pitch attitude reductions in response to low airspeed until terrain and obstruction clearance is assured.

On approach, avoid large thrust reductions or trim changes in response to sudden airspeed increases as an airspeed decrease may follow. Closely monitor vertical flight path instruments, such as vertical speed, altimeters and glideslope displacement. In addition, comparison of groundspeed and airspeed indications can provide additional information for timely windshear recognition. When potential for windshear exists, achieve a stabilized approach no later than 1,000 feet AGL.

High workload and distractions in the approach phase, particularly in marginal weather, may divert attention away from instruments that provide early recognition of flight path deterioration. Additionally, gradual application of thrust on approach may mask a decreasing airspeed trend.

Crews should be prepared to execute the recommended recovery procedure immediately if deviations from target conditions in excess of the following occur:

Takeoff/Approach

1) ±15 knots indicated airspeed

2) ±500 FPM vertical speed

3) ±5° pitch attitude

Approach

1) ±1 dot glideslope displacement

2) Unusual throttle position for a significant period of time.

These values should be considered as guidelines only. Exact criteria cannot be established. In certain instances where significant rates of change occur, it may be necessary to initiate recovery before any of the above criteria are exceeded. Other situations may exist where brief excursions, particularly in airspeed, resulting from known or anticipated local wind effects may not be an indication of significant hazard. The pilot flying (PF) is responsible for assessing the situation and using sound judgment to determine the safest course of action.

o Crew Coordination

The PF should focus attention on flying the airplane. In a windshear encounter, appropriate action should be taken in response to callouts.

The PNF should focus attention on airspeed, vertical speed, altitude, pitch attitude, glidepath deviation and thrust. If any significant deviations from normal indications are detected, the PNF should immediately call out the deviation. Callouts in the cockpit should be standardized and easy to understand to ensure timely recognition.

EXAMPLE:

"Vertical speed 1200 down--airspeed 115 decreasing--glideslope one dot low."

STANDARD OPERATING TECHNIQUES SUMMARY

o Takeoff

- o Know normal attitudes, climb rates, airspeed build-up.
- o Know/use all-engine initial climb attitude.
- o Make continuous rotation at normal rate.
- o Crosscheck flight director commands.
- o Minimize pitch attitude reductions.
- o Monitor vertical flight path instruments, call out deviations (PNF).
- o Know recovery decision guidelines.

- Approach
  - Know normal attitudes, descent rates, airspeeds, throttle position.
  - Crosscheck flight director commands.
  - Avoid large thrust reductions.
  - Monitor vertical flight path instruments, call out deviations (PNF).
  - Know recovery decision guidelines.

2.4.5 WINDSHEAR RECOVERY TECHNIQUE

The primary recovery technique objective is to keep the airplane flying as long as possible in hope of exiting the shear. A wide variety of techniques were considered to establish the one best meeting this objective. The best results were achieved by pitching toward an initial target attitude while using necessary thrust. Several factors were considered in developing this technique.

Studies show windshear encounters occur infrequently and that only a few seconds are available to initiate a successful recovery. Additionally, during high stress situations pilot instrument scan typically becomes very limited--in extreme cases, to only one instrument. Lastly, recovery skills will not be exercised on a day-to-day basis. These factors dictated that the recovery technique must not only be effective, but simple, easily recalled, and have general applicability.

Extensive analysis and pilot evaluations were conducted. Although a range of recovery attitudes (including 15° and the range of all-engine initial climb attitudes) provides good recovery capability for a wide variety of windshears, 15° was chosen as the initial target pitch attitude for both takeoff and approach. Additional advantages of 15° initial target pitch attitude are that it is easily recalled in emergency situations and it is prominently displayed on attitude director indicators.

Note: 1) L-1011 target attitudes:
Takeoff = 17.5°
Approach = 15°

2) Operators using pre-calculated target pitch attitudes such as all-engine attitude for normal takeoffs and go-arounds may use these attitudes in place of the recommended initial target recovery attitude.

While other more complex techniques may make slightly better use of airplane performance, these techniques do not meet simplicity and ease of recall requirements. Evaluations showed that the recommended technique provides a simple, effective means of recovering from a windshear encounter.

A detailed discussion of the recommended recovery technique follows. Recovery both during takeoff after liftoff and during approach is discussed together in the following section since the technique for both situations is identical. The recovery technique for encounters during takeoff on runway is presented later.

2.4.5.1/3 ENCOUNTER DURING TAKEOFF - AFTER LIFTOFF and ENCOUNTER ON APPROACH

Windshear recognition is crucial to making a timely recovery decision. The recommended recovery procedure should be initiated any time the flight path is threatened below 1000 feet AGL on takeoff or approach. The guidelines for unacceptable flight path degradation are repeated below:

- o Takeoff/Approach
  1) ±15 knots indicated airspeed
  2) ±500 FPM vertical speed
  3) ±5° pitch attitude
- o Approach
  1) ±1 dot glideslope displacement
  2) Unusual throttle position for a significant period of time.

Again, these should be considered as guidelines since exact criteria cannot be established. In every case, it is the responsibility of the pilot flying to assess the situation and use sound judgement in determining the safest course of action. In certain instances where significant rates of change occur, it may be necessary to initiate recovery before any of the above are exceeded.

If windshear is inadvertently encountered after liftoff or on approach, immediately initiate the recommended recovery technique. If on approach, do not attempt to land. (However, if on approach and an increasing performance shear is encountered, a normal go-around, rather than the recovery maneuver, may be accomplished.)

The technique for recovery from a windshear encounter after liftoff or during approach is the same for both cases. This technique is described as follows:

o THRUST

Aggressively apply necessary thrust to ensure adequate airplane performance. Disengage the autothrottle if necessary. Avoid engine overboost unless required to avoid ground contact. When airplane safety has been ensured, adjust thrust to maintain engine parameters within specified limits.

o PITCH

The pitch control technique for recovery from a windshear encounter after liftoff or on approach is as follows:

- o At a normal pitch rate, increase or decrease pitch attitude as necessary toward an initial target attitude of 15°. The autopilot/flight director should be turned off by the PNF unless specifically designed for operations in windshear, or unless using a pitch selectable flight director with desired attitude commanded.
- o Always respect stick shaker. Use intermittent stick shaker as the upper pitch limit. In a severe shear, stick shaker may occur below 15° pitch attitude.
- o If attitude has been limited to less than 15° to stop stick shaker, increase attitude toward 15° as soon as stick shaker stops.
- o If vertical flight path or altitude loss is still unacceptable after reaching 15°, further increase pitch attitude smoothly in small increments.
- o Control pitch in a smooth, steady manner (in approximately 2 degree increments) to avoid excessive overshoot/undershoot of desired attitude.
- o Once the airplane is climbing and ground contact is no longer an immediate concern, airspeed should be increased by cautious reductions in pitch attitude.

o CONFIGURATION

Maintain flap and gear position until terrain clearance is assured. Although a small performance increase is available after landing gear retraction, initial performance degradation may occur when landing gear doors open for retraction. While extending flaps during a recovery after liftoff may result in a performance benefit, it is not a recommended technique because:

1) Accidentally retracting flaps (the usual direction of movement) has a large adverse impact on performance.

2) If landing gear retraction had been initiated prior to recognition of the encounter, extending flaps beyond a takeoff flap setting might result in a continuous warning horn which distracts the crew.

o ADDITIONAL CONSIDERATIONS

If autopilot/flight director systems specifically designed for operation in windshear are engaged during approach, they should be used during the recovery maneuver. These systems may aid in recovery from an inadvertent windshear encounter. However, due to limited time available to recognize and respond, do not engage the autopilot or autothrottle if these systems were not engaged prior to recovery.

WARNING: A flight director and/or autoflight system which is not specifically designed for operation in windshear may command a pitch attitude change to follow target airspeeds or a fixed pitch attitude regardless of flight path degradation. This guidance may be in conflict with the proper procedures for windshear recovery. Such systems must be disregarded if recovery is required and, time permitting, switched off by the PNF.

Use of autopilot control wheel steering (CWS) has not been fully evaluated for its effectiveness in a windshear encounter. One consideration regarding CWS is that it is usually a single channel autopilot mode and as such has reduced control authority. In any case, if CWS is used during a windshear encounter, its use should be discontinued if it produces difficulty in achieving the desired attitude.

Some flight directors are equipped with a selectable pitch attitude mode. If normal procedures utilize this feature, the selectable pitch attitude mode may be effectively used in a windshear encounter provided the selected attitude is within the acceptable range. However, if an attitude other than the selected attitude becomes necessary, the flight director should be disregarded, and time permitting, switched off by the PNF.

Avoid stabilizer trim changes in response to short term windshear-produced airspeed/stick force changes. However, stabilizer trim should be used to trim out stick force due to thrust application.

Throughout recovery, the PNF should call out vertical flight path deviations using the barometric altimeter, radio altimeter, or vertical speed indicator as appropriate. For example,

"sinking 500, altitude 200, climbing 400, altitude 300, etc."

Operators of airplanes requiring a flight engineer may incorporate the second officer into the callout process.

Rapidly changing winds may cause rapid excursions in pitch and roll with little or no pilot input as well as varying the attitude for stick shaker activation.

As soon as possible, report the encounter to the tower. The airplane following may not have the performance required to recover from the same windshear encounter. The windshear also may be increasing in intensity making flight through it even more dangerous. Pilots and controllers must be aware that their timely actions may prevent a pending disaster--SECONDS MAY SAVE LIVES! The pilot report for windshear encounters should contain the following information:

1) Maximum loss or gain of airspeed

2) Altitude at which shear was encountered

3) Location of shear with respect to runway in use

4) Airplane type

5) Use the term PIREP to encourage rebroadcast of the report to other aircraft

Critical remarks are also helpful in establishing windshear severity (e.g. "...maximum thrust required", "...almost contacted terrain", etc.).

EXAMPLE:

"San Francisco Tower, PIREP, Flight 126 encountered windshear on final, loss of 20 knots at 300 feet approaching middle marker runway 27 right, Douglas MD-80."

After Liftoff/On Approach Windshear Recovery Technique

- **THRUST**
  - **Apply necessary thrust**
- **PITCH**
  - **Adjust toward 15°**
  - **Increase beyond 15° if required to ensure acceptable flight path**
  - **Always respect stick shaker**
- **CONFIGURATION**
  - **Maintain existing configuration**

2.4.5.2 ENCOUNTER DURING TAKEOFF - ON RUNWAY

Recognition of windshear is difficult during takeoff roll since airspeed is changing rapidly. In addition to visual clues described previously, unusual airspeed fluctuations, slow or erratic airspeed build-up may be indications of a windshear encounter.

The go/no-go criteria based on engine failure decision speed (V_1) may not be valid for windshear conditions since groundspeed can be much higher than airspeed (Figure 27). It therefore may not be possible to stop the airplane on the runway during a rejected takeoff. The ability to lift off is a function of airspeed; the ability to stop is largely a function of ground speed.

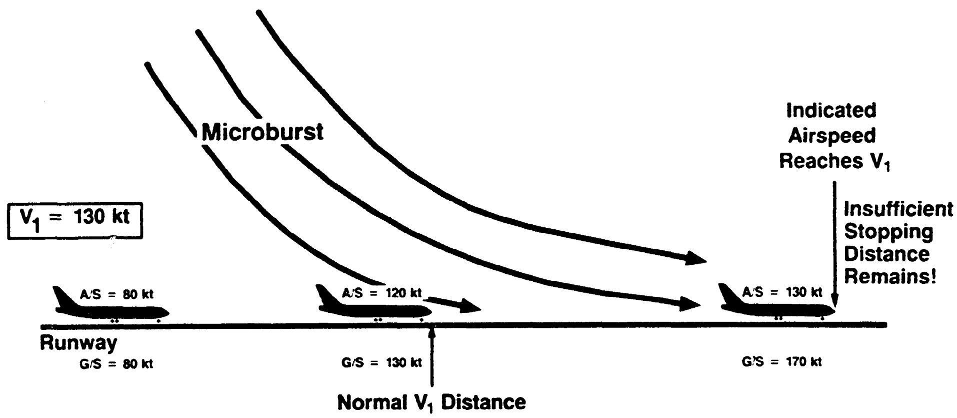

Figure 27. Windshear effects on go/no-go decision point. V_1 decision speed may not be attained until insufficient runway remains to abort takeoff.

Prior to V_1

The takeoff should be rejected if unacceptable airspeed variations occur below indicated V_1 and the pilot decides that there is sufficient runway remaining to stop the airplane.

After V_1

The takeoff must be continued if V_1 has been reached.

o THRUST

Aggressively apply necessary thrust to ensure adequate airplane performance. Avoid engine overboost unless necessary to ensure airplane safety. When airplane safety has been ensured, adjust thrust to maintain engine parameters within specified limits.

Overboost thrust alone, however, is NOT sufficient to offset the effects of an inadvertent windshear encounter. Proper pitch attitude control is the most important factor in recovery from windshear.

o PITCH

When V_R is reached, rotate at normal rate toward 15° pitch attitude. In severe windshear encounters, however, V_R might not be reached and the option to reject the takeoff may not exist. If this is the case, rotation must be initiated no later than 2,000 feet from the end of the usable surface (Figure 28).

Note: Transport category airplanes typically can lift off 5 to 10 knots prior to V_R (except 727, which cannot lift off prior to V_R).

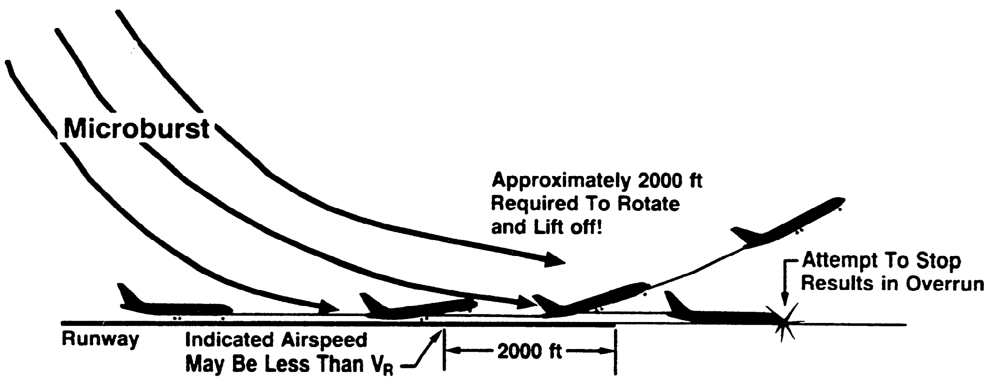

Figure 28. Windshear effects on rotation decision. Windshear effects may force rotation at speeds below V_R. Rotation should begin no later than 2000 ft from runway departure end.

Pitch attitude and rotation rate should not be restricted to avoid aft body contact since all available pitch attitude may be required to lift off in the available runway. Once airborne, follow the After Liftoff Recovery Technique discussed earlier.

Takeoff (On Runway) Recovery Technique

- **THRUST**
  - **Apply necessary thrust**
- **PITCH**
  - **Rotate toward 15° (no later than 2000 ft remaining)**
  - **Increase beyond 15° if required to lift off**

Note: After liftoff follow after liftoff recovery technique

The runway remaining during takeoff can be identified on runways having appropriate marking and lighting. While the markings discussed are usually to assist landing aircraft, they can also be used to determine runway remaining during a takeoff.

Figure 29 illustrates the markings and lighting typical of FAA and ICAO precision approach runways. For an airplane departing from left to right in the figure, the first pair of single hash marks on either side of the centerline indicates 3,000 feet of runway remaining (i.e. 1,000 feet until rotation must be initiated). As takeoff continues, the 2,000 feet remaining point is denoted by the first pair of double hash marks encountered. Note that the spacing of all hash marks is in 500 foot intervals from the departure end threshold.

Another indication of runway remaining may be the runway lighting. FAA/ICAO precision approach runways (Figure 29) have edge lights which are yellow rather than white for the last 2,000 feet of runway when viewed in the takeoff direction. In addition, centerline lighting can be used to identify the amount of runway remaining. The crew in an airplane taking off from left to right in the figure would see white centerline lights until 3,000 feet from the end of the runway (1,000 feet until rotation must take place). From 3,000 feet to the 1,000 feet remaining point the centerline lights alternate white and red. The centerline lights are all red for the last 1,000 feet of runway. A line of red lights perpendicular to the runway indicate the end of usable runway surface.

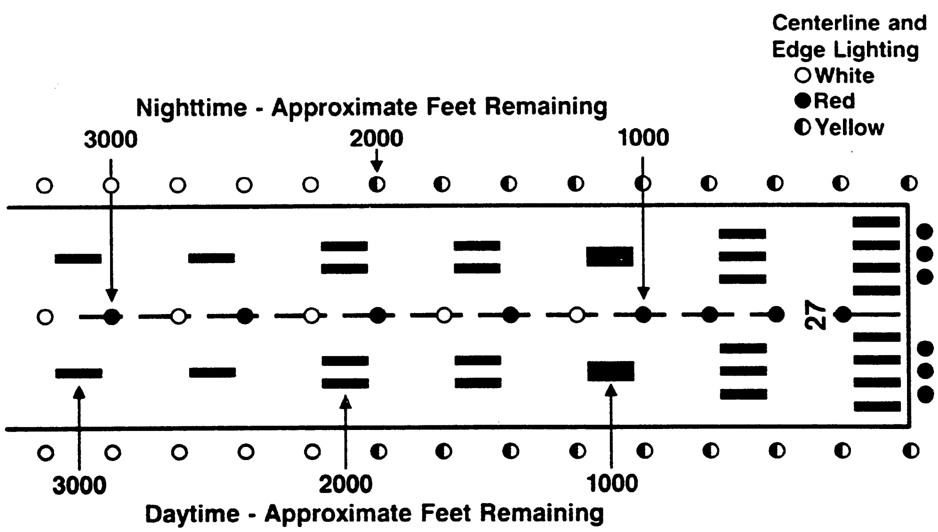

Figure 29. FAA ICAO precision approach runway markings and lighting.

Figure 30 illustrates the markings on an FAA non-precision approach runway. The main indicator of distance remaining on these runways is the fixed distance markings on either side of centerline approximately 1,000 feet from the runway threshold. For runways with these markings, pilot judgement and/or familiarity with specific features along the runway are required to estimate the 2,000 feet remaining point.

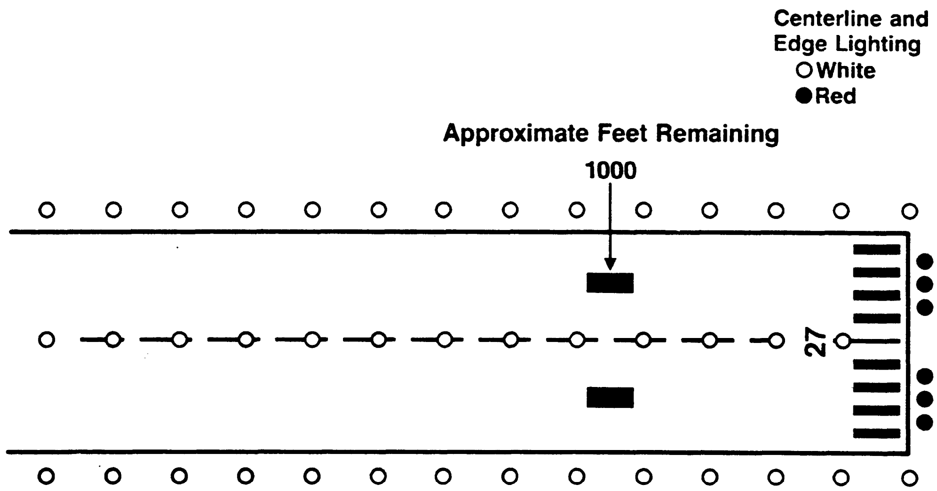

Figure 30. FAA nonprecision approach runway markings and lighting.

Runway markings and lighting on an ICAO non-precision runway are shown in Figure 31. This figure represents the optimum configuration that might appear. Most ICAO non-precision approach runways would include some, but not necessarily all of these features.

ICAO non-precision runways have single hash marks on either side of runway centerline at intervals of approximately 500 feet (150 meters) starting from the runway threshold. Fixed distance markers may also be present approximately 1,000 feet (300 meters) from the threshold. In addition, runway edge lights may be color coded similar to precision approach runways with yellow rather than white lights for approximately the last 2,000 feet (600 meters) of the runway.

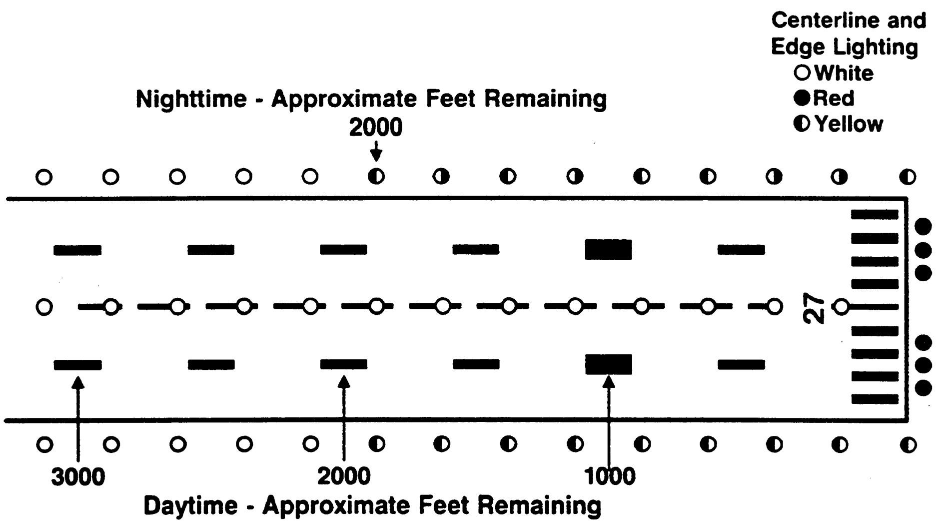

Figure 31. ICAO nonprecision approach runway markings and lighting.

- Other Recovery Techniques

Many windshear recovery techniques were evaluated while establishing the technique recommended above. The techniques below are NOT recommended since they may reduce the chances for surviving a windshear encounter.

- Attempting to maintain target airspeed does not utilize full climb capability of the airplane.

- Attempting to pitch directly to stick shaker does not maximize use of available airplane energy, and results in a degraded flight path and increased exposure to stall.

- Attempting to fly at best Lift/Drag angle-of-attack does not utilize the short-term maximum gradient capability of the airplane.

- Retracting flaps during approach recovery (per the normal go-around procedure) reduces margins to stick shaker and has an adverse impact on initial climb capability of the airplane.

- Use of inertial reference ground speed emphasizes control of speed which is contrary to the recommended recovery technique. In addition, this technique is oriented toward compensating for the windshear and continuing the approach rather than immediately initiating the recovery maneuver. While this technique is not appropriate for microburst encounters, it may be suitable for use in other types of windshears.

- Use of "dive" technique (lowering airplane nose in attempt to accelerate then pull up at some predetermined minimum altitude) exposes the airplane to potentially higher intensity horizontal winds, produces lower minimum recovery altitudes, requires high pitch rates and complicates the recovery procedure.

Again, best recovery results are achieved by properly controlling pitch attitude in conjunction with thrust application.

2.5 SUMMARY

This document has presented the latest air transport industry findings on windshear education and training. As with any learning, however, it must produce changes in attitude and behavior if it is to be effective.

Changes in attitude are necessary to heighten crew awareness of clues which indicate the presence of windshear. In past windshear accidents, significant clues apparently went unnoticed. Recall again that the best defense against the low altitude windshear hazard is to avoid it altogether. This is especially important since shears exist that are beyond the capability of any pilot or airplane. Since present weather information sources and detection systems cannot infallibly detect windshear, flight crews must be ever alert for the signals which will permit avoidance.

Behavior changes are also necessary. These changes involve appropriate pilot technique should the windshear avoidance process fail.

As was discussed in this Pilot Windshear Guide, some of the techniques presented regarding pitch attitude and airspeed control differ from those ordinarily used. However, the recommended techniques have been rigorously studied and evaluated for their effectiveness. Pilots must be prepared to apply these techniques and take decisive action should the need arise.

It is recognized that the value of this training will be challenged given the infrequency of its required use. Like many other piloting skills, windshear training will not be exercised daily and periodic recurrency training will be required to maintain proficiency. Through this process the knowledge and skills pertaining to windshear recognition, avoidance, and recovery will be available and ready for use when required.

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