# Use, Nonuse, and Abuse of Weather Radar

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**Proper use of weather radar is represented by numerous effective applications in government services and private meteorological groups. These applications include detection and identification of storms, measurement and extrapolation of storm motions, and, with 10-cm wavelength, measurement of heavy rains. An example of inappropriate nonuse of radar is given by high performance systems in the national radar network, whose data have not been dependably provided in real time as needed by aircraft pilots in terminal areas. This nonuse has contributed to inappropriate use of airborne C- and X-band radar equipment and of visual perceptions to support critical decisions to penetrate echoing regions. Indeed, fatal accidents have followed use of airborne radar and visual sightings to support decisions to penetrate convective clouds. We observe that all fatal aircraft accidents involving U.S. air carriers in convective weather have involved flight in heavy precipitation and that recent years have seen a marked rise in the proportion of accidents at terminals. While excellent research is under way to provide manifold improvements in the aviation weather system, some years will pass before the research can be applied in operations. Therefore, technology already available for communicating and displaying radar reflectivity data should be used to facilitate timely evaluation of convective weather and appropriate responses in terminal operations.**

## I. Introduction

THUNDERSTORM-RELATED fatal aircraft accidents involving U.S. air carriers since 1970 have claimed 7 aircraft and 617 lives, mostly during flight near terminals, as shown in Table 1.[1-3] The weather feature common to all of these fatal accidents was heavy precipitation; attendant wind shear was also a significant factor in most cases. Similarly, Luers has presented a compilation of accidents under the heading, "Wind Shear," including those with only injuries as well as fatalities, and has concluded that in 11 of the 15 accidents on his list, "a thunderstorm/rain environment existed. The aircraft was in an extremely heavy rain cell, often of very small dimensions, accompanying the wind shear...[and] these eleven accidents accounted for 86% of the fatalities and 83% of the injuries."[4]

The proportion of accidents near terminals has increased markedly since 1970, for reasons discussed in Ref. 5, an article written before the 1985 Dallas/Ft. Worth accident; this article was too sanguine about projected developments in the aviation weather system. Although ground-based radars that can map precipitation intensity have covered major U.S. airports and airways since the 1960's, their data have not been provided directly to aircraft controllers, but rather comes to them through meteorologists, with significant delays. This deficiency has pronounced consequences in the terminal control area because the many planes under surveillance there are confined to a relatively small space during stages of flight that are rather unforgiving of error. Inexpensive techniques for displaying radar indications of precipitation intensity in real time at controllers' stations have been available since the mid-1970's, but they have not been used operationally for this purpose in the terminal cabs. This constitutes inappropriate nonuse of a vital resource and is associated with abuses since aircraft operators are forced to resort to other aids that are inherently unsuited to their objectives.

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## II. National Radar Network

Figure 1 shows the distribution of federal weather radars in the United States. The small solid black circles represent WSR–57 or WSR–74 radars of the national network, both radiating at 10-cm wavelength, and hence capable of portraying the intensity of even heavy rains with useful accuracy. In fact, these radars are used appropriately today for warning the public of severe local storms, for estimating precipitation amounts and the likelihood of flash floods,[6,7] and for assisting aviation. Their data are regularly and appropriately accessed by media all across our country, especially radio and television stations, with techniques of the family described by Zittel[8,9] and illustrated in Fig. 2. The data are available for interpretation and message preparation by meteorologists at air traffic control centers, and the data are interpreted by other meteorologists who disseminate advisories from their weather offices to aviation centers and elsewhere, but a typical time lag is more than 10 min. This is too long to satisfy needs during severe weather at and near busy terminals.[10]

Echo intensity data from a suitably located network radar could be available to controllers in the terminal cabs in virtual real time (within one minute) as a display easily understood by nonmeteorologists, as shown in Fig. 2. For example, the controllers would only have to notice if a flight corridor were overlaid by a specific echo intensity, marked by labeled contours. Hazard thresholds at "possible" and "probable" levels, for example, could be represented by contours of $Z_E = 10^4$ and of $10^5$ mm$^6$/m$^3$, where $Z_E$ is the equivalent radar reflectivity factor.[11,12] Observation of such contours, relayed in near real time to pilots, would ensure that pilots' decisions on such critical matters as continuing an approach to landing or choosing to await improved weather, were appropriately informed with severe weather information. We have noted above that such data are indeed provided at air traffic control centers, where they are examined by meteorologists who prepare messages for crews of en route aircraft. Although this is useful, it is less vital than the unused terminal application because airborne radars are more effective for avoiding storms while en route than during terminal stages of aircraft flight, as discussed in the next section.

## III. Airborne Radar

All aircraft of U.S. carriers are equipped with weather radars. There is need for fine resolution, i.e., beamwidths not more than a few degrees; therefore, the antennas are made as large as the size and shape of the airframe permits. But this has not been large enough to permit use of the relatively long 10-cm wavelength in commercial aircraft. Since resolution with an antenna of a given size improves as the wavelength is decreased, 3- and 5-cm radars are used by air carriers. Both of these wavelengths are subject to attenuation in heavy rain. Consequently, the apparent intensity of echo sources can be reversed, with stronger storms appearing to be weaker, especially when precipitation is heavy and extensive along radials. Thus, the airborne radar cannot be relied upon for its indications of the absolute intensity of heavy sources, nor even for the relative intensities of adjacent heavy sources.

Nevertheless, when properly used, airborne radar has a very important function because it can clearly and accurately show the near edge of precipitation and indicate paths that avoid the precipitation. This is particularly true when the aircraft is outside the precipitation area at altitude while en route, when there is usually considerable advance warning, room for maneuvering, and not the plethora of tasks that the crew faces during takeoffs and landings. In the approach environment, the airborne radar is much less useful. As the systems manager for training at Delta Airlines reported concerning airborne radar: "The primary use of this type of radar . . . is en route weather avoidance . . . especially in the final approach stage, you are in a . . . heavy task burden of the flight, and . . . you have to do an awful lot of playing with the antenna tilt, and [since] you are also very close to the ground . . . you get a lot of ground return. So, it's the least useful in the approach phase of flight." (See Ref. 10, p. 54.) In any event, using airborne radar to guide penetration of storms represents an abuse because the tool is inherently unsuited to the task. Similarly, the optical view per-

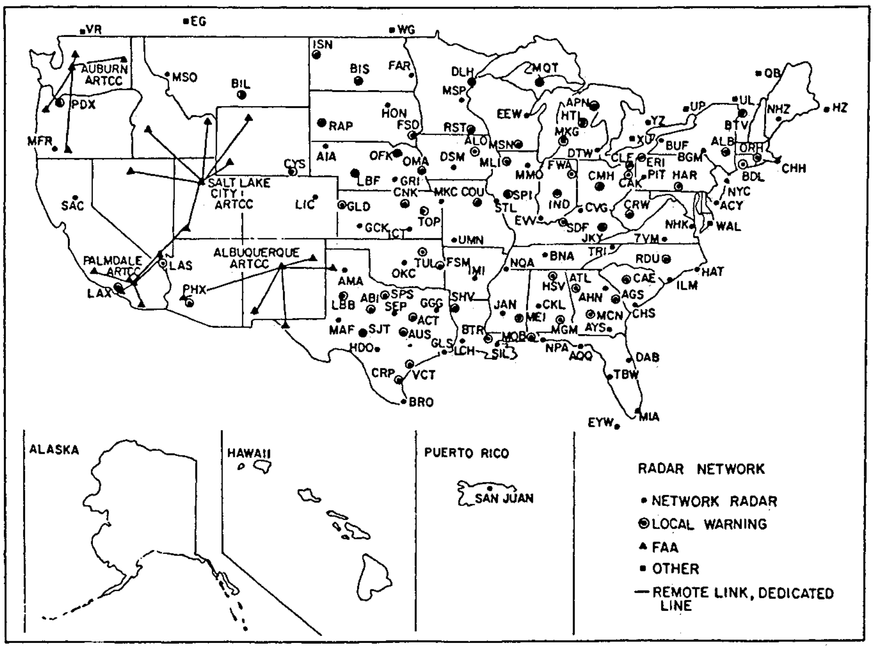



**Fig. 1 Radars used for meteorological purposes by the National Weather Service.[6]**

**Table 1 Fatal U.S. air-carrier accidents with thunderstorms and wind shear as cause or major factor[a]**

| Date | Aircraft type | Location | Takeoff, landing or en route | Weather condition or cause | Fatalities |
|---|---|---|---|---|---|
| Sept. 1, 1940 | DC-3 (2-eng prop) | Virginia | ENR | Lightning | 25 |
| May 29, 1947 | DC-3 (4-eng prop) | New York | Takeoff | Thunderstorm outflow | 43 |
| Aug. 29, 1948 | Martin 202 (2-eng prop) | Minnesota | ENR | Thunderstorm combined effects | 37 |
| June 25, 1951 | DC-4 (4-eng prop) | Lake Michigan | ENR | Thunderstorm combined effects | 58 |
| Apr. 28, 1951 | DC-3 (2-eng prop) | Indiana | ENR | Thunderstorm outflow | 11 |
| Feb. 15, 1953 | DC-6 (4-eng prop) | Gulf of Mexico | ENR | Thunderstorm combined effects | 46 |
| May 12, 1959 | Viscount (4-eng jetprop) | Maryland | ENR | Lightning and turbulence | 31 |
| June 27, 1959 | Cnstlltn (4-eng prop) | Italy | ENR | Lightning | 68 |
| Jan. 19, 1960 | Viscount (4-eng jetprop) | Virginia | ENR | Thunderstorm combined effects | 48 |
| Feb. 12, 1963 | B-720B (4-eng jet) | Florida | ENR | Thunderstorm drafts | 43 |
| July 2, 1963 | Martin 404 (4-eng prop) | New York | Takeoff | Thndstm shifting wind & rain | 7 |
| Dec. 8, 1963 | B-707 (4-eng jet) | Maryland | ENR | Lightning | 81 |
| Aug. 7, 1966 | BAC-111 (2-eng jet) | Nebraska | ENR | Thunderstorm turbulence | 42 |
| May 3, 1968 | Electra (4-eng jetprop) | Texas | ENR | Thunderstorm turbulence | 85 |
| July 23, 1973 | F-27 (2-eng jetprop) | Missouri | Landing | Thndstm outflow, ltng, & rain | 38 |
| Jan. 30, 1974 | B-707 (4-eng jet) | Samoa | Landing | Thunderstorm outflow & rain | 96 |
| June 24, 1975 | B-727 (3-eng jet) | New York | Landing | Thunderstorm outflow and rain | 112 |
| Apr. 4, 1977 | DC-9 (2-eng jet) | Georgia | ENR | Thunderstorm hvy rain & hail | 70 |
| June 12, 1980[b] | SA-226 (2-eng jetprop) | Nebraska | ENR | Thunderstorm turbulence & rain | 13 |
| July 9, 1982 | B-727 (3-eng jet) | Louisiana | Takeoff | Thundstm drafts, outflow & rain | 153 |
| Aug. 2, 1985 | L-1011 (3-eng jet) | Texas | Landing | Thundstm drafts, outflow & rain | 135 |

[a]After Lee & Beckwith,[1] National Research Council,[2] Reports of the National Transportation Safety Board, and the New York Times Index. See also Rudich.[3]
[b]Commuter airline, not classified as an air carrier.

ceives a cloud exterior, but little or nothing of its interior or of other storms that are obscured, and so it is not a reliable guide to interior conditions. These points are not new; they have been well known by authorities for practically two decades (e.g., Refs. 13–15).

## IV. NEXRAD Radar

The radars charted in Fig. 1 are aging, and starting in the late 1980's they are scheduled to be replaced with new weather radars having capability for Doppler (radial wind) measurements.[16] Plans call for the next generation of radars to be associated with far more computer and communications power than current weather radars, and they will have important abilities for three-dimensional measurements of wind phenomena such as gust fronts, discrete downdrafts and outflows (recently called downbursts[17]), tornadoes, and vertical variations of horizontal wind, for which little or no direct capability exists in the current radar system.[18] Emphasis on wind shear in relation to aircraft accidents is associated with support by the Federal Aviation Administration (FAA) to develop Doppler radar data processing routines that are aimed at deriving critical information on wind shear and its trends and communicating it in a timely fashion to pilots. This is a proper area for development, but it should be recognized that the nature of the outcome and the time of delivery of operationally valid products are both uncertain at this writing. There are at least two technical reasons for this.

First, the Doppler radar perceives only the radial component of the wind, and, notwithstanding some significant research, current projections of reliance on its identification of dangerous small-scale shears along directions tangent to the beam are premature. Second, the amount of velocity information that would be processed by a Doppler radar approaches an order of magnitude more than that from a conventional radar and poses a formidable challenge to capabilities for suitably direct and timely presentation. This problem may be assessed in light of the neglect noted previously in Sec. II, i.e., failure to use reflectivity-only data from current radars. It seems that the FAA program is substituting future possibilities for current probabilities. It should also be noted that when wind shears are accurately measured in a timely fashion operationally, the same associations of wind variations that have been observed during research programs will be seen, and avoiding shears will be closely related to avoiding convective precipitation. Heavy precipitation would continue to be a major hazard because of the loss of visual clues, even when wind shear is only moderate, as happened in the New Orleans accident.[19] This has been demonstrated in an insufficiently noticed report by Connelly.[20]

Thus, even at the uncertain date when velocity information from Doppler weather radars would be presented operationally and directly to controllers and/or flight crews, presence of heavy precipitation must continue as a limiting factor in terminal aircraft activities, at least until thoughtful research, including numerous flight tests with high-performance (military) aircraft [perhaps in an extension of the "Rough Rider" program (see Ref. 1, pp. 129–130)] demonstrates that aircraft can be threaded safely between dangerous and rapidly developing portions of severe storms. Staying well clear of heavy precipitation usually means avoiding strong shear and a safer flight, in any event. Means for presenting precipitation data to controllers in an easily understandable form are available in the Weather Service network radars and even in many radars operated by the FAA and not charted in Fig. 1. Their use now would represent a stage of orderly growth in the aviation weather system, a proper use of radar, and a good step toward a better system in the future that will develop from today's research.

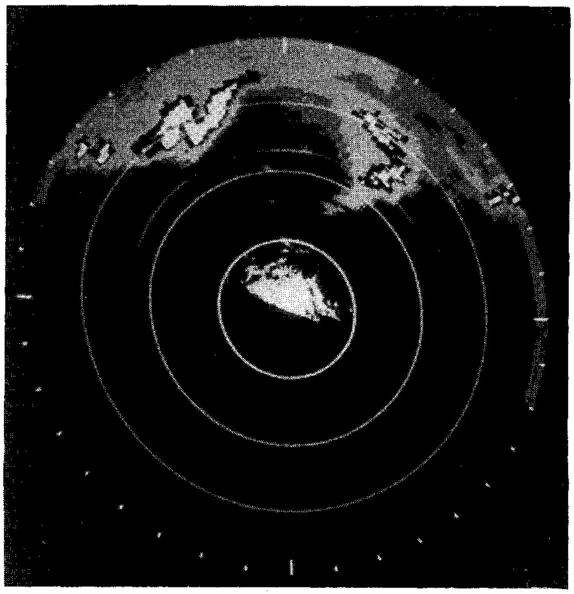
## V. Terminal Doppler Weather Radar

There is unwarranted concern that effective use of NEXRAD in the aviation weather system will be precluded by a commitment of the NEXRAD system to media and the public. This potential problem is perceived to have two facets: first, the radars may not be located for optimum coverage of major terminals; second, the data acquisition and processing routines may not be appropriately specified for aviation. To compensate for such perceived deficiencies, the FAA has been promoting an effort to develop a dedicated terminal Doppler weather radar system (TDWR), which incorporates NEXRAD technology to provide three-dimensional weather views virtually continuously and in great detail.

This effort is somewhat misguided, i.e., it represents an abuse to the extent that it comtemplates minute-by-minute discrimination between safe and unsafe corridors in storm environments long before a body of applied research has established high reliability of such an approach. It is also an abuse in its substitution of an uncertain high-technology future for early implementation of techniques by which dangerous precipitation and attendant shears could be effectively avoided in terminal areas. We have already noted that radars now in place provide the kind of data needed to avoid heavy precipitation and associated wind shears at busy airports; a few locations in the high plains, such as Denver, Colorado,[21] and some desert areas are possible exceptions with regard to shear. As previously noted, however, shear problems are much less serious when there is little or no precipitation and in less heavily traveled areas. With diminished pressures related to a long file of aircraft awaiting their turns, pilots and controllers are more likely to opt for "go around." The current effort in FAA toward improving national operations should be focused first on available technology because this technology is both very promising and significantly underutilized. If there are reasons unknown to the author for eschewing this approach, then the focus should be on NEXRAD itself or on the FAA's own ASR–8 or ASR–9 radars. The ASR–8 is already in place with a separate weather channel that is now generally unused, and the ASR–9 is already scheduled with a separate weather channel and Doppler circuits that were demonstrated to be effective in simulation studies.[22]

The NEXRAD radars, with numerous enhanced capabilities for data processing and communicating, would provide surveillance of airport weather at 5-min intervals, with respect to both precipitation intensity and velocity. This is fast enough if the objective is to avoid storms by a reasonable margin, even if the radars are less than optimally located for aviation. The capabilities in NEXRAD and/or the ASR–8's or ASR–9's should be implemented in the aviation weather system as soon as they are installed, and subsequently they should be evaluated in a deliberate fashion to determine if added dedicated radars would enhance the system at a later date.

The FAA's draft Integrated Wind Shear Program Plan[23] is the latest programmatic document on this subject that is available to the author at this writing. On page 8–2, it presents a timetable for implementing TDWR's with three-dimensional automatic processing of Doppler radar data and communicating of guidance on the tight schedules of busy airports. But no detailed implementation plan exists, nor can it exist because several critical problems have not been solved. On the same page it proposes only to explore means for implementing weather hazard displays from available radars, an exploration already conducted in depth by several researchers supported by the FAA, and by others. Furthermore, there is no mention of FAA's own ASR series of radars, which have important capabilities culminating in the ASR–9 already noted. Thus, we have a repetition of a condition that has endured for at least 10 years, i.e., costly and time-consuming efforts with uncertain outcome are scheduled and promoted, and feasible, less costly systems with demonstrated capability are neglected. In other words, a large effort toward a high technology solution to an entire problem is announced, while a readily realizable solution to a great part of the problem, involving lower technology, lower costs, and higher probability of success, is neglected. In the current context, unless the more manageable reflectivity problem is addressed aggressively, the aviation weather system

a) 

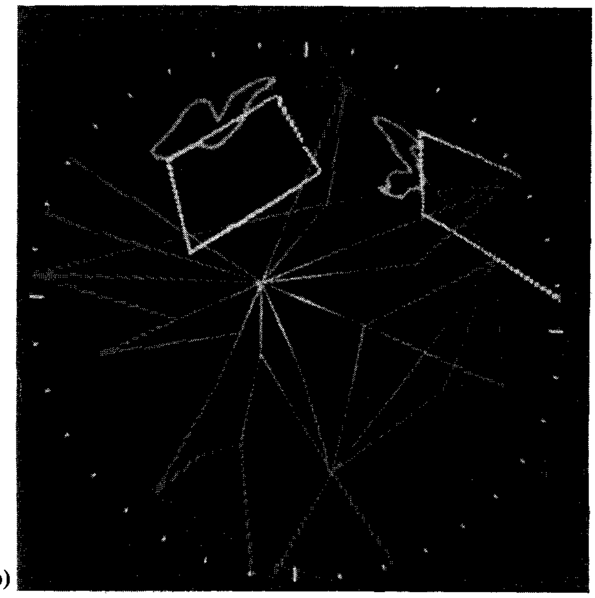
b) 

**Fig. 2 Illustration of two among many kinds of displays provided by the technologies of digital data processing and communication, and bright cathode ray tubes: a) radar echoes from severe weather within a wide-spread area of light to moderate precipitation; b) contours of selected intensity are superimposed on local airways. The rectilinear regions represent the projected motion of the contours as calculated from their behavior in the recent past (see Ref. 8).**

will continue to be left without needed protections for the long time required to develop a safe and reliable automated Doppler system. The draft plan is flawed in other respects because, as already suggested, radar fundamentals and asymmetries typical of wind shear events preclude using a single Doppler radar to provide reliable indications of the along-runway component of shear for all the runways of a large terminal[21,24] or to measure significant shears normal to the direction of the radar beam. Finally, a number of special problems must be resolved in the operational context before committing air carriers to a weather protection system based on automatic reporting from a terminal Doppler radar. These relate to occasional severe conditions with precipitation extended along radials, when second or even third trip echoes reduce capabilities for velocity discrimination. Attenuation could also be critically limiting at times if C-band is selected for a terminal Doppler system.

## VI. Summary and Conclusions

The flight of an aircraft responds to the ambient airflow and to aerodynamic properties of the aircraft, the latter being subject to control by the pilot and by automated onboard systems. Certainly the direct cause of most recent thunderstorm-related accidents lies in failure or inability to adjust thrust and control surfaces to compensate appropriately for wind variations, i.e., for wind shears. However, the direct focus on wind shears has produced a broad program of research and development[25,26] that gives virtually no place to early implementation of already available means for avoiding shear. The research is commendable, but substituting research for appropriate implementation is a serious abuse. To correct this, for example, radar reflectivity data available now could be provided in virtually real time to terminal controllers in a form that could be applied simply and objectively. The cost would be modest, and such a step would not only solve a large part of the problem posed by convective weather at terminals, but it would help direct and otherwise facilitate further research and development in the aviation weather system. Current directions embody needless and dangerous delay of changes that would rectify most of the current deficiency pertaining to communication and utilization of information on convective weather at busy terminals. Indeed, current emphasis raises the specter of occasional automatic accidents in a future system where accountability resides in computers rather than in people. This is not the kind of future that we should be developing.

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