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Summary of Findings from the PIREP-Based Analyses Conducted During the 1988 to 1990 Evaluations of TDWR-Based and TDWR/LLWAS-Based Alert Services Provided to Landing/Departing Pilots

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July 1992

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The Federal Aviation Administration (FAA) is developing the Terminal Doppler Weather Radar (TDWR). Starting in 1988, the TDWR Program conducted a series of evaluations of a TDWR-based alert service to provide wind shear and microburst alerts to landing and departing pilots. Starting in 1989, a second series of evaluations was initiated involving an integrated alert service consisting of TDWR and the Phase III Low Level Wind Shear Alert System (LLWAS). Evaluations are expected to continue through 1992.

The radio communications between Local Control and landing and departing pilots were analyzed for 224 of the 323 alert periods that occurred during the 1999 through 1990 and represents one component of the overall investigation that took place.

A key element of the communications were the pilot reports (PIREPs) of weather-related encounters and observations made during the alert periods. PIREPs were used to: (a) evaluate the accuracy of the issued alerts from the pilot's viewpoint as to the location and intensity of the wind-related encounters, and (b) identify situations in which pilots reported wind-related encounters that were not provided alert coverage.

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Doppler Weather Radar, Terminal Doppler Weather Radar, TDWR, Low Level Wind Shear Alert System, LLWAS, Microbursts, Wind Shear, Thunderstorms

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PREFACE

This study is sponsored by the U.S. Department of Transportation, Federal Aviation Administration, ANR-150. The study was performed by the U.S. Department of Transportation, Volpe National Transportation Systems Center and was conducted in support of the Terminal Doppler Weather Radar (TDWR) Program.

This report consolidates and summarizes the findings of five evaluations that took place from 1988 through 1990. The data collection activities and subsequent analyses on which the evaluations were based involved the cooperation of several organizations and many individuals. The support provided by the following organizations is gratefully acknowledged: the National Center for Atmospheric Research; Lincoln Laboratory of the Massachusetts Institute of Technology; the Air Traffic Service of Stapleton International Airport; Orlando International Airport; and Kansas City International Airport.

METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32) (5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
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1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0		1		2		3		4		5		6		7		8		9		10					
CENTIMETERS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

25.40

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

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EXECUTIVE SUMMARY

As of 1990, the TDWR Program had conducted three evaluations of a TDWR-based alert service at: (a) Denver's Stapleton International Airport in 1988, (b) Kansas City International Airport in 1989, and (c) Orlando International Airport in 1990. Two evaluations were also conducted of an integrated TDWR/LLWAS-based alert service at Stapleton International Airport in 1989 and 1990.

The role of the Volpe National Transportation Systems Center during these five evaluations was to analyze the pilot-controller radio communications for the alert periods and to describe what took place. The resulting analyses involved four general areas of investigation that: (a) characterize the wind-related encounters reported by landing/departing pilots, (b) evaluate the performance of the issued TDWR-based alerts, based on what pilots reported of their encounters, (c) evaluate the "value-added" performance of integrating LLWAS with TDWR, and (d) describe the operational impact of the provided TDWR-based and TDWR/LLWAS-based alert services.

Given the number of areas investigated, this report presents 22 findings. The four primary conclusions are:

1) TDWR provided landing/departing pilots with effective alert coverage of microbursts and partial alert coverage of gust fronts,

2) Integrating LLWAS with TDWR: (a) increased alert coverage of gust fronts, threshold-level outflows, and small-scale wind features, and (b) improved the overall accuracy of the alert intensity estimates (e.g., microburst alert, 30-knot loss, 1-Mile Final) when compared to pilot-reported airspeed variations,

3) Consideration should be given to increasing alert coverage to include: (a) a crosswind shear situation created when the head of a gust front becomes aligned with the final approach path and envelopes it, and (b) microburst-generated gust fronts, if TDWR is to be deployed at airports as a stand-alone alert system, and

4) The effort to reduce apparent alert overwarning (i.e., the high percentage of pilots that received an alert, flew into the alert area, and indicated something to the effect that "little or nothing was encountered") should continue in the post-1990 TDWR and TDWR/LLWAS evaluations.

The results presented in this report: (a) characterize the general operational performance capabilities of the early variations of the TDWR and Integrated TDWR/LLWAS systems tested

prior to 1991, and (b) should not be used, in isolation, to infer specific performance capabilities of the final operational systems. Based, in part, on the results of the 1988 to 1990 test sequence, significant software changes were made to both systems after 1990. These system changes may warrant additional study relative to determining the actual operational performance capabilities of the "fully operational systems" in their final form.

1. INTRODUCTION, CONCLUSIONS, AND SUMMARY OF RESULTS

The Federal Aviation Administration (FAA) is developing the Terminal Doppler Weather Radar (TDWR). Starting in 1988, the TDWR Program conducted a series of evaluations of a TDWR-based alert service to provide wind shear and microburst alerts to landing and departing pilots. Starting in 1989, a second series of evaluations was initiated involving an integrated alert service consisting of TDWR and the Phase III Low Level Wind Shear Alert System (LLWAS). Evaluations are expected to continue through 1992.

The Volpe National Transportation Systems Center (VNTSC) was involved in these evaluations from 1988 through 1990. VNTSC's role was to analyze the pilot-controller radio communication tapes for the alert periods and to describe what took place, such as:

a) How many alerts were issued?

b) To what extent did the pilots use the alerts for wind shear avoidance?

c) For those pilots that flew through the indicated alert area and reported the experience, how accurate were the issued alerts?

d) Were alerts provided to all landing/departing pilots that reported a wind-related encounter?

e) What was the expressed pilot reaction to the provided alert service?

To date, the results of the analyses for the five evaluations that took place from 1988 to 1990 have, with one exception, been reported informally. This report consolidates and summarizes these results, and represents one component of the overall investigation that has taken place during the evaluations.

1.1 BACKGROUND

Key elements of VNTSC's analyses depended on pilot reports (PIREPs) of weather-related encounters, observations, and reactions. PIREPs were obtained from those pilots that: (a) reported their experiences to Local Control by means of the Air Traffic Control (ATC) radio, and/or (b) utilized one of the mail-in questionnaires made available to a number of airlines at each of the test airports. The questionnaires were provided by the National Center for Atmospheric Research as part of the TDWR Program. The mailed-in questionnaires have been treated as confidential in that the data used from them have not been

identified as to pilot or airline.

As of 1990, evaluations of the TDWR-based alert service had been conducted at: (a) Denver's Stapleton International Airport in 1988, (b) Kansas City International Airport in 1989, and (c) Orlando International Airport in 1990. Evaluations of the integrated TDWR/LLWAS-based alert service were conducted at Stapleton International Airport in 1989 and 1990.

Local Control is responsible for landing and departing aircraft while they are on final approach, the runways, and initial takeoff climb. During the evaluations, an alpha/numeric display at each local controller station displayed the alerts in effect for the various runways. Whenever a pilot was to be issued clearance to take off or land, the local controller would look at the alert display and issue any alert in effect for that operation along with takeoff/landing clearance. At alert startup, the controller would issue the alert to impacted pilots that had already received takeoff/landing clearance.

The final form of the alert terminology used during the evaluations and a simplified interpretation of the alerts are as follows:

a) **Microburst alerts** were issued to pilots when a microburst outflow had a detected loss in wind speed across the outflow of at least 30 knots and had the form:

"Microburst alert, 30-knot loss 1-Mile Final."

b) **"Loss" wind shear alerts** were issued to pilots when an outflow had a detected loss in wind speed across the outflow of at least 15 knots but less than 30 knots and had the form:

"Wind shear alert, 15-knot loss over the runway."

c) **"Gain" wind shear alerts** were issued to pilots when a wind shift line (e.g., a gust front) had a detected gain in wind speed across the line structure of at least 15 knots and had the form:

"Wind shear alert, 15-knot gain 1-Mile Departure."

Alert coverage was provided to landing pilots for wind shear features inside 3-Mile Final and to departing pilots for wind shear features out to 2-Mile Departure (i.e., out to two miles beyond the departure end of the runway).

The five evaluations covered a total of 39 weeks. During that time, 323 alert periods took place and the runways were under alert status for approximately 64 hours. The ATC

communication tapes were analyzed for 224 of the alert periods covering 53 hours of operations, or 83% of the time that the runways were under alert status. During the 224 examined alert periods:

a) 1533 aircrews were issued an alert, and 656 (i.e., 43%) of those aircrews provided a pilot report on the experience (i.e., provided a PIREP), and

b) An additional 163 aircrews reported wind-related encounters for situations that were not provided alert coverage.

1.2 CONCLUSIONS

Relative to the PIREP-based analyses conducted over the five evaluations:

1) TDWR provided landing/departing pilots with effective alert coverage of microbursts and partial alert coverage of gust fronts.

2) Integrating LLWAS to TDWR: (a) increased alert coverage of gust fronts, threshold-level outflows, and small-scale wind features, and (b) improved the overall accuracy of the alert intensity estimates (e.g., microburst alert, 30-knot loss, 1-Mile Final) when compared to pilot-reported airspeed variations.

3) Consideration should be given to increasing alert coverage to include: (a) a crosswind shear situation created when the head of a gust front becomes aligned with the final approach path and envelopes it, and (b) microburst-generated gust fronts, if TDWR is to be deployed at airports as a stand-alone alert system.

4) The effort to reduce apparent overwarning (i.e., the high percentage of pilots that received an alert, flew into the alert area, and indicated that "little or nothing was encountered") should continue in the post-1990 TDWR and TDWR/LLWAS evaluations.

The results presented in this report: (a) characterize the general operational performance capabilities of the early variations of the TDWR and Integrated TDWR/LLWAS systems tested prior to 1991, and (b) should not be used, in isolation, to infer specific performance capabilities of the final operational systems. Based, in part, on the results of the 1988 to 1990 test sequence, significant software changes were made to both systems after 1990. These system changes may warrant additional study relative to determining the actual operational performance capabilities of the "fully operational systems" in their final form.

1.3 SUMMARY OF FINDINGS

The findings are numerous given the number of areas investigated. The summary and the report are organized as follows: (a) a characterization of the microburst and gust front encounters reported by landing and departing pilots (Section 1.3.1 and Section 2), (b) the performance of the TDWR-based alerts from the pilot's viewpoint (Section 1.3.2 and Section 3), (c) the impact of integrating LLWAS with TDWR at Stapleton International Airport (Section 1.3.3 and Section 4), and (d) the operational impact of the provided TDWR-based and TDWR/LLWAS-based alert services (Section 1.3.4 and Section 5).

1.3.1 Findings Concerning Microburst and Gust Front Encounters by Landing and Departing Pilots

1) Although potentially deadly, microbursts impacting arrival operations inside 3-Mile Final or departure operations inside 2-Mile Departure are dealt with on a weekly basis at certain airports during the summer thunderstorm season (e.g., at Stapleton International Airport and at Orlando International Airport).

2) For recognition purposes, pilots should be aware that microburst encounters are experienced and reported in a variety of ways depending on the portion of the microburst encountered and whether the pilot encounters the microburst on final approach, landing rollout, takeoff roll, or initial takeoff climb.

   a) On final approach, pilots tend to report one or more of the following: (1) a downflow/sinker, (2) loss in altitude, (3) variations in airspeed that can include a gain and/or a loss, (4) need to increase power, (5) crosswinds, if the aircraft crossed the outflow on one side of the microburst, and/or (6) turbulence, twisting of aircraft, or poor ride quality.

   b) On landing rollout, the wheels are on the pavement, and pilots are no longer sensitive to speed variations due to wind shear. PIREPs were rarely received in this situation and then only when the encounter involved significant crosswind.

   c) On takeoff roll, pilots are primarily concerned with following a takeoff acceleration profile, and they: (1) tend to report any inability to accelerate normally, using terms like "stagnation" or "hangup" in airspeed, and (2) may report a need to increase power.

   d) On initial climb, pilots tend to report one or more of the following: (1) difficulty in climbing or actually

picking up a rate of descent, (2) difficulty in accelerating, again tending to use the term "stagnation," (3) variations in airspeed that can include a gain and/or a loss, and (4) turbulence or poor ride quality.

3) Microbursts can occur individually or in groupings and can impact runway operations for a few minutes up to an hour and, in one observed case, for two hours.

4) Two types of gust front situations occurred in which pilots tended to report relatively-intense encounters:

a) When the head of a gust front, with its associated turbulence and downdrafts, became aligned with the final approach path and enveloped it, and

b) When the outer edge of a microburst outflow moved away from the downflow area and was encountered in its own right. This microburst-generated gust front is sometimes referred to as a "ring gust front" and can be quite vigorous.

1.3.2 Findings Concerning the Performance of the TDWR-Based Alerts from the Pilot's Viewpoint

5) TDWR provided pilots with effective alert coverage of microbursts.

a) In a check of the raw TDWR and LLWAS data for cases involving pilots that had not received a TDWR-based alert and yet reported a significant encounter (i.e., reported an airspeed variation of 20 knots or more, moderate turbulence, or a downdraft), it was found that none of the cases involved a microburst.

b) The same check, with the same result, was also made for those pilots in the TDWR/LLWAS-based evaluations that would not have received a TDWR-based alert if TDWR had been operated as a stand-alone alert system.

6) Relative to gust fronts, TDWR:

a) Did not provide alert coverage for gust fronts less than 10 kilometers in extent, which included microburst-generated gust fronts, and

b) Had difficulty providing alert coverage for gust fronts when the line structure became aligned with TDWR's radar beam.

7) Fewer than 3% of the pilots who were issued a TDWR-based alert received a late alert.

8) Pilot-perceived, alert false alarms were found to be a frequent occurrence in the evaluations (e.g., of the pilots issued a TDWR-based alert during the 1990 Stapleton evaluation and who flew into the alert area and reported the experience, 28% of the pilots reported something to the effect that "nothing was encountered" and another 15% of the pilots reported something to the effect that "nothing much was encountered"). Three factors are relevant to this finding:

a) To increase operational safety, the alert software generated alerts for wind shear features that were threatening as well as on the final approach and initial takeoff paths (i.e., for wind shear features within 0.5 miles of the final approach path or the straight-out takeoff path).

b) A review of the raw TDWR and LLWAS data has shown that the "alert" wind shear features were really there but were off the flight path in those cases when pilots reported "little or nothing encountered." In addition, the engineering component of the evaluations demonstrated that TDWR detects microbursts and gust fronts with a low false alarm ratio of a few percentage points.

c) A series of changes to the alert software, starting after the 1988 evaluation, has reduced the extent of the apparent overwarning.

9) Relative to the intensity estimate provided by each TDWR-based alert (e.g., microburst alert, 30-knot loss, 1-Mile Final):

a) It fulfilled its basic mission in that it provided the pilot with an effective upper limit on the airspeed variation that would be experienced during the wind shear encounter (i.e., no pilot reported an airspeed variation that exceeded the alert's intensity estimate by more than 5 knots).

b) It was accurate in a number of cases (i.e., of those pilots that reported some sort of wind-related encounter and reported the resulting airspeed variation, 35% of the pilots found the alert's estimate to be within ±5 knots of the airspeed variation experienced).

1.3.3 Findings Concerning the Impact of Integrating LLWAS with TDWR at Stapleton International Airport

10) The addition of the LLWAS channel to TDWR had the following primary, beneficial effects; it:

a) Increased the system's alert coverage of gust fronts, threshold-level outflows, and small-scale wind features (e.g., surface-level turbulence),

b) Improved the timeliness of the alerts issued to pilots in some cases, and

c) Improved the overall accuracy of the alert's intensity estimate (i.e., of the pilots who reported some sort of wind-related encounter and reported the resulting airspeed variation, the percentage of pilots who found the alert estimate to be within ±5 knots of the airspeed variation they experienced, increased from 35% with TDWR to 68% with TDWR/LLWAS).

11) Fewer than 2% of the pilots who were issued a TDWR/LLWAS-based alert received a late alert.

12) The addition of the LLWAS channel had little effect on the overall percentage of pilots that reported "little or nothing encountered."

13) Relative to TDWR, the integrated TDWR/LLWAS system increased the overall alert activity three- to four-fold. The increase was noted in the number of alert periods that occurred, the time that Stapleton's runways were under alert status, and the number of aircrews to receive an alert. Most of the additional alert activity consisted of 15-knot alerts, the system's minimum-intensity alert.

1.3.4 Findings Concerning the Operational Impact of the Provided TDWR-Based and TDWR/LLWAS-Based Alert Services

14) Relative to the alert period duration:

a) With TDWR, the time that an airport's active runways were under alert status varied from 9 minutes/week on average at Kansas City International Airport to 95 minutes/week at Orlando International Airport.

b) With TDWR/LLWAS, the runways at Stapleton International Airport were under alert status 150 minutes/week versus 50 minutes/week with TDWR alone. It is not known if this three-fold increase will be typical of other airports.

c) Note that these statistics do not relate to 24-hour-per-day coverage, but to the noon to 7 pm alert service coverage provided during the summer thunderstorm season.

15) Landing/departing operations did not always cease when microburst alerts were in effect.

a) The FAA maintained its traditional policy of leaving weather-related, go/no-go decisions to airline policy and pilot discretion,

b) Some pilots landed or took off with a microburst alert in effect (e.g., in 1990, at least 16 aircrews did so at Stapleton International Airport and at least 29 aircrews at Orlando International Airport),

c) The attitude expressed by one pilot "...used maximum power so no problem" suggests the attitude of these pilots, at least for the 30-knot and 35-knot microburst alerts. On occasion, this attitude will prove treacherous (e.g., in the 1989 Stapleton evaluation, a pilot was issued a 30-knot microburst alert, continued with the approach, and experienced a "5G" landing and structural damage to the aircraft).

16) Departure operations sometimes ceased when "loss" wind shear alerts were in effect.

a) Of the landing pilots directly issued a "loss" wind shear alert, 7% of the pilots elected not to complete their landings.

b) In contrast, of the departing pilots directly issued a "loss" wind shear alert, a relatively large percentage (i.e., 31% of the pilots) declined takeoff clearance. The data were insufficient to indicate whether the utilization of the "loss" wind shear alert for shear avoidance, and its impact on runway capacity, will increase or decrease over time.

17) Runway operations did not cease during periods when "gain" wind shear alerts were in effect, except when the runways were being shifted due to a shift in wind direction at the airport caused by the passage of the associated gust front.

18) The 15-knot alert, as the system's minimum-intensity alert, was brought into question in the 1989 and 1990 TDWR/LLWAS Stapleton evaluations, when it was found to be the dominant alert issued to pilots (i.e., 57% of the pilots issued an alert were issued a 15-knot alert).

19) A review of the PIREPs from the 1989 and 1990 TDWR/LLWAS Stapleton evaluations found that the 15-knot alert played a useful operational role:

a) In a small number of cases, the 15-knot alert apparently served to flag areas of significant turbulence or up/down drafts even though the detected wind shear was at modest levels.

b) The 15-knot alert forewarned numerous pilots of threshold-level encounters in which pilots would report a 10, 15, or occasionally, a 20-knot airspeed variation.

c) This level of encounter has been noted as significant by the aviation community: (1) during the evaluations, a number of pilots indicated on their mail-in questionnaires that a wind-induced airspeed variation of 10 or 15 knots was considered a significant encounter, and (2) at least one airline uses the guideline that a wind-induced, 15-knot, airspeed variation experienced by a pilot during landing or takeoff, when under 1000 feet AGL (above ground level), calls for corrective action in order to maintain flight path control. In addition, the FAA Wind Shear Training Aid also advises pilots to abort an approach when they experience an uncommanded 15-knot airspeed variation.

20) The evaluated TDWR-based and TDWR/LLWAS-based alert services were not designed to provide alert coverage for all wind-related situations reported by landing/departing pilots. A review was conducted of the more-intense encounters reported by pilots that were not provided alert coverage over the five evaluations. The results of that review found situations that were not provided alert coverage by:

a) Either the TDWR/LLWAS or the TDWR-based alert systems. These involved encounters: (1) outside 3-Mile Final, where alert coverage commenced, (2) beyond 2-Mile Departure, where alert coverage terminated, (3) with outflows or gust fronts below alert-threshold level, or (4) with vertical wind shear.

b) The TDWR alert system alone. These situations involved encounters with gust fronts that either: (1) became aligned with the TDWR radar beam and were no longer detected, or (2) were less than 10 km in extent, which represented one of the TDWR alert-threshold conditions. The latter situation generally involved a vigorous, microburst-generated gust front less than 10 km in extent and included pilot-reported gains of up to 30 knots and moderate turbulence. The microburst-generated gust front less than 10 km in extent was an area identified in the Conclusions for consideration of expanded alert coverage, if TDWR is to be deployed at airports as a stand-alone alert system.

c) The TDWR/LLWAS alert system alone. With one exception, the integrated alert system provided general alert coverage of all gust fronts, including microburst-generated gust fronts. The exception was intentional in that the TDWR/LLWAS system software was programmed so as not to provide alert coverage of crosswind shear situations, which were originally thought to be of secondary concern to

landing/departing pilots. (Note that this restriction did not apply to the TDWR alert system during the 1988 to 1990 evaluations.)

The end result of this restriction was that TDWR/LLWAS did not provide alert coverage of gust fronts when the head of a gust front, with its turbulence and downdrafts, became aligned with the final approach path and enveloped it. This situation occurred several times and caused numerous pilots to report significant encounters, including: (1) "pretty rough and miserable ride all the way down," (2) "as tough a landing as I have ever made," (3) "pretty large sinker at 50 feet, quite a large airspeed variation; going around," and (4) "15-knot loss and a marked wind shift at 200 feet... really ought to let people know." This was another area identified for consideration of expanded alert coverage in the Conclusions.

Incidently, it was determined that these particular situations identified in the review would not have been provided alert coverage by the TDWR alert system either, probably because they involved microburst-generated gust fronts less than 10 km in extent.

21) Pilot reaction to the provided alert service, as expressed to Local Control on the ATC radio or by means of the mail-in questionnaires, was as follows:

a) In the first evaluation at Stapleton International Airport in 1988, pilots expressed both encouragement and concern about overwarning (e.g., "Excellent safety device but accuracy is in doubt").

b) By the 1990 evaluations, after a sequence of changes to the alert software, expressed pilot reaction was overwhelmingly positive (e.g., "An excellent system, money well spent"). The three cautionary comments received did not involve overwarning but were concerned with non-alert situations and the effectiveness of the alert presentation in getting pilot attention.

c) The typical response in the mailed-in questionnaires was that the pilot: (1) considered the received warning useful whether it was a microburst alert, "loss" wind shear alert, or a "gain" wind shear alert, (2) used the alert to review the situation, and (3) increased landing/takeoff airspeed if the decision was to proceed with the landing or takeoff.

22) The eventual operational impact of alert overwarning is not known, but the effort to reduce it should continue in the post-1990 TDWR and TDWR/LLWAS evaluations.

a) To the extent that overwarning results in pilots not taking microburst alerts seriously when, in reality, the microburst is on the intended flight path, safety will be adversely affected.

b) To the extent that overwarning results in pilots not taking off or landing with an alert in effect when, in reality, the wind shear feature is safely off the intended flight path, runway utilization will be adversely affected.

c) Although pilots did not highlight overwarning as a concern in the 1990 evaluations as stated in Finding (21), Air Traffic personnel in the 1990 Orlando evaluation did express concern about lost runway operations on several occasions.

2. WIND SHEAR ENCOUNTERS REPORTED BY LANDING/DEPARTING PILOTS

The following observations are concerned with providing insight into wind shear encounters as they were experienced and reported by landing and departing pilots. The performance and utilization of the alerts issued to the pilots are discussed in later sections.

2.1 REPORTED MICROBURST ENCOUNTERS

The microburst is a wind shear feature of particular concern to landing and departing pilots when thunderstorms are in the vicinity of an airport. Microbursts are produced by powerful, small-scale downdrafts of relatively cold, heavy air that are generated within a thunderstorm cell or cumulus cloud. As the intense downdraft hits the earth's surface, it spreads out horizontally. Doppler weather radar and enhanced LLWAS detect the resulting outflow.

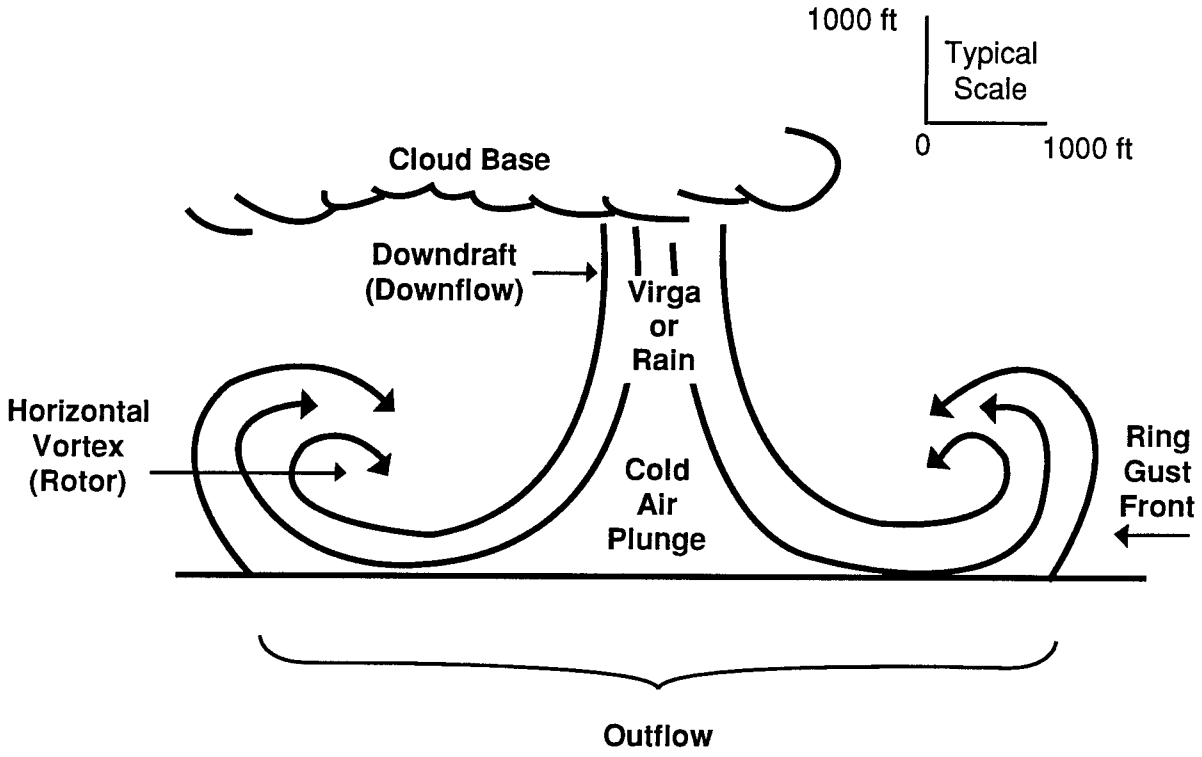
Generally, a downflow/outflow is defined as a microburst if the difference in wind speed across the outflow is at least 10 meters/second (i.e., approximately 20 knots) and the outflow is 4 kilometers or less in diameter (i.e., approximately 2.5 miles). (Note, the tested TDWR and TDWR/LLWAS alert systems did not increase an alert to "microburst alert" status until the wind speed difference reached 15 meters/second or 30 knots in order to reserve the term for outflows that had intensified to potentially hazardous levels for landing/departing pilots.)

The peak wind speed difference across a microburst's outflow over its lifetime is usually less than 60 knots and very rarely exceeds 90 knots. Typically, an outflow has a lifetime of about 15 minutes in which it builds in strength over a period of several minutes, maintains peak strength for several more minutes, and then dissipates. Figure 2-1 shows the common features of a microburst's downflow/outflow, as seen in cross-section. Viewed from above, a microburst's outflow is generally roughly circular to oblong in shape.

Finding 1 - Although potentially deadly, microbursts impacting arrival operations inside 3-Mile Final or departure operations inside 2-Mile Departure are dealt with on a weekly basis at certain airports during the thunderstorm season.

It has been well documented that microburst encounters have resulted in landing and takeoff accidents.

Although being faced with a microburst during landing or takeoff may be a rare event in the experience of the individual pilot, the situation occurs on a weekly basis during the thunderstorm season at Stapleton International Airport and Orlando International Airport. Clearly, pilots and controllers



(Source: The National Center for Atmospheric Research)

FIGURE 2-1: BASIC STRUCTURE OF THE MICROBURST SHOWING COMMONLY ASSOCIATED FEATURES

have been coping with microbursts routinely on the national level. The many successful faceoffs with microbursts are probably due to a number of factors: (a) it typically takes several minutes for a microburst's outflow to build up strength so the first "warning" encounter tends to take place prior to peak strength, (b) the maximum strength of the outflow may not exceed 30 knots and seldom exceeds 60 knots, (c) the outflow at full strength will generally only last a few minutes, (d) the stronger intensity outflows are probably accompanied in many cases by visual cues, such as blowing rain or dust, and (e) established pilot procedures for reacting to inadvertent wind shear encounters.

The following is an example of one airline's guideline to its pilots as to when an inadvertent wind shear encounter during landing or takeoff calls for corrective action. "The recommended recovery procedure should be initiated any time the flight path is threatened below 1000 feet AGL on takeoff or approach. The guidelines for unacceptable flight path degradation are:

TAKEOFF/APPROACH
±15 knots indicated airspeed deviation,
±500 fpm vertical speed deviation, or
±5 degrees pitch attitude deviation.

APPROACH
±1 dot glideslope displacement, or
Unusual throttle position for a significant period of time."

The following is an example of how a microburst situation was handled at Stapleton International Airport in 1982 prior to the TDWR-based evaluations. The first pilot on final approach to encounter the microburst reported:

"Quite a shear at 300 feet...had to almost go to takeoff power; going around."

Two pilots in trail behind the first pilot also declared their decisions to go around on hearing the first pilot's PIREP. During the go around, the first pilot and Local Control mutually agreed to try a second approach to the same runway to see if the wind shear had disappeared. On the second approach, made five minutes after the initial encounter, the pilot reported:

"A 20 knot-gain and then a 20-knot loss...going around."

At this point, Local Control advised the pilots of a decision to shift arrival operations to another runway, and the three aircraft landed without incident.

Finding 2 - For recognition purposes, pilots should be aware that

microburst encounters are experienced and reported in a variety of ways depending on the portion of the microburst encountered and whether the microburst is encountered on final approach, landing rollout, takeoff roll, or initial takeoff climb.

A microburst encounter by a landing or departing aircraft is typically portrayed as encountering a strong headwind, then a downdraft, and finally a tailwind. However, pilots should be aware that microburst encounters can be described in a variety of ways by pilots preceding them in landing and takeoff. Table 2-1 presents examples of how pilots experienced and reported microburst encounters on final approach, takeoff roll, and initial takeoff climb:

a) On final approach, pilots are primarily concerned with ride quality and their ability to track the glide slope and localizer. Table 2-1 provides examples of pilots that described microburst encounters in each of these areas of pilot attention. Examples 1 to 3 are typical of the types of PIREPs one normally expects in which the pilots speak of "sinkers," airspeed variations, loss of altitude, and the need to increase power. On the other hand, examples 4 and 5 involved crosswind situations where the pilots crossed the outflow on one side of the microburst. Examples 6 and 7 were concerned with turbulence and either the pilots made no mention of airspeed variations or stated that the airspeed was fairly stable.

b) During the five evaluations, landing pilots did not provide PIREPs of the microburst encounters that took place after touchdown. However, such PIREPs have been received during other evaluations (e.g, LLWAS evaluations at Stapleton) when significant crosswind shear was involved (i.e., when the aircraft's rollout crossed an outflow to one side of the microburst).

c) On takeoff roll, pilots are primarily concerned with their ability to follow a takeoff acceleration profile, and microburst encounters are typically described in terms of "stagnation" or a "hangup" in airspeed.

d) On the initial takeoff climb, pilots are primarily concerned with their ability to climb/accelerate and ride quality. Table 2-1 provides examples of microburst encounters described in each of these areas of pilot attention. The term stagnation continued to be used in speaking of not being able to accelerate.

Finding 3 - Microbursts can occur individually or in groupings and can impact runway operations for a few minutes up to an hour and, in one observed case, for two hours. This finding is self-explanatory.

TABLE 2-1: EXAMPLE PIREPs ILLUSTRATING HOW PILOTS EXPERIENCE AND REPORT MICROBURST ENCOUNTERS WHILE ON FINAL APPROACH, TAKEOFF ROLL, AND INITIAL TAKEOFF CLIMB

ENCOUNTERS ON FINAL APPROACH

1) "Heavy sinker...Full power...and still sinking." (Pilot went around.)
2) "Lost 45 knots and 400 feet at 2- to 3-Mile Final." (Pilot went around.)
3) "30-knot gain followed by a 30-knot loss...full power and could not climb" (Pilot went around.)
4) "Big gust from left rocked us pretty good." (Pilot went around.)
5) "Maximum crosswind this airplane can handle." (Pilot landed.)
6) "Twisting around of aircraft and pretty strong turbulence." (Pilot went around.)
7) "From 600 feet on down, got pretty badly beat up; moderate turbulence but airspeed fairly stable." (Pilot landed.)
8) "It got real exciting" (Pilot landed.)

ENCOUNTERS ON TAKEOFF ROLL

9) "Had stagnation for 500 to 700 feet before airspeed increased."
10) "At 90 knots, airspeed hung then bounced to 100 knots and hung again...pushed throttles full forward."
11) "Airspeed (acceleration) stopped for 5 seconds at rotation; it was not pretty."

ENCOUNTERS ON TAKEOFF CLIMB

12) "Gained 15 knots at 1000 feet AGL then stagnation in which the aircraft could not accelerate for about 1.5 miles."
13) "Gained 40 knots then lost 20 knots and encountered a 1000-foot-per-minute sinker; pretty rough."
14) "Difficulty climbing."
15) "Lost 15 knots at 2000 feet AGL...and our rate of climb slowed; some pretty good chop out here."
16) "Extremely rough ride."

2.2 REPORTED GUST FRONT ENCOUNTERS

A second wind shear feature of concern to aviation is the wind-shift line. Wind-shift lines generated by thunderstorms are commonly called gust fronts. Figure 2-2 shows the basic structure of a gust front in cross-section. The cross-section is part of a feature that is typically several miles in extent. The primary wind shear area extends along the leading edge of the gust front.

Finding 4a - A gust front situation in which relatively intense encounters were reported occurred when the head of a gust front became aligned with the final approach path and enveloped it.

This situation occurred on several occasions. The following is a composite of the more-intense encounters reported on those occasions: (A more-detailed listing of the encounters is presented in Section 5.4.):

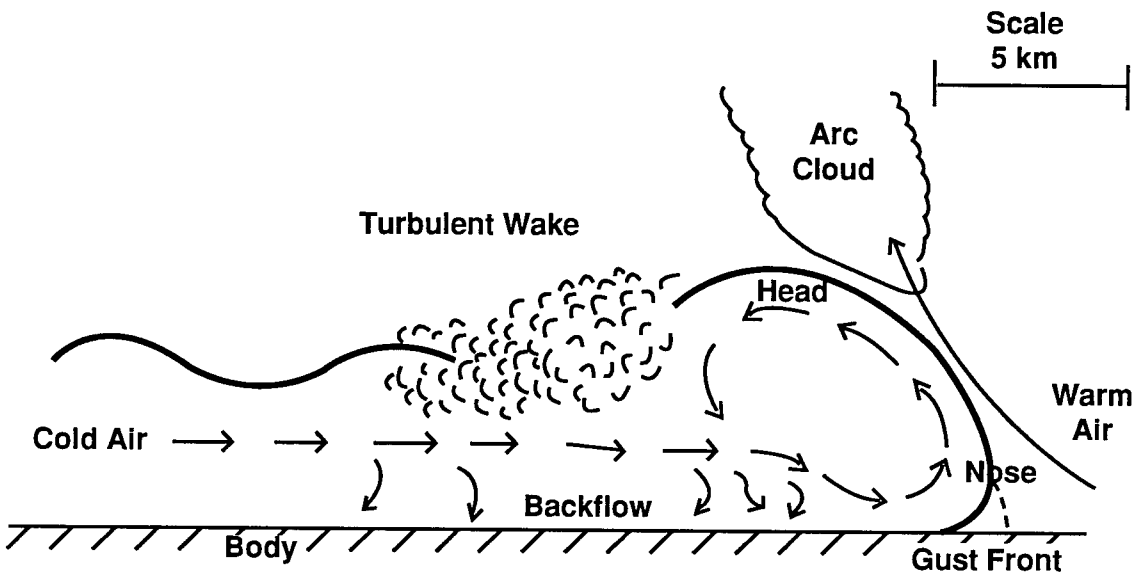
"As tough a landing as I have ever made",
"Pretty rough and miserable ride all the way down",
"15- to 20-knot fluctuations; a pretty wild ride",
"Real severe wind change at touchdown",
"Real big sinker over numbers",
"Lost 20 knots at 50 feet; severe wind shear",
"Lost 15 knots; good sinker at 100 feet and 50 feet; lots of power needed",
"Lost 20 knots at 150 feet; pretty good sinker and blowing dirt", and
"Lost 15 knots at 400 feet, a gain at 200 feet, and pretty rough on short final".

The "sinker" references are likely to have been encounters with the downflows that can exist in the head of the gust front and as depicted in Figure 2-2.

A final observation is that all of the pilots that reported the above encounters completed their landings; but in one case, Local Control shifted the arrival operation to another runway after receiving three such reports.

Finding 4b - A second gust front situation that caused relatively intense encounters to be reported involved microburst-generated gust fronts, also known as ring gust fronts.

Figure 2-1 shows the basic structure of a microburst. On occasion, the outer edge of the outflow would travel some distance from the microburst downflow area and was encountered in its own right, as a separate entity. Landing/departing pilots became involved with microburst-generated gust fronts on several occasions.



(Source: The National Center for Atmospheric Research)

FIGURE 2-2: BASIC STRUCTURE OF THE GUST FRONT SHOWING COMMONLY ASSOCIATED FEATURES

The following is a composite of the more-intense encounters reported by the pilots on those occasions: (A more-detailed listing of the encounters is presented in Section 4.2.)

"Nearly a bucking bronco...mostly in the last 200 feet",
"Gained 30 knots at 75 feet",
"At least moderate turbulence, it really was rough",
"Had a tough time killing off the airspeed gain",
"Gained 30 knots at 300 feet" (Pilot went around), and
"30-knot gain at 200 feet".

3. ALERT PERFORMANCE OF THE TDWR-BASED ALERT SYSTEM

The observations presented in this section: (a) deal with the performance of the TDWR-based alerts issued to pilots, and (b) were based on those pilots that received an alert, flew into the indicated area, and reported the experience.

3.1 BACKGROUND

The following completes the overview description of the evaluated TDWR-based alert service presented in the Introduction.

3.1.1 A Simplified Description of the Alert Areas Declared by TDWR for Microbursts and Gust Fronts

Figure 3-1 shows that the alert area declared by TDWR within a microburst consisted of the core of the outflow in which a pilot would encounter decreasing headwinds. Relative to aircraft performance, this is the wind shear area of primary concern to landing and departing pilots. The location of the microburst provided on the alerts was the location at which the pilot should first encounter this area of decreasing headwinds.

Typically, the outer edge of a microburst's outflow was in close proximity to the alert area and was covered by the microburst alert. Coverage by the microburst alert tended to be lost when the outer edge of the outflow moved away from the declared microburst alert area and became a microburst-generated gust front.

Figure 3-2 shows that the alert area declared by TDWR identified the wind shear along the nose of the gust front. The location of the gust front provided by the "gain" wind shear alert was the location at which the pilot should first encounter this line of wind shear. Much of the gust front structure was not included in the alert coverage provided by TDWR.

3.1.2 The Safety Corridor Concept

Alert coverage was provided to landing pilots for wind shear features inside 3-Mile Final and to departing pilots for wind shear features out to 2-Mile Departure. To increase safety, alert coverage was provided for wind shear features not just on the final approach path and initial takeoff path but for a corridor around these paths (i.e., for 0.5 miles on each side of these paths). Figure 3-3 shows the final form of the safety corridor geometries as of 1990. In the earlier evaluations, the safety corridor for departures extended out to 3-Mile Departure.

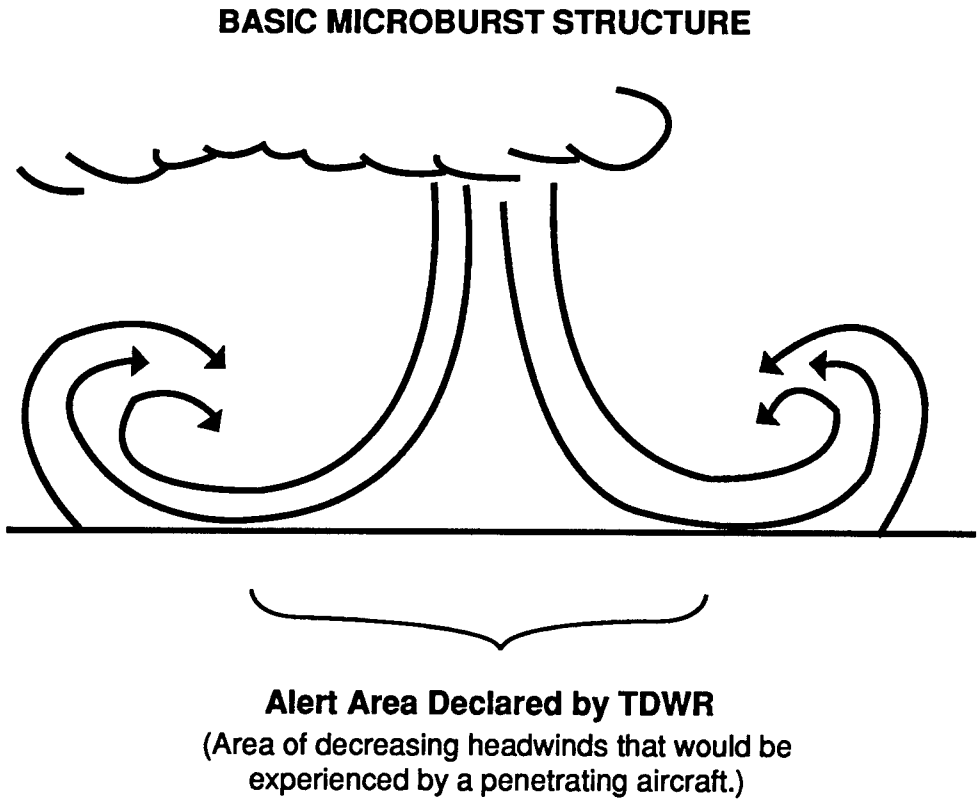


FIGURE 3-1: THE ALERT AREA DECLARED BY TDWR AS COMPARED TO THE OVERALL MICROBURST STRUCTURE

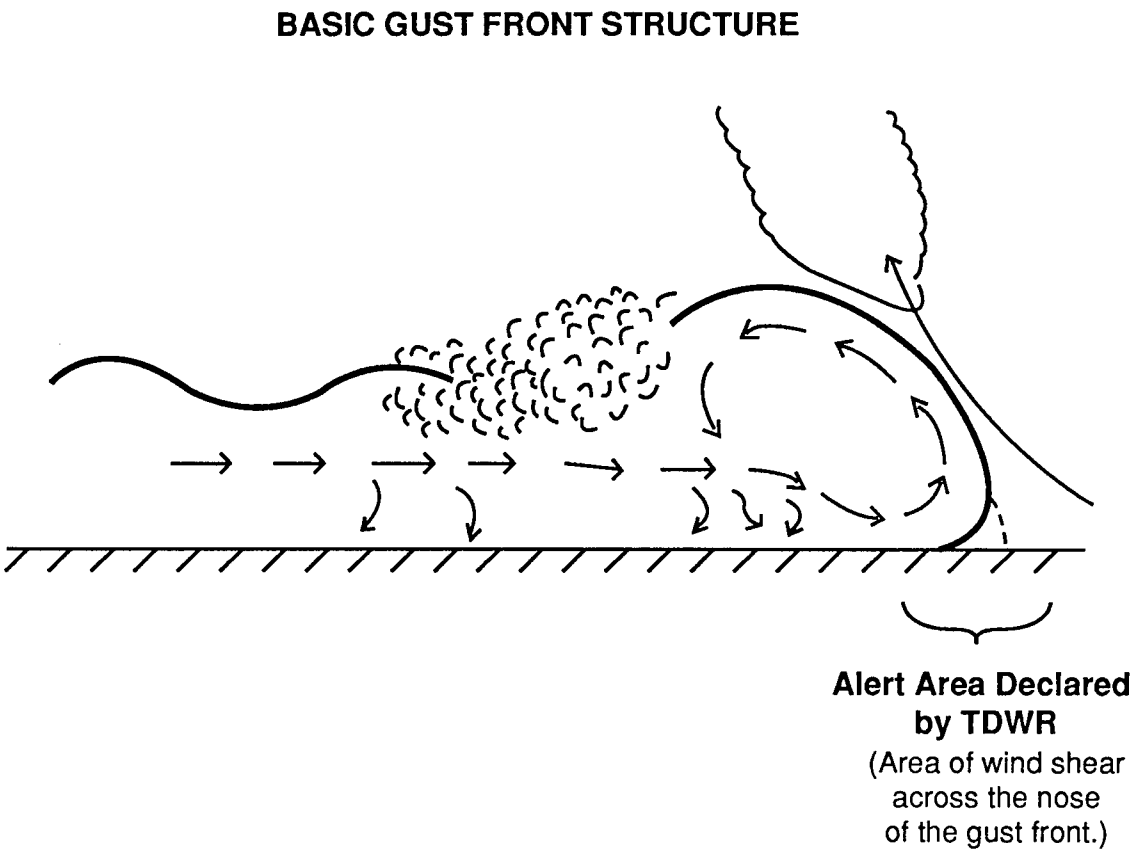
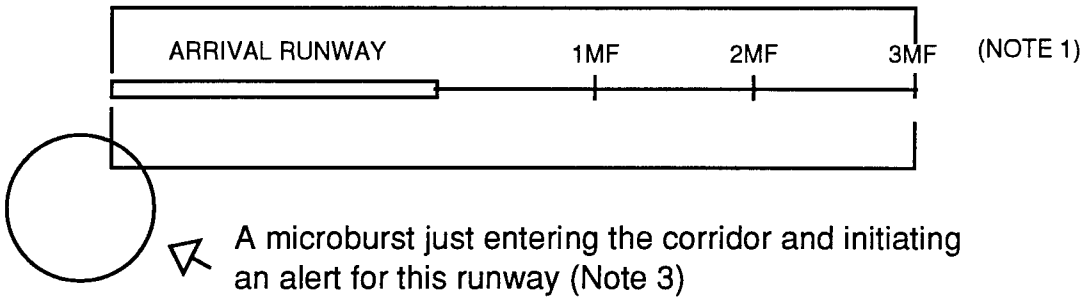


FIGURE 3-2: THE ALERT AREA DECLARED BY TDWR AS COMPARED TO THE OVERALL GUST FRONT STRUCTURE

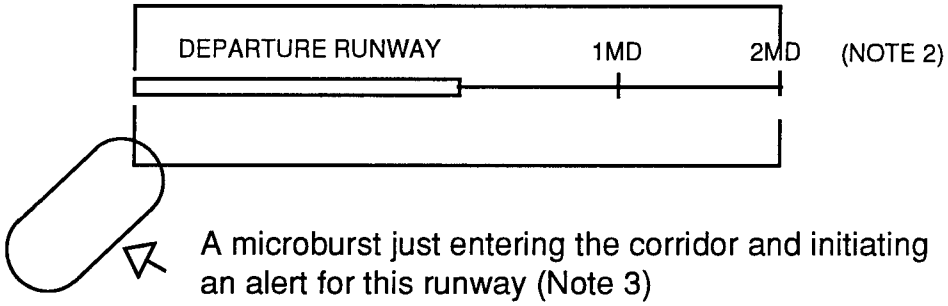
FOR ARRIVAL OPERATIONS

Safety Corridor One Mile Wide Overall



FOR DEPARTURE OPERATIONS

Safety Corridor One Mile Wide Overall



NOTES: (1) 3MF stands for "3-Mile Final"

(2) 2MD stands for "2-Mile Departure"

(3) The system software depicted microbursts in either of two shapes: The shape of a band-aid if the software sensed that the microburst's outflow had an elongated axis in some direction or the shape of a circle if it did not.

FIGURE 3-3: FINAL FORM OF THE SAFETY CORRIDOR GEOMETRIES USED IN THE EVALUATIONS

3.2 ALERT PERFORMANCE FROM PILOT'S VIEWPOINT

Finding 5 - TDWR provided pilots with effective alert coverage of microbursts.

The performance of TDWR fulfilled its primary mission which was to provide alert coverage to aircrews about to encounter a microburst. A check of the raw TDWR and LLWAS data was made for all cases in which a pilot did not receive a TDWR-based alert yet reported a significant encounter (i.e., reported an airspeed variation of 20 knots or more, moderate turbulence, or a downdraft). In every case, something other than a microburst had been encountered. What was encountered in these cases is discussed in Section 5.

This type of check was also done, with the same result, for those pilots in the TDWR/LLWAS-based evaluations that would not have received a TDWR-based alert if TDWR had been operated as a stand-alone alert system.

Three cases are presented to highlight the effectiveness of the microburst coverage provided by Doppler weather radar, in general, and TDWR, in particular. The first case involved a near crash that took place on May 31, 1984 at Stapleton International Airport. A Boeing 727 departure encountered a wind shear condition on takeoff roll and liftoff that resulted in the aircraft striking an instrument landing system antenna approximately 1100 feet beyond the departure end of the runway. The aircraft returned safely to the airport and was found to have a piece of the localizer antenna stuck in the bottom of the fuselage.

The National Center for Atmospheric Research, which operated Doppler weather radar units in the vicinity of Stapleton for meteorological research purposes, verified that the departure had encountered a microburst. Due to this incident, a Doppler weather radar-based alert service was put into operation at the airport on a temporary basis that summer. It involved alerts being manually generated by a meteorologist monitoring the radar display that were then relayed to landing and departing pilots by Local Control. The 1984 experience showed that timely microburst alerts could be provided to pilots and was the predecessor of the TDWR-based alert service provided each summer at Stapleton International Airport since 1988.

The second case took place on July 11, 1988 when five landing aircraft were provided TDWR alerts for a microburst that reached a maximum intensity of 80 knots. In a follow-up analysis of what occurred, a pilot of one of the aircraft provided the most-detailed description of a major microburst encounter obtained during the evaluations.

"Wave hit aircraft...gained 60 knots/smooth/tail rotated up...decided to go around; went to full power...violent burst hit the aircraft...aircraft moved up/down and hopped 200 feet to one side and then the other side...lost 400 to 500 feet of altitude...went down to 500 feet...was held there for 55 seconds in a death grip... should have been climbing at a 3500-to 4000-fpm rate."

The third case involved the situation presented in the Introduction in which a pilot proceeded to land with a microburst alert in effect and experienced a "5G" landing.

Pilot utilization of these alerts for microburst avoidance is discussed in Section 5.

Finding 6 - TDWR provided partial alert coverage of gust fronts.

As of 1990, the TDWR-based alert service had two gaps in the provided alert coverage of gust fronts; it:

1) Did not provide coverage for gust fronts less than 10 kilometers in extent due to false-alarm considerations, and

2) Tended to lose coverage for the gust fronts over 10 kilometers in extent whenever the gust front became aligned with the radar beam. The TDWR unit was located some distance off the airport and tended to lose contact with a gust front at the airport when the gust front lay along a straight line passing through the airport and the TDWR site.

Examples of the types of encounters that took place that were not provided alert coverage by TDWR in these two circumstances are presented in Section 4.2.

Finding 7 - Fewer than 3% of the pilots issued a TDWR-based alert received a late alert.

To paraphrase the Timeliness Requirement stated in U.S. Department of Transportation Order 1812.9: the TDWR System is to provide alerts to landing and departing pilots at least one minute before any pilot encounters hazardous wind shear or turbulence while at an altitude under 1500 feet AGL. The requirement does not define the term "hazardous."

During the evaluations, alerts were issued to landing and departing pilots along with landing and takeoff clearance by Local Control. Operationally, this meant that at least a one-minute warning was provided to landing pilots for any wind shear in the critical area inside 1-Mile Final, and almost a one-minute warning was given to departing pilots for wind shear in the critical lift-off area. The view adopted in the evaluations was that an alert was considered timely if it was issued along with

landing and departure clearance.

An alert was considered late only when three conditions were satisfied:

1) A landing/departing aircrew was issued landing or takeoff clearance when the assigned runway was not under alert status,

2) A short time later, Local Control issued an alert to the aircrew for the assigned runway, and

3) The aircrew reported some sort of wind-related encounter involving wind shear, turbulence, and/or a downdraft.

The situation in which a pilot completed a landing or takeoff and reported some sort of wind-related encounter shortly before an alert was generated for that runway was not considered a late alert situation. It was considered a case in which the system had not provided the pilot with an alert.

With alert timeliness defined in this way, it was found that of the 635 aircrews issued a TDWR-based alert during the evaluations, 16 (i.e., 2.5%) of the aircrews received a late alert.

The 635 aircrews included the: (a) 355 aircrews that were actually issued a TDWR-based alert, and (b) 280 aircrews that would have been issued a TDWR-based alert during the 1989 and 1990 evaluations of the integrated TDWR/LLWAS alert system if TDWR had been operated as a stand-alone alert system.

Although the number of late TDWR-based alerts was small, eight of them involved microburst alerts. To characterize the eight late microburst alerts, the following presents the TDWR alerts generated and the corresponding PIREPs:

-85KTS/RWY	"It wasn't 85 knots, but it was a handful"
-45KTS/RWY	"Concur with alert...it was not pretty"
-40KTS/3MF	"Pretty wild out there about 4 miles"
-40KTS/RWY	"Gained 20 knots on short final"
-40KTS/RWY	"Gained a lot then lost 5 knots at 50 feet"
-40KTS/3MF	"Lost 15 knots at about 1000 feet"
-30KTS/1MF	"Gained 15 knots at about 100 feet"
-30KTS/RWY	"Big gust from left"

The eight microburst alerts varied from being 55 to 155 seconds late and averaged 90 seconds. An alert was considered late by the number of seconds that elapsed between the time that clearance to land/takeoff was issued and the time that the alert was issued to the aircrew. In the above cases, Local Control took from 10 to 25 seconds to issue each of the alerts after it

had been first displayed.

Finding 8 - Pilot-perceived alert false alarms were found to be a frequent occurrence in the evaluations.

In the initial TDWR evaluation in 1988, it was found that the pilot-perceived, false-alarm ratio was:

34% to perhaps as high as 65%

(i.e., 34% of the aircrews reported something to the effect that "nothing was encountered" and another 31% reported something to the effect that "nothing much was encountered").

Table 3-1 presents the PIREP classification used in the analysis.

To increase operational safety, the alert software generated alerts for wind shear features threatening as well as on the final approach and initial takeoff paths (i.e., for wind shear features within 0.5 miles of the final approach path or the straight-out takeoff path). It is clear from the various tests/analyses that were conducted, that the wind shear features were present in almost every case in these situations but were not on the flight path. Starting with the 1988 evaluation, a sequence of changes to the TDWR software has been carried out in order to reduce the apparent overwarning.

Changes to the TDWR software reduced the pilot-perceived, false-alarm ratio at Denver to:

28% to perhaps as high as 43% in 1990.

It was also found that the false-alarm ratio varied from airport to airport. The 1990 TDWR alert software was evaluated at Orlando International Airport and at Stapleton International Airport. The pilot-perceived, false-alarm ratio was:

a) 28% to perhaps as high as 43% at Denver, and

b) 58% to perhaps as high as 74% at Orlando.

The high level of overwarning found at Orlando relative to Denver was probably due to climatological differences between the two airports. Due to the wet atmospheric conditions at Orlando relative to those found at Denver, the thunderstorm-related outflows at Orlando more frequently occur in close association with rain shafts at the surface. The Orlando pilots may have exploited the closer association of wind shears with rain cells at the surface to do a better job of deciding when to land and to take off with an alert in effect than was possible for pilots in the Denver area.

TABLE 3-1: PIREP CLASSIFICATION USED IN THE ALERT OVERWARNING ANALYSIS

ALERTS CONSIDERED AS APPARENT OVERWARNINGS

Those alerts followed by a PIREP indicating that "nothing was encountered"; example PIREPs:

- No wind shear
- Normal acceleration
- No problem
- No airspeed gain or loss
- Steady as a rock
- A normal takeoff

ALERTS CONSIDERED AS POSSIBLE ADDITIONAL OVERWARNINGS

Those alerts followed by a PIREP indicating that "nothing much was encountered"; example PIREPs:

- A little choppy
- Just squirrelly
- Slight airspeed hesitation
- Nearly normal landing
- 5-knot fluctuations
- Mild stagnation

ALERTS CONSIDERED AS ADVISING PILOTS OF A SIGNIFICANT FEATURE ACTUALLY ON THE FLIGHT PATH

Those alerts followed by a PIREP indicating that something of interest to landing/departing pilots was encountered (i.e., all PIREPs stating airspeed changes of 10 knots or more [see Note 1], greater than light turbulence/chop, and/or any indication of a downdraft); example PIREPs:

- A sinker
- Pretty good turbulence
- Twisting around of aircraft
- Lost 400 feet in altitude
- A lot of bouncing
- Gained 10 knots

NOTE: (1) During the evaluations, numerous pilots indicated on their mailed-in questionnaires that a wind-related airspeed change of 10 knots was considered a significant encounter while on final approach or takeoff. To date, only one pilot indicated that an airspeed change of less than 10 knots was considered to be a significant encounter.

Finding 9 - The accuracy of the intensity and location estimates provided by the TDWR-based alerts fulfilled their basic missions.

Each alert included two computer-generated estimates: (a) the maximum wind speed change that would be encountered if the pilot flew through the most-intense part of the wind shear feature, and (b) the location at which the wind shear feature would be first encountered by the pilot. The wind speed estimates were given in 5-knot increments (i.e, 15 knots, 20 knots, 25 knots, etc.), and the location estimates were given in terms of 3-Mile Final, 2-Mile Final, 1-Mile Final, over the runway, 1-Mile Departure, and 2-Mile Departure.

Ideally, a pilot would be able to use the alert intensity estimate as an indication of the maximum airspeed variation that would be experienced if the pilot proceeded through the indicated wind shear area. Of the 635 aircrews for which TDWR-based alerts were generated during the evaluations, 242 aircrews provided a PIREP of the experience, and 100 of those aircrews reported some sort of a wind-related encounter. Of the 100 aircrews that reported an encounter, 76 reported the airspeed variation experienced. Of those 76 aircrews:

a) No pilot reported an airspeed variation that exceeded the alert's intensity estimate by more than 5 knots; so the alerts fulfilled their basic mission in providing an effective upper limit on the extent of the airspeed variation that would be experienced by the pilot, and

b) 27 or 35% of the aircrews reported an airspeed variation within 5 knots of the alert estimate; so the alerts were accurate in a number of cases.

Of the 100 aircrews that reported some sort of a wind-related encounter, 63 reported the encounter location. Of these 63 aircrews:

a) 44 or 70% of the aircrews reported an encounter location that matched the estimate provided by the alert, and

b) Most of the remaining aircrews reported an encounter location adjacent to the one provided by the alert.

4. IMPACT OF INTEGRATING LLWAS WITH TDWR ON THE PROVIDED ALERT SERVICE

The observations presented in this section deal with the primary effects observed as to the operational impact of adding the LLWAS channel to TDWR.

4.1 BACKGROUND

In 1989 and 1990, an integrated TDWR and Phase III LLWAS alert system concept was evaluated at Stapleton International Airport. With certain exceptions, an integrated alert was generated whenever one or both channels indicated the need for an alert. In general, when the TDWR and LLWAS channels disagreed in their characterization of an alert situation, the generated alert would reflect the worst-case, wind shear condition. In all other regards, the provided TDWR/LLWAS-based alert service remained the same as the described TDWR-based alert service.

In order to investigate the "value-added" performance of of adding LLWAS to TDWR, two set of alerts were examined in the analysis: (a) the integrated alerts issued to pilots, and (b) the TDWR-based alerts that would have been issued if TDWR had been operated as stand-alone alert system.

It should be noted that the findings in this section relate to Stapleton International Airport. It is not known if the impact of adding the LLWAS channel to TDWR at Stapleton will be found to be typical of other airports.

4.2 IMPACT OF ADDING THE LLWAS CHANNEL TO THE TDWR

Finding 10a - The addition of the LLWAS channel to TDWR increased the system's alert coverage of gust fronts, threshold-level outflows, and small-scale wind features.

Adding the LLWAS channel to TDWR increased the alert coverage provided by the system. One measure of the increase was the 3.4-fold increase in the alert coverage provided to those aircrews that actually reported a wind-related encounter (i.e., from the 54 aircrews that would have received an alert if TDWR had been operated as a stand-alone alert system versus the 185 aircrews that received an integrated alert).

To characterize the increased alert coverage, a review of the raw TDWR and LLWAS data was conducted for the more-intense encounters reported by pilots for which: (a) an integrated alert was or would have been issued over the five evaluations, but (b) a TDWR-based alert was not or would not have been issued. Table 4-1 presents the results of that review. It is seen that the addition of the LLWAS channel to TDWR increased alert coverage of:

TABLE 4-1: A CHARACTERIZATION OF THE MORE-INTENSE ENCOUNTERS REPORTED BY PILOTS IN THE 1988 TO 1990 EVALUATIONS FOR WHICH TDWR WAS SILENT BUT FOR WHICH THE TDWR/LLWAS DID OR WOULD HAVE PROVIDED ALERTS

OUTFLOWS AND GUST FRONTS BELOW ALERT-THRESHOLD LEVEL
(12 encounters)

8-19-89 (1)"A wild ride."
8-26-89 "Stagnation and 10 knot fluctuations."
"Stagnation."
"Stagnation."
9-02-89 "Pretty good sinker."
(1)"Sinker, had to add a bunch of power."
9-07-89 "Gained 15 knots one mile out."
"Confirm wind shear."
"15-knot gain."
"15-knot gain at 300 feet."
8-19-90 (1)"Up and down drafts, insufficient power to maintain a stabilized approach." (Pilot went around.)
8-24-90 (1)"Had to add a bunch of power."

TURBULENT, SURFACE WIND CONDITIONS WHICH WERE NOT COVERED BY TDWR-BASED ALERTS, SUCH AS FOUND IN THE OUTFLOW AREA BEHIND GUST FRONTS (Nine encounters)

8-24-89 (1)"Gained 30 knots then dropped to a 10-knot gain."
"Gained 15 knots then lost 10 knots."
"A gain then a 15-knot loss."
"A gain then a 15-knot loss."
"A 15-knot gain followed by a 10-knot loss."
7-01-90 (1)"Wild airspeed fluctuations on roll."
8-11-90 (1)"Moderate turbulence." (Pilot went around.)
8-19-90 (1)"Up and down drafts." (Pilot went around.)
8-23-90 "Gained 20 knots at 300 feet, moderate turbulence."

GUST FRONTS ALIGNED WITH THE TDWR RADAR BEAM (Sixteen encounters)

8-11-89 "Wind shear on Final."
"Major shift in direction over the threshold."
(1)"Wind shear on Short Final." (Pilot went around.)
"Increase at 100 knots then stagnation to about half-way down runway."
"Confirm 15-knot gain at 50 feet."

(CONTINUED)

NOTE: (1) Highlights one of the more significant encounters reported by landing/departing pilots either because the pilot went around or due to the intensity of the reported encounter.

TABLE 4-1: A CHARACTERIZATION OF THE MORE-INTENSE ENCOUNTERS REPORTED BY PILOTS IN THE 1988 TO 1990 EVALUATIONS FOR WHICH TDWR WAS SILENT BUT FOR WHICH THE TDWR/LLWAS DID OR WOULD HAVE PROVIDED ALERTS (CONTINUATION)

GUST FRONTS ALIGNED WITH THE TDWR RADAR BEAM (CONTINUED)

7-28-90		"Gust in excess of 20 knots at 20 feet."
		"Gained 20 knots at 100 feet."
		"Gained a bunch of airspeed."
		"A 25-knot gain at 50 feet."
		"Gained 20 knots instantly at 100 feet."
		"Gained 20 knots at 300 feet."
	(1)	"Gained 30 knots on Short Final." (Pilot went around.)
		"A 25-knot gain at 200 feet."
8-01-90		"Moderate turbulence at runway end."
8-04-90		"A 20-knot gain at 50 feet."
8-15-90		"Gained 30 knots on takeoff roll."

GUST FRONTS LESS THAN 10 KILOMETERS IN LENGTH (The significant situations of this type occurred when a microburst-generated gust front moved away from the microburst downflow area and was no longer covered by the TDWR-based microburst alert) (Fifteen encounters)

7-02-88	(1)	"Nearly a bucking bronco, 15-knot fluctuations."
	(1)	"Gained 30 knots at 75 feet."
		"Gained 25 knots on Short Final."
		"Gained 25 knots."
7-09-88	(1)	"At least moderate turbulence."
		"A 15-knot loss at 300 feet, a 20-knot gain at 120 feet."
		"Lost 15 knots at 1000 feet."
		"Had a tough time killing off the airspeed gain."
		"20-knot fluctuations on Final."
		"Lost 20 knots at 150 feet."
		"A 20-knot loss at 150 feet."
	(1)	"Gained 30 knots at 300 feet."
		"A 20-knot gain on Short Final."
7-16-88		"Moderate turbulence under 600 feet."
8-18-90	(1)	"A 30-knot gain at 200 feet."

NOTE: (1) Highlights one of the more significant encounters reported by landing/departing pilots either because the pilot went around or due to the intensity of the reported encounter.

a) Gust fronts,

b) Threshold-level outflows in situations where the outflow satisfied the alert-threshold conditions of the LLWAS channel but not the stricter conditions of the TDWR channel, and

c) Small-scale wind features, such as turbulent surface winds, for which TDWR did not provide direct alert coverage (i.e., TDWR only provided alert coverage for two distinct wind-related features: gust fronts and outflows of microburst or near-microburst status).

Note that although the LLWAS channel should make up for any TDWR difficulties in detecting microburst outflows either due to low-reflectivity conditions (i.e., when there is a low density of water droplets, dust, insects, seed, etc. in the outflow to act as radar reflectors) or due to the asymmetry of the outflows (i.e., when the radar detects a weak outflow along the radar radial, but in reality the outflow is of significant strength perpendicular to the direction of the radar beam), no such cases were found in the review.

In terms of the alert periods that occurred, it was observed that the LLWAS channel supplemented the TDWR-based alert coverage by:

a) Starting alert periods sooner,

b) Expanding the alert zone declared by the TDWR-based alerts to include other runways,

c) Extending the alert periods beyond the time that would have been the case if the TDWR had been operated as a stand-alone system, and

d) Creating additional alert periods, which primarily provided the increased gust front coverage.

A number of cases were observed in which the increased alert coverage of threshold-level outflows provided by LLWAS caused earlier alert declaration of outflows that would ultimately reach microburst alert status.

Finding 10b - The addition of the LLWAS channel improved the timeliness of the TDWR-based alerts.

If TDWR had been operated as a stand-alone alert system in the 1989 and 1990 TDWR/LLWAS evaluations at Stapleton, six aircrews that reported some sort of wind-related encounter would have received a late TDWR-based alert. The addition of the LLWAS channel improved the situation in half the cases, in that it

provided a timely alert in one of the six cases and reduced the lateness of the alerts by 120 and 140 seconds in two of the other cases.

Finding 10c - The addition of the LLWAS channel improved the overall accuracy of the alert intensity estimates.

Of the 1,143 aircrews for which integrated TDWR/LLWAS alerts were generated during the evaluations, 433 aircrews provided a PIREP of the experience, and 215 of those aircrews reported some sort of an encounter. Of the 215 aircrews that reported an encounter, 171 reported the airspeed variation experienced. Of these 171 aircrews:

a) 116 or 68% of the aircrews reported an airspeed variation within 5 knots of the intensity estimate specified on the integrated alert, (This is nearly double the corresponding 35% finding for TDWR-based alerts; see Section 3.2.) and

b) The alert intensity estimates underestimated the airspeed variation experienced and reported by pilots by as much as 10 knots in one case. By this measure, the alert intensity estimates fulfilled their intended purpose by providing aircrews with an effective upper limit on the airspeed variation that would be experienced.

Of the 215 aircrews that reported some sort of a wind-related encounter, 170 reported the encounter location. Of these 170 aircrews:

a) 104 or 61% of the aircrews reported an encounter location that matched the estimate provided by the TDWR/LLWAS-based alert, and

b) Most of the remaining aircrews reported an encounter location adjacent to the one provided by the alert.

Finding 11 - Fewer than 2% of the pilots issued an integrated alert, received a late alert.

The methodology underlying the alert timeliness analysis was discussed in Section 3.2. Using that methodology, it was found that:

> Of the 1143 aircrews issued an integrated alert during the 1989 and 1990 TDWR/LLWAS evaluations, 19 or 1.6% of the aircrews received a late alert.

Of the additional alerts generated by LLWAS, the late alerts consisted solely of 15-knot alerts. The 15-knot alert was the minimum-intensity alert provided by the alert systems.

Finding 12 - The addition of the LLWAS channel had little effect on the overall percentage of pilots that reported "little or nothing encountered."

The pilot-perceived, false-alarm ratio of the integrated alerts in 1990 was a couple of percentage points higher than the ratio that would have occurred if TDWR had been operated as a stand-alone alert system. See Section 3.2 for details.

Finding 13 - The addition of the LLWAS channel increased the overall alert activity of the system by three- to four-fold.

Relative to what would have occurred if TDWR had been operated as a stand-alone alert system, the addition of the LLWAS channel at Stapleton in 1989 and 1990 increased the:

a) Number of alert periods from 56 to 211 (i.e., a 3.7-fold increase),

b) Average time that Stapleton's runways were under alert status from 45 to 138 minutes/week (i.e., 3.1-fold increase), and

c) Number of aircrews issued an alert from 280 to 1143 (i.e., a 4.1-fold increase).

5. OPERATIONAL IMPACT OF THE ALERT SERVICES PROVIDED BY THE TDWR-BASED AND INTEGRATED TDWR/LLWAS-BASED ALERT SYSTEMS

These observations are concerned with the operational consequences of the provided alert services.

5.1 A CHARACTERIZATION OF THE ALERT PERIODS THAT OCCURRED

During the evaluations, the alert service was provided from noon to 7 pm, local time, seven days a week, provided the equipment was operating properly. If weather conditions warranted, the service would be extended beyond 7 pm.

Finding 14 - The following are some alert period statistics.

With TDWR, the alert period statistics are characterized as follows:

a) Kansas City International Airport represented the low end in alert period statistics in that an average of one alert period occurred each week with an average duration of 9 minutes. The alert period statistics would have been significantly higher if the TDWR had been located so as to provide better alert coverage of the gust fronts that swept over the airport during the evaluation.

b) Orlando International Airport represented the high end in the statistics in that an average of 4 to 5 alert periods occurred each week with an average duration of 22 minutes per alert period. The runways were under alert status for an average of 95 minutes per week.

c) Stapleton International Airport was near the midpoint in that an average of 2 to 3 alert periods occurred each week with an average duration of 18 minutes per alert period. The runways were under alert status for an average of 50 minutes per week.

d) The shortest alert periods lasted 1 to 2 minutes at each of the airports.

e) The longest alert periods ranged from 18 minutes at Kansas City International Airport to 67 minutes at Orlando International Airport to 77 minutes at Stapleton International Airport. One unusually lengthy alert period occurred at Stapleton in 1988 that lasted 136 minutes.

With TDWR/LLWAS at Stapleton International Airport, the alert period statistics were:

a) 150 minutes/week for the average weekly extent that the runways were under alert status versus 50 minutes/week with TDWR alone,

b) Less than a minute for the shortest alert periods; and the number of short alert periods increased sharply (e.g., in the 1990 evaluation, the number of alert periods that lasted less than 3 minutes was 54 versus 9 for those alert periods that would have occurred with TDWR alone), and

c) 109 minutes for the longest alert period versus 77 minutes if TDWR had been operated as a stand-alone alert system.

5.2 PILOT UTILIZATION OF THE ALERTS

Finding 15a - the FAA maintained its traditional policy of leaving weather-related, go/no-go decisions to airline policy and pilot discretion during the evaluations.

Prior to each evaluation, the aviation community at the test airport would be briefed. The following is an example of the resulting guidelines provided by one airline to its pilots:

> "During the conduct of this test, as is currently the case, a 'windshear' alert must be given serious consideration by the flight crew. All pertinent factors relating to a planned takeoff or approach must be critically examined before the specific course of action, e.g., normal procedures, precautions, or avoidance action is decided upon...A 'microburst' alert, however, clearly indicates that avoidance action is required. A FLIGHT MUST NOT DEPART NOR CONDUCT AN APPROACH THROUGH AN AREA WHERE A MICROBURST ALERT IS IN EFFECT. Delay the takeoff or approach until the condition no longer exists along your intended flight path."

Finding 15b - Some pilots landed or took off with a microburst alert in effect.

Some pilots have continued to land or take off with a microburst alert in effect throughout the evaluations, typically at the beginning of the alert periods. In 1990, at least 16 aircrews did so at Stapleton International Airport and at least 29 aircrews at Orlando International Airport.

Finding 15c - This finding addresses the attitude of those pilots that land/depart with a microburst alert in effect.

The attitude expressed by one pilot in 1989, who received a 35-knot microburst alert, may provide some insight into the general attitude of those landing pilots that received a microburst alert and continued the approach.

> "Initial contact with tower a 'microburst alert' was issued...Company policy requires a go around; however, we continued knowing we would go around at some point. We encountered turbulence and some airspeed loss at 200

feet; not enough in itself to go around. At 50-100 feet we encountered a little airspeed change but enough turbulence to demand a go around. I should add approach was flown with +20 knots of speed..."

Over the course of the evaluations, this attitude was echoed by other pilots, such as the pilot who proceeded to take off with a 30-knot microburst alert in effect and said:

"Lost 20 knots...used maximum power so no problem"

The attitude suggested by these statements is that some pilots seem to use at least the lower-intensity microburst alerts as a signal to increase their margin of safety by increasing airspeed and vigilance and then to proceed with the landing or takeoff with the assumed confidence that they will be able to get out of any microburst encounter.

One pilot that may have shared this attitude received a 30-knot microburst alert and proceeded to land. The aircraft reportedly experienced a "5G" landing and suffered structural damage. The pilot made the following comments on the ATC radio to Local Control after landing:

"...we confirm microbursts; +35 knots and at least -30 to -35 knots all the way down from 1000 feet AGL...I suggest that you abandon approaches to (Runway) 26. It is very, very rough; near impossible to get the thing on the ground safely."

This hard landing demonstrates that the pilot attitudes expressed above will occasionally prove treacherous.

Finding 16 - Departure operations sometimes ceased when "loss" wind shear alerts were in effect.

A review of the 1989 and 1990 evaluations at Stapleton International Airport, Orlando International Airport, and Kansas City International Airport indicated that of:

a) 323 landing pilots directly issued a "loss" wind shear alert, 7% of the pilots elected not to complete their landings, and

b) 228 departing pilots directly issued a "loss" wind shear alert, 31% of the pilots declined takeoff clearance.

The reluctance of some pilots to take off with a "loss" wind shear alert in effect was captured by one local controller who announced shortly after departure operations ceased during one of the alert periods:

"Attention all aircraft; I...expect that no one will depart with a microburst (alert), and I won't ask you to...But for anybody that will not go with a wind shear (alert), that is what I really need to know...Just for the purpose of frequency congestion and stuff, there is no point in finding out who can take 10 knots, who can take 15 knots, etc. Right now we have got a microburst situation...as soon as it changes back to wind shear, then I will start asking."

The "who can take 10 knots" reference in the above quotation is puzzling given that the 15-knot alert was the minimum-intensity alert generated by the system. One explanation is that it referred to those aircrews that would not take off whenever any "loss" wind shear alert was in effect.

The data were insufficient to indicate whether the utilization of the "loss" wind shear alert for shear avoidance by departing pilots, with its impact on runway capacity, will increase or decrease over time.

Finding 17 - Runway operations did not cease during periods when "gain" wind shear alerts were in effect, except when the runways were being shifted due to a shift in wind direction at the airport caused by the passage of the associated gust front.

A review of the 1989 and 1990 evaluations at Stapleton, Orlando, and Kansas City International Airports indicated that few pilots did not complete the landing/takeoff with a "gain" wind shear alert in effect.

a) Of the 382 landing pilots directly issued a "gain" wind shear alert, 3% elected not to complete their landings, and

b) Of the 169 departing pilots directly issued a "gain" wind shear alert, 6% declined takeoff clearance.

From the communication tapes, it is clear that the pilots were generally more concerned with a prevailing tailwind condition than with the issued alert in a number of the cases in which the pilot did not complete the takeoff/landing. Figure 2-2 shows that a pilot about to cross a gust front will tend to be flying in a tailwind situation until the gust front is encountered. Local Control typically shifted the runways for a better wind orientation whenever pilots started to decline to land/takeoff due to tailwind conditions on or near the operational runways.

5.3 THE OPERATIONAL ROLE OF THE 15-KNOT ALERT

Finding 18 - The 15-knot alert and its role as the system's minimum-intensity alert was brought into question during the 1989 and 1990 TDWR/LLWAS evaluations at Stapleton.

The minimum-intensity alert issued by the system was the 15-knot alert. In the various evaluations, the frequency of occurrence of the 15-knot alert varied widely from infrequent to commonplace. Relative to the alert periods for which the communication tapes were examined, the 15-knot alert:

a) Occurred infrequently during the TDWR evaluation at Orlando in 1990, when only 5% of the 119 pilots issued an alert received a 15-knot alert,

b) Was commonplace during the TDWR/LLWAS evaluations at Stapleton International Airport in 1989 and 1990, when 57% of the 1144 pilots issued an alert received a 15-knot alert, and

c) Would have been commonplace even if TDWR had been operated as a stand-alone alert system during the 1989 and 1990 Stapleton evaluations (i.e., 35% of the pilots that would have received a TDWR-based alert in those evaluations would have received a 15-knot alert).

If kept as the system's minimum-intensity alert, the 15-knot alert will be commonplace, at least at some airports, and particularly with the integrated TDWR/LLWAS version of the alert system. What is its operational role?

Finding 19 - This finding addresses the operational usefulness of the 15-knot alert.

An examination of the 15-knot alerts issued in the 1989 and 1990 TDWR/LLWAS evaluations at Stapleton International Airport found that:

a) It forewarned numerous pilots of threshold-level encounters in which a pilot would report a 10, 15, or, occasionally, a 20-knot airspeed variation. This level of encounter has been noted as significant by the aviation community: (1) during the evaluation, a number of pilots indicated on their mailed-in questionnaires that a wind-induced airspeed variation of 10 or 15 knots was considered a significant encounter, and (2) at least one airline uses the guideline that a wind-induced, 15-knot airspeed variation experienced by a pilot during landing or takeoff when under 1000 feet AGL calls for corrective action in order to maintain flight path control.

b) In a small number of cases, the 15-knot alert apparently served to flag areas of significant turbulence or up/down drafts even though the detected wind shear was at modest levels. At least seven such cases occurred in 1990 in which pilots reported:

"Sinker at flare"	(Pilot landed.)
"Big updraft on short final"	(Pilot landed.)
"Wild airspeed variations on roll"	(Pilot took off.)
"Moderate turbulence"	(Pilot went around.)
"Had to add a bunch of power"	(Pilot landed.)
"Up and down drafts"	(Pilot went around.)
"Up and down drafts, insufficient power to maintain a stabilized approach"	(Pilot went around.)

5.4 ALERT COVERAGE OF THE WIND-RELATED ENCOUNTERS REPORTED BY PILOTS

The provided TDWR-based and TDWR/LLWAS-based alert services were not designed to provide alert coverage for all wind-related situations reported by landing and departing pilots.

Finding 20 - This finding characterizes the types of non-alert situations that were encountered.

The characterization was based on a review of the raw TDWR and LLWAS data for the more-intense of the 163 encounters reported by pilots during the evaluations for situations not provided alert coverage.

Table 5-1 provides examples of the more-intense encounters reported by landing/departing pilots for five non-alert situations for which neither TDWR nor TDWR/LLWAS were designed to provide alert coverage: (a) outside 3-Mile Final, (b) beyond 2-Mile Departure, (c) vertical wind shear, (d) outflows and gust fronts below alert-threshold level, and (e) turbulent, surface wind conditions not in close association with a microburst or a gust front. (Note that TDWR/LLWAS did provide partial alert coverage of this last category but did not provide alert coverage for the encounters listed in the table.)

Table 5-2, together with Table 5-1, completes the characterization of the situations not provided alert coverage by TDWR/LLWAS for which pilots reported significant encounters. With one exception, the integrated alert system provided general alert coverage of all gust fronts. The exception was intentional in that the TDWR/LLWAS system software was programmed so as not to provide alert coverage for crosswind shear situations, which were originally thought to be of secondary concern to landing/departing pilots. (Note that this restriction did not apply to the TDWR alert system during the 1988 to 1990 evaluations.) The end result of this restriction was that TDWR/LLWAS did not provide alert coverage of gust fronts when the head of the gust front, with its turbulence and downdrafts, became aligned with the final approach path and enveloped it (see Figure 5-1). This was the standout situation in terms of the number and intensity of the pilot-reported encounters received and was one of the two

TABLE 5-1: A CHARACTERIZATION OF THE MORE-INTENSE ENCOUNTERS REPORTED BY LANDING/DEPARTING PILOTS IN THE 1988 TO 1990 EVALUATIONS FOR WHICH TDWR AND TDWR/LLWAS DID NOT PROVIDE ALERT COVERAGE

OUTSIDE 3-MILE FINAL (Two microburst-related encounters)

8-12-88 "Not very calm out here."
(1)"Rough 5 miles out, lost 40 knots at Outer Marker."

BEYOND 2-MILE DEPARTURE (Two microburst-related encounters)

7-01-90 "Gained 40 knots after handoff to TRACON."
(1)"40-knot gain, then a 20-knot loss and a 1000-foot-per-minute sinker, pretty rough."

VERTICAL WIND SHEAR (Four encounters)

8-21-89 "20-knot loss at 100 feet."
"Pretty good shear at 50 feet."
"Lost 15 knots at 50 feet."
8-19-90 "20-knot crosswind starting at 100 feet."

OUTFLOWS AND GUST FRONTS BELOW ALERT-THRESHOLD LEVEL (Five encounters)

8-21-89 "Lost 15 knots on short final."
8-26-89 "Airspeed hung at 100 knots on roll and 10-knot fluctuations on initial climb."
"Quite a bit of airspeed stagnation between 120 and 140 knots."
7-28-90(1)"Slow acceleration, advise no more departures."
8-11-90 "Stagnation for 1500 feet halfway down runway."

(CONTINUED)

NOTE: (1) Highlights one of the more significant encounters reported by landing/departing pilots due to the intensity of the reported encounter.

TABLE 5-1: A CHARACTERIZATION OF THE MORE-INTENSE ENCOUNTERS REPORTED BY LANDING/DEPARTING PILOTS IN THE 1988 TO 1990 EVALUATIONS FOR WHICH TDWR AND TDWR/LLWAS DID NOT PROVIDE ALERT COVERAGE (CONTINUATION)

TURBULENT, SURFACE WIND CONDITIONS NOT IN CLOSE ASSOCIATION WITH A MICROBURST OR GUST FRONT, SUCH AS THE OUTFLOW AREA BEHIND GUST FRONTS (Ten encounters)

8-09-89	"15-knot airspeed lag for 2000 feet toward the end of the runway."
8-21-89	"Significant airspeed stagnation on takeoff."
8-24-89	"15-knot gain."
	"Gained 15 knots at 200 feet."
	"Moderate chop."
	"Lost 8 knots at rotation and then lost 15 knots at 800 feet AGL."
	"Got that loss also, a good one."
8-26-89	"Stagnation at 130 knots."
	"Stagnation in airspeed at 130 knots."
	"Stagnation at 130 knots; it lasted 3 or 4 seconds."
	"Stagnation but no loss in airspeed."
	"5 to 10-knot fluctuations all the way down the runway, gained 15 knots at rotation."

NOTE: (1) Highlights one of the more significant encounters reported by landing/departing pilots due to the intensity of the reported encounter.

TABLE 5-2: A CHARACTERIZATION OF THE MORE-INTENSE ENCOUNTERS REPORTED BY LANDING/DEPARTING PILOTS THAT WERE NOT PROVIDED ALERT COVERAGE DUE TO AN ALERT RESTRICTION UNIQUE TO TDWR/LLWAS

CROSSWIND SHEAR SITUATIONS (The significant crosswind shear situations occurred when the head of a gust front became aligned with final approach and enveloped it; pilots reported 17 such encounters.) (Note 1) (Note 2)

8-04-89 "25 knot loss on short final."
"Pretty good turbulence on final."
(3)"Pretty large sinker at 50 feet; quite a large airspeed variation." (Pilot went around.)
"Sinker at about 450 feet but no airspeed change."
"Got the hole but no change in airspeed."

8-11-90 (3)"Pretty rough and miserable ride all the way down."
(3)"As tough a landing as I have ever made."
"15- to 20-knot fluctuations; a pretty wild ride."

8-24-90 "10-knot loss; real good sinker at 100."
(3)"15-knot loss; good sinker at 100 feet and 50 feet; lots of power needed."
"20-knot loss at 150 feet; pretty good sinker..."
"15-knot loss at 400 feet, a gain at 200 feet, and pretty rough on short final."
"20-knot loss at 1200 feet."

9-02-90 (3)"15-knot loss and a very marked wind shift at 200 feet...really ought to let people know."
(3)"Real severe wind change at touchdown."
(3)"<u>Real</u> big sinker over numbers."
(3)"20-knot loss at 50 feet; severe wind shear."

NOTE: (1) The TDWR/LLWAS system software was intentionally programmed so as not to provide alert coverage for crosswind shear situations, which were originally thought to be of secondary concern to landing/departing pilots.

(2) It was determined that TDWR would not have provided alert coverage in these particular situations, probably because they involved microburst-generated gust fronts less than 10 km in extent.

(3) Highlights one of the more significant encounters reported by landing/departing pilots either because the pilot went around or due to the overall intensity of the reported encounter.

areas identified for consideration of expanded alert coverage in the Conclusions.

Table 4-1, together with Table 5-1, characterize the situations not provided alert coverage by TDWR for which pilots reported significant encounters. Table 4-1 presents those situations missed by TDWR for which TDWR/LLWAS provided alert coverage and illustrates that TDWR: (a) provided less alert coverage of threshold-level gust fronts and outflows than TDWR/LLWAS, probably due to differences in the alert-threshold criteria used by the two systems, (b) did not provide alert coverage of turbulent surface wind conditions not in close association with a gust front or an outflow, (c) could drop alert coverage of a gust front if detection was lost due to the gust front becoming aligned with the radar beam, and (d) did not provide alert coverage of gust fronts that were less than 10 km in extent, which represented one of the TDWR alert-threshold conditions. The last situation listed generally involved a vigorous microburst-generated gust front less than 10 km in extent and was another area identified in the Conclusions for consideration of expanded alert coverage, if TDWR is to be deployed at airports as a stand-alone alert system.

Incidently, it was also determined that the particular situations listed in Table 5-2 would not have been provided alert coverage by the TDWR alert system, probably because they involved microburst-generated gust fronts less than 10 km in extent.

5.5 PILOT REACTION TO THE PROVIDED ALERT SERVICE

Pilots could express their opinion of the provided service by means of: (a) the ATC radio channel in communications contact with Local Control, and (b) mail-in questionnaires. As part of the TDWR Program, questionnaires were made available by the National Center for Atmospheric Research to the pilots of a number of airlines operating out of the test airports.

Finding 21 - This finding characterizes the expressed pilot reaction to the provided alert service.

In the initial, TDWR evaluation at Stapleton in 1988, pilot comments tended to express both encouragement and concern about overwarning. Typical comments were:

"Excellent safety device but accuracy is in doubt"
"It appeared that 'wolf' was being cried by ATC"

Overwarning was addressed over the next two years. By the 1990 evaluations at Stapleton International Airport and Orlando International Airport, the pilot comments were overwhelmingly positive, and the three cautionary comments received no longer involved overwarning. Typical of the positive comments were:

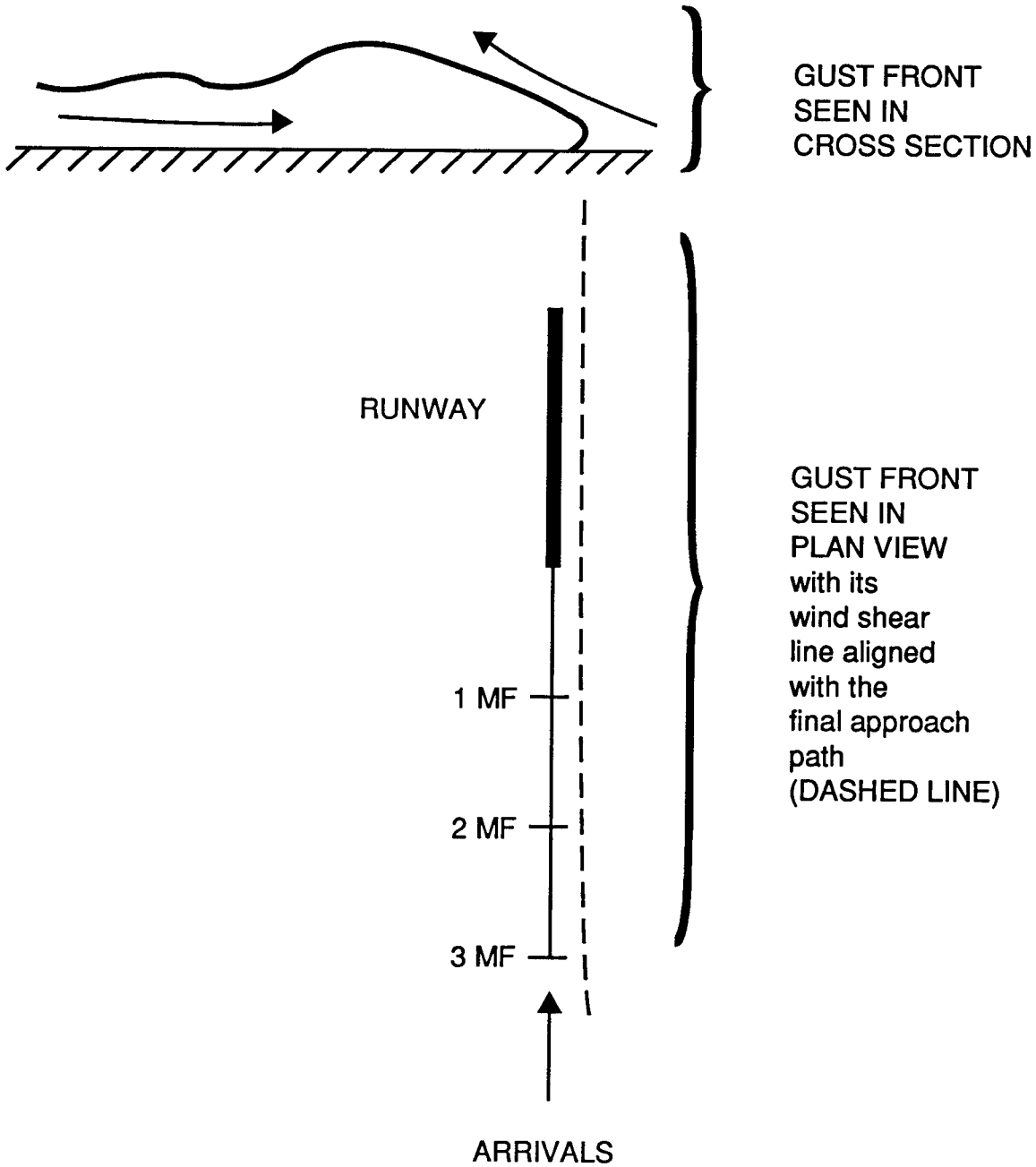


FIGURE 5-1: GUST FRONT ALIGNED WITH THE FINAL APPROACH PATH - A SITUATION NOT PROVIDED ALERT COVERAGE DURING THE EVALUATIONS BY THE TDWR/LLWAS ALERT SYSTEM

"An excellent system, money well spent."
"Microburst alert given as we approached 100 knots...next time I'll discontinue the takeoff with any microburst alert. Wind shear encounter exactly as presented in simulator."
"Very timely warning...invaluable information."
"The microburst alert decisively turned a 'gray' situation to 'red'; it made the decision...easy."

Two of the three cautionary comments received in 1990 involved encounters in which the pilots had not received an alert, experienced a 15-knot airspeed variation, and thought an alert should have been issued. The third comment was concerned with the effectiveness of the microburst alert presentation in getting pilot attention:

"I feel that the microburst warning (is) too 'soft.' (It) does not adequately get a pilot's attention during a busy approach. They are given very casually, e.g., 'American 123 cleared to land, microburst alert.' Even though an actual microburst alert was issued, the significance of it was lost on (a particular landing aircraft was identified) that continued the approach and landed. He then told the Tower that it was so rough below 500 feet that he felt no one else should attempt the approach...I doubt that they ever picked up the phrase microburst in the warning by Tower. He seemed very surprised at the turbulence encountered."

The typical response in the mailed-in questionnaires was that the pilot: (a) considered the issued warning useful whether it was a microburst alert, a "loss" wind shear alert, or a "gain" wind shear alert, (b) used the alert to review the situation, and (c) increased the landing/takeoff airspeed if the decision was to proceed with the landing or takeoff. In other words, the alerts were useful to the pilots even when the pilots chose not to avoid a possible wind shear encounter.

5.6 ALERT OVERWARNING

Finding 22 - The eventual operational impact of alert overwarning is not known, but the effort to reduce it should continue in the post-1990 TDWR and TDWR/LLWAS-based evaluations.

Overalarming became a recognized operational problem partway through the 1988 Stapleton evaluation when the TDWR-based alert service was temporarily taken out of service due to ATC concerns about overwarning, and the decision was made to revise the microburst alert software. The software changes lessened but did not eliminate overwarning during the remainder of the 1988 evaluation.

There has been an active effort to reduce overwarning since

the 1988 evaluation through a series of software changes. At Stapleton, the changes reduced the extent of the overwarning:

a) In the 1988 evaluation,

   1) 34% of the pilots issued an alert indicated something to the effect that "nothing was encountered," and

   2) Another 31% of the pilots indicated that "nothing much was encountered."

b) In the 1990 evaluation,

   1) 28% of the pilots issued a TDWR-based alert indicated that "nothing was encountered," and

   2) Another 15% of the pilots indicated that "nothing much was encountered."

Overwarning was not an issue in the 1989 evaluation at Kansas City International Airport due to the small number of landing/departing aircraft issued an alert. However, the overwarning issue gained new vigor in the 1990 Orlando evaluation where microburst outflows were found to be more closely associated with surface rain cells and, consequently, more visible than in the Denver area.

Partway through the 1990 Orlando evaluation, ATC concerns about lost runway operations due to apparent overwarning resulted in software changes being made. Once again, the extent of the overwarning was reduced, but was not eliminated. Overwarning remained an expressed concern of some Air Traffic personnel after the software changes had been put into effect. The following excerpts from two alert periods were obtained from the daily logs maintained by the on-site, evaluation personnel:

a) "(At startup of the TDWR-based alert service one day, TDWR) came up with (a microburst alert) on both runways. Airport was already impacted by (weather) and supervisors were unhappy with the additional delays from the (microburst), which was not perceived as an operational hazard...Supervisor commented: 'we have been running flights for last hour and now everybody is holding'...feels TDWR is overwarning, too conservative."

b) "...supervisor...commented that either the width of the (safety corridor) should be reduced or the size of the (areas used to depict microbursts) or the airlines should <u>not</u> have a policy of not landing whenever they hear the word 'microburst'..."

Apparent overwarning may have also influenced how pilots

utilized the microburst alerts over the course of the Orlando evaluation. Near the beginning of the evaluation, 78% of the aircrews that were directly issued a microburst alert elected not to land/takeoff; by the middle portion of the evaluation, the percentage had dropped to 46%; and near the end, the percentage had dropped to 29%.

The eventual operational impact of alert overwarning, if it is not remedied, is not known. However, to the extent that overwarning results in:

a) Pilots not taking microburst alerts seriously when, in reality, the microburst is on the intended flight path, safety will be adversely affected, and

b) Pilots not landing or taking off with an alert in effect when, in reality, the wind shear feature is safely off the intended flight path, runway utilization will be adversely affected.