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Session IX. Airborne Passive Infrared

N91-24146

Status of Turbulence Prediction System's AWAS III
Pat Adamson, Turbulence Prediction Systems

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H. Patrick Adamson

Turbulence Prediction Systems

Advance Warning Airborne System (AWAS)

- AWAS I 1987
- AWAS II 1988
- AWAS III 1990

Funded in part by NASA SBIR Contracts

Flight Tests

- AWAS I — Piper Apache , Cessna Citation II & NASA B 737
- AWAS II — Cessna Citation II
- AWAS III — Cessna Citation II, MD 80 & NASA 737

FAA CERTIFICATION

- AWAS II STC: 1 Installation
- AWAS III STC: 4 Installations
  Production model
  Platform Independent STC

PASSIVE INFRARED SYSTEM RECORDS THE FIRST EVER VALIDATED IN-FLIGHT PREDICTION OF A MICROBURST

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Paper Presented at SAE S7 Meeting
Cincinnati, Ohio
October 8, 1990

ABSTRACT

On July 7, 1990, a passive infrared system flown on the University of North Dakota Cessna Citation II atmospheric research aircraft achieved the first ever advance warning of an in-flight windshear encounter.

The Cessna, following vectors from a ground based Terminal Doppler Weather Radar (TDWR) operated by MIT and NASA, intentionally flew towards a known windshear. The infrared system on the aircraft recorded the detection of the windshear with a 35 second advance warning.

The aircraft continued to fly into the windshear to record the encounter. The aircraft was equipped with a: 1) Turbulence Prediction Systems (TPS) passive infrared Advance Warning Airborne System (AWAS), 2) inertial navigational system (INS), and 3) air data measurement device. The data recorded in-flight by the infrared system was later compared to and found to agree with the data recorded by the TDWR and the in-situ air data.

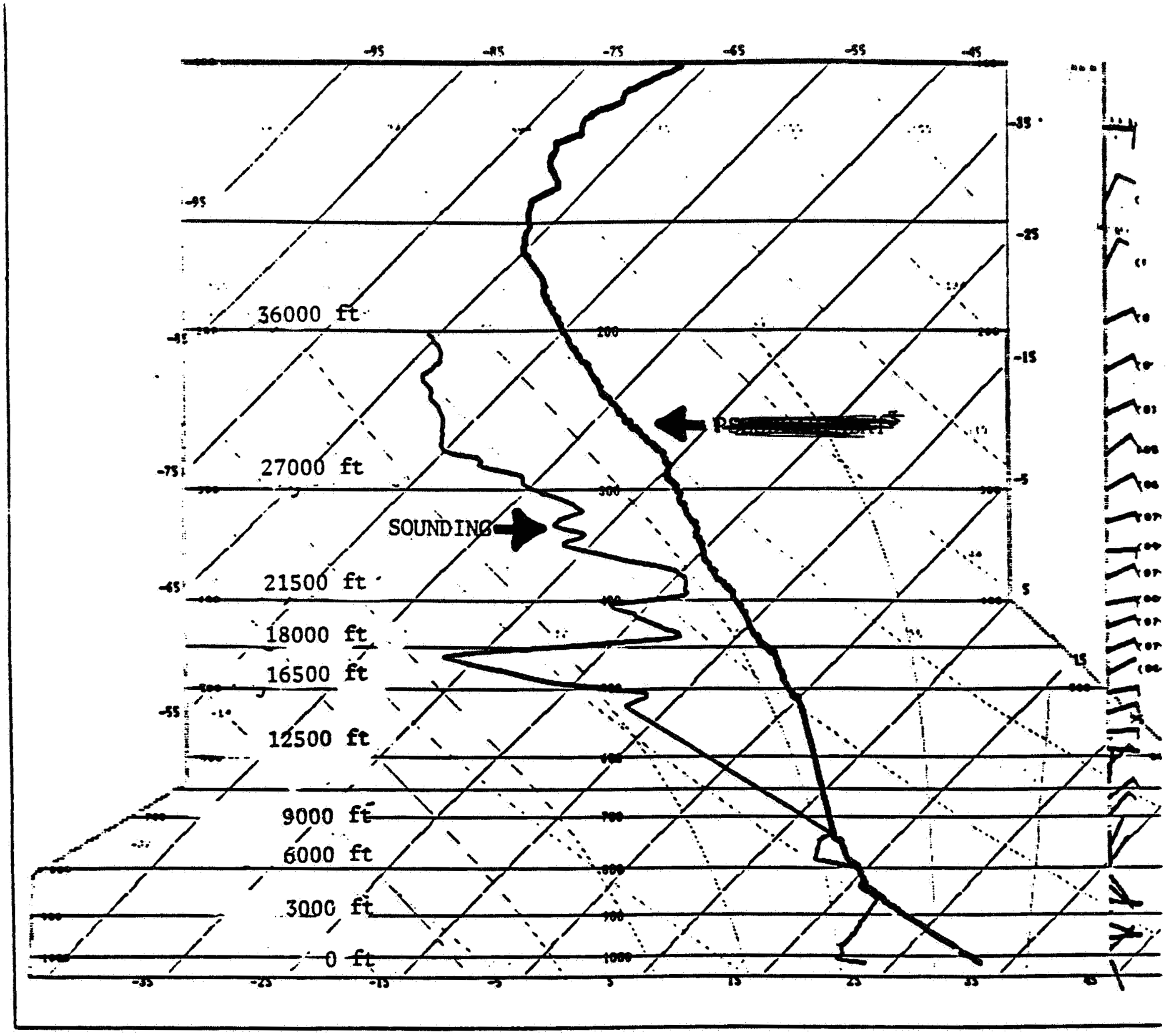
Background and Introduction

The hazard to aircraft resulting from an unexpected encounter with low-level windshear is well established. In studies using flight simulators, it was proven that the amount of warning time provided to the flight crew was the most significant factor in ensuring a successful recovery from a microburst encounter.[1] The AWAS-III, which is the third generation system and is in the process of FAA certification, provides advance warning by sensing the temperature signature of a microburst ahead of the aircraft. A number of studies have demonstrated that there is a reliable relationship relating the severity of the microburst hazard to the change in temperature between the ambient air and the microburst.[2] The AWAS senses this change in temperature and through the use of a proprietary algorithm, constructs a hazard index.[4]

When this index exceeds a pre-determined level, an alert is provided to the flight crew through an aural warning and the illumination of a red warning lamp in the cockpit.

The following describes the performance of the AWAS during the approach to and the penetration of a severe microburst in Orlando, Florida. To judge this performance, the data recorded by the AWAS is compared to that recorded by the in-situ aircraft sensors and by the ground based TDWR.

Significant advance warning (10 seconds or more) prior to a microburst encounter has not been available until now. The Turbulence Prediction Systems (TPS) Advance Warning Airborne System (AWAS), a passive infrared spectrometer, provided the first ever verified advance warning (more than 35 seconds) of a severe windshear event. This historic event occurred on July 7th, 1990.

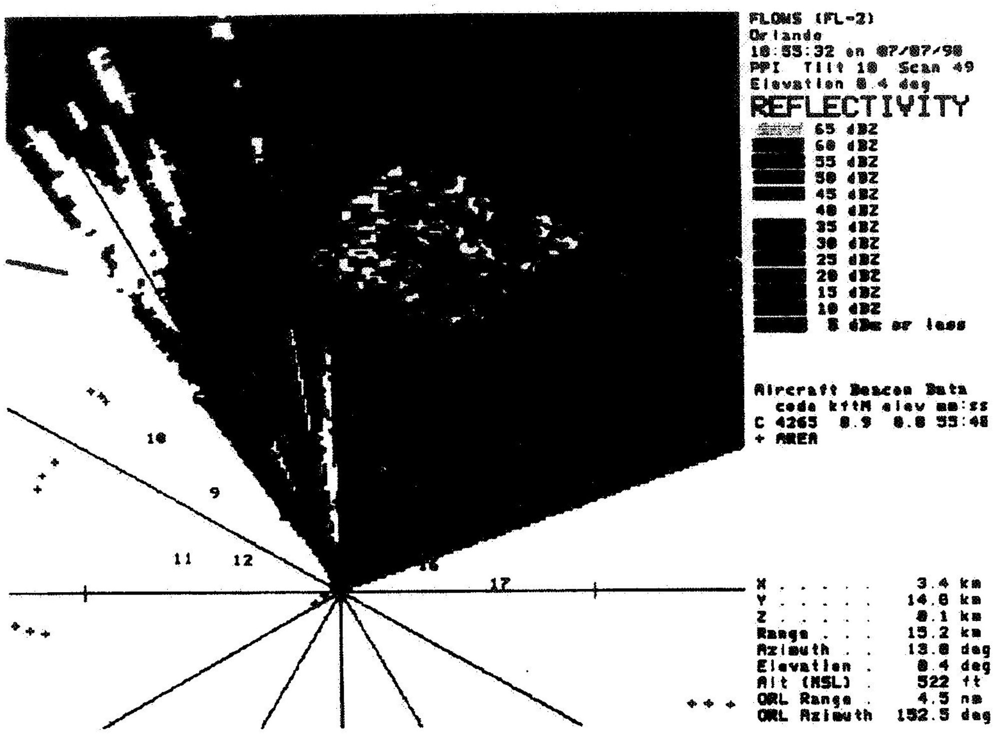


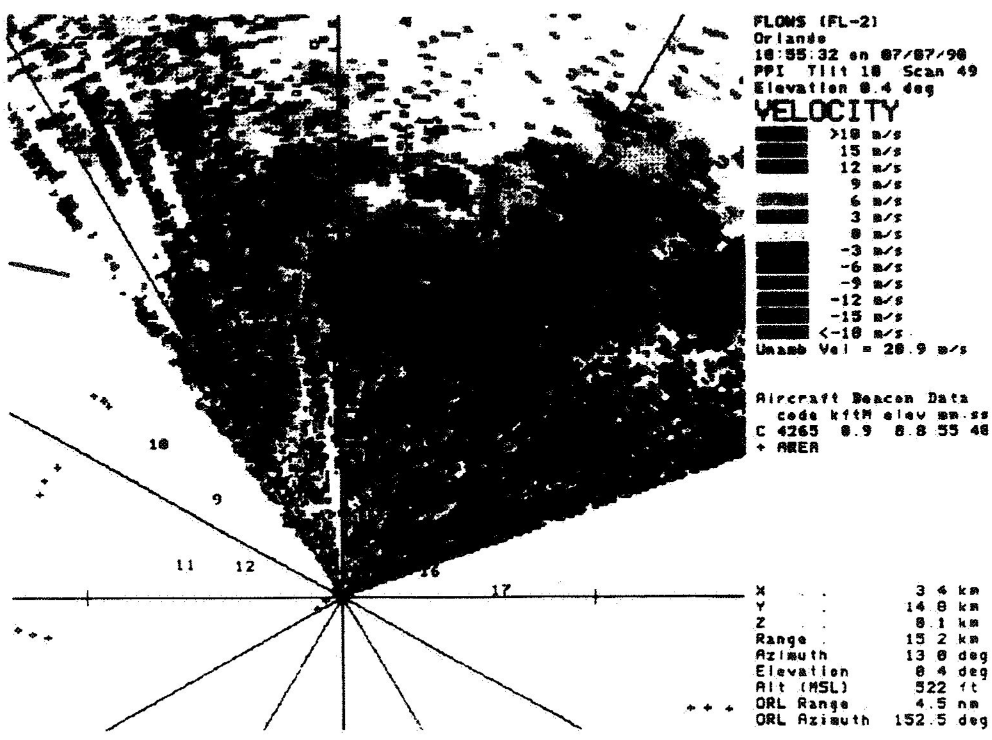
RAWINDSONDE Data - Figure 1

Massachusetts Institute of Technology Lincoln Laboratory (MIT) conducted a RAWINDSONDE (sounding) of the air over Orlando at 16:50 GMT, approximately two hours before the microburst developed. This sounding revealed a very wet layer of air from 18,000 to 23,000 feet. Just below this wet air was a layer of dry air extending down from 18,000 feet to the 9,000 foot level. Another dry layer also existed below the 6,000 foot level. This type of configuration in the upper atmosphere, i.e., a wet layer with underlying dry layers is believed to constitute the conditions which favor the formation of wet microbursts.[3]

FRED REMER
UND FLIGHT SCIENTIST NOTES

14:31:30	Engine start. A cell is developing just to the northeast of the airport. There are towering cumulus all quadrants. Plan is to get up early and hope a cell drifts over the airport. Planning on successive ILS 17 approaches. The 1753 Z ATIS is 4,500 SCT, 25,000 bkn, visibility 12 miles, temperature 95, dew point 71, wind 110 @ 4 kts, altimeter 30.03". Crew: Kent Streibel, Frederickson, Remer, Copp.
14:43:55	Airborne. Climbing out to the south. ATC is taking us high (6000 ft.).
14:50:10	Downwind for ILS 17. The storm is situated over the approach end of Runway 17. It is 60 dbZ. Lots of anvil. Lots of precipitation.
14:51:07	The storm is starting to produce a microburst at the surface. It is just off our left wing. We are trying to keep the approach short so we can penetrate.
14:52:09	FL-2 observes a 25 knot divergence over the approach end of Runway 17. We are on final and heavy precipitation is obscuring the view of the airport.
14:57:29	Climbing out after penetration. Strong downdraft in precipitation and increasing tailwind as we exited the precipitation. Excellent study. Down air was 15 m/s.





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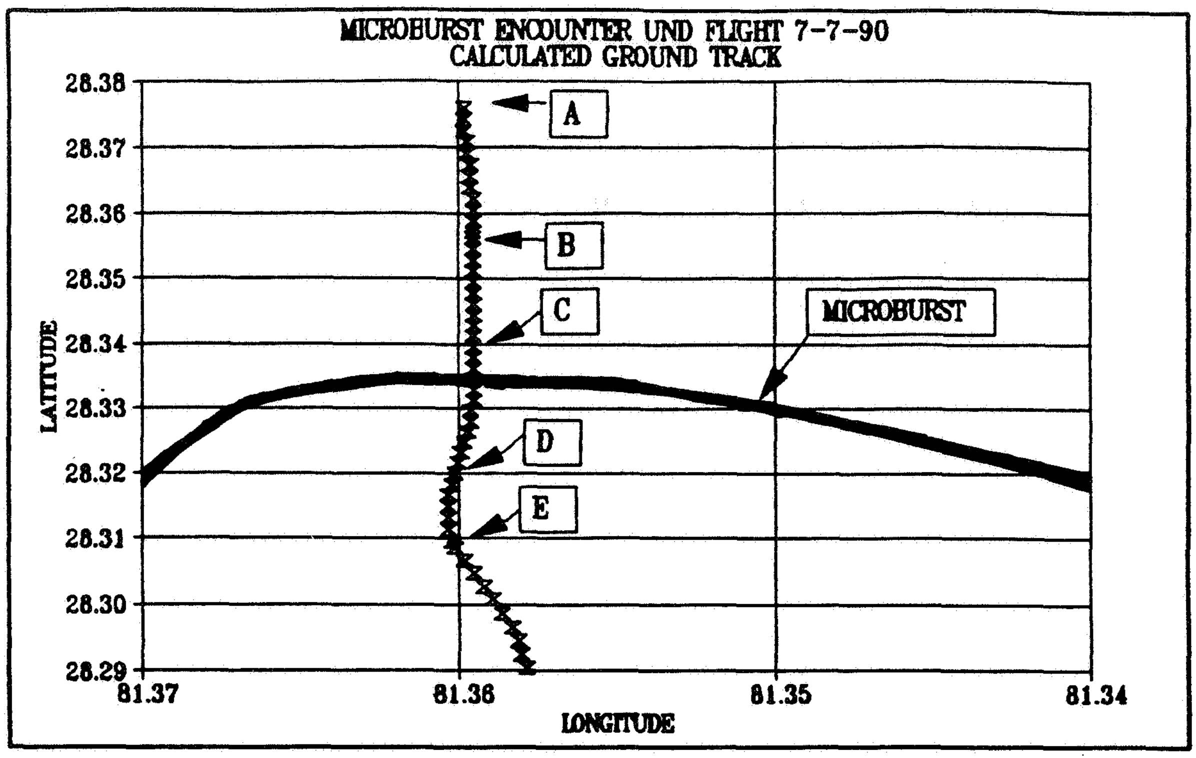
TDWR Data - Figure 2
(pictured on previous page)

The TDWR scans provided by MIT clearly show a well developed microburst just north of the airport with a measured wind divergence of 23 m/s or about 50 kts. over a distance of approximately 3 miles. The peak TDWR windshear index calculated by Bowles/Hinton was 0.15.[5] The peak horizontal windshear occurred near the center of the microburst at about 1.5 kts/sec. with a peak downdraft of 1000 feet per minute. The beacon from the aircraft (indicated by the letter "C" in the scan) shows that the sequences and related aircraft altitudes were in agreement for both the TDWR and the aircraft sensors. The reflectivity scan represents the rain rate per hour. A 60 dBz reading is greater than 9.98 inches per hour. The velocity scan represents the horizontal winds. The minuses represent winds blowing toward the TDWR while the positive readings represent winds blowing away from the TDWR. The horizontal windshear occurs between the positive and negative readings. A reading of -12 m/s indicates a horizontal wind of approximately 24 knots.



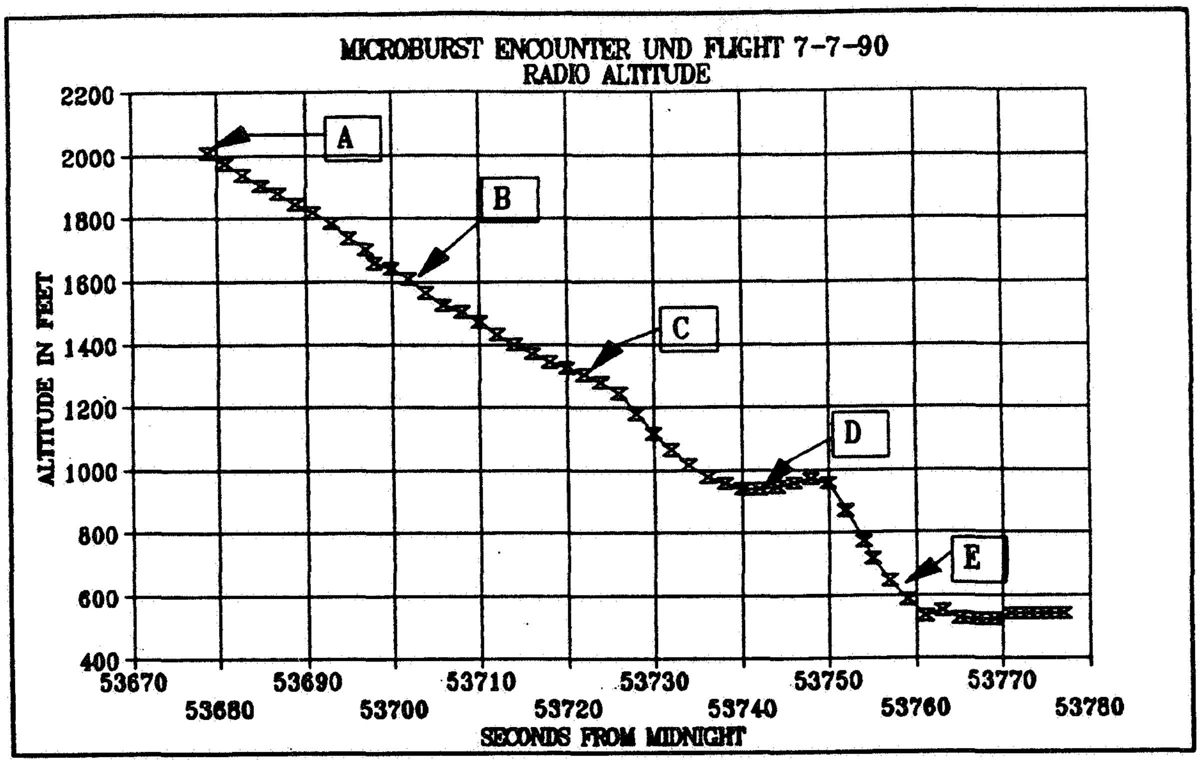
Ground Track - Figure 3

The Cessna Citation II was stabilized on an approach path toward the developing microburst in time to allow the AWAS to view the microburst for 90 seconds prior to penetration. When the aircraft was 90 seconds from penetration, the microburst (which was almost 3 miles in diameter) occupied approximately 40 degrees of the field of view. Since the AWAS has a field of view of only two degrees, the AWAS sensed the event throughout the entire approach.

The five letters, A through E, depicted in all of the graphs represent the following:

	LOCAL	GMT	SECONDS
A: Start of Stabilized Flight	14:54:29	18:54:29	53669
B: First AWAS Peak	14:55:02	18:55:02	53702
C: First AWAS Alert	14:55:22	18:55:22	53722
D: Second AWAS Alert Condition	14:55:42	18:55:42	53742
E: Peak Inertial Hazard	14:55:57	18:55:57	53757

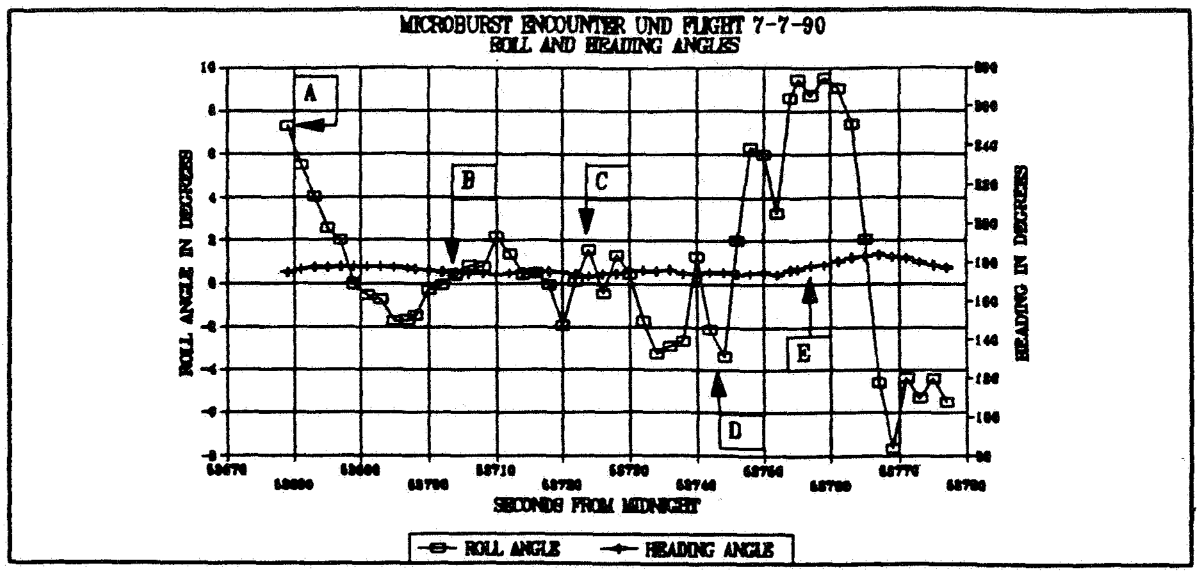
Flight scientist notes indicate that at 14:50:10 (53410 sec) the TDWR is indicating that the storm detected near Runway 17 has a reflectivity of 60 dbZ. This corresponds to a rain rate of greater than 9.98 inches per hour. ATC reports at 14:54:24 (53664 sec) a divergence of 40 knots.

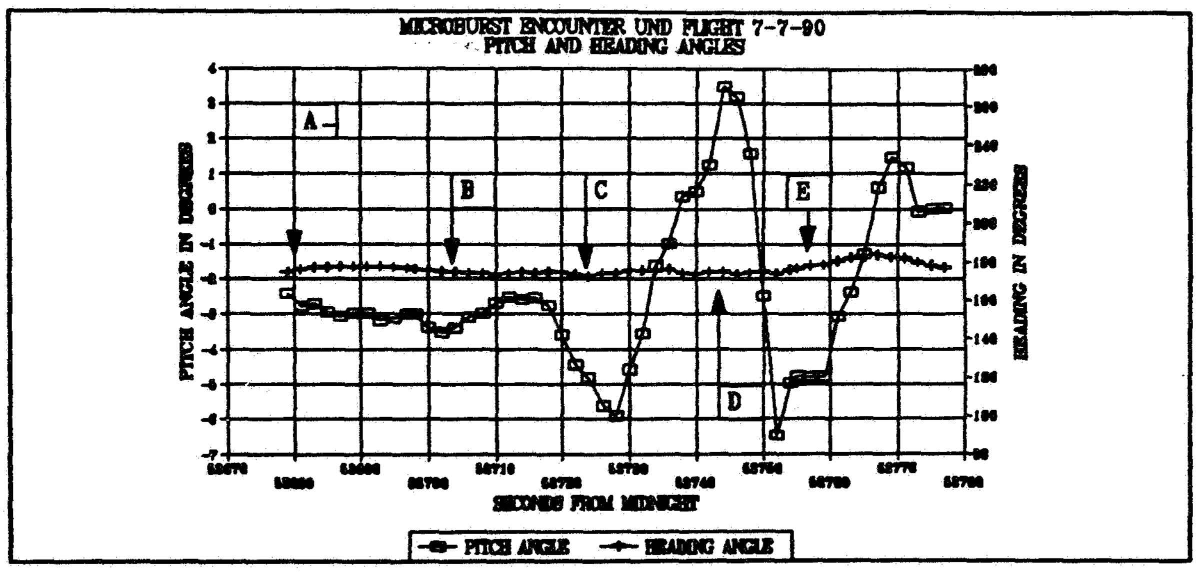


Altitude Profile - Figure 4

While approaching the microburst, the aircraft maintained a 3.5 degree glide slope. The aircraft (just before point 'D') leveled off while penetrating the microburst. Later it continued its glide path until it leveled off at approximately 500 feet.

The microburst maximum shear occurred at point 'E', where the combination of the horizontal and vertical winds combined @ ~650' AGL. The pilot countered the threat with increased throttle and continued through the event.



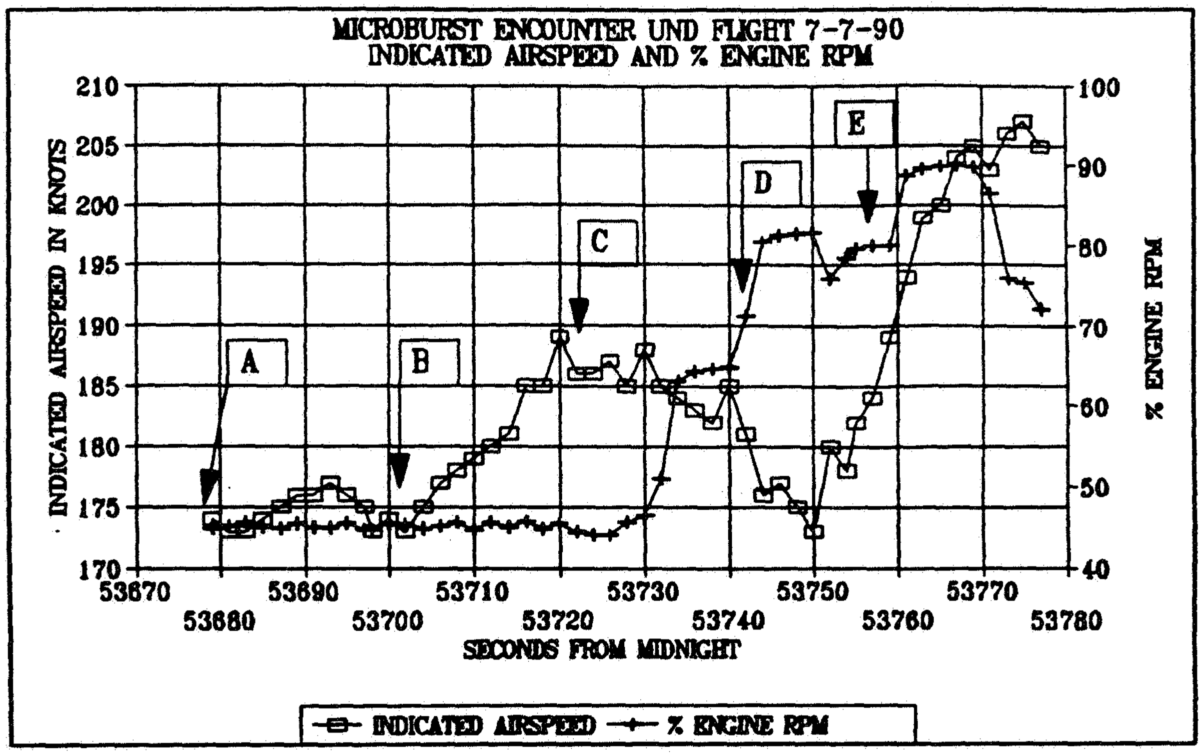


Roll, Pitch, and Heading Profiles - Figure 5 and 6

A constant heading is important for a predictive system because it is necessary to be observing the atmosphere in the expected flight path. The heading, as indicated in Figure 5, was constant throughout the approach to and the penetration of the microburst encounter.

The roll profile had a maximum deviation of 10 degrees during the encounter with the microburst. Roll angles varied from +2 to -4 degrees prior to penetration. During maximum shear, the greatest roll moment occurred (+10 to -5).

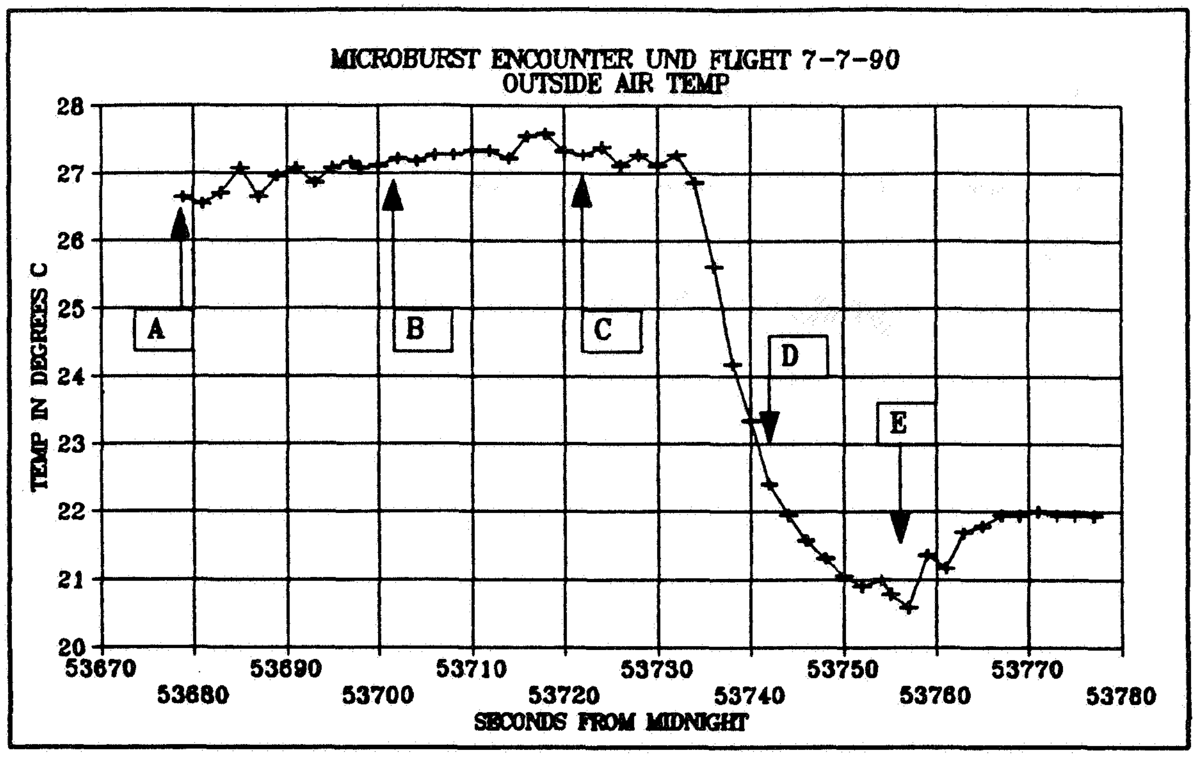
The increasing changes in pitch as the aircraft approached the microburst is indicative of the increasing turbulence encountered. The greatest changes (-6 to +4) occurred on penetration of the microburst.



Airspeed and Thrust Profile - Figure 7

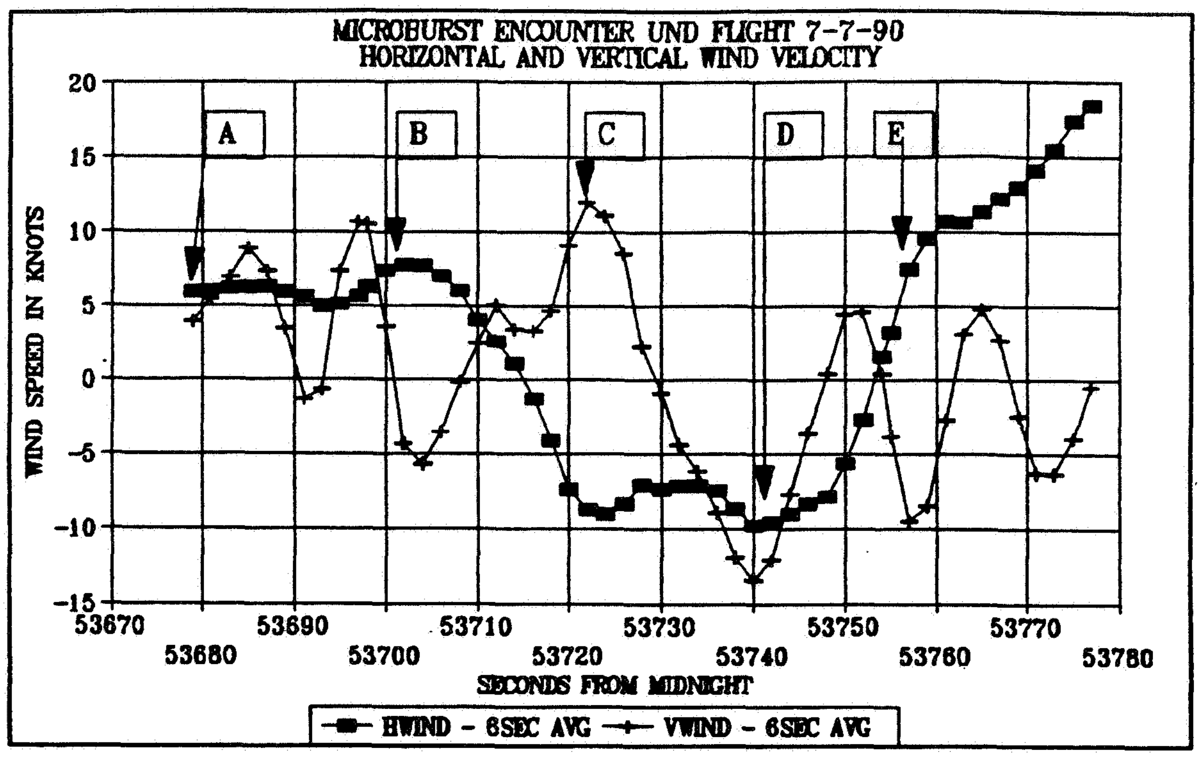
In preparation for penetrating the microburst, the pilot increased airspeed by 10 knots going from 175 to 185 knots. The pilot then leveled out the descent angle and increased the engine RPM by 20%, going from 45 to 65%.

During initial penetration (prior to point 'D'), the aircraft recorded a substantial reduction in performance. Even though the pilot increased engine thrust, the airspeed decreased by 10 knots. A significantly greater decrease in performance could be expected in an aircraft with less power capacity, i.e., a lower thrust to weight ratio.



Outside Air Temp Profile - Figure 8

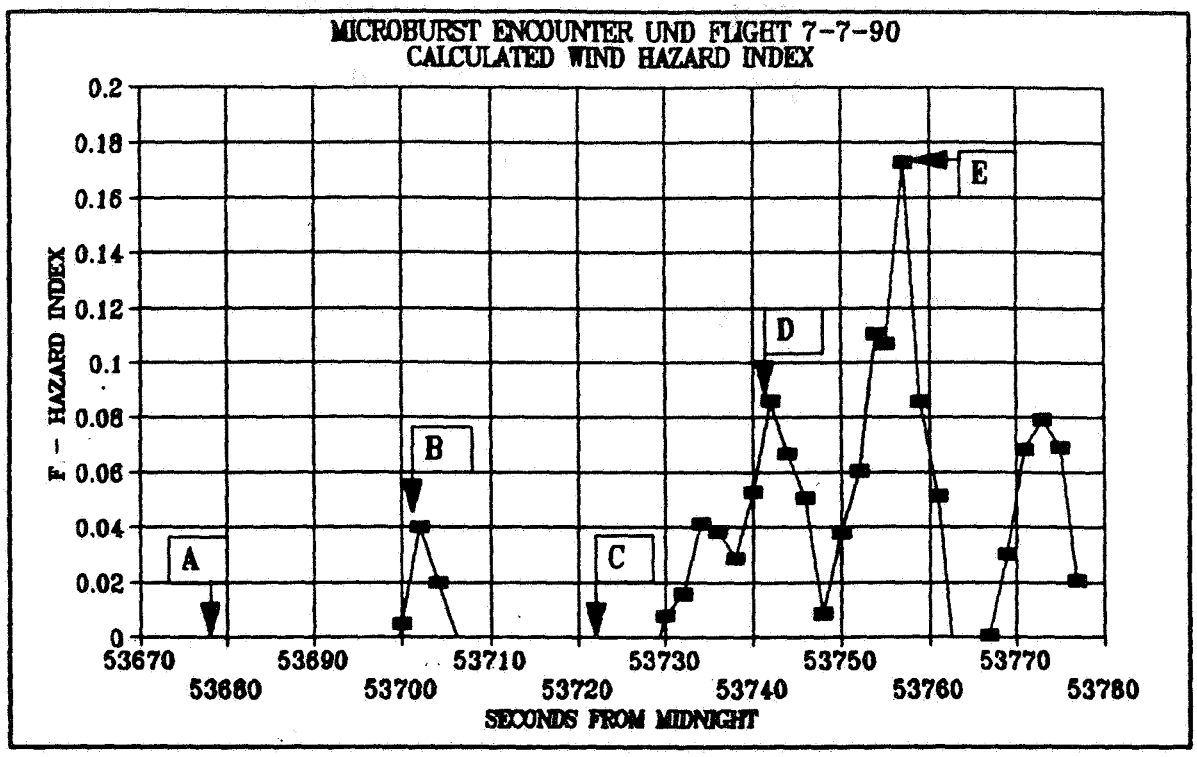
The outside air temperature profile obtained from the standard Citation instrument indicates a 6^0 C temperature decrease existing between the edge of the microburst and the maximum shear. This is the temperature change that is remotely sensed by the infrared system.



Horizontal and Vertical Wind Profile - Figure 9

These winds were calculated from the on-board INS sensor as the Cessna approached and passed through the microburst. While some degradation of the wind data was probably introduced by the turbulent flight, the major wind features of a typical microburst were recorded. The horizontal winds first shift from a slight tail wind to a performance increasing head wind as the microburst is approached. This occurs several seconds before point 'C'. This performance increasing head wind shifts rapidly to a tail wind near the axis of the microburst at point 'E'. The vertical winds indicate a major down draft beginning at 'C' and continuing throughout most of the event.

It should be noted that the maximum shear occurs with the combination of the horizontal wind and the second vertical downdraft at point 'E'. It is this combination of a changing horizontal wind (decreasing performance) and a downdraft that maximize the hazard to the aircraft.



Hazard index F (threat) - Figure 10

The hazard index (F) represents the threat to the aircraft. F multiplied by the acceleration due to gravity (g) represents the thrust in kts/second necessary to maintain level flight.

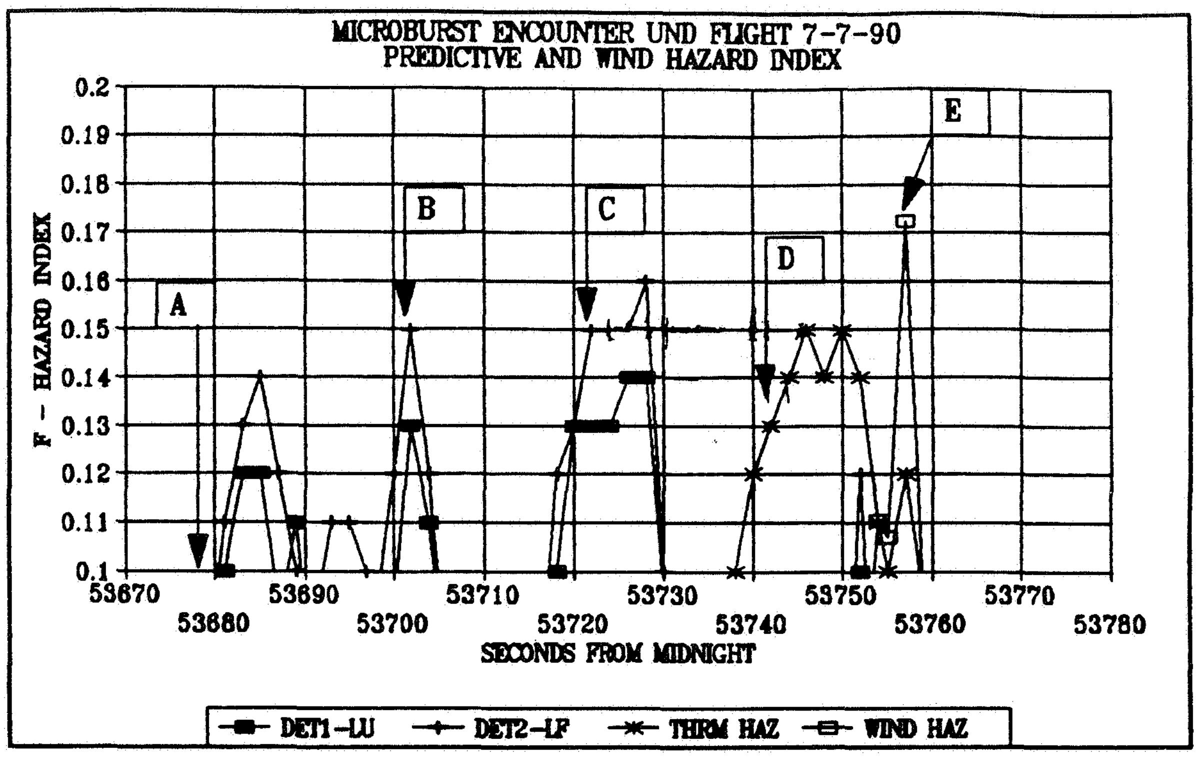
In this flight, the wind hazard index was calculated from the INS winds. The one hertz data from the UND aircraft was used for high fidelity information. The winds are averaged over a 6 second period in order to reduce the effects of atmospheric transients which may be turbulent but not sustained. The 6 second running average is used to compute the wind hazard index by the following equation[6]:

$$F = (dWH/dt)/g - VW/AS$$

where dWH/dt is the change per unit time in flight path wind velocity. The units are kts/sec:

g is acceleration due to gravity in kts/sec (19.04 kts/s)
VW is the vertical wind velocity in kts
AS is the air speed of the plane in kts

In the instance where F = 0.17, the thrust required to negate the threat is 3.24 kts/s (0.17 x 19.04). This is within the performance capabilities of the Cessna Citation II.



AWAS Performance vs In-Situ - Figure 11

The actual performance of the AWAS, in respect to accurately predicting the hazard to the aircraft, is provided in Figure 11. The only in-situ reference is at point 'E' indicating a hazard of 0.17.

The AWAS first sensed a hazard of 0.15 at point 'B'. Because this predicted threat was calculated above the altitude limit of 1500 feet, the alarm was not sounded. This did represent however, a potential predictive warning of 55 seconds.

The first AWAS infrared (IR) based predictive alert was recorded at point 'C'. Both aural and visual alerts were enabled at 1302 feet. This represented a predictive warning of 35 seconds.

At point 'D', the AWAS provided an alert based on outside air temperature (OAT). The use of this sensor provided a hazard of 0.13 and a 15 second warning.

The preset hazard thresholds in the AWAS are 0.15 for the IR and 0.13 for the OAT. The alerts were active at points 'B' and 'D' but because the present software inhibits aural and visual warnings at or above 1500' AGL, the alarms were inhibited at point 'B'.

AIRCRAFT VIDEO OF MICROBURST ENCOUNTER

A forward looking video camera mounted in the UND aircraft affords a pilot's eye view of the approach to the event. This video, along with flight scientist notes, is used as a confirmation tool- i.e. to identify pilot reactions, onset of rain, etc.

Conclusions:

TDWR F Index[5] = 0.15

In Situ F Index = 0.17

AWAS F Index = 0.15 55 seconds advance warning
0.16 35 seconds advance warning
0.~~15~~ 15 seconds advance warning
0.13

FAA Certification

FAA certification is in process. The application was filed in January 1990 and completion is expected in early 1991.

An FAA STC for AWAS-III installation on the UND Cessna Citation II was issued on 05/17/90. Research flights of the UND Citation since 05/17/90 will be used for Proof of Intended Function. Most recently the Citation has flown in the Orlando TDWR study (5/90 through 9/90) and in a Denver area dry microburst study (9/90). Numerous hazardous conditions occurred during these flights. The relevant flight and TDWR data is currently being analyzed by TPS, NASA Langley and UND Aerospace Sciences personnel.

An FAA STC for AWAS-III installation on American Airlines MD-80 (specifically DC-9-82 & 83) was issued 09/27/90.
The first of three AWAS-III installations was completed 09/27/90. Preliminary flight test data has been collected with actual commercial flight data expected soon. Data will be collected over 1000 flights to assist in operational aspects of certification.

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3 - Caracena, F. and Maier, M.W., 1987: "Analysis of a Microburst in the FACE Meteorological Mesonetwork in Southern Florida", American Meteorological Society.

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5 - Bowles, R. L. and Hinton, D. A., 1990: "Windshear Detection: Airborne System Perspective", Presented at WINDSHEAR-One Day Conference, London, England, 11/90.

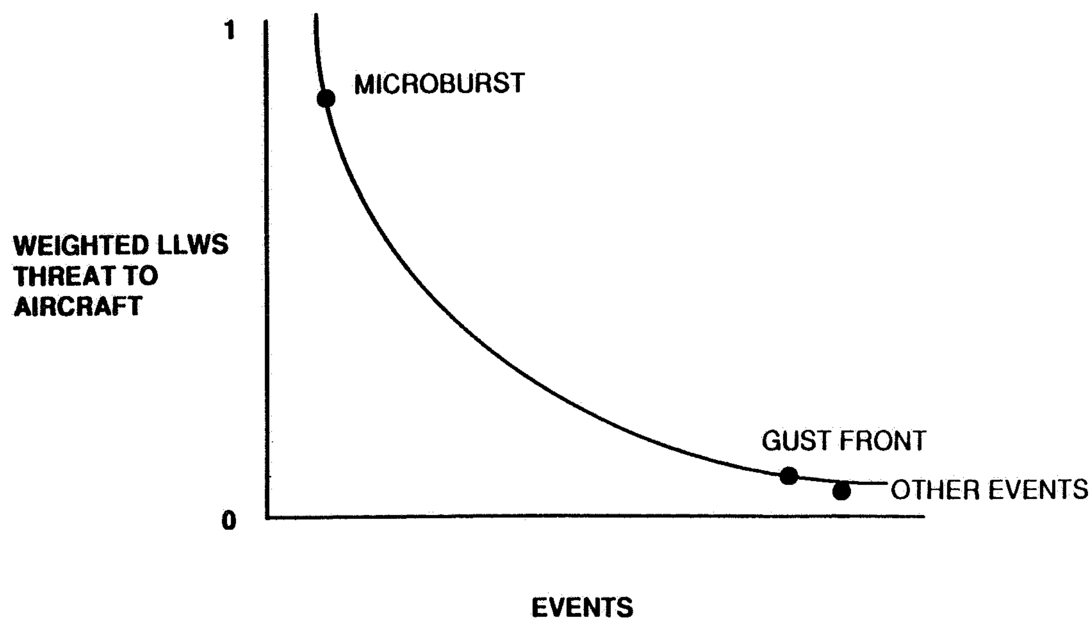
6 - Bowles, R. L. and Hinton, D. A., 1990. Same as Above.

FUTURE ISSUES FOR PREDICTIVE LLWS SYSTEMS

- Define LLWS threat by type
- Define system requirements
- Define certification methodology
- SAE S-7 to instigate TSO effort

DEFINE LLWS THREAT BY TYPE

(Revise AC 0050)



DEFINE SYSTEM REQUIREMENTS

- Min/Max warning time
- Approach corridor rain rate $\leq$ 40 dbz
- Wet and dry microburst detection
- Probability of detection
- Nuisance alert criteria

DEFINE CERTIFICATION METHODOLOGY

- Success criteria plan (ref AC25-12)
    - analysis
    - modelling data
    - flight data
    - combination of above
- Supporting documentation

Status of Turbulence Prediction System's AWAS III
Questions and Answers

Q: MARILYN WOLFSON (MIT Lincoln Laboratory) - Can your sensor be used to detect clear air turbulence? If so, do you have any data that shows its effectiveness?

A: PAT ADAMSON (Turbulence Prediction Systems) - Yes. We'll be doing clear air turbulence tests in the American Airlines program. I forgot to mention it in the talk. We expect to get six minutes warning at high altitude in clear air turbulence.

Q: MIKE GALE (American Airlines) - Based on the positive reaction by the "scientific community" to the 35+ second predictive warning of the AWAS III in relatively heavy rainfall on 7/7/90, has the question regarding IR penetration distance been laid to rest?

A: PAT ADAMSON (Turbulence Prediction Systems) - I don't know if it has been laid to rest. From my perspective we certainly look through some of the rain. We're still trying to analyze how far through the rain we looked. One of the things we hope to get out of the UND sensor is the rain rate from the aircraft. So we'll get some numbers from that work.

ROLAND BOWLES (NASA Langley) - I'll answer the same question that was addressed to Pat because I think it was addressed to both of us. Data is data. If Pat has no problem, anybody that wants it can take it home with them. My conclusion is I saw the performance increase on the back side of the microburst right in the rain core. From best estimates anywhere from 5 to 6 inches per hour, maybe as high as 7 inches per hour of rain, that's pretty wet . Objectively it looked like it saw through it. So, I'll share that data with anybody.

UNKNOWN - Would you share it with the Long Beach Aircraft Certification Office?

ROLAND BOWLES (NASA Langley) - Any time they are ready.

HERB SCHLICKENMAIER (FAA) - We're in the throws of putting together a briefing for Long Beach of not only this meeting but some of the technical topics that they might want to review with us as well. Guice Tinsley is also interested in coming down here with his team, as soon as funds are available to travel, to get a review of what this meeting did and what happened.