PROGRAM STATUS/SCHEDULES

MICROBURST/GUST FRONT PHENOMENOLOGY AND DATA
MEMPHIS (TN)/HUNTSVILLE (AL)
DENVER (CO)

MICROBURST DETECTION ALGORITHM STATUS

1988 TEST PLANS
## FAA Goals for TDWR Performance

<table>
<thead>
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<th>Microburst</th>
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<tr>
<td>&gt; 90% Probability of Detection</td>
<td>20 Minute Advance Warning</td>
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<td>&lt; 10% Probability of False Alarm</td>
<td>Very Low False Alarm Rate</td>
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<tr>
<td>± 5 Knots (or 20%) Accuracy on Strength</td>
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MICROBURST DETECTION OUTPUT PRODUCTS

IDENTIFICATION
QUANTIFICATION
LOCATION
TREND

'MICROBURST 80 Knot Loss, 1 Mile Final, Increasing'

'MICROBURST 60 Knot, Loss, on the Runway, Decreasing'

desired output for users.
LINCOLN WEATHER RADAR PROGRAMS

FIELD EXPERIMENTS
S-BAND
C-BAND
ASR

ALGORITHMS
MICROBURST

Surf
Front

NEXRAD (100 SYS)
TDWR (100 SYS)
ASR-9 (101 SYS)

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415
DOPPLER WEATHER RADAR PROGRAM MAJOR ELEMENTS

- TESTBED RADARS FOR DATA ACQUISITION AND FEASIBILITY DEMONSTRATION
- EXECUTION OF MAJOR MEASUREMENT AND PRODUCT DEMONSTRATION PROGRAMS IN VARIOUS REGIONS
- ANALYSIS OF DATA AND DEVELOPMENT OF HAZARD DETECTION ALGORITHMS
LOCATIONS OF WINDSHEAR EVENTS RECORDED IN RADAR LOG (April-November 1985)
RADAR/MESONET COMPARISON

MESONET DATA

24-hr TIME SERIES PLOTS

SYNOPTIC PLOTS

RADAR DATA

MB IDENTIFICATION (Real/Post Real-Til)
(Record In Radar Log)

MB IDENTIFICATION

COMPARE FOR MISSED DETECTIONS
Flows Mesonet

Total Rainfall vs Peak Wind Speed in Microbursts

Rainfall (mm)

Peak Wind Speed (m/s)
FLOWS MESONET

CHANGE IN TEMPERATURE vs PEAK WIND SPEED IN MICROBURSTS

\[ |\Delta T| \, (^\circ \text{C}) \]

Peak Wind Speed (m/s)
The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology under Air Force Contract F19628-85-C-0002.

During 1984 and 1985 M.I.T. Lincoln Laboratory, under the sponsorship of the Federal Aviation Administration (FAA) conducted a measurement program in the Memphis, Tennessee, area to study low-level wind shear events and other weather phenomena that are potentially hazardous to aircraft operations, with particular emphasis on those issues related to the Terminal Doppler Weather Radar (TDWR). The principal sensor for the measurement program was the S-band FAA-Lincoln Laboratory Testbed Doppler Weather Radar (FL2) which incorporates many of the functional features of the TDWR. Both FL2 and a Chend Doppler Weather Radar operated by the University of North Dakota (UND) obtained reflectivity, mean velocity and spectrum width measurements with a radar geometry and scan sequences to facilitate determining the surface outflow features of microbursts at the anticipated TDWR ranges. A 30-station network of automatic weather stations (mesonet) collected 1-min averages of temperature, humidity, pressure, wind speed and direction, and total rainfall, plus the peak wind speed during each minute; this system operated from about March through November 1984 and 1985. Finally, the UND Citation aircraft operated two 3-week periods during 1985, collecting thermodynamical, kinematical and microphysical data within and around selected storms in the area as well as providing in situ truth for locations and intensity of turbulence.

This report describes the principal initial results from the Memphis operations, stressing the results from 1985 when the FL2 radar was fully operational. These results are compared to those from previous studies of wind-shear programs, e.g., NIMROD near Chicago, JAWS and CLAWS near Denver. During 1985, 102 microbursts were identified in real time along with 81 gust fronts. One of the dominant results is that most microbursts in the mid-south are wet; that is, they are accompanied by significant rainfall. This is in contrast, for example, to the results from Denver where more than half of all microbursts have little or no appreciable rain reaching the ground. Aside from this major difference, microbursts near Memphis were similar to those found elsewhere in the country in terms of wind shear magnitude. The report also gives more representative results from the aircraft operations and discusses the effectiveness of the ground clutter filters used on the FL2 radar.
This report focuses on the detectability of microbursts using pulse Doppler weather radars and surface anemometers. The data used for this study were collected in the Memphis, TN area during the FLOWS* project of 1985. The methods used for declaring a microburst from both Doppler radar and surface anemometer data are described.

The main objective of this report was to identify the results that were generated by comparing the 1985 radar detected microbursts (which impacted the surface anemometer system) with the surface mesonet detected microbursts. In so doing, the issue of missed microburst detections, for which there occurred two (both by the radar), is identified. Possible reasons as to why these two microbursts were not detected are discussed in detail.

*FAA/Lincoln Laboratory Observational Weather Studies
TEMPORAL DISTRIBUTION OF MICROBURSTS

NUMBER OF MICROBURSTS PER DAY

MEMPHIS
1985

HUNTSVILLE
1986

MONTH
APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  FEB

COUNT
0  2  4  6  8  10  12  14  16
ALGORITHM SCORING PROCEDURE

RADAR OBSERVATIONS

OUTFLOW DETECTION ALGORITHM

MULTIPLE DOPPLER ANALYSIS

HUMAN ANALYSTS

SINGLE-DOPPLER GROUND TRUTH

COMPARE

DETECTION/FALSE ALARM STATISTICS

COMPARE

AREA OVERLAP SHEAR QUANTIFICATION

DUAL-DOPPLER GROUND TRUTH
### 1986 GROUND TRUTH DATABASE (10/7/87)

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<tr>
<th>DATE</th>
<th>TAPES</th>
<th>DATA AVAILABLE (UT)</th>
<th>TRUTH TYPE</th>
<th>TRUTH PERIOD (UT)</th>
<th>WEATHER SYNOPSIS</th>
<th>TRUTH GRADE</th>
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During the period June through July 1986, NASA conducted the Satellite Precipitation and Cloud Experiment (SPACE) in the central Tennessee, northern Alabama, and northeastern Mississippi area. In addition to SPACE, the Microburst and Severe Thunderstorm (MIST) Program, sponsored by the National Science Foundation, and the FAA-Lincoln Laboratory Operational Weather Study (FLAWS), sponsored by the Federal Aviation Administration, operated concurrently under the acronym of COHMEX (COoperative Huntsville Meteorological Experiment). The COHMEX field program incorporated measurements from remote sensors flown on high altitude aircraft (ER-2 and U-2), Doppler and conventional radars, rawinsondes, satellites, cloud physics research aircraft, and various surface observational systems.

This document contains a brief description of the field program and a daily data collection summary. Chapter 2 summarizes the program instrumentation and facilities, and includes sample selected data products. Chapter 3 provides a meteorological summary, operations overview, and an inventory of the data collected for each day of the field program. The purpose of this document is to provide the researcher and scientist with a tool to select data sets for case studies and instrument evaluation.
 Terminal Weather Sensors Near Stapleton Airport for FAA 1987 Wind Shear Measurement Programs
1987 DENVER MICROBURST REFLECTIVITIES

NUMBER OF OCCURRENCES

REFLECTIVITY (dBz)

0 10 20 30 40 50
0-10 11-20 21-30 31-40 41-50 51-60 61-70
1987 DENVER GUST FRONT WIND SHEARS

NUMBER OF GUST FRONTS

VELCITY (m/s)

< 10 10-15 16-20 21-25 26-30 > 30
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<th>DATE</th>
<th>TAPES</th>
<th>DATA AVAILABLE(UT)</th>
<th>TRUTH TYPE</th>
<th>TRUTH PERIOD(UT)</th>
<th>WEATHER SYNOPSIS</th>
<th>TRUTH GRADE</th>
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<th>SCCS VERSION</th>
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<td>Surface</td>
<td>2309-0033(1.5)</td>
<td>Wet, Line</td>
<td>B</td>
<td>LL</td>
<td>1.1</td>
</tr>
<tr>
<td>SEPT 2</td>
<td>A-G</td>
<td>1722-0039(7.3)</td>
<td>Surface</td>
<td>2223-2310(0.9)</td>
<td>Line TRW's</td>
<td>B</td>
<td>LL</td>
<td>1.2</td>
</tr>
</tbody>
</table>
OUTFLOW DETECTION ALGORITHM

RADIAL VELOCITY → SHEAR SEGMENT IDENTIFICATION → AZIMUTHAL ASSOCIATION → TIME CORRELATION → OUTFLOW DETECTIONS

PROJECT: FLOWS
RADAR: FL-2
DATE: 26 JUNE 1985
TIME: 18:40:44 UT
SCAN: 32
TILT: 1 (0.0°)

ORIGINAL PAGE IS OF POOR QUALITY
CONFIGURATION FOR REAL-TIME DEMONSTRATION

- Color Display
- Recording
- Central Computer (Perkin Elmer)
  - Raw data
  - Products
    - Feature Extraction (SUN)
    - Symbolic Processing (Symbolics)
- Product Coordination
- Verifier
- Product Distribution
- Communications
- Stapleton Tower TRACON
- Remote Situation Display

[Diagram showing flow of data and processes]
Introduction

The Federal Aviation Administration (FAA) will be conducting an experimental measurement program using pulse Doppler weather radars during 1987 around Stapleton International Airport, Denver, CO to obtain information on low altitude wind shear phenomena and other terminal aviation weather hazards. The objective of the FAA measurement program for 1987 is to develop and validate techniques for the automatic detection of phenomena such as microbursts and gust fronts, turbulence and heavy rain. The results of this development program will be incorporated into the hardware and/or software components of the Next Generation Weather Radar (NEXRAD) and the Terminal Doppler Weather Radar (TDWR) systems which are being procured by the FAA.

A principal objective of the program is to develop techniques for detecting low-altitude wind shear* events which are potentially hazardous to aircraft taking off or landing at an airport. A particularly dangerous wind shear situation occurs when a microburst, or downburst, from a storm spreads out horizontally on reaching the ground as illustrated in Figure 1. When an aircraft encounters such a wind situation, there is often a rapid change from a headwind, which increases the lift of the airplane, to a tail wind, which reduces the lift of the airplane. In extreme cases, the sudden loss of lift from the tail wind can cause the airplane to crash. Encounters with wind shear events may have contributed to as many as 25 aircraft accidents worldwide over the past 10 years, resulting in over 500 fatalities.

Wind shear events can be caused by a number of meteorological situations. Thunderstorms often produce strong outflows and downdrafts which can spread out upon hitting the surface. Large thunderstorms are capable of producing long duration outflows, the leading edge of which are called "gust fronts." Gust fronts can extend several miles away from the rain area and last for periods as long as an hour or more.

Small storms and even relatively innocuous looking clouds are capable of producing small but intense downdrafts which can be just as hazardous (if not more so!) than those of their larger cousins. The smaller storms produce what has been termed "microbursts" by some scientists. These microbursts are often only a mile or two in diameter and last for as little as 5 minutes. Nevertheless, if a microburst were to occur near an airport while an aircraft is taking off or landing, an accident could result.

*The term wind shear is used to describe situations in which the wind encountered by an aircraft changes rapidly along the flight path. Not all wind shears are hazardous.
Figure 1. Symmetric Microburst. An Airplane Transiting the Microburst Would Experience Equal Headwinds and Tailwinds.
Low-altitude wind shear measurement and detection programs have been conducted at a number of locations (Chicago, Denver, Memphis (TN), and Huntsville (AL)) over the past few years. Denver was the site for:

1. The Joint Airport Weather Studies (JAWS) project, a study of the basic physics of microbursts conducted during the summer of 1982, and

2. The Classify, Locate and Avoid Wind Shear (CLAWS) project, in which real time wind shear warnings were provided to the FAA control tower at Stapleton Airport during a 45-day period in the summer of 1984. The warnings were produced manually by research meteorologists from the National Center for Atmospheric Research (NCAR) who monitored data from a research Doppler weather radar. The warnings were provided to controllers who then informed pilots of hazardous weather events. CLAWS demonstrated that properly interpreted Doppler weather radars could provide operationally useful warnings of low-altitude wind shear.

The Denver Area Measurement Program

The measurement program in 1987 focuses on transitioning the scientific and operational knowledge gained in the previous measurement programs to a fully automated wind shear detection system.

Figure 2 shows the locations of the various ground weather sensing systems being used in the 1987 measurement program. The FAA test-bed Doppler weather radar developed and operated by the Lincoln Laboratory of the Massachusetts Institute of Technology (MIT) for the FAA will be the primary data collection tool for the measurement program. This S-band radar (designated by the letters FL-2 in Fig. 2 and shown in Fig. 3) uses a 28-ft. diameter antenna and a powerful signal processing system to record, process and display the Doppler measurements. This radar utilizes certain advanced digital processing techniques (e.g., digital clutter suppression filters and automatic choice of signal waveforms) which will be required in the systems the FAA is procuring. The FL-2 radar will be located on the Buckley Air National Guard airbase approximately 10 miles southeast of Stapleton Airport.

The second Doppler radar used in the 1987 testing will be a C-band system operated by the University of North Dakota (UND). This radar, located approximately 8 miles northeast of Stapleton (designated UND in Fig. 2), will provide additional confirmation of wind shear events near Stapleton as well as enable the FAA to determine the effects of wavelength on the measured reflectivity of wind shear events.
SURFACE WEATHER STATIONS

△ LOW-LEVEL WIND SHEAR SYSTEM ANEMOMETERS

Figure 2. Terminal Weather Sensors near Stapleton Airport for FAA 1987 Wind Shear Measurement Programs.
A network of 30 automatic weather stations (denoted by circles in Fig. 2) located in open areas is collecting data on temperature, humidity, pressure, wind speed and direction and rainfall, 24 hours a day. Data are averaged over 1-minute intervals and transmitted from each of the stations to the GOES-East geostationary satellite every half hour. The data are downlinked and provided to the project scientists by telephone line or computer tape for analysis or display. The wind data from the weather stations are used to validate the wind shear detection performance of the Doppler radars while the other weather station data are used to accomplish meteorological analyses of the wind shear events.

Additional information on the surface wind characteristics during wind shear events will be provided by data from the 12 FAA Low-Level Windshear Alert System (LLWAS) anemometers located about Stapleton (which are designated by triangles in Fig. 2).

UND is also operating its Citation jet aircraft equipped with instruments to measure the winds, temperature and humidity conditions near storms as well as the numbers and sizes of cloud droplets and raindrops encountered within storms. The Citation aircraft will furnish the data on the upper air environment associated with wind shear as well as direct measurements of turbulence to confirm the accuracy of Doppler radar-based turbulence detection algorithms.

The development and validation of algorithms to automatically determine the location and intensity of hazardous low altitude wind shear phenomena is a principal objective of the 1987 program. In June 1987, real time testing of the microburst outflow detection algorithm and the gust front detection algorithm will commence at the FAA test-bed radar site.

These algorithms, based on experimental programs and data analyses over the past few years by researchers at NCAR, NSSL, Lincoln Laboratory, and the University of Chicago will operate in real time on the FL-2 data processing system with the algorithm outputs being displayed on a color display workstation.

Researchers from NCAR, Lincoln Laboratory, and the National Severe Storms Laboratory (NSSL) will perform an initial evaluation of wind shear events and the algorithm performance in real time. A more detailed assessment of the weather phenomenology encountered and the algorithm performance (using data from the UND radar and surface weather sensors as well as FL-2 data) will be accomplished in post-measurement analyses.

The algorithms to be tested in 1987 have demonstrated operationally useful performance on wind shear events measured by the FL-2 system in 1985 near Memphis, TN and in 1986 near Huntsville, AL. The microburst events encountered in the humid southeast portion of the U.S. were typically accompanied by heavy rain. By contrast, many Denver area microbursts are associated with much lighter precipitation producing storms. Thus, it is
necessary to demonstrate that the algorithms have adequate performance on Denver wind shear events before the automated wind shear detection products can be provided to the air traffic controllers at Stapleton.

If an operationally useful detection capability is achieved against the Denver area windshear events measured in 1987, the FAA plans to conduct a full operational demonstration during 1988 in which automatically generated hazardous weather warnings will be provided to controllers for transmission to pilots.

Additionally, the 1987 program will explore the possibility of future enhancements to the near term automated products. A group of researchers from NCAR will review the FL-2 data in real time to determine whether expert radar meteorologists can reliably predict the imminent (e.g., 5-10 minutes) occurrence of microbursts and/or the development of thunderstorms.

FAA Weather Radar Procurement

The Federal Aviation Administration is participating in 3 weather radar programs. These are the Next Generation Weather Radar (NEXRAD), terminal NEXRAD, and Terminal Doppler Weather Radar (TDWR). The NEXRAD Program is a joint effort of the FAA, the National Weather Service, and the Air Force to develop and procure a national network of weather radars.

The terminal NEXRAD Program involves the use of 17 NEXRAD units reconfigured for terminal operations and installed near major airports such as Denver Stapleton, Dallas-Fort Worth, and Chicago. These radars will be operated for an interim period until the TDWR is available after which the terminal NEXRAD systems will be reconfigured as standard NEXRAD systems and relocated to Alaska, Hawaii, and the Caribbean.

The TDWR systems being procured by the FAA will provide pilots and controllers with an indication of wind shear and other hazardous weather conditions. These systems will be installed at major airports beginning about 1992.

The Denver test program supports all of these activities.

Details on the scope and time schedule of the FAA weather radar program can be obtained from Mr. Donald Turnbull [telephone (202) 267-8429].

Additional information on the Lincoln Laboratory, NSSL, and NCAR participation in the above measurement program can be obtained from Drs. James Evans [(617) 863-5500 X814-433], Dusan Zrnic' [(405) 366-0403] and Cleon Biter [(303) 497-8937], respectively.