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Microbursts: Will Technology Ever Catch Up

LaDawn M. Conway

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MICROBURSTS: WILL TECHNOLOGY EVER CATCH UP?

LaDawn M. Conway

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OVERVIEW

ALTHOUGH THE aviation community has recognized the negative impact of wind shear on aircraft since the days of piston aviation, it was not until 534 passengers and crew members died in a string of serious aircraft accidents beginning in 1970 that the degree of danger presented by this phenomenon was correctly assessed.1

As a consequence, atmospheric scientists, meteorologists, and the meteorological community as a whole, have, through intensive study, greatly advanced both the understanding of the phenomenon and the technology for its combat. Despite these advances, the scientific community is still unable to effectively overcome the problem.

This Comment examines the development of wind shear science and technology, and explores questions that arise as a result. Scientific advances, as evidenced by technological devices from the simple anemometer to the sophisticated Doppler radar, are described in detail.2 The crucial need for human involvement in the accumulation

1 Trunov, Wind Shear Revisited, ICAO Bulletin 26 (October 1986); see Corps, Wind Shear: Corrective Measures Have Proven Successful, ICAO Bulletin 11 (April 1988) summarizing the larger fatal accidents involving wind shear from 1970-1985:

<table>
<thead>
<tr>
<th>Date</th>
<th>Airline</th>
<th>Aircraft</th>
<th>Airport</th>
<th>Fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/20/70</td>
<td>Flying Tigers</td>
<td>DC-8</td>
<td>Naha, AB, Okinawa</td>
<td>4</td>
</tr>
<tr>
<td>7/23/73</td>
<td>Ozark</td>
<td>F-27</td>
<td>St. Louis Missouri</td>
<td>36</td>
</tr>
<tr>
<td>1/30/74</td>
<td>Pan Am</td>
<td>B-707</td>
<td>Pago Pago Samoa</td>
<td>96</td>
</tr>
<tr>
<td>6/24/75</td>
<td>Eastern</td>
<td>B-727</td>
<td>New York (JFK)</td>
<td>112</td>
</tr>
<tr>
<td>7/9/82</td>
<td>Pan Am</td>
<td>B-727</td>
<td>New Orleans, Louisiana</td>
<td>153</td>
</tr>
<tr>
<td>8/2/85</td>
<td>Delta</td>
<td>L-1011</td>
<td>Dallas, Texas</td>
<td>133</td>
</tr>
</tbody>
</table>

TOTAL 534

Id. at 12.

2 See infra notes 43-100 and accompanying text for a discussion of technological advances.
of knowledge needed to perfect technology is also addressed. Finally, issues are discussed relating to potential liabilities created by the shift of detection responsibilities when new technology is implemented, and, more importantly, the impact such a shift might have on the future development of science in this field.

I. The Development of the Science of Wind Shear

Modern atmospheric scientists describe wind shear as "a change in windspeed and/or direction in space, including updrafts and downdrafts." A microburst is a species of wind shear occurring at a low altitude. The sophisticated understanding of this phenomenon presently held by the meteorological community is a result of many years of intensive study and experimentation.

A. Early Development

Serious accidents resulting from the necessity of flying military aircraft during bad weather in World War II encouraged organizations such as the National Advisory Committee for Aeronautics and the Weather Bureau to focus on a weather hazard that had yet to be thoroughly

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3 See infra notes 101-137 and accompanying text for a discussion of the need for human involvement in the development of the science of wind shear.

4 See infra notes 138-154 and accompanying text for a discussion of the impact of advanced technology.

5 Wind Shear, ICAO CIRCULAR 1 (1987). The Federal Aviation Administration similarly describes wind shear as "a change in wind direction and/or speed in a very short distance in the atmosphere." Air Safety: The State of the Art, Av. Week & Space Tech., March 30, 1987, at 51 [hereinafter Air Safety]. For example, meteorologists have observed 180 degree changes in wind direction as well as speed changes of more than 50 kilometers per hour, within 200 feet of the ground. Id. Wind shear can be caused by a number of forces, including: the wind profile in the lower levels of the atmosphere, wind flow around obstacles, wind flow associated with frontal surfaces, the land/sea breeze effect, and the wind flow in and around convective clouds and especially thunderstorms. Thunderstorms are by far the most important source of low level wind shear—of the kind that has proved to be lethal for aircraft in both the approach/landing or take-off/climb-out phases of operation.

Fox, ICAO Circular Soon to be Published on Low Level Wind Shear, ICAO BULLETIN 12-13 (April 1987).
investigated: the thunderstorm. For the purpose of researching this phenomenon, these organizations created the Thunderstorm Project (the Project) shortly after World War II ended in 1945. Through research and extensive testing, scientists involved with the Project acquired a basic understanding of the structure of simple thunderstorms, and, more importantly, downdrafts.

The Project’s researchers determined that downdrafts are initiated during the second stage of a thunderstorm cell’s life cycle. The initial stage of thunderstorm cell development involves drafts of air swept upwards through the cell. When the updraft reaches a height where the air is much colder, vapor condenses, and water droplets and ice crystals develop. Eventually, the weight of individual water droplets and ice crystals become so heavy that the updraft cannot support them and they begin to fall, creating a downdraft. As the moving air of the downdraft reaches the earth’s surface, it does not come to rest but instead changes direction of motion “as would any jet stream striking a plate.” The vertical downdraft

---


7 Id. “[The Project] made possible the release for peacetime use of equipment, airplanes, and personnel to perform thunderstorm investigations on a much more complete scale than up to this time had been considered possible.” Id.

8 Interview with Alan Moller, Chief Forecaster with the National Weather Service, in Fort Worth, Texas (October 8, 1989) [hereinafter Moller Interview]. “From studies [by the Project], it is now known that the thunderstorm consists of a group of cells in which are concentrated the gustiness, drafts, hail, and other weather elements that make flights through the storm hazardous.” Thunderstorm, supra note 6, at 133. The Project also learned that the life cycle of the thunderstorm’s cell is divided naturally into three stages:
1. Cumulus stage—characterized by updraft throughout the cell.
2. Mature stage—characterized by the presence of both updrafts and downdrafts at least in the lower half of the cell.
3. Dissipating stage—characterized by weak downdrafts prevailing throughout the cell. Id. at 19.

9 Thunderstorm, supra note 6, at 19.

10 Id. at 20.

11 Id. at 21.

12 Id. at 24.
becomes a horizontal surface current that flows outward from the area of rainfall. Today, researchers know that updrafts and downdrafts are integral elements of all types of wind shear, including microbursts. The Project's initial study of downdrafts was a crucial first step toward solving the current weather-related aircraft accident crisis.

B. **Downbursts**

The study of thunderstorms and wind shear intensified in reaction to aircraft incidents in the 1960's and 1970's. T. Theodore Fujita of The University of Chicago, an "old fashioned, 'real' scientist," studied natural thunderstorm phenomena in relation to aircraft incidents. In the 1970's he determined that certain downdrafts are "damaging" downdrafts, or, as he coined the term, "downbursts." A "downburst," as described by Fujita, is a very strong downdraft which causes an outburst of damaging winds on or near the ground. This low-level wind condition is similar to pointing a high-pressure air hose at the ground; the vertically descending air fans out in all directions. Fujita examined aircraft accidents and downburst damage to crops, trees, and buildings, and concluded that an intense downburst could generate tornado-like damage.
Fujita further subdivided downbursts into macrobursts and microbursts according to their horizontal scale of damaging winds.\(^2\) A macroburst can be characterized as a large downburst with outburst winds typically extending beyond 2.5 miles. Lasting five to thirty minutes, these winds reach velocities as high as 60 meters per second (134 miles per hour) and often cause extensive, tornado-like damage.\(^2\) A microburst, on the other hand, is a small downburst, generally lasting under ten minutes, with a horizontal dimension of less than 2.5 miles.\(^2\) The microburst’s smaller scale and shorter duration are deceptively dangerous however, because an intense microburst can contain damaging winds as high as 75 meters per second (168 miles per hour).\(^2\)

Fujita’s “downburst” theory was initially rejected in the meteorological community. Most meteorologists believed that a downdraft, regardless of its initial strength inside the cloud, weakened to an inconsequential speed long before reaching the earth’s surface.\(^2\) Convinced that unusually strong, small scale downdrafts not only existed but posed a serious threat to aviation, Fujita obtained scientific support for project NIMROD (Northern Illinois Meteorological Research on Downbursts) near Chicago in

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\(^2\) Id. at 8.

\(^2\) Id.

\(^2\) Id. “[A] microburst is a downburst having a horizontal dimension at the surface no greater than four (4) km [2.5 miles].” U.S. Department of Commerce (Fernando Caracena, Ronald L. Holle, Charles A. Doswell, III), Microbursts: A Handbook for Visual Identification 20 (February 1989) [hereinafter Visual Identification]; The National Transportation Safety Board (NTSB) describes the microburst as “a part of the evaporation condensation process that produces cumulonimbus clouds, heavy rain showers and thunderstorms... [t]he wind shear results from the convective movement of the air wherein low-level air heated by the ground rises and is replaced by cold air descending from aloft.” Air Safety, supra note 5, at 51.

\(^2\) T. Fujita, supra note 17, at 8.

\(^2\) Wolfson, supra note 15, at 372. The meteorological community generally accepted the theory that stage three of a thunderstorm cell’s life cycle involved “dissipation” or a general weakening of the downdraft. Id.
1978, project JAWS (Joint Airport Weather Studies) near Denver in 1982, and project MIST (Microbursts and Severe Thunderstorms) near Huntsville, Texas in 1986. It was not until Pan American World Airways Flight 759 crashed shortly after takeoff at New Orleans International Airport in July 1982, that the Federal Aviation Administration (FAA) took action and formed the National Academy of Sciences Committee for the Study of Low-Altitude Wind Shear and Its Hazard to Aviation. The final report of this committee noted that scientists “have recently begun to recognize the importance of storm downdrafts that are unusually small in horizontal cross sections and that are of short duration. Such downdrafts have been called microbursts.” Finally, the meteorological community accepted Fujita’s theory of

26 T. Fujita, supra note 17, at 4. NIMROD was the first field program to study the downburst. It was conducted in 1978 by the University of Chicago, with Fujita and Srivastava as principal investigators. The purpose of the project was to define the structure of downbursts in general. The NIMROD network operated for 42 days and depicted a large number of downbursts (using Doppler radars and 27 PAM (Portable Automated Mesonet) stations), including both macrobursts and microbursts. Id. See supra notes 21-25, and infra notes 27-42 and accompanying text. After NIMROD, the downburst was redefined “as ‘an outburst of damaging winds on or near the ground’ where ‘damaging winds’ referred to winds of at least 18 [meters per second]; microbursts were simply wind events of this magnitude on a smaller scale.” Wolfson, supra note 15, at 372.

27 T. Fujita, supra note 17, at 4. JAWS was the second field program to study the downburst. This three-month field program was conducted jointly by the University of Chicago and the National Center for Atmospheric Research and included 100 scientists, engineers, and technicians. The principal investigators were Fujita, McCarthy, and Wilson. JAWS was designed to depict microbursts, rather than macrobursts, “because a number of microburst-related accidents and incidents kept occurring in various parts of the world.” Id. Through the JAWS experience, the “microburst was redefined as having a ‘differential Doppler velocity across the divergence center greater than or equal to 10 [meters per second] and the initial distance between maximum approaching and receding centers less than or equal to [2.5 miles].’” Wolfson, supra note 15, at 372. Denver was chosen for the experiment because of “the area’s 65 thunderstorms on average each year, which ranks it among the highest in the nation.” Wind Shear Microbursts Focus of Weather Study, Av. Week & Space Technology, June 14, 1982, at 41, 43 [hereinafter Microbursts Focus].

28 Wolfson, supra note 15, at 372.

29 Id. All 149 persons on board and eight persons on the ground died. Id.

30 Id.

31 Id.
microbursts and their danger to aviation.\textsuperscript{32}

C. Microbursts

Fujita identified low-altitude wind shear found in a microburst as an important factor in jet aircraft accidents/incidents during takeoffs and landings.\textsuperscript{33} In order to understand the potential for accidents in these circumstances, it is necessary to distinguish between a tornado and a microburst. Put simply, a tornado rotates around a vertical axis and a microburst rotates around a horizontal axis.\textsuperscript{34} The microburst's horizontal rotation develops when a thunderstorm's downdraft crashes to the ground and deflects initially into an outburst flow which subsequently curls up from the ground to form a ring vortex with a horizontal axis.\textsuperscript{35} As apparent from Diagram A, this occurrence is typically radial. From an aerial viewpoint, damage from a microburst results in a roughly circular "starburst pattern."\textsuperscript{36}

Microbursts, occurring close to the earth's surface, are most dangerous to aircraft during take-off and landing. The airplane's intended flightpath is disturbed by the microburst's rotation around its horizontal axis. Rapid,
severe changes in headwind and tailwind are typical during the encounter, and often the aircraft is simply thrust into the ground.\textsuperscript{37} The schematic drawing below depicts an aircraft encountering a microburst while on approach. (Diagram B depicts cross section). As the airplane enters the microburst, it first encounters the upswing of the vortex circling a horizontal axis. This causes an increased headwind which lifts the airplane above its intended flight path (glideslope).\textsuperscript{38} Next, the airplane travels into the central downflow, causing an increased tailwind which

\textsuperscript{37} Corps, supra note 1, at 11. "[The] so-called microburst \ldots is the most dangerous \ldots when it is encountered relatively close to the runway by an aircraft that is landing or taking off. The [microburst] \ldots may literally thrust the aircraft towards the ground, or at the very least cause major changes in headwind/tailwind that severely upset the aircraft's flight path." \textit{Id.}

\textsuperscript{38} This sudden lift often encourages the pilot to attempt to nose the aircraft down, back to its intended flight path. This natural response is incorrect in light of the downdraft the aircraft will encounter immediately thereafter. \textit{See infra} note 91 and accompanying text.
pushes the airplane below its intended glideslope.\textsuperscript{39}

The stage of microburst which endangers an aircraft during takeoff lasts one to three minutes. The dangerous winds are generally confined to within 100 feet above the ground.\textsuperscript{40} Fujita concludes that this evidence of the rapid evolution of a microburst is a "warning signal to a pilot that an aircraft could encounter a strong wind shear a very short time after a preceding aircraft, departing from the same runway, reported no wind shear."\textsuperscript{41}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{diagram_b.png}
\caption{(Diagram B)}
\end{figure}

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\textsuperscript{39} T. Fujita, supra note 17, at 14; see also Wolfson, supra note 15, at 372.

\textsuperscript{40} T. Fujita, supra note 17, at 24.

\textsuperscript{41} Id. at 25. As noted by Donald Engen of the Federal Aviation Administration:

If the pilot of Pan American 759 had waited 10 minutes to take off at New Orleans, he wouldn't have gone down. . . . If Delta 191 had gone around at Dallas/Ft. Worth, it would not have crashed. When we talk about avoiding hazardous weather in the terminal area, we're talking very brief delays—only minutes.

Lansford, Avoiding Hazardous Weather, Airline Pilot, April 1987, at 19;

\textit{Good news is ancient news}. If information from a pilot who took off or landed just ahead of you is more than one minute old, it may be too late to help you. When conditions are right, convective weather hazards can develop with incredible speed . . . the storm that Delta 191 flew into [was a] 'convective explosion.'

\textit{Id.} at 23.
II. THE DEVELOPMENT OF WIND SHEAR TECHNOLOGY

A microburst can occur inside a major airport without being noticed by those outside the airport. Indeed, a very small microburst could affect one runway, causing grave danger, without touching adjacent runways. Because of its small size and short life, the microburst can easily escape detection. As a consequence, a low flying aircraft could encounter a microburst unexpectedly.

Ground-based anemometers represent the first modern effort to measure wind speed. An anemometer is a simple, mechanical device consisting of a wheel to which cups are attached. Wind is measured by the corresponding velocity of the spinning cups. While this method may seem archaic, it is effective; the wind speed announced on the evening news is generally measured in this manner.

Since the anemometer only measures wind speed, rather than wind direction, the ground-based anemometer is clearly incapable of detecting a microburst.

A. The Development of Conventional and Doppler Radar for Meteorological Purposes

Shortly after World War II, meteorologists realized that the strength and intensity of thunderstorms could be measured by well calibrated radar. Weather radar has since become a valuable tool in the investigation and prediction of mesoscale phenomena.

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42 T. Fujita, supra note 17, at 8 (as opposed to a macroburst which could affect several states).
43 Id. at 8-9. Indeed, "[a] similar encounter could be experienced by cars and trucks on highways or by boats and ships on rivers, bays, and oceans." Id. at 9.
44 Interview with James A. Horn, Specialist, Federal Aviation Administration, in Euless, Texas (October 22, 1989) [hereinafter Horn Interview].
45 Id.
46 T. Fujita, supra note 17, at 8.
47 Wieler, NEXRAD: A Doppler Weather Radar for Aviation Use, ICAO BULLETIN 28 (September 1986). "Mesoscale phenomena" refers to weather on the storm scale, that is the space scale of 2 to 2,000 km and time scale of 0 to 24 hours. Examples of these phenomena include: flashfloods, high winds, thunderstorms, tornadoes, and hail. "It is on this scale . . . that weather of the greatest significance is experienced." Id.
48 Id.
1. Conventional Radar

Initially, weather radar came in the form of conventional radar. This ground based radar, still widely used in both the meteorological and aeronautical communities, is usually located at remote radar sites. At the Federal Aviation Administration (FAA) Control Center, National Weather Service (NWS) personnel receive data from the radar for conveyance to the airport. This procedure is noteworthy because it begins to define responsibility and possible liability.

Technically, conventional radar measures thunderstorms by transmitting short pulses of electromagnetic energy as its antenna scans past a storm’s activity. The radar then “listens” to the energy scattered back by the storm. This process is repeated many hundreds of times each second and eventually a “map” (radar echo) of the storm’s precipitation is created. A conventional radar will only measure the intensity of the returned echo. The impact of this limitation is that tornadoes, turbulence, microbursts, and other hazards cannot be detected by conventional radar alone.

A weather radar’s usefulness is not limited to the identification of severe weather. The aviation industry can use highly accurate radar data to detect hazardous clear-air turbulence, to route flights using the most favorable winds and to anticipate wind shifts for more efficient routing of aircraft on approach and take-off.

Id.

49 Horn Interview, supra note 45 (remote in the sense that the radar are placed off the airport and away from the FAA Control Center).

50 For a discussion of potential liabilities, see Section IV “Impact of New Technology,” infra notes 138-154 and accompanying text.

51 Ray, Brown, and Ziegler, Doppler Radar, WEATHERWISE, April 1979, at 68 [hereinafter Doppler] (“The time difference between when the pulse is transmitted and returned tells the radar operator the distance to the echo.”).

52 Id. “An exception is the rare case when the large circulation in which tornadoes are imbedded establishes spiral patterns in the rain, giving rise to the well-known hook echo.” Id. An additional problem with conventional radar is that it is built with outdated equipment that is very expensive to maintain and, quite simply, is falling apart. Moller Interview, supra note 8. “[Doppler] radar is designed to replace the aging weather radars now being used by the NWS [U.S. National Weather Service], AWS [Air Weather Service] and FAA [Federal Aviation Administration].” Wieler, supra note 48, at 28.
Nonradar weather detecting devices located on airport grounds have also proved limited in their ability to adequately detect microbursts. For example, at the time of the Delta 191 accident, Dallas/Ft. Worth International Airport (DFW) utilized a ground-based Low Level Wind Shear Alert System (LLWAS). This system, comprised of anemometers and other instruments measuring wind velocity and direction, went into alert twelve minutes after the Delta Airliner had crashed.\textsuperscript{53}

2. \textit{Doppler Radar}

To overcome the critical limitations seen in both the conventional radar and ground-based detecting systems, scientists developed the pulse Doppler microwave radar.\textsuperscript{54} Doppler radar operates exactly as conventional radar except it is able to detect the speed of targets moving either toward or away from the radar. The Doppler measures


The LLWAS has several limitations: winds above the sensors are not detected; winds beyond the peripheral sensors are not detected; updrafts and downdrafts are not detected; and if a shear boundary happens to pass a particular peripheral sensor and the centerfield sensor simultaneously, an alarm will not occur. In addition, the dimensions of some meteorological phenomena—microbursts or macrobursts—may be smaller than the spacing between the sensors and thus may not be detected. However, since the downward flow in macrobursts and microbursts turns horizontally as it approaches the ground, an outward flowing shear boundary is established which eventually affects one of the sensors and places the system in alert. The controllers in the DFW Airport tower cab stated that the LLWAS went into alert either about the time the storm reached the north end of the airport or about 10 to 12 minutes after the accident, and when they checked the display, all sensors were in alarm.

\textit{Id.} Additionally, the project director of JAWS testified that the "LLWAS system does a good job with gust fronts. We found in an analysis of our work in Denver in 1982 that it did not do a particularly good job with microbursts." \textit{Id.} at 33.

\textsuperscript{54} \textit{Id.} at 56. "The only available equipment that can detect and track a microburst throughout its entire cycle is the pulse Doppler microwave radar." \textit{Id.} The Doppler radar referred to in this Comment is the TDWR System to be utilized in NEXRAD, discussed \textit{infra} notes 68-79.
the frequency change in the transmitted pulse caused by
the target's motion. The conventional radar's wave-
length and frequency do not change as the beam reflects
off of the storms precipitation back to the station. Con-
versely, rain droplets moving away from a Doppler radar
station appear as longer wavelengths of low frequency
and droplets moving towards the radar station appear as
shorter wavelengths of high frequency. In other words,
"Doppler radar sees the direction of movement within the
storm, allowing rotation to be detected; conventional ra-
dar only reads storm intensity." The introduction of
Doppler radar into severe storm research added a new,
illuminating dimension.

Doppler, supra note 52, at 68. This is similar to the operation of a police radar. Also, "[a]n analogous change in frequency is apparent as a train passes you with its whistle blowing. These frequency changes are called Doppler shifts, from whence the Doppler radar gets its name." Id. See also Microbursts Focus, supra note 27, at 41. "[Conventional] weather radar measures precipitation density while Doppler radar measures both precipitation levels and wind velocity." Id. When, for example, detecting a tornado,

[a] Doppler radar takes advantage of the Doppler shift: the change
in pitch of a sound wave or of an electromagnetic wave generated or
reflected from a moving object. The portable Doppler radar, which
is battery operated, directs a microwave beam at the funnel of [the]
tornado. The signals are reflected off the swirling debris and rain in
the cloud and return to the radar unit. Electromagnetic waves re-

dected by material in the funnel that is moving away from the unit
are shifted down in frequency; objects that are approaching the unit
shift reflected energy up in frequency. By analyzing the shifts the
operator can ascertain the wind speed in the tornado and also the
direction in which the storm is moving.

Technology Eye On the Storm, SCIENTIFIC AMERICAN 22, 24 (1987). For the more
technically minded, the Doppler radar signature for a microburst involves a dipolar
shift pattern

similar to a mesocyclone signature, but oriented such that the axis
of the dipole is aligned roughly parallel to the beam instead of or-

dogonal to it. This orientation is due to the strong divergence in
the near-surface wind at the base of a microburst. Divergence
causes the strong gradient in the radial component of the wind that
is responsible for the dipole Doppler shift alignment with the beam.


See Doppler, supra note 52, at 68. Doppler radar technology as applied to
weather radars "has contributed to a better understanding of the causes and the
development cycles of weather phenomena, and has led to vast improvements in
our ability to detect, identify and predict severe weather." Wieler, supra note 48,
at 28.
One obvious limitation to both types of radar is the fact that echoes are only returned if rain droplets, hail, or some other solid mass exists that can deflect the pulse. This presents a problem in certain situations. For example, dry microbursts\textsuperscript{58} often occur at relatively long distances from the parent hail-storm and its associated heavy radar echo. Thus, the radar detects only the parent storm, seriously misleading the observer to believe that areas around the storm are hazard free.\textsuperscript{59} The Doppler radar is also more effective than conventional radar in this context. The Doppler’s resolution is superior because its beam width is smaller than that of conventional radar.\textsuperscript{60} This results in fifty-percent greater detail and, hence, a better picture. Additionally, Doppler radar is capable of detecting some particles that are smaller than water droplets; consequently, dry microbursts containing debris, dust, and even insects occasionally can be detected by Doppler radar.\textsuperscript{61}

Doppler radar, however, is limited in a temporal context. The radar’s antenna operates in a three dimensional vertical tilt sequence.\textsuperscript{62} One full sequence lasts from six to eight minutes. A microburst can only be detected one to four minutes before it occurs.\textsuperscript{63} While a one to four

\textsuperscript{58} For characteristics of wet and dry microbursts, see infra note 119 and accompanying text.
\textsuperscript{59} VISUAL IDENTIFICATION, supra note 23, at 22. In the case of a dry microburst “pilots and others watching weather conditions on their radar scopes could have easily misjudged the weather hazards in areas far from the storm’s heavy radar echo. By themselves radar echoes therefore may be very misleading . . . .”

Radar is a vitally important tool for detecting hazardous weather, but it shows us only what’s happening in part of a thunderstorm—the rainy downdraft region. . . . At low altitudes, you can have very strong windshear lines 10 to 12 miles, maybe even as far as 15 miles, from the storm echo itself on the radar. Pilots may think they're avoiding the bad stuff by deviating around the strong radar echo, . . . but that can be an extremely dangerous area for trying to land or take off . . . .

Lansford, supra note 42, at 22 (quoting Alan Moller).
\textsuperscript{60} The Doppler’s beam width is one degree rather than two degrees for the conventional radar.
\textsuperscript{61} Moller Interview, supra note 8.
\textsuperscript{62} Id.
\textsuperscript{63} Id.
minute lead time is adequate to keep an aircraft from landing or taking off, the detection process, at a minimum, takes two minutes too long—Doppler’s warning may simply come too late.64

Another severe limitation on the Doppler radar’s effectiveness is that it is only capable of detecting movement traveling either toward it or away from it.65 A microburst usually has a radial “starburst” pattern.66 Thus a typical microburst, with winds bursting in all directions, will certainly contain winds moving precipitation or debris either toward or away from the radar’s beam, allowing for detection. Often, however, the horizontal winds do not travel in all directions. For example, it is quite possible that the burst of precipitation and debris will travel only to the east and west. If the Doppler’s pulse is traveling from north to south, perpendicular to the wind movement, detection is not possible.

3. **NEXRAD**

Despite its shortcomings, the Doppler radar is a significant advance in technology. Thus far, it has only been used in a research environment at Stapleton Airport in Denver. Fortunately, NEXRAD (the next generation weather radar system), a joint project of the National Oceanic Administration, Department of Defense, and the FAA, will provide the meteorological community with automated Doppler radar for use in weather forecasting.67 NEXRAD is a nationwide weather radar network designed to serve a variety of needs. The Defense Department is interested in Doppler radar for protecting air bases; the National Oceanic Administration proposes to study many areas of weather phenomenon;68 and the FAA is inter-

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64 Id.
65 Id.
66 For a discussion of microburst patterns, see supra note 36 and accompanying text.
67 Wieler, supra note 48, at 28.
68 Moller Interview, supra note 5. “The system has been designed with expan-
ested in microburst detection to avoid weather-related aircraft disasters.

Specifically, the FAA will use a variation of NEXRAD in airport terminals. Referred to as the Terminal Doppler Weather Radar System (TDWR System), this program will have characteristics similar to NEXRAD, but with modifications that enhance its ability to function specifically for the purpose of detecting and tracking severe weather conditions occurring in and around airports. In 1982, MIT Lincoln Laboratory, under contract to the FAA, began developing the TDWR System. The FAA moved the TDWR System to Denver for extensive testing to determine the feasibility of providing real-time low-altitude wind shear information to air traffic controllers at Denver’s Stapleton airport in the summer of 1988. Extensive experimentation revealed that by combining Doppler radar with data processing and highly advanced displays, the TDWR System will detect, measure, track, and report variants in meteorological phenomena.1

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69 Doppler Radar Selected for Wind-Shear Detection in the U.S., ICAO BULLETIN 30 (October 1988) [hereinafter Doppler Radar Selected]; Wieler, supra note 48, at 28.
70 Wolfson, supra note 15, at 373. The radar was first moved to Memphis, Tennessee in mid-1984 to participate in the multi-year FLOWS (FAA-Lincoln Laboratory Operational Weather Studies) Project of 1985. When the FLOWS project moved in 1986 to Huntsville, Alabama, the radar was moved again, and, during testing, microbursts were indeed found and datasets with scanning strategies suitable for use in an automatic microburst detection system were collected. Most microbursts in Memphis and Huntsville were caused by the collapsing phase downdrafts of isolated, air-mass thunderstorms, and were accompanied by very heavy rain. These storms appear to be very similar to those that have caused a large number of aircraft accidents . . . .

71 Id. at 373 (at that time called “FL-2”).
72 Id. “Denver was chosen for the experiment because of the area’s 65 thunderstorms on average each year, which ranks it among the highest in the nation.” Microbursts Focus, supra note 27, at 43.
73 Doppler Radar Selected, supra note 70, at 30. Specifically, “[r]aw radar data will be routed through signal processing necessary to generate base data (reflectivity, velocity and spectrum width), which will then be sent to the product generation processor. Terminal area products will be produced using existing NEXRAD al-
As planned, NEXRAD will automatically detect meteorologically significant events and display appropriate alert information to meteorologists, forecasters, and operations personnel. The TDWR System, by virtue of its storm tracking and prediction capabilities, will provide information regarding the past, present, and predicted future position of each storm. Additionally, for ease of interpretation, a typical NEXRAD display will superimpose such products as hail, mesocyclone and tornado vortex signatures in graphic format against a map background.

The TDWR System's automatic meteorological algorithm processing will aid in the interpretation of weather phenomena and enable forecasts and warnings to be issued earlier than currently possible, reducing the number of aborted take-offs, landings and go-arounds.
This sophisticated processing will execute computer analyses to examine weather conditions and trigger automatic alerts, directing attention to potential hazards. These automatic alerts are updated at five-minute intervals and issued and distributed within five seconds of detection of severe weather. Under the proposed plan, 102 systems will be installed, beginning in late 1991, providing nearly total coverage of the contiguous United States.

B. Airborne Radar, Pilot Training, and Aircraft Improvements

Avoidance is the safest procedure for dealing with wind shear. Avoidance, however, is not always possible. A strategy for survival is therefore needed once an aircraft enters a microburst.

Upon encountering a microburst, the pilot must manage the energy available in the aircraft, and maximize engine power, thus prolonging airborne time and hopefully riding out the relatively short-lived wind shear phenomenon. Achieving maximum engine power is critical to combat the extreme wind shear encountered in microburst conditions. Early detection of wind shear is an obvious prerequisite to quickly achieving maximum engine power. Achieving maximum power can be difficult considering the limited amount of time the pilot has to evaluate the situation and initiate recovery techniques. If the wind shear is severe, five to fifteen seconds must suffice.

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77 Id. at 31. "The automated alert capability reduces operator fatigue and permits concentration on the important phenomena, warnings and forecasts." Id.

78 Doppler Radar Selected, supra note 70, at 30. The nationwide system will cost more than $282 million. "Automated storm surveillance, with pinpoint accuracy, will permit continuous tracking and prediction of severe storms and tornadoes. With ... NEXRAD units, the network will allow about 90 per cent of complete coverage for the contiguous states (the incomplete coverage lying exclusively in the mountainous west of the U.S.). Wieler, supra note 48, at 30.

79 See infra note 98 and accompanying text explaining the importance of energy management during an encounter with a microburst.

80 Corps, supra note 1, at 11.

1. Airborne Radar and Pilot Training

The early detection of microbursts by airborne radar is sometimes hampered by the pilot’s misuse of or lack of confidence in the radar equipment itself, or, lack of proper radar operation training.

Pilots who lose confidence in their radar may allow outside sources to make decisions for them. They may let the controller decide for them. Most of the aircraft that have crashed in convective weather were operating in an air traffic control (ATC) radar environment. The controller can be a useful advisor, but the ATC radar won’t tell the controller much about the weather, and it’s not the controller’s job to make decisions for the pilot about avoiding hazardous weather.\(^\text{82}\)

Airborne radar are usually short beamed conventional radar. While these radar are incapable of detecting wind movement, they can determine storm intensity. This is important because storm intensity is directly related to storm height and “tall” storms are likely to contain wind

\(^{82}\)Lansford, supra note 42, at 23. Evidence concerning the use of airborne radar on Delta Flight 191 supports the notion that such radar are often ignored and misused:

Between 1751 and 1800 [the accident occurred at 1805:52], the [thunderstorm] cell had intensified . . . and flight 191’s nose was pointed at the cell until 1759:37 . . . . During this period the flight crew would have been free to use the [airborne] weather radar to scan the cell and to manipulate the antenna tilt to acquire the best possible radar picture. Since the storm cell had [increased in intensity] by 1800, the cell would have reached contouring levels of intensity for the radar sometime during this period. However, the CVR [Cockpit Voice Recorder] contains no conversation referring either to what was or was not displayed, difficulties involved with manipulating the radar antenna tilt, or the inadequacies of the radar in this area of flight. Since it is also possible that the flight crew did try to use the radar but did not engage in any discussion over the results of the attempt, the Safety Board is unable to determine if the radar had been turned off, or whether the flight crew tried to use it during the final moments of descent and as the flight approached the outer marker. Furthermore, because of the conflicting evidence, the Safety Board cannot determine the capability of the weather radar in a low-altitude, close-range weather situation.

\(^{\text{NTSB Delta 191 Report, supra note 54, at 68.}}\)
shear. For example, a storm with a top higher than 30,000 feet has a hazard probability of thirty-three percent, while a 37,000 foot height increases the probability to fifty percent. What pilots must do, then, is determine a storm's height by using their airborne radar.

Airborne radar utilize precise tilt management to measure cloud-top height. Oversimplified, at high altitudes, the pilot must position the tilt so the radar looks down in order to see the mid-levels of a storm. In the terminal area, the radar must be aimed up to scan the same levels of the storm. Obviously, if a pilot flying an aircraft at low altitude has the tilt elevated only five degrees, he may well scan beneath areas of heavy precipitation emitting intensity information. With the tilt at ten degrees, however, heavy precipitation is detected and thus the true hazard potential of the storm is revealed. Once the tilt is correct, precipitation is reflected on the radar as "radar shadow." These shadows appear because the radar beam is incapable of completely penetrating intense rainfall, and the signal is thus "absorbed" by the rain, leaving nothing to reflect back to the radar antenna. If correct intensity detection is accomplished, the pilot will know when a thunderstorm is at an intensity level likely to produce microbursts. Although airborne radar can alert pilots to the presence of most convective storm hazards except dry microbursts, on board radar used in conjunction with knowledge of atmospheric conditions and subtle clues that differentiate the merely strong or large echoes

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83 Lansford, supra note 42, at 23.
84 Id. "[T]all storms must be avoided . . . ." Id.
85 Id. at 23-24.
86 Id. at 23.
87 Id. at 24. "[I]dentifying the radar shadow is the most critical radar operating technique, and the ultimate radar rule is never, never continue flying toward a radar shadow." Id. For example, the absence of ground returns behind an area of heavy rain indicates that the radar signal is being fully absorbed by extremely intense precipitation. Id. In color radar (as opposed to monochrome radar), the most severe weather appears red, less severe weather appears yellow, and mild weather appears green. Id.
88 Id. "If the energy from your transmitter cannot penetrate a target, there is no way you can fly through it." Id.
from the truly hazardous ones provides the most comprehensive detection system.\textsuperscript{89}

The early detection of a microburst does not necessarily mean successful wind shear avoidance or survival. A danger lies in the fact that pilots are traditionally trained to respond to weather conditions in ways that are not only inadequate in a microburst encounter, but tend to worsen the situation.\textsuperscript{90} This pilot problem is twofold:

First when the aircraft encounters the increasing headwind and updraught, there is a tendency for the pilot to reduce engine thrust to maintain the desired flight path. When the strong downdraught and tailwind are then encountered at reduced thrust, the aircraft becomes vulnerable. There is a delay before the engines can respond to a demand for high thrust.

The rapid decrease in airspeed to alarm-level low values leads to the second part of the piloting problem. The pilot has been trained to lower the nose of the aircraft to regain lost airspeed. Unfortunately, in a severe wind shear encounter the atmosphere is already causing the aircraft to offer a dramatic loss of climb performance, or an excessive descent rate. Nosing down at this time makes matters worse.

Even if the pilot has been trained to recognize a microburst encounter and knows enough to sacrifice airspeed for ground clearance, care must be taken to ensure that the aircraft does not stall. This 'tightrope walk' under conditions of severe turbulence is a considerable challenge to the skill of the pilot and is the reason for the provision of guidance instrumentation to assist him in establishing the correct pitch attitude.\textsuperscript{91}

\textsuperscript{89} Id. "And it should never be used to make a decision to penetrate a convective weather system, but rather as a gauge of how far to circumnavigate it . . . . Id. Such "atmospheric conditions and subtle clues" are discussed infra notes 115-137 and accompanying text, in connection with the visual identification of microbursts.


\textsuperscript{91} Id. at 14-15. This lowering of the aircraft's nose to pick up airspeed when it is falling off in a wind shear situation, could be fatal because "[y]ou have traded too much potential energy for kinetic energy. You hit the tailwind generated by
In response to this critical need for training, regulatory agencies and airlines train air crews in an environment designed to simulate clear air turbulence, jetwash, and wake vortex turbulence. Currently, the FAA requires simulator manufacturers to provide realistic wind shear simulation capabilities before it will grant higher training-phase approvals.92

2. Aircraft Improvements

Another answer to wind shear detection is aircraft improvement. For instance, Airbus Industrie of France ensures that the rapid application of engine power necessary for wind shear survival is achieved through its “Alpha Floor” protection.93 Alpha Floor is an autopilot and autothrust system that both detects and reacts automatically to wind shear.94 The system utilizes “angle-of-attack.”95 Specifically, the angle-of-attack meter sends a signal to the autopilot when the angle-of-attack of the wing, responding to severe weather, increases to a certain level and direction typically encountered in a microburst. Therefore, if the wing angle exceeds predetermined thresholds, engine power necessary to execute a “go-around” is automatically applied.96

An Airbus aircraft’s other principal defense against wind shear is the speed reference system (SRS). The SRS assists pilots in achieving the best conversion of kinetic energy to potential energy and vice versa.97 Essentially,
the SRS energy conversion guidance enables the pilot to timely apply the maximum power needed to pull through the microburst. An aircraft is very vulnerable when traveling at approach speed; if the speed of the airplane is too low when encountering the wind shear, recovery may be impossible. By detecting abnormal sink rates too minute for detection by human senses, the SRS keeps the plane at the lowest safe speed. The advantage of this system is that it guides the pilot through the microburst, rather than simply warning the pilot that the problem exists.

III. **The Human Supplement: Forecasting Based on Environment and Visual Identification of Microbursts**

"A gap exists between what is available to researchers in the way of detection, and what is available to the public in the way of protection from microbursts." Even the Doppler radar, the most sophisticated tool current technology has to offer, is incapable of ensuring microburst detection. Technology still requires human supplementation.

In the context of weather generally and microbursts specifically, information gathered by instrumentation alone is insufficient to assure detection. Natural forces are nonlinear—they contain random elements not solvable by equations. Unfortunately, computerized instrumentation such as the Doppler radar operate by interpreting linear data. It is therefore necessary to introduce other

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on their attitude director indicator (ADI) or through the autopilot pitch channel to prevent the aircraft losing height until the lowest safe flying speed is achieved—it is at this rate that the aircraft has to descend." Id.

96 Horn Interview, supra note 45. Mr. Horn argues that if the pilot of Delta Flight 191 had applied full power seconds earlier, the plane would have likely pulled through the microburst. Id. 99a See supra note 92 and accompanying text for a discussion of wind shear dynamics during the approach phase.

98 See supra note 91 and accompanying text for a discussion of wind shear dynamics during the approach phase.

100 Horn Interview, supra note 45.

101 Visual Identification, supra note 23, at v.

102 Moller Interview, supra note 8.
elements into the effort to avoid weather-related aircraft accidents.

One theory gaining attention proposes that the combination of technology, research, and training will, as conclusively as possible, accurately solve the problem. This approach would utilize current technology, continue research to further develop the science, and train people for visual identification of microbursts.\textsuperscript{103} The last aspect actually complements the two former ones because visual identification of microbursts will both supplement the insufficiencies of current technology and aid in gathering knowledge.\textsuperscript{104} In this sense technology is merely an aid which well trained humans can employ in the acquisition of knowledge and the further development of the science.\textsuperscript{105}

Visual identification operates on two levels: (1) forecasters identify the environments in which microbursts are likely to occur, and (2) trained spotters visually identify microbursts.\textsuperscript{106}

\textsuperscript{103} Id. Moller is convinced that visual evidence of microbursts exists which pilots, meteorologists, Federal Aviation personnel (in the control tower), and amateur "spotters" in and around airports could be trained to identify. This human supplement could fill the gap created by the insufficiency of current technology.

\textsuperscript{104} Id. Moller suggests an example which illustrates the usefulness of the human element. In a given number of potential tornado conditions Doppler radar will emit identical preliminary information. Only fifty percent of the time, however, will a tornado occur. Moller proposes that a human spotter could see obscure differences undetected by the machine element and thereby (1) supplement current inefficiencies in detection, and (2) further the science by acquiring knowledge. \textit{Id.} Visual identification will help fill gaps in forecasting and remote sensing of microbursts and furnish the National Weather Service with a means of obtaining observational data on microbursts to complement from other sources such as NEXRAD [next generation radar] and the TDWR [Terminal Doppler Weather Radar] which should begin to be available in 1991.

\textsuperscript{105} Moller Interview, \textit{supra} note 8.

\textsuperscript{106} \textit{Visual Identification, supra} note 23, at vi.
A. Forecasting Based on Environment

Although a great variety of environments can produce microbursts, they generally occur in one of two extreme environments: either extremely dry conditions in which most of the water evaporates before reaching the ground or extremely wet in which microbursts are embedded in very heavy rain. Atmospheric scientists and forecasters determine typical characteristics of each extreme by analyzing both the variances of air temperature at different altitudes and the layering of saturated and dry air.

The dry extreme typically develops in the semi-arid regions of the West. Rain showers virtually evaporate before reaching the surface, but nevertheless produce a type of wind shear known as dry microbursts. Techniques for forecasting dry microbursts are well developed and utilized regularly for environmental forecasting. The extremely wet environment contains a dry source layer that ejects pockets of dry air into underlying rain-filled air, producing the evaporative cooling that can result in a microburst. Certain areas, however, such as

107 Id. at 15-16. "Severe wind shear . . . includes both wet microbursts associated with heavy rain from thunderstorms, like the one that got Delta 191 [D/FW International Airport, 1985], and the dry microbursts that you encounter at Denver and other western airports in the high plains and the intermountain region." Lansford, supra note 42, at 19.

108 VISUAL IDENTIFICATION, supra note 23, at 9 (description below Figure 8).

In the extremely dry environment, where moist convection is just barely possible, cumulus clouds with very high bases form in a more protected environment that is nearly saturated at about 3 km [10,000 feet] above the surface; below this high-based cloud layer there is a deep, dry adiabatic layer; dew point depressions are higher nearer the surface where they may approach 30 [degrees] C. Id. at 15.

109 See id. at 16. Forecasting techniques for the dry extreme microburst are "based on linear predictive models and discriminate function analysis." Id.

110 Id. at 9.

The wet microburst environment is marked by a deep, nearly saturated layer with a nearly moist pseudoadiabatic lapse rate that is topped by an elevated dry layer. The equivalent potential temperature of the dry layer is cold enough and the layer is sufficiently high above the surface that, when it is reduced to its wet bulb temperature by saturation and mixed (in equal parts) with the warm updraft, there is still enough negatively buoyant potential energy to drive a
Texas and other states eastward along the coast of the Gulf of Mexico often present an intermediate environment that fit neither the wet nor dry conceptual models, but have some characteristics of both. Even under such moderate conditions, meteorological researchers have identified typical environmental characteristics which are indicators of microburst potential.

Forecasters not only utilize formulas based on air temperature and saturation, but also estimate maximum downdraft speeds based on data obtained from “soundings” emitted from conventional radar. The most effective method, however, for estimating potential downdraft strengths may be a relatively simple index derived from both surface data and conventional sounding.

Id. at 16. Although researchers understand the dry extreme better than the wet extreme, and consequently have developed more definitive techniques for forecasting the dry, several techniques are utilized for computing the downdraft potential in the wet extreme. Two proposed methods are:

1. [Using] the fixed layer between 700 and 500 mb to compute the downdraft potential energy; 2. [Using] floating levels that center the dry layer on the potentially coolest air.

Id. at 16-17.

Id. at 17. These common atmospheric vertical temperature and moisture profile characteristics are:

1. Large positive area [large area of thermal instability].
2. Little or no capping inversion.
3. A dry adiabatic lapse rate layer, at least 5000 ft deep, below the cloud condensation level.
4. A moist midtropospheric layer between 5000 and 15,000 ft.
5. An elevated dry layer above 15,000 ft.

Id. These characteristics indicate that in an intermediate microburst environment “subcloud evaporation is still quite capable of producing a microburst, but... absolute humidity is high enough to produce very heavy rain as well.” Id. at 18.

Id. at 18-19. In 1985, Srivastava, a weather scientist, developed a one-dimensional evaporatively driven downdraft model that uses such parameters as raindrop size distributions, rain-water mixing ratios, and sub-cloud lapse rates to predict the maximum velocity in a downdraft. This model indicates that the downdraft maximizes when rainwater with a high mixing ratio is dispersed as very small drops and falls into a deep dry-adiabatic sub-cloud layer.

Id.; see also Srivastava, A Simple Model of Evaporatively Driven Downdraft: Application to Microburst Downdraft, 42 J. ATMOSPHERIC SCIENCE 1004 (1985).
At present, unfortunately, no such index exists.\textsuperscript{114}

B. Visual Identification of Microbursts

Skill in visual identification of microbursts is important for pilots, controllers, and weather observers. Such identification may be the final line of defense in avoiding a microburst-related aircraft accident or disaster.\textsuperscript{115} An analysis and theoretical treatment of photographic documentation provides a strong basis for visually identifying microbursts.\textsuperscript{116}

1. Visual Identification by Spotters

Since visual classification of an event such as a microburst, macroburst, or simply a gust front is often difficult, trained spotters could first estimate cloud height, degree of cloud cover and visibility.\textsuperscript{117} A spotter could then determine whether a downburst is a microburst by comparing its size with features of known scale, such as a grid of roads one mile apart, a copse of trees, or a row of lamp posts.\textsuperscript{118}

Before classification can occur, however, the spotter must first see the downburst. The dry microburst can be deceptive because at first glance it may present a fair-weather appearance. Often, the only clue to potential microburst development may be the existence of fibrous-looking clouds coupled with scattered virga shafts.\textsuperscript{119} The

\textsuperscript{114} VISUAL IDENTIFICATION, supra note 23, at 19.
\textsuperscript{115} Id. "Accident investigators and aviation weather experts believe that [wind shear related] accidents occur because pilots fail to perceive the hazardous conditions that exist, and that the solution for that is more knowledge of how to recognize such conditions." Lansford, supra note 42, at 19.
\textsuperscript{116} VISUAL IDENTIFICATION, supra note 23, at 19.
\textsuperscript{117} Id. at 20. Difficulty in classification occurs because "a downburst may initially reach the surface as a microburst (or perhaps several microbursts) and subsequently expand into a larger scale downburst (macroburst)." Id. It is further possible that "the parent storm could continue to develop into a supercell storm [a storm that is always severe and often produces the most extreme severe weather events] or squall line [a narrow line of storms], resulting in the downburst's developing continuously into a large-scale gust front." Id.
\textsuperscript{118} Id. at 20-21.
\textsuperscript{119} Id. at 18. As the microburst develops, the ring of dust spreads out over the
microburst itself may be rendered visible by an expanding ring of dust on the earth’s surface forming immediately below a prominent shaft-like protrusion (virga) of cloud extending from the high base of the cumulonimbus.120

The wet extreme offers better visual evidence than its dry counterpart. Both high-based and low-based thunderstorms provide visual clues for microburst detection. A high-based thunderstorm121 producing heavy rain at the surface may produce a foot-shaped bulge between the cloud base and the earth’s surface extending outward from the center of the rain downpour. This bulge, a characteristic mark of a microburst, is made up of strong horizontal winds carrying precipitation outward from the impact center of the downdraft.122

Similar to high-based thunderstorms, low-based clouds also produce heavy rain with this same foot-shaped evidence of an embedded microburst. In this situation, a mass of heavy rain reaching the surface with a relative clearing immediately above the cloud mass suggests a strong downdraft and a possible microburst.123

earth’s surface. At very close range "blowing dust might be seen, but only a portion of the ring might be visible." Id. at 21-22.

120 Id. at 14.
121 A high-based thunderstorm is a thunderstorm in which the cloud base-line is very high.
122 VISUAL IDENTIFICATION, supra note 23, at 22.

High-based thunderstorms with heavy rain should be of particular concern in air safety since they signal a deep mixed layer . . . and plenty of precipitation to fuel a strong downdraft . . . . For example, at Dallas-Fort Worth International Airport a thunderstorm based about 3 km [1.9 miles] above the surface produced intense wind shear that caused Delta Flight 191 to crash . . . .

Id. at 25.
123 Id. at 24 (language below Figure 22b). "A descending wet microburst may first appear as a darkened mass of rain descending through light rain . . . [or] a clearing out of precipitation in its wake . . . [which] is one visual indicator of a potential microburst." Id. at 26. This phenomenon results when a strong downdraft conveys rain toward the surface at a much faster rate than it can fall at terminal velocity through still air. As the downdraft approaches the ground it decelerates in the vertical, allowing a heavy load of water to accumulate above the ground. This results in an opaque low-flying base to the rain shaft.

Id.
Plainly, the telltale visible signs of an embedded microburst are either a curved swirl of dust in dry areas or a spray of raindrops in wet areas. In either case, the light dust or rain spray delineates the swirling outflow that could strengthen into a microburst. These upward curls indicate embedded microbursts with vortex circulations that carry the dust or rain spray back up toward the cloud.

Field experiments such as JAWS supplied general rules useful for visual detection. For example, microbursts are normally a mid-afternoon, mid-summer phenomena. Again, dry microbursts generally occur in arid or semi-arid portions of the country and wet microbursts in humid areas. Exceptions, however, exist: dry microbursts have been observed in such humid areas as Wichita, Kansas, and near Chicago, while wet microbursts have occurred in arid Tucson, Arizona. In any part of the country there is some mix of wet and dry microbursts occurring outside the normal statistical time and season. Observers, therefore, should remain alert to out-of-season microbursts because "[w]herever and whenever it occurs, and regardless of its type, a microburst can cause an airplane crash, and should be taken seriously."

2. Visual Identification by Pilots

Many forecasters and atmospheric scientists emphasize that with improved training the pilot can judge the potential hazard of a storm by analyzing its structure and strength. With knowledge of the storm type, and its potential for interaction with its environment, pilots can esti-
mate its hazard potential, at least qualitatively. One serious problem is that many pilots tend to neglect visual clues and other sources of data valuable for evaluating weather hazards.

Cloud shapes hold visible clues a pilot can use to determine whether a takeoff or landing may take the aircraft through wind shear or other weather dangers. A basic understanding of the types of convective storms and their potential for wind shear can help pilots do a much better job of avoiding hazardous weather. Meteorologists classify thunderstorms into four categories:

(1) Single-cell storms, which can be non-severe or severe.
(2) Multicell storms, which can be non-severe or severe.
(3) Supercell storms, which are always severe. (4) Squall lines, which can be non-severe or severe.

Additionally, pilots and researchers, with support from the FAA, have developed probability guidelines for visual detection of wind shear by pilots. These guidelines include:

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151 Lansford, supra note 42, at 20-21 (quoting Alan Moller).
152 Id. at 20.
153 Id. Archie Trammell, radar expert, maintains that many pilots assume that air traffic control (ATC) radar does a better job of depicting hazardous weather than does their airborne radar system. That assumption is totally false, ATC radar is designed to paint aircraft, not weather; to depict aircraft in spite of heavy weather. Controllers use it to maintain separation between aircraft. It is not their responsibility to maintain separation between aircraft and weather.

Lansford, supra note 42, at 20-21 (quoting Alan Moller).
154 Id. at 21-22. Single-cell storms generally grow almost vertically, causing the downdraft and updraft to cancel each other out, usually eliminating the possibility of severe weather. Occasionally, however, the single-cell storm can bring about a short episode of severe weather and potentially, a microburst.

Because the severe single-cell storm is so small and develops so rapidly, it often appears without any severe-weather warning from forecasters or controllers. Thus it calls for special vigilance from pilots—this kind of storm brought down Delta 191 at Dallas/Fort Worth and Pan Am 759 at New Orleans.

Id. at 25.
Presence of convective weather near intended flight-path:

[1] With localized strong winds (tower reports or observed blowing dust, rings of dust, tornado-like features, etc.).

Probability of wind shear: High

[2] With heavy precipitation (observed or radar indications of contour, red, or attenuation shadow).

Probability of wind shear: High


Probability of wind shear: Medium


Probability of wind shear: Medium


Probability of wind shear: Medium

[6] With moderate or great turbulence (reported or radar indications).

Probability of wind shear: Medium


Probability of wind shear: Medium\textsuperscript{136}

These visual identification techniques and environmental forecasting capabilities both aid in the avoidance of microburst related accidents and supplement the inadequate linear-based interpretation of data provided by current detection devices. More importantly, the human element fosters the development of a more dependable technology. For now, however, the only measure more important than visual and radar identification, more critical than survival techniques is avoidance.

Avoidance is the most critical factor. It’s important for pilots to know how to respond if they find themselves in a microburst, but they should never get into one if they can possibly avoid it. Pilots should remember that some microbursts are so severe that they cannot be flown with any known recovery technique.\textsuperscript{137}

\textsuperscript{136} Id.

\textsuperscript{137} Id. at 24-25. In connection with this need for avoidance and the ability to visually detect a microburst, the findings of the National Transportation Safety Board in connection with the Delta 191 Crash are as follows:
IV. IMPACT OF ADVANCED TECHNOLOGY

Advanced technology may have an impact on aspects of aviation other than decisions made in the cockpit. There is a growing concern over possible increased liability for controllers and weather personnel due to new technological requirements and procedures related to the use of Doppler radar.

A. Potential Liability and Its Impact

Controller/weather personnel liability generally stems from either a failure to timely transmit information or incorrect data interpretation.\(^{138}\) As seen in the Delta 191 trial, both national weathermen and FAA personnel located off the airport terminal have a legal duty to advise incoming aircraft of extreme and hazardous weather in and around the airport.\(^{139}\) Judge Belew found that although this duty existed, the causal connection is terminated if the aircraft’s crew already has such information.\(^{140}\) The trial transcripts demonstrate that a great deal of time was spent discussing the impact of the national weatherman’s absence from his station due to a dinner break, when the microburst formed.\(^{141}\) Delta alleged that as a result of his absence,

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The National Transportation Safety Board determines that the probable causes of the accident were the flightcrew’s decision to initiate and continue the approach into a cumulonimbus cloud which they observed to contain visible lightning; the lack of specific guidelines, procedures, and training for avoiding and escaping from low-altitude wind shear; and the lack of definitive, real-time wind shear hazard information. This resulted in the aircraft’s encounter at low altitude with a microburst-induced, severe wind shear from a rapidly developing thunderstorm located on the final approach course.

\(^{138}\) Horn Interview, supra note 45.

\(^{139}\) Delta Flight 191 Court Ruling of Crew Error in 1985 Dallas Crash Examines Sequence of Flight into Thunderstorm, 3 AIR SAFETY WEEK 1 (1989).

\(^{140}\) Id. at 2.

\(^{141}\) NTSB DELTA 191 REPORT, supra note 54, at 78.

The absence of the CWSU meteorologist from his station between 1725 and 1810 [accident occurred at 1805:52], and the failure of CWSU procedures to require the position to be monitored by a
the NWS and FAA failed to relay crucial weather information to the pilot in a timely manner. This turned out to be, in the eyes of the court, a harmless error since evidence illustrated that the aircraft's crew already had the information. The court reaffirmed that weather personnel and controllers have a legal duty to relay information in a timely manner. New technology does not impact this duty.

One area where advancing technology may alter the duties of ground personnel is in the TDWR System. A crucial difference between current operations and the proposed NEXRAD program is that TDWR output will be relayed primarily to terminal radar approach control facilities ("TRACON") and tower controllers. Under the current system, NWS personnel and the conventional radar from which they obtain data are located off the airport premises. When the weatherman receives information from the radar, he sends it to tower personnel (located on the airport), who then convey it to approaching/departing pilots. Under the TDWR System, the Doppler radar will be located on the airport premises and will display the information directly to tower controllers. The controllers will then convey the information to approaching/departing pilots. This will create a shift in responsibility. A fundamental question arises out of this shift in responsibility: will it impact the legal status of the NWS and FAA when weather related accidents occur? If the answer to the question is yes, the shift in liability may, in turn, indirectly hamper further efforts to develop superior technology and continue to expand the science.

qualified person during his absence precluded detection of the intensification of the weather echo north of the DFW Airport.

Id. at 3. The cockpit voice recorder revealed the following conversation: "At 1804:18 [the accident occurred at 1805:52], the first officer said, 'Lightning coming out of that one [cloud].' The captain asked, 'What,' and the first officer repeated 'Lightning coming out of that one.' The captain asked, 'Where' and at 1804:23, the first officer replied, 'Right ahead of us.'" Id.

Doppler Radar Selected, supra note 70, at 30.

Horn Interview, supra note 45.
Liability may indirectly hamper technological growth because, as seen recently in the medical field, the possibility of liability discourages people from entering the affected field. Employees of both the NWS and FAA are simply afraid to interpret data because of the responsibility and consequential liability attached to this task. The fact that the FAA and NWS are often vicariously liable for their employee's conduct carries little weight in this context given the fact that employees causing the liability are frequently dismissed. Therefore, the employees are personally affected by such liability, and may consider this possibility when making a career choice. The data interpretation aspect of the Doppler Radar System is critical for future technological growth. If people are afraid to engage in data interpretation because of possible liability, technological growth is impeded and improvements to flight security are delayed.

Possible solutions to this growth impediment are discussed below. These options are merely the author's opinion presented very broadly and intended simply to provoke consideration. A detailed analysis of each is outside the scope of this comment.

B. Possible Responses to Growth Hampering Liability

1. The Black Box System

Depending upon the manner of implementation, the TDWR System may impact weatherman/controller liability in the context of data interpretation. Controllers and meteorologists are, as a general rule, reluctant to interpret Doppler radar data. They would prefer that the Doppler radar be completely automated—a sort of "black box" device that will "sound an alarm" if a microburst is detected—rather than requiring data interpretation, and hence, possible fallacy by the controller or meteorologist. A "black box" device eliminates potential liability

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145 Moller Interview, supra note 8.
146 Id.
for inaccurate data interpretation. The duty to timely convey such information, of course, would still exist.

The "black box" method, however, will hinder scientific and technological growth. Similar to the visual identification process discussed above, the human involvement and interpretation in the Doppler radar context also allows for detection of obscure irregularities that cannot be translated into linear equations. If the alarm sounds only when predetermined, programmed events occur, the opportunity for learning is eliminated and growth is hampered.

Requiring data interpretation, however, necessarily imposes extended responsibility on controllers which carries with it potential liability. The after-the-accident campaign to pin a "duty" on weather personnel, controllers, and pilots, removes society's focus from where it arguably should be—on solving the problem of wind shear. Society hurts itself by creating a litigious atmosphere where no one will take the steps necessary for scientific progress because the risk of liability is too high.

2. The Tort System

Presently, disputes involving aircraft accidents are resolved through conventional case-by-case adjudication of liability. Generally accepted rules concerning the liability of air traffic controllers and pilots have emerged which dictate that both the pilot and controller owe a duty of care to aircraft passengers. Additionally, case law gen-

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147 See supra notes 115-37 and accompanying text for discussion relating to visual identification of microbursts.
148 Moller Interview, supra note 8.
149 Redhead v. United States, 686 F.2d 178, 182 (3rd Cir. 1982) cert. denied, 459 U.S. 1203. As noted by the court, "[b]oth the pilot and the air traffic controller owe a duty of care to passengers in an airplane. Negligence by the pilot does not, in and of itself, absolve the government of liability. Each is responsible for the safe conduct of aircraft and the safety of its passengers . . . . Thus, there may be concurrent liability." Id. (citations omitted). In a later case, Rodriguez v. United States, 823 F.2d 735 (3rd Cir. 1987), the court referred to its earlier opinion in Redhead, stating:

Although we recognized that the pilot bears 'final authority' for air-
erally holds that the day-to-day decisions made by FAA air traffic controllers as they control aircraft typically fall outside the Federal Torts Claim Act's (FTCA) "discretionary function" exception to liability.\(^{150}\)

A possible response to growth-hampering liability lies in either the modification of the FTCA or a decision by the judiciary to foreclose liability in defined circumstances.

First, the FTCA could be amended to remove liability from FAA air traffic controllers and National Weather Service (NWS) personnel. Specifically, a narrow exception to liability could be created in circumstances where


Section 2674 states the general provisions of the FTCA:

The United States shall be liable, respecting the provisions of this title relating to tort claims, in the same manner and to the same extent as a private individual under like circumstances, but shall not be liable for interest prior to judgment or for punitive damages.

If, however, in any case wherein death was caused, the laws of the place where the act or omission complained of occurred provides, or has been construed to provide, for damages only punitive in nature, the United States shall be liable for actual or compensatory damages, measured by the pecuniary injuries resulting from such death to the persons respectively, for whose benefit the action was brought, in lieu thereof.

\(\text{Id.}\) The relevant exception to the general provision set forth above is found in Section 2680:

(a) Any claim based upon an act or omission of an employee of the Government, exercising due care, in the execution of a statute or regulation, whether or not such statute or regulation be valid, or based upon the exercise or performance or the failure to exercise or perform a discretionary function or duty on the part of a federal agency or an employee of the Government, whether or not the discretion involved be abused.

\(\text{Id.}\) Judicial interpretation of the FTCA consistently places day-to-day decisions made by air traffic controllers as "operational" decisions, rather than "discretionary," and thus beyond the scope of the exception. In \textit{Ingham v. Eastern Air Lines, Inc.}, 373 F.2d 227 (2d Cir. 1967), \textit{cert. denied} 389 U.S. 931, the court held that negligent directions given by an air traffic controller to an airplane pilot was not immune from attack under the FTCA discretionary function exception. 373 F.2d at 238.
wind shear is a significant causal factor in a weather-related aircraft accident and incorrect or inadequate data interpretation by controllers or weather personnel occurred. Alternatively, specific types of data interpretation (for example, interpreting data from a Doppler radar) could be designated a per se "discretionary function."

While this modification may appear to unfairly favor NWS and FAA employees over pilots, if the goal is to nullify specific sources of liability that impede scientific and technological growth it is a necessary step. Liability for incorrect interpretation of data from a Doppler radar is precisely the type of liability that hampers growth. The fact that controllers and NWS personnel are given such duties and thus, are the individuals protected, is fortuitous. On the other hand, pilots and commercial airlines are a necessary part of our society. The removal of liability from the government likely shifts liability to pilots and commercial airlines; a result that is both unfair and detrimental to their continued existence. This problem can be resolved under the following alternative.

Second, the judiciary could simply foreclose liability in certain defined circumstances by determining that no duty is owed and thus no negligence exists. That is, the judiciary can determine that a controller has no duty to accurately interpret data from a Doppler radar. Additionally, case law can dictate that the conduct of pilots and commercial airlines does not reach the level of tortious negligence (under the theory that no duty exists, no breach occurred, or no causal relationship exists) when a very specific, narrow set of circumstances exist.151

While these proposals may seem drastic and even dangerous, the obvious fact is that no pilot wants to risk his life, nor his passenger’s lives in a weather-related accident. Neither do air traffic controllers nor weather personnel wish to be responsible for the death of others due

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151 The requirement of specific, narrow circumstances should be strictly construed with proof of any other existing circumstances obviating the liability exemption.
to their error. The threat of legal liability provides little in the way of additional deterrence. The possibility of personal injury or responsibility for injury of another has sufficient deterrent effect. Individuals unaffected by this possibility surely would not be deterred, in any event, by the added threat of legal liability.

3. No Fault Compensation System

Another option for resolving the hampering effect of liability in wind shear related aircraft accidents is the implementation of a no fault compensation system. The presence of wind shear as a significant causal factor in the accident would trigger the no fault system, allocating a predefined amount of compensation to injured individuals. Payment of compensation could be borne by both the government and the commercial airline involved. Thus, compensation for the injured would ultimately come from the public through higher prices paid for airline services and higher taxes paid to the government. The cost spreading effect of the system puts the burden on the public—the beneficiary of the services. The certainty created by this option would obviate the detrimental effects of liability and permit technological growth.

4. Mandatory Arbitration Method

The damaging effects of increased litigation will eventually create a critical void in the aeronautics field. As seen recently in the medical field, increased liability discour-

152 The focus here is on the pilot, air traffic controller, and NWS employee. Obviously, the threat of legal liability encourages the airlines and government to implement training programs designed to prevent liability incurring accidents. In most contexts the deterrence effect on the company is very relevant. This comment, however, focuses entirely on the fact that, with current technology, wind shear related aircraft accidents are not entirely avoidable. Thus, no amount of penalties assessed against a commercial airline or the government will deter accidents because no one can currently prevent these accidents. In this context, the tort system's liability allocations are justifiable only in the compensation arena.

153 Arguably, those who do not fly are not beneficiaries and therefore should not have to share the burden of compensating victims of weather-related aircraft accidents.
ages participation. People tend to avoid high liability fields. Required prelitigation arbitration is a possible answer to this problem. Arbitration is less expensive than litigation and creates at least a minimal amount of certainty; advantages that attenuate constraints on growth.

5. Societal Decision to Limit Liability

Society is capable of limiting liability in order to allow continued development of science and technology. Without this limitation the problem of wind shear will be prolonged, and possibly never resolved. Some of the propositions noted above require society to relinquish its right to compensation. While this may seem a high price to pay, the goal is worth the sacrifice because perfected technology would all but prevent microburst related air traffic accidents. The opinion expressed is based on the assumption that society believes these prevention capabilities are of utmost importance. It is difficult to believe otherwise considering the fact that a large portion of society frequently flies. In any event, assuming society is unwilling to relinquish compensation rights, society, at a minimum, should be willing to forego certain demands in the name of progress, and ultimately, safety.

The flying public contributes to the overall problem of weather related accidents by creating a dilemma for commercial airlines and pilots. The public (particularly the business traveler), when selecting an air carrier for travel, places primary importance on departure/arrival timeliness. Since the American economic system is capitalistic, the competitive efforts by airlines to be timely is good and necessary. To the extent this effort encourages pilots to go through, instead of around, potential microbursts, the system perpetuates the problem. The real question soci-

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154 The high cost of litigation is found, primarily, in excessive awards. For example, the parents of a 15-year-old girl who died in the 1985 crash of Delta Flight 191 were awarded $3.4 million in damages in federal court. The court of appeals, in lowering the amount, ruled that the original award was "excessive, inflated by emotional evidence [the lower court] had allowed into the trial." *Fort Worth Star Telegram*, December 9, 1989.
COMMENTS

While science and technology have recently achieved new heights with the discovery of Doppler radar, wind shear-related aircraft accidents continue to occur. The implementation of Doppler radar through NEXRAD will prevent some accidents but leave many microbursts undetected. While technological devices are visible evidence of progress, the human element must be emphasized and supported, for it is the source of such growth. To fully develop the science of wind shear and in turn perfect its technology, society must be willing to make sacrifices that alleviate growth-hampering liability. Such forebearances are a small price to pay for safer air travel.