Journal of Air Law and Commerce

Volume 49 | Issue 2 Article 3

1984

Recommendations for Coping with Microburst Wind Shear: An Aviation Hazard

John McCarthy

RECOMMENDATIONS FOR COPING WITH MICROBURST WIND SHEAR: AN AVIATION HAZARD

JOHN MCCARTHY*

I. THE SCOPE OF THE PROBLEM

IT WAS A humid afternoon in New Orleans on July 9, 1982. Pan Am Flight 759 taxied out into what seemed to be a typical summer thunderstorm situation in New Orleans. Exactly 60 seconds after the pilots of the Boeing-727 aircraft released the brakes, and only 20 seconds after liftoff, the flight crashed just east of New Orleans International Airport, killing all 145 persons aboard and 8 persons on the ground.[1] In its report of the crash, the National Transportation Safety Board (NTSB) listed the probable cause of the disaster as the aircraft's encounter with severe low-altitude wind shear.[2] The report also stated that "[c]ontributing to the accident was the limited capability of current ground-based, low-level wind shear detection technology to provide definitive guidance for controllers and pilots for use in avoiding low-level wind shear encounters."[3]

Low-altitude wind shear, in the aviation context, is a rap-

* Director of the Joint Airport Weather Studies (JAWS) Project of the National Center for Atmospheric Research, Boulder, Colorado; B.A., 1964, Grinnell College; M.S., 1967, University of Oklahoma; Ph.D., 1973, University of Chicago.

[1] NATIONAL TRANSPORTATION SAFETY BOARD, REP. NO. NTSB-AAR - 83- 2, AIRCRAFT ACCIDENT REPORT - PAN AMERICAN WORLD AIRWAYS, CLIPPER 759, BOEING 727 - 235, N4737, NEW ORLEANS INTERNATIONAL AIRPORT, KENNER, LOUISIANA, JULY 9, 1982, 1 (1983) [hereinafter cited as NTSB REPORT].

[2] *Id.* Low-altitude wind shear is sometimes called low-level wind shear, but this term is being replaced by the former to avoid confusion regarding the magnitude of the shear.

[3] NTSB REPORT, *supra* note 1, at 1.

idly changing wind, in either space or time (or both, since space and time are in a sense interchangeable with an appropriate transformation).[4] The effect of wind changes, particularly near the earth's surface, can be quite serious for an aircraft, especially if the change is large over a short distance. Figure 1 illustrates the effect of such change on an aircraft during a particularly severe form of low-altitude wind shear—that occurring in a microburst.[5] In this scenario, an aircraft on takeoff first encounters an increasing headwind, next a downdraft and finally an increasing tailwind. This sequence results in a serious energy loss for an aircraft on either short final landing approach or immediately after takeoff.[6]

---

[4] *See generally* FAA, ADVISORY CIR. NO. 00-50A, LOW LEVEL WIND SHEAR 1 (1979) (defines wind shear as a change in wind direction and speed in a very short distance in the atmosphere). *See also* Hardy, *Wind Shear and Clear Air Turbulence*, 42 J. AIR L. & COM. 165 (1976) (defines wind shear as "the change of the horizontal wind speed or direction with height").

The most common cause of significant low-altutude wind shear is the gust front associated with thunderstorms. *Id.* at 167-68. A gust front is the boundary at the leading edge of a thunderstorm which is formed when a large volume of warm air enters the thunderstorm at low levels and rises until evaporative cooling causes it to fall rapidly. *Id.* This falling mass of air, a so-called "downdraft", pushes rapidly towards the surface where it spreads out in all directions and forms a very sharp boundary or gust front with the warm environmental air. *Id.*

Wind shear also is often associated with the passage of low level weather fronts, the surfaces of which separate two air masses of different characteristics. *Id.* at 167-71. Not all fronts produce significant wind shear — some have broad transition zones which contain gradual changes in wind direction and speed. *Id.* A front is likely to have sharp, narrow transition zones and, therefore, produce significant wind shear if there is a temperature difference across the front of 10 degrees Fahrenheit or more or if it is moving at a speed of 10 knots or more. *Id.* Temperature inversion, or increase of temperature with height, can also cause wind shear. *Id.*

[5] Microbursts are defined and discussed *infra* in text accompanying notes 14-18. A more detailed account of the statistics and data presented in this article and its basis is found in McCarthy, Roberts & Schreiber, *JAWS Data Collection, Analysis Highlights, and Microburst Statistics*, in PREPRINT VOLUME AMS 21ST CONFERENCE ON RADAR METEOROLOGY 19-23 SEPTEMBER 1983, EDMONTON, ALBERTA, CANADA 596-601 (1983).

[6] As an aircraft on takeoff encounters a microburst cell, the steadily increasing headwind increases lift and causes the aircraft to climb at a greater angle. Frost, Chang, McCarthy & Elmore, *Aircraft Performance in a JAWS Microburst*, in PREPRINT VOLUME AMS 21ST CONFERENCE ON RADAR METEOROLOGY 19-23 SEPTEMBER 1983, EDMONTON, ALBERTA, CANADA 630 (1983) [hereinafter cited as *Aircraft Performance*]. This reduces the ground speed of the aircraft. *Id.* At the center of the microburst, the aircraft encounters a downdraft that causes a decrease in the aircraft's angle. *Id.* This results in a loss of lift. Also, the aircraft is carried downward by the sinking air mass. *Id.* This combination of the loss of lift and the sinking nature of the downdraft causes a rapid loss in altitude. *Id.* If this does not cause the aircraft to strike

Figure 2 diagrams the probable performance effect of a microburst on a Boeing 727 aircraft when the microburst is penetrated on an approach-to-landing. The computer simulation on which the diagram is based indicates that the pilot of the aircraft would not be able to avoid a crash.

The crash of Pan Am Flight 759 was not an isolated event. Of 19,332 NTSB reports of accidents and incidents in airport terminal areas, at least 27 involved larger aircraft (greater than 12,000 lbs) in encounters with wind shear.[7] These accidents and incidents are detailed in Table 1. In addition, in 1981 alone, 662 fatal accidents occurred in general aviation aircraft, with "weather" accounting for approximately 40 percent of them.[8] Due to inadequate investigation and lack of reconstruction data, it is not known to what extent wind shear was a causative factor in these accidents. It can be presumed, though, that wind shear played a significant role in many of them. While low-altitude wind shear crashes are not common, they clearly make a sizable impact on air carrier injuries and fatalities when they do occur.[9] Consequently, the aviation community must better understand wind shear in order to adequately address long-term solutions to aviation safety problems.

---

the ground, it will enter the tailwind zone. *Id.* The increasing tailwind will further reduce the aircraft's angle but more importantly will cause a loss of airspeed and a corresponding loss of lift. *Id.*

[7] *See* COMMITTEE ON LOW-ALTITUDE WIND SHEAR, LOW-ALTITUDE WIND SHEAR AND ITS HAZARD TO AVIATION 14-15 (1983). Table 1 was compiled from data provided by: FAA, WIND SHEAR RELATED AIRCRAFT ACCIDENTS 1971-1978 (Dec. 1982); T. FUJITA, MANUAL OF DOWNBURST IDENTIFICATION FOR PROJECT NIMROD (May 1975) (Satellite and Mesometeorology Research Project Paper 156 at the University of Chicago); J. SHRAGER, THE ANALYSIS OF NTSB FIXED-WING AIRCRAFT ACCIDENT/INCIDENT REPORTS FOR THE POTENTIAL PRESENCE OF LOW LEVEL WIND SHEAR, FAA-DOT-77-169 (1977); Fujita, *Downbursts and Microbursts - An Aviation Hazard,* in PREPRINTS OF THE AMS NINTH CONFERENCE ON RADAR METEOROLOGY 94 (1980); Fujita & Byers, *Spearhead Echo and Downburst in the Crash of an Airliner,* MONTHLY WEATHER REV., Feb. 1977, at 129; Fujita & Caracena, *An Analysis of Three Weather-Related Aircraft Accidents,* 58 BULL. AM. METEOROLOGICAL SOC'Y 1164 (1977); Wurtele, *Meteorological Conditions Surrounding the Paradise Airline Crash of March 1, 1964,* J. APPLIED METEOROLOGY, Oct. 1970, at 787; Letter from NTSB to FAA (March 25, 1983); and miscellaneous NTSB Fixed-Wing Aircraft Accident/Incident Reports.

[8] FEDERAL AVIATION ADMINISTRATION, FAA STATISTICAL HANDBOOK OF AVIATION CALENDAR YEAR 1981 (1981).

[9] *See, e.g.*, NTSB REPORT, *supra* note 1.

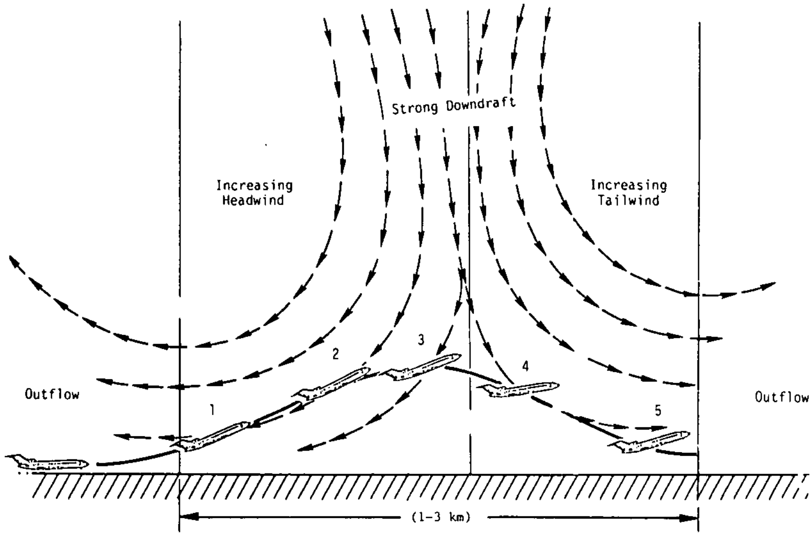

Figure 1. Schematic representation of takeoff accident in a microburst situation similar to that encountered by Pan Am Flight 759. (See text at notes 1-2.) The aircraft first encounters a headwind and experiences increasing performance. This is followed in short succession by a downdraft and a strong tailwind, both causing serious performance loss, possibly resulting in a crash.

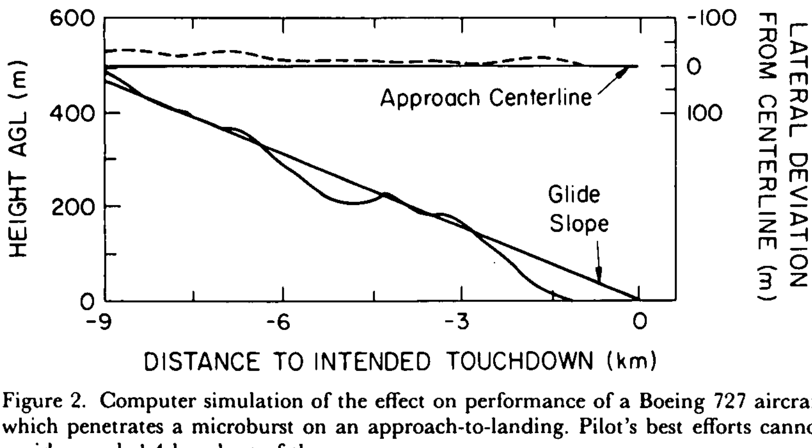

Figure 2. Computer simulation of the effect on performance of a Boeing 727 aircraft which penetrates a microburst on an approach-to-landing. Pilot's best efforts cannot avoid a crash 1.4 km short of the runway.

The Joint Airport Weather Studies (JAWS) project was begun in order to improve understanding of this serious meteor-

TABLE 1 AIRCRAFT ACCIDENTS AND INCIDENTS RELATED TO LOW-ALTITUDE WIND SHEAR (1964-1982)

No	Year & Date	Time (LST)	Location	Airline Flt No (Aircraft type)	T/O or LDG (Runway)	Fat/Inj	Wind Shear Experienced	Weather Systems
1	1964 MAR 01	1129	Lake Tahoe NV	Paradise 901A (L-1049)	●LDG ---	85/0	During climbout after a missed approach	Strong mountain lee wave during snowstorm
2	1964 JUL 01	2134	JFK New York NY	AA 64 (B-720B)	●LDG 31R	0/0	Windshift from headwind to crosswind	Thunderstorm with a sharp pressure rise
3	1965 MAR 17	1858	Kansas City MO	TWA 407 (B-727)	●LDG 36	0/0	Wind direction change on final, 310°-21kts to 280°-22kts	Unstable moist air
4	1968 JUN 08	1351	Salt Lake City UT	UAL 8327 (B-727)	●LDG 34L	0/1	260°-13kts at 1351 to 280°-12kts at 1354	Heavy thunderstorm with suspected gust front
5	1970 JUL 20	1136	Naha AB Okinawa	FFLY TIG 45 (DC-8)	●LDG 18	4/0	10kts tailwind near threshold	Heavy rainshower one mile in diameter
6	1970 DEC 10	1926	St Thomas VI	Carib-Atl (CV-640)	●LDG 09	NA	Landing in 080°-20kts wind	Lee side flow in rainshower
7	1971 JAN 04	1832	LGA New York NY	FAA N-7 (DC-3)	●LDG 04	0/2	Tailwind changed into headwind.	Frontal Shear
8	1972 MAY 18	1421	Ft Lauderdale FL	EAL 346 (DC-9)	●LDG 09L	0/3	180°-10kts at 1418 to 130°-12kts at 1426	Heavy thunderstorm
9	1972 JUL 26	1406	New Orleans LA	NA 32 (B-727)	●LDG 28	0/0	IAS dropped 162 to 122kts	Intense rainstorm and thunderstorm
10	1972 DEC 12	2256	JFK New York NY	TWA 669 (B-707)	●LDG 04R	0/0	42kts tailwind at 1500′ to 5kts headwind at the surface	Frontal shear; Fog and drizzle
11	1973 MAR 03	1250	Wichita KS	TWA 315 (B-727)	●LDG 19R	0/0	100°-10kts at 1240:00 to 170°-10kts to 070°-10kts at 1249:10	Thunderstorm
12	1973 JUN 15	1403	ORD Chicago IL	Airlift 105 (DC-8)	●LDG 22R	0/0	Estimated downdraft 50fps at 3000′, 13fps at 500′ AGL	Heavy rainstorm
13	1973 JUL 23	1643	St Louis MO	OZ 809 (FH-227B)	●LDG 30L	38/6	Up- and downdrafts	Outflow shear; Thunderstorm, sharp pressure rise
14	1973 NOV 27	1851	Chattanooga TN	DL 516 (DC-9)	●LDG 20	0/42	Low-altitude wind shear	Outflow shear; Thunderstorm outflow

15	1973	DEC 17	1543	Boston MA	Iberia 933 (DC-10)	●LDG 33L	0/16	200°-24kts at 500′, 260°-12kts at 200′, 315°-08kts at surface	Frontal shear; Rain and fog
16	1974	JAN 30	2341	Pago Pago SAMOA	PAA 806 (B-707)	●LDG 05	96/5	Decreasing headwind and/or downdraft during the final 4 seconds	Outflow shear; Heavy rain-shower
17	1975	JUN 24	1457	JFK New York NY	EAL 902 (L-1011)	○LDG 22L	—	8kts headwind to 6kts tailwind with 20fps down-draft	Small downburst or microburst; Strong thunder-storm
18	1975	JUN 24	1505	JFK New York NY	EAL 66 (B-727)	●LDG 22L	112/12	14kts headwind to 1kt headwind with 21fps down-draft	Small downburst or microburst; outflow shear; Strong thunderstorm
19	1975	AUG 07	1511	Denver CO	CO 426 (B-727)	●T/O 35L	0/15	IAS decreased 158 to 116kts in 5 seconds	Small downburst or microburst; Outflow shear; Thunderstorm
20	1975	NOV 12	2002	Raleigh NC	EAL 576 (B-727)	●LDG 23	0/1	10° windshift, gust up to 20kts	3 inch per hour rain fall rate
21	1975	DEC 31	1056	Greer SC	EAL (DC-9)	●LDG 03	0/0	200° change in wind direc-tion	Light rain and fog
22	1976	JUN 23	1612	Philadelphia PA	AL 121 (DC-9)	●LDG 27R	0/87	65kts headwind to 20kts tailwind	Microburst; Outflow shear; Fast-moving thunderstorm
23	1976	DEC 12	2326	Cape May NJ	Atl Cty 977 (DHC-6)	●LDG 19	3/7	Gust to 50kts	Frontal shear
24	1977	JUN 03	1258	Tucson AZ	CO 63 (B-727)	●T/O 21	0/0	30kts headwind to 30kts tailwind	Microburst; Outflow shear; Downdraft in thunderstorm
25	1979	AUG 22	1412	Atlanta GA	EAL 693 (B727)	○LDG 27L	—	strong downdraft and headwind	Microburst; Thunderstorm rainshower
26	1982	JUL 09	1509	New Orleans LA	PAA 759 (B-727)	●T/O 10	153/9	Headwind tailwind and downdraft shear	Microburst with heavy rain
27	1982	JUL 28	1521	LGA New York NY	TWA 524 (B-727)	○LDG 22	—	Severe wind shear at 20-100′ AGL	Strong thunderstorm with gusty winds

TOTAL: ● 24 Accidents; ○ 3 Incidents; 491 Fatalities / 206 Injuries ological and aviation problem, low-altitude wind shear.[10] The convective microburst,[11] the probable cause of the crash of Pan Am Flight 759,[12] was the principal focus of the JAWS field program conducted near Stapleton International Airport between 15 May and 13 August 1982. In the sections and illustrations to follow, this comment will examine in some detail the progress made during the JAWS project in the identification, description, and detection of microbursts.[13] This article concludes with recommendations that, if followed, will substantially, if not completely, eliminate low-altitude wind shear as a serious aviation hazard.

II. THE MICROBURST EXAMINED

For our purposes, a microburst is defined as a downdraft-induced, diverging, horizontal flow of air near the earth's surface which has an initial horizontal dimension of less than 4 kilometers (km) and a differential velocity of greater than 10 meters per second (m/s).[14]

Figure 3 is a multiple Doppler radar[15] analysis of a

---

[10] JAWS was initially conceived in 1980 with the idea of combining the expertise of three scientists representing three important subdisciplines. Professor Theodore Fujita of the University of Chicago had previously discovered the existence of the microburst phenomena, but desired a greater examination of the event. James Wilson of the National Center for Atmospheric Research (NCAR) had been addressing operational wind shear detection by Doppler radar and wanted to further pursue similar objectives. The author had extensively examined aircraft performance in low-altitude wind shear and wanted to gather more information in this area. We believed that many aspects of the microburst wind shear problem had not been adequately addressed, from both basic scientific and applied aviation hazard perspectives.

[11] Microbursts are defined and discussed *infra* in text accompanying notes 14-29.

[12] *See supra* text accompanying notes 1-3.

[13] *See infra* text accompanying notes 14-55.

[14] *See* Fujita, *Tornadoes and Downbursts in the Context of Generalized Planetary Scales,* 38 J. ATMOSPHERIC SCI. 1511, 1528 (1981).

[15] Doppler radar systems work on the principle of the Doppler effect. The Doppler effect is the change in the observed frequency of sound, light or other waves caused by motion of the source or the observer. A familiar example of the Doppler effect for sound waves is the increase in pitch of a train whistle as the train approaches. *Doppler Effect,* in 4 MCGRAW-HILL ENCYCLOPEDIA OF SCIENCE & TECHNOLOGY 375 (5th Ed. 1982). Doppler radar systems are capable of measuring the relative velocity of the radar system and the radar target (in this context, an air mass). The operation of such systems is based on the fact that the Doppler frequency shift in the target echo is proportional to the radial component of target velocity. *Doppler Radar*, in 4 MCGRAW-HILL ENCYCLOPEDIA OF SCIENCE & TECHNOLOGY 376 (5th Ed. 1982). Wind speed

microburst that occurred over the JAWS instrumented research network on July 14, 1982.[16] This pattern is illustrative of the diverging air flow seen at the earth's surface and the intense downdraft seen in the microburst center. Figure 4 shows the frequency of microbursts detected by Doppler radar over a 91-day period as a function of the time of day at which they were detected.[17] Notice that microburst events tended to peak during the early afternoon and again in the early evening and were generally associated with convective weather peaks.[18]

The intensity of Doppler radar-detected microbursts can be seen in Figure 5, which shows the microburst frequency as a function of the maximum differential wind velocity near the earth's surface.[19] In this illustration, the maximum headwind velocity difference is shown. This change in velocity ranged from 10-50 m/s (approximately 20-100 knots). One microburst observed by Doppler radar had a differential of 48 m/s (100 knots).[20] In Figure 6, data from both the Low-Level Wind Shear Alert System (LLWSAS) and the NCAR Portable Automated Mesonet (PAM)[21] surface weather station system have been combined to show the maximum wind velocity for a particularly severe microburst event at Stapleton. In this case, the velocity differential over the north-south runways is approximately 85 knots. This shear was one of the most severe seen in JAWS and is believed to be unflyable either on an approach-to-landing or immediately upon takeoff. The microburst velocity differential that brought down

---

can be determined from Doppler systems utilizing acoustic waves, microwaves or lasers. *See Hardy, supra* note 4, at 178-81.

[16] Wilson & Roberts, *Evaluation of Doppler Radar For Airport Wind Shear Detection*, in PREPRINT VOLUME AMS 21ST CONFERENCE ON RADAR METEOROLOGY 19-23 SEPTEMBER 1983, EDMONTON, ALBERTA, CANADA 14, 15-16 (1983).

[17] *Id.* at 600.

[18] Convection is the transfer of thermal energy by actual physical movement from one location to another of a substance in which the thermal energy is stored. *Convection (Heat)*, in 3 MCGRAW-HILL ENCYCLOPEDIA OF SCIENCE & TECHNOLOY 607 (5th Ed. 1982). In the context of weather, heat is carried upward in the air mass that contains it. *Id.*

[19] McCarthy, Roberts & Schreiber, *supra* note 5, at 600.

[20] *Id.*

[21] See *infra* notes 35-48 and accompanying text for a discussion of these systems.

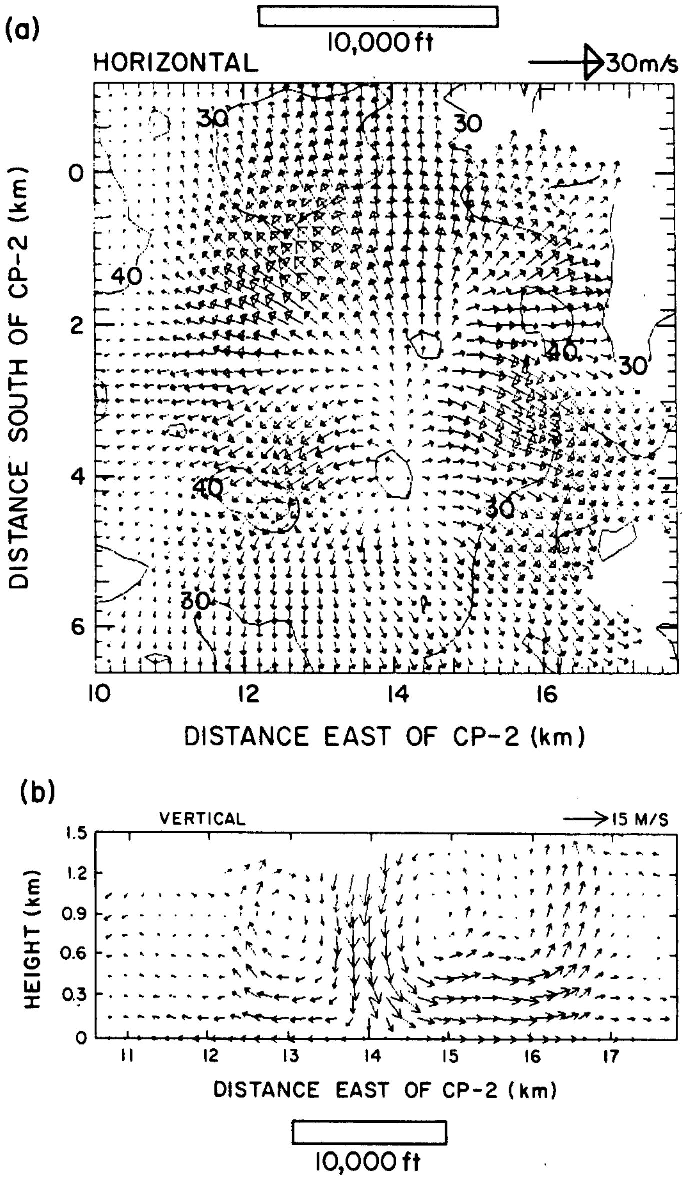

Figure 3. Dual Doppler radar analysis of a severe microburst, as seen over the JAWS network on 14 July 1982. Shown are (a) the horizontal wind field near the earth's surface (notice the strong diverging outflow typical of a microburst), and (b) a vertical cross section through (a) which shows the downdraft, outflow, and a commonly observed horizontal vortex circulation. Note also how remarkably similar this cross section airflow is to the "schematic" of Figure. 1. For reference, typical 10,000 ft jet runways are shown on the figure. This illustrates the small scale of the microburst.

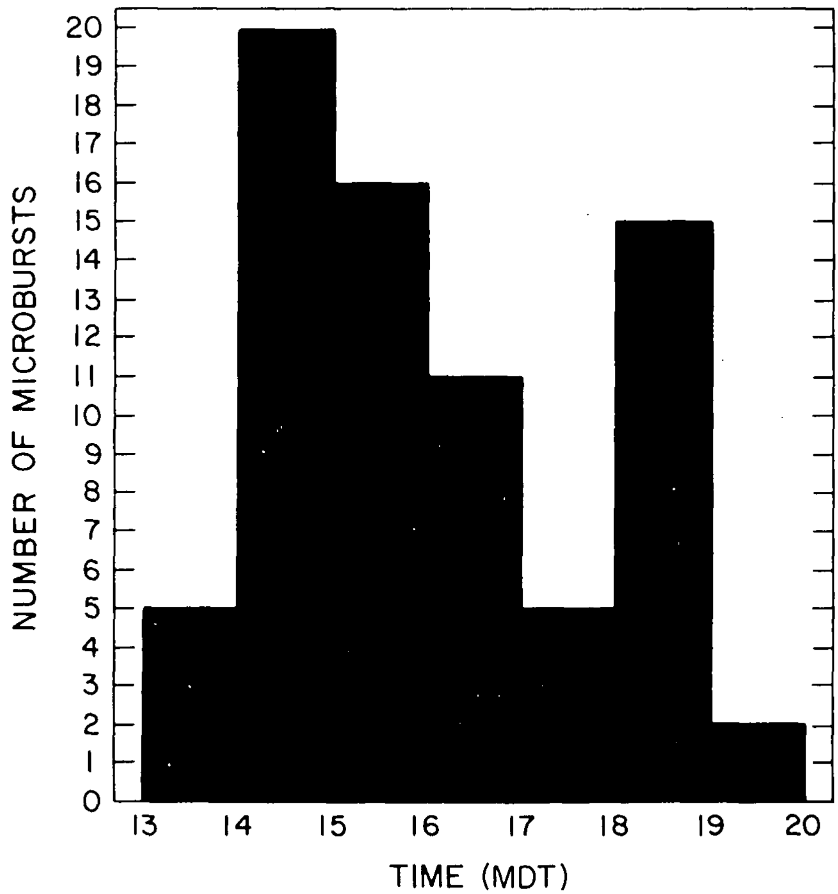

Figure 4. Number of JAWS microbursts identified by Doppler radar over a 91-day period as a function of the time of day. These microbursts are clearly related to convective phenomena, with significant peaks near 1400 and 1800 hours.

Pan Am Flight 759 was only 24 m/s,[22] or approximately the median value of radar-observed JAWS microbursts.[23]

When 40 microbursts were examined thoroughly with Doppler radar, it was found that 50 percent reached their maximum intensity within 5 minutes after first detection while 95 percent did so within 10 minutes from the time the

[22] NTSB REPORT, *supra* note 1, at 28.
[23] McCarthy, Roberts & Schreiber, *supra* note 5, at 600.

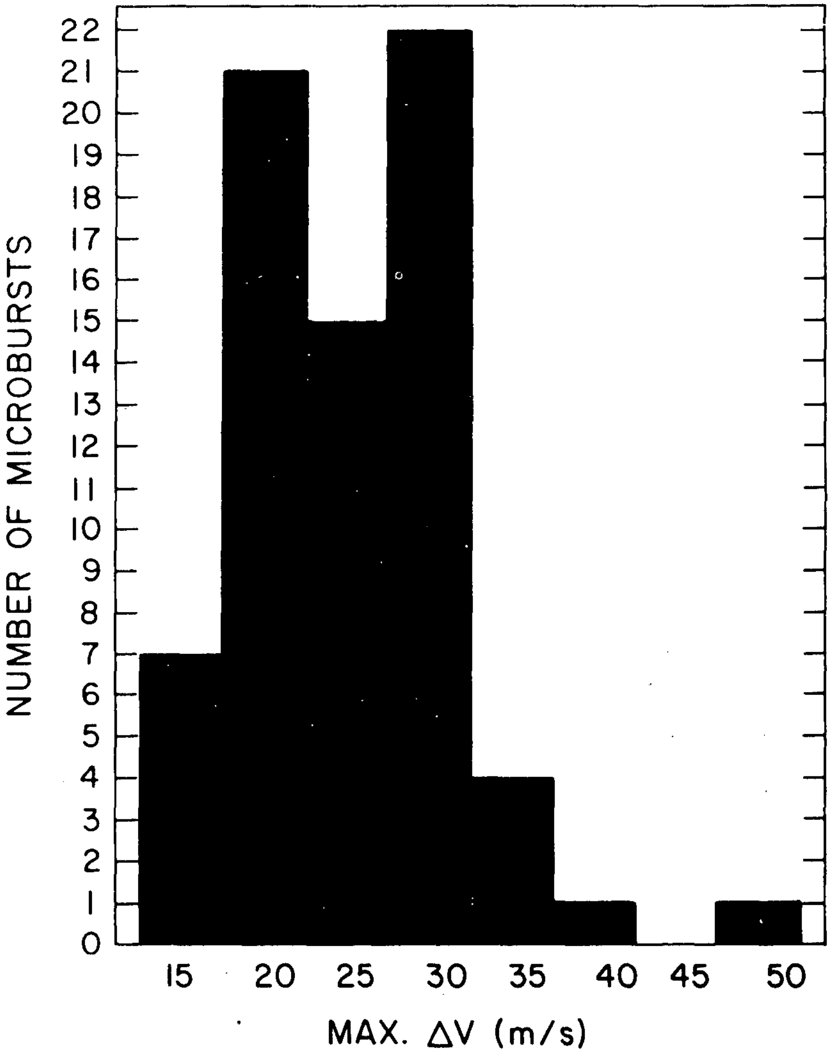

Figure 5. Number of JAWS microbursts as a function of the maximum differential velocity measured near the earth's surface by Doppler radar. The figure shows the approximate maximum headwind-to-tailwind shear that an aircraft would encounter.

diverging outflow first appeared at the surface.[24] Sometimes the microbursts dissipated within 5 to 10 minutes, with the maximum velocity differential increasing from 12 to 24 m/s

[24] Wilson & Roberts, *supra* note 16, at 617-18.

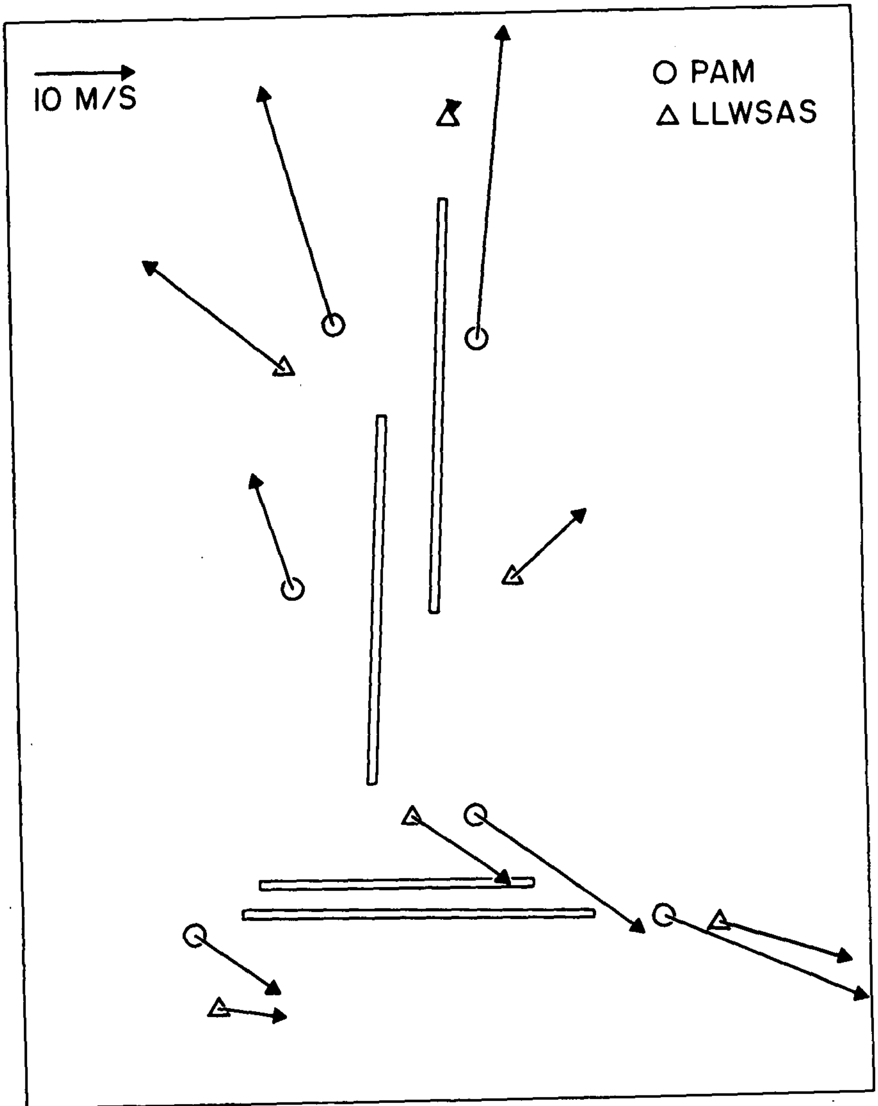

Figure 6. Merging of LLWSAS and NCAR PAM wind velocity data for 1359 Mountain Daylight Time, 15 July 1982, over Stapleton. In this situation, a 43 m/s (85 knot) headwind/tailwind differential existed along the pair of N-S runways. This is considered to be a lethal low-altitude wind shear which, fortunately, no aircraft encountered.

in this period.[25] Furthermore, it was found that microbursts are not circularly symmetric in their horizontal diverging outflow as implied in Figure 1,[26] but are decidely asymmetric.[27] They are also clearly small-scale events, being only 1.8 km in diameter when first detected and growing to only 3.1 km on the average in 6.4 minutes.[28] Figure 7 is a composite drawing of a microburst life-cycle as observed by Doppler radar. Notice that the full sequence is seen to last 15 minutes, with the event being small-scale at the surface for only several minutes.[29]

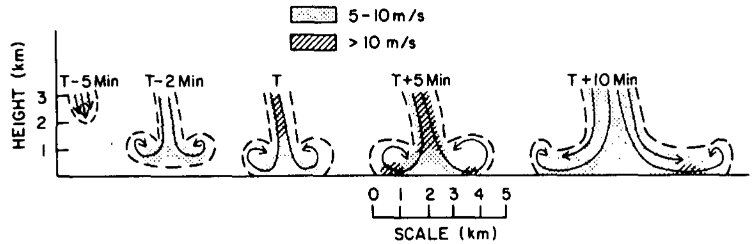

Figure 7. Vertical cross-section of the evolution of the microburst wind field, based on a summary of data collected by examining 50 microbursts with Doppler radar. "T" is the time of initial divergence reaching the surface. Notice that it takes about 5 minutes after "T" for the microburst to reach maximum intensity. In addition, the divergence is observed above the earth's surface several minutes before impact with the surface. Note also the small scale of the phenomena, typically less than the length of a jet runway.

III. Detection of the Microburst

A. *Radar Reflectivity*

Conventional aviation wisdom uses radar echo intensity (radar reflectivity) as an indication of storm severity.[30] The more intense the return is, the more likely the "thunder-

---

[25] *Id.*

[26] *See supra* text accompanying notes 5-6.

[27] Wilson & Roberts, *supra* note 16, at 618.

[28] *Id.*

[29] *Id.* at 617-18. The JAWS Project data presented in this section represents the first time microburst activity has been observed and recorded in such detail.

[30] *See generally Radar Meteorology*, in 11 McGraw-Hill Encyclopedia of Science & Technology 232 (5th Ed. 1982).

storm" will be severe.[31] Of course, a conventional weather radar cannot measure windspeed.[32] Figure 8 shows the correlation between microburst echo intensity (reflectivity) as seen on conventional radar and maximum velocity differential.[33] Clearly, there is no correlation, with strong microburst wind shears having reflectivities ranging from nearly zero to above 70 dBZ.[34] Hence, it is clear that a conventional airborne or ground-based radar cannot be used to detect severe microburst wind shears.

B. *The Low Wind Shear Alert Systems*

The Low-Level Wind Shear Alert System (LLWSAS) is the only wind shear detection and warning system in routine operation.[35] Fifty-nine systems are operating at major airports in the United States, while 51 additional systems are expected to be installed by 1984.[36] The system consists of an array of wind speed and direction measuring devices that are spaced in a ring around a centerfield site, as shown for Denver's Stapleton International Airport in Figure 9.[37] A computer maintains a running, two- minute average of the wind velocity and direction at the centerfield site.[38] Once every seven to ten seconds, the computer compares wind velocity and direction at the surrounding sites with the centerfield average.[39] If the computer detects a change of significant magnitude, an alert is given to the control tower.[40]

---

[31] *Id.*

[32] Conventional weather radar can measure windspeed only if reflective targets such as rain drops or small insects are being carried along by the wind. *Id.* at 235.

[33] McCarthy, Roberts & Schreiber, *supra* note 5, at 5-6.

[34] *Id.*

[35] JOINT AIRPORT WEATHER STUDIES PROJECT, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH, REPORT NO. 01-83, STATISTICS FROM THE OPERATION OF THE LOW LEVEL WIND SHEAR ALERT SYSTEM (LLWSAS) DURING THE JAWS PROJECT: AN INTERIM REPORT FROM THE JAWS PROJECT AT NCAR 7 (September 30, 1983) [hereinafter cited as LLWSAS REPORT].

[36] *Id.*

[37] *Id.* at 6-7. The wind speeds shown in Figure 9 indicate that a microburst lasting only 50 seconds has occurred at the southeast site.

[38] *Id.* at 6.

[39] *Id.*

[40] *Id.*

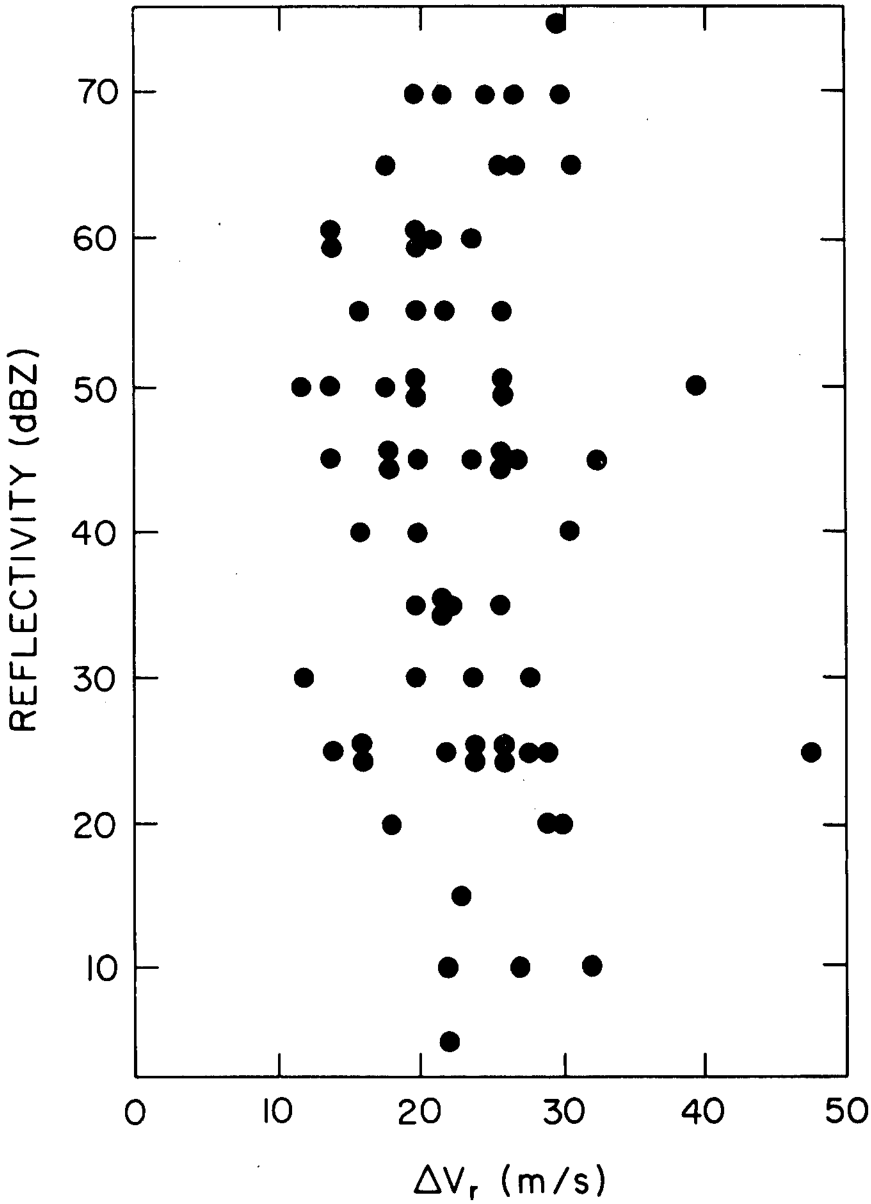

Figure 8. Plot of maximum radar reflectivity (echo intensity) as a function of maximum velocity differential. Serious low-altitude microburst wind shear can occur in a wide range of convective intensity, from non-thunderstorms (reflectivities generally less than 30 dBZ) to intense thunderstorms (reflectivities greater than 50 dBZ). In addition, severe shear can occur when the reflectivities are quite low, requiring very sensitive detection capabilities.

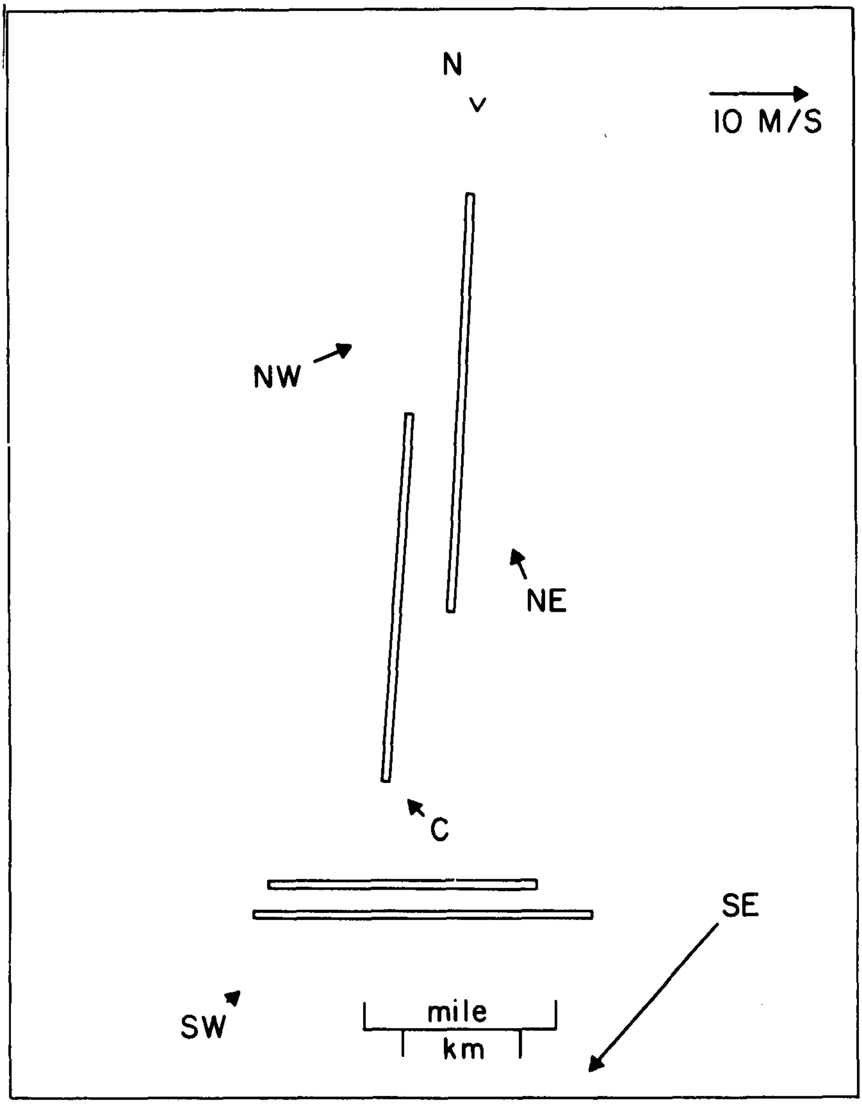

Figure 9. Plot of LLWSAS detected wind vectors at 1410 Mountain Daylight Time on 14 July 1982. This figure also indicates the positions of the LLWSAS sites in JAWS. The 20 m/s gust at the SE sensor represents a microburst seen at the local site for only 50 seconds. This demonstrates the highly localized and short-lived nature of the phenomena.

Figure 10 shows the number of LLWSAS alarms recorded during the JAWS project, by number per day, in comparison to the number of microbursts seen by using the NCAR Portable Automated Mesonet (PAM) surface weather station system.[41] Notice that the LLWSAS indicates the presence of shear events on days when microbursts are not present. Scrutiny of those days suggests that the LLWSAS is triggered for events that do not seem, upon inspection, to be significant.[42]

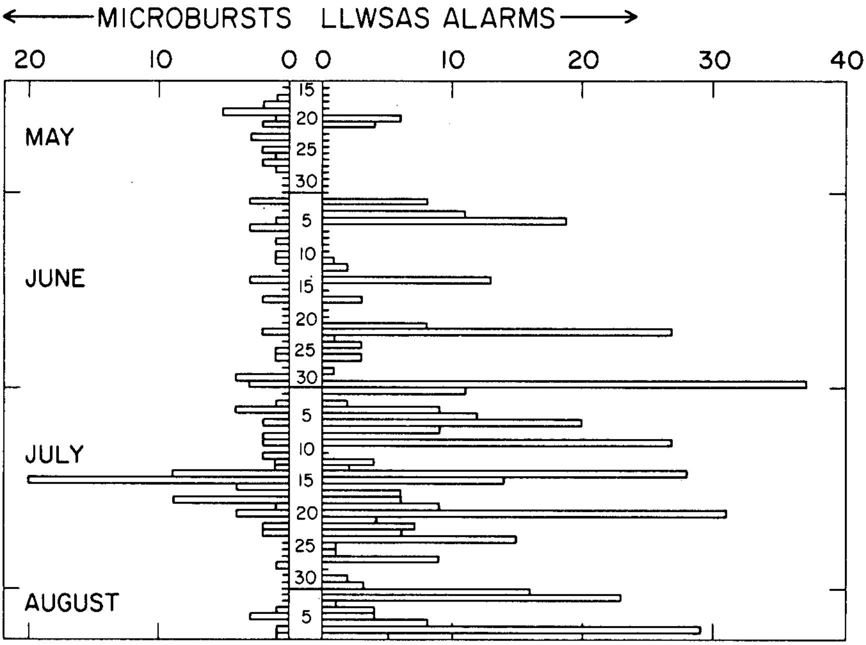

Figure 10. Comparison, by day, of the number of microbursts seen by the NCAR PAM system in the Stapleton area to the number of LLWSAS alarms. An in-depth study indicates that the LLWSAS registers an alert in many instances when significant low-altitude wind shear is absent.

[41] The Portable Automated Mesonet (PAM) developed by NCAR provides 27 surface-based weather stations capable of automatically measuring temperature, humidity, wind speed and direction, atmospheric pressure, and rainfall, which is averaged and reported each minute. Also recorded is the peak wind speed gust during the minute for each station. The stations, designed to be left unattended, report by a radio link each minute to a computerized base station. *See* Brock & Govind, *Portable Automated Mesonet in Operation*, 16 J. APPLIED METEOROLOGY 299 (1977).

[42] LLWSAS REPORT, *supra* note 35, at 14-16.

Preliminary conclusions regarding the LLWSAS analysis suggest that the current system is deficient because its station spacing is not dense enough to adequately detect all microbursts.[43] The average spacing between an LLWSAS centerfield sensing station and remote sites is 3 km.[44] Since data from at least two stations are necessary to distinguish wind shear activity from simple gusts, microbursts smaller than 3 km are not detected.[45] Furthermore, the centerfield site is not wind-shear effective because its "averaging period" is too long. A brief high wind encounter at centerfield is not identified unless it is of large magnitude.[46]

While the LLWSAS clearly can detect some wind shear events at the surface, such as gust fronts and larger microbursts, the system needs improvement. This can be accomplished by decreasing the averaging period of the centerfield site, by increasing station density, and by improving data quality.[47] In addition, by recording the LLWSAS data at all locations, the national wind shear statistical data base would be improved. This is sorely needed because there is not a clear understanding of low-altitude wind shear frequency nationwide.[48]

C. *Terminal Doppler Radar*

The great success of Doppler radar[49] in detecting microburst wind shear during the JAWS effort has led to the concept of an airport terminal Doppler radar.[50] Figure 11 shows several Doppler radar positions in and around an airport (in this case, Stapleton). Positions (a) represent a dual

---

[43] *Id.* at 22.

[44] *Id.*

[45] *Id.*

[46] *Id.* Other limitations of the LLWSAS are that surface wind events outside the three km radius of the sensors are not detected; vertical motions (i.e, downdrafts) are not directly sensed; flight path winds are not directly measured; and diverging horizontal winds that occur above the surface are not detected. *Id.* at 23.

[47] *Id.* at 24-25.

[48] *Id.* at 25.

[49] Doppler radar is described *supra* note 15.

[50] Wilson & Roberts, *supra* note 16, at 616.

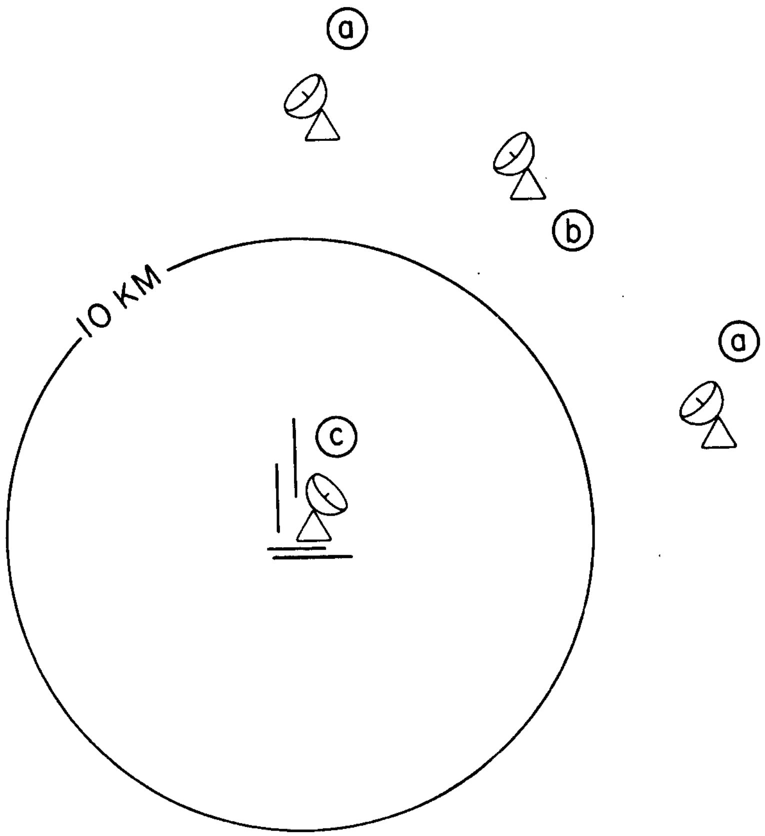

Figure 11. Proposed locations for three Doppler radar systems to be used in detecting low-altitude wind shear near an airport. The radars labeled represent (a) an optimum but expensive dual-Doppler system, (b) a single radar system that is off the airport, and (c) a single radar near the airport center.

Doppler layout which would provide an optimal means by which the full three-dimensional velocity picture of wind shear events over the airport could be measured. Position (b) represents an off-airport location for a single Doppler radar, and position (c) represents the location for a single radar on the airport.[51] Figure 12 illustrates the detection capabilities of various radar placements. Figure 12(a) shows the horizontal velocity field for a microburst, with a 10,000 ft (3 km)

---

[51] *Id.* at 620.

northwest-southeast airport runway superimposed. In this example, the microburst is not circularly symmetric but shows diverging outflow principally along the runway axis and, to a lesser degree, to the northeast. This pattern is what would be seen from the two radars shown in position (a) in Figure 11. Figure 12(b) shows the velocity seen from a radar situated off-airport to the northeast. Figure 12(c) shows the radial velocity seen from a single radar (not shown) 13 km to the southeast along the runway centerline.[52] Notice that this radar is capable of seeing the headwind/tailwind component along the runway, while the northeast radar (Figure 12(b)) barely sees the microburst event. It is, in fact, the headwind/tailwind component that most affects aircraft performance loss in a severe low-altitude wind shear.[53]

From studies such as these, it has been tentatively concluded that a Doppler radar on or very close to the airport center is the best solution to the terminal-area hazard, although more work is needed to clarify this point.[54] The system must be fully automatic and have a 60-second update rate.[55] Such a system would be capable of detecting most, but not all, microburst wind shear situations, as well as other convective shears such as gust fronts. In addition, this system would be quite capable of detecting frontal and terrain shears whenever precipitation is present. Installing such systems would be quite expensive, and therefore, they could not be located at every airport.

IV. RECOMMENDATIONS FOR THE FUTURE

The ongoing analysis of the JAWS data discussed in this article has led to the following set of recommendations for

---

[52] *Id.* at 621.
[53] *See supra* note 6 and accompanying text.
[54] Wilson & Roberts, *supra* note 16, at 622-23.
[55] *Id.* at 622.

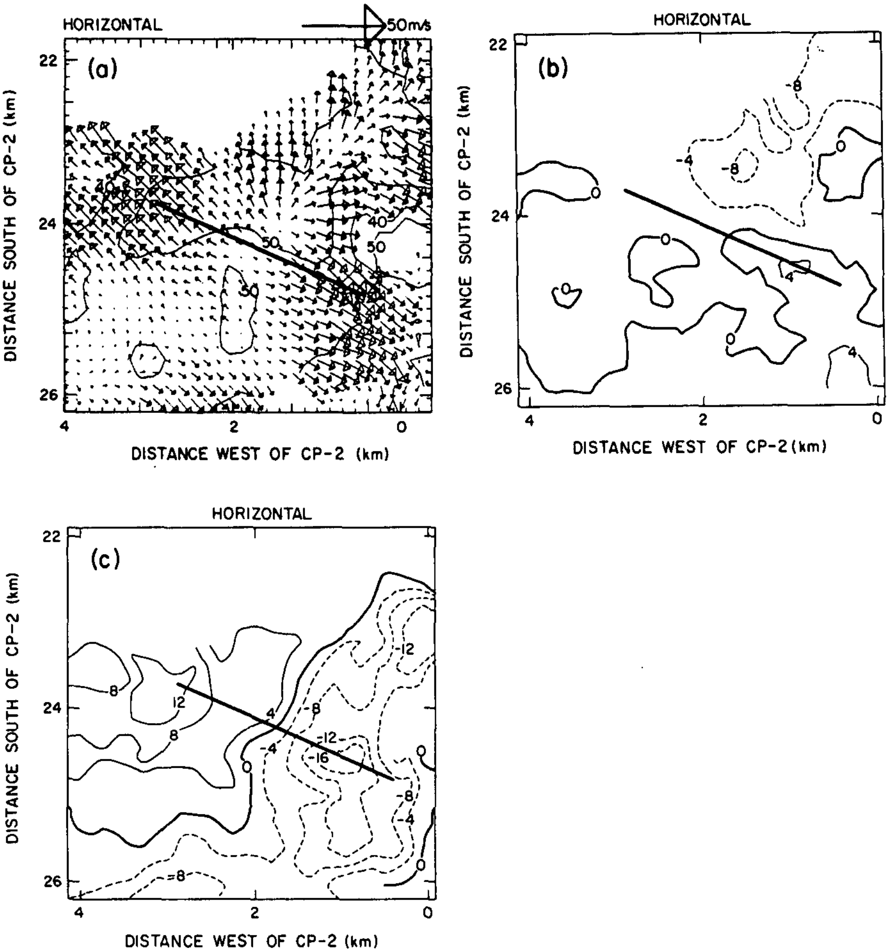

Figure 12. Simulation of the radial velocity field observed by two hypothetical off-airport radars viewing a microburst as 1846 Mountain Daylight Time on 5 August 1982.

Figure 12(a). Actual horizontal windfield at a height of 50-80m, agl based on a dual-Doppler analysis. The hypothetical runway of 2.7 km is superimposed on the microburst. The contours represent radar reflectivity factors (dBZ).

Figure 12(b). Simulated Doppler radial winds for a radar located 13 km northeast of the airport.

Figure 12(c). Simulated Doppler winds for a radar located southeast of the airport.

Figure(a) represents an optimal (but expensive) view; Figure (b) seriously underestimates the magnitude of the headwind/tailwind shear that an aircraft would encounter along the runway; Figure (c) represents an accurate estimate of the runway shear. A single Doppler radar at airport center has the best chance of measuring the shear intensity along each active runway, assuming a dual system is not implemented. However, an off-airport site has the best chance of observing incipient clues of microburst information.

improving aviation safety in relation to the hazard of wind shear:

A. *Increased Awareness and Training*

Pilot and air traffic controller awareness regarding the serious nature of low-altitude wind shear needs to be greatly increased.[56] Many pilots apparently feel that they can successfully penetrate all wind shear situations, in spite of the record of accidents. Also, controllers often are not aware of the need to rapidly disseminate highly perishable pilot reports of wind shear and other observations. Pilot training must stress a philosophy of "reading all of the danger signs." Clues such as events seen on the current or improved LLWSAS, visual characteristics of wind shear events seen from the cockpit, reports of encounters from other pilots, signs from cockpit flight instrumentation, and other sources must be evaluated by the pilot to avoid severe wind shear.

B. *Improved Penetration Procedures*

Wind shear penetration flight procedures must also be improved to better equip pilots to cope with encountered wind shear. Although the best plan is to avoid severe shear if possible, it is imperative that aircraft manufacturers develop improved techniques for successful penetrations and that airline training personnel transmit such procedures to flight crews.

C. *Improved Detection Techniques*

LLWSAS must be improved by increasing station density and by enhancing the capability of the centerfield sensor by decreasing its averaging time. LLWSAS data must also be

[56] To aid in this effort, the JAWS Project at NCAR, under sponsorship of the FAA, has recently completed a wind shear information video tape entitled "The Probable Cause." This tape is designed to provide pilots and controllers with current information regarding the nature and severity of low-altitude wind shear, and to provide methods for pilots to use should they happen to encounter wind shear. In addition, data sets such as those shown in Figures 3 and 12a are being prepared for improved high resolution wind shear models for flight training. *See generally Aircraft Performance, supra* note 6. For example, Figure 2 shows the vertical and horizontal flight profile for a B-727 aircraft on approach through a JAWS microburst data set, as determined from a numerical model of aircraft performance. As can be seen, the aircraft crashes about 1.4 km short of the runway. Studies such as these are instrumental in providing improved safety through pilot simulator training.

recorded nationwide to provide a national statistical base on wind shear occurrences, to provide a record for accident investigation, and to allow for improved routine maintenance of systems. Also, an excellent and available solution to the problem of detection appears to be terminal Doppler radar systems situated on or near major airports. Although such systems would not be foolproof, a high degree of protection would be provided to those airports that had such installations.

Probably the ultimate solution for wind shear detection is the successful development of an effective airborne detection and warning system capable of detecting wind shear in all known conditions several miles ahead of an aircraft. Such a system could be based on a pulsed, microwave Doppler radar. Current airborne wind shear detection and warning systems do not allow for significant avoidance, since these systems merely alert the pilot of the in-situ presence of shear conditions.

V. Conclusion

The examination of JAWS data and the conclusions drawn lead to several imperatives. It is important to accept the fact that no single solution to the low-altitude wind shear problem is sufficient. A variety of solutions is required, including better basic scientific understanding of the windshear phenomenon, better training, and better detection instrumentation. In addition, the nation's aviation system requires a carefully integrated wind shear effort to accomplish the improvements described herein. With such a broad spectrum approach, it is possible to eliminate hazardous wind shear encounters.[57]

[57] Approximately 125 scientists, engineers, technicians, pilots, managers, and administrators were directly involved in research during the JAWS Project. We thank them all, but especially my two JAWS associates, Theodore Fujita and James Wilson; Robert Serafin, Director of the Atmospheric Technology Division of NCAR; Richard Carbone, Manager of the Field Observing Facility at NCAR; Wilmot Hess, Director of NCAR, whose support of JAWS during our darkest funding hours was vital; Phyllis O'Rourke, JAWS Project Administrator; and Shelley Zucker, JAWS Project Administrative Secretary. JAWS is funded by NCAR, the National Science Foundation, the FAA through Interagency Agreement DTFA01-82-Y-10513, NASA through Interagency Agreement H-59314B, and NOAA through a cooperative agreement with the Program for Regional Observing and Forecasting Services of NOAA's Environmental Research Laboratories.

Casenotes and Statute Notes