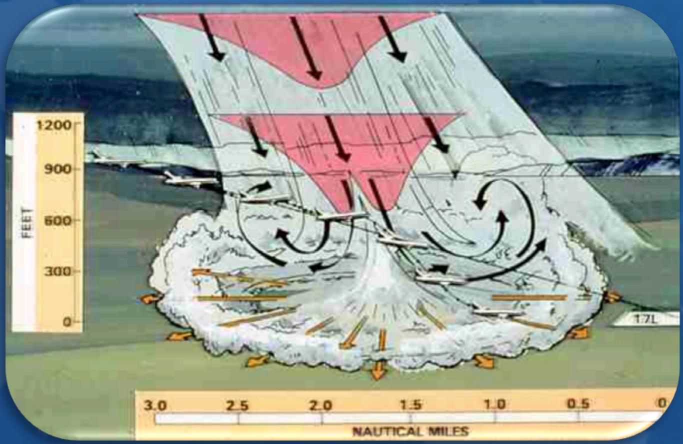
# Wind Shear
# Hazards to Aviation Operations

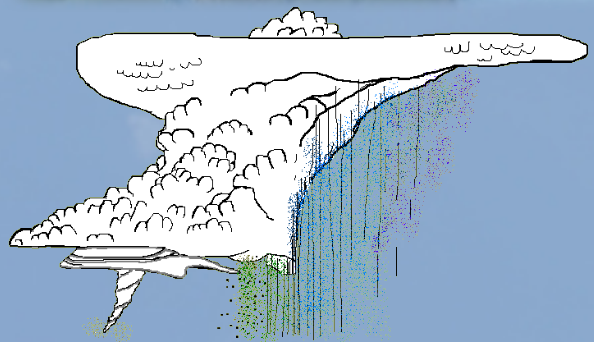
## Wind Shear Program
## Background, Overview, and
## Alert Interpretation




National Center for Atmospheric Research (NCAR)
July 2012

# Background

Most scientists believed that microburst wind shear, if it existed, could only be produced by severe thunderstorms.



NASA Image

# Background

In 1982, the FAA, NCAR and University of Chicago set out to prove or disprove the theory the microbursts existed and were a potential threat to aircraft. Doppler radars, anemometers, and sounding systems were deployed in eastern Colorado to search for microbursts.

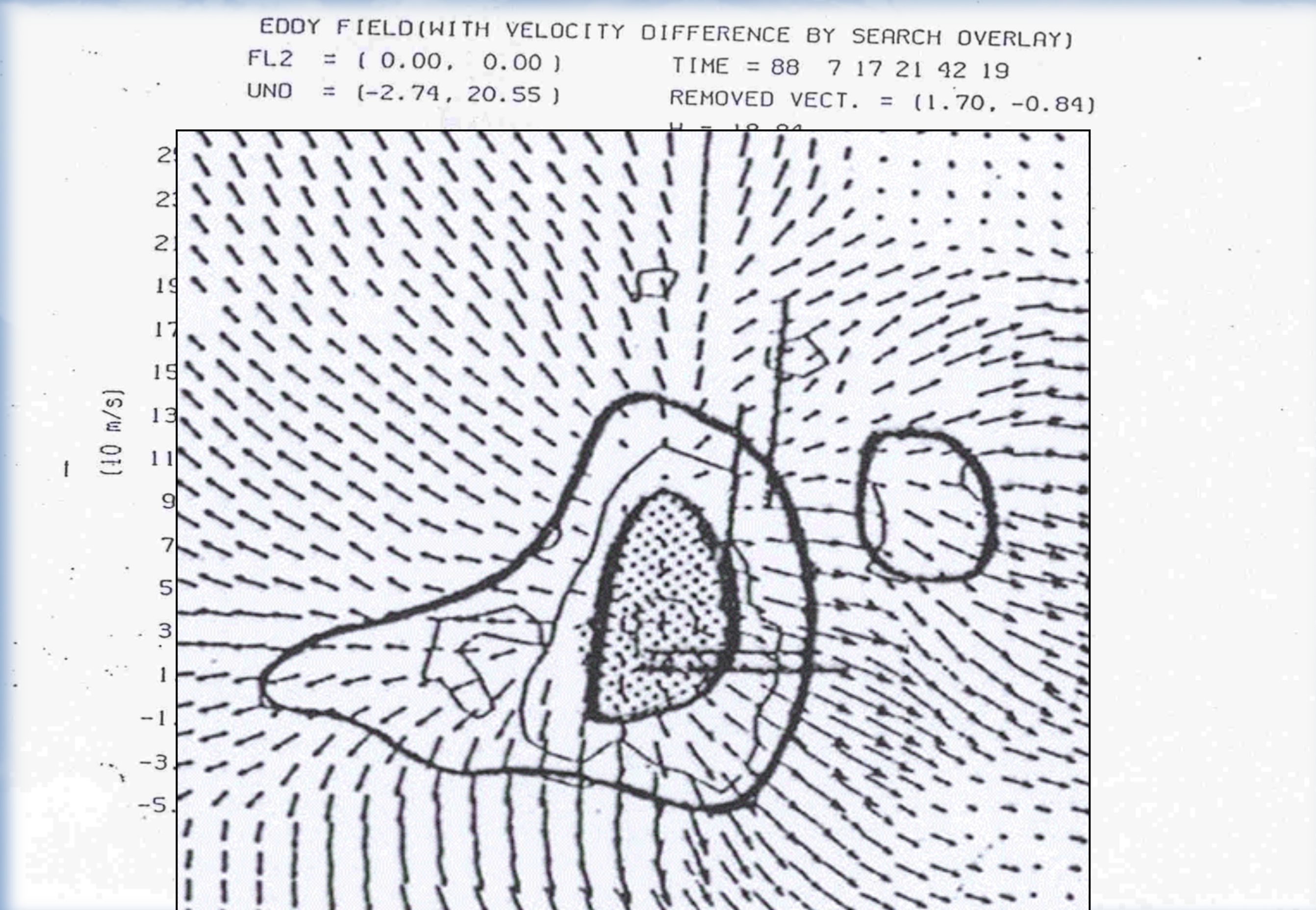
The project was called the “Joint Airport Weather Studies Project (JAWS)”

# Background

During the summer of 1982, approximately 99 microburst events were detected within 10 nm of Denver's Stapleton Airport.

Most of the microbursts were associated with high based cumulus clouds with little precipitation hitting the ground. These "dry" microbursts are the most hazardous because they provide few visual clues for pilots.

# Microburst Morphology




**Microburst divergence pattern as measured by dual-Doppler radar near Denver's Stapleton airport in 1988.**

# Known Wind Shear Accidents

Takeoff:

1956 - BOAC 252/773 Kano, Nigeria (32 dead, 11 injured)
1975 - Continental 426 (B727) Denver (15 injured)
1977 - Continental 63 (B727) Tucson (0 injured)
1982 - Pan Am 759 New Orleans (152 dead, 9 injured)
1984 - United 663, Denver (airframe damage, no injuries)
2008 – Continental 1404, Denver (airframe destroyed, injuries)*

* Investigation pending, or windshear contributing factor

# Known Wind Shear Accidents

Landing:

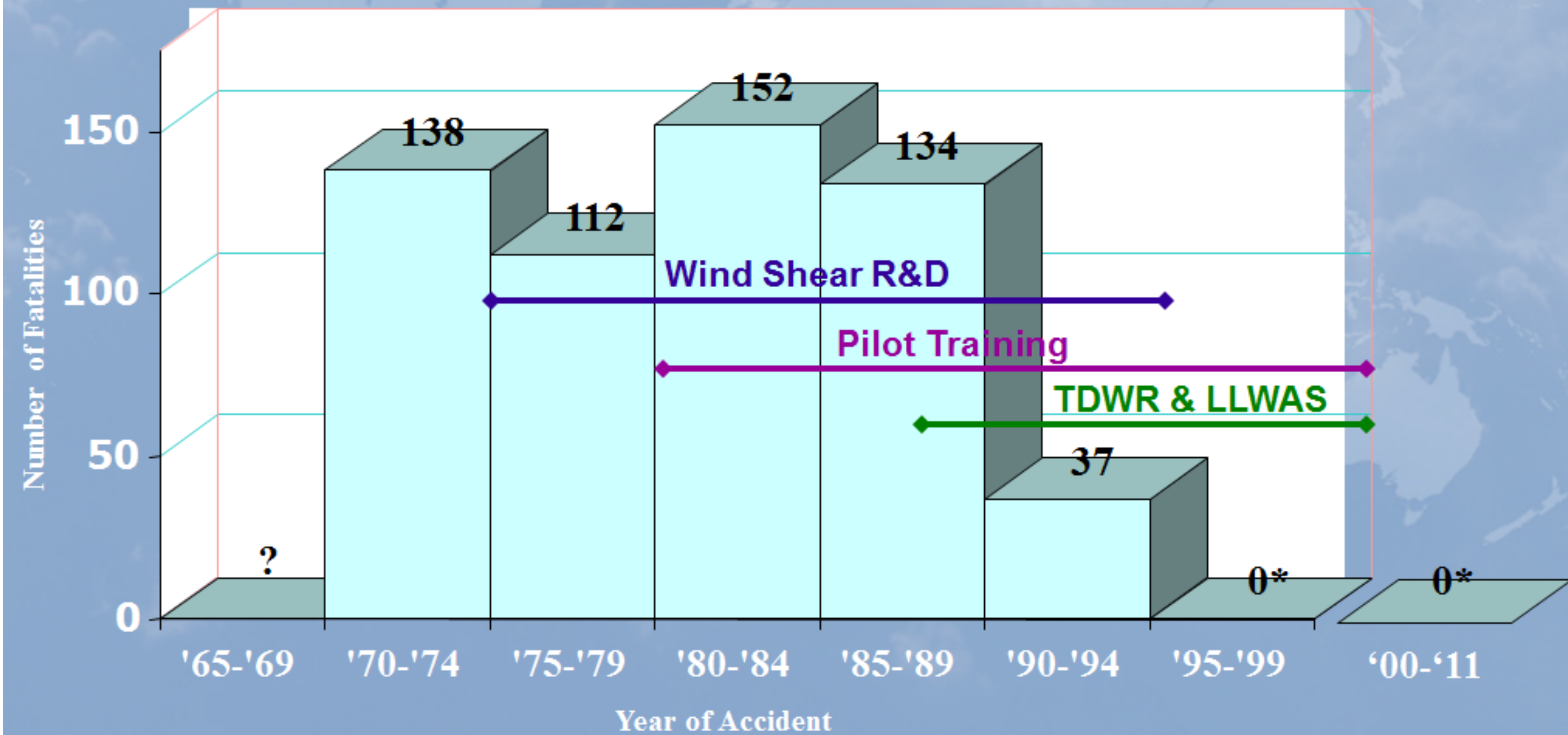
1974 - Pan Am 806 Pago Pago (96 dead)
1975 - Eastern 66 (B727) JFK, New York (112 dead, 12 injured)
1976 - Royal Jordan 600 Doha, Qatar (45 dead, 15 injured)
1976 - Allegheny 121 Philadelphia (86 injured)
1985 - Delta 191 (L-1011) DFW Dallas (134 dead)
1989 - IL-62 Cuba, Santiago (169 dead)
1992 - (DC-10) Faro, Portugal (54 dead)
1994 - US Air, Charlotte (37 dead)
1999 – *American 1420, Little Rock, Arkansas (11 dead, 89 injured)
1999 – *China Air, Hong Kong (3 dead, 211 injuries)
2009 - Federal Express, Narita Airport (2 dead) ???

* Windshear or crosswind shear contributing factor

# FAA Wind Shear System Timeline

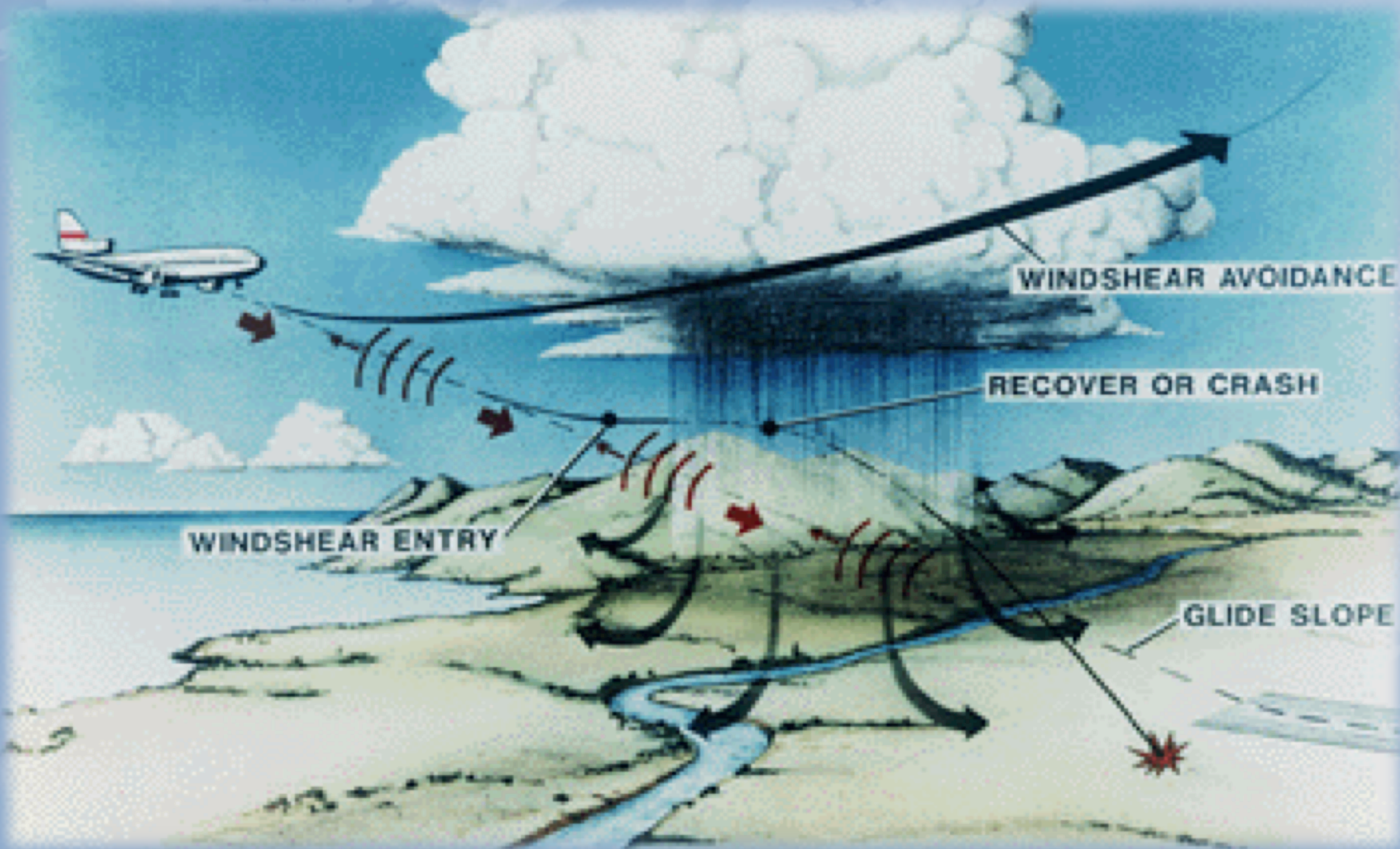
- 1982 – Joint Airport Weather Studies Project (JAWS)
- 1985 – Manual demonstration of detection using radar
- 1986 – FAA funds TDWR & LLWAS (Phase-3) development
- 1988 – First operational demonstration of TDWR & LLWAS-3
- 1988 – FAA conducts cost/benefit study to guide procurement
- 1989 – FAA tenders LLWAS-NE and TDWR systems
    - Raytheon awarded TDWR contract
    - Loral awarded LLWAS contract
- 1991 – First demonstration of TDWR/LLWAS integration
- 1993 - 1998 System implementation in US.
- 1998 - Implementation of the WSP systems
- 2008 – Testing of WindTracer® lidar at Las Vegas begins

# Fatalities Associated with U.S. Aviation Wind Shear Accidents (1965 through 2011)




Source: NTSB/National Research Council

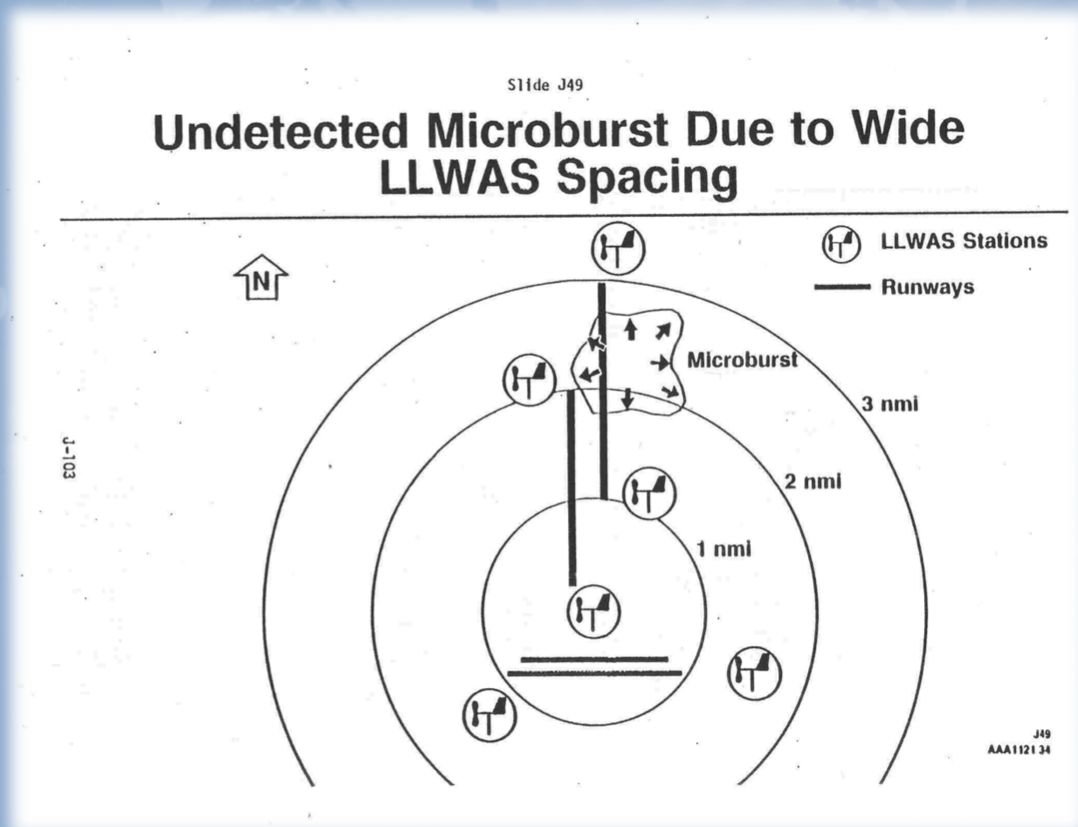
# Wind Shear Detection Systems




JAWS research resulted in scientific knowledge that led to the development of several windshear detection solutions.

# Original Low-Level Wind Shear Alert System (LLWAS) (~1979-1988)

The original LLWAS was designed to detect large scale phenomena such as gust fronts and sea breeze fronts.

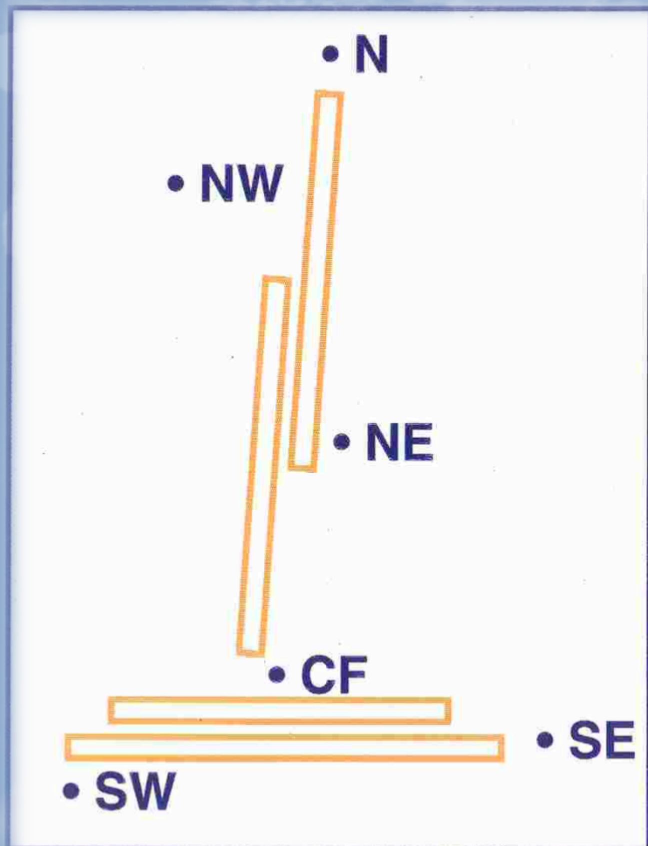


# Original LLWAS

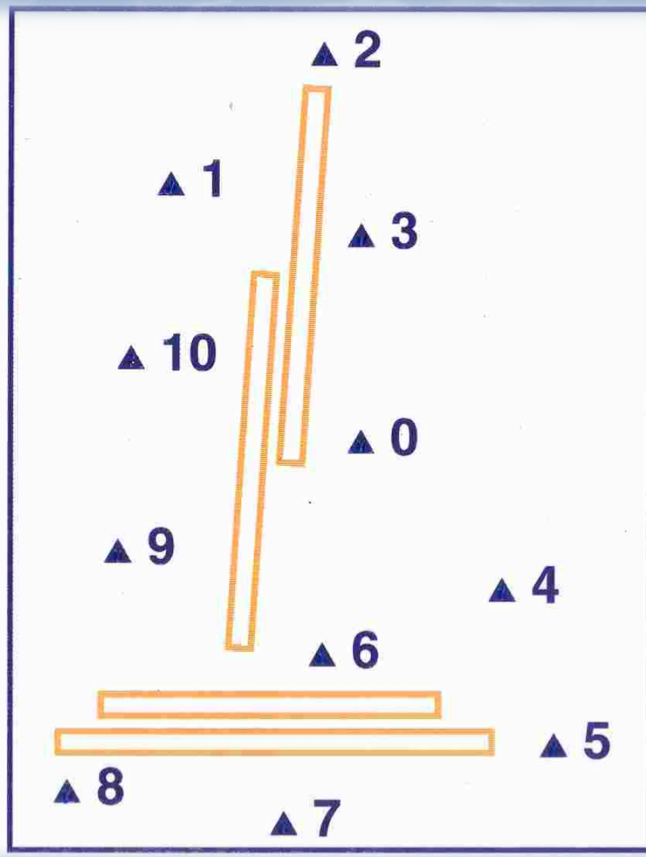
The original LLWAS Only calculated wind differences (> 15 kt vector) from the center field station.

Pilots received raw wind data from final controllers.

# LLWAS Upgrade




Original LLWAS Network




LLWAS – Network Expansion

The LLWAS Network Expansion (Phase-3) included a significant upgrade to the LLWAS wind shear detection algorithm.

# FAA Windshear Program

- After the JAWS project, the FAA and NASA pursued four primary research paths for addressing windshear:
  - Anemometer based system (LLWAS)
  - Terminal Doppler Weather Radar (TDWR)
  - Airport Surveillance Radar (ASR) system
  - On-board systems
    - Reactive
    - Forward looking

LLWAS

ASR-9

TDWR

# LLWAS & TDWR User Group

- NCAR, under direction of the FAA, put together a stakeholder user group to address system design for FAA windshear systems
- The User Group met between 1987 and 1993
- Participants included:
  - Airlines
  - Pilots
  - FAA Flight Standards
  - FAA Air Traffic
  - NTSB
  - NCAR
  - Lincoln Lab
  - Boeing Aircraft

# LLWAS & TDWR User Group

- The FAA & TDWR User Group guided the design of the LLWAS and TDWR in areas including:
  - Alert type
  - Alert content
  - Alert presentation
  - Alert priorities
  - Alert timeliness (system update rate)
  - ATC procedures

The windshear systems were developed, tested and implemented on a very aggressive schedule. Not all potential issues related to system design were considered.

# User Group Defined System Performance Expectations

Convective Wind Shear/Microburst Detection:

- Probability of Detection (POD): 90% or better
- False Alarm Rate (FAR): 10% or better

All FAA windshear solutions had to be designed to meet these performance requirements.

# Wind Shear Detection Products

**Wind Shear/Microburst Detection Alert Content**

- Description:  Detection of windshear (convective & clear-air)
- Inputs:  Surface Anemometers (later radar radial velocity)
- Alert Content:  Type – Intensity – Location
- Terminology:  "Windshear" or "Microburst"; Gains or Losses
- Alert Coverage: Out to 3 nautical miles from runway (max)
- Alert Resolution: 1 nautical mile (~2 km)
- Alert Update Rate: 10-15 seconds (depends on network size) for LLWAS and 60 seconds for radar

# Wind Shear Alert Types

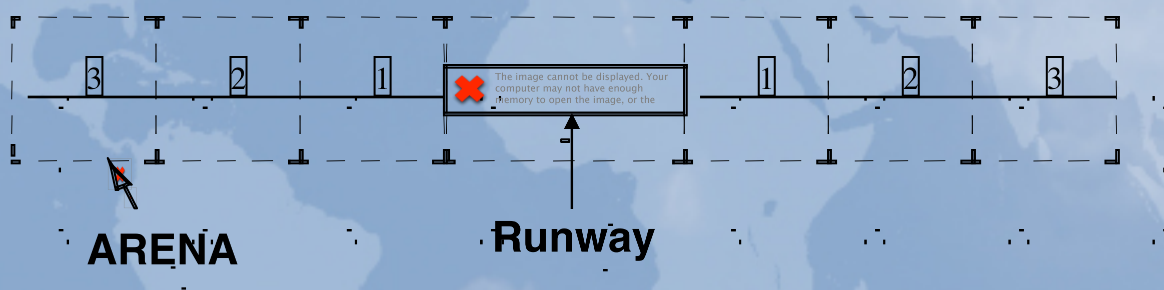
**Alert Intensity Thresholds**

Wind Shear Alert**:** 15 to 29 knot wind speed loss, or greater than 15 knot wind speed gain.

Microburst Alert: 30 knot or higher wind speed loss.

# Alert Message Content

## Wind Shear System - Alert Message Content




| ALERT TYPE | ALERT INTENSITY | | LOCATION |
|---|---|---|---|
| | | | 1 NM |
| Microburst | Loss | Knots | 2 NM Approach |
| Windshear | Loss/Gain | Knots | 3 NM |
| | | | 1 NM |
| | | | 2 NM Departure |
| | | | 3 NM |
| | | | Runway |

# Alert Format (LLWAS, TDWR, WSP, Lidar)

**Alert Message Format**

- The FAA's Alphanumeric Alarm Display (AAD) was limited to 25 characters per line and had 10 lines. The character limitation was due to a limit in the FAA display hardware.
- The alert content was designed to fit the FAA's 25 character limit.

09A MBA 35k- 3MF

Runway ID — Alert Type — Intensity — Location

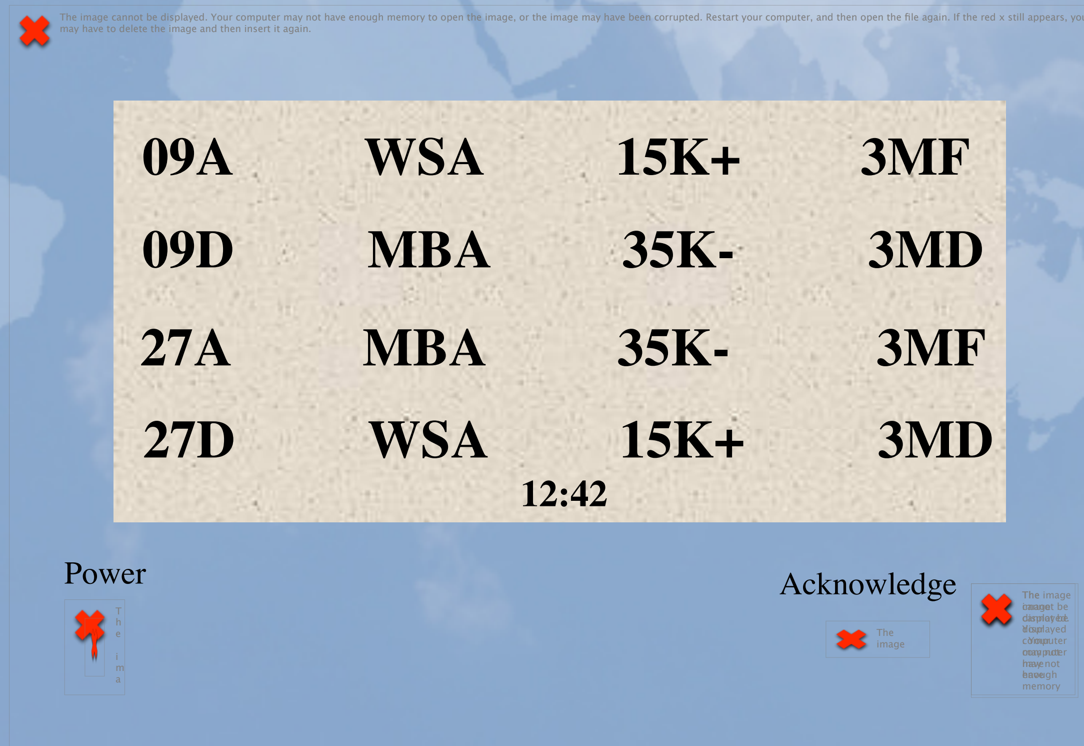
"United 555, microburst alert, expect a thirty-five knot loss at three miles final."

# Wind Shear Detection System Displays

## Alphanumeric Alarm Display (AAD) or Ribbon Display Terminal

**The AAD is used by the Final Controllers to provide windshear alerts to the pilots approaching and departing aircraft.**

**All alert intensities are calculated as headwind changes.**



# Wind Shear Detection System Displays

**The GSD is used by the Air Traffic Supervisors to monitor windshear events around the airport to plan and optimize airport operations in th presence of wind shear.**

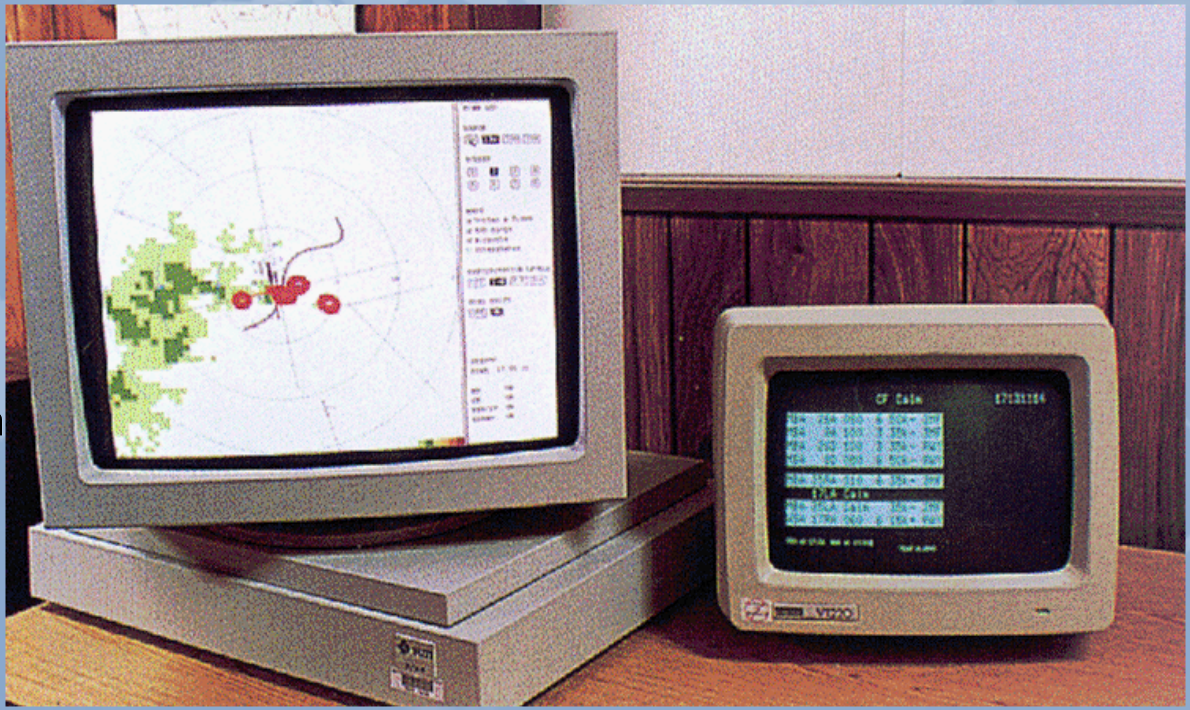
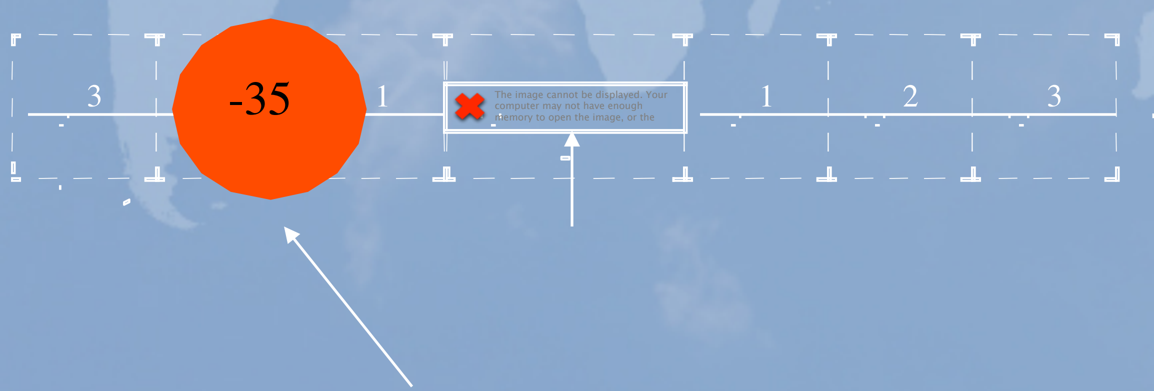


Photo of prototype LLWAS and TDWR display Systems. (NCAR, 1988)

# Basic Alert Process

➢ When a detected windshear event of sufficient strength intersects an ARENA(s), an alert is provided.

➢ Alert intensities are computed along the approach/ departure corridors to best estimate headwind changes.




**Microburst event intersecting alert corridor**

# Alert Message Content

## Multiple Events

When more than one type of event has been detected along an approach/departure corridor, the alerts are prioritized for that corridor.

Highest = 1 Lowest = 6

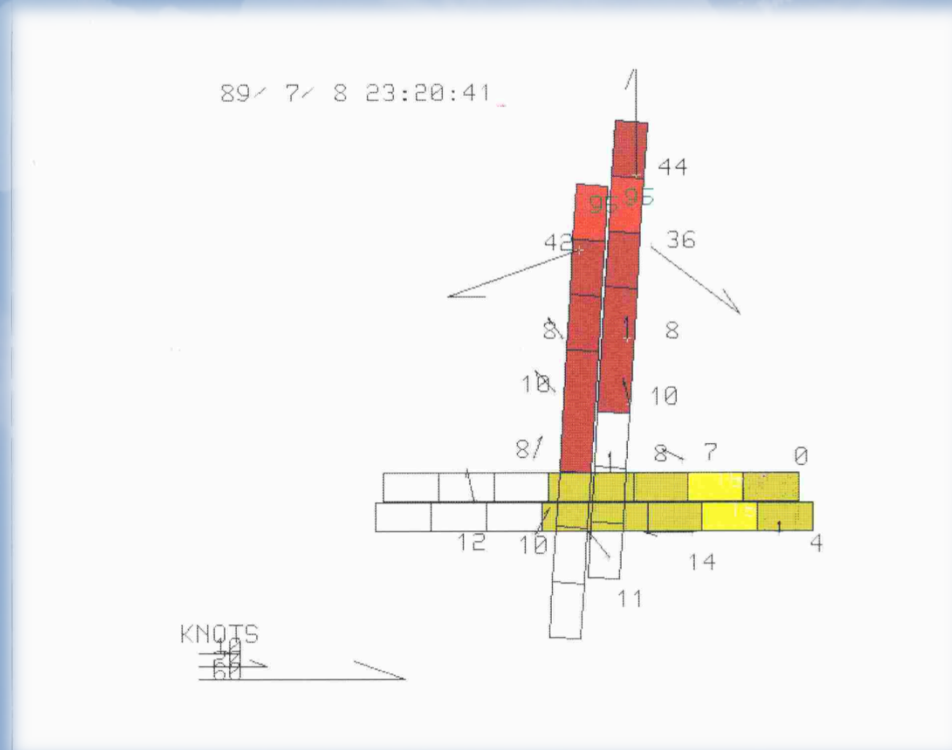
1 - Microburst Event (loss 30 knots or greater)
2 - Windshear Event
3 – Windshear Event (large gain) (>14 knots over windshear event loss)
4 – Windshear Event (small loss)
5 – Windshear Event (small gain)
6 – No Alert

# LLWAS Wind Shear Detection

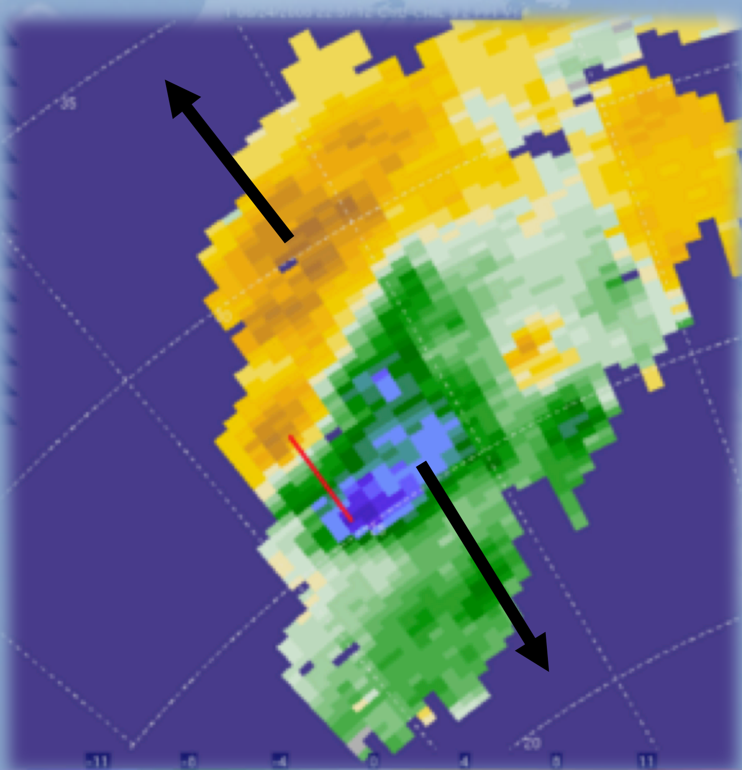
aircraft approach

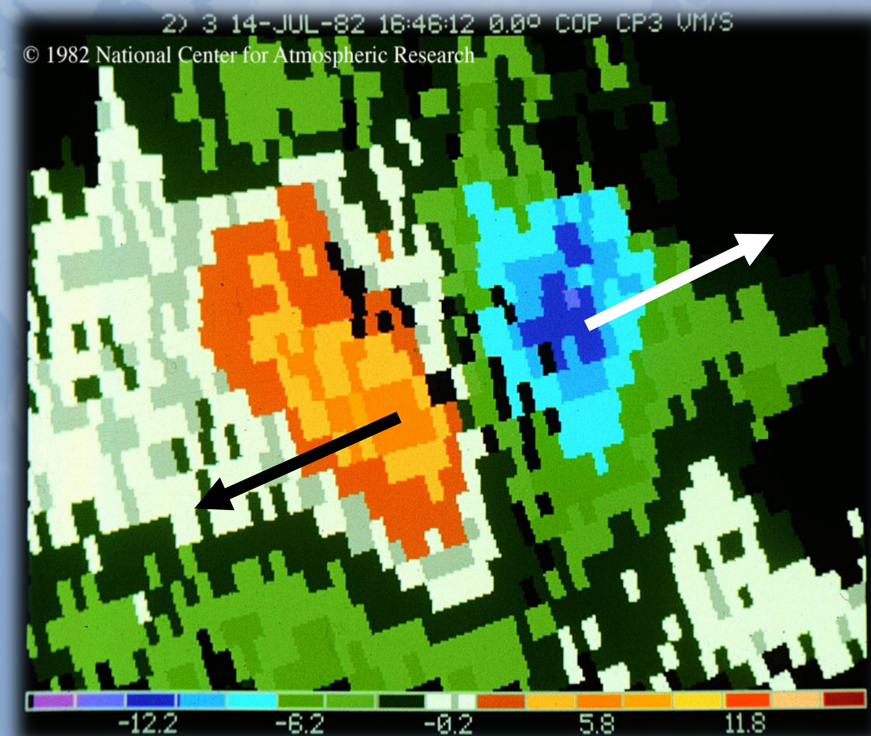
Strongest microburst recorded by an LLWAS system at Denver's Stapleton Airport on 9 July 1989.

The 95 knot microburst alert saved an aircraft from crashing. The aircraft was approaching to land on runway 17L.



# Radar Wind Shear Detection






Divergent outflow from microbursts measured by Doppler radar

# Detectability Definition

- An *in situ* sensor system such as LLWAS will have the best wind shear detection performance since it is not dependent on light or radio frequency scatterers (aerosols or precipitation).
- Remote sensing systems can miss events if there is no radar or lidar power return (signal).
- <u>However,</u> few LLWAS systems are large enough to cover all runways out to 3 NM!

# Wind Shear System Effectivities - Microbursts

**Table 1. Estimated Microburst Wind Shear Probability of Detection**

| Technology | Estimated POD for Wind Shear Alert | Comments |
|---|---|---|
| Doppler Weather Radar | 0.90 to 0.93 | Will generally miss very 'dry' microbursts. |
| LLWAS | 0.95 to 0.97 | For microburst events within network. Network may not extend to 3 NM from runways. |
| Lidar | 0.50 | Assumes that 50% of events will occur in moderate or greater precipitation. |

Based on: Cho, J.Y.N., R. Hallowell, M Weber, 2008. Comparative analysis of terminal wind-shear detections systems. 13 Conf. on Aviation, Range, and Aerospace, AMS.

# Wind Shear System Effectivities - Gust Fronts

## Table 2. Estimated Gust Front Wind Shear Probability of Detection

| Technology | Estimated POD for Wind Shear Alert | Comments |
|---|---|---|
| Doppler Weather Radar | 0.8 | Provides good coverage out to 18-km, which would also provide approximately 20 minutes of lead time (for a gust front moving at 15 $ms^{-1}$) for a wind shift event. Will generally miss 'dry' gust fronts and/or dry sea breezes. |
| LLWAS | 0.95 to 0.97 | For gust front/sea breeze events within network. Network may not extend to 3 NM from runways. |
| Lidar | 0.7 | Assumes that 30% of events will occur when there is moderate or greater precipitation resulting in beam attenuation. The limited range of the lidar will reduce the wind shift prediction lead-time over radar system (lidar range is ~12 km and represents a 66% reduction of the desired 18 km range) |

Based on: Cho, J.Y.N., R. Hallowell, M Weber, 2008. Comparative analysis of terminal wind-shear detections systems. 13 Conf. on Aviation, Range, and Aerospace, AMS.

# Wind Shear System Effectivities - Microbursts

**Table 3. Estimated Microburst Wind Shear Probability of Detection**

| Technology | Estimated POD | Comments |
|---|---|---|
| Doppler Radar + LLWAS | 0.95 to 0.97 | Radar extends coverage area and LLWAS detects 'dry' (and 'wet') events. |
| Doppler Radar + Lidar | 0.94 to 0.96 | Radar detects 'wet' events while lidar improves sensing of 'dry' events. |
| LLWAS + Lidar | 0.95 to 0.97 | LLWAS detects 'wet' (and 'dry') events and lidar extends the coverage region to 3NM for dry events if the LLWAS network detection coverage does not extend to 3 NM. |

Based on: Cho, J.Y.N., R. Hallowell, M Weber, 2008. Comparative analysis of terminal wind-shear detections systems. 13 Conf. on Aviation, Range, and Aerospace, AMS.

# Summary

- There are pros and cons for each wind shear system.
- The main differentiators are:
  - Ability to detect 'dry' wind shear events
  - Ability to detect asymmetric events
  - Range of coverage
- A combination of a remote and *in situ* sensor system provides excellent detectability in all weather conditions and generally reduces false alarm ratio to below 10%.