USAir 1016 SUBMISSION
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I. EXECUTIVE SUMMARY

USAir Flight 1016 crashed in Charlotte due to a failure to detect the hazard. The personnel, the equipment and the procedures; each failed in some measure. The safety net designed to prevent the windshear accident, and predicated upon layers of redundancy, was compromised. It was not a single event, or even two, which caused this accident. Rather, this accident was the tangible manifestation of a series of failures and deficiencies. And it was predictable.

At approximately 18:42 local time (22:42 UTC) on July 2, 1994, a DC-9-31 operating as USAir flight 1016 crashed while executing a go-around from the ILS approach to 18R at Charlotte-Douglas Airport (CLT) in Charlotte, North Carolina. At the time of the accident, the aircraft was embedded in an extremely heavy localized rainshower.

Twenty two seconds after the initiation of the go-around, the aircraft touched down hard in a field, which immediately failed the main landing gear. The aircraft slid across the field for 300 feet, and was then destroyed as it traveled through about 500 to 600 feet of wooded area. The cockpit came to rest on a road, while the tail section continued further until impacting a private residence. Thirty seven of the fifty seven persons on board (five crew, 50 adults, two lap children) received fatal injuries. All crewmembers survived.

The investigation of this accident revealed that the aircraft encountered a severe microburst close to the runway threshold, and was unable to escape the resultant windshear. The misleading and incomplete weather information which was relayed to the aircraft seriously biased the flight crew's decision-making process, and encouraged them to proceed unknowingly into a grossly deteriorating situation.

Like all accidents, this accident was the culmination of a series of events and circumstances. An examination of the whys and hows of this accident chain reveals a series of deficiencies, irregularities, and oversights within the National Airspace System. Many of these items are directly attributable to the known weak link, the human element.

After at least twenty years of known windshear accidents, the existing system is still incapable of providing adequate microburst protection. Industry must embrace a fresh approach in order to resolve this situation. For this reason, the solution to prevent other windshear accidents will not be easily attained.

II. FACTUAL INFORMATION and ANALYSIS

LESSONS LEARNED?

Through the investigation of a number of windshear accidents spanning a period of at least twenty years, many National Airspace System deficiencies have been identified. To its credit, following each accident, the NTSB has made numerous comprehensive recommendations aimed at preventing a recurrence. Despite these facts, the existing System is still incapable of providing adequate microburst protection. Unfortunately, industry has not embraced these recommendations either swiftly enough or comprehensively enough. The crash of USAir Flight 1016 irrefutably demonstrates this situation.

The reader is urged to consider the following previously-issued NTSB statements and recommendations while reading this report of the circumstances and events which led to the crash of USAir Flight 1016. In fact, a reexamination of these recommendations upon completion of this report will undoubtedly convince the reader of a major contention of both the NTSB and ALPA: In the arena of windshear accident prevention, progress has been alarmingly slow.

Eastern 66, June 24,1975 (NTSB-AAR-76-8)

Regarding the flight crews' assessment of the conditions on the approach, this accident: "discloses the hazards of a reliance on the success of pilots of preceding flights when dynamic and severe weather conditions exist."

Regarding flight crews' knowledge of the weather conditions, and relay of that information to the aircraft by ground personnel: "workloads... and ...frequency congestion can lead to omissions and assumptions, and confusion about who is aware of what."

Regarding the failure of ATC personnel to relay critical weather information to the aircraft: "The Safety Board...believes that no useful purpose would be served by dwelling critically on individual actions or judgments within the system...A better means of providing pilots with more timely weather information must be designed."

On a similar subject: "...little progress has been made in...the dissemination of radar-detected severe weather information to the air traffic control system"

Recommendation #6: "Develop and institute procedures whereby approach controllers, tower controllers and pilots are provided timely information regarding the existence of thunderstorm activity near...approach flightpaths."

Allegheny 121, June 23,1976 (NTSB-AAR-78-2)

Regarding the provision of real time, definitive precipitation information, the system should "include a multiple intensity classification scheme." Relay guidance stated: "Transmit this information to pilots either via controller as a safety advisory or via an electronic data link." (NTSB Recommendation A-77-63)

Regarding classification and notification of weather activity based on the NWS' six-level scale: "promote its widespread use as a common language" and "indoctrinate pilots and air traffic control personnel in the use of this system". (A-77-64)

Member P. A. Hogue wrote a dissenting probable cause which stated: "...the probable cause of the accident was severe wind shear... Contributing was the controller's failure to provide all available weather information in a timely manner."

Eastern 693 Incident, August 22,1979 (NTSB-AAR-80-6)

The NTSB conclusion: "...the probable cause of this incident was the unavailability to the flightcrew of timely information concerning a rapidly changing weather environment along the...final approach course."

Pan Am 759, July 9, 1982 (NTSB-AAR-83-02)

Recommendations included:

"Review all Low Level Wind Shear Alert System to identify possible deficiencies...and correct such deficiencies without delay." (A-83-13)

"Expedite the developing, testing and installation of advanced Doppler Weather Radar to detect hazardous wind shears...and expedite the installation of more immediately available equipment such as add-on Doppler to provide for detection and quantification of wind shear in high risk airport terminal areas." (A-83-23)

USAir 183, June 13, 1984 (NTSB-AAR-85-01)

Findings included:

"19. The air traffic controllers did not note the...special weather observation which contained important weather information about thunderstorm activity."

"20. The local controller failed to provide runway visual range information after the prevailing visibility dropped to 1 mile."

The Probable Cause statement included: "... the airplane encountered severe wind shear. The failure of air traffic control personnel at the airport to provide additional available weather information deprived the flightcrew of information which may have enhanced their decisionmaking process."

Delta 191, August 2, 1985 (NTSB-AAR-86-05)

After at least ten years of windshear accidents and multiple recommendations aimed at preventing them, Delta Flight 191 was lost to a windshear accident. In its report, the NTSB reviewed and reemphasized many of these recommendations. Nine years later, industry has not made significant progress, and many of the previously noted deficiencies still exist today.

These examples and quotes clearly illustrate that for twenty years, industry has unsuccessfully attempted to modify the existing hardware and procedures in order to relegate windshear accidents to the past. History has proven that flight crews cannot rely on ground based personnel for the timely relay of critical weather information. The role of these ground-based personnel in this information interpretation and transfer process must be reduced significantly or eliminated altogether.

The time has come to initiate a fundamental change in the approach to solving this problem. The solution is to provide flight crews with direct access to real time weather information.

SUMMARY of EVENTS

This accident occurred on the fourth leg of the first day of a three day trip. The day originated in Pittsburgh (PIT), and was planned to consist of the following routing: PIT-LaGuardia (LGA) - Charlotte (CLT) - Columbia, South Carolina (CAE) - CLT - Memphis (MEM).

The crew had departed CLT at approximately 2050 Universal Coordinated Time (all times herein are UTC unless otherwise noted) and arrived without incident in CAE at approximately 2130. The flight departed CAE on schedule at 2210 as US1016 for the return leg to CLT, and it was during this approach into CLT that the accident occurred. Figure 1 presents an overview of the approach events.

USAir Flight 1016 was a Douglas DC-9-31 equipped with JT8D-7 engines and registered as N954VJ. The flight release indicated a takeoff weight of 86325 lbs, including 9000 lbs for passengers, 1575 lbs of cargo and 14000 lbs of fuel. The planned trip fuel burn was 4100 lbs. This resulted in an estimated landing weight of 82225 lbs at a CG of approximately 25.3% MAC.

The First Officer (F/O) was the pilot flying (PF) the CAE-CLT leg. The cruise segment of this flight was planned for and flown at 12000' (all altitudes MSL unless noted), with a planned total time enroute of 23 minutes. The enroute forecast was the same as it had been for the flight from CLT to CAE; no significant weather, with the exception of some scattered thunderstorms. Approximately 30 miles from CLT, at 2223, the Captain obtained CLT ATIS information 'Yankee', which was in part as follows:

> " Five thousand scattered. Visibility six miles haze. Temperature eight eight, dew point six seven. Altimeter three zero zero one. ILS approaches 18L, 18R.....in use..."

There was convective activity in the area, but as the flight was vectored onto a downwind for 18R, the airport visually appeared clear to the crew, with a cell located approximately one mile south of the field. The flight was told to expect a visual approach, but at 2237 (about 5-1/2 minutes prior to the expected landing time) this was amended to the ILS.

At 2235, the Tower Supervisor remarked within the Tower cab that it was "raining like hell" on the south end of the airport. About the same time, the Final West controller noted a VIP Level 3 cell "pop-up" over or very close to the field on his ASR-9 radar scope. The Columbia (CAE) NEXRAD (WSR-88D) indicated a VIP Level 5 cell over the airport. By 2240, the tower visibility had decreased to one mile, a Special Observation noted thunderstorms and the visibility deterioration, and a new ATIS reflecting these conditions had been issued. RVR decreased rapidly, reaching a minimum of approximately 500 feet. Though required by the Air Traffic Controllers handbook (FAA Order 7110.65, Air Traffic Control), none of this pertinent information was relayed to USAir 1016.

CVR and ATC transcripts revealed that the crew was aware of the potential for windshear. However, the limited information received by the crew indicated benign conditions. The onboard radar did not indicate any significant precipitation between the aircraft and the airport. The crew solicited Pireps and received "smooth ride" reports from the two preceding aircraft. Approximately 40 seconds prior to landing, the aircraft entered light rain. Shortly thereafter, rain intensity increased dramatically, and the Captain lost sight of the runway. Deteriorated cockpit visibility, the wet runway and the crosswind reports (100/19, 110/21) prompted the Captain to call for a go-around. At this point the aircraft was approximately 200' AGL and over the Middle Marker (MM).

The initial segment of the published missed approach for CLT 18R calls for a straight out climb. Since this route would take the aircraft under or into the convective cell they had observed south of the field, the crew had previously discussed a plan to deviate to the right should a missed approach become necessary. Although it had no bearing on the accident, the crew neglected to obtain prior approval from ATC for this potential deviation. The aircraft began a climbing turn to the right as the crew advanced the power and retracted the flaps to the 15 degree go-around setting.

Approximately 200 feet of altitude was gained before the airspeed and vertical acceleration started decreasing rapidly. The airspeed decay was on the order of 2-1/2 knots/second, while the vertical acceleration went from 1.2g to less than 0.5g in about 10 seconds. The crew attempted to maintain an appropriate airspeed, and the throttles were advanced to firewall power.

Twenty two seconds after the initiation of the go-around, the aircraft touched down hard in a field, which immediately failed the main landing gear. The aircraft slid across the field for 300 feet, and was then destroyed as it traveled through about 500 to 600 feet of wooded area. The cockpit came to rest on a road, while the tail section continued further until impacting a private residence. Thirty seven of the fifty seven persons on board (five crew, 50 adults, two lap children) received fatal injuries. The five crewmembers survived.

Analysis of the FDR and CVR revealed that the aircraft encountered a severe microburst and resultant windshear. Analysis indicates that, at the time the go-around was initiated, the aircraft was already 15 seconds into the microburst encounter. The shear consisted of a headwind to tailwind difference of 70 knots, with a peak gradient of approximately 10 knots/second. Only a few seconds before impact did the flight crew recognize that they were experiencing a windshear encounter. The northwest LLWAS sensor did not go into alarm, nor did the on-board Honeywell windshear detection system (reactive, with no guidance capability) produce an alert.

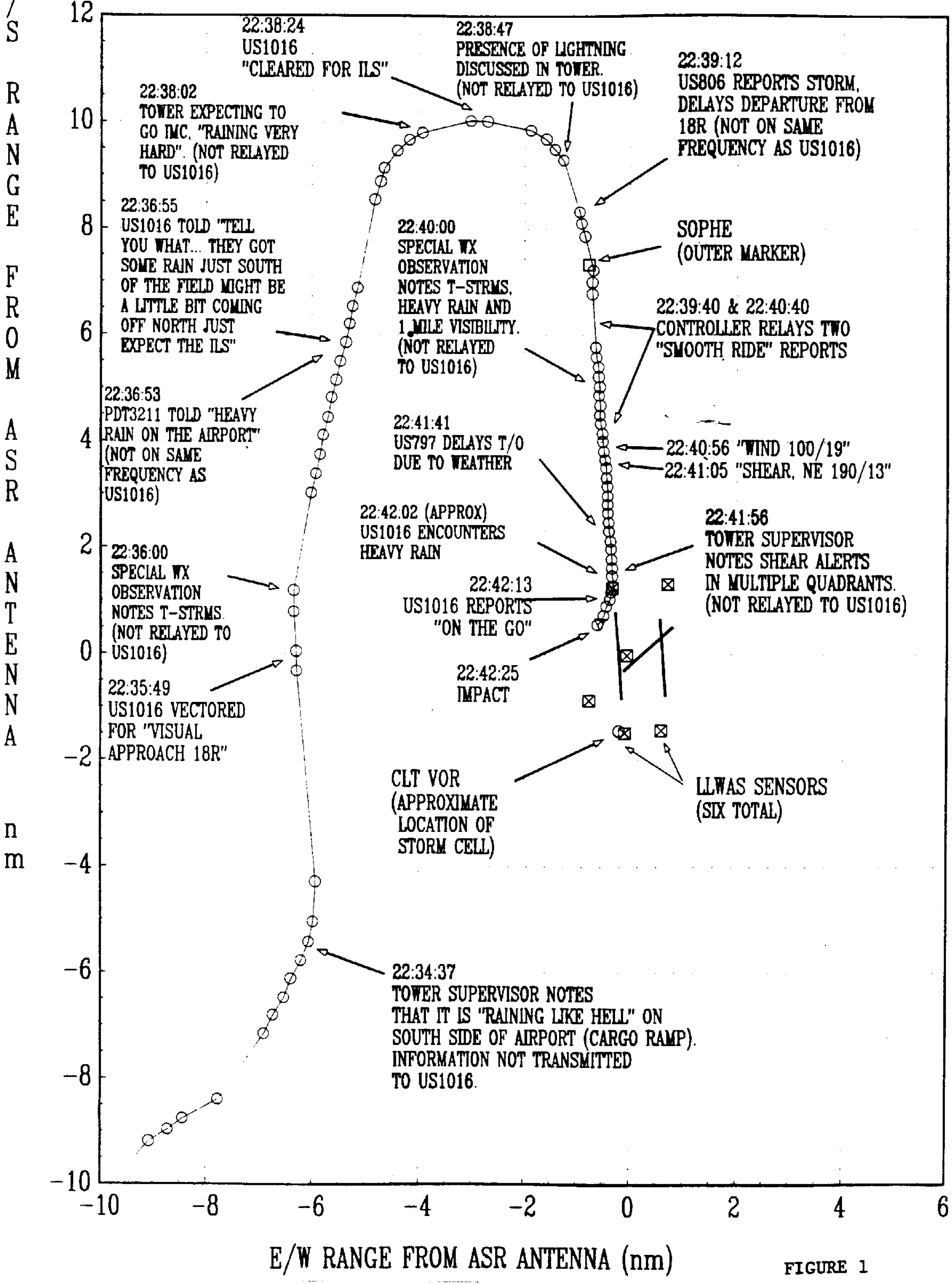
Based on the limited weather information presented to them and the absence of specific windshear warnings, the crew initiated a normal go-around, not a windshear escape maneuver. The misleading and incomplete weather information which was relayed to the aircraft seriously biased the flight crew's decision-making process, and thereby encouraged them to proceed unknowingly into a rapidly deteriorating situation.

Like all accidents, this accident was the culmination of a series of events and circumstances. An examination of the whys and hows of this accident chain reveals a series of deficiencies, irregularities, and oversights within the National Airspace System. Many of these items are directly attributable to the known weak link, the human element.

After at least twenty years of windshear accidents, the existing system is still incapable of providing adequate microburst protection. For this reason, the solution to prevent other windshear accidents will not be easily attained.

The following pages examine the various aspects of this accident on an individual basis. This examination will include roles of the personnel, the equipment and the procedures involved in the accident chain, and present recommended solutions which the Air Line Pilots Association believes will significantly reduce the likelihood of another windshear accident.

USAir 1016
RADAR GROUND TRACK



22:38:24
US1016
"CLEARED FOR ILS"

22:38:47
PRESENCE OF LIGHTNING
DISCUSSED IN TOWER.
(NOT RELAYED TO US1016)

22:39:12
US806 REPORTS STORM,
DELAYS DEPARTURE FROM
18R (NOT ON SAME
FREQUENCY AS US1016)

22:38:02
TOWER EXPECTING TO
GO IMC, "RAINING VERY
HARD". (NOT RELAYED
TO US1016)

22:36:55
US1016 TOLD "TELL
YOU WHAT... THEY GOT
SOME RAIN JUST SOUTH
OF THE FIELD MIGHT BE
A LITTLE BIT COMING
OFF NORTH JUST
EXPECT THE ILS"

22:40:00
SPECIAL WX
OBSERVATION
NOTES T-STRMS,
HEAVY RAIN AND
1 MILE VISIBILITY.
(NOT RELAYED
TO US1016)

SOPHE
(OUTER MARKER)

22:39:40 & 22:40:40
CONTROLLER RELAYS TWO
"SMOOTH RIDE" REPORTS

22:36:53
PDT3211 TOLD "HEAVY
RAIN ON THE AIRPORT"
(NOT ON SAME
FREQUENCY AS
US1016)

22:41:41
US797 DELAYS T/O
DUE TO WEATHER

22:40:56 "WIND 100/19"
22:41:05 "SHEAR, NE 190/13"

22:42:02 (APPROX)
US1016 ENCOUNTERS
HEAVY RAIN

22:41:56
TOWER SUPERVISOR
NOTES SHEAR ALERTS
IN MULTIPLE QUADRANTS.
(NOT RELAYED TO US1016)

22:36:00
SPECIAL WX
OBSERVATION
NOTES T-STRMS
(NOT RELAYED TO
US1016)

22:42:13
US1016 REPORTS
"ON THE GO"

22:42:25
IMPACT

22:35:49
US1016 VECTORED
FOR "VISUAL
APPROACH 18R"

CLT VOR
(APPROXIMATE
LOCATION OF
STORM CELL)

LLWAS SENSORS
(SIX TOTAL)

22:34:37
TOWER SUPERVISOR NOTES
THAT IT IS "RAINING LIKE HELL" ON
SOUTH SIDE OF AIRPORT (CARGO RAMP).
INFORMATION NOT TRANSMITTED
TO US1016.

FIGURE 1

WEATHER EQUIPMENT & INFORMATION

The following sections discuss the various equipment, systems and organizations which are used to detect, quantify and disseminate weather information. For the sake of clarity, these items are addressed separately. However, it must be recognized that these items are all individual elements whose function cannot only be considered independently; they must also be examined within the context of the overall weather information detection and dissemination scheme.

AUTOMATIC TERMINAL INFORMATION SERVICE

This section will show that:
1) Weather conditions were deteriorating rapidly at CLT.
2) The recorded nature of ATIS limits the timeliness of the information
3) ATC procedures have been prescribed to accommodate this limitation.
4) CLT ATC personnel did not adhere to these procedures.

At 2223, when US1016 was approximately thirty miles from CLT, the flight crew obtained CLT arrival ATIS information 'Yankee'. Information Yankee was current for 2151 and specified in part:

> "...5000 scattered, visibility 6 miles haze, temperature 88, dewpoint 67, wind 150/8, altimeter 30.01, ILS approaches runway 18L, 18R, localizer back course runway 23 approach in use..."

Seventeen minutes later, at 2240, ATIS 'Zulu' was initially broadcast. It was current for 2236 and was based on a Special weather observation. Information Zulu specified in part:

> "...measured ceiling 4500 broken, visibility 6 miles, thunderstorm, light rainshower, haze, temperature 88, dewpoint 67, wind 110/16..."

The crew of US1016 did not obtain ATIS Zulu, nor would they be expected to, since it was not broadcast until after they had checked in on the Arrival Radar West (ARW) frequency with information Yankee. At the time of the initial broadcast of Zulu, US1016 was just inside the outer marker SOPHE, in radio contact with Local Control West (LCW), and approximately 2 -1/2 minutes from touchdown.

Weather conditions at CLT were deteriorating rapidly, and by the time ATIS Zulu was broadcast, another Special weather observation was being recorded. By this time (2240), the tower visibility had decreased to less than one mile and "heavy" rain was falling on the field.

The recorded nature of ATIS inherently limits the timeliness of the data being broadcast. In rapidly changing weather, this 'lag' can result in a significant difference between the broadcast and actual conditions. For this reason the Controller's handbook (FAA Order 7110.65, Air Traffic Control) requires the following:

- Rapidly changing conditions will be issued by ATC, and the ATIS will contain the following: "Latest ceiling/visibility/altimeter/wind/(other conditions) will be issued by approach control/tower"
- Controllers shall broadcast on all appropriate frequencies to advise aircraft of a change in the ATIS code/message.
- Controllers shall ensure that pilots receive all operationally pertinent information.

The TRACON Flight Data Controller (FDC) is the individual responsible for the preparation of the arrival ATIS, and the TRACON supervisor is required to review and approve each ATIS message prior to broadcast. The TRACON and ATCT supervisors are responsible for ensuring that the positions in their respective charges are aware of and issuing changes in ATIS information.

ATIS equipment functioned as designed. However, ATC personnel did not adhere to the prescribed procedures, and not one of the noted requirements was accomplished for US1016.

The remedy for this particular aspect of the accident must be shouldered by ATC. ATC personnel must be strongly reminded of the role and limitations of ATIS, and the applicable procedures designed to accommodate these limitations. Adherence to the procedures is not discretionary conduct. In fact, there is perhaps no better way to emphasize this point than to use this accident as the example.

AIRPORT VISIBILITY AND RVR

This section will show that:

1) *CLT has two independent means to determine visibility conditions.*
2) *CLT visibility conditions deteriorated to well below the mandatory reporting levels just prior to the accident.*
3) *This information was available to and known by CLT ATC and Weather personnel.*
4) *Although required by ATC procedures, this information was not made available to US1016.*

Two independent methods are available to ATC and WEATHER personnel to determine visibility conditions at CLT. The first method involves the use of visibility charts, and is used to determine prevailing visibility and/or the visibility in a particular direction. The second method is through the use of Runway Visual Range (RVR) equipment, which provides a measure of the 'seeing-conditions' at various points along the runway.

Two visibility charts (one and five miles) are available for CLT. Each chart consists of a series of concentric circles overlaid on a planview of prominent local landmarks and features, and graduated in nautical miles. Certified ATC personnel (including the ATCT controllers on duty at the time of the accident) correlate their observations with the information on these charts to determine the visibility.

CLT is equipped with three RVR measuring devices referred to as transmissometers. These three transmissometers are formally identified as the 36L Rollout (RO), 05 Touchdown (TD) and 36L TD units. Positionally, they equate respectively to the TD, Midfield (MID) and RO zones of runway 18R. These instruments provide a measure of the conspicuity of the runway edge, touchdown zone and centerline lights. Although this conspicuity is directly related to the 'seeing-conditions' and values are reported in feet, RVR is not a measure of surface or tower visibility.

The CLT transmissometers operate continuously, and the raw data is continuously recorded by a strip chart system located in the National Weather Service (NWS) office. Figure 2 presents the three RVR time histories for the twenty minute period surrounding the accident. These values were derived from the NWS strip chart data. These plots clearly illustrate the magnitude and rapidity of the RVR deterioration, including the decay of the 18R MID RVR to less than 500 feet.

The TD, MID and RO RVR values themselves are relayed to repeater displays in the radar room and tower cab of the ATCT. The repeater displays present the RVR values on several LED panels, including one at the LCW position. The Controllers handbook (7110.65) procedures require that RVR values be reported to flight crews whenever prevailing visibility is one mile or less or the RVR is 6000 feet or less. Since the LED panels do not operate continuously, they must be selected 'ON' by a controller in order for him to report the RVR.

CLT procedures dictate that whenever visibility falls to less than four miles, the observer (ATCT or NWS) noting it first will notify the other of that condition. The lower of the two values (ATCT or NWS) will be used in reporting visibilities to aircraft.

Between 2236 and 2240, the CLT prevailing visibility decreased from six miles to less than four, but there is no record of exactly when this occurred. At 2236 and again at 2238, the ATCT Supervisory Controller (SC) noted to the Radar Coordinator Arrival (RCA) that CLT was going to go IMC very quickly. At 2240, the SC announced that tower visibility had decreased to one mile. By 2241, the 18R TD zone RVR had decreased to approximately 3000'.

Despite the noted requirements and conditions, at no time during the approach of US1016 did ATC personnel inform the flight crew that the visibility was deteriorating rapidly and significantly. Not once was US1016 informed that visibility had decreased to one mile or less, and not once were the required RVR values ever relayed to the flight.

Controllers have access to a considerable amount of information, much of it literally at their fingertips. Flight crews *need* this information so that correct decisions may be made. ATC awareness of the significance and value of this information, and the consequent need to disseminate it as rapidly and accurately as possible, is paramount. We must ensure that this message, *this concept*, permeates ATC.

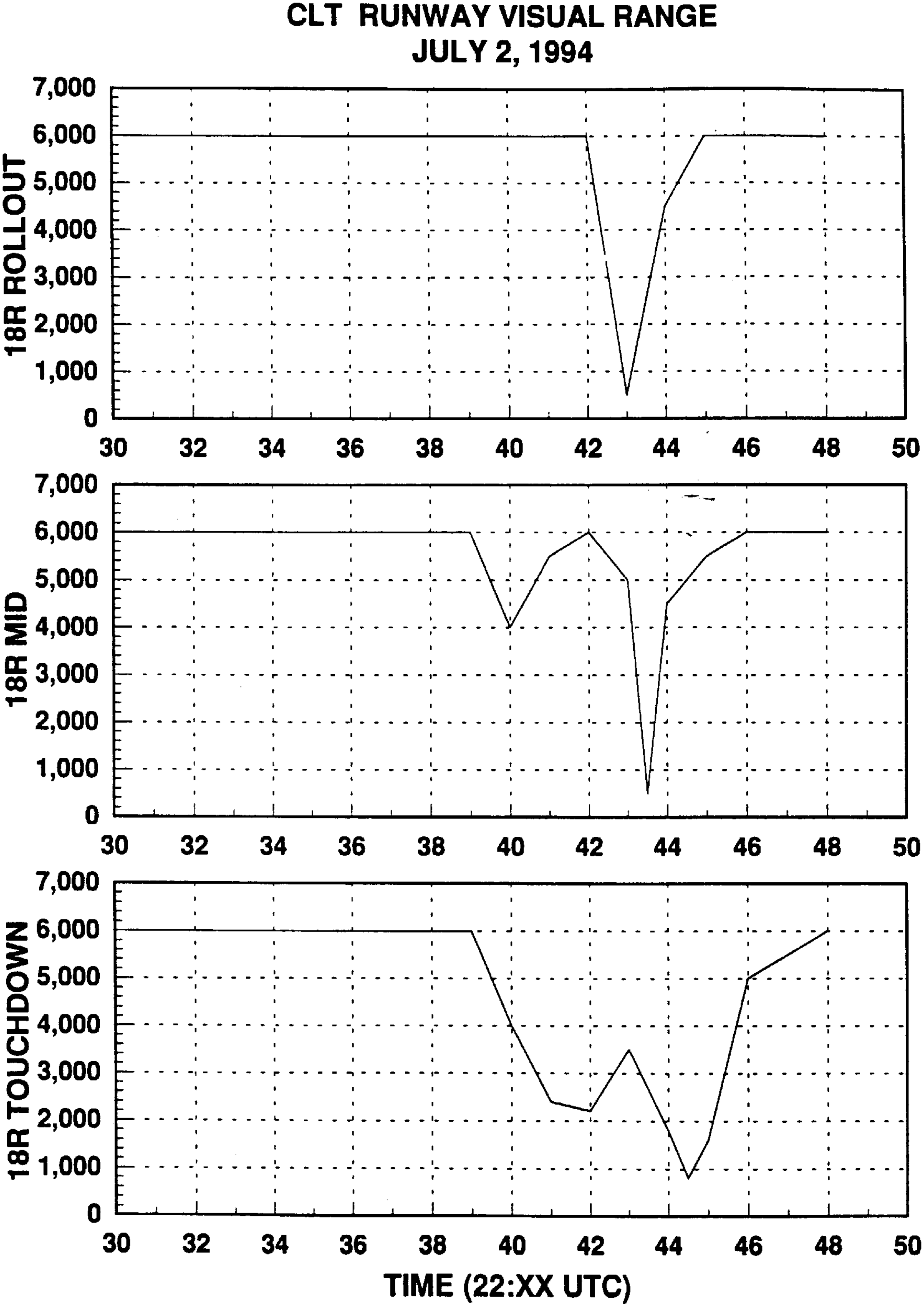

CLT RUNWAY VISUAL RANGE
JULY 2, 1994
18R ROLLOUT
18R MID
18R TOUCHDOWN
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
30
32
34
36
38
40
42
44
46
48
50
TIME (22:XX UTC)

FIGURE 2

LLWAS

This section will show that:

1) CLT LLWAS has several known deficiencies, some of which were known to the FAA over a one year period prior to this accident.

2) The CLT NW LLWAS sensor alerted after US1016 had transited the area.

3) These known deficiencies likely prevented an earlier NW quadrant alarm.

CLT is equipped with a Phase II Low Level Windshear Alert System (LLWAS). This system consists of six wind speed and direction sensors linked to a central computing and warning mechanism. This mechanism compares the vector differences of the winds at the various sensors, and uses a predetermined algorithm to issue alarms which warn of the likely presence of windshear.

The Phase II designation for the CLT LLWAS denotes that the system software has been upgraded from the original Phase I system in order to reduce false alerts (down to 7% probability of false alert) and to provide modest (**62%** probability of detection) microburst protection. Phase II systems are considered to be interim measures, bridging the gap between the original system (which was not designed for microburst detection) and a dedicated microburst detection system.

As currently planned, a dedicated microburst detection system would consist of either a Phase III LLWAS system (15 or more sensors), Terminal Doppler Weather Radar (TDWR), or both. Phase III LLWAS has a 97% probability of detecting microbursts, and reduces the false alarm probability to 4%.

As is the case with any system, LLWAS is subject to certain limitations and deficiencies. During the period from April to June 1993, more than a year prior to this accident, several written communications within the FAA noted problems with the CLT LLWAS . The specific issue was "inaccurate reporting of wind conditions" and requests for funding to rectify these deficiencies. As of the date of the accident, no modifications had been made to the CLT LLWAS.

Although siting criteria for LLWAS sensors have been established, real-world limitations can sometimes preclude satisfying all the criteria for all the sensors. When siting criteria are not met, the effects will typically take two forms; sheltering and channeling. Both are differences between the sensed wind and the actual wind. Sheltering refers to a reduced measured wind speed, while channeling refers to a distorted or false wind direction. The net result of these effects, either separate or in combination, is that the system accuracy will be adversely affected. In other words, the system will be more likely to issue false alerts and/or fail to detect actual microburst/windshear events.

The CLT Centerfield (CF) sensor was the first to go into alarm; this sensor alerted at 2240:37. The Northeast (NE) and Southeast (SE) sensors went into alarm next at 2241:07. Within approximately ten seconds, Local Control West (LCW) transmitted a

NE (only) sensor alert to US1016, and within another ten seconds relayed it to a second aircraft on approach to 18R. US1016 was approximately ninety seconds from impact.

At 2242:02, with the same three sensors in alert, the FRW controller issued an "all quadrant alert", but US1016 had already changed over to the LCW frequency. The LCW made no such "all quadrant" broadcast, despite the fact that he possessed the same information as the FRW. Just as US1016 passed over the NW sensor, and for reasons unrelated to windshear, the flight crew initiated their go-around. Approximately twenty to thirty seconds later, the NW sensor went into alarm, but US1016 had already crashed.

In a memo (Exhibit 5-E, pp 17-18) dated August 4, 1994, the FAA responded to an NTSB inquiry concerning performance of the CLT LLWAS. Of significant note are the following excerpts:

1) "...at the time of the installation of the CLT LLWAS, the concern was to detect gust fronts, not microbursts" and that the siting "...standards were less stringent than those now currently utilized."

2) An FAA Site Performance Evaluation Study (SPES) determined that sensors 2 (Northeast) and 6 (Northwest) were sheltered to a degree "...significant enough to degrade the system." However, this memo does note that "sensor 6 was not sheltered in the direction of the prevailing winds on July 2, thus it is not likely that it contributed to further degradation of the system".

Also as a result of this accident, Massachusetts Institute of Technology's Lincoln Laboratory (MIT LL) conducted a study of the CLT LLWAS to determine the system's performance. The obvious questions for this study are: 1) Did the system detect the microburst? and 2) If so, did it detect the event within a reasonable time period? The conclusion drawn by the MIT LL study was that "the system performed according to design".

The following paragraphs will show that although the conclusions of the MIT LL study and the FAA SPES are essentially accurate, the CLT LLWAS Northwest sensor did exhibit a delay in alerting to the presence of the microburst. This delay was within the system operating parameters, but had it not been present, US1016 likely would have had sufficient time to either avoid the microburst altogether, or knowingly transit it at a higher altitude while conducting the windshear escape maneuver.

Page 13 of Exhibit 5-J presents Speed Ratio (sensed speed divided by average network speed) data for the six sensors as a function of wind direction. These data are essentially 'calibrations' of the speed sensors. Ratios greater than 1.0 denote that the sensor is indicating a wind speed higher than average; the reverse is true for ratios below 1.0.

The data for Station 1 (Center Field) shows that this sensor indicates a mean wind speed 40% higher than network average. The data for Station 6, the Northwest (NW) sensor located near the Middle Marker (MM) for CLT runway 18R, shows that this sensor indicates a mean wind speed 20% lower than network average.

During the last minute of US1016's approach, Center Field (CF) was indicating a wind from 100°, while the NW sensor indicated winds from 180°. According to the MIT LL data, the CF sensor would likely have been indicating a wind speed 50 to 60% higher than actual, while the NW indication would have been approximately 15 to 20% high.

Figure 3 presents the wind speeds as measured by the CF(1) , NE (2) and NW(6) sensors. This plot shows that the biased sensor readings, discussed above, would result in an artificially smaller speed difference between the two sensors.

In his testimony, Dr. Wes Wilson of MIT Lincoln Lab noted that approximately one minute prior to the accident, the NW sensor missed the alarm threshold by seven tenths (0.7) of a knot. He further stated that, in order to reduce the number of false alarms, there was a certain amount of conservatism built into the algorithm, and that "the system didn't give alerts as early as we would have liked them".

An independent post-accident study of the CLT LLWAS was also conducted by Dr. Theodore Fujita. Dr. Fujita's study (Appendix A) presents essentially the same facts as the MIT study, and reaches similar conclusions, including:

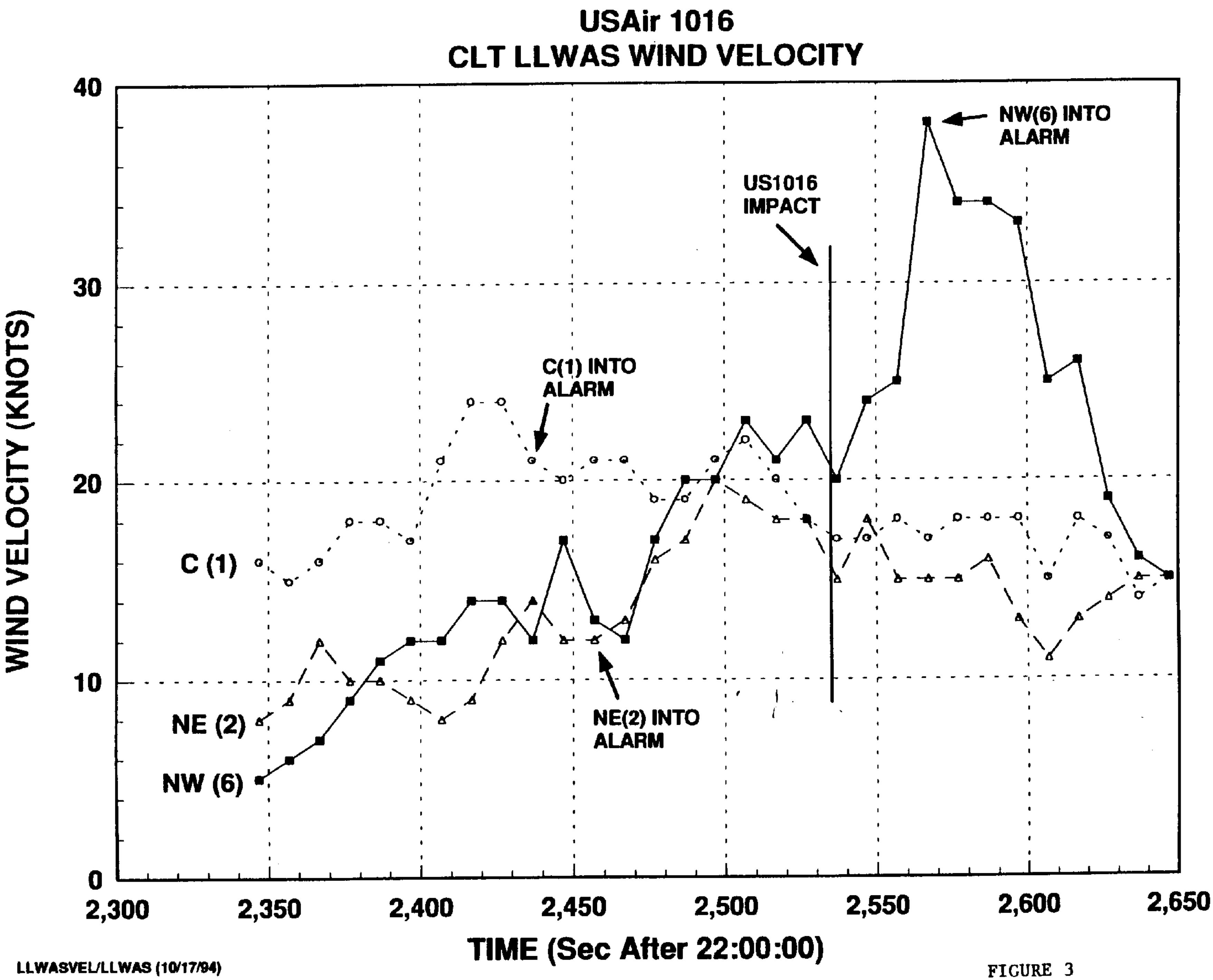
- The original CLT LLWAS installation does not meet current siting criteria.
- This condition is exacerbated by the subsequent growth of the surrounding trees.
- The Phase I software was too prone to false alerts; Phase II software seems to have had the opposite effect of desensitizing the system to actual events.
- These limitations prevented the system from issuing timely alerts on July 2, 1994.

Typically, when LLWAS sensors are installed, they meet the existing siting criteria. However, as the surrounding trees grow, their presence begins to impact the sensors in the form of sheltering and channeling, driving the sensor out of compliance with the installation criteria and yielding sub-standard performance. As the study results demonstrate, this situation applies to CLT.

This raises the question of how many other LLWAS installations are affected by this same phenomenon, and to what extent. It is unconscionable to consider that an aircraft accident is required to reverify LLWAS compliance with its design and installation criteria, particularly if the 'fix' is something as straightforward as trimming the surrounding trees.

CLT LLWAS's performance was documented prior to this accident, but it seems that the accident had to occur before the system was examined in detail. The CLT LLWAS was in place. The system to identify and correct problems with it was in place. Yet both failed

These details demonstrate limitations which can be associated with any Phase II LLWAS installations, not just CLT. Some appear to be readily correctable, while others do not. The catastrophic implications of these deficiencies dictate that, as a minimum, the current performance of all LLWAS installations be evaluated, and that flight crews be educated as to the limitations. The broader reaching solution requires a thorough assessment of the current system elements (personnel, procedures and hardware), and an expedited transition to dedicated microburst detection systems.



LLWASVEL/LLWAS (10/17/94)

FIGURE 3

ASR-9

This section will show that:

1. *The Final Radar West (FRW) ASR-9 radar detected a region of VIP Level 3 precipitation which "popped up" along the approach path of US1016.*
2. *This Level 3 activity was most likely the descending high reflectivity core which manifested itself as the microburst which US1016 encountered.*
3. *The existence and/or Level of this activity was not relayed to US1016.*
4. *This lack of controller information transfer to the flight crews is not an isolated problem.*

The CLT Airport Surveillance Radar (ASR-9) was commissioned in May 1991, and is considered to be a 'next generation' system. Although the primary purpose of the ASR-9 is aircraft tracking, the system was also designed to provide ATC personnel with quantitative precipitation reflectivity data. The National Weather Service (NWS) categorizes precipitation into six groups as a function of radar reflectivity, and which are referred to as VIP (Video Integrator Processor) levels. These correspond to the following degrees of precipitation intensity:

Level 1 = Light
Level 2 = Moderate
Level 3 = Heavy

Level 4 = Very Heavy
Level 5 = Intense
Level 6 = Extreme

The system allows the controller to select and display any two of the six VIP levels on his screen. The existence of precipitation levels higher than those selected is annunciated on a panel above the primary display. Since precipitation information is a secondary task of this system, a study was conducted to determine the fidelity of the ASR-9 VIP level depiction. This study determined that the ASR-9 indicated the correct level 79% of the time, and within one level of the correct value 97% of the time.

Terminal radar antennae are designed to "provide a uniform high gain fan beam pattern" which results in a cone shaped loss of coverage region over the antenna site. This region is known as the 'cone of silence'. In addition, according to the FAA National Data Communications Systems Engineering Division, the system software contains inhibits which define a cylinder, centered around the antenna, oriented vertically and with a radius of 1/8 to 3/16 mile, as an area from which returns are not processed. In contrast, however, Dr. Mark Weber, of MIT Lincoln Lab, indicated that the ASR-9 will detect rain reaching the ground "right up to the radar" antenna. This discrepancy has not been resolved.

Using the conservative approach, this report will consider that precipitation above the antenna site will generally not be detected unless it extends beyond the boundaries of these two zones. In addition, the ATC factual report notes that a storm of sufficient intensity (Level 5 or 6) would overcome the software inhibits and exhibit a return within the cylinder.

The Final Radar West (FRW) controller's display was set for Levels 1 and 3, and for the altitude block from the surface to 6000' MSL. This controller stated that, when US1016 made initial voice contact with him, he saw "weather" on his display on or around the approach end of 23, but that he did not note any "weather" in his airspace or on final to 18R. However, not long thereafter, the FRW saw "weather" developing on the airport or just north of 18R. He noted that this "just popped up as a Level 3"; he did not see it as a Level 1 or 2. The FRW controller stated in testimony that this occurred when US1016 was "approximately on mid field down wind" and that this Level 3 region remained present for at least thirty minutes. Experience has shown that most flight crews will deviate around areas which controllers report to contain Level 3 or higher activity.

Just prior to the accident, the Local Control West (LCW) controller observed three cells on his display. Two were to the south of the airport, and one appeared to be situated between the approach ends of runways 23 and 18L, northeast of the field. The controller could not distinguish the Level of the northeast cell due to the fact that it was directly over the radar antenna. In interviews and testimony, the controller stated that he could not recall either the VIP Level or the altitude limit settings on his ASR-9 display at the time of the accident.

There are two possible explanations for the 'sudden' appearance of the Level 3 activity on the FRW's display. It was either a rapidly developing precipitation field, or it was moving beyond the boundaries of the two zones previously described.

MIT Lincoln Laboratory conducted a study to determine what the ASR-9 display would likely have been showing during the period in question. This study utilized Columbia, South Carolina (CAE) WSR-88D data to define precipitation field locations and intensities, which was then used as input data to an ASR-9 simulation model. This study showed that a high reflectivity core (Level 5) was initially situated *above* the ASR-9 radar beam, within the cone of silence, and therefore went undetected.

This high-altitude, high reflectivity core was the beginning of the downburst which eventually struck US1016. As this core descended, it moved into the area of coverage of the ASR-9, and the study indicates that it probably would have appeared as a Level 3 or 4 on the ASR-9 display. In terms of both timing and appearance, these simulation results correlate well with the controllers' recollections.

It is well documented that very heavy rain was falling on the first third of runway 18R, and to the north of this as well. The CLT ASR-9 antenna is located approximately one mile SSE of the 18R threshold. Therefore, even applying the conservatism of the 3/16 mile radius within which no returns are processed, the ASR-9 should have displayed the rain quite prominently on the controllers' screens.

Neither the FRW or the LCW relayed any specifics of their ASR-9 indications to the crew of US1016. The only reference to any precipitation activity at all was made by the

FRW at 2237 when he stated: "Tell you what, USAir 1016, they got some rain south of the field, might be a little bit coming off north just expect the ILS now".

In view of the fact that the Federal Government has invested substantial monies and effort to bring the ASR-9 on line, it is significant to note that an October 1989 General Accounting Office (GAO) report concluded that the:

> "FAA has not established formal procedure for sending ASR-9 weather data from air traffic controllers to pilots...." and that the FAA wanted to wait until it learned more about "precipitation effects on aircraft and the work load effects on controllers."

Dr. Weber stated that, to his knowledge, nothing further had been done in this area since the GAO study. The events and circumstances surrounding this accident seem to substantiate that observation, and demonstrate its catastrophic implications.

ASR-9 equipment has been operational for several years; its capabilities must be utilized to the fullest. Flight crews understand and use VIP levels; so should ATC. Aggressive formulation and promulgation of ATC procedures which accomplish this is the recommended near term solution. A preferred long term solution is one which would eliminate the ATC human element from this loop, either by uplinking ground based weather data directly to the aircraft or installing more capable onboard systems. This issue will be discussed further in the section entitled 'Additional Near-Term Microburst Detection Equipment'.

WSR-88D

This section will show that:

1) CAE WSR-88D is not a dedicated aviation facility.
2) CAE WSR-88D detected significant atmospheric activity over CLT.
3) WSR-88D results were not readily available to Atlanta or CLT weather personnel, and were not provided to CLT ATC or weather personnel.
4) Inexpensive, readily available interim means exist to provide such results to these facilities.
5) WSR-88D indications were neither available to nor provided to US1016.

The new Doppler-equipped Weather Surveillance Radar (WSR-88D) is also referred to as NEXRAD (NEXt generation RADar). This equipment is an outgrowth of the WSR-57 radar, with several significant improvements: Doppler technology, increased resolution and sensitivity, and the highly automated generation of end-user products. The purpose of the WSR-88D network is to "support public weather forecasts and warnings". These are *not* dedicated aviation facilities, nor do they yet have products specifically oriented towards the detection of microbursts or their precursors.

The principal improvement is the incorporation of Doppler technology, which enables the WSR-88D to detect and quantify air and precipitation motion. This radar has a much narrower beam width (0.95° vs 2.2°), which provides greater resolution and results in finer scale structure of the displayed information. This higher resolution allows the detection of small, high-reflectivity cores which are associated with microbursts. The WSR-88D's higher system sensitivity enables the detection of smaller strength signatures associated with gust fronts, outflow boundaries and very light precipitation.

The WSR-88D system is also highly automated. It utilizes sophisticated computer algorithms and processing capabilities to provide the users with meteorological and hydrological products, as opposed to raw data. One of these products, Vertically Integrated Liquid content (VIL), is a radar parameter which enables the establishment of thunderstorm updraft strength. This is an aid in determining which storms will be severe. Another product is the relative velocity map, which quantifies the internal motion of fast moving thunderstorms. Again, this permits ready assessment of the strength or severity of the storm. Additionally, efforts are underway to incorporate microburst/windshear recognition algorithms into this system.

Each full volume (azimuth and altitude) scan requires six minutes to complete. Some of the data products are available while that scan is still underway, while others require the full set of scan data. Consequently, some products are near real-time, while others can be several minutes old.

Plans call for the installation of 162 WSR-88D units throughout the US As of August 1994, approximately 90 systems had been implemented. This is continuing at a rate of four per month, and complete implementation is planned for early 1996.

'Implementation' denotes that the system is installed and functioning (data being utilized). Full checkout of the system, along with ensuring the existence of a spares pipeline, results in the commissioning of the individual units. As of August 1994, approximately ten units had been commissioned. This is slightly behind schedule, primarily due to spares difficulties.

WSR-88D data can be accessed via several means. In descending-capability order, these include Principal User Processor (PUP), Meteorological Weather Processor (MWP), NEXRAD Information Dissemination Service (NIDS), and telephone inquiries to the individual WSR-88D facility. The PUP and the MWP are the two principal means employed by the NWS.

The PUP is a highly sophisticated workstation which provides the user full access to the system's capabilities and data. A PUP is linked directly to one and only one radar facility, but can accommodate up to three other facilities via dial-up. This dial-up access is restricted, both in terms of which radar facilities can be linked, and which data can be accessed. Lacking PUP access to a specific facility, users can run their MWP in a dial-up mode to obtain limited interaction with the WSR-88D data.

NIDS is an approach devised to permit private sector access to NEXRAD information. This is accomplished by allotting contracts to commercial vendors, who in turn sell software and access to private users. Estimated user cost, once equipped with a PC, is $150 plus modest on-line charges.

The Columbia, South Carolina (CAE) and Raleigh, North Carolina (RDU) WSR-88D facilities are the only ones which currently provide coverage of the CLT region. Lacking a PUP or a MWP, the only means for the CLT NWS office to obtain WSR-88D observations is via telephone communication with NEXRAD facility personnel.

Although Atlanta Center Weather Service Unit (ZTL CWSU) has PUP dial-up access to RDU, the RDU system was not operating on the night of the accident. As of the date of this accident, the ZTL CWSU did not have direct or dial-up PUP access to the CAE facility, despite two previous written requests by the ZTL CWSU Meteorologist-In-Charge.

On September 13, 1994, seventy three days after this accident, ZTL CWSU was provided with dial-up access to CAE.

The following summarize the CAE WSR-88D indications from July 2, 1994. Figure 4 of Appendix A presents a graphic illustration of some of these WSR-88D results.

At 2223, the storm over CLT was still in the growth phase.

At 2229, growth was continuing at the higher elevations. The data show Level 5 reflectivity at the mid elevations, indicating the probability of heavy rain on the ground within 5 to 10 minutes.

> At 2235, VIP Level 5 activity was showing at 8000 ft, indicating heavy rain was most likely beginning on the ground. This agrees with ground observations. The strongest internal gradients of the storm were over the Northwest corner of the airport, and tops were at 30000 feet. The storm is beginning its 'rainout' or decay phase, which is the period associated with downdrafts and microbursts.
>
> By 2241, upper elevations were displaying significantly lower reflectivities. This is characteristic of a descended reflectivity core, which can produce outflow, downdrafts and microbursts. US1016 was down by 2243.

According to the meteorologist from the NWS Advanced Development and Demonstration Lab, neither the VIL nor the relative velocity maps showed activity sufficient to warrant concern about 'severe weather'. However, as this accident clearly demonstrates, weather conditions which pose a hazard to aviation can be well below the NWS general public 'severe weather' threshold.

This meteorologist also noted that a WSR-88D facility located within approximately 20 miles of CLT (compared to 77 miles for CAE) would provide the resolution and low altitude coverage necessary to enable better assessment of local airport conditions. This would be particularly useful in detecting certain weather threats to arriving and departing aircraft.

Despite the obvious significance of some of these data, none of the CAE WSR-88D indications discussed above were observed in real time by either ZTL CWSU or CLT NWS personnel. Consequently, this information was not relayed to either CLT ATC or the crew of US1016.

Although it is not a dedicated aviation weather facility, the WSR-88D is clearly a useful tool in the detection of conditions hazardous to aviation. The fact that ZTL CWSU was given access to the CAE facility soon after the accident demonstrates recognition of this assertion.

The technology and hardware are available; what seems to be lagging (or lacking altogether) are the networks, links and procedures which will best utilize these valuable resources. This issue will be addressed further in the discussions concerning the NWS.

TERMINAL DOPPLER WEATHER RADAR

This section will show that:
1) Proven, operational hardware for ground-based microburst detection exists.
2) CLT is at least two years behind schedule in acquiring this capability.
3) It occasionally requires an Act of Congress to induce FAA progress.

Terminal Doppler Weather Radar (TDWR) is one of the next microburst detection devices scheduled to come on line. This weather radar utilizes a highly focused beam and Doppler technology to map out the winds and precipitation reflectivity of the surrounding atmosphere. This system will update the near-surface winds once per minute, and will take another two and one half minutes to perform the full vertical scan.

The TDWR uses a microburst detection algorithm which automatically recognizes, quantifies and geographically locates microburst activity for the controllers. Development testing of the system has shown the detection reliability to be extremely high, approaching nearly 100 percent. The probability of false alarms is proportionately low.

Current plans call for the installation of approximately 47 TDWR units throughout the United States, including Charlotte Douglas (CLT). Originally, all 47 were scheduled to be delivered by the end of 1995, but land acquisition problems have slipped this schedule by approximately a year and a half.

CLT was to be the fifth US airport to get TDWR, and this was originally supposed to occur in early 1993. Several problems, primarily land acquisition difficulties, stalled this particular effort. At the time of the US1016 accident, CLT had slipped to number 38 in the sequence to acquire an operational TDWR.

Subsequent to this accident, Congress mandated that CLT TDWR be brought on line by the end of 1995.

In December 1994, ALPA received word that the FAA is attempting to expedite the implementation of TDWR. Indications are that complete network deployment is now targeted for the end of 1996, which is closer to the schedule originally planned. The Air Line Pilots Association commends this renewed focus on TDWR implementation.

ADDITIONAL NEAR-TERM MICROBURST DETECTION EQUIPMENT

This section will show that:

1) *Additional technology and hardware for ground-based microburst detection are under development.*
2) *These methods should enable extensive US coverage when implemented.*
3) *The preferred solution is airborne predictive windshear detection equipment, which is just entering the implementation phase.*

In addition to LLWAS and TDWR, another ground-based microburst detection technology slated to become operational in five to six years is actually an upgrade to the existing ASR-9 system. This plan calls for the piggybacking of Doppler hardware and software onto the existing ASR-9 equipment. This will enable the automatic detection and location of microbursts and gust fronts, and present this information directly to the controllers on their screens. Detection and false alarm probabilities are worse than TDWR, but this system is much less expensive than TDWR. It will provide good microburst protection at many smaller airports which otherwise would not have any coverage. Current plans call for the procurement of 35 of these units.

Still another ground-based microburst (and other hazardous weather) alerting mechanism expected to become operational towards the end of this century involves the provisioning of TDWR units with predictive capabilities. TDWR data will be combined with ASR-9 and LLWAS data (when and where available), and concise, readily interpretable results will be data linked to the cockpit. This system is known as the Integrated Terminal Weather System (ITWS). ITWS demonstration evaluations were conducted with five domestic operators at Orlando and Memphis during the spring and summer of 1994. This system is expected to provide a two to three minute advance prediction of a microburst.

The most encouraging technology in this arena is the development of onboard predictive windshear detection equipment. ALPA has been a strong advocate of this approach for many years. Bendix and Westinghouse were recently granted FAA Certification for onboard predictive windshear detection systems. The detection capability and display symbology of these and similar systems have the potential to significantly assist aircraft so equipped in avoiding areas of windshear hazard.

These approaches are promising indications of the progress being made in the establishment of microburst detection and avoidance. Currently, all ground-based systems rely on some means to transfer the information from its source to those who need it most, the cockpit crew. Today, that means is the Air Traffic Controller. Twenty years of known windshear accidents conclusively demonstrate that the human element is prone to failure. This recognized weak link must be eliminated whenever and wherever possible. ALPA strongly encourages industry to vigorously pursue these enabling technologies, and urges the FAA to expedite their implementation.

CHARLOTTE NATIONAL WEATHER SERVICE

This section will show that:

1) The function of the CLT NWS is to gather, record and disseminate weather information.

2) CLT NWS is not a dedicated aviation weather facility, nor does it provide aviation advisories.

3) The role of the NWS and the interaction between the NWS and ATC must be examined and revised.

The CLT NWS office is located about one mile southeast of the ATCT. The primary function of this office is to make and disseminate surface weather observations. Only the issuance of 'public warnings' (severe thunderstorms, tornadoes, etc.) takes precedence over these duties. The NWS does not issue aviation advisories.

Severe thunderstorms are defined as those with tops above 50000' or with Level 5 cores above 26000'. Rainfall rate is not a criteria for severe weather.

The CLT NWS is equipped with a standard array of weather instruments. The only on-site weather radar this office has is the WSR-74C unit, which is used as a backup whenever the network radar (from Bristol, Tennessee) is down. However, due to ground clutter, the CLT WSR-74C cannot detect weather in the region above the airport. The CLT NWS does have the option of telephoning other radar facilities for observations. The CLT NWS rarely receives verbal/telephone briefings from the Atlanta Center Weather Service Unit, and did not receive one the night of the accident.

The CLT NWS office principally disseminates its observations via two methods; the Automation of Field Operations and Services (AFOS) 'long line' to the central NWS computer, and the Automatic Weather Information System (AWIS) local network to ATC and some airline users. CLT NWS policy is to first enter the data on the AFOS system as a means of quality control, and subsequently retransmit this information on AWIS. It typically takes three to five minutes between the completion of an observation and its transmittal on AWIS.

The CLT NWS makes regular Surface observations (SA) at 50 minutes past each hour, and Special observations (SP) as conditions warrant. Since the SA's are issued at predetermined times, it would be obvious to ATCT personnel if an SA record had not been received. However, since SP's are issued at irregular intervals, and the NWS does not have a procedure in place to verify receipt of their SP's, ATCT personnel have no automatic means to either ensure that they are receiving all the records being sent to them, or to alert them to the fact that an SP has been issued.

In Public Hearing testimony, the CLT NWS Weather Service Specialist revealed a disturbing irony. The CLT NWS had virtually no specific information, particularly the VIP level, about the thunderstorm which was directly overhead. The CAE WSR-88D facility, located 77 miles away, did. Atlanta ARTCC, located approximately 200 miles away, also did. This particular storm was a VIP Level 5, and the hazard it posed is now well documented.

It is incumbent upon all parties involved to develop and promote the networks and procedures required to ensure accurate and timely transfer of critical weather information. Clearly, there are no major technical challenges. There is a necessity to improve aviation safety, and this is a needed step towards that improvement.

ATLANTA ARTCC CENTER WEATHER SERVICE UNIT

This section will show that:
1) The function of the Atlanta ARTCC CWSU is to provide macro scale weather information for air traffic planning purposes.
2) An assessment of the NWS and its role in aviation is required.

The Atlanta ARTCC Center Weather Service Unit (ZTL CWSU) is responsible for providing meteorological consultation and advice to the Atlanta ARTCC, approximately fifteen ATCTs (including CLT) in the Southeast US, and occasionally to various Flight Service Stations. Its purpose is to keep these facilities advised of the weather conditions in order to maintain the safe and efficient flow of traffic. In essence, this facility provides macro scale coverage for planning purposes.

ZTL CWSU obtains its data from a variety of sources, including several ATC and weather radar facilities. (Recall the WSR-88D access discussions in a previous section) Aside from verbal/telephone briefings to customer ATC facilities, principal products include Weather Bulletins (map, synopsis and generalized forecast), Meteorological Impact Statements (MIS), and Center Weather Advisories (CWA). CWA's can be Airmets and Sigmets.

The Weather Bulletin and MIS sent to CLT the evening of the accident called for widely scattered thunderstorms in the region. The CWSU Meteorologist-In-Charge (MIC) testified that it is his discretion as to whether VIP Level information is disseminated to the various remote ATC facilities.

This meteorologist stated that the workload that evening was "light". He further stated that prior to the accident, he was preoccupied with other regions of his airspace, and was not paying close attention to the CLT area. Upon reviewing various data after the accident, including the CAE WSR-88D indications, he stated that there was nothing in the data which would have caused him concern or to issue a CWA for the CLT area.

When the CWSU MIC was asked if he had a "wish list" for his facility, his response included the following:

- Switchable (instead of dial-up) access to other WSR-88D facilities.
- Improvements to the 'user-friendliness' of the MWP workstations.
- Manpower was generally adequate, but during widespread thunderstorm activity, the staff's capabilities are taxed.

With respect to the detection and dissemination of pertinent weather information, one perception that this accident imparts is that the necessary individual components exist, but they have not quite been assembled into a smoothly functioning system. A system approach is needed, or needs to be revitalized. Particular attention must be paid to the humans' roles in these systems. The roles of the NWS remote offices (such as CLT) and the CWSUs must be considered individually and as elements of the overall system. Their capabilities must be brought into alignment with the needs of aviation, and any deficiencies must be addressed.

GROUND BASED WEATHER OBSERVATIONS AND RELATED ACTIVITY

This section will show that:
1) Significant, rapidly deteriorating weather conditions existed at CLT.
2) This situation was apparent to most CLT ATC and weather personnel.
3) This information was not made available to US1016.

Details gathered during the initial stages of this investigation, and later at the Public Hearing, make it clear that various ground personnel possessed a significant quantity of information concerning the severity of the weather, but that virtually none of this information was relayed to US1016. This situation reinforces the fact that a workable system to detect significant meteorological conditions and relay that information as rapidly and efficiently as possible to the end user, the flight crew, does not yet exist.

The following items are primarily excerpts from the ATC transcripts, and, in conjunction with the preceding several pages, should help the reader to form a more complete picture of the storm's timing and intensity.

For reference purposes, US1016 first contacted Arrival Radar West (ARW) with ATIS information 'Yankee' at 2227, and crashed at approximately 2242.

> At 2234 the Tower Supervisory Controller (SC) noted to the Radar Coordinator Arrival (RCA) that it was "raining like hell" at the cargo ramp area of the airport.
>
> At 2236, a Special Observation noting thunderstorms, and which was eventually broadcast as ATIS 'Zulu', was completed.
>
> At 2236 and again at 2238, the Local Controller East (LCE) transmitted to Piedmont 3211 that the airport was experiencing "heavy rain".
>
> Also at 2238, the SC requested that the airport standby generators be turned on because he expected that CLT was "going to go IMC very quickly " and that it was "raining very hard".
>
> At 2239, US806 reported the storm to Local Control West (LCW) and delayed its departure from 18R.
>
> At 2240, the SC announced to the tower controllers that tower visibility had decreased to one mile.
>
> Also at 2240, US1655 questioned Ground Control East (GCE) as to whether anyone had "brought the airport to a halt for the thunderstorm?" .

At 2241, due to the intensity of the rain, GCE could no longer see US983. US983 had just landed on 18R and was located on taxiway Bravo, approximately 3000 feet from the ATCT.

Also at 2241, US797 delayed its takeoff from 18R due to weather.

At 2242, approximately 30 seconds before US1016 crashed, the SC announced "windshear alerts in multiple quadrants" to the RCA.

None of this information was relayed to USAir Flight 1016.

The above events demonstrate that, despite all the communication and activity prompted by the deteriorating weather, those who would be affected most, the flight crew, were not included in the information loop.

AIRBORNE WEATHER OBSERVATIONS AND RELATED ACTIVITY

This section will show that:

1) Visual, airborne radar and ATC reports led the flight crew to believe that weather conditions were much less severe than they actually were.

2) The resulting inaccurate perception adversely biased the crew's decision making process.

3) US1016 was not unique in its perception of or reaction to the conditions at CLT.

At 2223, US1016 obtained ATIS 'Yankee', and shortly thereafter contacted CLT Approach (Arrival Radar West, ARW). US1016 was heading northeast toward CLT, and the only weather which caused the crew any concern was a cell situated approximately over CLT VOR, about two miles south of the airport. This cell showed on the airborne radar as a yellow region with a red core. The aircraft was descending from 10000 ft to 6000 ft, and the airport was in sight.

At 2235, US1016 contacted the Final Radar West (FRW) controller, who issued them vectors for the visual approach and cleared them to 2300 ft, the final approach altitude for visual approaches. Three minutes later, the FRW amended the altitude and clearance and told US1016 to expect the ILS, due to a "little bit" of rain. As the flight progressed from downwind to final, the crew completed their landing preparations. These included discussion of the possibility of windshear, and a plan to turn to the west to avoid the cell over the VOR if a missed approach became necessary. As noted previously, the crew neglected to inform ATC of this possible deviation.

As the aircraft turned onto final, the crew reacquired visual contact with the airport. However, a thin veil of rain was now falling between the aircraft and runway 18R. The Captain was still satisfied that he would be able to see the runway throughout the approach. After crossing the outer marker, the Captain solicited Pireps from ATC, who responded with two "smooth ride" reports. What the controller did not relay, however, was that one report was several minutes old, and conditions had changed dramatically since then. During this period, the tower visibility had dropped to one mile, but no mention of this or its cause, the heavy rain, was forthcoming from ATC.

US1016's perception now was that the final approach would be a smooth ride through light rain, with a commensurate decrease in visibility. The Captain testified that his radar did not indicate anything to the contrary regarding precipitation on the final approach path.

The failure of the heavy rain on final to show on the airborne radar is easily understood. An unintentional effect of aircraft radar attenuation circuitry causes the system to display close range precipitation at a lower reflectivity level than it actually is. The Collins WXR-700X system installed on the DC-9 was originally equipped with a means to alert the pilots when severe attenuation occurs; a yellow arc, the 'PAC Alert Bar', appears at the outermost range mark. At levels below this threshold, attenuation still occurs. This results in the reduced return levels, but without any annunciation. This feature has been deactivated on the USAir DC-9 fleet, apparently to standardize the radar with that on the B-737 fleet.

One crewmember of US392, a flight preparing for departure from CLT, experienced the same effect on the ground. His written statement noted that the radar "painted nothing despite very heavy precipitation". His efforts included using the various range scales of his radar.

When US1016 was approximately midway between the outer marker and the runway, winds of 100/19 and a NE sensor windshear advisory were broadcast. Shortly after entering the light rain, US1016 unexpectedly encountered very heavy rain. This was the crew's first indication that conditions were substantially different from those that they had been led to expect. This rain, combined with the nearly direct crosswind, prompted the Captain to initiate a normal go-around. By this time, however, the aircraft was well entrenched in the undetected microburst.

In accordance with the normal go-around procedures, the crew began retracting the flaps to the 15° position. This action placed the onboard windshear detection computer into a standby mode, which prevented the system from providing a warning for approximately seven seconds. The Honeywell windshear computer software incorporates this delay feature in order to prevent nuisance warnings when the flaps are in transition. Honeywell's analysis indicates that the system still should have provided a warning, albeit only 3 to 4 seconds prior to impact. This will be discussed further in the AIRCRAFT PERFORMANCE section.

US1016 was not the only aircraft on approach to CLT 18R at that time. US983 had landed on 18R just prior, having circled from runway 23. They did not fly through any significant rain. They did not experience any turbulence or airspeed deviations, but did encounter the heavy rain on their rollout and subsequent taxi.

Carolina 5211 was close in trail to US1016. The FRW had informed this flight that the tower visibility was one mile. The Captain of 5211 did notice a localized area of rain, with the heaviest portion over the center of the field, and did recall at least two LLWAS warnings. As they entered the rain, they experienced "moderate turbulence", "10 to 15 kt A/S fluctuations" and "heavy rain" which reduced "forward visibility to near zero". The Captain further stated that "the rain and turbulence... was heavier than I had expected from my visual observation". At this point (approximately 600' AGL), due to the loss of contact with US1016, CLT ATCT instructed 5211 to go around.

US332 was a B-727 following Carolina 5211. US332 "encountered heavy precipitation and noticed 'down drafting' trend on the G/S", but made a "normal recovery". They continued down to about "500' AGL in heavy rain, nil visibility, but smooth ride", when they were instructed by CLT ATCT to go around.

These events clearly demonstrate that what may be obvious on the ground is not necessarily obvious from the air. As discussed previously and will be further amplified in other sections of this report, the controllers relayed virtually no useful weather information to US1016. Airborne radar failed to reveal the hazard to US1016. And at least two other flights in close trail to US1016 were proceeding into and through the same conditions which brought down US1016, only to be waived off by ATC due to the loss of US1016. The crew of US1016 was unable to predict the conditions that awaited them, as were other flight crews following behind.

The importance of flight crews' need for critical information cannot be overstated. However, information alone is not the panacea. In a high workload, dynamic situation, too much information can be just as counterproductive as insufficient information. The type, content, form and quantity of information all contribute towards its utility to the flight crew. It is these aspects which must be addressed in the determination of a solution to this problem.

THE MICROBURST

This section will show that :
1) A strong microburst enveloped the approach and threshold area of CLT 18R.
2) NASA classified it as the "most intense" they have simulated to date.
3) The timing of US1016's arrival coincided with the peak intensity of this microburst.

The NASA Langley Research Center performed an analysis of the CLT microburst to determine its characteristics, including size, intensity and duration. This analysis was conducted with the NASA 'TASS' computer program, which uses meteorological and aircraft flight recorder data as the inputs. This program is used by the FAA in the certification of look-ahead windshear sensors. The NASA study produced the following results:

- This microburst exhibited a peak wind shear of approximately 70 knots.
- This velocity change occurred over a distance of approximately 1/2 nm (1 km).
- The vertical wind component was approximately 14 knots (1400 fpm).
- The microburst exhibited a 1 km average F-factor of 0.3.
- The rainshaft was approximately 1 to 3 nm in diameter.
- The estimated rain content was 4.5 to 9 grams/cubic meter.
- The rainshaft preceded the downburst.
- This microburst ramped up to its peak and down again in within 5 minutes.
- This microburst reached its peak intensity within 2 minutes of starting.
- US1016 encountered the microburst at or near its peak intensity.

F-factor is a non-dimensional value used to quantify the effect of a microburst on aircraft performance, and is a function of horizontal shear, vertical velocity and aircraft velocity. F-factors are presented as 1 km averages; peak values can be significantly higher. The FAA considers an F-factor of 0.1 to be hazardous; the microburst which Delta 191 encountered in Dallas was quantified as having a 0.25 F-factor.

A positive F-factor is a decrement to the flight path gradient. Flight path gradient is the change in height divided by the horizontal distance traversed. Therefore, the 1km F-factor seen here equates to a 17° decrease in the flight path angle for a horizontal distance of approximately 3200 feet. This is an *average* value; localized effects were much more severe.

This NASA study indicates that this particular event differs from the generally accepted image of a microburst in two respects. First, Dr. Wilson noted that there "is strong evidence that (it was) a complex microburst event" (multiple surges). Second, this microburst was relatively small yet very intense. In addition, the reader must be reminded that a 'supercell' is not required to generate a severe microburst. The cell which spawned the DFW event was no higher than 23000 feet, and this CLT cell topped out at approximately 30000 feet.

This NASA study details the rapidity and intensity with which these phenomena can occur, and highlights the need for reliable microburst detection capability.

ATC PERFORMANCE

THE CONTROLLERS

This section will show that:

1) *CLT ATC personnel were fully qualified, and their equipment was fully operable the evening of the accident.*
2) *CLT ATC personnel failed to adhere to prescribed procedures concerning the relay of pertinent weather information to US1016.*

The approach into CLT required US1016 to be in communication with three separate controllers; Arrival, Final and Local West (ARW, FRW and LCW, respectively). The ARW and FRW positions are physically located in a windowless room referred to as TRACON or the radar room. The LCW position is in the ATCT cab. All three individuals at these positions at the time of the accident were Full Performance Level (FPL) personnel. All equipment was reported to be in good operating condition. US1016 spent fifteen minutes, nearly half its total flight time, in contact with these three positions. Figures 4a-4d present a timeline transcript of these ATC communications.

US1016 contacted ARW at 2227 with ATIS 'Yankee', and remained on frequency for eight minutes. During that period, ARW was handling only two other aircraft. This controller did not issue any weather information. The announcement of heavy rain on the field by the ATCT to the TRACON was made approximately fifteen seconds before US1016 left the ARW frequency.

US1016 then contacted FRW, and remained on frequency for four minutes. During this period, the FRW was handling three other aircraft. The FRW is responsible for the airspace to the west of CLT below 6000 feet. His principal function is to turn aircraft onto final, clear them for the approach and pass them to LCW. This controller can obtain weather information from his supervisor, Pireps, ATIS and his ASR-9 radar.

In statements and testimony, this controller stated that his workload was "light" and the complexity was "light to none". When questioned whether this situation allowed him to "perform additional duties", including "issuing weather information" this controller responded in the affirmative and added "I issued the weather to the pilot. That's why I changed him from the visual to the instrument approach". This controller also accurately stated that he has "a legal ... obligation to issue an aircraft any pertinent weather that would be adverse to his flight."

In fact, the *only* weather information that this controller passed to US1016 was (in its entirety): "Tell you what, USAir 1016, they got some rain south of the field might be a little bit coming off north just expect the ILS now"

This was despite the fact that the ATCT supervisor (SC) had informed the Arrival Radar Coordinator (RCA) of heavy rain on the field, and that the FRW had noted the 'Level 3 pop-up' discussed previously in this report.

The Controller's Handbook presents examples of phraseology to be used when relaying weather information, and these examples specifically cite VIP Levels. In his testimony, the FRW controller noted that as an OJT instructor at CLT, he would not tolerate any student deviation from the phraseology examples in the Handbook. Furthermore, this controller stated that his supervisor expected him to follow the Handbook phraseology guidance whenever he was controlling aircraft. A review of the ATC transcripts for this accident indicates that this controller did not utilize the recommended phraseology while he was in contact with US1016.

At 2240, US1016 was handed off to LCW, and remained on this frequency for the final three minutes of its existence. During this period, the LCW was handling two departures and four arrivals, not including the accident flight. This position is responsible for aircraft landing on and departing 18R.

The Local West controller categorized his workload as "moderate" with "routine" complexity. His testimony included the following particulars concerning conditions and events at CLT just prior to the accident:

- This controller stated that "weather was not impacting 18R".
- He had no recollection of the VIP Levels set or indicated on his radar screen.
- He had no recollection of lightning.
- He did see a "general rain shower".
- He did notice that the threshold of 18R was "obscured", but could not tell whether the obscuring phenomenon was rain or cloud. (Note: 18R threshold is approximately 3000' from the ATCT).
- Tower visibility decreased to one mile approximately ten seconds after US1016 joined the LCW frequency.
- This controller had no recollection of the SC announcing that tower visibility was one mile.
- In spite of the fact that this controller is certified to make visibility observations, he stated that he was not aware that visibility had decreased to one mile.
- He has no recollection of any written documentation concerning the activation of the RVR display panel.
- When asked whether he thought US1016 "knew about the weather", he replied in the affirmative. He based this presumption on the fact that US1016 was requesting Pireps.
- Despite communications with US806 and US797 regarding the weather, this controller, when questioned if he knew why these aircraft had delayed their departures, responded "No, I don't".

- ATIS Zulu was first broadcast when US1016 was on this frequency.
- This controller never relayed this information or any other pertinent weather information to US1016.

While the above details are critical of the performance of the individual manning the LCW position at the time of the accident, criticizing individual performance will not improve safety. As noted previously, adherence to procedures is not discretionary conduct. But we must look beyond these individual failures, to the underlying causes, if any progress towards improving safety is to be made.

The accident history has conclusively demonstrated that the human is the weak link, and that we should not be surprised when the human does fail. ATC is a system, and as such, no position or individual functions in a vacuum. Attention to human failures must be addressed using a system approach; the known weaknesses of the human element must be considered in the revamping of the ATC system and its procedures.

THE SUPERVISORY CONTROLLER

This section will show that:

1) The CLT ATCT Supervisory Controller was not aware of certain aspects of the duty requirements and the activities of his personnel the evening of the accident.

2) The CLT ATCT Supervisory Controller did not adequately ensure the performance of some personnel in his charge.

The ATCT Supervisory Controller (SC) is responsible for the overall operation of the tower cab. Part of the SC's oversight is accomplished by monitoring, via headset, the various controllers' communications. Multiple positions can be monitored simultaneously. This link also enables the SC to communicate with the TRACON supervisor in the radar room. However, the SC cannot simultaneously communicate with the TRACON supervisor and the tower cab controllers, nor can these controllers hear the conversations between the SC and the TRACON supervisor. The SC qualified the workload as "light to....moderate", and was monitoring LCE at the time of the accident.

During the course of the SC's testimony, the following facts were noted:

- The SC announced to his controllers in a 'community voice' that visibility had decreased to one mile.
- He did not receive any acknowledging feedback from the controllers.
- These two items were in accordance with CLT ATCT operating procedures in effect at the time.
- The SC engaged in discussions concerning the lightning activity at CLT.
- The SC did not see any lightning.
- The ATCT does not have the authority to suspend operations due to weather.
- The ATCT does have a responsibility "to forward the weather information to the aircraft."
- The SC turned on the runway and taxiway lights.
- He does not recall who turned on the RVR displays.
- He does not recall whether any controller issued RVR values.
- He was not aware of any previous problems with the LLWAS.
- Despite being trained and qualified to operate the ASR-9 radar, the SC was not aware of the meaning or significance of a VIP Level 3 indication on the display.
- Regarding the relay of weather information to pilots by controllers, the SC stated that the controller is not required to use VIP Levels, but that he (the SC) "would expect (the controller) to describe it in a way that can best be used by the pilot."
- As of September 1994, no procedural changes had been made at CLT ATCT.

All individuals involved were Full Performance Level (FPL) personnel. This denotes that, due to their training and experience, they are expected to provide the level of service required to ensure the safe operation of aircraft in their jurisdiction. The ATCT

Supervisor failed to adhere to the ATC procedures, failed to ensure that his personnel adhered to those procedures, and failed to demonstrate good operating practice.

There are two categories of errors, those of commission and those of omission. The details above attest to the fact that in the case of US1016, the latter condition prevailed. ATC failed to adhere to procedures and relay pertinent weather information to the flight crew.

Together, ATC and the flight crews comprise the backbone of a safe air transportation system. Their mutual dependence requires that each meet their respective responsibilities continuously and to the highest standards. Just as important, however, is the requirement to design a system which minimizes dependence on the weakest link, the human element.

The events of this accident bear striking similarities to the events of the Delta DFW windshear accident in 1985. The errors of omission which occurred at CLT on July 2, 1994 are indicative of symptomatic weaknesses in the system. It is this aspect which must be addressed if we are to reduce the likelihood of future weather-related accidents.

USAIR 1016
ATC ACTIVITY

ATC TIME	ARRIVAL WEST	FINAL WEST	LOCAL WEST	OTHER
2227:06	US1016 reports on frequency with ATIS 'Yankee'			**ATIS:** 'Yankee' -21:51Z 5000 scattered, visibility 6, winds 150/8.
2230:09	US1016 swings 5 deg to avoid buildup			
2233:15	US1016 requests 5 deg left in about 15 nm. Ctller notes 1016 will be turned prior to that.			
2234:34				**LCE:** "rain...midfield in sight"
2234:37				**CAB/SC:** "rain on S side of airport...cargo ramp....raining like hell"
2234:42				**CAB/RCA:** "OK, heavy rain to the SE"
2235:06	US1016 last transmission on frequency			
2235:16		US1016 reports on frequency		
2235:44				**LCE:** sights lightning ESE or SSE
2235:49		US1016 issued vectors for visual 18R		
2236:00				**ATIS:** 'Zulu' -22:36Z special observation, M4500 broken, visibility 6, thunderstorms, *light* rain showers, winds 110/16
2236:13			US677 reports "good ride all the way down"	

FIGURE 4a

ATC TIME	ARRIVAL WEST	FINAL WEST	LOCAL WEST	OTHER
2236:21				**CAB/SC:** "probably going to go IMC ...pretty quickly"
2236:53				**LCE:** (to PDT 3211) "raining heavy rain on the airport, wind 150/13"
2236:55		"Tell you what USAir1016, they got some rain south of the field might be a little bit coming off north just expect the ILS now"		
2237:33				**LCE:** (to PDT 3211) "heavy rain on airport, wind 150/14"
2238:02				**CAB/SC:** "generators on....going to go IMC very quickly raining very hard"
2238:24		US1016 cleared ILS 18R		
2238:25	"rain on airport, expect ILS" to CDL5233			
2238:38				**LCE:** PDT 3211 reports smooth ride on 23 final .
2238:47-59				**CAB/SC/USARC:** lightning discussion
2239:12-20			US806 reports CLT storm, delays T/O from18R	
2239:18				**LCE:** US52 rqsts hold on rwy 18L to check radar

SHADING DENOTES WHEN US1016 ON FREQUENCY

FIGURE 4b

ATC TIME	ARRIVAL WEST	FINAL WEST	LOCAL WEST	OTHER
2239:25		US1016 last transmission on frequency		
2239:38			US1016 reports on freq	
2239:40			Controller relays US677 "smooth ride" report	
2239:47			US1016 requests pirep from A/C ahead (US983)	
2239:58				**CAB/SC:** "Tower vis is one mile"
2239:59				**CAB/RCA:** "Tower visibility is one mile"
2240:00				Special Weather Observation: Thunderstorms, heavy rain, visibility one mile.
2240:01		"Attn all A/C, tower visibility 1 mile"		
2240:11				ATIS Zulu broadcast
2240:26				**GND/US1655:** "Have you brought the airport to a halt for the Tstrm?"
2240:29				**GCE:** "no, tower vis is one mile, ...some wind shear alerts..."
2240:33			US983 reports "smooth ride"	
2240:40			Controller relays US983 "smooth ride" report	
2240:44			US1016 requests winds	
2240:50			"Winds 100/19"	
2240:56			"Winds 110/21"	
2240:59				**GND/US983:** "clear of 18R to C-11"

SHADING DENOTES WHEN US1016 ON FREQUENCY

FIGURE 4c

ATC TIME	ARRIVAL WEST	FINAL WEST	LOCAL WEST	OTHER
2241:04				**GCE:** requests US983 taxi exit usage (due to loss of visual contact).
2241:05			"Wind shear alert NE boundary wind 190/13"	(Center,NE, & SE sensors in alarm)
2241:08				**LCE:** "Attn all A/C, shear alert, surface 100/20, NE 190/16"
2241:09				**GND/US983:** "reverse high speed Echo"
2241:13				**GND/US983:** "coming on Bravo now"
2241:17			Clears CC5211 to land, adds "wind 100/20, wind shear alert NE... 190/17"	
2241:41			US797 delays T/O from 18R due to weather	
2241:56				**CAB/SC:** "windshear alerts multiple quadrants"
2242:02		"Attn all A/C, wind shear alerts all quadrants"		
2242:10				LCE: US52 reports "heavy rain" on 18L roll
2242:13			US1016 "on the go"	
2242:22			US1016 Last transmission	

ATIS - Automatic Terminal Information Service
CAB - Tower cab
GCE - Ground Control East
LCE - Local Control East

RCA - Radar Coordinator - Arrival
SC - Supervisory Controller
USARC -- USAir Ramp Control

SHADING DENOTES WHEN US1016 ON FREQUENCY

FIGURE 4d

AIRCRAFT PERFORMANCE

AIRCRAFT SYSTEMS and FDR DATA

This section will show that:
1) With one exception, all aircraft systems functioned normally.
2) The on-board windshear detection computer was "useless" to the flight crew.
3) FDR data details some of the performance parameters of this flight.

Examination of the wreckage and FDR data, combined with post-accident interviews with the flight crew, revealed that, with one exception, the aircraft and all its systems appeared to have functioned normally throughout the flight. The exception was the on-board windshear detection computer.

This aircraft was equipped with a reactive windshear detection computer manufactured by Honeywell. As noted in Exhibit 9B, Honeywell's analysis indicated that the unit (with the current logic) should have produced an alarm approximately three to four seconds prior to impact, but did not. The reason for this failure has not been determined, and it is doubtful that it will be.

One finding which did result from this event was that, as currently configured and certified, the windshear detection algorithm goes into a standby mode when the flaps are in transit. This was designed into the logic to prevent nuisance warnings. In the case of US1016, this feature delayed the warning timing (the earliest that the device could have produced an alarm) by at least seven seconds. In the NTSB's opinion, with which ALPA concurs, this feature rendered the system "useless" to the flight crew. As a result of this finding, on November 28, 1994, the NTSB issued Safety Recommendations A-94-208 through -210.

USAir 1016 was equipped with an eleven parameter FDR. Figure 5 presents time history data for five of these parameters and two derived parameters (True Air Speed and Ground Speed) for the 45 seconds prior to the accident. Initially, the two traces follow one another with a constant offset (the headwind). At T=533, the TAS trace shows a 12 knot rise which indicates initial contact with the microburst outflow. Soon after this, the shear manifests itself as the ground speed begins to diverge from the air speed. Within 20 seconds the aircraft ground speed decreased by 40 knots. The airspeed decreased 30 knots in less than 15 seconds.

At T=548, approximately 22 seconds before impact, the crew initiated a standard go-around as evidenced by increases in the pitch attitude and the Engine Pressure Ratios (EPR). Pitch attitude increased to a peak of approximately +15° (nose up), but then decreased to a minimum of approximately -5° (nose down) before rising again to +5° just prior to impact.

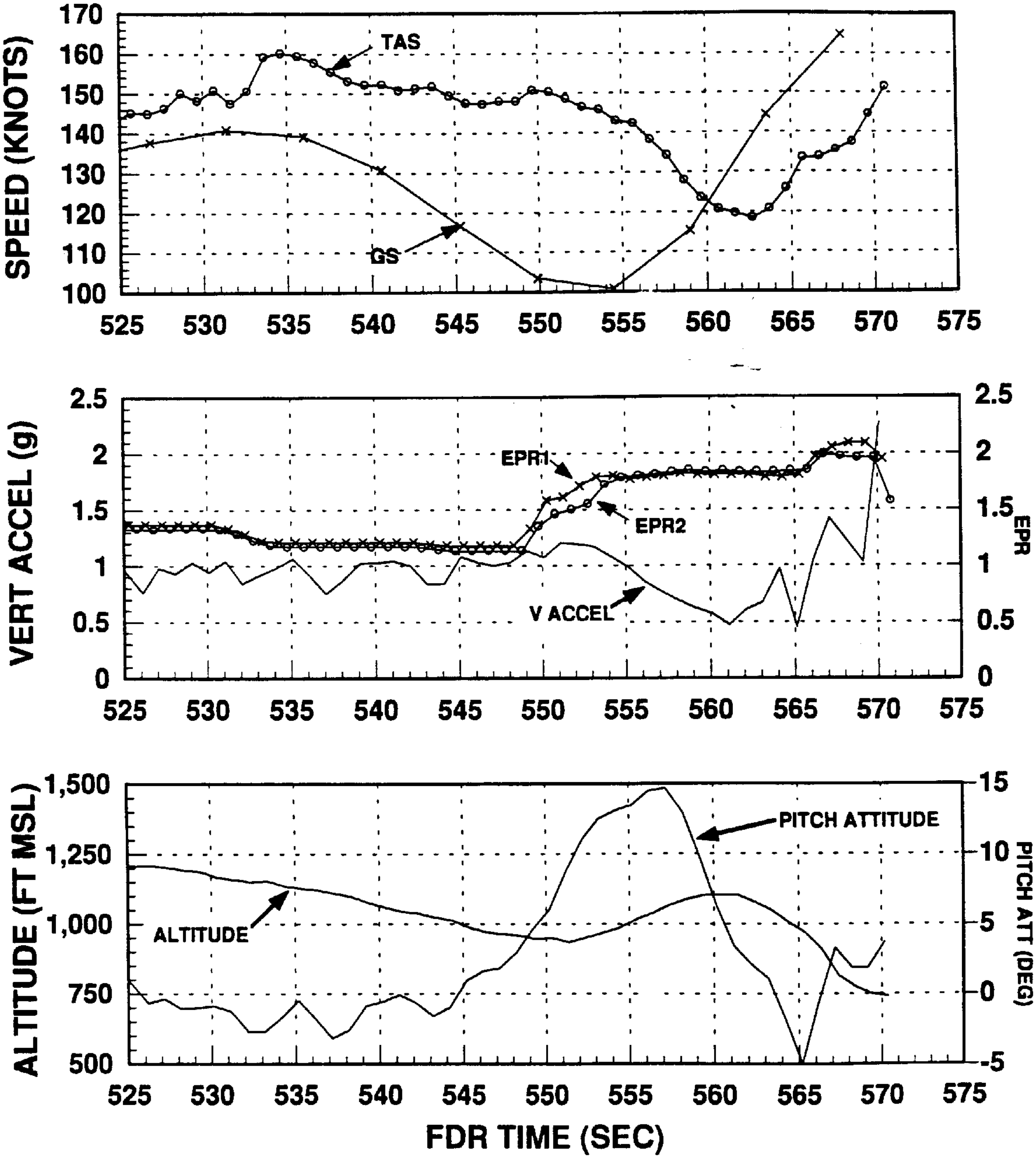
Target go-around EPR was approximately 1.9. In accordance with standard go-around procedure, the throttles were moved to their approximate required position, yielding an EPR of approximately 1.8. Time and events prevented the crew from the normal 'fine tuning' of the power. At T=566 the throttles were advanced to firewall power. Douglas Aircraft has of yet failed to provide definitive performance data which quantifies the effect of this reduced EPR.

At T=552, the Vertical Acceleration trace began to decrease, reaching a minimum of approximately 0.5g. Approximately three seconds after initiation of the go-around, the aircraft began to climb. It gained about 150 feet before the effects of the microburst caused it to descend into the terrain.

As of December 22, 1994, the Douglas Aircraft Company (DAC) had not yet provided certain data required to fully analyze the aircraft performance. DAC is scheduled to provide simulated flight path data using several scenarios which incorporate the NASA 3-D wind field of the microburst.

To date, DAC has not provided the control force and control authority data required to fully address the questions concerning the aircraft pitch attitude throughout this encounter. Without this information, it is unknown what control forces the crew experienced or were required to exert in order to maintain the desired airspeed and/or flight path. These control forces could have been well beyond the normal values expected, and could have been extremely difficult or impossible to achieve. Furthermore, without control authority data, it is unknown whether the aircraft was even capable of being flown out of this shear, as DAC contends in its simulation data (Exhibit 13C). It is imperative that control force and control authority data be provided in order to correctly and accurately analyze the crew's and aircraft's performance. Any performance analyses conducted without these data will be speculative.

USAir 1016
FDR & BEACON DATA



cmpravg3/fdrcut1/xyvreg10.dat (7/27/94)

FIGURE 5

DERIVED WINDS

This section will show that:

1) FDR and Radar data enabled the derivation of the microburst horizontal winds.
2) This microburst exhibited a horizontal shear of approximately 70 knots.
3) The aircraft encountered this microburst at approximately 400 feet AGL, but did not experience the strongest shear until it was approximately 200 feet AGL.

CLT radar data and FDR data from the accident aircraft were used to derive the horizontal components of the atmospheric winds during the last 2-1/2 minutes of flight. This technique involves the comparison of the aircraft's ground-relative motion to its air-relative motion; any differences between the two are attributed to the effects of the horizontal components of the atmospheric winds.

Two separate but similar methods were employed to derive the winds. The first method used the CLT radar data to calculate aircraft ground speed. Radar X (east-west) and Y (north-south) position data was differentiated to generate X and Y velocities. These X and Y velocity components were smoothed using a tenth order fit, and were then combined to yield aircraft ground speed.

FDR longitudinal and normal (vertical) acceleration data was used to derive the vehicle inertial velocity components (ground speed) in the second method. Both the first and second methods utilized FDR airspeed, heading, and altitude, and assumed zero sideslip (beta), to determine the air-relative motion. The results from the two methods compared well, which increases the confidence in these values.

Figure 6 presents a comparison of the inertially derived flight path with the raw (unsmoothed) and smoothed ASR-9 radar data. The differences are primarily attributed to the lack of lateral acceleration data due to the fact that the FDR does not record, this parameter.

The derived winds are presented in Figure 7 as time history data. These data show the onset of the microburst outflow at T= 534. Headwinds peak around T= 550, and the strongest shear is experienced within the next 15 seconds. The radar based calculations indicate a total shear magnitude of close to 80 knots, while the inertially derived values indicate a total shear magnitude of approximately 60 knots.

Figure 8 presents the microburst horizontal winds in vector format.

Three other parties (NTSB, Douglas Aircraft and Honeywell) derived microburst wind values, and there was generally good agreement among the four sets of wind data. These computations are complex, and the minor differences are attributed to variations in such factors as accelerometer biases, timing correlation, assumptions, and other specifics.

These results clearly show that US1016 encountered a severe microburst approximately 400 feet above ground level (AGL), and that the full effect of this microburst does not manifest itself until approximately fifteen seconds later, when the aircraft is only 200 feet AGL. Impact occurred after the aircraft had penetrated the core of the microburst, while it was still in the decreasing performance (increasing tailwind component) region of the microburst.

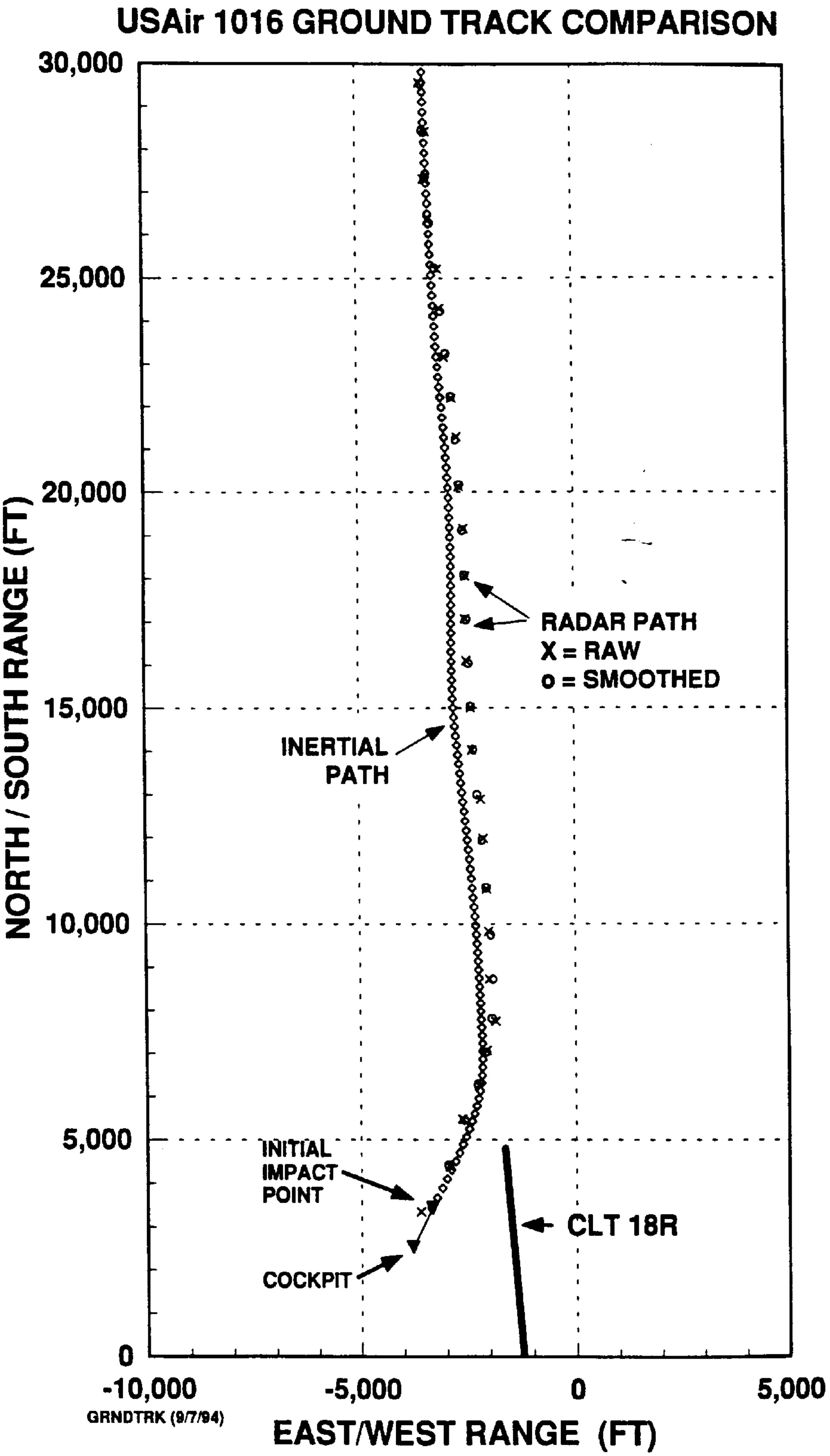
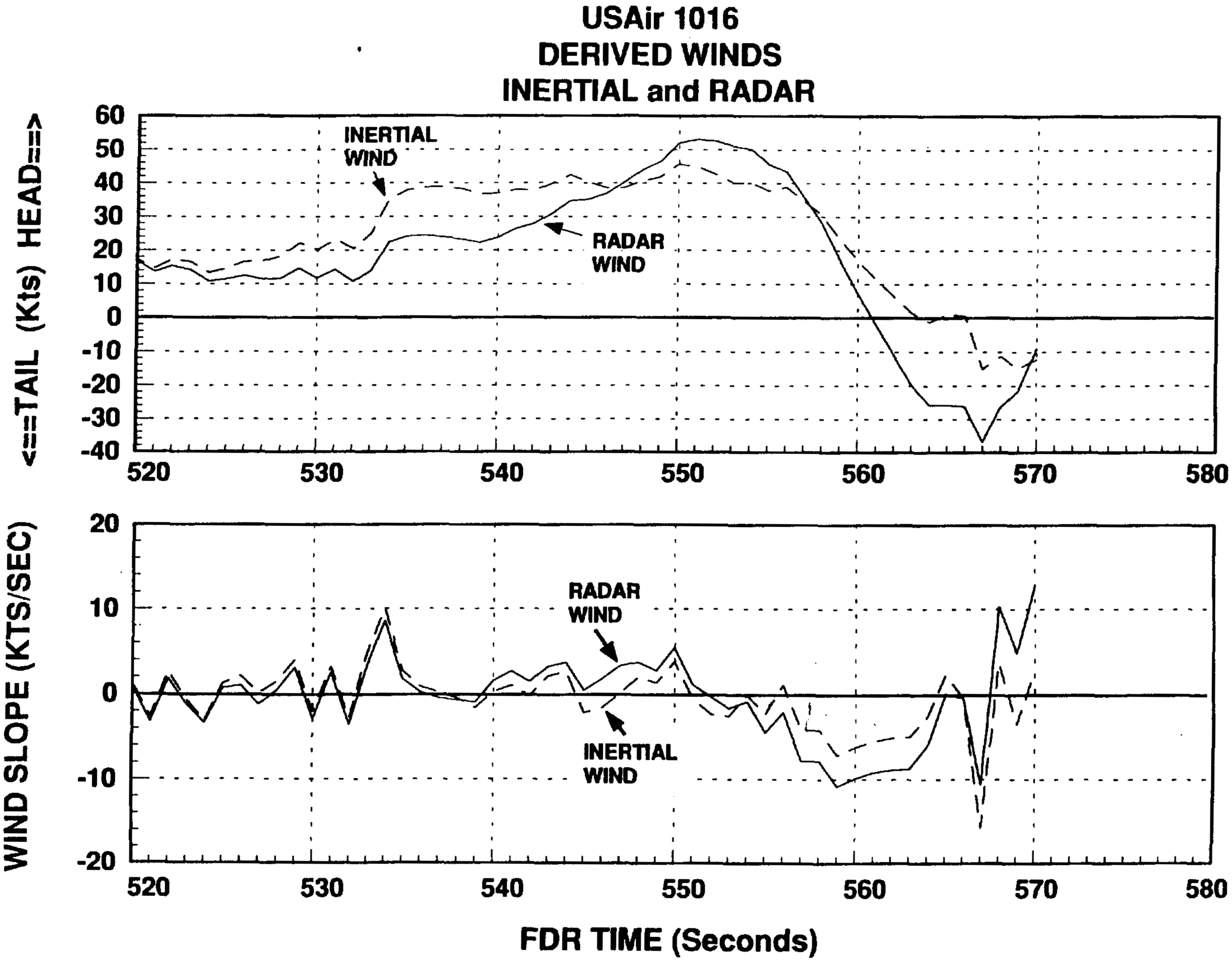

USAir 1016 GROUND TRACK COMPARISON
30,000
25,000
20,000
15,000
10,000
5,000
0
NORTH / SOUTH RANGE (FT)
-10,000
-5,000
0
5,000
EAST/WEST RANGE (FT)
GRNDTRK (9/7/94)
RADAR PATH
X = RAW
o = SMOOTHED
INERTIAL PATH
INITIAL IMPACT POINT
COCKPIT
CLT 18R

FIGURE 6



WSLPTST/WINDVCTR (12/29/94)

FIGURE 7

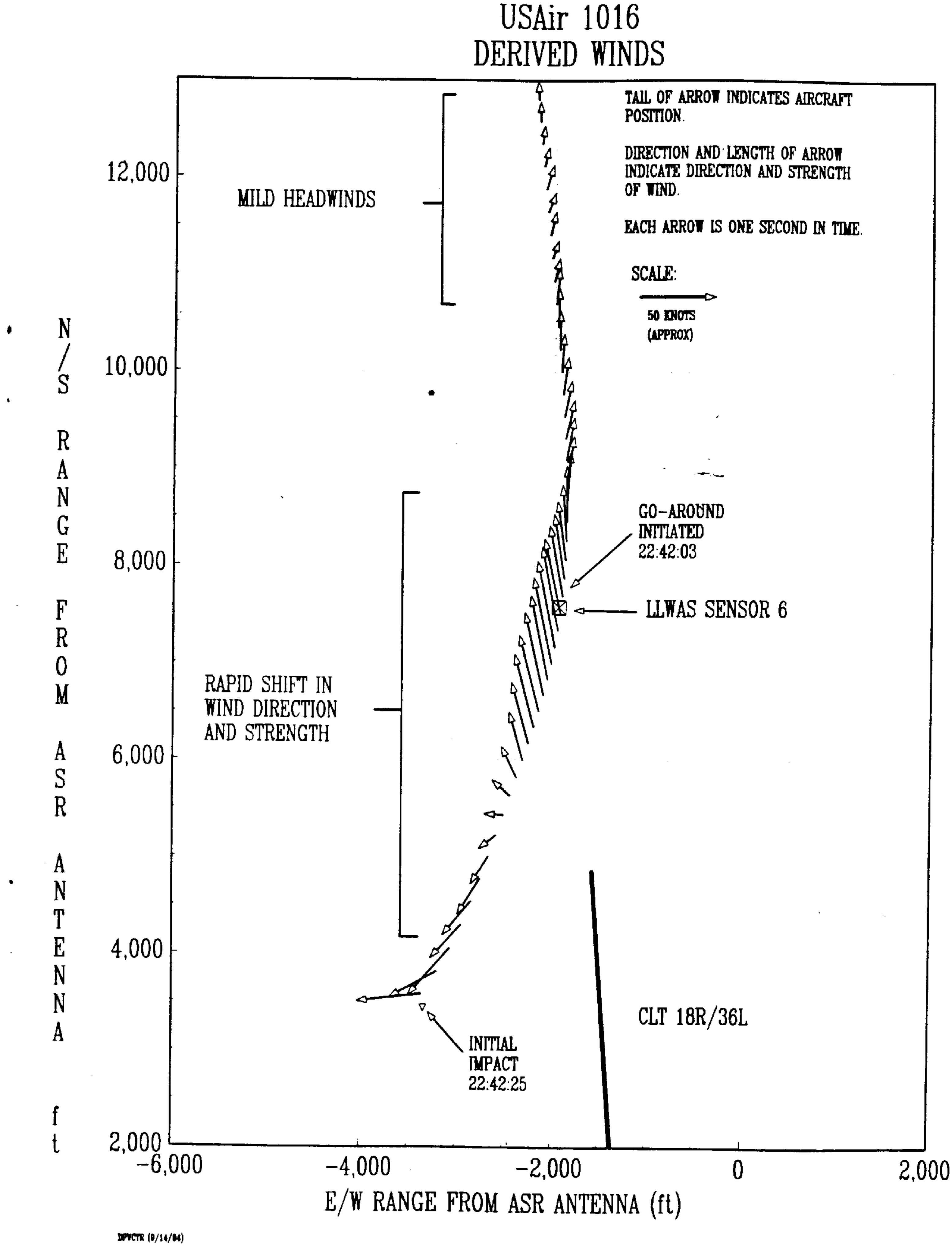

USAir 1016
DERIVED WINDS
TAIL OF ARROW INDICATES AIRCRAFT POSITION.
DIRECTION AND LENGTH OF ARROW INDICATE DIRECTION AND STRENGTH OF WIND.
EACH ARROW IS ONE SECOND IN TIME.
SCALE:
50 KNOTS (APPROX)
MILD HEADWINDS
RAPID SHIFT IN WIND DIRECTION AND STRENGTH
GO-AROUND INITIATED 22:42:03
LLWAS SENSOR 6
INITIAL IMPACT 22:42:25
CLT 18R/36L
N/S RANGE FROM ASR ANTENNA ft
12,000
10,000
8,000
6,000
4,000
2,000
-6,000
-4,000
-2,000
0
2,000
E/W RANGE FROM ASR ANTENNA (ft)
DPVCTR (9/14/94)

FIGURE 8

EFFECT of HEAVY RAIN

This section will show that:
1) Heavy rain can impose significant performance penalties on transport aircraft.
2) Available data suggests that this was not the case for USAir Flight 1016.
3) The possibility exists that minor, rain-induced performance degradation could have affected the outcome of this flight.

Numerous studies (both wind tunnel and full scale) have been conducted in an effort to qualify and quantify the effects of heavy rain on airfoil and aircraft performance. Principal conclusions derived from these studies indicate that heavy rain will affect performance in several ways. For a given angle of attack (alpha), the drag will increase and the lift will decrease. The maximum alpha capability of the airfoil (and consequently, the maximum lift) will also decrease.

The effects of heavy rain are considered to be negligible when an aircraft is in the clean configuration and at a low alpha. These effects increase with increases in alpha and the extension of leading- and trailing-edge devices (slats, flaps) and the landing gear. This was the configuration of US1016 at the time it encountered the heavy rain at CLT.

Douglas Aircraft (DAC) and Honeywell generated angle of attack time history data for the accident flight. Correlation of these alpha values with the estimated effects of heavy rain tend to indicate that US1016 was not in a flight regime where heavy rain would be expected to significantly affect aircraft performance. In Public Hearing testimony, a NASA Langley researcher stated that, based on estimated rainfall rates, exposure time and the calculated alpha values, "there was probably not a performance decrement effect due to rain".

The rainfall rates at CLT will never be known with a high degree of accuracy. Comparison of DAC and Honeywell alpha values reveal differences of up to five degrees. In light of these facts, it is possible that these values could have been such that the rain did result in small performance decrements. A review of the final seconds of the altitude trace of US1016 shows that the aircraft was close to leveling out when it impacted the ground. Therefore, even a small rain induced performance decrement could have contributed to the inability of the aircraft to fly out of this shear.

ENGINE PERFORMANCE

This section will show that:
1) According to the engine manufacturer, engine performance was unaffected by the heavy rain.

The effects of water ingestion by turbine engines have been studied thoroughly, and is in fact part of the FAA Certification testing requirements. Pratt & Whitney provided analysis of the engine spool-up characteristics (see Exhibit 13A) by comparing the US1016 FDR engine data to theoretical engine performance. The P&W analysis indicates that the engines performed satisfactorily.

USAir procedures for severe precipitation encounters call for the selection of engine ignition to the 'OVRD' (override) position. Although the flight crew did not select this position, the P&W analysis indicates that this did not seem to be a factor in the operating performance of these engines.

DOUGLAS AIRCRAFT COMPANY SIMULATIONS

This section will show that:
1) Douglas Aircraft has modeled two scenarios in connection with this accident.
2) The model used to generate these results has several limitations which restrict the applicability of the results.
3) Douglas is still working to complete several additional scenarios, and these will be subject to analysis by the participating parties to the investigation.

Exhibit 13C presents the DAC simulations of aircraft flight paths which result from application of the normal go-around procedure and the wind shear escape maneuver. The simulator used to generate these flight paths is a mathematical model of the aircraft performance data, and as such has several limitations associated with it. Although these studies are useful, the limitations seriously limit the conclusions which can be drawn from the data.

As noted previously, these data do not account for control forces or for control authority. Aircraft pitch attitudes and thrust levels are two input parameters which do not accurately replicate pilot response capabilities. In light of these facts, the DAC results must viewed for what they are, engineering study data. These data are useful to examine various 'what-if' scenarios, but in their current form, they must not be used to draw definitive conclusions regarding the survivability of this windshear.

As of December 22, 1994, DAC was still engaged in the 3-D modeling of the wind field in preparation to run several scenarios. Once this is accomplished, DAC will run the scenarios to provide flight path data, and the results will be scrutinized by the aircraft performance group (NTSB, ALPA, USAir, and Honeywell). Once those efforts are completed, it is highly likely that ALPA will issue an addendum to this performance section.

FLIGHT CREW PERFORMANCE

CREW WINDSHEAR EXPECTATIONS AND INFORMATION

This section will show that:

1) Windshear probability determination criteria have been established for flight crews at USAir.

2) Information provided to the crew of US1016 concerning weather conditions at CLT was incomplete and misleading.

3) This information adversely biased the crew's decision making process regarding the probability of windshear.

ATC has the responsibility to keep aircraft apprised of any weather conditions which would affect the safety of the operation. Accordingly, flight crews have the legitimate expectation that they will be kept so informed.

Cockpit Voice Recorder and ATC transcripts reveal that during the approach, the crew was aware of the possibility of windshear at CLT. Their state can be qualified as alert but not alarmed. This attitude is demonstrated by the "chance of shear" comment by the Captain and his querying of ATC. This crew actively solicited information in an attempt to quantify the probability of windshear, but their efforts were stymied by a variety of miscues, including a lack of timely, accurate and complete information from ATC.

The March-June 1994 edition of the USAir flight crew information publication "Flight Crew View" contains a checklist-type method to quantify the probability of windshear. This checklist consists of 13 accepted industry standard conditions or observations and the respective associated windshear probability. Figure 9 recreates this list and annotates it with two additional data items: whether the conditions were present at CLT, and whether the crew of US1016 was afforded that information.

Examination of this chart reveals the misleading and incomplete nature of the input that the flight crew was receiving.

MICROBURST WINDSHEAR PROBABILITY GUIDELINES

OBSERVATION	PROBABILITY OF WINDSHEAR	EXISTED AT CLT	KNOWN TO US1016
FORECAST OF CONVECTIVE WEATHER.....	Low	Yes	Yes
PRESENCE OF CONVECTIVE WEATHER NEAR INTENDED FLIGHT PATH:			
- With localized strong winds (Tower reports or observed blowing dust rings of dust, tornado-like features, etc.).....	High	No	No
- With heavy precipitation (observed or radar indications of contour, red or attenuation shadow).....	High	Yes	Yes*
- With rain shower.....	Medium	Yes	Yes
- With lightning.....	Medium	Yes	No
- With virga.....	Medium	No	No
- With moderate or greater turbulence (reported or radar indications).....	Medium	No	No
- With temperature/dew point spread between 30 and 50 degrees Fahrenheit.....	Medium	No	No
LLWAS ALERT / WIND VELOCITY CHANGE			
- 20 knots or greater.....	High	No	No
- Less than 20 knots.....	Medium	Yes**	Yes**
PIREP OF AIRSPEED LOSS OR GAIN:			
- 15 knots or greater.....	High	No	No
- Less than 15 knots.....	Medium	No	No
ONBOARD WINDSHEAR DETECTION SYSTEM ALERT			
- Reported or observed.....	High	N/A	No

NOTES: * US1016 unaware of existence of heavy rain until they encountered it.
** LLWAS alert was for another quadrant.

FIGURE 9

DECISION MAKING

This section will show that:

1) The in-cockpit decision making process regarding the weather conditions was procedurally valid.

2) Given the inputs this crew had, the outcome of this process was predictable.

Two primary weather related decisions were made by the crew during the approach and go around of this flight. First, should the approach be initiated? Second, should the approach be discontinued? We know what answers the crew arrived at, and with hindsight, know what answers would have served them better. The underlying specifics (the hows, whys and whens) which contributed to each decision are the key to understanding this issue. It is these aspects of the second question (should the approach be discontinued?) which require careful examination.

The products and results of cockpit decision making are usually readily apparent, even to the novice. However, the process itself is not always so evident or well defined. Dr. Judith Orasanu's published works and Public Hearing testimony provided substantial insight into the machinations of this process. Significant points from these sources, which must be considered in the analysis of this accident, include the following:

The process

- Reduced to its primary components, decision making consists of two elements: situation assessment and option identification.
- Sub-tasks of this process include pre-planning, contingency planning and task & workload management.
- Additional, normal cockpit activities must continue to be accomplished while the crew makes decisions. It is these 'parallel tasks' which necessitate workload management.
- Most cockpit decision making is supported by guidance, in the form of regulations, procedures and guidelines.

Decision type

- The missed approach decision is considered to be 'recognition-primed', in the sense that it involves 'condition-action' pairings. Stated another way, this can be considered an 'if-then' situation.
- Accurate cue interpretation is paramount in determining the 'conditions' required to elicit the respectively paired 'actions' and resolve the problem. In other words, the 'ifs' must be accurately known in order to initiate the 'thens' required to provide a satisfactory solution.
- Dr. Orasanu notes that "the cognitive work..." in these decisions requires "...situation recognition, response generation and response evaluation." The flight crew must accurately assess the situation (define the 'ifs'), select and initiate the appropriate response (choose and conduct the 'thens') and subsequently re-assess the situation to determine the results of their actions. This process is iterative and continuous, and is carried out in parallel with other cockpit tasks.

Cues

- Cues are the information elements used to develop the situation assessment.
- Individual cues can conflict with other cues, negating one or both.
- Clear, readily interpretable cues can induce ambiguity and confusion when they conflict with an otherwise consistent set of information.
- The absence of information is information.
- Once an interpretation of existing cue indications has been formed, a considerable amount of contradicting cues are required to 'undo' this conclusion.

One additional factor which must be considered is the influence that operating to a schedule has upon decision making. Operators, passengers, ATC and the flight crews all expect that the flights will proceed with a minimum of deviation and delay. These operational pressures are always present. Regardless of their nature, strong, clear cues are generally easily interpreted and incorporated into the decision making process. However, the sometimes subtle operational pressures are not so readily assessed, or even consciously considered. Cockpit crews must be taught to recognize and address this occasionally insidious influence on their decision making processes.

Dr. Orasanu stated that the crews' activities possessed all the elements of good decision making. They conducted an active, continual situation assessment. They formed a contingency plan. Their "task management was clearly very good." Windshear avoidance and recovery guidance was available. So where did the crew's decision making process falter?

The strongest indication derives from the fact that the crew conducted a normal go-around instead of a windshear escape maneuver. Until very late in the sequence, this crew never realized that they were experiencing a windshear encounter. They had a low expectation of an encounter on the approach, and even when experiencing one, it took them nearly thirty seconds to recognize that fact. In short, the crew had failed to assess the situation accurately.

Simulator windshear training imbues pilots with a programmed response to the unambiguous cue provided by this system. During this go-around, the Honeywell onboard windshear detection computer did not issue a warning to the crew. Although it is speculation, it seems highly likely that if this system had issued the warning, the crew would have responded immediately and correctly with the applicable windshear escape procedures. Conversely, it seems equally likely that they interpreted this lack of warning as a lack of windshear, at least until evidence to the contrary became overwhelming.

An analysis of NTSB accident reports found that "in most cases, crews exhibited poor situation assessments rather than faulty decision making". Accurate and reasonably complete information is required to produce a valid situation assessment, and the dearth of useful information at this crew's disposal has been well documented. This crew's inaccurate situation assessment was the predictable result of misleading and missing weather cues.

TRAINING

This section will show that:

1) Windshear training consists of avoidance and recognition & escape techniques.

2) The avoidance and escape techniques appear valid, but the recognition training requires re-evaluation.

The role of training in this accident must be examined. Specifically, does the training adequately and realistically prepare the flight crews for windshear? The Principal Operations Inspector (POI) for USAir noted that the ground school material is dedicated to windshear avoidance, while the simulator training focuses on reinforcing the escape maneuver procedures.

In this accident, the role that operational (schedule) pressures played in the crew's decision to initiate the approach was minor. Since the crew anticipated only a small probability of windshear, the need to 'avoid' was low, and the decision to proceed was straightforward. However, as noted earlier, these pressures do exist, and will become more significant as weather conditions deteriorate. Judgment and experience, not training, are the primary factors which enable flight crews to weigh these pressures in their decision making process. Training can be used to educate the crews on the role of operational pressures, but it cannot be a substitute for judgment and experience.

Avoidance of a windshear encounter requires prior knowledge of its existence or likely existence. Until this point, all discussions regarding the contribution of cues and miscues to the 'poor situation assessment' have been predicated upon the premise that the current 'cue set' for the presence of windshear is valid

Comparison of the details of this accident with the ground-school information indicates that the predictive cues (those related to the potential for windshear) appear to be valid. In the case of US1016, the flight crew just did not receive sufficient or pertinent information. However, when the more reactive cues (those which signal shear encounter) are compared, discrepancies appear between the training cues and the actual cues.

A fifteen knot airspeed rise is the industry standard threshold value used to signal recognition of a windshear encounter. Ten knot deviations are not uncommon on normal approaches. The FDR on US1016 recorded a twelve knot deviation, the pilots called it "ten" on the CVR. In either case, the 'trigger value' was not reached.

Turbulence, another sensory 'trigger', is an integral part of simulator windshear models. In post accident interviews, both US1016 crew members commented on the lack of turbulence prior to or during the encounter. The majority of the USAir simulator windshear scenarios incorporate noticeable turbulence, and to this crew, the lack of turbulence in this encounter was another contra-indication of windshear.

When undergoing simulator training or checking, crews are typically predisposed to expect a windshear encounter, and are consequently more attuned to the trigger cues. Due to the nature and lack of the information coming from ATC, the crew's expected probability of windshear became increasingly diminished as the approach progressed. Their predisposition towards windshear was decreased, and consequently, in spite of their efforts, they may have been desensitized to the significance of certain cues. The fact that the cues were more subtle served to exacerbate their difficulty in recognizing the encounter.

These results pose the following dilemma: Was the crew overly desensitized to trigger cues, or does simulator training introduce very specific, unambiguous recognition triggers which are not necessarily representative of actual encounters? Whatever the cause, this situation indicates that re-evaluation of windshear training premises and methods is needed. Areas of examination should include training scenario dynamics (shear magnitude, aircraft response, etc.), frequency of training and the amount of emphasis placed on this phenomena.

Corrective actions would likely include changes to the both the classroom- and simulator-based training, and would target recognition criteria and the simulator models. Flight crews must be educated to the fact that severe microbursts can be spawned from relatively small convective cells with tops as low as 20000-25000 feet. Industry must examine its windshear training syllabus to ensure that some of the subtle cues of this event do not mislead other crews into believing that they are in benign conditions.

THE ENCOUNTER

This section will show that:

1) US1016 was embedded in the microburst a total of approximately thirty seconds.
2) The crew initiated a normal go-around procedure.
3) Criticisms of certain crew actions have been made, and possible explanations for these actions are offered.
4) Specific aircraft performance data is required to definitively address certain issues.

Analysis of the FDR data indicates that US1016 was embedded in the microburst for a total of approximately thirty seconds. Much has been said regarding the crew's go-around activities and procedures, and their bearing on this accident. It will never be known with absolute certainty why this crew performed as it did, but the following discussions are offered as insights and possible explanations.

The microburst first manifested itself as an approximate twelve knot rise in the airspeed, which occurred essentially simultaneously with the onset of the heavy rain. Within several seconds the airspeed returned to its previous value. By this time, the Captain's attention was focusing on discontinuing the approach. The Captain cited loss of visibility, wet runway and crosswind as the basis for initiating the go-around.

A normal go-around was initiated. The crew proceeded to advance the throttles, pitch the aircraft up, and retract the flaps. The crew stated that at this point, the attitude, altitude and airspeed trends appeared normal, and the FDR confirms their assessment. Just after this, the airspeed and vertical acceleration began to decay severely. The crew attempted to maintain adequate airspeed, and the throttles were advanced to firewall power.

One issue of discussion is the manner in which the throttles were advanced, specifically that the target EPR was not achieved until late in the go-around. Recall that this crew was conducting a normal go-around, and did not initially perceive a significant threat. Standard procedure on aircraft without autothrottles is to bring the power levers to their approximate required position, allow the engines to spool up, and then 'fine tune' the power settings. In accordance with this procedure, this crew had accomplished the first two steps. Time and events prevented the orderly accomplishment of the third step; the throttles were firewalled when the crew recognized that the aircraft was not responding as required. Some effects of these actions are addressed in the AIRCRAFT PERFORMANCE section.

A second topic of discussion is the Captain's "push it down" remark on the CVR, and its relationship to the fact that the pitch attitude decreased to nearly 5° nose down during the go-around. Both crewmembers testified that, prior to listening to the CVR, they had no recollection of this statement. When questioned about this, the Captain offered a possible explanation. The Captain stated that he had likely made similar remarks at other times in his career. He noted that a lightly loaded DC-9 (as US1016 was) will climb very rapidly, and that he might make this remark to command a lowering of the pitch attitude in order to prevent climbing through the assigned altitude.

The First Officer, who was flying the aircraft, noted that since he had not heard the remark, he did not respond to it. However, he did note that the airspeed was decaying very rapidly, and that, at least to some extent, he was attempting to use pitch to slow or stop this decay.

Another question which is raised in the analysis of this accident is why it took the crew twenty or more seconds to recognize and react to the shear encounter and the aircraft's deteriorating performance. Again, this answer will never be known with certainty, but several possible factors could have individually or jointly influenced the crew's performance. Again, it must be recalled that at the time of the go-around, the crew did not perceive a significant threat, and they were essentially of the mindset that a windshear was not present. As Dr. Orasanu noted, once an interpretation of cues has been formed, a considerable amount of contradicting information is required to 'undo' this conclusion.

Some possible contributing factors which may have slowed the crew's response are (in no particular order):

1) Unfamiliar cue set - The various cues which the crew needed to assimilate did not form a coherent cue set. These included decreasing airspeed, moderate pitch attitude, high power, light weight, but no significant airspeed fluctuations or turbulence.
2) 'Startle effect' - The unexpected encounter with extremely heavy rain, and/or fixations or diversions could have impeded the crew's performance.
3) Somatogravic illusion - Longitudinal acceleration can cause the sensation of a change in the gravity vector. This would be interpreted as an increase in pitch attitude, and can introduce contradictory cues.
4) Fatigue or other physiological impairment - These can adversely affect the individual's cognitive skills.

As noted in the AIRCRAFT PERFORMANCE section, the Douglas Aircraft Company (DAC) has not yet provided the control force and control authority data required to fully address the questions concerning the aircraft pitch attitude throughout this encounter. It is imperative that control force and control authority data be provided in order to correctly and accurately analyze the crew's and aircraft's performance. Any analyses conducted without these data will be speculative.

SURVIVAL FACTORS

CHILD RESTRAINTS

This section will show that:
1) Two 'lap children' were aboard US1016; only one survived.
2) The NTSB has made recommendations regarding child restraints, and the industry is active on this subject.

In compliance with FAA regulations and USAir policy, two infants traveling as 'lap children' were aboard US1016. Lap children are those under two years old who are permitted to travel on their parent's lap without a separate seat or ticket. Only one of these children (nine months old, seat 21C) survived the accident. The seating location of the mother and child was the deciding factor in this infant's survival.

A portion of the aft fuselage remained intact and essentially upright after the accident, and the cabin area was relatively free of fire damage. Row 21 is the last row of cabin seats, and the seats in both this row and row 20 remained attached to the cabin floor. During the crash, this mother was unable to hold onto her child, but the child and mother were both removed from the aircraft by other individuals.

The NTSB has issued a recommendation that the FAA mandate improved child restraints capable of tolerating the crash loads defined by FAR 25.560 & 25.561. ALPA supports the required use of child restraints.

RESCUE and FIRE FIGHTING

This section will show that:

1) Operational difficulties were noted during the analysis of the RFF response.

2) These included determining and accessing the accident site location, and maintaining an adequate airport protection index level.

For many aircraft accidents, the response time of the Rescue and Fire Fighting (RFF) personnel is crucial to the survival of the aircraft occupants. US1016 touched down in a field on airport property, but came to rest in a residential neighborhood. It is estimated that the first public (city, county) RFF vehicles reached the scene approximately eight minutes after the accident, while the CLT airport units required an additional minute.

The initial response to the accident was impeded by the lack of specific knowledge as to exactly where the crash site was located. Communications transcripts show that the ATC personnel could only suggest a location in general terms, as evidenced by the transmission "proceed across runway 18L in a southwesterly direction toward the approach end of runway 5."

The 911 telephone calls began approximately one minute after the accident, and most callers were very specific as to the location of the wreckage. The difficulty encountered here was the inability to convey this information readily to the Airport RFF vehicles. A pre-plan should be established to ensure coordination between public RFF dispatchers and their airport counterparts. In addition, on-scene activities revealed the need to ensure close coordination of all personnel (fire fighting and medical) with the incident commander.

The fact that the accident was off-airport also created another problem for the ARFF vehicles. The existing plan called for the vehicles to exit airport property through gates activated by magnetic-swipe cards. The gate was initially opened, and then began to close again before all the vehicles could pass through. Repeated attempts to keep the gate open failed, and the ARFF personnel believe that this was caused by the swiping speed and the gate logic being incompatible. These personnel finally 'crashed' the gate by driving through it. Break-away gates, different gate logic, or ATCT operated gates are some suggested solutions to this problem.

The majority of the CLT ARFF vehicles and personnel were dispatched to this accident, and did not return for several hours. The CLT ACM Emergency Plan states that "When Charlotte/Douglas International Airport's total equipment and manpower falls below the requirements of Index D, the Aviation Director will issue a NOTAM for re-classification of index, and will notify all air carriers operating at Charlotte/Douglas International Airport." In spite of the fact that these conditions were met, no such NOTAM was issued, and takeoff and landing operations continued. Therefore, ALPA recommends that the airport authorities review the procedures to ensure that all responsible personnel understand their duties as defined in the Airport Emergency Plan.

THE ENCOUNTER

This section will show that:

1. *US1016 was embedded in the microburst a total of approximately thirty seconds.*
2. *The crew initiated a normal go-around procedure.*
3. *Criticisms of certain crew actions have been made, and possible explanations for these actions are offered.*
4. *Specific aircraft performance data is required to definitively address certain issues.*

Analysis of the FDR data indicates that US1016 was embedded in the microburst for a total of approximately thirty seconds. Much has been said regarding the crew's go-around activities and procedures, and their bearing on this accident. It will never be known with absolute certainty why this crew performed as it did, but the following discussions are offered as insights and possible explanations.

The microburst first manifested itself as an approximate twelve knot rise in the airspeed, which occurred essentially simultaneously with the onset of the heavy rain. Within several seconds the airspeed returned to its previous value. By this time, the Captain's attention was focusing on discontinuing the approach. The Captain cited loss of visibility, wet runway and crosswind as the basis for initiating the go-around.

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One issue of discussion is the manner in which the throttles were advanced, specifically that the target EPR was not achieved until late in the go-around. Recall that this crew was conducting a normal go-around, and did not initially perceive a significant threat. Standard procedure on aircraft without autothrottles is to bring the power levers to their approximate required position, allow the engines to spool up, and then 'fine tune' the power settings. In accordance with this procedure, this crew had accomplished the first two steps. Time and events prevented the orderly accomplishment of the third step; the throttles were firewalled when the crew recognized that the aircraft was not responding as required. Some effects of these actions are addressed in the AIRCRAFT PERFORMANCE section.

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III. RECOMMENDATIONS

For at least twenty years, NTSB recommendations have emphasized the necessity of providing timely and accurate hazardous weather reports to flight crews. Despite this continued emphasis, the situation has not improved to the point where flight crews can be confident that critical weather information will make it to their cockpits in time to enable prudent go/no-go decisions. Twenty years of windshear accident history make it very clear that at least one fundamental change to the National Airspace System is required. Pertinent weather information must be provided to the flight crews accurately, directly and in near real-time.

Therefore, in response to this situation and additional deficiencies which were revealed by this investigation, the Air Line Pilots Association offers the following safety recommendations:

1) Require the installation of airborne predictive wind shear detection equipment on all aircraft operating under Part 121 or providing scheduled service under Part 135.

2) Expedite the installation of microburst detection systems. As a minimum, these systems should be comprised of a Phase III LLWAS coupled with a Terminal Doppler Weather Radar (TDWR) or other technologies (such as piggy-backing Doppler capabilities on ASR-9 systems) where appropriate.

3) Expedite the development and implementation of uplinking and/or communication of composite ground-based microburst sensor array data directly to aircraft. (Some examples include those systems currently installed or under evaluation at Denver, Orlando and Memphis.)

4) Conduct performance evaluations of all existing LLWAS installations, and correct any noted deficiencies. Promulgate findings to ATC and Airline personnel until deficiencies are corrected.

5) Provide WSR-88D Doppler Weather Radar data products directly to Terminal ATC facilities.

6) Expand and integrate the meteorological data collected by the FAA and NWS such that the timely dissemination of this information to flight crews is enhanced.

7) Improve the adherence of ATC personnel to prescribed procedures. Particular attention should be focused on the dissemination of hazardous weather information to aircraft which are on initial departure or final approach.

8) Devise and implement methods to reinforce air traffic controllers' understanding and support of the flight crews' need for timely, accurate reporting of hazardous weather information.

9) Modify subparagraph 'a.' of paragraph 2-116 of FAA Order 7110.65H, 'Air Traffic Control' so that the phrase "Rapidly deteriorating weather conditions (convective activity, lightning, heavy rain, etc.) which could affect the safety of flight operations, and" precedes the existing text.

10) Modify subparagraph 'a.' of paragraph 2-121 of the FAA Order 7210.3K, 'Facility Operation and Administration' to add the sentence "Procedures should also be established to ensure the timely dissemination, to all aircraft operating in the terminal area, of information regarding rapidly deteriorating weather conditions (convective activity, lightning, heavy rain, etc.) which could affect the safety of flight operations." This sentence would be inserted after the first sentence.

11) Refine existing industry windshear training standards. Ensure that ground school curricula incorporate the most current microburst/windshear knowledge available. Ensure that simulator models provide high fidelity representations of actual microburst/windshear characteristics, particularly with respect to recognition cues.

12) Immediately conduct a Certification review of all airborne reactive windshear detection systems. Any system characteristics which affect the ability to provide timely warnings should be disseminated throughout the industry.

13) Continue efforts to design and certify child restraint devices.

14) Encourage airport authorities and surrounding municipalities to develop methods and procedures to ensure better coordination between airport and public rescue and firefighting units with respect to response time and on-scene activities.

APPENDIX A

A Report

to

The Air Line Pilots Association

ALPA

on

The LLWAS at Charlotte, North Carolina in Relation to the Microburst of July 2, 1994

by

William H. Haggard, C.C.M.

in collaboration with

Dr. T. Theodore Fujita

Asheville, North Carolina

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PREFACE

At the request of the Air Line Pilot Association, **ALPA**, an investigation was made of the effectiveness of the LLWAS (Low Level Wind [Shear] Alert System) at Charlotte, North Carolina in detecting and warning of the small, but strong microburst associated with the crash of USAir 1016 on the evening of July 2, 1994.

After assembling and reviewing operational weather data, Air Traffic Control (ATC) Transcripts and related data, the investigators visited the Charlotte Douglas Airport on August 1, 2, and 3, 1994 where they viewed and photographed the LLWAS sensors, National Weather Service Office, meteorological equipment and pertinent terrain features.

Key data from the non-commissioned National Weather Service Weather Surveillance Doppler Radar (WSR-88D) at Columbia, South Carolina and recordings of detailed data from all sensors of the LLWAS at Charlotte were obtained from the National Transportation Safety Board and made available by ALPA.

The investigation of the full dynamics of the Charlotte Microburst event is only partially completed at the time of drafting this report, and is continuing.

The objectives of this report are to review the development and use of the LLWAS system in general; at Charlotte, North Carolina in particular; and to assess the effectiveness of the system at Charlotte to detect and warn of the small, but strong microburst encountered by the accident aircraft.

These inherent limitations of the LLWAS II were further aggravated by a number of defects in the installation, maintenance and operation of the system at Charlotte, North Carolina. The most serious of these was the non-representativeness of the winds sensed by several of the perimeter sensors due to the effects of complex terrain and the presence of tall trees in close proximity to the sensors.

The system at Charlotte, North Carolina was first installed in 1981 as an LLWAS I, which had a greater wind shear alerting capability and a higher "false alarm rate," but virtually no microburst alerting capability.

Conversion of the system (by changes in computer software without sensor changes) in 1988 lowered the false alarm rate, lessened the system responsiveness to localized shears, and did not materially enhance its microburst alerting capability.

9. Despite an "unsatisfactory condition report" of the failure of the system at Charlotte to alert during intense convective activity over the field, made in 1993, no corrective action was taken prior to the July 2, 1994 accident.

10. Ongoing research - confirmed by the circumstances of the USAir 1016 crash at Charlotte - indicate the need for more sophisticated systems involving combinations of volume scanning radar coupled with augmented LLWAS and expanded educational programs to reduce the risk of future terminal area microburst related air crashes.

11. These new systems are not likely to be developed and extensively implemented for many years, leaving a high risk of future crashes in this decade.

FIGURES

I. Why LLWAS?

The most significant operational hazard to aviation is wind shear that is the product of convective activity in the vicinity of airports (McCarthy and Cline, 1987).

From 1964 to 1986 at least 32 wind shear accidents and incidents occurred. They resulted in over 600 fatalities and 250 injuries (FAA, 1988).

As early as 1975, the concept of "downburst cells" in connection with thunderstorm activity at JFK Airport in New York - leading to the crash of Eastern Air Lines Flight 66, a Boeing 727, on the approach to Runway 22-L - was introduced (Fujita, 1976). The author stated: "At the present time, there is no way of predicting the occurrence of these phenomena... in time and space. Additional anemometers at and around the major airports and **better real time assessment of wind and radar data, coupled with knowledge of these small but violent downbursts, will be of great help in the future for minimizing accidents of this nature."**

The FAA responded to the recognized threat of wind shear at airports by the Low Level Wind Shear Alert System (LLWSAS) - now simply LLWAS - the early development of which was undertaken at the National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, New Jersey (Goff, 1980).

The system as originally developed and installed at some major airports was soon found inadequate and underwent considerable evolution - described in a later section of this report labeled "Evolution of LLWAS."

II. Wind Shear and Microbursts

In meteorology, wind shear is the local variation of wind velocity in a given direction. In aviation, wind shear is the time variation of wind velocity along the path of a given aircraft. A rather full discussion of the effects of wind shear upon lift force (of aircraft) is contained in the book **The Downburst** (Fujita, 1985).

Many meteorologists believed the wind shears affecting aircraft came from "gust fronts" associated with larger scale, less concentrated thunderstorm outflow, the leading edge of onshore movement of sea breezes, and similar phenomena (Fujita, 1992).

III. History of Microbursts in Aviation

The National Academy of Sciences tabulated 27 aircraft accidents and incidents between 1964 and 1982 in the U.S. (NRC-NAS, 1983). These included 24 accidents and 3 incidents. Of the 27 occurrences, 24 were during landings and 3 were during take-offs. Since the list ended in 1982, it did not include such subsequent notable accidents as: Delta 191 at DFW on 8/2/85 during landing - with 134 deaths and 29 survivors; USAir 183 at Detroit on 6/13/84 during landing - with no deaths; and United 663 at Denver, CO on 5/31/84 during departure - with no deaths.

Microbursts are not confined to the U.S. Locations of pre-1985 microburst related accidents are shown in Figure 1, on page 21 (taken from Fujita, 1985).

IV. Evolution of LLWAS

Following several airline crashes during the mid-1970's, the FAA developed the Low Level Wind Shear Alert System (LLWSAS) (Goff, 1980). Initiated by NOAA's National Severe Storms Laboratory (NSSL), the initial system consisted of an array of wind-velocity measuring instruments located on poles or towers on the ground at or near airports.

The initial LLWSAS installation typically consisted of a Centerfield sensor and four or five outlying sensors, normally about two miles from the center site. The sensor locations were selected by the FAA on the basis of meteorological factors, terrain considerations, logistical constraints and to favor the Instrument Landing System (ILS).

The sensors have propeller vanes on standards that rose about 10 to 60 feet above the ground as necessary to obtain clear airflow above terrain or other obstructions. (NRC-NAS, 1983).

This system has, subsequently, become known as LLWAS I.

Each site was polled once every 10 seconds. The Centerfield site was considered a reference site, for which a running 2-minute average of wind velocity was maintained.

LLWAS I was controlled by a central mini processor (usually located in the Airport Control Tower) which maintained the 2-minute running average of the Centerfield wind. That information was continuously displayed in the Tower; used by controllers; and relayed to pilots.

These limitations were a direct result of the initial design assumptions. LLWAS I was designed for the detection of frontal shears under the assumption that hazardous wind shear is associated with large scale meteorological features. (Goff and Gramzow, 1989)

LLWAS I was deployed at 110 airports between 1977 and 1987.
LLWAS I had **no microburst detection capability and had excessive false alerts.** (Wilson and Cole, 1993). The initial LLWAS I installation at Charlotte, North Carolina was made in 1981.

LLWAS II was developed to reduce the false alert rate of LLWAS I and was intended to provide "a modest microburst detection capability." (Wilson and Cole, 1993).

The hardware was not altered. The difference between LLWAS I and II was primarily a software change.

Whereas LLWAS I alerted on a 15 knot vector difference between the Centerfield 2-minute wind and any perimeter sensor 10-second wind, LLWAS II uses a complex algorithm relating **system mean winds** with each sensor (including 10-second values at the Centerfield - not previously considered) and computes values of divergence and convergence over the system, utilizing a complex of sensor combinations in triangles and lines.

The anemometer readings are telemetered every 10 seconds to a central point, where the data are processed. A wind shear advisory is issued (by the computer to a display in the Control Tower) if one of the anemometers records winds that **differ from the network mean** by at least 15 knots, or if the network detects **divergence in the wind field.** (NRC-NAS, 1994).

This new complex algorithm applied to the sensors of LLWAS I converted the LLWAS I system into LLWAS II. It was a direct response to recommendations of the NRC-NAS, 1983 following the 1982 microburst crash in New Orleans. It avoided the time delays and costs that would be involved in procuring and installing an expanded, modernized and upgraded system. These "upgrades" to convert LLWAS I to LLWAS II were made between 1988 and 1991 at the 110 airports having LLWAS I systems. (Wilson and Cole, 1993).

3. Alerts shall be runway-specific and contain the following information:

   i. the type of shear: MBA or WSA,

   ii. the location of the shear integer nautical miles from the end of the runway,

   iii. the intensity of the shear magnitude of headwind lost or gain to the nearest 5 knots.

4. The system shall have few false alerts (not quantified).

The primary quantitative measures of the performance of LLWAS are the probability of detection (POD) and the probability of false alert (PFA). The probability of detection is the probability that the system will issue a wind shear or a microburst alert whenever a microburst occurs within the hazard region, the runway corridors extending to 3 miles beyond the ends of the runways. The probability of false alert is the probability that an issued alert is false, there is no evidence of wind shear. The NAS requirements are that POD shall be greater than .90 and PFA shall be less than .10.

The LLWAS III WSMB algorithm is designed to satisfy all of these requirements. The output is an alert message for Air Traffic Control of the form:

RUNWAY	ALERT	LOSS/GAIN	LOCATION
17D	MBA	-40k	IMD

where "17D" indicates the runway affected, in this case departure Runway 17, "MBA" indicates that a shear of microburst strength was detected, "-40k" indicates that a headwind loss of 40 knots will be encountered, and "IMD" indicates that an aircraft departing on Runway 17 may encounter wind shear within 1 mile of the departure-end of the runway. The other alert possibility is WSA for wind shear alert. An MBA is issued if the estimated headwind loss exceeds 30 knots and a WSA is issued for a headwind loss between 15 and 25 knots or for a headwind gain.

In the WSMB algorithm, all wind shear and microburst alerts are based on the detection of a significant convergence or divergence of the horizontal wind field. The algorithm measures the divergence of the wind field on edges and triangles formed by pairs and triples of sensors. Edges must have lengths between 1 km and 5 km. Triangles must have sides that are acceptable edges and must have no angles of less that 25 degrees. It is permissible for the triangles to overlap one another. The redundant coverage provides better detection than would be afforded by a strict triangulation. Since the size of these divergence-detecting elements is limited, the detection analysis is unaffected by the size of the senor network.

The aircraft overflew the east sensor before the ground level starburst outflow reached that sensor.

Figure 2 shows the relationship of the microburst outflow to the airport and the sensors. At the time of the crash, the microburst outflow was less that 3 kilometers (2 miles) in diameter [less than one mile in radius] and less than one minute old.

Delta 191 crashed on approach to Runway 17L at DFW at 1806 CDT on 8/2/85 during an encounter with a descending microburst head and the stretching roll vortices of the starburst outflow. **The LLWAS installed at DFW failed to detect and warn of the microburst** until after the crash, because the outflow did not reach the Northeast sensor until after the plane (an L-1011) had failed to gain altitude in its "go-around" attempt.

Again the microburst was about one minute old and its outflow - at the surface - was only 6.5 kilometer (3.3 miles) in diameter [1.6 miles in radius]. It occurred off the field, in the airport wind shear hazard zones, undetected by ground sensors.

Figure 3 shows the relationship of the microburst to the airport and the sensors.

VI. The Microburst at Charlotte, North Carolina On July 2, 1994

A small, but strong wet microburst descended from a parent thunderstorm cloud to the ground near the north end of Runway 18R (36L) at Charlotte Douglas International Airport on July 2, 1994. Ground impact of the descending core of high radar reflectivity was at approximately 1840 UTC (6:40 pm EST), when the outflow microburst winds at the ground began.

The core of high (above 50 DBZ) reflectivity was recorded at descending heights on six successive volume scans of the non-commissioned WSR-88D radar at the National Weather Service at Columbia, South Carolina, the nearest radar operating in Doppler Mode. The volume scans were at six minute intervals, giving only six "fixes" over thirty minutes of the core of high reflectivity on its descent.

These three successive vertical profiles of reflectivity are shown in **Figure 4**. Only one LLWAS sensor (No. 6, at the middle marker north of Runway 18L) was affected by the microburst outflow. Under the algorithm of LLWAS I, it would have alerted at 2239:57 UTC (1839:57 EDT), **[see Figure 5]**, but it was operating on the algorithm of LLWAS II and did not alert until 2242:57 UTC (1842:57 EDT), which was after the microburst encounter and crash of USAir 1016 (which occurred at 2242:25 UTC or 1842:25 EDT).

The Monrovia, Louisiana Microburst of July 20, 1986 did not impact an airport or relate to an aviation accident, but was extensively and continually monitored by sophisticated multiple radars and simultaneous photography. The combination of dual Doppler Radar winds, Range Height Indicators (RHI) continuous analysis, photography and airborne observations permitted a more detailed analysis of the dynamics of the cloud and microburst than ever before was possible.

The Monrovia Microburst is described in detail on page 119-125 and 276-278 of Fujita, 1992a. Pages 123-125 are replicated in Appendix 1 to this Report. Of special note (because of the similarity to events at Charlotte on 7/2/94) are Figures 4.3-7 on page 123, 4.3-10 on page 124, and 4.3-11 on page 125 of that publication.

The Mayaguez Microburst of June 7, 1992 (Fujita, Haggard, and Bohan, 1992b) provides another example of a microburst associated with the collapse of a high level core of high radar reflectivity and the descent of the microburst "head" to the ground.

Figure 7 is a replica of Figure 21 from that report, showing the track of the diminishing radar echo (as indicated in the radar images as the falling high reflectivity passed through the beam height of the San Juan, PR Radar), the mesoscale outflow, and the microburst outflow which was, unfortunately, encountered by a landing commuter aircraft during approach to the Mayaguez Airport.

The strong similarities in the four microbursts of August 1,1983, July 20, 1986, June 7, 1992, and July 2, 1994, may offer knowledge of importance to future aviation safety when they are fully analyzed.

VIII. LLWAS at Charlotte, North Carolina

Initially installed in Charlotte in 1981, the LLWAS System there contained six sensors - as shown in **Figure 8**. All were mounted on telephone poles at various heights of:

1.	Centerfield	20 feet
2.	Northeast	56 feet
3.	Southeast	68 feet
4.	Southwest	55 feet
5.	West	58 feet
6.	Northwest	60 feet.

These guidelines on heights and sites were not followed at Charlotte, and the **problems have worsened through the years** as the woods surrounding the airport have grown taller, reaching and exceeding the heights of some sensors.

Specific quotes and their applicability to the sensors include:

- "The wind direction is affected by ridges, troughs and embankments. This effect is most pronounced if the wind is blowing at an angle to the ridge, trough, or escapement."
  [This is applicable to the "tree canyon" of sensor 6 - the northwest senser north of Runway 18L.

- "For sensor locations in an area that is heavily forested with trees of fairly uniform heights, the anemometer should be 20 feet higher than the tallest trees and the sensor position should not be closer than 500 feet from the forest edge...**a very tall mast may be required**" (emphasis added).

  [This is applicable to **all the perimeter sensors at Charlotte,** but is **especially pertinent to sensor 6, the northwest sensor**, which is below the tops of trees within 500 feet].

- "With irregular tree tops, the sensors should be 30 feet or more above the tops.... Large clearings in a dense forest should be avoided for sensor locations, since these produce extremely irregular (turbulent) and virtually undefinable wind conditions."

  [This is applicable to the NE, SE, SW and W sensors at Charlotte.]

- "If an obstruction to the wind exists at a preferred sensor location..., it is preferable to locate the sensor further away from the runway threshold, rather than closer. This should be done to increase rather than decrease the warning capability of LLWAS. The closer a critical anemometer is to a runway threshold, the less time there is available for shear detection and distribution of data to pilots."

  [This is true for large scale, frontal wind shear, but not so for microbursts].

When the LLWAS I at Charlotte, which had a high incidence of "false alarms" was converted to LLWAS II (by software modifications only), in 1988, it is evident that these siting criteria were not re-checked, despite the steady growth of the pine forests (with probably as much as two feet per year height increase of the trees).

The algorithm in use for LLWAS II is complex, and no longer simply compares the perimeter sensors 10-second winds to the Centerfield 2-minute average.

In addition to the perimeter sensor values and Centerfield 2-minute average, the Centerfield 10-second values are considered, as well as complex computations of convergence and divergence within and between triangles and lines.

These are:

Triangle 1 with vertices at sensors 1, 2 and 3
Triangle 2 with vertices at sensors 1, 3 and 4
Triangle 3 with vertices at sensors 1, 3 and 5
Triangle 4 with vertices at sensors 1, 4 and 5
Triangle 5 with vertices at sensors 1, 6 and 2
Triangle 6 with vertices at sensors 2, 3 and 5
Triangle 7 with vertices at sensors 3, 5 and 6.

Edge 1 with end points at sensors 1 and 2
Edge 2 with end points at sensors 1 and 3
Edge 3 with end points at sensors 1 and 4
Edge 4 with end points at sensors 1 and 5
Edge 5 with end points at sensors 1 and 6
Edge 6 with end points at sensors 2 and 3
Edge 7 with end points at sensors 2 and 4
Edge 8 with end points at sensors 2 and 5
Edge 9 with end points at sensors 2 and 6
Edge 10 with end points at sensors 3 and 4.
Edge 11 with end points at sensors 3 and 5
Edge 12 with end points at sensors 3 and 6
Edge 13 with end points at sensors 4 and 5
Edge 14 with end points at sensors 4 and 6
Edge 15 with end points at sensors 5 and 6.

A wind shear advisory is issued when the computer finds that:

a) one of the anemometers records winds that differ from **the network mean wind** [different from the Centerfield 2-minute average] by at least 15 knots; or

b) the network data, when processed, indicate significant divergence in the wind field, (NRC-NAS, 1994).

The failure of the system to provide timely alerts on July 2, 1994 is inherent in all LLWAS II **limited area** coverage systems and in all **solely ground based systems** to detect the falling head of a microburst until it has reached the ground and the stretching roll vortices create the starburst pattern damaging winds.

X. Potential for Detection and Warning of Terminal Area Microbursts

Work which has been done at Denver Stapleton Airport, largely in cooperation with the National Center for Atmospheric Research (Coruman and Mahoney, 1991 and RAP, 1990 and 1991) and work underway at Orlando International Airport (Wilson and Cole, 1993) - especially discussion of LLWAS III and LLWAS IV - is in agreement with the published comments of Fujita (Fujita, 1992a) that detection and early warning of Terminal Area Microbursts requires **integrated systems of volume scanning radar** and greatly expanded surface sensing systems.

That these systems are not to be deployed until very late in this decade or even into the next century, leaves **the continuing potential for future Terminal Area Microburst related accidents** until the implementation of combined volume scan radar/expanded - denser network LLWAS systems on a large scale.

Even with the eventual installation of systems with a potential for earlier (1 to a few minutes) alert time potential, there will be a great need for education and training on the utilization of these systems and understanding of capabilities and limitations (McCarthy, 1987 and McCarthy and Sand, 1990).

TABLE 2

LLWAS Centerfield Data and Vector Difference Winds

● Indicates potential LLWAS alerts using the "old" LLWAS I algorithm. Centerfield winds are in degrees magnetic and knots. Vector differences are in degrees and knots. Time is minutes and seconds past 18:00:00 EDT (mmss: mm = minutes, ss = seconds).

Time	$\bar{C}$		C-$\bar{C}$		2-$\bar{C}$		3-$\bar{C}$		4-$\bar{C}$		5-$\bar{C}$		6-$\bar{C}$	
3427	150	8.9	212	2.0	276	5.1	18	3.8	309	2.1	55	2.3	205	5.7
3437	151	8.9	186	1.3	279	5.0	354	4.7	240	1.1	67	0.8	248	5.4
3447	151	8.7	90	0.6	303	3.2	327	3.7	225	1.0	90	0.6	219	4.3
3457	150	8.5	69	1.9	286	5.1	338	4.6	277	0.9	346	0.5	204	4.8
3507	148	8.6	91	3.8	284	5.3	316	0.6	349	1.7	272	1.2	235	4.7
3517	148	8.8	105	2.7	306	4.4	0	1.0	302	3.3	354	2.1	237	1.8
3527	147	9.1	48	0.7	349	3.5	46	3.0	316	3.2	334	3.1	277	5.0
3537	148	9.3	211	1.3	342	5.7	0	1.6	43	2.8	320	3.4	312	4.7
3547	149	9.8	159	4.2	342	5.1	345	1.9	353	3.2	322	3.9	308	3.1
3557	149	10.5	158	5.5	316	5.8	350	2.7	341	2.6	323	5.6	310	2.7
3607	148	11.3	147	5.8	313	4.5	332	4.3	22	2.4	330	6.3	343	3.4
3617	147	11.7	152	2.3	321	6.8	337	8.0	321	2.7	331	8.8	340	7.1
3627	146	12.1	150	2.9	307	8.4	328	6.1	327	2.1	325	6.1	308	6.8
3637	146	12.4	199	2.4	311	8.2	336	6.6	3	3.2	325	6.4	298	7.0
3647	146	12.8	185	1.4	316	8.2	350	7.0	339	4.0	328	6.6	296	6.4
3657	147	13.2	334	0.2	321	9.3	340	6.5	327	4.2	328	6.2	285	8.1
3707	148	13.4	87	1.1	315	9.1	333	8.5	330	6.4	342	7.9	287	8.1
3717	149	13.9	133	3.2	316	8.4	335	7.0	336	8.1	330	7.9	302	9.2
3727	148	14.5	82	3.1	321	8.7	332	8.5	333	9.6	325	8.5	312	11.0
3737	146	15.0	53	6.2	317	9.3	331	10.1	326	13.0	327	9.0	305	11.1
3747	143	15.2	45	7.5	310	12.7	328	11.3	322	8.2	320	9.2	301	9.9
3757	140	15.2	46	6.2	302	10.7	325	10.3	327	6.2	309	6.3	297	10.2
3807	137	15.1	40	7.4	280	11.2	320	10.1	307	6.2	292	6.0	290	11.7
3817	132	15.3	30	9.0	271	11.8	306	10.5	308	9.3	284	8.0	281	12.0
3827	128	15.2	14	8.4	267	10.4	306	10.2	307	9.2	302	8.3	281	12.8
3837	124	15.3	27	6.7	263	13.4	306	10.4	277	7.9	292	8.7	279	10.9
3847	120	15.5	27	4.8	257	14.5	305	8.6	280	7.2	277	9.0	288	11.2
3857	116	15.8	20	4.6	256	13.0	297	8.8	277	7.5	275	10.3	270	12.8
3907	112	15.9	19	2.8	262	12.7	304	8.3	264	9.2	276	12.8	275	13.4
3917	108	15.8	351	1.9	253	12.7	290	8.8	266	7.9	268	11.1	266	13.4
3927	106	15.8	46	0.5	239	14.4	271	8.3	268	9.9	261	11.8	260	18.0 ●
3937	104	15.9	113	2.1	247	15.3 ●	252	8.1	274	7.1	264	10.6	252	16.9 ●
3947	103	16.1	94	1.9	244	12.9	262	8.1	271	8.5	258	10.2	241	14.6
3957	102	16.2	150	1.2	248	14.0	267	10.0	246	9.6	261	9.5	238	15.6 ●
4007	101	16.6	109	4.4	253	14.2	273	10.9	236	9.8	262	13.1	243	19.0 ●
4017	102	17.3	100	6.8	253	18.4 ●	278	11.3	233	9.6	265	13.0	236	18.6 ●
4027	102	18.1	109	5.9	243	17.5 ●	280	12.1	247	8.9	265	12.8	237	18.4 ●
4037	102	18.5	83	2.6	239	19.4 ●	276	11.7	248	11.7	269	12.4	244	18.4 ●
4047	102	18.8	44	2.1	247	20.7 ●	277	12.0	249	11.7	273	14.6	228	18.6 ●
4057	103	19.3	139	2.1	248	20.9 ●	280	13.3	247	11.6	270	13.1	243	19.3 ●
4107	103	19.7	108	1.3	248	22.7 ●	282	11.7	256	12.7	268	15.7 ●	247	19.9 ●
4117	103	20.0	262	1.1	243	24.8 ●	287	13.1	270	17.0 ●	254	15.3 ●	236	22.4 ●
4127	103	20.3	266	1.3	242	26.0 ●	280	11.3	273	17.7 ●	259	11.2	230	24.0 ●

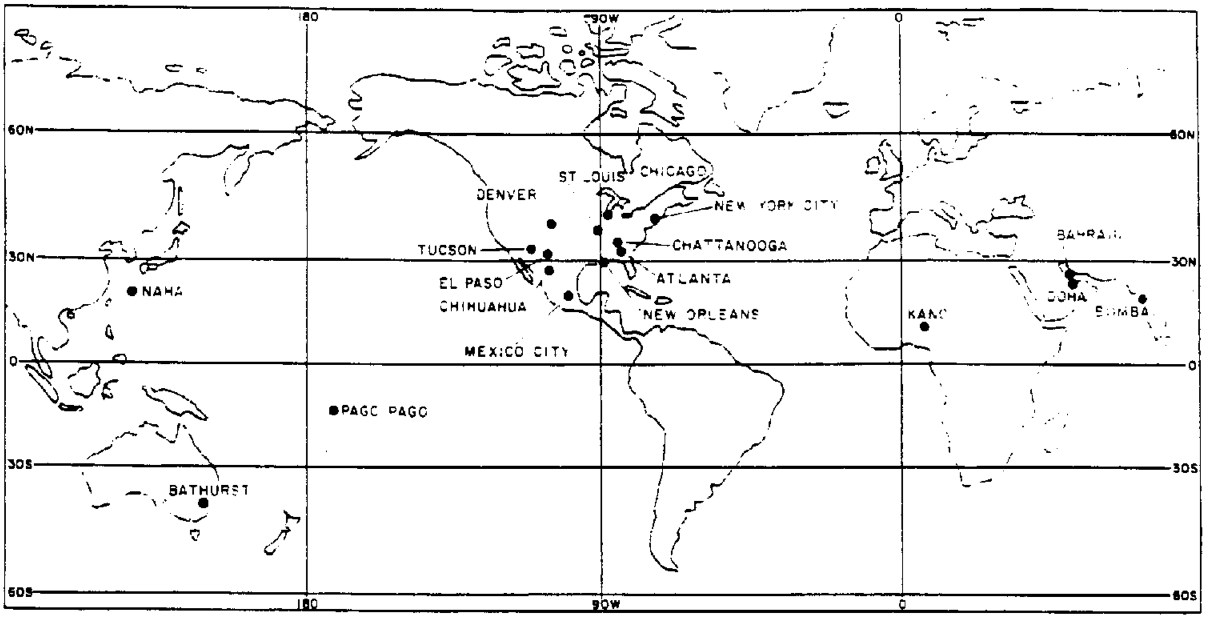


Fig. 3.4 Locations of microburst-related aircraft accidents/incidents around the world. Based on both confirmed and unconfirmed reports available to the author as of December 1984.

Figure 1. Pre - 1985 microburst related air crashes [from Fujita (1985)]

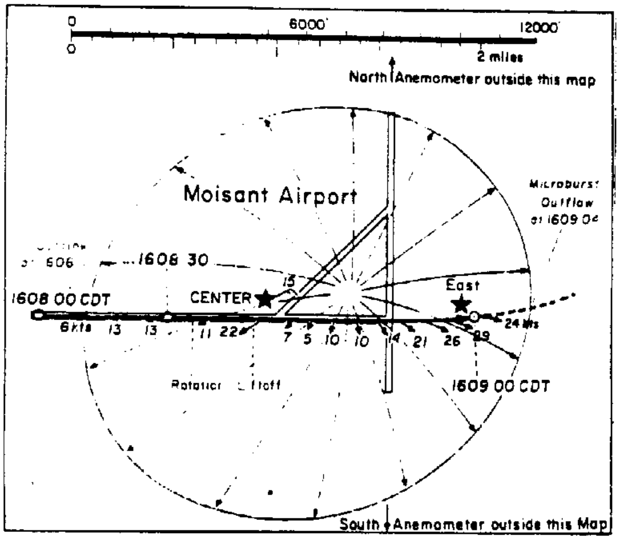


Fig. 4.1-7 The PAA 759 microburst on 9 July 1982 at Moisant Airport, New Orleans, Louisiana. This microburst intensified very rapidly while the aircraft was climbing above Runway 10.

Figure 2. The New Orleans Microburst of July 9, 1982 [from Fujita (1992a]

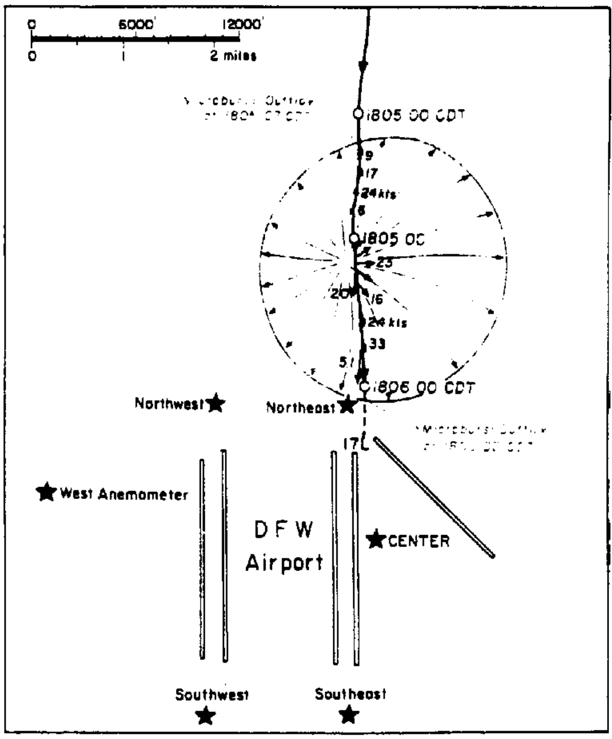


Fig. 4.1-9 The Delta 191 microburst which escaped detection by the six anemometers encircling the runway area. The microburst touched down outside the airport and expanded quickly into the runway area.

Figure 3. The DFW Microburst of August 2, 1985 [from Fujita (1992a)]

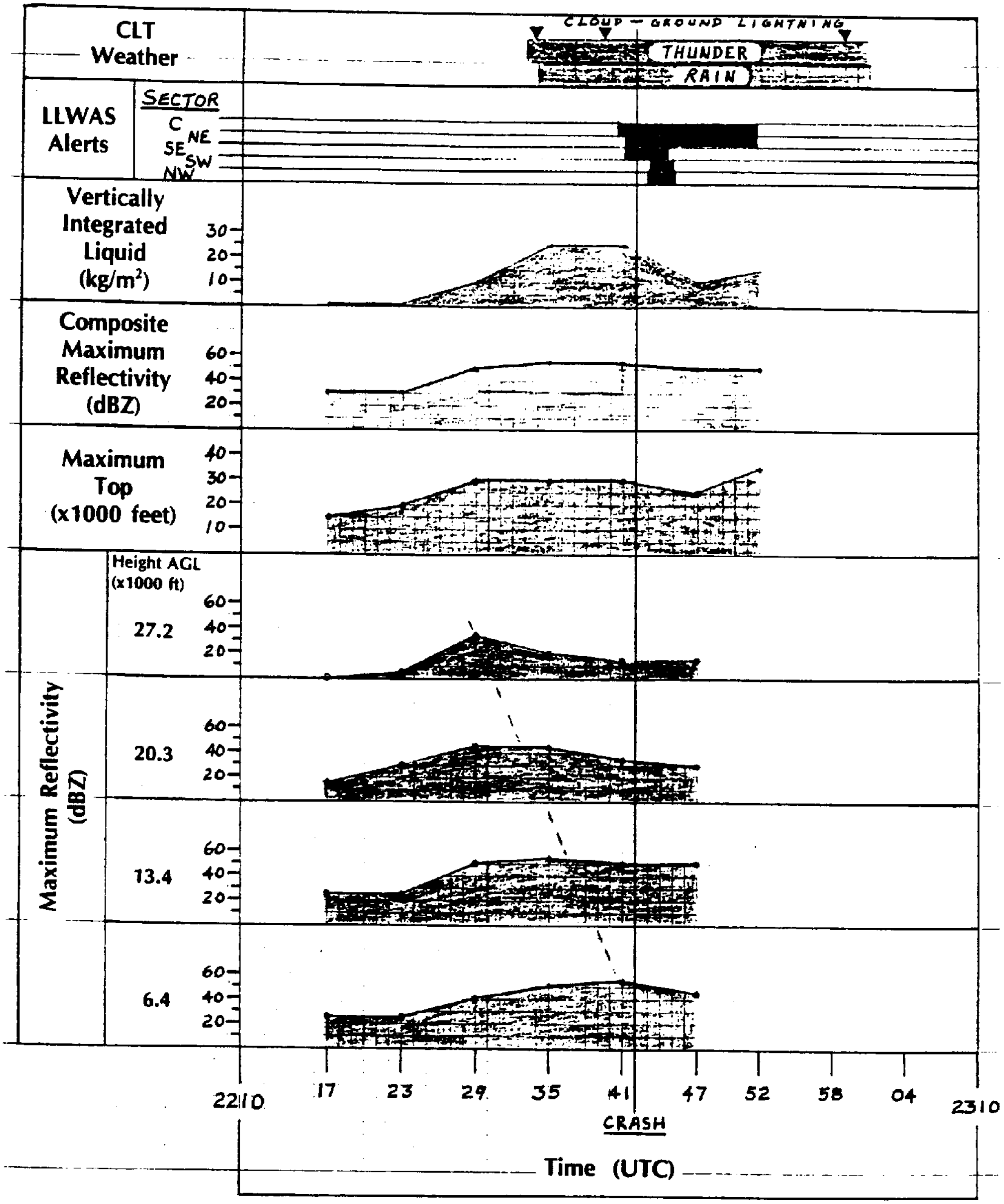


Figure 4. Time sequences of: Charlotte (CLT) weather (top graph); LLWAS II sector alerts (2nd graph); liquid water in CLT storm by radar (3rd graph); composite maximum radar reflectivity in CLT storm (4th graph); maximum radar echo heights in CLT storm (5th graph); and downward progression of maximum radar reflectivity [falling head] in CLT storm (bottom 4 graphs).

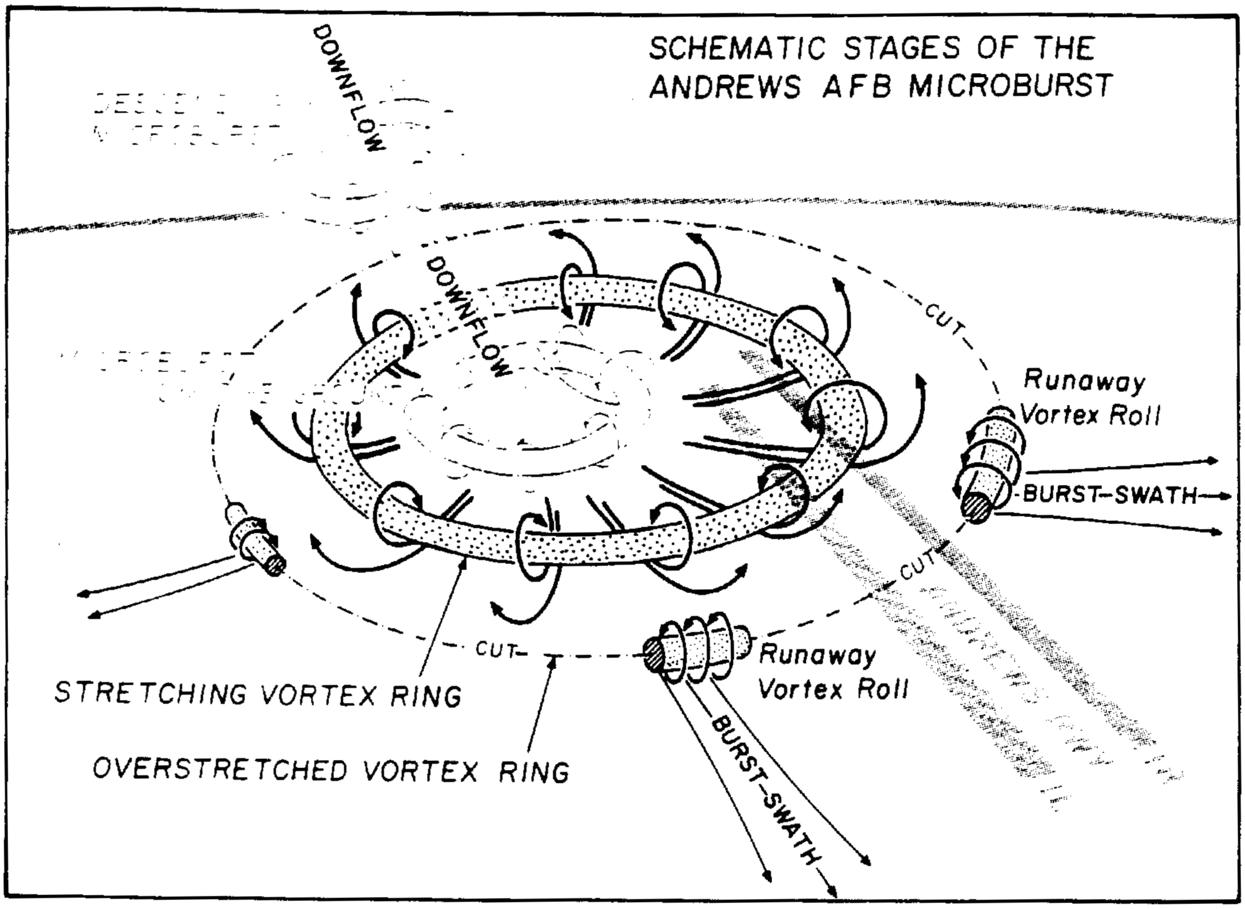


Figure 5. Four stages of the Andrews Air Force Base Microburst of August 1, 1983 [from Fujita (1983b)]

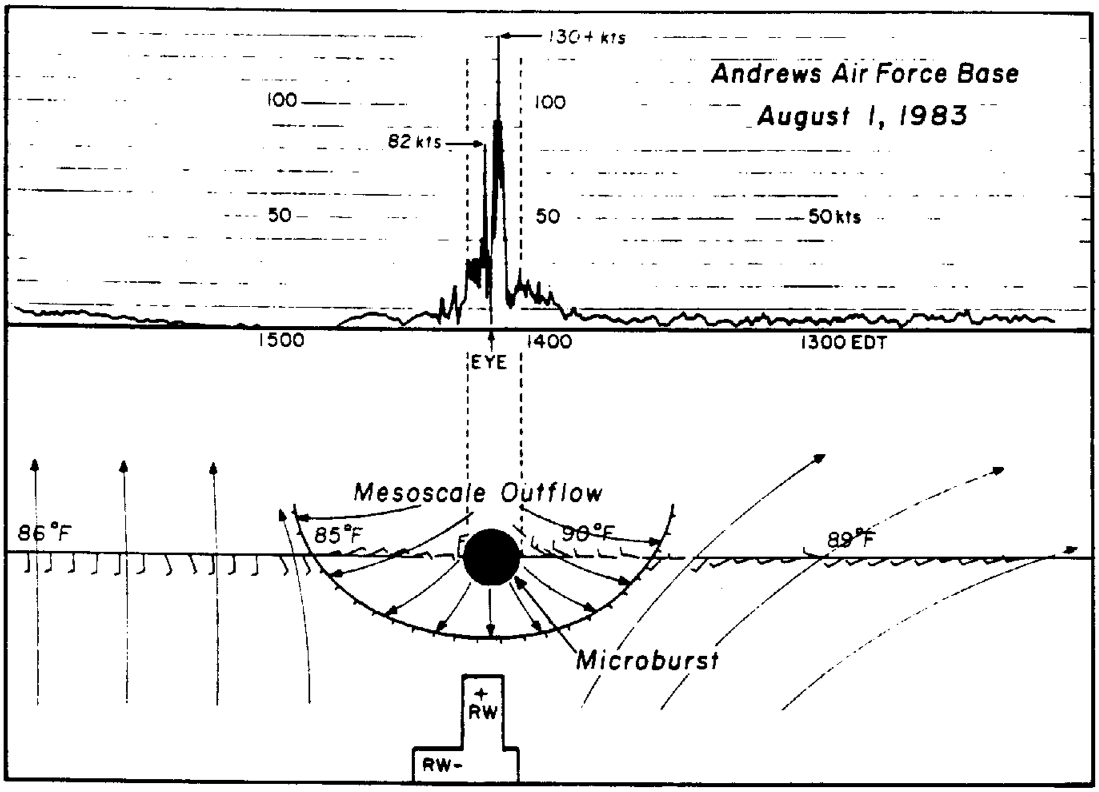


Figure 6. Two scales of wind flow (meso- and micro-) of the Andrews Air Force Base Microburst of August 1, 1983 [from Fujita (1983b)]

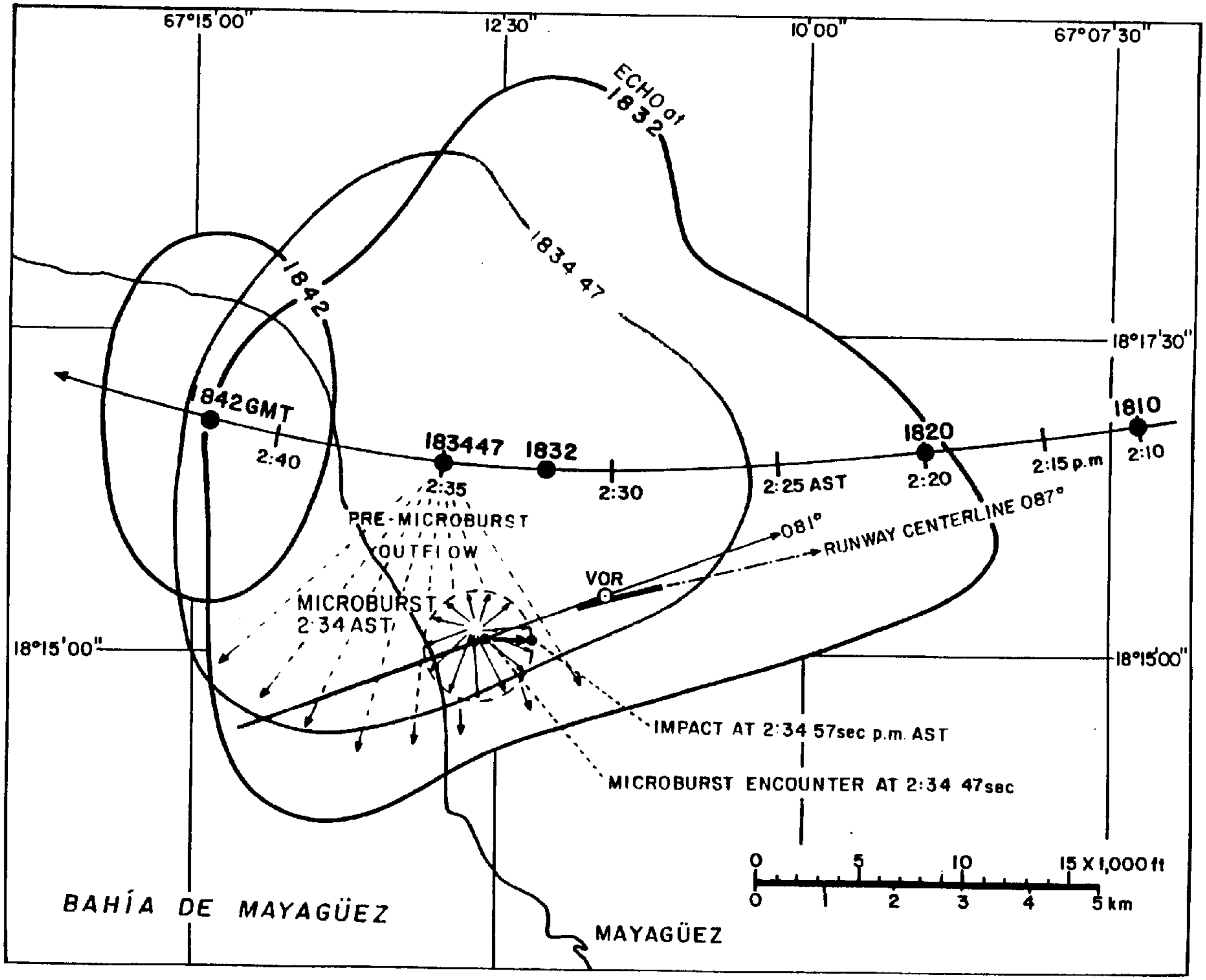
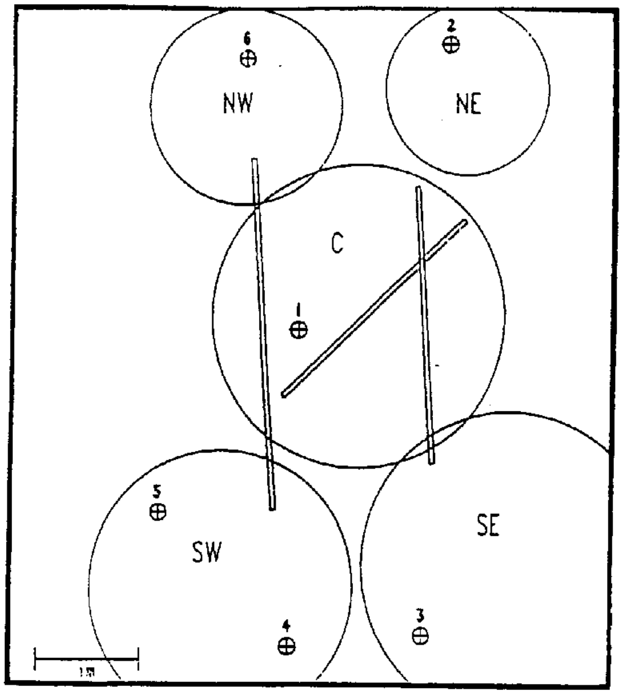


Figure 7. Motion and collapse of the radar echo of the Mayaquez Microburst on June 7, 1992 [from Fujita, et al (1992b)]

Figure 8. Placement of LLWAS sensors at Charlotte



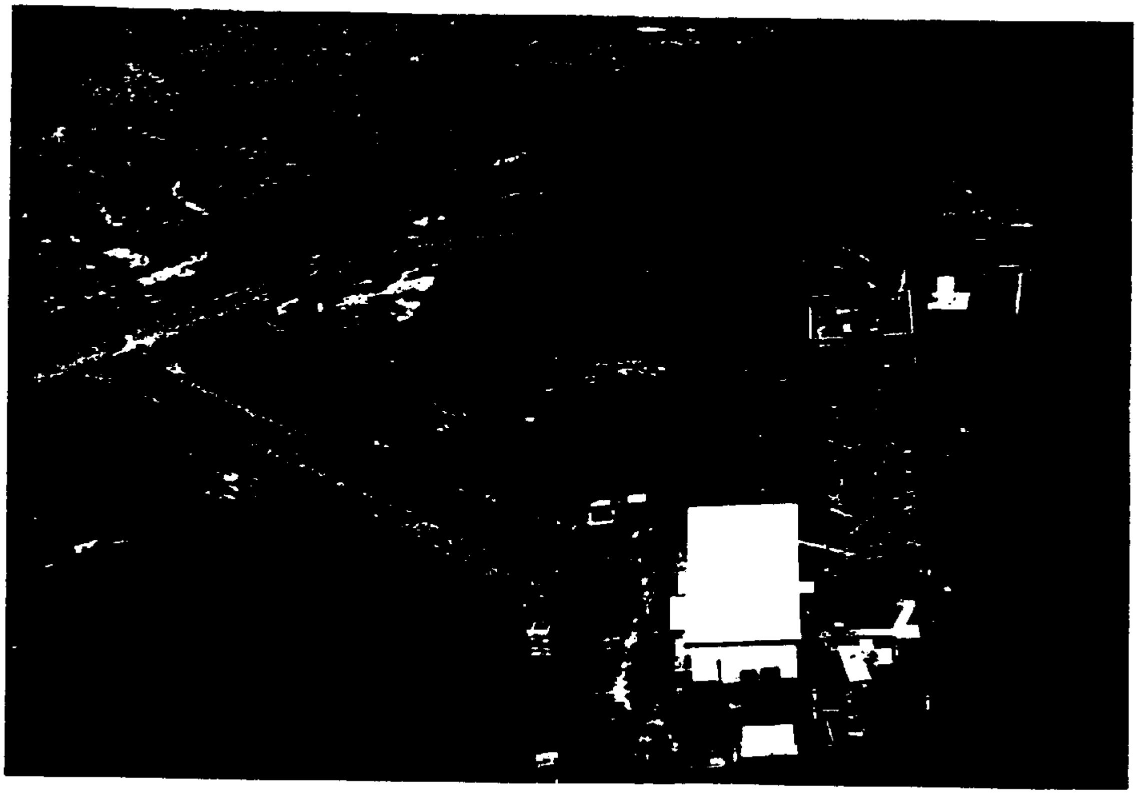


Figure 9. Centerfield LLWAS and ASR at Charlotte

Figure 10. NE LLWAS at Charlotte

Figure 11. SE LLWAS at Charlotte

Figure 12. SW LLWAS at Charlotte

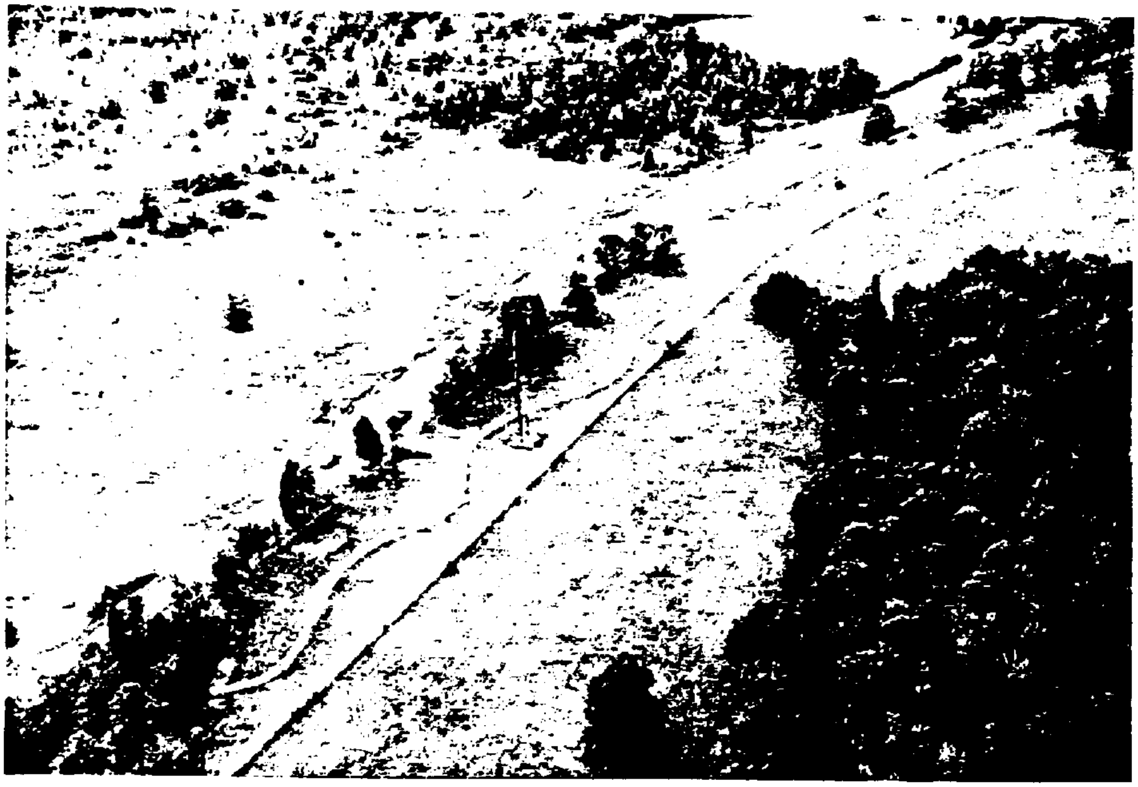


Figure 13. W LLWAS at Charlotte

Figure 14. NW LLWAS at Charlotte seen from the south

I-24

Figure 15. NW LLWAS at Charlotte seen from the north

A Report

to

The Air Line Pilots Association

ALPA

on

The LLWAS at Charlotte, North Carolina in Relation to the Microburst of July 2, 1994

by

William H. Haggard, C.C.M.

in collaboration with

Dr. T. Theodore Fujita

Asheville, North Carolina

September, 1994

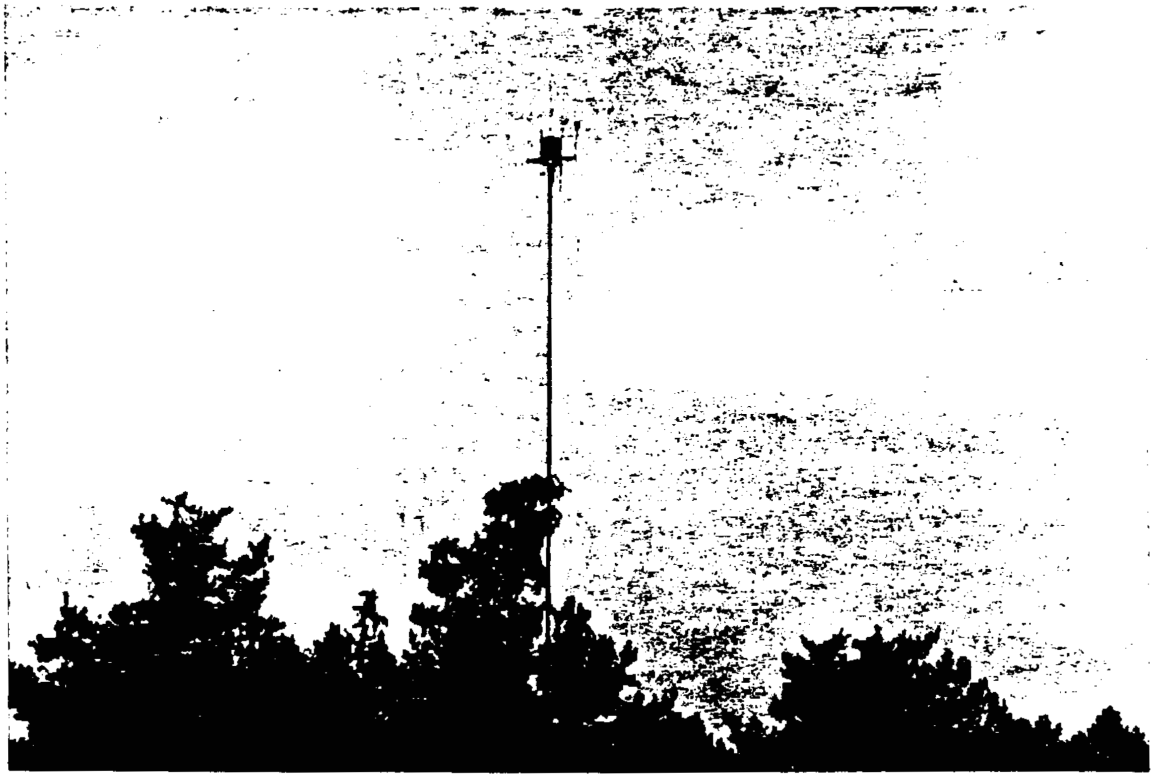


Figure 16. LLWAS "tall tower" at Asheville, NC

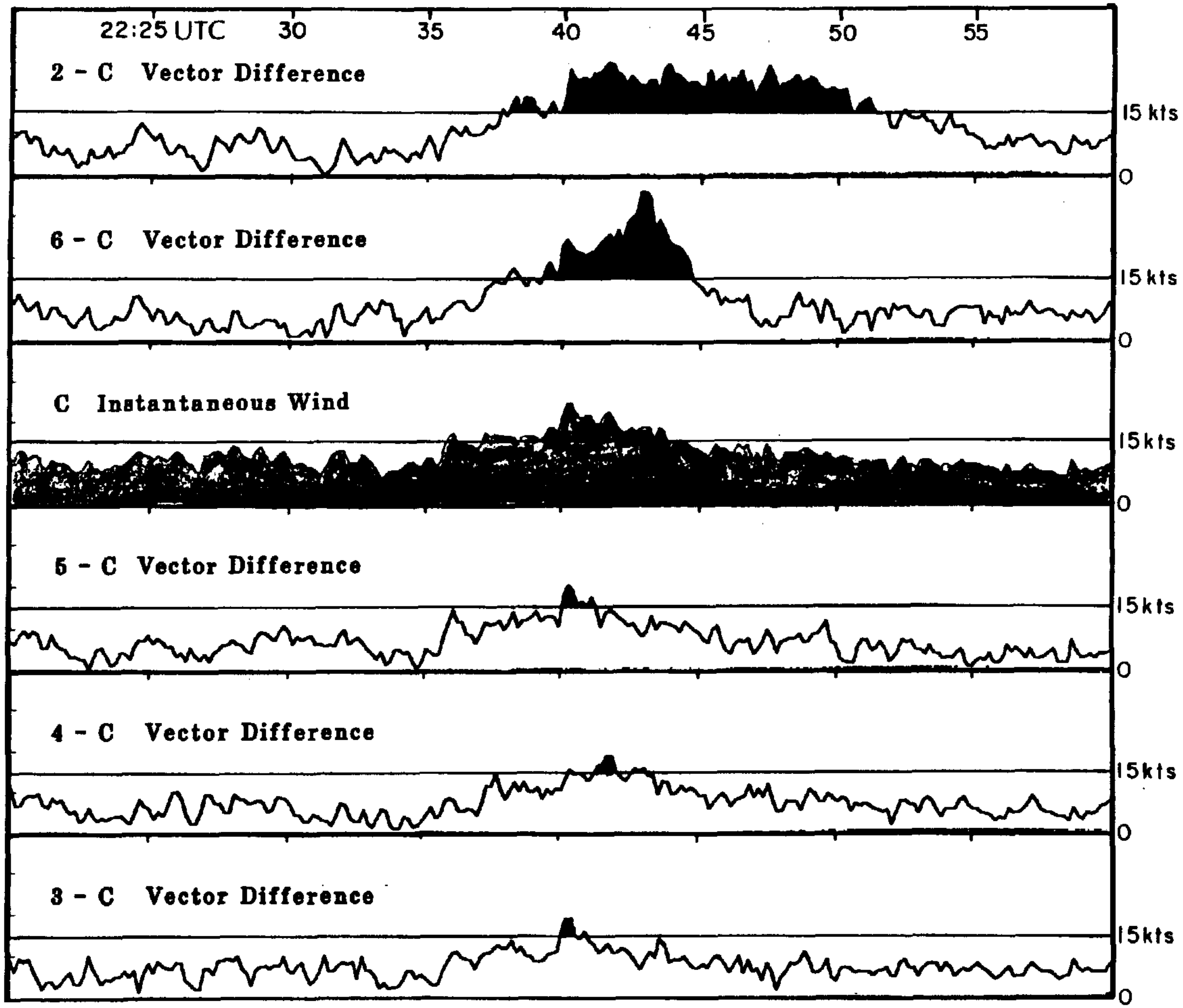


Figure 17. Vector Differences (knots) of each sensor (from Centerfield) 2220 UTC to 2300 UTC July 2, 1994 at Charlotte

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RAP, 1991 - Research Applications Program, NCAR, 1991: The 1990 Demonstration and Evaluation of an Integrated Wind Shear and Gust Front Detection and Warning System: Based on the Integration of a Functional Prototype Terminal Doppler Weather Radar System (TDWR) with the Operational Low-Level Wind Shear Alert System (LLWAS) at Stapleton International Airport, Boulder, CO, 1991.

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4.3 Monrovia Microburst

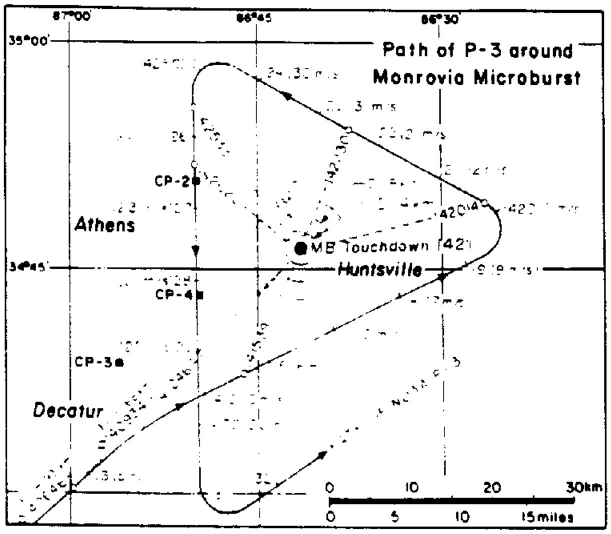

Fig. 4.3-1 A triangular path of NOAA P-3 at 500 mb pressure altitude. A rare view of the Monrovia cloud in growing, microburst, and decaying stages was witnessed by Mr. Saburo Onodera, a meteorologist of Japan Air Lines on board the P-3.

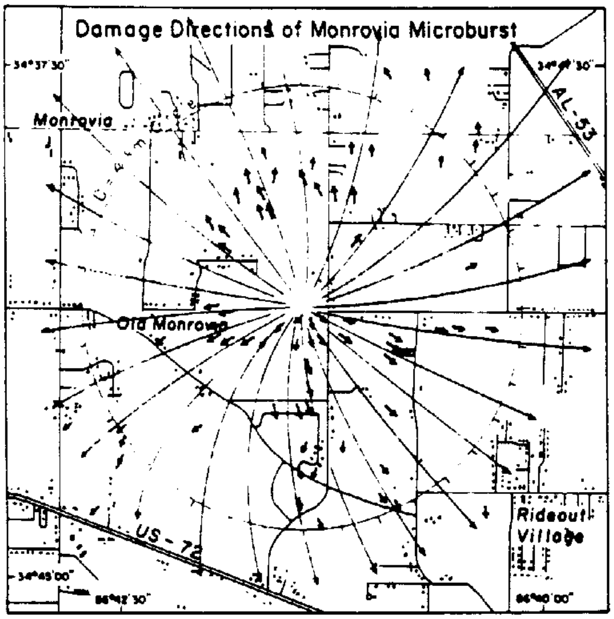

Fig. 4.3-2 Damage directions of the Monrovia microburst. A circle of 4 km in diameter shows the upper limit of the microburst dimension.

The Monrovia microburst occurred on 20 July 1986 during the **Microburst and Severe Thunderstorm (MIST)** Experiment (June and July 1986). Unusual data of the microburst cloud was obtained by NCAR's CP-2, CP-3, and CP-4 and a NOAA P-3. The aircraft was made available by Dr. C. B. (Gus) Emmanuel to support my microburst research. Gus, then the Director of NOAA/OAO in Miami, was convinced that my research will contribute to the safety of NOAA's hurricane flights over the Atlantic Ocean.

During the MIST experiment, I directed the P-3 in search of microburst clouds. On 20 July, while holding over northwest of Birmingham, I saw a towering cumulus near Huntsville. Simultaneously, Roger Wakimoto detected a fast-growing echo on the CP-4 display. We agreed immediately to work on the cloud. While approaching the cloud in northeast heading, I took the first picture at 140646 CDT from 93 km away (Fig. 4.3-1).

Thereafter, I completed three flight legs in a triangle with the cloud at the center. Next day, Greg Forbes and I surveyed the area beneath the cloud, obtaining a beautiful starburst pattern (Fig. 4.3-2) which resembles my laboratory model of microburst (Fig. 4.3-3).

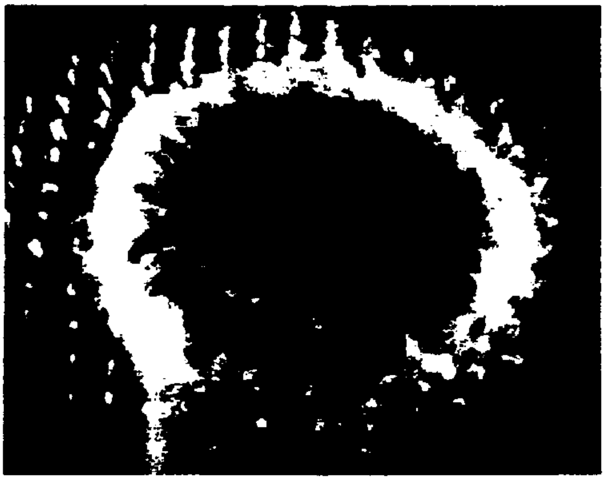

Fig. 4.3-3 A laboratory model of a microburst which resembles the Monrovia microburst.

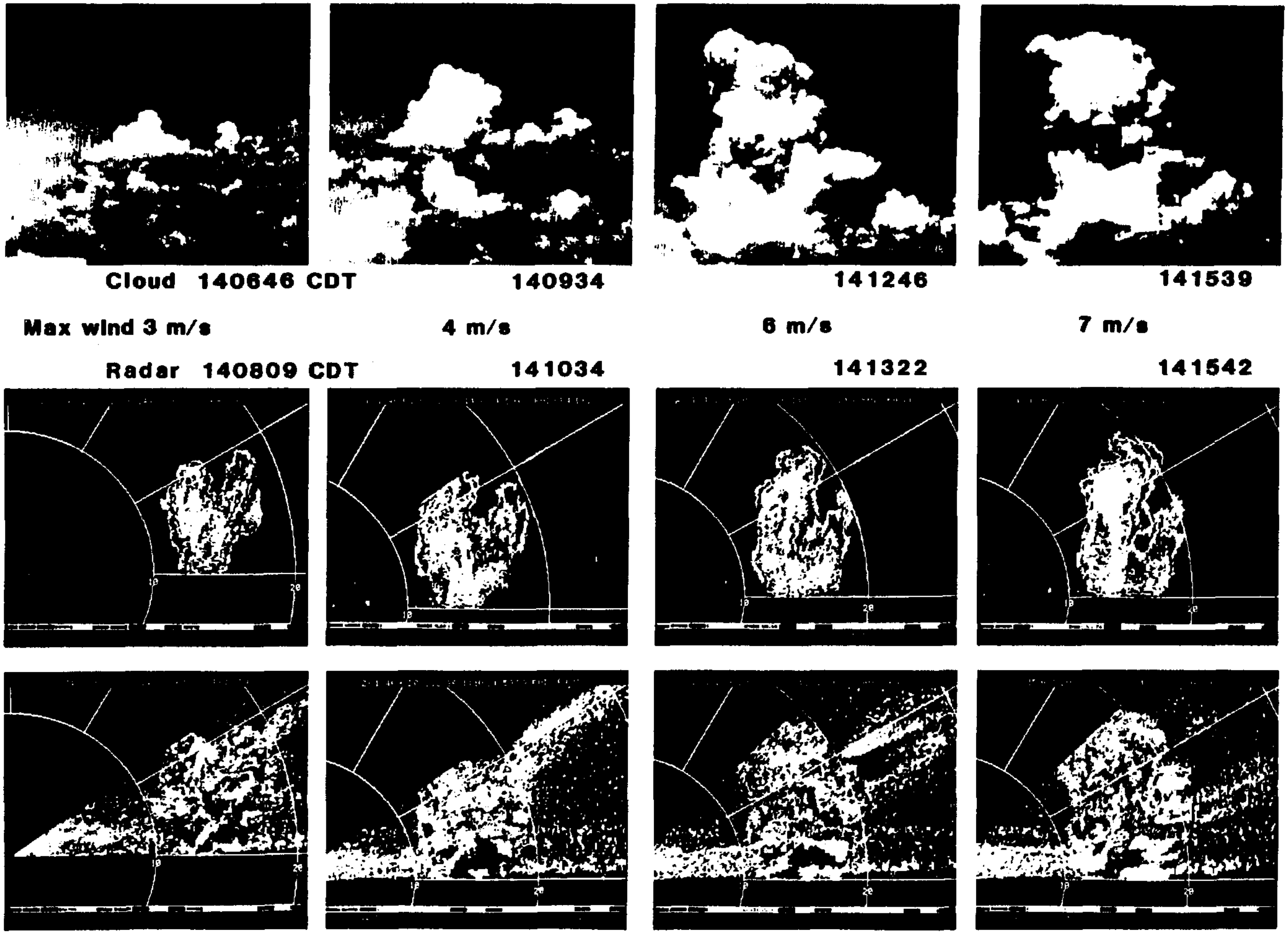

Fig. 4.3-4 The Monrovia cloud on 20 July 1986 in its pre-anvil stage. At 140646 and 140934 CDT, the cloud was in towering-cumulus stage and Doppler velocities were characterized by a yellow-colored flare, indicationg that large particles near the echo top were being carried upward. At 141322 CDT, the color of the flare velocity changed into red, suggesting that particles began falling.

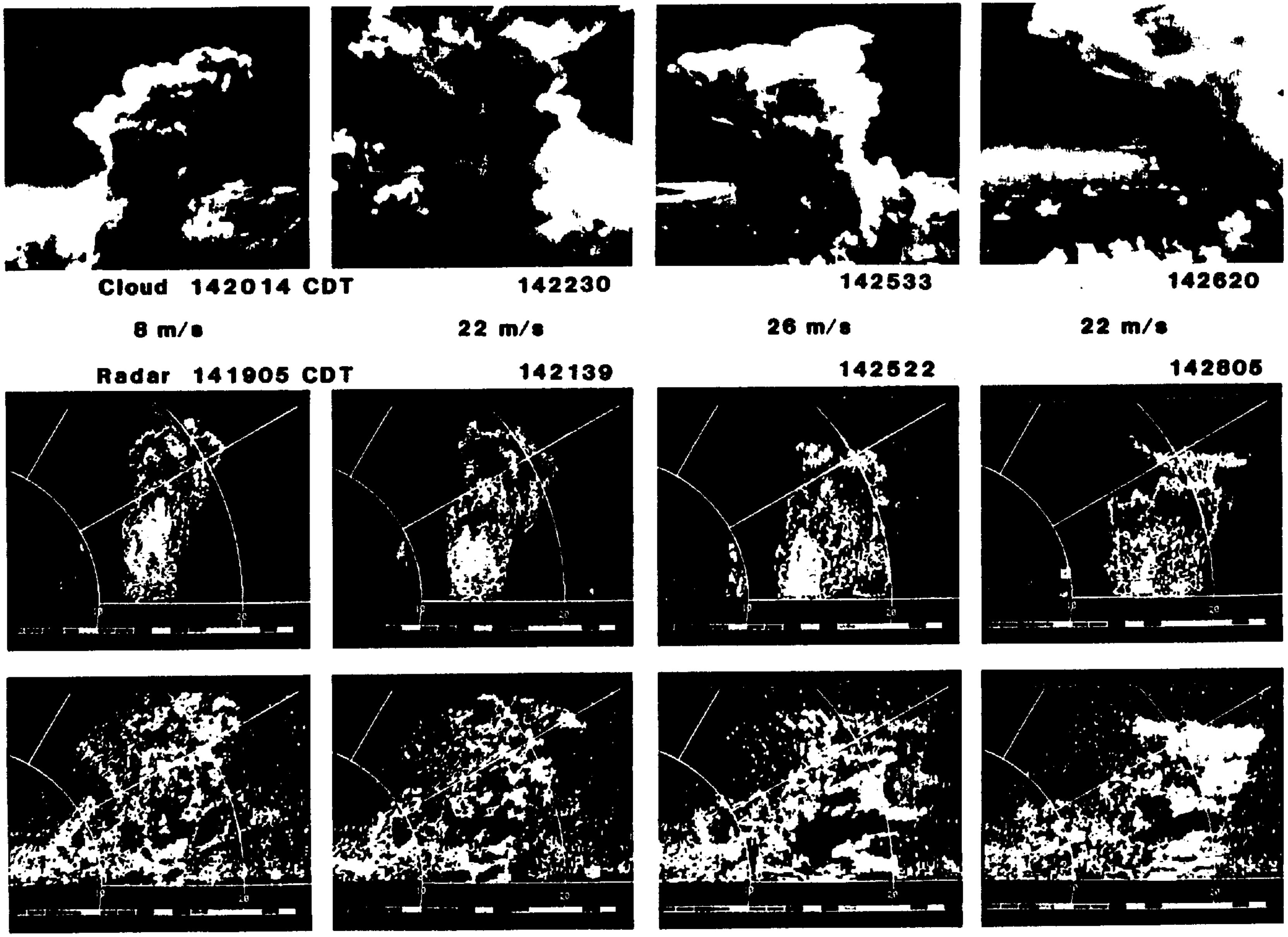

Fig. 4.3-5 The Monrovia cloud at the peak microburst stage. The cloud shape, however, does not imply a strong microburst in progress. At 141905 CDT when the high-reflectivity, flare-causing echo descended, the area of the apparent flare velocity became very small.

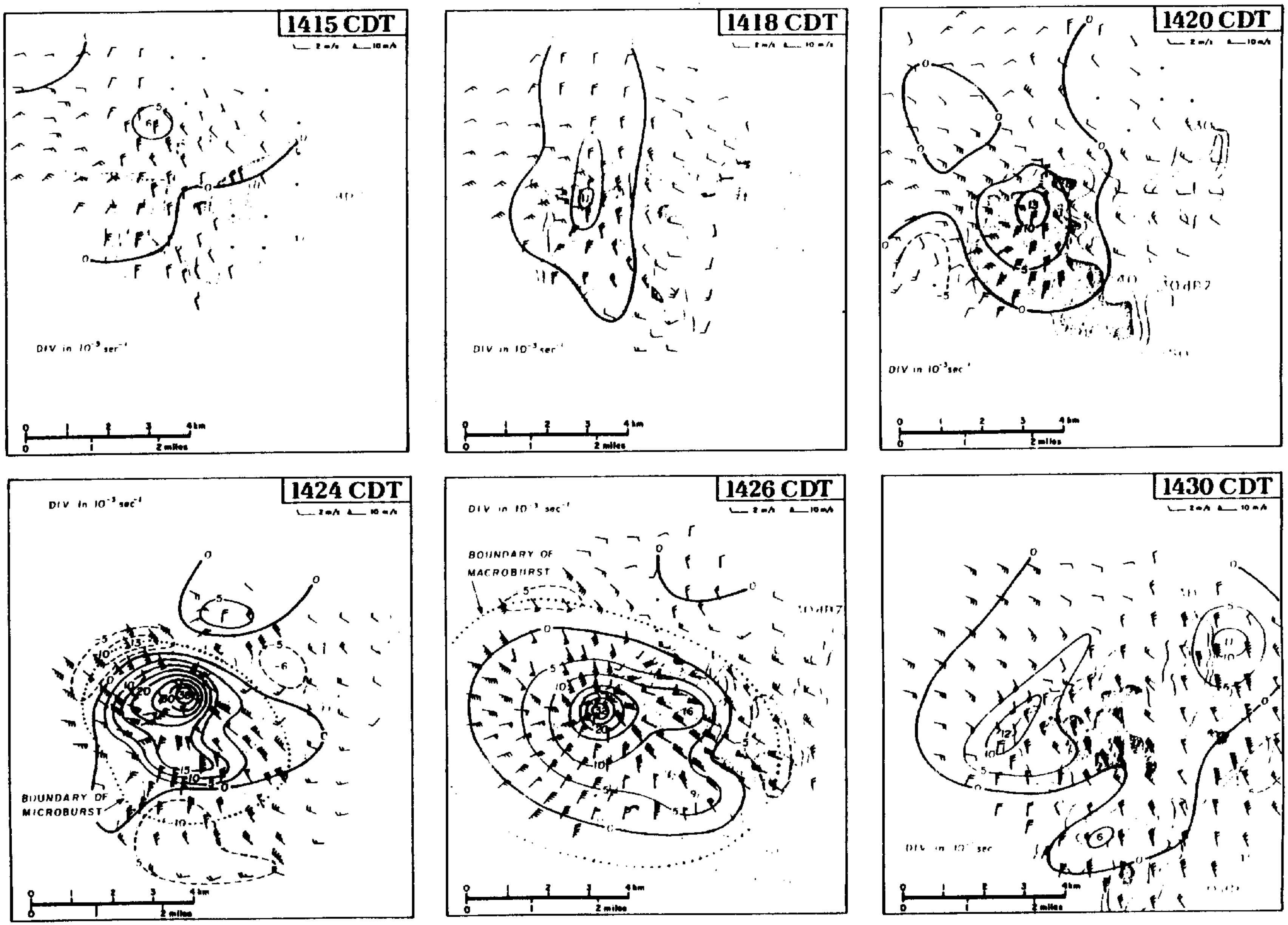

Fig. 4.3-6 Dual Doppler winds computed from CP-2 PPI and CP-4 RHI scans for the 15-min period, before, during, and after the Monrovia microburst of 20 July 1986. The maximum divergence measured at 1424 CDT was 0.038 per second which would induce a 19 m/s downflow at 500 m AGL. At 1425 CDT, the microburst expanded into a macroburst.

Shown in Figs. 4.3-4 and 5 are a chronological sequence of Roger's RHI scans showing reflectivity (middle) and Doppler velocity (bottom) and my cloud pictures taken within 3 sec to 105 sec of the radar scan time. My dual Doppler winds revealed that microburst winds began shortly after 1420 CDT when the P-3 was flying toward the northwest on the second leg. The peak wind occurring at 1423 was 31 m/s (Fig. 4.3-6).

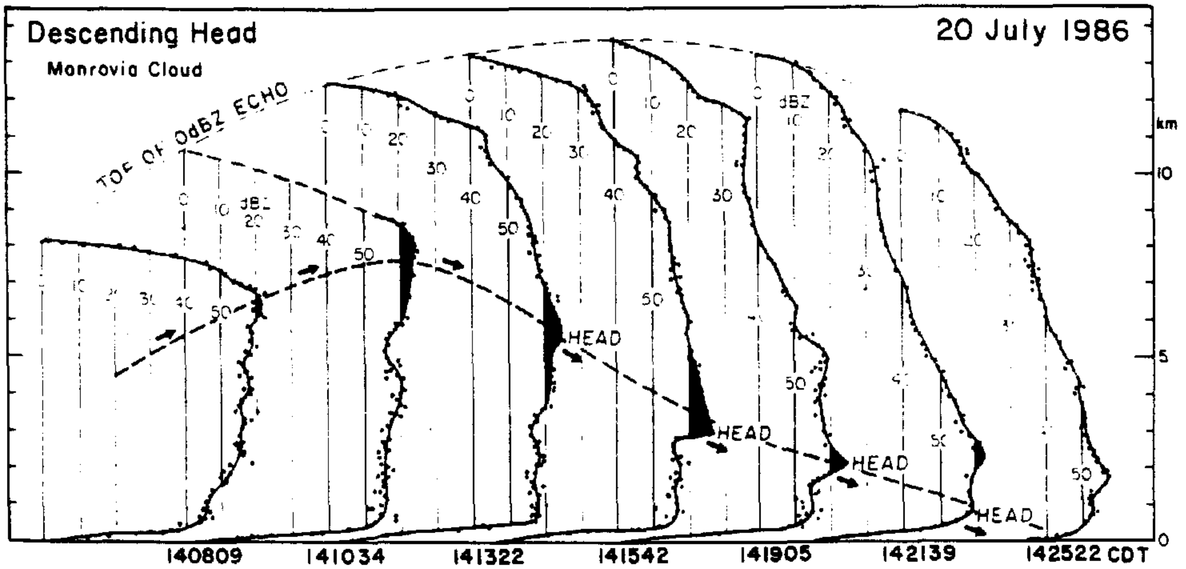

Fig. 4.3-7 Time sequence of reflectivity showing a rapid fall of the high-reflectivity (60+ dBZ) core which started 10 min before the onset of the microburst.

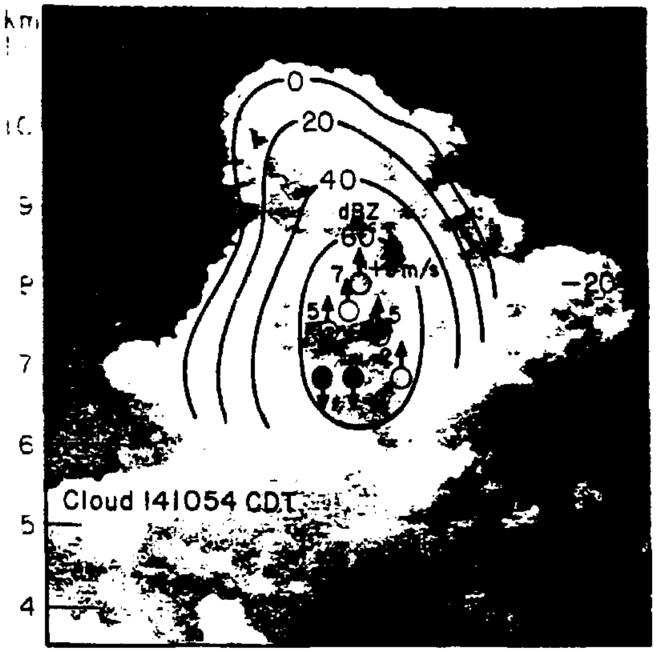

Fig. 4.3-8 CP-4 reflectivity at 141034 CDT superimposed upon the cloud picture taken at 141054 from the P-3. High-reflectivity particles were rising at 2 to 9 m/s.

Descent of Reflectivity Core

When vertical distributions of the reflectivity of each RHI scan were arranged into a time sequence (Fig. 4.3-7) a rapid fall of the 60 dBZ core became evident. The falling core, somewhat like the head of microburst (p112), began falling from about 8 km MSL and reached the ground at 1421 when microburst winds began.

The position of the core at 141034 CDT relative to the cloud picture at 141054 CDT suggests an accumulation of large particles near the 50-dBZ echo top (Fig. 4.3-8). It is likely that the downflow descended along with the head of high-reflectivity core, because microburst winds started when the core reached the ground.

Use of Apparent Flare Velocity

Jim Wilson and I called the Doppler radar signatures of both reflectivity and velocity fields in clear air behind the Monrovia cloud the **flare.** In 1988, Jim published a paper on flare, emphasizing the reflectivity and I worked on the application of the flare velocity, publishing a paper by Fujita and Black (1988a).

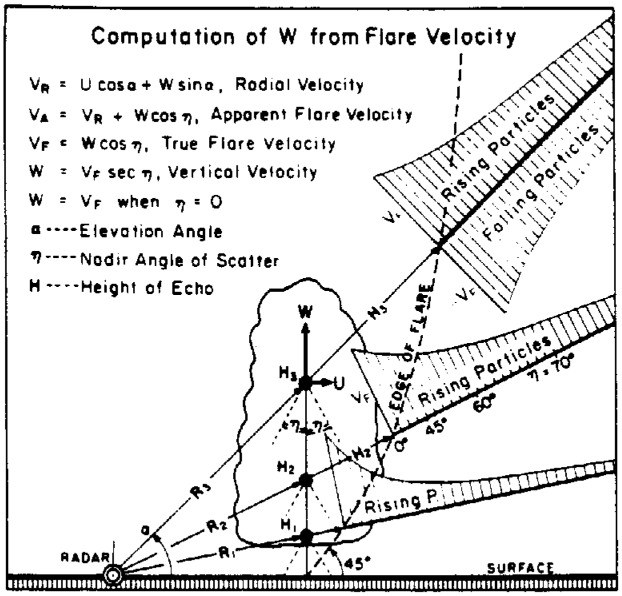

Fig. 4.3-9 A diagram showing the flare echo appearing in the clear area behind a high-reflectivity cloud. Doppler velocity of flare echo (apparent flare velocity) can be used in computing the vertical motion of the flare-causing particles.

A set of simple equations indicates that the velocity displayed by the flare echo, the **apparent flare velocity** is the sum of the radial velocity and the **true flare velocity.** The true flare velocity begins at the R+H range from radar and extends outward (Fig. 4.3-9).

Due to the cosine effect of the nadir angle of scatter, the true flare velocity decreases from the edge of the flare outward as the nadir angle increases from 0° to 90°. Because the function of the velocity decrease is known, the true flare velocity at H+R can be computed mathematically.

After computing these vertical velocities, the Monrovia cloud was lined up into a time sequence (Fig. 4.3-10), finding that high-reflectivity particles were transported upward at 3 to 9 m/s by a strong updraft inside the Monrovia cloud in its towering cumulus stage. Upon reaching just beneath the echo top at 141034 EDT, the high-reflectivity core began falling fast.

At 141539 CDT, my cloud photograph showed a significant constriction of the cloud tower (Fig. 4.3-11). This **constriction phenomenon** suggests a large-scale entry of dry air into the tower. The 1300 CDT sounding at Redstone Arsenal indicates layers of dry air above the 5.2-km MSL.

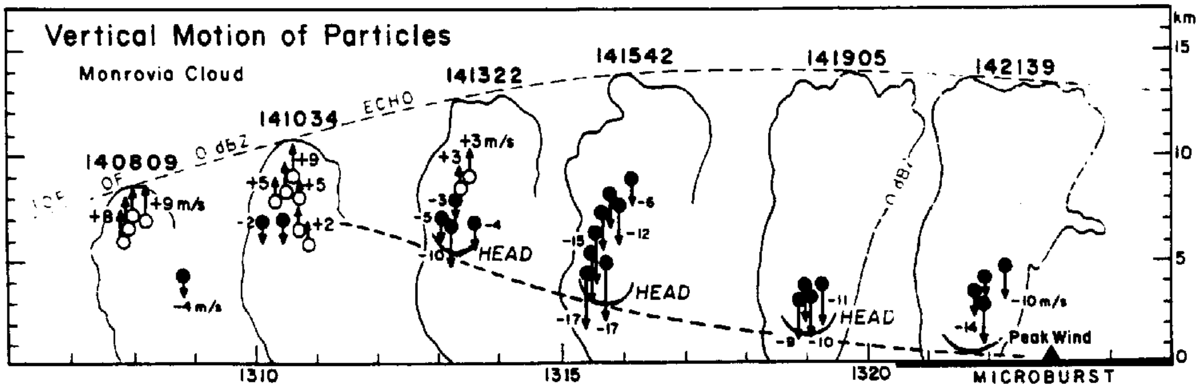

Fig. 4.3-10 Vertical velocity of the flare-causing particles. During the towering-cumulus stage, 140809-141034, particles were rising fast. Suddenly, particles began falling fast, reaching the ground with heavy rain, small hail, and microburst winds (see also Fig. 4.3-7).

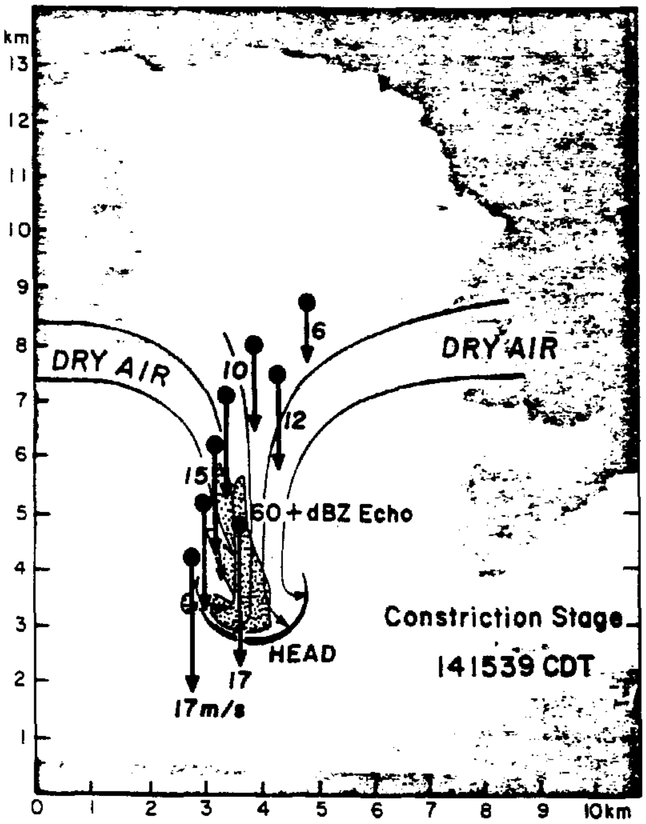

Fig. 4.3-11 The constriction stage of the Monrovia cloud depicted by combining the cloud photo at 141539 CDT and CP-4 echoes at 141542. Vertical velocities of flare-causing particles were computed from apparent flare velocities in Fig. 4.3-9.

Recommendation of Convection Termination Studies

Convection initiation is important in the short-range forecast (0 to 6 hrs) of storms. For warning aircraft on microburst hazards, on the other hand, the usual lead time is extremely short (0 to 10 min). This research on the Monrovia microburst, along with my study on the Hickory Ridge (Fig. 4.3-11) and Dogwood Road microbursts on 26 June 1985 in the FLOWS Memphis Network, evidenced that a high-reflectivity core began falling about 10 min in advance of each microburst.

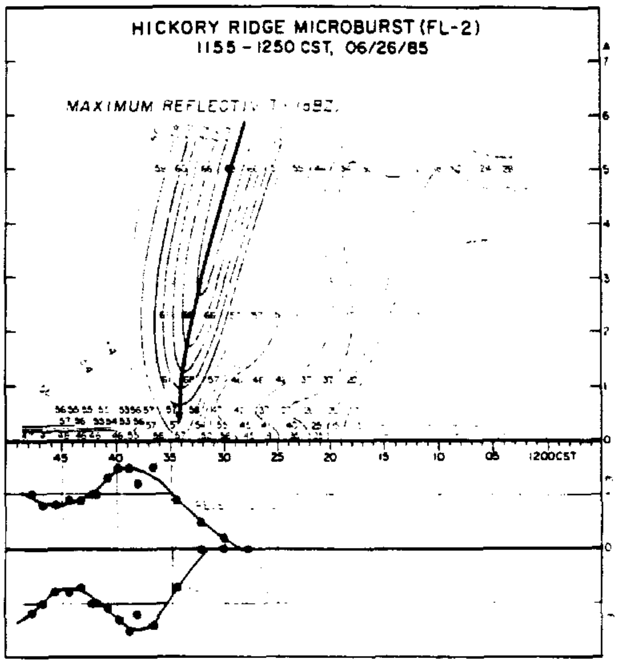

Fig 4.3-12 Time cross section of the Hickory Ridge microburst of 26 June 1985 inside the FLOWS Memphis, Tennessee network.

In view of my assessment that not a single detection system by itself can be used in warning microburst hazards without cry wolf or giving a false sense of security, I wish to propose an experiment to establish a physical relationship between the falling core and microburst intensity. Results of the proposed experiment on Convection Termination will lead us to the design of a Falling Core Detection Radar (FCDR), a 5-cm radar placed 10 to 20 km from an airport.

The following three systems will be used for a microburst watch followed by warning, similar to tornado watch and warning:

Watch by	**FCDR**	3-10	min leadtime
Warning by	**TDWR**	0-3	min leadtime
Warning by	**LLWAS**	0-1	min leadtime

I expect that the accuracy of FCDR can be improved for issuing warnings instead of just watches.

The Monrovia cloud at 142505 CDT when the 30 m/s peak winds (p122) were in progress. The reflectivity core was already on the ground, giving an impression of little wind shear at low altitudes beneath the cloud.

ABOUT THE AUTHORS:

Dr. T. Theodore Fujita, Professor Emeritus, Director of Wind Research Laboratory, University of Chicago:

1920	Born October 23, Kitakyushu, Japan
1943	B.S. in Mechanical Engineering, Meiji College of Technology, Japan, Assistant Professor of Physics, Meiji College of Technology, Japan
1950	ScD from Tokyo University, Japan Research Associate, University of Chicago
1956	Research Professor, University of Chicago
1961	Director of Mesometeorology Research Program, University of Chicago
1962	Associate Professor of Meteorology, University of Chicago
1964	Director of Satellite and Mesometeorology Research Program, University of Chicago
1965	Professor of Meteorology, University of Chicago
1968	Became U.S. Citizen
1988	Director of Wind Research Laboratory, University of Chicago
1989	Charles E. Merriam Distinguished Service Professor, University of Chicago
1991	Charles E. Merriam Distinguished Service Professor Emeritus, University of Chicago

Dr. Fujita has authored over 200 articles or books on aspects of severe storms. He is the recipient of numerous international awards for contributions to aviation safety.

NATIONAL AIR TRAFFIC CONTROLLERS ASSOCIATION
MEBA/AFL-CIO
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January 6, 1995

Mr. Gregory Feith
Office of Aviation Safety
National Transportation Safety Board
Major Investigation Division
490 L'Enfant Plaza East, SW
Room 5321
Washington, DC 20594

Re: USAir 1016, July 2, 1994
Charlotte Douglas International
Airport, North Carolina

Dear Mr. Feith:

In accordance with 49 CFR 845.27 enclosed please find the Submission of the National Air Traffic Controllers Association (NATCA) in the above referenced accident investigation. Copies of the submission are also being provided to all party coordinators in this investigation.

Thank you for the coopertion and assistance from your office in allowing NATCA to participate in this investigation process. If you have any comments or questions pertaining to air traffic control, please feel free to contact Mr. Gary Parham at (404)954-1960, or myself for assistance.

Sincerely,

James C. Morin
Director of Accident Investigation

Enclosure

JCM/ss

Mr. Gregory A. Feith
Air Safety Investigator
Office of Aviation Safety
Major Investigations Division, AS-10
490 L'Enfant Plaza East, S.W., Room 5265
Washington, DC 20594

Dear Mr. Feith,

In accordance with the Board's Rule 845.27, the National Air Traffic Controllers Association (NATCA) submits the following comments and recommendations regarding the accident involving US Air Flight 1016 at Douglas Airport, Charlotte, North Carolina, which occurred on July 2, 1994.

1. AIR TRAFFIC CONTROL

It has become evident that air traffic controllers are being called on more and more to disseminate weather information. As was the case in Charlotte for USA1016, there was a lot of information that was passed to the flight crew, and there was also some information that was not passed. It is NATCA's opinion that this situation can be attributed to two main problems:

1) Aside from being certified to determine the tower visibility, air traffic controllers are not certified weather observers. Any observations that they make are merely that: observations, and cannot be used as official weather. An air traffic controller can advise that it "appears" to be raining on the field, but can neither qualify the precipitation as rain nor quantify it as rain, heavy rain, or light rain. The same is true for storms. A controller can advise a pilot that he can see lightning or hear thunder, but cannot classify a storm as a thunderstorm. This presents the controller with an interesting dilemma: does he pass information to a pilot that may be of some value even though he is not actually certified to make these observations, or does he elect not to pass any information and instead wait for an official observation to come from the National Weather Service (NWS)?

2) The FAA Order 7110.65 requires air traffic controllers to pass certain weather information on to flight crews and allows other information to be passed on a workload basis. Low level wind shear advisories, tower visibility, runway visual values, and braking action advisories are all required to be issued by controllers, yet information such as thunderstorm activity, turbulence, inflight icing, or areas of precipitation are not. Because most controllers take the time to gather and disseminate all weather information that is available, pilots have become dependent on this, and have a tendency to rely on the air traffic controller as the primary source for weather information. In most cases the controller can pass enough information to allow for a safe flight, but separation of aircraft is his primary duty, and the dissemination of weather is secondary. While controllers do a very good job of getting most weather information to the flight crews, it must be understood by everyone that not only does the volume of traffic and frequency congestion in his sector affect his ability to pass information, but the lack of information to disseminate is also a factor. There are times when the information is available, but it does not get to the controller, and consequently cannot be forwarded to the pilot. Limitations of the radar itself can also be a factor in providing useful information to the cockpit.

control system. The FAA must also establish guidelines for the levels of weather air traffic controllers shall monitor and disseminate to pilots.

3. DOPPLER RADAR

This equipment will allow controllers to advise pilots in a more timely manner of developing wind shears. This fact was proven by testimony of experts on the improved capability of the Doppler radar compared to the LLWAS system and the limitation of the ASR-9 radar--both now being used at the Douglas Airport in Charlotte, North Carolina.

RECOMMENDATION: The FAA should put the installation of Doppler radar at the Douglas Airport on a fast track course. A realistic date for on-line operation of the Doppler radar should be established and met. This can begin by immediately purchasing the land needed for this project which was established at the public hearing as the reason the Doppler radar was not available on July 2, 1994.

4. CENTER WEATHER SERVICE

Because of the size of the area a center meteorologist is responsible for, it is not reasonable to assume only one area of hazardous weather will develop at any given time during periods of rapidly developing weather associated with convective activity.

RECOMMENDATION: The FAA should expand the capability of the Center Weather Service to monitor more than one Doppler radar site at one time.

5. INTERFACILITY COORDINATION

The events leading to the crash of USA1016 indicate that the lack of specific procedures for interfacility dissemination of weather information may exist. Standard operating procedures at the Charlotte Air Traffic Control Tower allowed for critical information to be passed via a general "community broadcast" in lieu of a procedure that would ensure that each and every controller responsible for an operational position received that information. The nature and complexity of large air traffic control facilities requires sectorization. This allows a controller to concentrate on the traffic in his sector and the immediate area around him, but does not facilitate an easy exchange of information. The size of the Operational working area, the workload at the sector, and environmental factors such as background noise all influence the ability to effectively disseminate information. The only way to ensure that pilots receive critical information is to ensure that each and every controller has that information available.

RECOMMENDATION: The FAA must establish a national order that requires air traffic facilities to ensure that critical information be disseminated to individual control positions. This requirement should be included in each facility's standard operating procedures

6. PROCEDURAL AND OPERATIONAL INFORMATION, PLANNING, AND DISSEMINATION AT THE CHARLOTTE APPROACH CONTROL TOWER

This became evident in the special air traffic control public hearing which took place in Charlotte during October 1994, which focused on how a clerical mistake could allow three different orders addressing the same operational procedure to be followed concerning visibility changes at the Douglas Airport in Charlotte, North Carolina.

RECOMMENDATION: The FAA at Charlotte Approach Control Tower should follow procedures for Impact and Implementation of new procedures and operational changes to allow more controller input as a check-and-balance procedure on these changes. They should also immediately move forward to adopt the Quality Through Partnership (QTP) process to expand the base of controller and first-line supervisor input into the rapidly changing procedures from reinventing the FAA and upgrading air traffic control equipment through the year 2000.

NATCA views the responsibility for each involved party and probable cause, in their simplest terms as follows:

PILOT: The Captain did not maintain a totally professional cockpit and did not follow USAir procedures exactly as required concerning checklist, ILS approach procedures, and missed approach procedures.

CONTROLLER: The controller had no causal responsibility for the accident and followed all procedures required by FAA rules and orders given all the information available at the time of the accident.

WIND SHEAR: The probable cause of the USA1016 accident was due to the presence of and severity of the wind shear encountered, given the fact that no warning was available to the cockpit in advance or at the time of encounter and also given the fact that the encounter occurred at the time a missed approach was initiated (flaps in transit from 40° down to 15° up).

We appreciate this opportunity to offer our comments on this investigation.

Sincerely,

J. Gary Parham

J. Gary Parham, ATCS
NATCA Coordinator

association of flight attendants AFL-CIO
1625 MASSACHUSETTS AVENUE, N.W., WASHINGTON, D.C. 20036 202-328-5400 TLX-904097

December 7, 1994

Mr. Gregory A. Feith
Office of Aviation Safety
Major Investigations Division
National Transportation Safety Board
490 L'Enfant Plaza East, S.W.
Washington, DC 20594

Dear Greg:

The Association of Flight Attendants (AFA), which represents 8,477 flight attendants at USAir, Inc. welcomes the opportunity to submit safety recommendations to the National Transportation Safety Board (NTSB) for consideration. Our recommendations are based on proposed findings gleaned from the accident investigation of USAir Flight #1016.

1./ FLIGHT ATTENDANT RESTRAINT TESTING

Mr. Richard DeMary, the "A" flight attendant, stated in his interview with the Survival Factors Group that he had difficulty releasing his seatbelt because he had to search for the buckle. He believed this was due to the fact that this forward jumpseat harness was the one continuous loop restraint type.

After he had initially taken his jumpseat, tightened his seatbelt and had taken his brace position, he tightened the seatbelt again just before impact. He was not certain whether the action of the second tug on the seatbelt or the jolt of the impact caused the buckle to move a couple inches to the left of center.

Flight attendants are trained to fasten their seatbelts with the buckle centered at their waist to ensure a quick release. A flight attendant should not have to search for a buckle. Every second counts in an emergency evacuation.

AFA advises the NTSB to recommend that the Federal Aviation Administration (FAA) Civil Aeromedical Institute (CAMI) initiate testing of this type seat belt to determine if it is as effective and reliable as other type flight attendant seatbelt harnesses.

2./ CHILD RESTRAINT USE

How many more lap children have to needlessly die or suffer injury in aircraft accidents before the government and the industry provide rules to protect them? Federal rules require that nearly all loose items in the aircraft cabin are restrained for ground movement, takeoff, and landing. Incredibly, this does not apply to children under the age of two.

Once again, a lap child has perished in an aircraft accident. Will the NTSB's final analysis reveal that this child would have survived had it been in an FAA-approved child restraint? The need for child safety seat use does not end with aircraft accidents. According to an FAA study, turbulence related injuries are the most frequent serious injuries to flight attendants and passengers in scheduled Part 121 air carrier non-fatal accidents.

The Board has enthusiastically advocated the use of child restraints based on its accident investigations for years. What will it take to convince the FAA and the industry that these children are entitled to the same degree of safety as other members of the traveling public?

AFA submits that the NTSB recommend that the FAA require infants under the age of two years to be seated in FAA-approved child restraint devices when transported aboard U.S. commercial aircraft.

3./ ENSURE TIMELY AND ACCURATE ACCOUNTING OF ALL PASSENGERS

During the rescue effort of Flight #1016 there was much confusion and delay in determining the number of passengers on board. The NTSB should recommend that the FAA ensure that carriers are in compliance with FAR 121.693(e) which requires that a load manifest contain the names of <u>all</u> passengers on board, including lap-held children.

FAA Action Notice No. 8430.29 states that "the word 'passenger,' as used throughout the Federal Aviation Regulations, means any passenger regardless of age..."

Furthermore, the FAA should ensure that carriers are in compliance with Air Carrier Operations Bulletin No. 8-91-2, Accident Notification and Manifest Accounting Procedures. This bulletin requires that carriers provide airport rescue and fire fighting personnel with accurate and timely numbers of all passengers on board the accident aircraft.

Interestingly, both of the afore noted FAA documents were issued as a direct result of NTSB accident investigation recommendations.

4./ SEAT LOCATION LABELING

Finally, AFA recommends that all crew jumpseats and passenger seats be labeled as to their location on the aircraft to assist in the post-accident investigation of crash dynamics. This simple action of labeling the seats would aid in expediting the Survival Factors Groups' task of documenting the crash site.

In summary, AFA submits the following safety recommendations to the NTSB for consideration:

1./ FAA CAMI should evaluate the one continuous loop restraint harness to determine its effectiveness and reliability.

2./ The FAA should require that all infants under the age of two are transported on board U.S. carriers in FAA-approved child restraint devices.

3./ The FAA should ensure that carriers are in compliance with FAR 121.693(e), Action Notice No. 8430.29 and Air Carrier Operations Bulletin No. 8-91-2.

4./ All crew and passenger seats should be labeled to indicate their location in the aircraft cabin.

We would like to thank you and your staff for the professional manner in which the investigation was conducted.

Respectfully,

Nancy L. Gilmer

Nancy L. Gilmer
Master Executive Council
Safety & Health Chairperson

Enclosures

§ 121.693 Load manifest: Air carriers and commercial operators.

The load manifest must contain the following information concerning the loading of the airplane at takeoff time:

(a) The weight of the aircraft, fuel and oil, cargo and baggage, passengers and crewmembers.

(b) The maximum allowable weight for that flight that must not exceed the least of the following weights:

(1) Maximum allowable takeoff weight for the runway intended to be used (including corrections for altitude and gradient, and wind and temperature conditions existing at the takeoff time).

(2) Maximum takeoff weight considering anticipated fuel and oil consumption that allows compliance with applicable en route performance limitations.

(3) Maximum takeoff weight considering anticipated fuel and oil consumption that allows compliance with the maximum authorized design landing weight limitations on arrival at the destination airport.

(4) Maximum takeoff weight considering anticipated fuel and oil consumption that allows compliance with landing distance limitations on arrival at the destination and alternate airports.

(c) The total weight computed under approved procedures.

(d) Evidence that the aircraft is loaded according to an approved schedule that insures that the center of gravity is within approved limits.

(e) Names of passengers, unless such information is maintained by other means by the air carrier or commercial operator.

[Doc. No. 6258, 29 FR 19226, Dec. 31, 1964, as amended by Amdt. 121-159, 45 FR 41596, June 19, 1980]

§ 121.701 Maintenance log: Aircraft.

(a) Each person who takes action in the case of a reported or observed failure or malfunction of an airframe, engine, propeller, or appliance that is critical to the safety of flight shall make, or have made, a record of that action in the airplane's maintenance log.

(b) Each certificate holder shall have an approved procedure for keeping adequate copies of the record required in paragraph (a) of this section in the airplane in a place readily accessible to each flight crewmember and shall put that procedure in the certificate holder's manual.

§ 121.703 Mechanical reliability reports.

(a) Each certificate holder shall report the occurrence or detection of each failure, malfunction, or defect concerning—

(1) Fires during flight and whether the related fire-warning system functioned properly;

(2) Fires during flight not protected by a related fire-warning system;

(3) False fire warning during flight;

(4) An engine exhaust system that causes damage during flight to the engine, adjacent structure, equipment, or components;

(5) An aircraft component that causes accumulation or circulation of smoke, vapor, or toxic or noxious fumes in the crew compartment or passenger cabin during flight;

(6) Engine shutdown during flight because of flameout;

(7) Engine shutdown during flight when external damage to the engine or airplane structure occurs;

(8) Engine shutdown during flight due to foreign object ingestion or icing;

(9) Engine shutdown during flight of more than one engine;

(10) A propeller feathering system or ability of the system to control overspeed during flight;

(11) A fuel or fuel-dumping system that affects fuel flow or causes hazardous leakage during flight;

(12) A landing gear extension or retraction or opening or closing of landing gear doors during flight;

(13) Brake system components that result in loss of brake actuating force when the airplane is in motion on the ground;

(14) Aircraft structure that requires major repair;

(15) Cracks, permanent deformation, or corrosion of aircraft structures, if more than the maximum acceptable to the manufacturer or the FAA;

(16) Aircraft components or systems that result in taking emergency actions during flight (except action to shut down an engine); and

(17) Emergency evacuation systems or components including all exit doors, passenger emergency evacuation lighting systems, or evacuation equipment that are found defective, or that fail to perform the intended functions during an actual emergency or during training, testing, maintenance, demonstrations, or inadvertent deployments.

ACTION NOTICE

U S DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

A 8430.29

Subject ACTION ACTION NOTICE - Federal Aviation Regulations (FAR) Section 121.693(e)

Approval Date December 30. 1988

From Acting Director, Flight Standards Service, AFS-1

Expiration Date December 30. 1989

To All Regional and Aeronautical Center Directors
Director, Europe, Africa, and Middle East Office
Attention: Flight Standards Division Managers
Superintendent, FAA Academy, AAC-900
Manager, Flight Standards Staff, AEU-200
All GADO's, ACDO's, and FSDO's

Reply to Attn of Cremer:267-8094

Recently, during the course of an accident investigation, it was learned that some air carriers may not be recording the names of certain passengers as required by Section 121.693(e) of the FAR. Specifically, these air carriers appear to be excluding, from the load manifest, certain non-revenue passengers such as children under the age of 2 who are being held on the lap of an adult, dead-heading crewmembers, and other non-ticketed persons.

Section 121.693(e) of the FAR requires that air carriers include as part of the load manifest, the "Names of passengers, unless such information is maintained by other means by the air carrier." Other means could be ticket stubs, a computer source, etc. The principal reason for this regulation is to facilitate the rapid and accurate determination of how many passengers are on board an aircraft and who they are in the event of an emergency situation such as an accident or hijacking. Not having an accurate record of all passengers could, for example, hamper the efforts of rescue workers during a post-accident rescue operation.

A legal interpretation, concerning the "manifest accounting for all non-crewmembers," was issued by the FAA's Office of the Chief Counsel. It states that "The word 'passenger,' as used throughout the Federal Aviation Regulations, means any passenger regardless of age...." That interpretation also states that "The word passenger, as used in Section 121.693, is not qualified and means any passenger." A crewmember as defined in Section 1.1 of the FAR means " a person assigned to perform duty in an aircraft during flight time."

NOTE: THE CONTENTS OF THIS ACTION NOTICE, IF APPROPRIATE, SHALL BE INCORPORATED INTO THE DIRECTIVES SYSTEM WITHIN 12 MONTHS AFTER THE DATE OF APPROVAL.

Distribution: A-XY-1; A-X(FS)-2; A-Y(AY)-2; AEU-1/200(5 cys); A-FFS-1,2,7(MAX);
Info: AAC-950 (80 cys); AMs-420 (1 cy)

Initiated By: AFs-220

FAA Form 1320-18 (12-84) Supersedes FAA Form 1320 Test

Any person provided transportation on an air carrier aircraft, who is not a crewmember with assigned duties, must be recorded as a passenger and listed as required by Section 121.693(e). Crewmembers include the pilot in command, second in command, other required flight crewmembers such as flight engineers, navigators, relief pilots, required and non-required flight attendants (who are assigned duties by the air carrier), and any other persons (e.g., pursers, a customer service agent, etc.) assigned duties during flight time. All other persons are passengers (e.g., non-revenue passengers, children (regardless of their age and whether they occupy a seat), deadheading crewmembers or other company employees not assigned duties during flight time, FAA or NTSB safety inspectors, law enforcement officials, etc).

Principal operations inspectors are requested to review his/her certificate holder's procedures to ensure that those procedures are in compliance with Section 121.693(e) of the FAR and that all passengers and their names are recorded by an acceptable means and, if appropriate, attached to the load manifest.

Work must be accomplished using available FAA resources.

DCBeaudette
\Robert L. Goodrich

* 992. <u>AIR CARRIER OPERATIONS BULLETIN NO. 8-91-2--ACCIDENT NOTIFICATION AND MANIFEST ACCOUNTING PROCEDURES (NTSB SAFETY RECOMMENDATION A-90-105).</u>

a. The problems associated with the recovery efforts involving a recent air carrier accident, in which a night takeoff was aborted and the airplane ended up running off the end of a runway and into a body of water, were compounded because rescue personnel did not know exactly how many persons were on board the airplane. This situation was detrimental to the rescue effort since it created an uncertainty as to how many persons had been on board versus how many had been accounted for during the rescue operation. The National Transportation Safety Board (NTSB) recommended to the Federal Aviation Administration (FAA) that air carriers be required to provide airport rescue personnel accurate and timely numbers of all persons aboard an aircraft involved in an accident or incident and that they assist in determining the whereabouts of persons who have been recovered from the scene of an accident.

b. The FAA agrees with the NTSB that air carriers should be able to provide accurate and timely information to an appropriate airport and/or Government authority with respect to the total number of persons on an aircraft and that air carriers should assist the appropriate authorities in determining the whereabouts of persons who have been recovered from the scene of an accident. The sum of the persons on board an aircraft includes, e.g., crewmembers, revenue passengers, non-revenue passengers, children being held in the lap of an adult, and persons occupying cabin or cockpit jumpseats.

c. Federal Aviation Regulations (FAR) Section 121.693 requires that all certificate holders prepare a load manifest that includes, at the time of takeoff, the names of passengers (unless the passenger names are maintained by some other means). FAR Section 135.63(c) requires, for multiengine aircraft, a load manifest that includes, at the time of takeoff, the number of passengers. On December 30, 1988, the FAA issued Action Notice 8430.29, the primary purpose of which was to provide guidance concerning a recent legal interpretation of FAR Section 121.693(e) regarding the "manifest accounting for all non-crewmembers" and the recording of passenger names. That guidance is still valid and states, in part:

(1) "Section 121.693(e) of the FAR requires that air carriers include as part of the load manifest, the "Names of passengers, unless such information is maintained by other means by the air carrier." Other means could be ticket stubs, a computer source, etc. The principal reason for this regulation is to facilitate the rapid and accurate determination of how many passengers are on board an aircraft and who they are in the event of an emergency situation such as an accident or hijacking. Not having an accurate record of all passengers could, for example, hamper the efforts of rescue workers during a post-accident rescue operation.

(2) "The word 'passenger,' as used throughout the Federal Aviation Regulations, means any passenger regardless of age...." That interpretation also states that "The word passenger, as used in Section 121.693, is not qualified and means any passenger." A crewmember as defined in Section 1.1 of the FAR means "a person assigned to perform duty in an aircraft during flight time." *

(3) Any person provided transportation on an air carrier aircraft, who is not a crewmember assigned by the certificate holder to perform duties during flight time, must be recorded as a passenger and listed as required by Section 121.693(e). Crewmembers include the pilot in command, second in command, other required flight crewmembers such as flight engineers, navigators, relief pilots, required and non-required flight attendants (who are assigned duties by the air carrier), and any other persons (e.g., pursers, customer service agents, etc.) assigned duties during flight time. All other persons are passengers (e.g., non-revenue passengers, children (regardless of their age and whether they occupy a seat), deadheading crewmembers or other company employees not assigned duties during flight time, FAA or NTSB safety inspectors, law enforcement officials, etc).

d. In addition to the load manifest required by these regulations, which requires, as applicable, the names or numbers of passengers on board at the time of takeoff, the certificate holder should also have a procedure which ensures that the total number of persons on board any aircraft, including the total number of crewmembers, is available at the time of takeoff. The procedures should, as a part of the manual requirements of FAR Sections 121.135(b)(22) and 135.23(d) (accident notification procedures) contain guidance, instructions, and procedures regarding the local authorities (e.g., airport police, management, and/or fire department) which should be contacted by the certificate holder's personnel in the event of an accident or incident and what information should be included in the notification, including the total number of persons on board the aircraft. The certificate holder should, if appropriate, also have a procedure which provides assistance to those authorities in determining the whereabouts of persons that the certificate holder knows have been recovered from the scene of the accident.

e. If an airport is certificated in accordance with FAR Part 139 it must have, in accordance with FAR Section 139.325, an airport emergency plan. Air carriers and commercial operators should, as necessary and to the extent possible, review the plans of those certificated airports to which they operate to ensure that the procedures they have developed in accordance with FAR Section 121.135(b)(22) and/or FAR Section 135.23(d) are consistent with the airport emergency plan that has been developed by the airport certificate holder. Additional information concerning airport emergency plans is contained in FAA Advisory Circulars in the 150 series (e.g., 150/5200-14, Airport Emergency Plans).

f. Principal operations inspectors shall bring this bulletin to the attention of their assigned certificate holders and shall request that their certificate holders develop and implement the procedures described above.

993. - 1000. <u>RESERVED</u>. *

USAir

Submission of USAir, Inc.
to the
National Transportation Safety Board

in connection with the

accident involving USAir Flight 1016

at

Douglas Airport, Charlotte, North Carolina

on

July 2, 1994

December 9, 1994

TABLE OF CONTENTS

1. FACTUAL INFORMATION

1.1 HISTORY OF FLIGHT 1016

Before departing Columbia (South Carolina) for Charlotte, the crew of Flight 1016 checked the weather conditions. The weather enroute and at Charlotte was visual meteorological conditions, and forecast to remain so. [Ex. 2-A, "Statement of Captain Michael Reese Greenlee," ¶ 21]

The 1810 departure from Columbia was uneventful, and Flight 1016 flew into the Charlotte area in primarily visual conditions. Transcript of Proceedings Before the United States National Transportation Safety Board, testimony of Captain Michael Greenlee, p. 277 [hereinafter "Greenlee, Tr. 277"]. Approximately 40 to 45 miles from Charlotte, Captain Greenlee obtained ATIS information Yankee, which contained the following information:

> "Charlotte International Airport arrival information Yankee Charlotte two one five one zulu weather five thousand scattered visibility six miles haze temperature eight eight dew point six seven wind one five zero at eight altimeter three zero zero one ILS approaches runways one eight left one eight right localizer back course two three approach in use if unable to comply with speed restrictions advise read back all hold short instructions advise you have information Yankee."

At approximately 1827 local time, Flight 1016, flying inbound on the 232° radial of the Charlotte VOR, checked in on Charlotte Arrival West (ARW) frequency at 12,000 feet. [Ex. 12-A] At that time, Captain Greenlee noticed a small cell south of the Charlotte VOR, which is located south of the end of Runway 18R. [Greenlee, Tr. 278]

At 1828:20, ARW cleared Flight 1016 to descend and maintain 10,000 feet, and at 1830:15, Flight 1016 advised that it was turning five degrees to the right to avoid some cumulus clouds present on the radial. At 1833:19, Flight 1016 informed ARW that they could see a cell building on the radial approximately 15 miles in front of them, and

ARW indicated he would be turning the aircraft before they reached the cell. At 1834:00, ARW turned 1016 left downwind to a heading of 360°. [Ex. 12-A]

As Flight 1016 was on downwind, the crew could see a cell located one to two miles south of the airport, directly off the departure end of 18R. Captain Greenlee was using the on-board weather radar, which painted two cells; one south of Runway 18R and a smaller cell east of the field. [Ex. 2A, "Statement of Captain Michael Reese Greenlee," ¶ 25] Captain Greenlee recalled that the cell which was south of Runway 18R was extremely small and round, with "some red" returns in it. [Greenlee, Tr. 291]

At 1835:09, ARW instructed Flight 1016 to contact Approach (Final Radar West), and at 1835:18, Flight 1016 checked in on Final Radar West ("FRW") frequency. FRW cleared Flight 1016 down to 4,000 feet, and told the crew to expect a visual approach to Runway 18R. At 1836:59, FRW informed Flight 1016 of "some rain just south of the field might be little bit coming off north just expect the ILS amend your altitude maintain 3,000." [Ex. 12-A] At that point, Flight 1016 was located west of the airport and north of the threshold of Rwy 18R, and was still in visual conditions. [Greenlee, Tr. 279]

At 1837:44, FRW instructed Flight 1016 to turn right to a heading of 090°, the base leg of Flight 1016's approach. At 1838:27, FRW turned 1016 right to a heading of 170°; at that time, FRW told the 1016 crew it was 4 miles from SOPHE, the outer marker for an ILS approach to Runway 18R. [Ex. 12-A] Throughout the base leg, and as they turned on final, Captain Greenlee could see the airport. [Greenlee, Tr. 280] Once on final, Captain Greenlee again used the onboard weather radar to scan the airport area; he set the radar to optimize the picture of Flight 1016's intended flight path, and of the cell off the departure end of Runway 18R, the only weather cell the crew observed.

[Greenlee, Tr. 280] At that time, the cell did not appear to have moved since the crew first observed it while approaching the Charlotte terminal area. [Greenlee, Tr. 300]

At 1839:02, Captain Greenlee told First Officer Hayes that, in the event of a missed approach, they would fly the aircraft to the right away from Charlotte Airport. [Ex. 12-A] At 1839:20, Captain Greenlee reminded First Officer Hayes that there was a chance of windshear. [Ex. 12-A] Captain Greenlee decided to fly to the right in the event of a missed approach, and mentioned windshear, because of the weather cell off the south end of the runway. [Greenlee, Tr. 279, 280]

At 1839:24, FRW instructed 1016 to contact Charlotte Tower (Local Control West). [Ex. 12-A] At 1839:38, 1016 checked in on Local Control West ("LCW") frequency. [Ex. 12-A] At 1839:42, Flight 1016 was cleared to land on runway 18R following a FK 100 on short final. The crew was told that the previous arrival reported a smooth ride all the way down, but Captain Greenlee requested another PIREP from the aircraft in front of Flight 1016 which was about to land. [Ex. 12-A] At 1840:10, First Officer Hayes remarked that the edge of a small rain shower appeared to be just on the north side of the airport. [Ex. 12-A] First Officer Hayes testified that this was a thin veil of rain through which he could see the runway. [Hayes, Tr. 415]

At 1840:42, in response to Flight 1016's request for a pilot report, LCW told the crew that the FK 100 also experienced a smooth ride. Flight 1016 then requested and received a report on the winds on the airport, which were given as one one zero at twenty-one knots. [Ex. 12-A] Captain Greenlee then reminded First Officer Hayes to stay heads up. [Ex. 12-A] At this point, because the preceding aircraft had reported smooth rides, and because the weather cell remained several miles south of the field, Captain Greenlee saw no reason to abort the approach. [Greenlee, Tr. 302] Neither Captain Greenlee nor First Officer Hayes saw any lightning in the area. [Greenlee, Tr. 324; Hayes, Tr. 390]

At 1841:06, LCW issued a windshear alert for the northeast boundary of the airport, with winds of one nine zero at thirteen knots. [Ex. 12-A] First Officer Hayes felt it was not unusual to receive a windshear alert when surface winds are gusty. [Hayes, Tr. 424] The approach continued to be smooth and stable, according to Captain Greenlee. [Greenlee, Tr. 282, 302]

At 1841:54, Captain Greenlee turned on the wipers as the aircraft was encountering light rain; approximately 5 seconds later, the crew noticed an increase in airspeed of 10 knots. [Ex. 12-A; Greenlee, Tr. 331] Shortly after the wipers were turned on, the rain intensified, and Captain Greenlee realized they would not be able to see the runway at decision height. [Greenlee, Tr. 281] Prior to encountering the heavy rain, the weather conditions experienced by the crew conformed to their expectations. [Greenlee, Tr. 320] The crew of Flight 1016 had no indication that heavy rain was falling on the airport, and in their flight path, prior to actually flying into it. [Greenlee, Tr. 359] First Officer Hayes testified that the aircraft handled very well in the rain, and the approach remained stable and smooth. [Hayes, Tr. 404]

At 1842:14, Captain Greenlee instructed First Officer Hayes to execute a go-around to the right (west) side of the runway. [Ex. 12-A] At 1842:17, Captain Greenlee began calling out the missed approach procedures; the first items on the checklist were max power and fifteen degrees of flaps. [Ex. 12-A] Captain Greenlee saw the engine power coming up, and the nose of the aircraft rising. [Greenlee, Tr. 283]

Just a few seconds after the crew brought the flaps to fifteen degrees, the aircraft dropped. [Greenlee, Tr. 283] At that point, Captain Greenlee felt the aircraft had entered a severe windshear. [Greenlee, Tr. 310] Captain Greenlee called for firewall power at 1842:28. [Ex. 12-A] The aircraft continued to sink, however, and the first sound of impact came at 1842:35. [Ex. 12-A]

1.7 METEOROLOGICAL INFORMATION

1.7.1 NATIONAL WEATHER SERVICE

According to the National Weather Service (NWS) surface weather observations at Charlotte Airport, a rapidly changing weather picture presented itself in the minutes preceding and immediately following the crash of Flight 1016. A record observation at 1751 (local time) indicated a scattered ceiling at 5,000 feet with 6 miles of visibility. [Ex. 5-A, p.2] At 1836, a special observation noted a ceiling of 4,500 feet with broken clouds, 6 miles visibility, thunderstorms and light rain showers. [Ex. 5-A, p.3]

Four minutes later, at 1840, another special observation was made with a measured ceiling of 4,500 feet overcast, 1 mile visibility, thunderstorms and heavy rain showers. [Ex. 5-A, p.3] By 1850, a record observation noted a measured ceiling of 4,500 feet overcast, and a return to 6 miles visibility, with thunderstorms and heavy rain showers. [Ex. 5-A, p.3]

Surface weather observation forms at Charlotte indicate that the thunderstorm over the airport area began at 1833 and ended at 1900. [Ex. 5-A, p.3] Light rain showers began at 1834, and ended at 1837. [Ex. 5-A, p.3] Heavy rain showers started at 1837 and ended at 1901. [Ex. 5-A, p.3]

1.7.2 AUTOMATED TERMINAL INFORMATION SERVICE

The Charlotte Automated Terminal Information Service (ATIS) broadcasts relevant to the Flight 1016 incident are broadcasts Yankee, effective at 1751, and Zulu, effective at 1836. Pertinent weather information related by ATIS Yankee to aircraft operating in the vicinity of Charlotte was that the ceiling was 5,000 feet scattered with 6 miles visibility. [Ex. 3-A, p.4] The ATIS Zulu broadcast for the Charlotte Airport related a ceiling of 4,500 broken clouds with 6 miles visibility, and a thunderstorm and light rain, but this message was not placed on the radio tape for transmission until after 1843 and was not heard by the crew of Flight 1016. [Ex. 3-A, p.4]

1.7.3 LOW LEVEL WINDSHEAR ALERT SYSTEM (LLWAS)

The Charlotte Airport is equipped with a Phase II Low Level Windshear Alert System (LLWAS). [Wilson, T. 656] It is a windshear detection system that operates through the use of five wind-measuring devices plus one back-up device. [Wilson, Tr. 656] The Phase II LLWAS was created as an interim measure while the Phase III LLWAS was being developed.

The Phase III system has a network of fifteen or more anemometers, nominally spaced 1.2 miles apart for a full three miles beyond each runway end. The placement is designed for full coverage of the potential hazard area, and a Phase III system has the ability to detect microbursts detection with a high reliability. Phase III systems involve the installation of sensors on property that is remote from the airport property. [Wilson, Tr. 658] As a result almost all LLWAS systems are Phase II.

The Phase II LLWAS, such as the one in use at Charlotte on July 2, 1994, operates with a significantly lower number of anemometers (5) than does the Phase III system, and it has a windshear detection probability of 40%. [Wilson, Tr. 659] However, the false alert probability of only 7% is comparable to the Phase III system. [Wilson, Tr. 660] The sensor system is small in a Phase I and II system. Thus, the algorithm written for the computer monitoring unit is written to detect a very strong or anomalous wind at a single sensor. [Wilson, Tr. 663] This is unlike the Phase III system, which has a greater number of sensors, thus allowing the algorithm which drives the alert system to interpolate data from the very strong signal received when a microburst lands in a dense sensor network. [Wilson, Tr. 662]

Phase II LLWAS also requires four separate and consecutive anomalous winds to be detected before an alert will issue. A forty second delay then results from detection to alert because the LLWAS Phase II unit samples winds every ten seconds. [Wilson, Tr. 664] This protective sampling method was incorporated in the Phase II LLWAS to minimize false alarms. [Wilson, Tr. 669] With respect to the Phase II LLWAS at Charlotte, and the events of July 2, 1994, sensors one (center field), two (northeast sector), and six (northwest sector) are critical, and it was a sensor two alert (northeast sector) that was given to Flight 1016. [Wilson, Tr. 670]

In the few minutes preceding the crash, the system detected winds at center field which were a bit stronger than those in other areas. The wind was generally from the southeast at a nominal speed. One minute later, however, the wind had shifted to 110°

and increased in velocity. [Wilson, Tr. 677] The system first detected windshear at the center field sensor, and it was based on the fact that the sensor was detecting winds from a differing direction and higher velocity. [Wilson, Tr. 677] A windshear alert was also detected in the southeast sector, and the sensor triangle of the Northeast, South and Center Field Sensors exhibit a diverse wind feature which resulted in difficulty in determination whether the windshear was to the north or the south. [Wilson, Tr. 679]

The LLWAS is designed to make a distinction between shear winds and operational winds. The system has a threshold of 15 knots of wind in order to trigger the alert mechanism. The particular wind in question only surged to approximately 13 knots. [Wilson, Tr. 680] Immediately after the last communication between ATC and Flight 1016, the northwest sector of the Charlotte Airport experienced a wind surge to 14.3 knots; just below the alert trigger threshold. [Wilson, Tr. 685] Further, the LLWAS Phase II system is not capable of detecting microbursts, and the controller receiving a windshear alert from a Phase II LLWAS can only issue a windshear alert. [Wilson, Tr. 683]

Analysis of the winds detected at the various sensors suggests the event that claimed Flight 1016 was a form of microburst event that was undersampled by the LLWAS network at Charlotte. [Wilson, Tr. 689]

Dr. Wilson attributed his assessment of a complex microburst event to the fact that there were two distinct wind pulses and because of the special cell discovery uncovered by the NEXRAD scan. [Wilson, Tr. 689-690]. He believes that the inadequacies of the Charlotte LLWAS are attributable to its sparse sensor network, but that the system operated as intended and designed on July 2, 1994. [Wilson, Tr. 690]

He also believes that the evidence is strong that this complex microburst event occurred just as Flight 1016 was trying to fly in the area. [Wilson, Tr. 691].

1.7.4 ASR-9 AIRPORT SURVEILLANCE RADAR

The ASR-9 radar system is primarily used to detect and track aircraft, but it is also capable of giving a controller nearly "real-time" qualitative information on precipitation reflectivity. [Weber, Tr. 725] Controllers are able to select, at any one time, two of six weather channels in two separate display modes. The ASR-9 operates by processing data from a high beam out to a range of nearly 30 kilometers (15 nautical miles), and then switching to a low beam beyond 30 kilometers. [Weber, Tr. 726-728] As a function of altitude there is a "cone of silence" above the antenna at altitudes above 5,000 feet. [Weber, Tr. 743-744]

An analysis based on NEXRAD scans done of the Charlotte area from the Colombia, South Carolina doppler weather radar was conducted by Dr. Mark Weber of MIT's Lincoln Laboratory to evaluate the weather being depicted on the ASR-9 at and before the time of the accident.

At 1835, the controllers could have seen a "pop-up" level three cell. [Weber, Tr. 743] A "pop-up" cell confirms the existence of a microburst situation. [Weber, Tr. 744] The volume scan at 1841, just prior to the accident, indicates heavy precipitation falling into the lowest NEXRAD beam.[1] The ASR-9 should have been painting a level four cell centered on the west side of the airport at this time. [Weber, Tr. 740]. When the rain is

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[1] The lowest level of the NEXRAD beam is at approximately 3,000 feet above ground level. [Saffle, Tr. 624]

reaching the ground, the radar should reflect it regardless of the rain's location relative to the antenna. [Weber, Tr. 745] When it was raining heavily at the Charlotte airport, the ASR-9 should have been painting an accurate picture of the intensity of the rain right up to the radar antenna. [Weber, Tr. 759]

The overall trend in the area of the Charlotte Airport in the minutes before the crash indicate the maximum weather level on the ASR-9 increased from level two to level four. The cell drifted northward from a position of about 3 kilometers south of the airport to the airport's center at an average drift of 8 knots, with a descending reflectivity core consistent with the development of a fairly classic microburst scenario directly on top of the airport. [Weber, Tr. 751]

Dr. Weber also has surmised, based on the simulation and reports from the flight crew, that Flight 1016 entered the area of microburst activity at the very beginning of its existence. [Weber, Tr. 761]

1.7.5 WSR-88D NEXRAD RADAR

The WSR-88D (NEXRAD) system is used primarily to support public weather forecasts and warnings. [Saffle, Tr. 635] It is a form of Doppler radar technology which operates with a much higher power than conventional radars and has a very fine resolution beam. [Saffle, Tr. 597] The chief difference is that NEXRAD combines basic radar with sophisticated computer processing capabilities. The National Weather Service has 90+ NEXRAD systems operational, and it is implementing them at a rate of about four per month. Only eight or ten of the systems are, however, commissioned because of a problem with spare parts shortages. [Saffle, Tr. 598] Even though formally uncommissioned, the radars are in use. [Saffle, Tr. 599]

The closest NEXRAD system to Charlotte is located 77 nautical miles to the south at Columbia, South Carolina. The system is accurate, however, to within 800 feet. [Saffle, Tr. 599] The map background accuracy at the range of 77 nautical miles would be 3 kilometers, and it is accurate to within 1½ miles of geographic boundaries and landmarks. [Saffle, Tr. 600]

The methods employed and the data used in the simulation for Charlotte came from the WSR-88D at Columbia. [Saffle, Tr. 601] The model used reflectivity for hail, and an attempt was made to reduce that to an appropriate rainfall rate, although no hail was reported. The rainfall rate is capped at 4.08 inches per hour. [Saffle, Tr. 602] However, the rainfall rate can reach extreme values over small periods of time -- up to an order of magnitude greater than the average reported value. [Ex. 5G, p. 1] The rainfall rate for a very short period of time could exceed 40" per hour.

The NEXRAD display allows a four-panel view of the weather, and the center of the beam in the Charlotte area would be between 7,000 and 8,000 feet. [Saffle, Tr. 608] The lower left panel in each display identifies vertically integrated liquid: the estimate of a total mass of water in a column over a given unit area on the ground. [Saffle, Tr. 613] The NEXRAD scans indicate that at 1829 (local time), reflectivity in the storm near the Charlotte Airport had increased to 40 dBZ. [Saffle, Tr. 619] The storm had grown to a a VIP Level 3 to the south-southeast of the center of the airport. In the mid-levels of the cell, reflectivity was around 50 dBZ which approximates a VIP Level 5 cell. [Saffle, Tr.

620] The 1829 scan also shows an outflow away from the radar at the lowest elevation angle. [Saffle, Tr. 621]

At 1835, the NEXRAD showed reflectivity of 50 dBZ at the .5 degree angle, or approximately VIP Level 5. It is highly likely that heavy rain was then falling to the surface at Charlotte, and the strongest gradient of the storm was toward the north-northwest part of the storm. [Saffle, Tr. 622] The storm was off to the northwest edge of the runway, and the initial impact point was in the center of the 50 dBZ echo area on the .5 degree NEXRAD display. [Saffle, Tr. 623]

At 1841, the storm had begun to decay. [Saffle, Tr. 626] Reflectivities had decreased in the higher altitudes, and the reflectivity core was descending. This would create an outflow boundary or gust front on the surface that could be classified as a microburst or downburst. [Saffle, Tr. 627] The clouds tops were at 30,000 feet just east of the impact site, and at 1847, NEXRAD showed the storm decreasing in intensity. [Saffle, Tr. 630]

1.7.6 TERMINAL AREA SIMULATION SYSTEM (TASS)

The Terminal Area Simulation System (TASS) was used to model the suspected microburst event at Charlotte on July 2, 1994. In summary, the event exhibited a large wind velocity change on the order of 70 knots, or 35 meters per second. This velocity change occurred over an area of only one kilometer, and in that area was an F-factor of 0.3. [Proctor, Tr. 785] The event was also associated with moderate to heavy rainfall. [Proctor, Tr. 786] It was generated from a thunderstorm with a cloud top of about

30,000 feet, and it is one of the most intense microbursts ever numerically simulated. [Proctor, Tr. 786]

The TASS system has been accepted by the FAA and has been used to examine other windshear events, such as the 1985 DFW Delta crash. [Proctor, Tr. 787] Perhaps the most unusual element of the Charlotte event was that there was a very steep lapse rate of approximately 80 from the surface to a height of 3 kilometers. There was a stable layer around 7 kilometers which limited cloud tops to 30,000 feet, and the moisture in the atmosphere was fairly deep. [Proctor, Tr. 787]

The F-factor is a unit of measurement to describe the degree of hazard from a windshear. The FAA considers 0.1 F-factor to be hazardous. The flight data recorded from Flight 1016 indicates an F-factor of 0.3. Even the 1985 DFW crash measured only 0.25 F-factor. [Proctor, Tr. 789]

As Flight 1016 approached for landing at Charlotte, it encountered a very strong headwind of about 40 knots. Then, over the distance of only 1 kilometer, it encountered a strong tailwind of approximately 40 knots. [Proctor, Tr. 792] This evidences a very strong windshear encounter over a very small distance. [Proctor, Tr. 793] The aircraft entered a performance-enhancing area due to the increase in headwind, but as it passed into the microburst, the F-factor rapidly increased to 0.265 in the TASS model, and to 0.3 on the flight data recorder. [Proctor, Tr. 794] The TASS model also indicates that Flight 1016 was encountering mild updraft values of 2 meters per second in the area of headwind, but suddenly shifted into a severe downdraft on the order of 1400 feet per minute. [Proctor, Tr. 794] The TASS model can calculate values to areas as low as 100 to 100 feet above ground level. [Proctor, Tr. 795]

Additional characteristics of this storm indicate its multi-cellular composition. The storm formed new cells as it grew. [Proctor, Tr. 799] The storm also developed embedded microbursts within the original outflow. When matched with time clocks, the accident time correlates with the time of peak rainfall rate and peak F-factor values. [Proctor, Tr. 800]

Rainfall rates one minute prior to impact were significantly greater than one minute after the accident. This indicates that the encounter with the microburst occurred at the time when rainfall rate was rapidly increasing. The F-factor was also rapidly increasing at this time, and it was three times the FAA hazard threshold. [Proctor, Tr. 800] Because the microburst contained several divergent centers, it wasn't an "idealized" single downdraft with a symmetric flow field. The microburst was driven by a very small diameter rainshaft with radar reflectivities of about 52 dBZ near the surface. [Proctor, Tr. 802] The F-factor values are in the top one percent of microburst intensities, and Flight 1016 entered the microburst early in its existence and at its moment of peak intensity. [Proctor, Tr. 803]

2. ANALYSIS

2.1 GENERAL

2.2 FLIGHT 1016 CREW

2.2.1 CREW DECISION MAKING

Dr. Judith Orasanu, an investigator at NASA Ames Research Center, testified there are four factors characteristic of good decision-making: situation assessment, contingency planning, task/workload management, and communications. [Orasanu, Tr.

442] Dr. Orasanu saw all of the elements of effective decision-making in the actions of Flight 1016's crew. [Orasanu, Tr. 444]

The crew of Flight 1016 continually reassessed their situation throughout the approach, and aggressively sought information to assist in their assessment. The crew first saw a small cell while approaching the terminal area, and monitored the cell throughout the base and final legs of the flight. At 1839:20, Captain Greenlee noted there was a chance of windshear, and shared that information with First Officer Hayes. [Ex. 12-A] At 1839:49, after learning that a previous aircraft landing on Runway 18R reported a smooth ride, Captain Greenlee immediately requested another ride report from the aircraft landing directly in front of Flight 1016. [Ex. 12-A] That aircraft also reported a smooth ride. After receiving the second ride report at 1840:42, Captain Greenlee requested information on the wind conditions on the airport. At 1841:05, Captain Greenlee reminded First Officer Hayes to stay heads up. At 1841:06, the crew received a windshear alert in a quadrant which was not in their flight path. [Ex. 12-A]

Dr. Orasanu testified that the Flight 1016 crew faced a very difficult situation, in light of the ambiguous clues they were receiving. [Orasanu, Tr. 447] Dr. Orasanu testified that it is much more difficult to assess a given situation, and to make appropriate decisions, when the crew is faced with ambiguous cues. [Orasanu, Tr. 437] Dr. Orasanu also testified that she would expect an experienced decision-maker to solicit information in an attempt to clarify an ambiguous situation. [Orasanu, Tr. 440] The ongoing requests for additional information by the flight crew exemplified the appropriate response to an ambiguous weather situation. [Orasanu, Tr. 439]

In addition, Dr. Orasanu noted the presence of the other three elements of effective decision-making by the crew of Flight 1016. In discussing the missed approach procedure, the crew was engaged in contingency planning. [Orasanu, Tr. 444] The crew's task and workload management was clearly very good, as evidenced by their performance of their assigned tasks. [Orasanu, Tr. 444] Lastly, the crew communicated with each other regarding the weather as it was known to them, the chance of windshear, and the appropriate flight path in the event of a missed approach. [Ex. 12-A] The crew's actions, therefore, encompassed all of the elements of effective decision-making. [Orasanu, Tr. 444]

Based upon the information they had, Flight 1016's crew made appropriate decisions, initiating a missed approach when the weather cues dictated that was the proper action. The crew knew of only one small weather cell off the south end of the runway. They were aware of the possibility of light rain in their approach path, but were not aware of any lightning over the airport or in their approach path. They received two pilot reports which indicated the approach was smooth and non-turbulent. Lastly, the windshear alert they received did not affect their intended approach path or the active runway they were using. Visually, the crew could see the landing environment until the heavy rain began; the missed approach was initiated shortly thereafter.

2.2.2 FLIGHT 1016 CREW'S DETECTION OF WINDSHEAR

The crew of Flight 1016 had no cues which would indicate that they were about to encounter an extremely severe windshear/ microburst event.

During the NTSB Public Hearing regarding the "Microburst Windshear Probability Guidelines" contained at page 84 of the March-June 1994 Flight Crew View [Ex. 2-F] were discussed. The Probability Guidelines state they "apply to operations in the airport vicinity (within 3 miles of the point of takeoff or landing along the intended flight path and below 1000 feet agl)." During this approach, the only convective activity of which the Flight 1016 crew was aware was south of the Charlotte VOR, approximately 2.2 miles from the approach end of Runway 18R. [Ex. 2-B] Captain Greenlee testified that while on downwind, the Flight 1016 crew saw the cell located one to two miles south of the airport and that it appeared to be in approximately the same position while on final. Runway 18R is 10,000' long [Ex. 15-B], so a cell located one to two miles south of the runway was three to four miles south of Flight 1016's intended touchdown point. In addition, the cell was not along Flight 1016's intended flight path. In fact, the 1016 crew planned a flight path away from that convective activity in the event a go-around was necessary. These guidelines are therefore not directly applicable in this situation.

The crew was not aware of, and did not expect to encounter, heavy rainfall or severe winds in their intended flight path. They were told there might be "a little bit" of rain on the north side of the airport, and the crew noticed a thin veil of rain when the aircraft was on short final. The crew was also not aware of any lightning in the terminal area; First Officer Hayes testified he would have alerted Captain Greenlee if he saw any, and Captain Greenlee testified he would have discontinued the approach if he saw lightning. There were no reports of turbulence in the terminal area, nor did Flight 1016 encounter any turbulence on approach. The temperature/dew point spread was 21 degrees Fahrenheit, well below the 30 to 50 degrees which indicates a medium probability of microburst windshear activity. The crew received successive pilot reports of smooth rides. Lastly, the LLWAS alert they received indicated only an 8 kt. difference between the centerfield wind, reported at 21 kts., and the northeast boundary wind, reported at 13 kts. Further, the shear was performance enhancing, and not along their route of flight.

In addition, it would have been extremely difficult to detect the event prior to flying into it, because it appears to have occurred simultaneously with Flight 1016's flight through the area. Dr. Wes Wilson noted strong evidence that this microburst occurred at the time Flight 1016 was trying to fly through that airspace. [Wilson, Tr. 691] In addition, Dr. Fred Proctor testified that Flight 1016's penetration of the microbursts occurred when the surface rainfall was rapidly increasing [Proctor, Tr. 800], and that the encounter was early in the microburst's lifetime and during its period of highest intensity. [Proctor, Tr. 803, 811] It appears that the microburst was developing above Flight 1016, rather than in front of them, and the airborne weather radar therefore provided no assistance to the crew in assessing the weather.

2.2.3 FLIGHT CREW RESPONSE

Having initiated a normal go-around consistent with their training, First Officer Hayes increased the power toward go-around power and pitched the aircraft toward 15 degrees. Captain Greenlee reset the flaps to 15 degrees from 40 degrees, thus initiating a configuration change in the aircraft. The change in pitch in a normal environment produces a loss of airspeed initially, and properly requires the flight crew to be sensitive to not over-pitching the aircraft in a low speed, low altitude environment, and may have properly caused Captain Greenlee to caution First Officer Hayes not to over rotate. The effect of pitching the aircraft up as part of the missed approach effectively masked the actual cause of the airspeed loss as the aircraft began to penetrate into the microburst.

Since the existence of the severe shear was masked until the aircraft penetrated the downdraft, First Officer Hayes quite properly did not try to force the nose up in the face of the decreasing airspeed.

As the aircraft suddenly penetrated the downdraft, the flight crew experienced a complete reversal of aerodynamic response. With their minds on the problem of not getting the nose too high, in order to preserve airspeed and not exceed their assigned altitude, the nose suddenly dropped due to the combined force of the change in flaps, the loss of airspeed and a 1400 foot/minute downdraft. In a moment's time the flight crew had to change their mind set from trying to preserve airspeed, to trying to trade airspeed for altitude. In fact, within a few seconds the flight crew did realize the problem and began the proper corrective action, but there was neither sufficient altitude nor time in the face of a .3 F-factor microburst.

2.3 USAIR'S TRAINING PROGRAM

USAir provides training for nearly 15,000 pilots, flight attendants, and dispatchers in approximately 130 separate training programs. [Bowden, Tr. 572] Within this group, USAir trains over 5,000 pilots. [Ex. 2-A, p. 6] The FAA's Principal Operations Inspector ("POI") approves all USAir training programs and oversees the FAA's surveillance of USAir's operations. [Bowden, Tr. 528]

Under USAir's FAA-approved recurrent training program, each Captain is required to take a proficiency check in the simulator each 12 months. [Ex. 2-A, p. 9] However, each Captain also must have completed either a proficiency check or proficiency training within any preceding six month period. [Ex. 2-A, p. 9] First Officers must complete a proficiency check each 24 months. However, each First Officer also must have completed either a proficiency check or proficiency training within any preceding 12 month period. [Ex. 2-A, p. 9] In each of these check and training sessions, both a Captain and a First Officer participate. [Johnson, Tr. 502-03] First Officers, therefore, participate in simulator training more frequently than the requirements dictate. [Ex. 2-A, p. 9] In fact, each First Officer participates in an extra training period each year; that is, one every six months. [Johnson, Tr. 474] Despite the increased expense to the company, USAir voluntarily conducts this training in order to emphasize the crew concept during each and every training session. [Johnson, Tr. 491] No other airline has such a requirement. [Johnson, Tr. 507-08]

USAir has voluntarily instituted several programs through which it monitors the effectiveness of the training it provides for its pilots. In 1989, USAir voluntarily implemented FAA advisory circular AC-120-59, "Air Carrier Internal Evaluation Program." [Ex. 2-A, p. 6] Under that program, USAir conducts periodic audits of the performance of its operations programs. [Johnson, Tr. 487] The Director of Flight Safety and Quality Assurance, who initiates the audits, reports the results directly to the Vice President of Flight Operations. [Johnson, Tr. 486] Since 1991, USAir has conducted five evaluations. [Ex. 2-A, p. 6-7] Agencies external to USAir conducted four of these audits. [Ex. 2-A, p. 6-7]

In close cooperation with the POI, USAir also participates in a unique voluntary program further designed to evaluate and improve its operations. Under the "Compliance Through Partnership" program, the POI analyzes data gathered from enroute flight checks conducted by FAA inspectors. [Bowden, Tr. 537] These flight checks, over 3,000 of which were conducted in 1993, assess the performance of crews during actual line operations. [Bowden, Tr. 535] The purpose of the inspections is three-fold. First, inspectors look for compliance with Federal Aviation Regulations. [Bowden, Tr. 534] Noncompliance in this area has not been a problem at USAir. [Bowden, Tr. 535] Second, inspectors evaluate USAir's training program. There have been no adverse trends in this area. [Bowden, Tr. 535] Third, inspectors evaluate compliance with USAir's own procedures. This broad area produces trend data which is useful in designing emphasis areas for USAir's training programs.

The POI evaluates data from these enroute checks and identifies trends which may be present. Bowden, Tr. 537. If unfavorable trends develop, the POI and USAir's Director of Safety and their staffs conduct a two week assessment of the applicable training programs. [Bowden, Tr. 536] At the end of the assessment, USAir and the POI develop programs to provide the proper training emphasis to reverse the trend. USAir's Altitude Awareness Program was such a program. [Bowden, Tr. 537] Three years ago, an unfavorable trend developed in altitude deviations, resulting in three to four deviations per month. [Bowden, Tr. 537] Since implementation of the program, the number of deviations has dropped dramatically, now averaging less than one-half a deviation per month. [Bowden, Tr. 537] In May 1994, USAir and the POI implemented a similar program designed to emphasize standardization and compliance with USAir's procedures. [Bowden, Tr. 537]

2.3.1 MISSED APPROACH TRAINING

USAir pilots execute a missed approach during every simulator flight, whether it is a proficiency check or recurrent training. Each USAir pilot participates in a simulator flight each six months. [Johnson, Tr. 474] A missed approach event is a part of the DC-9 recurrent LOFT scenario. [Ex. 2-Q, pp. 10-11] Further, the USAir Check Airman's Handbook directs accomplishment of missed approach events during proficiency training. [Ex. 2-P, p. 11] The Check Airman Handbook also directs accomplishment of missed approaches during proficiency checks, in accordance with 14 C.F.R. § 121, Appendix F. [Ex. 2-P, p. 9]

2.3.2 WINDSHEAR TRAINING

In response to an FAA Advisory Circular containing a windshear training aid issued in October, 1989, USAir revised its existing windshear training program. [Johnson, Tr. 482] By November of that year, USAir had its simulator programs qualified and approved. In September 1990, USAir again revised and improved its program, based on POI input. [Bowden, Tr. 554]

Windshear training must be accomplished during each proficiency training period and each proficiency check given in lieu of proficiency training. 14 C.F.R. §§ 121.409(d), 121.433(e). [Ex. 2-O, p. 6; Ex. 2-P, p. 4] USAir's DC-9 recurrent training LOFT contains a windshear event [Ex. 2-Q, p. 10-11], and USAir's Check Airman Handbook mandates windshear training during each proficiency training session. [Ex. 2-O, p. 4]

USAir conducts windshear training for its pilots during recurrent training, through both ground and simulator flight training. [Ex. 2-O, p. 6] The ground training focuses on the meteorology of windshear and stresses avoidance as USAir's standard operating procedure. [Ex. 2-O, p. 6] Ground training includes a video emphasizing avoidance, recognition, and recovery. [Ex. 2-O, p. 7; Johnson, Tr. 483] USAir's ground school program also emphasizes avoidance of windshear through test questions on proper avoidance techniques. [Bowden, Tr. 555] Pilots are taught in this phase that not all windshear is survivable, and they also receive test questions on that concept. [Johnson, Tr. 484]

Before accomplishing windshear training in the simulator, there must be a briefing period during which recognition, avoidance, and proper recovery procedures are stressed. [Ex. 2-P, p. 4] Following the flight training, a debriefing session is required. It must include a discussion of avoidance as the best defense against windshear. [Ex. 2-P, p. 5]

Although only required to train to three windshear scenarios during flight training in the simulator, USAir trains instead to six, all approved by the FAA. [Ex. 2-P, p. 4] Some of the scenarios introduce turbulence as a lead-in to the situation, but not all. [Johnson, Tr. 482] The scenarios present windshear in visibility conditions ranging from VFR down to 1-1/2 miles. [Johnson, Tr. 483] The DC-9 simulator incorporates the Honeywell windshear detection system, as does the aircraft itself. [Johnson, Tr. 507-08]

USAir assigns a different windshear scenario for training each 12 months in order to insure pilots experience a different scenario during each required training session. [Johnson, Tr. 507-08] One purpose of the training is to illustrate the difficulty of maintaining flight path control in windshear conditions, thereby reinforcing avoidance as the best defense. [Johnson, Tr. 507-08]

Finally, USAir uses its pilot-oriented safety publication, Flight Crew View, to supplement other training on various topics, particularly seasonal ones like windshear. [Bowden, Tr. 555] The edition of Flight Crew View which was current at the time of the accident contained a 51-page article on windshear recognition, avoidance, and recovery, which was at least the second time the article had been published in Flight Crew View since 1990. [Johnson, Tr. 485] Captain Greenlee had picked up his current copy of Flight Crew View the morning of the accident, but had not yet had the opportunity to read it. [Greenlee, Tr. 356] He had, however, read similar articles in the publication before. [Greenlee, Tr. 356]

In his four years overseeing USAir's training, the FAA's POI has never received any criticism of the substance of USAir's windshear training program from any of his inspectors. [Bowden, Tr. 565] In the only instance where implementation of the program was criticized, a check airman incorrectly administered windshear training in a recurrent simulator, then mistakenly logged the event as complete. [Ex. 2-K, p. 8] Instead of having each pilot experience the windshear event in both the flying and non-flying role as required, only one event was flown. [Bowden, Tr. 551] Consequently, one of the pilots had not "flown" the event. [Bowden, Tr. 551] Immediately upon learning of the incident through the POI, USAir decertified the check airman and removed the pilot from the line schedule. [Bowden, Tr. 551] The pilot was not allowed to return to the flying schedule until successfully completing the event. [Bowden, Tr. 551]

Both pilots aboard USAir Flight 1016 reported having received windshear training during every recurrent simulator training session or proficiency check. [Greenlee, Tr. 317, 354-55; Hayes, Tr. 383] Both pilots' training and proficiency check requirements were current at the time of the accident. [Ex. 2-A, pp. 25-26] Captain Greenlee described a "substantial block of time" being devoted to windshear training during recurrent ground school. [Greenlee, Tr. 313] The ground school training included a multiple choice quiz, and if any student missed a question, the topic was repeated to make sure the class understood the answer. [Greenlee, Tr. 313] As for the flight training in the simulator, Captain Greenlee described the windshear cues as consisting not only of turbulence, but also audio cues from simulated air traffic control and other aircraft. [Greenlee, Tr. 314] During training, Captain Greenlee recalled, each pilot had the opportunity to be the pilot flying the aircraft during a windshear encounter. [Greenlee, Tr. 315]

First Officer Hayes also described receiving windshear training with each simulator session. [Hayes, Tr. 383] He, too, confirmed that each pilot in each simulator session had the opportunity to experience a windshear event from both the flying and non-flying pilot positions. [Hayes, Tr. 404-05] First Officer Hayes also related that the cues to the onset of a windshear situation during simulator training were not limited to those provided by the onboard warning system or turbulence, but also included recognition through other cues, notably, airspeed fluctuations. [Hayes, Tr. 413-14]

2.3.3 CREW RESOURCE MANAGEMENT TRAINING (CRM)

In 1990, USAir redeveloped its existing Crew Resource Management program following the FAA's issuance of advisory circular 120-51. [Johnson, Tr. 480] USAir enlisted the advice and assistance of NASA/UT and the Airline Pilots' Association in developing the program. [Johnson, Tr. 489, 494] Although not required to do so, USAir consulted NASA/UT because of that agency's acknowledged expertise in the field. [Johnson, Tr. 489] During development of USAir's CRM program, Dr. Judith Orasanu, the principal investigator in NASA's Ames Research Center's Human Factors Research Group, attended a developmental session. [Orasanu, Tr. 426, 430] Although the program she observed was still in the developmental stage, she was "impressed" that the program included all the critical elements and used class exercises to illustrate points, rather than mere discussions. [Orasanu, Tr. 426, 430] She felt the program included the latest in contemporary thinking in crew resource management principles. [Orasanu, Tr. 430-31] In fact, other organizations have visited USAir to observe the CRM program, among them the Aircraft Owners and Pilots Association, the Department of Defense, Conrail, nuclear power plant operators, and major air carriers. [Johnson, Tr. 493-94] USAir has even included flight attendants, dispatchers, and representatives from the FAA Flight Standards District Office in its CRM training sessions. [Johnson, Tr. 498-99] The FAA POI stated he is very pleased with USAir's efforts in its CRM program, particularly with the fact that First Officers participate at twice the required rate, despite the additional expense. [Bowden, Tr. 563-64]

Under the program, each pilot attends a one-day seminar designed as an introduction to the concepts of CRM. [Ex. 2-O, p. 1] After attending the initial training, each pilot must attend a yearly recurrent ground training session designed to reinforce the principles of CRM introduced in the initial seminar. [Ex. 2-O, p. 1] In addition, each pilot participates in CRM training in conjunction with recurrent flight training. [Ex. 2-O, p. 1] In each proficiency check or proficiency training simulator, the check airman must stress the importance of CRM to the successful and safe operation of the aircraft. [Ex. 2-P, p. 2]

USAir's recurrent training program, including windshear training, exceeds FAA requirements both in frequency and in content. In at least the past four years, there has been no substantive criticism by FAA inspectors of USAir's windshear training program. The program stresses recognition and avoidance as the best defenses to windshear. Each pilot experiences a windshear encounter in the simulator each six months, from the perspective of both the flying and non-flying pilot positions. The varied scenarios, twice the number required, allow USAir to present its pilots with fresh and challenging windshear training during each semi-annual simulator training or check session. Each of the pilots aboard USAir Flight 1016 had participated fully and successfully in these training programs and benefitted from them.

Further, USAir has voluntarily implemented programs to enhance the effectiveness of its training programs. In developing and implementing its CRM program, for example, USAir sought the assistance of the best minds in the field, who now have high praise for USAir's approach to CRM. Further, USAir voluntarily initiated a system of internal and external audits of its operations to enhance overall compliance and safety. USAir has in place an enviable training program which provides its pilots with comprehensive and effective training far exceeding the FAA's minimum requirements.

2.4 EFFECTS OF HEAVY RAIN ON AERODYNAMIC PERFORMANCE

Studies have shown that aerodynamic performance is decreased during periods of high intensity rain. Heavy rain causes a reduction in maximum lift capability and a corresponding increase in drag. This effect, which can generate a loss of lift of up to 15 to 20 percent in rainfall equaling a rate of 40 inches per hour, also causes an associated decrease in the angle of attack at which maximum lift occurs. [Ex. 13D, figs. 20, 21] In general, this performance decrease is attributable to the uneven distribution of waterfilm over the airfoil and the accumulation of water near the trailing edge of the airfoil, thereby effectively changing the airfoil's shape. [Tang, Experimental Investigation of Heavy Rainfall Effect, AGARD Conference, Tolouse, France, April 29-May 1, 1994, attached as Appendix A]

Aerodynamic performance is most affected by heavy rain when an aircraft is in a high-lift configuration and performing at maximum angle of attack. [Ex. 13D, p. 1] As a result, the effects of high intensity rain are particularly acute when encountered during severe low-altitude windshear. During such windshear, piloting procedures require the aircraft to perform at maximum angle of attack. Studies have shown that heavy rain can have a significant negative effect on the ability of an aircraft to recover from a microburst encounter.[2] [Vicroy, Aerodynamic Effect of Heavy Rain on Airplane Performance, AIAA Flight Simulation Conference, September 17-19, 1990, attached as Appendix B]

On the evening of July 2, 1994, the area near runway 18R at Charlotte Douglas International Airport experienced one or more severe microbursts. Doppler radar

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[2] Heavy rain may contribute, through a miscompare in the angle of attack vanes, to a failure of on-board windshear detection systems to activate under conditions such as those at Charlotte on July 2, 1994. [Exh. 9A, p.8]

indicated that rainfall in the area reached rates of 4 to 11 inches per hour. [Ex. 5G, p.2] Rainfall of this magnitude can cause up to a 5 percent loss in lift capability and 1.5 to 2 degree reduction in maximum angle of attack. [Dunham, Tr. 828] However, rainfall rates can reach extreme values over short periods of time up to an order of magnitude greater than the average reported rainfall. [Ex. 5G, p. 1] This suggests rainfall rates exceeding 40 inches per hour could be experienced, with a corresponding 15 to 20 percent loss in lift and a 5 degree decrease in maximum angle of attack. The evidence is consistent with an extremely high localized rainfall falling in the vicinity of USAir Flight 1016 in its final moments of flight. The Runway 36 "Rollout" transmissometer registered a drop in visibility beginning at 1840 and culminating in a drop to 29% transmittance at 1845, indicating visibility had dropped to 800 feet. [Ex. 5A, p. 4] Such a spike of reduced visibility for a short period is not a common occurrence. [Ex. 5A, p. 14] Witnesses reported that parts of the airfield were covered by a "virtual wall of water," [Proctor, Tr. 786], and the Charlotte Tower Local East controller reported that it was the heaviest rain he had ever seen. [Ex. 3A, p. 20] This heavy rainfall also was described as "a sheet or granite wall of water, solid, and very white looking" by a pilot approaching Charlotte at the time. [Ex. 5A, p. 4] A witness on the ground near the crash site stated that when the heavy rain began he entered the cab of his truck, and from there he could not see the hood. [Ex. 5A, p. 22]

The TASS computer model simulating the microburst event compared to the accident aircraft's flight path shows that it encountered this severe microburst at the precise time the rainfall reached its peak rate. [Proctor, Tr. 800] Due to the heavy rain and loss of visibility, the crew of Flight 1016 executed the go-around maneuver and increased the aircraft's pitch angle to 15 degrees. With the pitch angle in this position, the aircraft was most susceptible to the performance decreasing effects of severe rain. This fact, coupled with the sudden downdraft and performance decreasing windshear, likely made the microburst encounter unrecoverable.

3. CONCLUSIONS

3.1 FINDINGS

(1) The crew of Flight 1016 exhibited good decision-making abilities, engaging in situation assessment, contingency planning, task/workload management, and communications throughout the approach to Charlotte/Douglas airport.

(2) USAir's recurrent training program, including windshear training, exceeds FAA requirements both in frequency and in content.

(3) The windshear/microburst event which caused this accident was, at .3 F-factor, in the top one percent of such events based on severity and intensity.

(4) Initiation of the missed approach procedure masked the initial onset of the decreasing performance shear.

3.2 PROBABLE CAUSE

The probable cause of this accident was Flight 1016's inadvertent entry into a .3 F-factor microburst and subsequent collision with the ground.

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AGARD CONFERENCE PROCEEDINGS 496

Effects of Adverse Weather on Aerodynamics

(Les Effets des Conditions Météorologiques
Adverses sur l'Aérodynamique)

Papers presented and discussions held at the Fluid Dynamics Panel Specialists' Meeting held in Toulouse, France, 29th April—1st May 1991.

North Atlantic Treaty Organization
Organisation du Traité de l'Atlantique Nord

Recent Publications of the Fluid Dynamics Panel

AGARDOGRAPHS (AG)

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AGARD AG-319, November 1991

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AGARD AG-318 (E), April 1991

Techniques Expérimentales Liées a l'Aerodynamique à Basse Densité
AGARD AG-318 (FR), April 1990

A Survey of Measurements and Measuring Techniques in Rapidly Distorted Compressible Turbulent Boundary Layers
AGARD AG-315, May 1989

Reynolds Number Effects in Transonic Flows
AGARD AG-303, December 1988

REPORTS (R)

Aircraft Dynamics at High Angles of Attack: Experiments and Modelling
AGARD R-776, Special Course Notes, March 1991

Inverse Methods in Airfoil Design for Aeronautical and Turbomachinery Applications
AGARD R-780, Special Course Notes, November 1990

Aerodynamics of Rotorcraft
AGARD R-781, Special Course Notes, November 1990

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AGARD R-774, Special Course Notes, November 1989

ADVISORY REPORTS (AR)

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AGARD AR-270, September 1991

Appraisal of the Suitability of Turbulence Models in Flow Calculations
AGARD AR-291, Technical Status Review, July 1991

Rotary-Balance Testing for Aircraft Dynamics
AGARD AR-265, Report of WG11, December 1990

Calculation of 3D Separated Turbulent Flows in Boundary Layer Limit
AGARD AR-255, Report of WG10, May 1990

Adaptive Wind Tunnel Walls: Technology and Applications
AGARD AR-269, Report of WG12, April 1990

CONFERENCE PROCEEDINGS (CP)

Effects of Adverse Weather on Aerodynamics
AGARD CP-496, December 1991

Manoeuvring Aerodynamics
AGARD CP-497, November 1991

Vortex Flow Aerodynamics
AGARD CP-494, July 1991

Missile Aerodynamics
AGARD CP-493, October 1990

Foreword

In recent years, a number of weather-related accidents, along with the introduction of new types of anti-icing fluids and apparent uncertainties in certification and operation procedures, have stimulated renewed research activities. Aircraft operators, the aircraft industry, as well as research institutes and certification authorities, are participating in such activities.

This situation has led the Fluid Dynamics Panel to organize a specialists' meeting on the "Effects of Adverse Weather on Aerodynamics".

Since the effects of adverse weather on aerodynamics involve a broad range of weather-related phenomena and devices — different forms of precipitation, wind shear, anti-icing fluids and devices, etc. — an in-depth coverage of these effects within the confines of a meeting required some focussing. To this end, the scope of this FDP Specialists' Meeting focussed on the degradation of aerodynamics performance due to different forms of precipitation, such as ice accretion, and due to anti-icing fluids and devices. This degradation of performance continues to be a concern in aircraft operations and is also a significant factor in aircraft design.

A complementary coverage of weather-related effects — wind shear, fog, etc. — on aircraft performance is provided in AGARD CP-470, "Flight in Adverse Environmental Conditions" (AGARD FMP Symposium held in Norway in May 1989).

The purpose of the present specialists' meeting was, in particular:

1. To provide an update of the state-of-the-art with respect to the prediction, simulation, and measurement of the effects of icing, anti-icing fluids, and various forms of precipitation on the aerodynamic characteristics of flight vehicles;
2. To communicate research results obtained in recent years on the following topics:
   - theoretical and empirical modelling of ice accretion on airfoils, wings, control surfaces, propellers, rotors, air intakes, etc.,
   - experimental and computational simulation, and flight test verification of the effects of icing on aerodynamic characteristics,
   - experimental and computational simulations of the effects of de-icing and anti-icing fluids, and devices on aerodynamics,
   - effects of (heavy) rain and other forms of precipitation on aerodynamic characteristics;
   - effects of the type of ice (rime, glaze) on aerodynamic characteristics;
   - facilities and experimental techniques (including flight tests) for simulating and measuring the effects of icing, anti-icing fluids, and heavy rain on the aerodynamics of flight vehicles and their components;
   - certification and operation procedures and regulations.

For the sake of statistics it is mentioned that of the 24 papers offered to the Programme Committee, 19 (including invited papers) could be accommodated within the time frame available.

These 19 papers were ordered into 3 sessions:

- Icing 1 Introduction and survey papers, certification issues.
- Icing 2 Prediction and simulation of ice contamination and its effect on aerodynamics.
- Effects of heavy rain and de anti-icing fluids.

In alphabetical order of country of origin there was were

2 papers from Belgium
3 papers from Canada
3 papers from France
1 paper from Germany
1 paper from the Netherlands
1 paper from Spain
1 paper from the United Kingdom
7 papers from the United States.

Two papers could not be presented because of sudden travel restrictions.

The Programme Committee gratefully acknowledges that 2 of the 4 invited papers were provided by the Flight Mechanics Panel (FMP) and the Propulsion and Energetics Panel (PEP) of AGARD.

It is finally mentioned that the Technical Evaluation Report, written by Mr J. Reinmann of NASA Lewis is available as AGARD Advisory Report No.306.

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SESSION II – ICING 2 – PREDICTION AND SIMULATION OF ICE CONTAMINATION AND ITS EFFECTS ON AERODYNAMICS

Chairman: J L. Van Ingen

SESSION III – EFFECTS OF HEAVY RAIN AND DE/ANTI-ICING FLUIDS

Chairman: F. Monge

EXPERIMENTAL INVESTIGATION OF HEAVY RAINFALL EFFECT ON A 2-D HIGH LIFT AIRFOIL

by

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SUMMARY

The effects of simulated heavy rainfall on a 2-D high lift airfoil have been studied in a wind tunnel experimental programme. The experiment was carried out in the 2-dimensional test section of the 1.5m X 1.5m blowdown wind tunnel of the High Speed Aerodynamics Laboratory. The model used in the investigation was a modified NACA 65,215 multi-element airfoil with a basic chord of 254 mm. The Mach number was fixed at M=0.2, typical of the landing speed of transport type aircraft. The chord Reynolds number range was 1.7 to 8.8×10^6.

Measurements included lift, drag and pitching moment of the airfoil obtained by side wall balances and the flow rate from a water spray manifold.

The effects of the simulated rainfall to the airfoil performances are very significant. The loss in maximum lift coefficient ranged from 6% to a high of 16%. The drag levels at constant lift are up to 43% higher under wet conditions. A smaller performance degradation was noted when the model was stripped of the smooth epoxy paint with which it was originally finished.

Symbols

C_D	drag coefficient
C_L	lift coefficient
C_M	pitching moment coefficient about quarter chord
LWC	liquid water content, gm/m^3
M	freestream Mach number
RR'	equivalent rainfall rate at $R_e = 8.8\times10^6$, (50 mm/hr)
RR_e	equivalent rainfall rate, mm/hr
R_e	Reynolds number based on basic model chord (254 mm)
ΔC_D	drag coefficient increment between wet and dry conditions at constant lift
ΔC_L	lift coefficient increment between wet and dry conditions at constant lift
ΔC_M	pitching moment coefficient increment between wet and dry conditions at constant lift
$\Delta C_D'$	"normalized" drag coefficient increment between wet and dry conditions at constant lift, $\Delta C_D/RR_e\cdot RR'$
$\Delta C_L'$	"normalized" lift coefficient increment between wet and dry conditions at constant lift, $\Delta C_L/RR_e\cdot RR'$
$\Delta C_M'$	pitching moment coefficient increment between wet and dry conditions at constant lift, $\Delta C_M/RR_e\cdot RR'$
α	angle of attack

INTRODUCTION

In recent years there have been a number of spectacular and often fatal weather related aircraft accidents which received a lot of attention from the news media and the concern of scientific community. The most likely cause of these weather related accidents is a meteorological phenomenon called the microburst. Severe low altitude wind shear has been noted as the major factor in a microburst, however, heavy rainfall is also observed most of the time during a microburst sighting (Reference 1). An initial study by Luers and Haines (Reference 2) on the effects of rain on aircraft aerodynamic characteristics generated substantial interest in this area. A number of experimental and theoretical studies (Reference 2-7) have since been published. Most of the experimental works were carried out in relatively low Reynolds number, around $R_e = 3\times10^5$, with the exception of Reference 5, which went up to R_e = 3.3 million. Reference 7 gives a succinct account of the results obtained in various investigations. In general, most results show a substantial reduction in maximum lift coefficient under simulated heavy rain conditions. The airfoil performance degradation has been attributed to the uneven water film distribution over the model surfaces, early flow separation due to the introduction of minute droplets as a result of rain impact on the airfoil and surface roughness effects. Water also tends to accumulate towards the airfoil trailing edge, effectively changing the camber.

This paper describes the measurements carried out in the 2-D test section of the IAR blowdown wind tunnel. Data are presented for the force and moment coefficients on the model under simulated rainfall rates of 50 mm/hr to 300 mm/hr. It should be noted that a rainfall rate of 1 mm/hr is classified as light rain; whereas heavy rain is usually referred to a rate of about 15 mm/hr. The term 'cloudburst' is reserved for the description of rainfall rates in the range of 100 mm/hr to 1000 mm/hr. Although the occurrence is very rare, rainfall rates of up to 1828 mm/hr have been recorded.

TEST FACILITY

The experiments were conducted in the Institute for Aerospace Research 1.5m blowdown wind tunnel. The 2-dimensional test section (38 cm×152 cm) of the wind tunnel as shown in Figure 1 was used. The model was located approximately 240 cm downstream of the start of the parallel section. It was mounted on two external side wall balances for measurement of axial

Reynolds number the water film that formed on the model was probably very uneven and is believed to be the main cause for the non-uniform lift curves. The mean lift curve slopes are significantly lower for the water spray on ($dC_L/d\alpha = 0.052$) than for the off conditions ($dC_L/d\alpha = 0.064$).

Figure 7 shows the drag polars obtained under the same test conditions. For a lift coefficient of 1.8, the drag coefficient was increased by 30% for the wet cases. At the higher lift coefficient of 2.3, the drag penalty was up to 43% higher under wet conditions.

Figure 8 shows the variation of pitching moment coefficient with angle of attack. The changes due to increasing angle of attack is more gradual under wet conditions. At higher angles of attack, the curves tend to converge to the same value under wet or dry conditions. Pitching moment is significantly increased by the presence of water.

Case 2 (Moderate Reynolds number)

Figure 9 shows the lift curves obtained at a chord Reynolds number of 4.6×10^6. The wet condition results were obtained at lower rain rates, 75 mm/hr and 100 mm/hr than the first case. The effect of the change in rain rate results in clearly measurable differences in C_L. It will be noted that the lift curves are now much smoother as compared with the lower Reynolds number case. A maximum lift coefficient of about 2.65 is obtained at an angle of attack of about 15° under wet conditions, while a maximum lift coefficient of 2.9 is obtained under dry condition at an angle of attack of about 16°. The increase in maximum lift under dry conditions at this higher Reynolds number is to be expected. The reduction of about 9% in maximum lift coefficient under wet condition is observed. It should be noted that the decrease in lift under wet conditions is constant over the entire angle of attack range which is not the same as in Case 1.

Figure 10 shows the drag polars obtained at $R_e = 4.6\times10^6$. The drag penalty under wet condition at low lift is relatively low, about 9% at a C_L of 1.8. This was increased to 19% at a C_L of 2.3. At their respective maximum C_L values, the drag level is almost identical under wet or dry conditions.

The variation of pitching moment coefficients with angle of attack are shown in Figure 11. The discussion for the lower Reynolds number case applies here as well.

Case 3 (High Reynolds number)

Figure 12 shows the lift curve obtained at a chord Reynolds number of 8.8×10^6, which is a more realistic value for a transport type aircraft at landing configuration, and at a rain rate of 50 mm/hr. Also shown on the same figure are lift curves from the previous two cases for comparison. Note that the rain rates are not the same for all cases. With this difference in mind, it can be seen that under wet conditions, the lift curve slopes are getting steeper as the Reynolds number increases from 1.7×10^6 to 8.8×10^6, which is the usual Reynolds number effect, while at the same time the stall angle decreases from 16° to 14°. The latter is believed to be the effect of increases in effective rain rate. In the low angle of attack range (-5° to 0°), the combined effect of Reynolds number and rain rate are very small among the wet cases. However, at -5° the lift coefficient of the wet cases is about 19% lower than that of the dry condition. The large variations in lift among the wet cases show up much more at higher angles of attack. The penalty due to wet condition to maximum C_L for the $R_e = 8.8\times10^6$ case is about 8.6%.

Figure 13 compares the drag polars of the wet and dry conditions obtained at $R_e = 8.8\times10^6$. At low lift coefficient, the differences between the dry and wet cases are small. For the $R_e = 8.8\times10^6$ case, at a lift coefficient of 1.8, the drag penalty due to the wet condition is about 6.7% and that increases to 9.5% at C_L of 2.3. The drag level at maximum lift is about the same for the wet and dry condition.

The pitching moment coefficient curves are shown in Figure 14. At 0°, there is a 17% difference in the pitching moment coefficient between 'wet' and 'dry'. The difference is reduced to a 7% difference at 19°.

The foregoing comparisons in each case have all been with respect to differing rainfall rates. In order to separate the effects of rainfall rate from Reynolds number, lift, drag and pitching moment coefficients increment from dry to wet conditions have been "normalized" by the ratio of the effective rainfall rate to the effective rainfall rate obtained at the $R_e = 8.8\times10^6$ condition (RR_e/RR', where $RR' = 50$ mm/hr). The results are shown in Figures 15, 16 and 17 which plot $\Delta C_L'$, $\Delta C_D'$ and $\Delta C_M'$ versus C_L. They clearly show that the more serious effects occur at the higher Reynolds number cases.

Case 4 (Surface Effect)

The epoxy paint was stripped off the model to investigate the effect of different surface finish when subjected to heavy rainfall. Although the bare metal model finish is very fine, it is however not as smooth as the painted surface. Water tends to bead more readily on the painted surface than on the bare metal surface.

Figure 18 shows the C_L-α curves with the two different model surface finishes obtained under the same rain rate (50 mm/hr) and at the same Reynolds number of 8.8×10^6. When compared to the results obtained from the dry condition, the painted surface data show a larger (8.6%) degradation in lift than that from the metal surface data (5.9%). The decrease in lift is almost constant in magnitude through-out the entire angle of incidence range.

CONCLUSIONS

The following conclusions are drawn based on the limited amount of data obtained from the wind tunnel measurement:

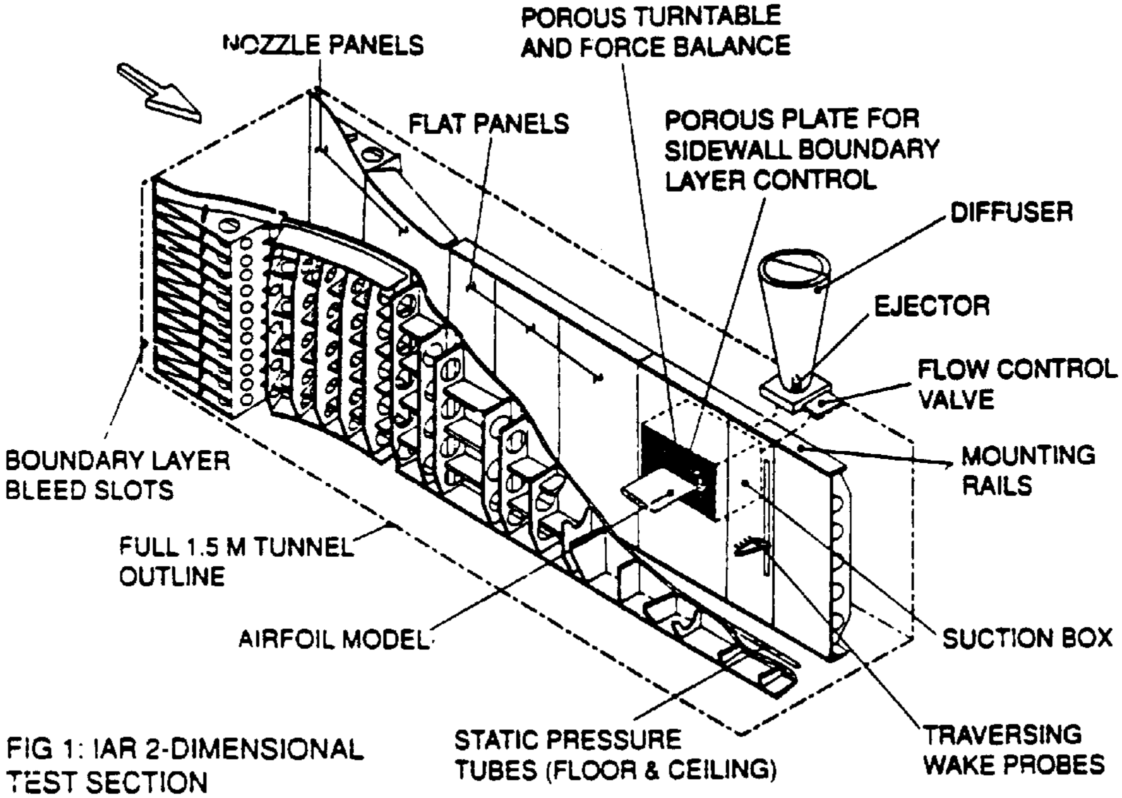

FIG 1: IAR 2-DIMENSIONAL TEST SECTION

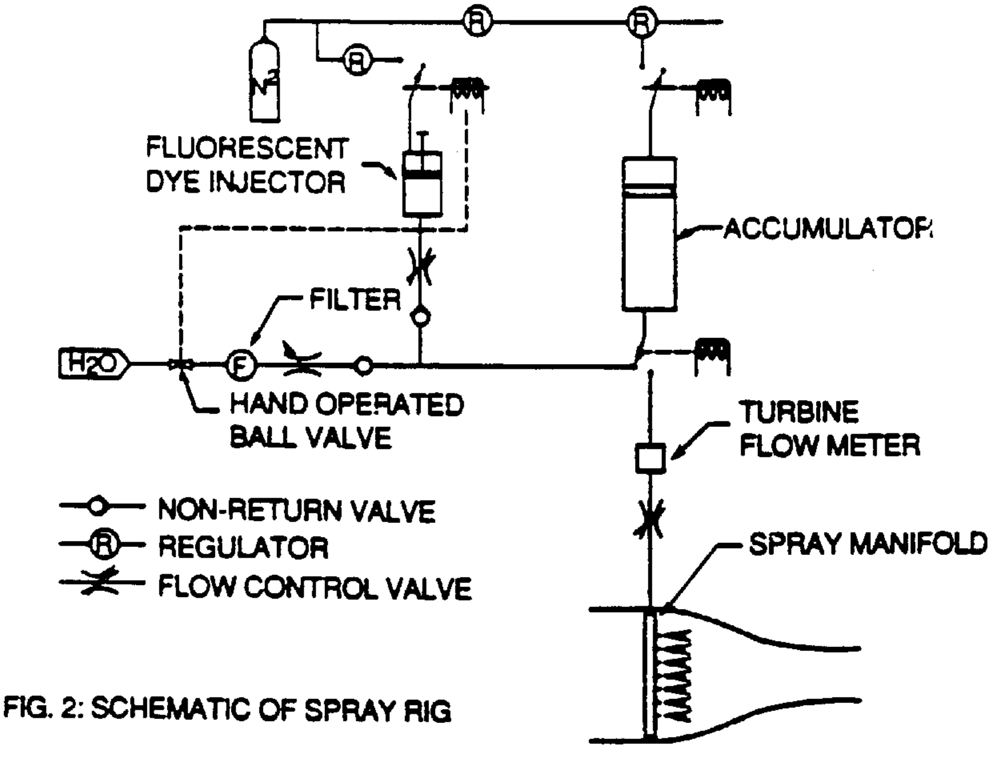

FIG. 2: SCHEMATIC OF SPRAY RIG

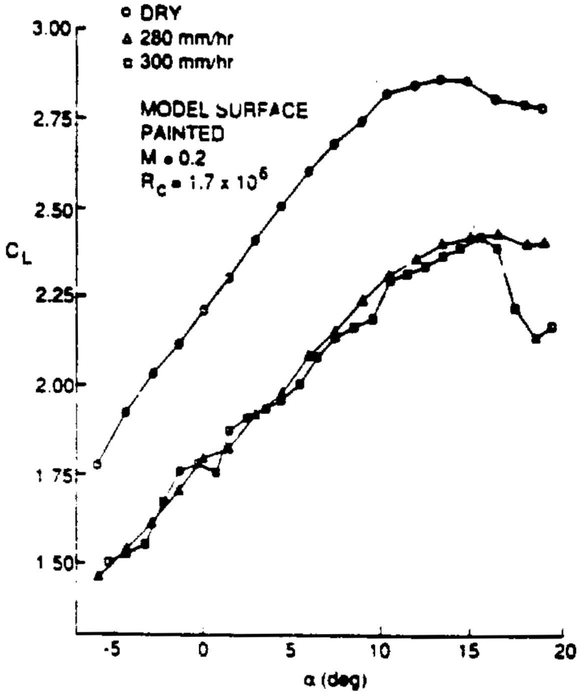

FIG. 6 LIFT COEFFICIENT VERSUS ANGLE OF ATTACK

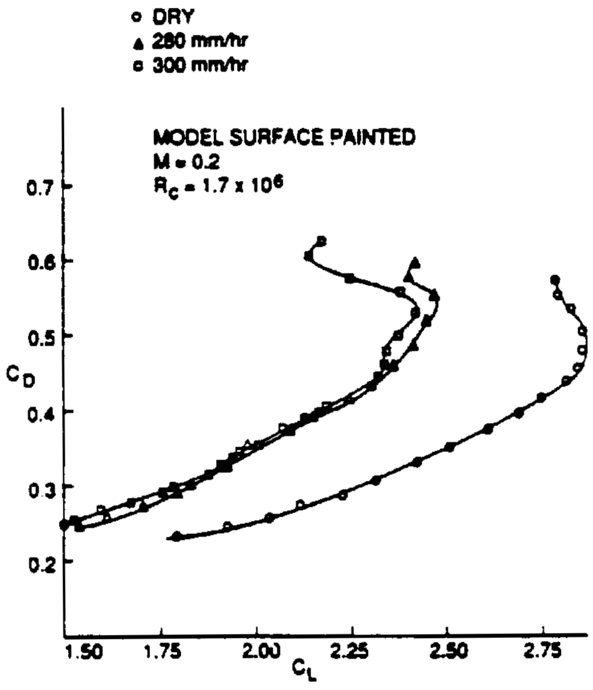

FIG 7. DRAG COEFFICIENT VERSUS LIFT COEFFICIENT

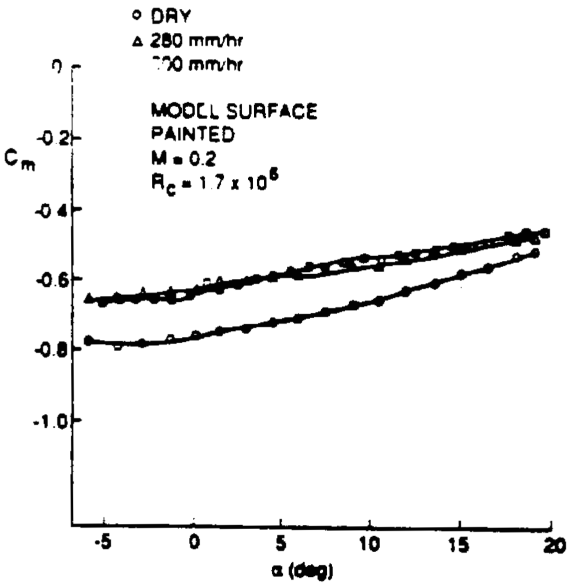

FIG. 8: PITCHING MOMENT COEFFICIENT VERSUS ANGLE OF ATTACK

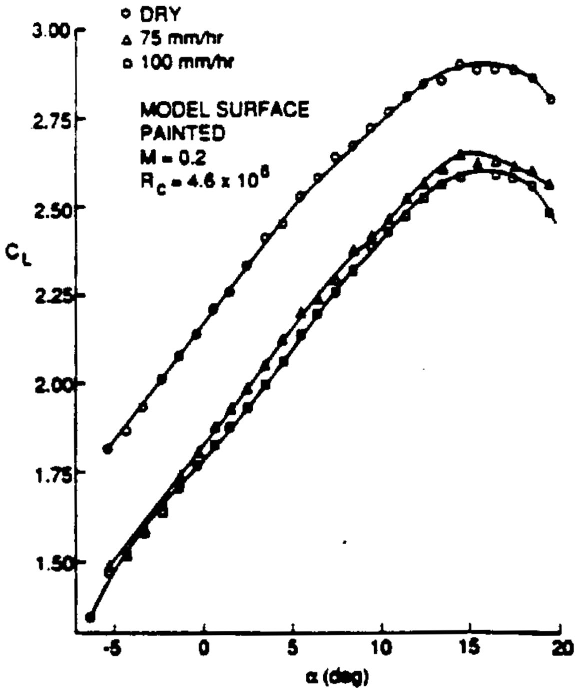

FIG. 9: LIFT COEFFICIENT VERSUS ANGLE OF ATTACK

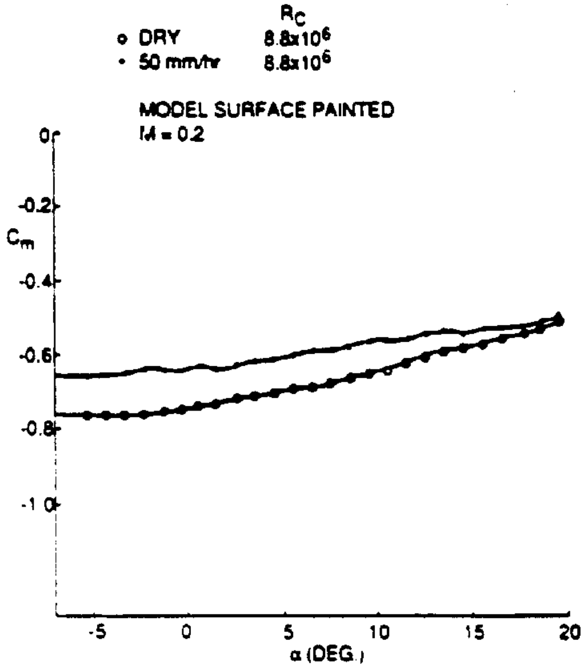

FIG. 14 PITCHING MOMENT COEFFICIENT VERSUS ANGLE OF ATTACK

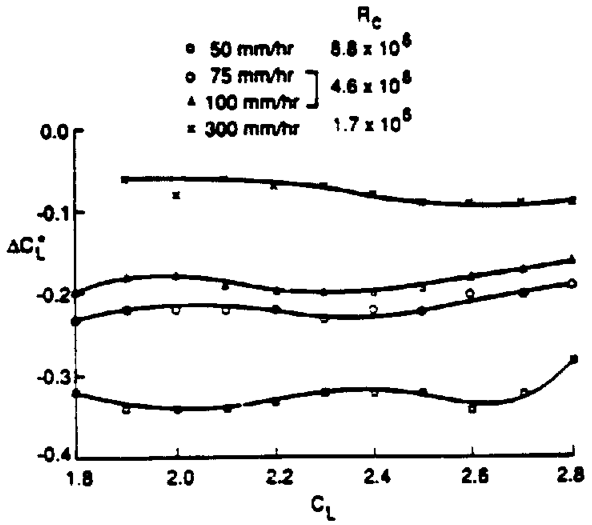

FIG. 15: VARIATIONS OF "NORMALIZED" LIFT COEFFICIENT INCREMENT VERSUS LIFT COEFFICIENT

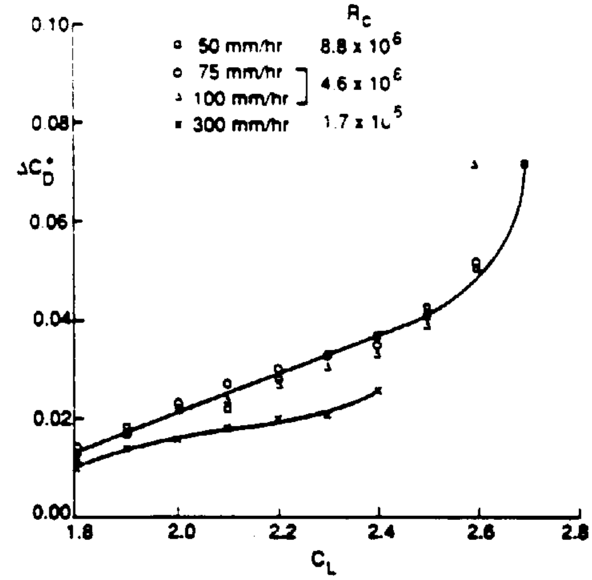

FIG. 16: VARIATIONS OF "NORMALIZED" DRAG COEFFICIENT INCREMENT VERSUS LIFT COEFFICIENT

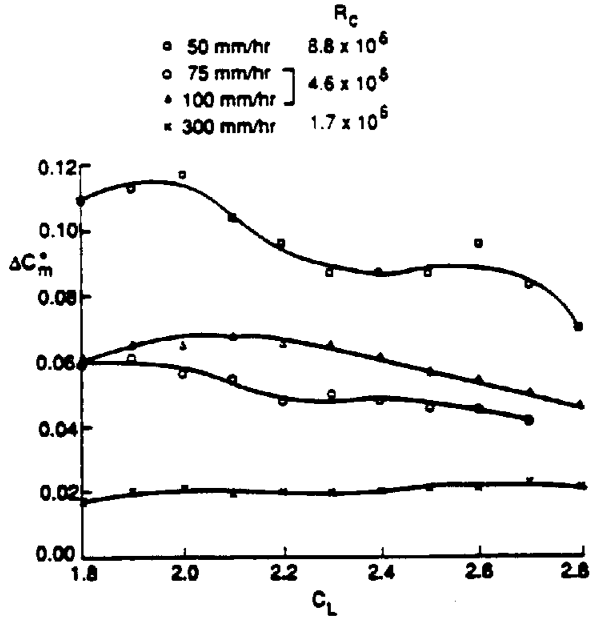

FIG. 17: VARIATIONS OF "NORMALIZED" PITCHING MOMENT COEFFICIENT INCREMENT VERSUS LIFT COEFFICIENT

B

THE AERODYNAMIC EFFECT OF HEAVY RAIN ON AIRPLANE PERFORMANCE

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Paper presented at the AIAA Flight Simulation Technologies Conference
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Dayton, Ohio

THE AERODYNAMIC EFFECT OF HEAVY RAIN ON AIRPLANE PERFORMANCE

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Abstract

The National Aeronautics and Space Administration has been conducting a series of tests to determine the effect of heavy rain on airfoil aerodynamics. The results of these tests have shown that heavy rain can significantly increase drag as well as decrease lift and stall angle of attack. This paper describes a recent effort to use the heavy rain airfoil data to determine the aerodynamic effect on a conventional twin-jet transport. The paper reports on the method used to model the heavy rain aerodynamic effect and the resulting performance degradation. The heavy rain performance effect is presented in terms of the diminished climb performance associated with increasing rain rates. The effect of heavy rain on the airplane's ability to escape a performance-limiting wind shear is illustrated through a numerical simulation of a wet microburst encounter. The results of this paper accentuate the need for further testing to determine scaling relationships and flow mechanics, and the full configuration three-dimensional effects of heavy rain.

Symbols

b	wing span
c	chord
$\bar{c}$	mean aerodynamic chord
cd	section drag coefficient
cl	section lift coefficient
C_D	total drag coefficient
C_L	total lift coefficient
F	wind shear hazard index
g	gravitational acceleration
Sl	span load coefficient $\left(\frac{c\,cl}{\bar{c}\,C_L}\right)$
V	true airspeed
W_h	vertical wind component, updraft positive
$\dot{W}_x$	rate of change of horizontal wind component, tailwind positive
α	angle of attack

Introduction

Wind shear is considered by many in the aviation industry to be one of their major safety issues. Numerous accidents and incidents have occurred which were attributed to low-altitude wind shear. Many of these were accompanied by rain, some of which was classified as intense or heavy rain. The effects of rain on airplane performance under normal operating conditions, are generally not considered to be significant. However, in a performance limiting wind shear, the airplane may require large angles of attack to maintain a safe altitude. The performance influence of heavy rain under these conditions may be considerable.[1]

The objective of this study was to estimate and characterize the effect of heavy rain on the performance of a conventional twin-jet transport. This required the development of an aerodynamic model of the airplane which included the rain effect. This paper will discuss the development of such a model based on the results of a series of tests which measured the effect of heavy rain on airfoil aerodynamics. The paper will initially summarize the results of the heavy rain airfoil tests. The method used to develop the heavy rain aerodynamic model will then be discussed. This will be followed by a performance analysis with the heavy rain model. The final section illustrates the effect of heavy rain on the airplane's ability to escape a performance limiting wind shear through a numerical simulation of a wet microburst encounter.

Heavy Rain Airfoil Tests

In an effort to measure the effect of heavy rain on airfoil aerodynamics a series of tests was conducted in the NASA Langley 14- by 22-Foot Subsonic Tunnel on a cambered airfoil section representative of the type used on commercial transport aircraft.[2] The section model had a rectangular planform with a 2.5 foot chord and a 8 foot span, mounted between rectangular end plates. The airfoil section was a NACA 64-210. The model was tested in a cruise and a high lift configuration. The high lift configuration had a leading edge slat and a trailing edge double slotted flap as shown in figure 1. The rain was simulated by injecting a water spray horizontally toward the model from a rain spray system mounted upstream. The spray system could produce water mass concentrations from 16 to 46 g/m^3. A photograph of the wind tunnel model immersed in the water spray is shown in figure 2.

The results of the wind tunnel tests showed a reduction in maximum lift capability and stall angle of attack and a corresponding increase in drag with increasing concentrations of liquid water. The tests also showed that the cruise configuration was less sensitive than the high lift configuration to the rain environment. The lift and drag coefficient data obtained from the tunnel test for the cruise

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and high lift configuration are presented in figures 3 and 4, respectively. The data were collected at a dynamic pressure of 50 lb/ft^3 and a chord based Reynolds number of 3.3 million.

The scaling laws required to extrapolate the heavy rain wind tunnel data to full-scale have not been fully established. A series of full-scale airfoil tests in a simulated rain environment is being conducted at NASA Langley's Aircraft Landing Dynamics Facility (ALDF) in an effort to determine the scaling effects and to understand the primary influences and flow mechanics of this two phase flow environment.[3,4] The ALDF is an outdoor test facility which is generally used for landing gear and tire studies but was modified for this series of tests. The facility consists of a large carriage which is propelled down a track. The full-scale airfoil section model is mounted atop the carriage. An array of spray nozzles is suspended above the track to simulate the rain environment. The carriage with the attached airfoil section is capable of speeds up to 170 knots. The rain spray system can produce water mass concentrations of 2, 9, 26, and 35 g/m^3. A photograph of one of the heavy rain full-scale test runs is shown in figure 5.

Preliminary results of the ALDF full-scale tests show that the maximum lift coefficient and stall angle of attack are reduced in the same manner as the wind tunnel test results. A comparison of the wind tunnel and full-scale lift curves at similar rain rates is shown in figure 6. The agreement between the data sets may indicate a lack of significant scaling effects at these conditions. The ALDF tests are continuing at reduced rain rates to determine the sensitivity to rain rate and the minimum rate at which significant performance penalties exist.

Modeling Methodology

Currently, there is no experimental data base of the aerodynamic effect of heavy rain on a full configuration airplane. However, by assuming the scaling effects of the heavy rain wind tunnel data to be small, and integrating the airfoil section data across the planform of the airplane, an approximation of the full configuration effect can be developed.

The commercial twin-jet transport configuration selected for this study was that of NASA Langley's Transport Systems Research Vehicle (TSRV) shown in figure 7. An existing simulation model of the TSRV was used as the dry baseline model. The span-wise lift distribution of the airplane was used to weight the integration of the wind tunnel section data across the wing planform.

$$C_L = \frac{2}{b} \int_0^{\frac{b}{2}} Sl(y)\, cl(y)\, dy$$

$$C_D = \frac{2}{b} \int_0^{\frac{b}{2}} Sl(y)\, cd(y)\, dy$$

The airplane wing planform with the inboard and outboard flap locations are shown in figure 8, along with the span-load coefficients at various flap settings. The span-load coefficients were computed with a vortex-lattice computer code for the different flap positions.[5]

A comparison of the lift coefficient computed by the planform integration method for the dry condition with that of the baseline airplane model is shown in figure 9. As can be seen, the integration is not an accurate method of estimating the total lift of the airplane, particularly at the high lift flap settings. This can be attributed to a number of factors, two of which are: a) the wind tunnel airfoil model is not the same airfoil and flap configuration as on the airplane, and b) the vortex-lattice method used to compute the wing loading is not an accurate method for multi-element flap and slat configurations. Consequently, a direct modeling of the integrated results would not accurately represent the wet airplane aerodynamics. However, the wet airplane aerodynamics could be approximated by modeling the change in the lift and drag with liquid water content from the integrated results, and apply this perturbation model to the dry baseline aerodynamic model. This was the technique used in this study.

Two examples of the resultant wet airplane aerodynamic model are presented in figures 10 and 11 for a take-off and landing configuration, respectively. The decrease in maximum lift coefficient and stall angle of attack, which was prevalent in the airfoil data is also evident in the airplane model, but to a lesser extent than the high lift section data. There is also a considerable drag increase at the higher lift coefficients.

Heavy Rain Effect on Climb Performance

The performance impact of heavy rain was demonstrated by computing the airplane's climb performance under increasing rain concentrations. Figures 12 and 13 show the steady-state rate of climb as a function of airspeed with rain concentrations of 0, 10, 20 and 30 g/m^3, for a take-off and landing configuration, respectively. The take-off and landing configurations were defined as follows:

	Take-off	Landing
Flaps	5°	25°
Gear	up	down
Gross Weight	100,000 lbs	89,000 lbs

The climb rates were computed at take-off thrust (~24,000 lbs) to simulate a wind shear escape condition.

the take-off case. This is primarily due to the increased drag reducing the airspeed, thus decreasing the energy of the airplane and extending the exposure time in the wind shear.

Concluding Remarks

The results from earlier sub-scale and full-scale airfoil tests have documented a reduction in the maximum lift capability and stall angle of attack and a corresponding increase in drag with increasing rain concentrations. Based on the data from these earlier tests, a estimate of the heavy rain effect on a commercial twin-jet has been developed. The results of this analysis indicate that the aerodynamic penalty associated with heavy rain can substantially reduce the airplane's performance. A loss in climb performance of at least 200 ft/min was noted at rain concentrations of 20 g/m^3 and greater. This represented a loss of at least 12 percent of the climb performance margin of the airplane. A performance loss of this degree can critically impair an airplane's ability to escape a performance limiting wind shear. The drag increase associated with the heavy rain had the greatest impact on the wind shear recovery performance. This was primarily due to the drag reducing the airspeed and thus extending the wind shear exposure time and reducing the airplane's energy state.

The analysis presented here was based on a very limited data set with some rather broad assumptions. This paper illustrates the need for further heavy rain testing of sub-scale and full-scale airfoil sections to determine the scaling relationships and flow mechanics involved. It also illustrates the need for full configuration testing. The effect of heavy rain on the fuselage and empennage was not included in this analysis and is expected to further degrade the airplane's performance.

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Figures 12 and 13 show a loss in climb performance of at least 200 ft/min at rain concentrations of 20 g/m^3 and greater, for both the take-off and landing configurations. The greatest performance loss occurred at the low speeds where the higher angles of attack were required.

The performance effect of heavy rain can be equated to that of wind shear through the wind shear "F-factor".[6] The F-factor is a hazard index which represents the rate of specific energy loss due to wind shear and is defined as:

$$F = \frac{\dot{W}_x}{g} - \frac{W_h}{V}$$

Figure 14 shows the steady-state rate of climb as a function of airspeed at various F-factor values, for the take-off configuration. By cross-plotting figures 12 and 14, an equivalent F-factor curve can be derived for each rain concentration curve. Figures 15 and 16 show the equivalent F-factor as a function of airspeed for the take-off and landing configurations, respectively. For the 20 g/m^3 case, the equivalent F-factor was about 0.02 for the majority of the speed range. An F-factor of this magnitude represents 20 percent of the currently accepted wind shear alert threshold. At the low speeds the F-factor was significantly greater. From figure 14, it can be seen that an F-factor of 0.16 or more may result in the airplane being unable to climb or maintain altitude. The 20 g/m^3 case therefore represents a loss of at least 12 percent of the climb performance margin of the airplane.

In an effort to determine how much of the heavy rain performance degradation was due to the increased drag versus the decreased lift, the rate of climb was computed including only the rain effect on lift and excluding the effect on drag. Alternately, the climb rate was then computed including only effect on drag. The results of this analysis are shown in figures 17 and 18 for the take-off and landing configurations, respectively. The increased drag had the greatest effect on the climb performance, particularly at the higher speeds. At the lower speeds the loss of lift effect was more pronounced, but never accounted for more than half the total performance degradation.

Wet Wind Shear Recovery Performance

In the event of an inadvertent wind shear encounter, the FAA recommended wind shear recovery procedure may require the airplane to be operated at or near the stick shaker angle of attack.[7] The results of the heavy rain airfoil tests showed that the rain can reduce the stall angle of attack. This generated some concern that in a wet wind shear encounter, the airplane may stall prior to the stick shaker angle of attack, requiring significant modification of the recommended recovery procedure. Figure 19 shows the angle of attack margin between stick-shaker and stall at rain concentrations of 0, 10, 20 and 30 g/m^3 for each flap setting. The stall margin may be reduced by as much as 50 percent at the highest rain concentration, but the airplane does not stall prior to stick shaker angle of attack.

To illustrate the effect of heavy rain on wind shear recovery performance a batch simulation of a wet microburst encounter was conducted. The point mass airplane simulation model of reference 8 was modified to include the microburst model of reference 9 and the heavy rain aerodynamic model described earlier. The simulation was conducted for a take-off and an approach to landing situation. The take-off case was initiated at an airspeed of 138 knots, an altitude of 10 feet, and the previously defined take-off configuration. The landing case was initiated at 300 feet, 137 knots, on a 3 degree glide slope in the landing configuration.

The axisymmetric microburst model had a maximum outflow of 37 knots at an altitude of 120 feet and a radius of 2,391 feet. The severity of the shear is representative of microbursts which have caused aircraft accidents. The rain was simulated as a step input when within the 2,391 foot microburst radius, at concentrations of 0, 10, 20 and 30 g/m^3. The center of the microburst was located 3,000 and 4,000 feet down range of the starting point for the take-off and landing cases, respectively.

The wind shear recovery procedure used in the simulation, modeled the FAA recommended procedure. The recovery was initiated when the wind shear hazard index (F-factor) reached the alert threshold value (0.12). At that point the throttles were advanced to take-off thrust and the airplane pitched to an initial target attitude of 15 degrees. If the airplane was unable to avoid descending at the initial target attitude, the pitch was increased until level flight could be maintained. Throughout the recovery the target pitch was limited to the value corresponding to the airplane's stick shaker angle of attack. The pitch rate of the airplane was limited to 3 degrees per second.

The results of the simulated wet microburst encounter are presented in figures 20 and 21 for the take-off and landing cases, respectively. The higher rain concentrations had a considerable impact on the recovery performance of the airplane. At 30 g/m^3, the airplane was unable to recover from an otherwise recoverable microburst encounter.

The sensitivity of the recovery performance to the increased drag versus the decreased lift was studied in a similar manner as was done in the climb performance analysis. Figures 22 and 23 show the sensitivity results at 20 g/m^3 of rain for the take-off and landing cases, respectively. Again, the increased drag had the greatest effect on the overall recovery performance, particularly for

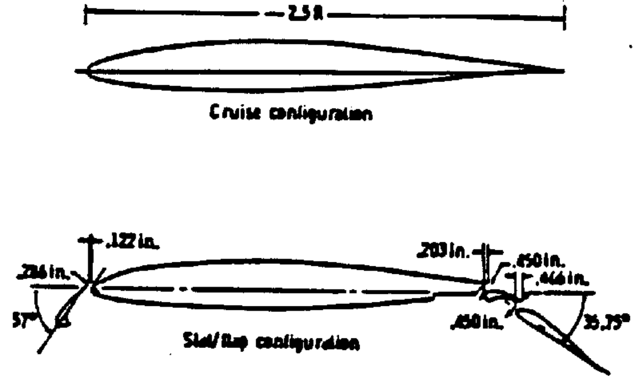

Fig. 1. Cross section of NACA 64-210 airfoil model and details of slat and flap installation.

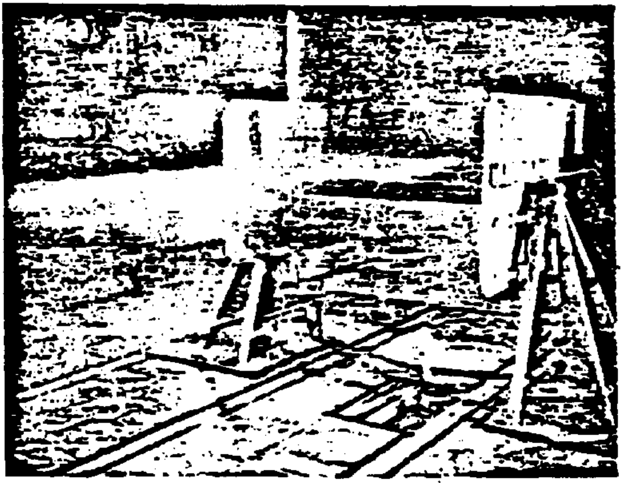

Fig. 2. Photograph of heavy rain airfoil test in NASA Langley 14- by 22-Foot Subsonic Tunnel.

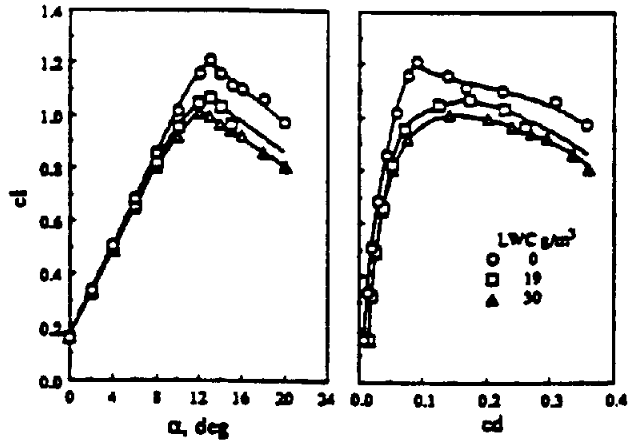

Fig. 3 Wind tunnel lift and drag measurements for the cruise configuration.

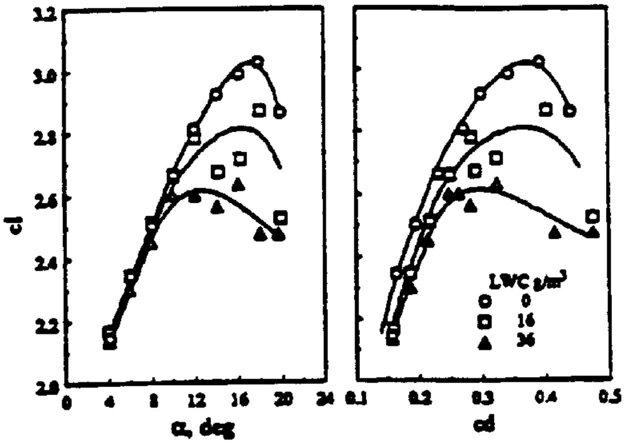

Fig. 4 Wind tunnel lift and drag measurements for the high lift configuration.

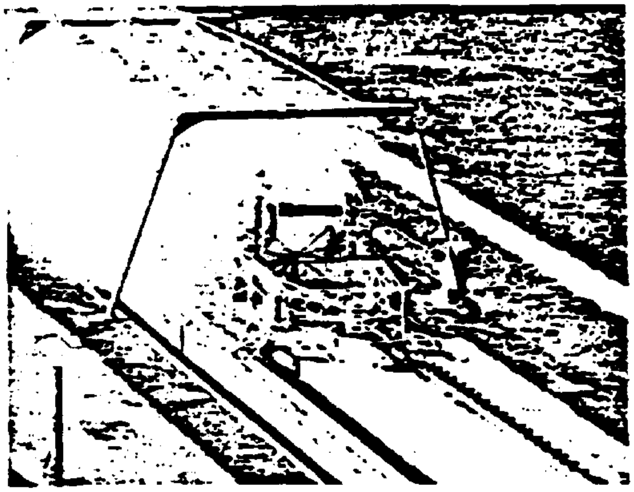

Fig. 5 Photograph of heavy rain full-scale airfoil test at NASA Langley's ALDF.

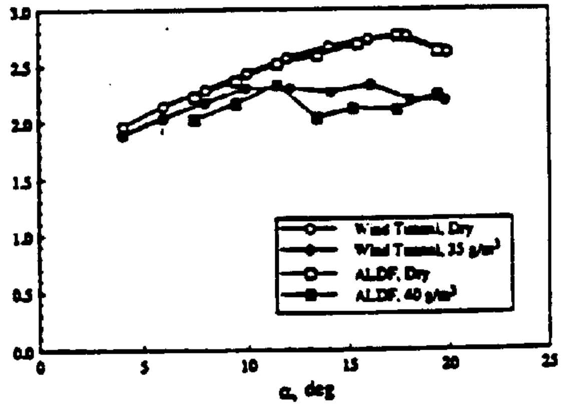

Fig. 6 Comparison of lift coefficient data from wind tunnel and ALDF tests.

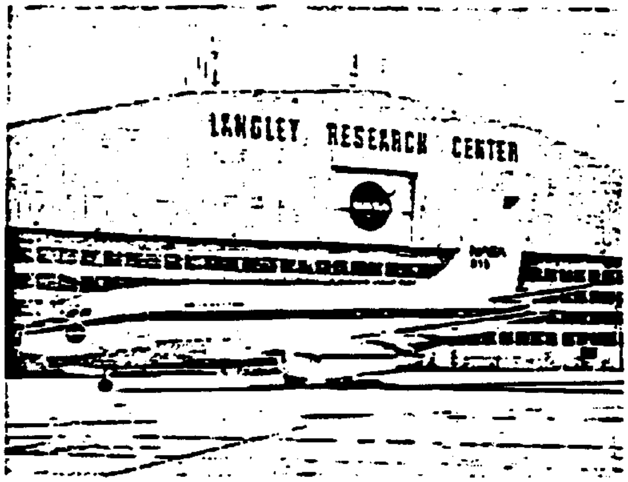

Fig. 7 Photograph of TSRV.

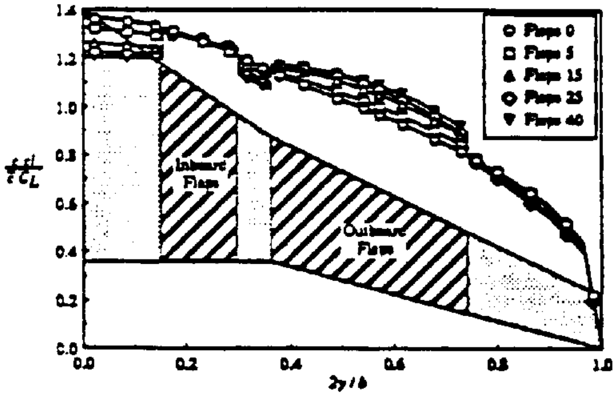

Fig. 8 TSRV wing planform and span-loading.

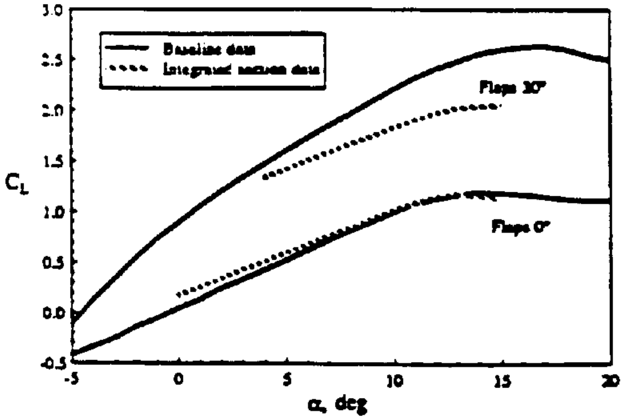

Fig. 9 Comparison of baseline and computed lift curve.

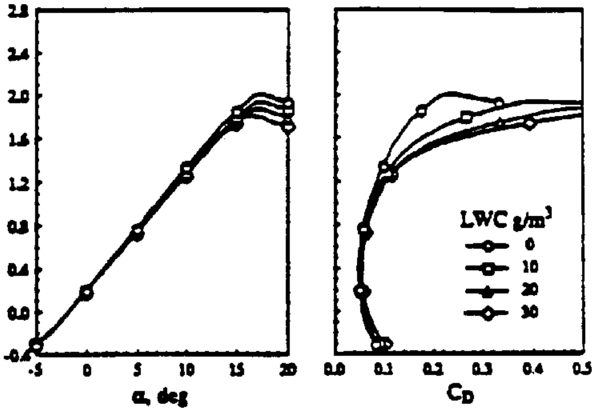

Fig. 10 Heavy rain aerodynamic model for airplane in a take-off configuration. (Flaps 5°, Gear up)

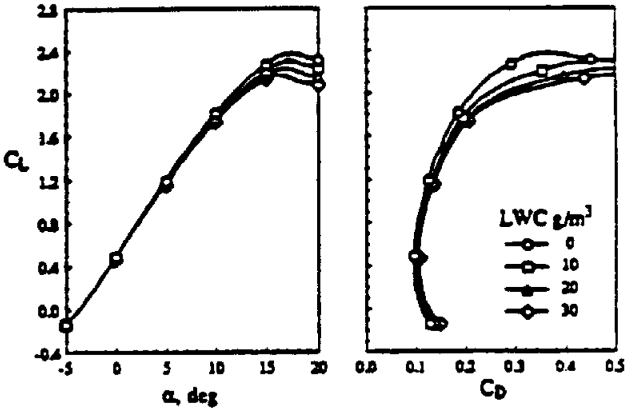

Fig. 11 Heavy rain aerodynamic model for airplane in landing configuration. (Flaps 25°, Gear down)

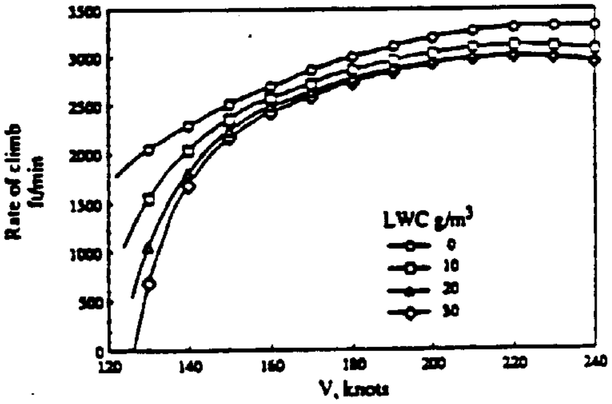

Fig. 12 Effect of heavy rain on climb performance in a take-off configuration.

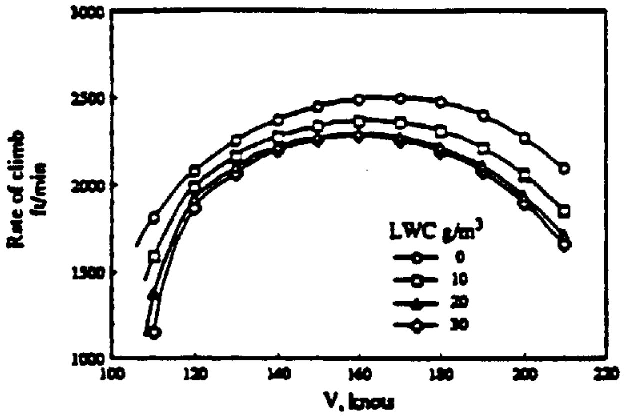

Fig. 13 Effect of heavy rain on climb performance in a landing configuration.

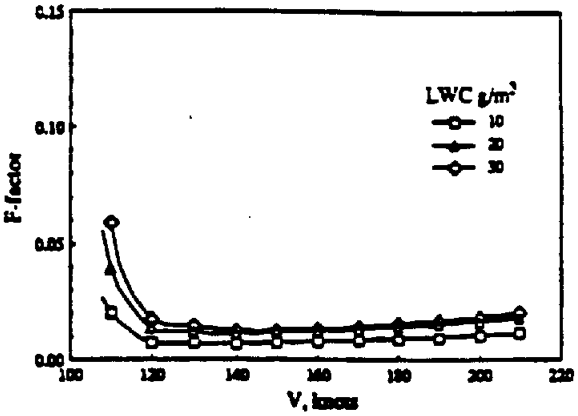

Fig. 16 Heavy rain equivalent F-factor in a landing configuration.

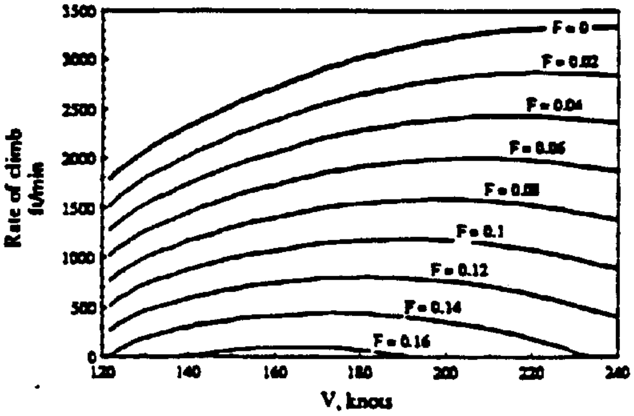

Fig. 14 Effect of wind shear on climb performance in a take-off configuration.

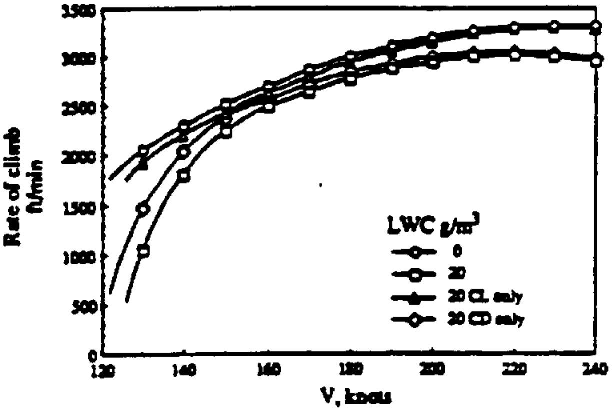

Fig. 17 Sensitivity of lift and drag on climb performance in a take-off configuration.

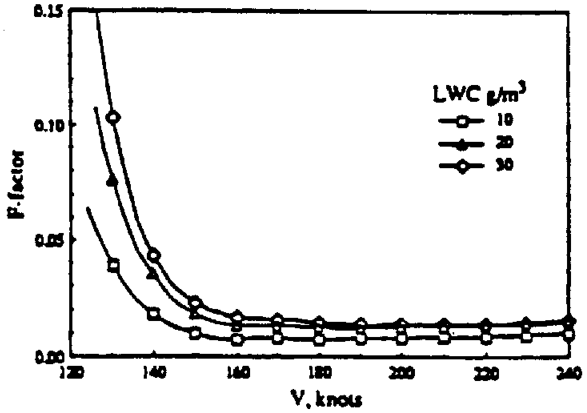

Fig. 15 Heavy rain equivalent F-factor in a take-off configuration.

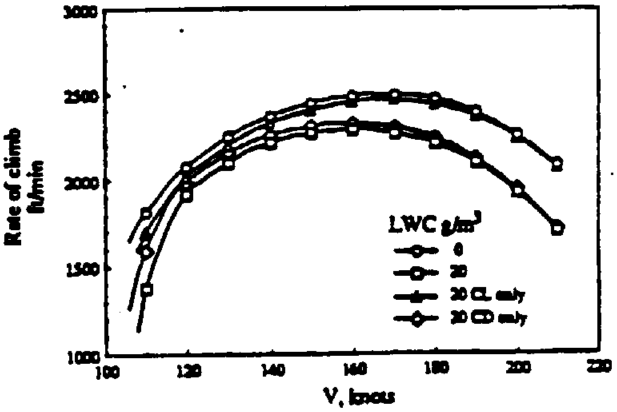

Fig. 18 Sensitivity of lift and drag on climb performance in a landing configuration.

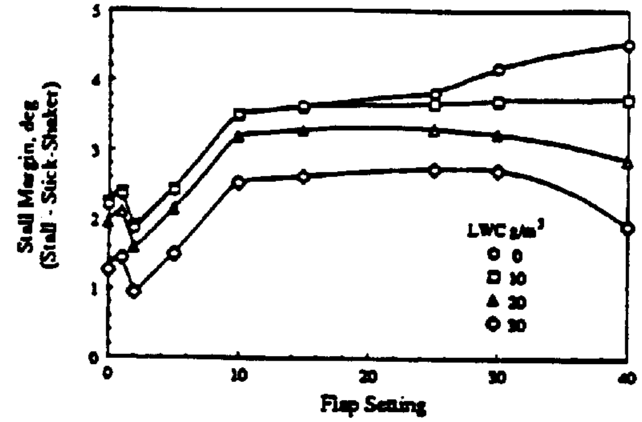

Fig. 19 Effect of heavy rain on stall margin.

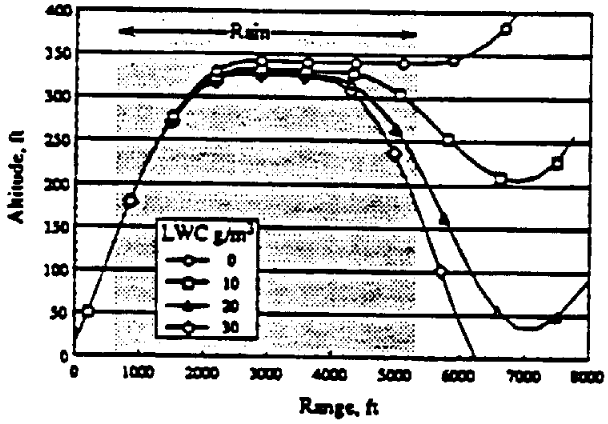

Fig. 20 Effect of heavy rain on wind shear escape performance in a take-off configuration.

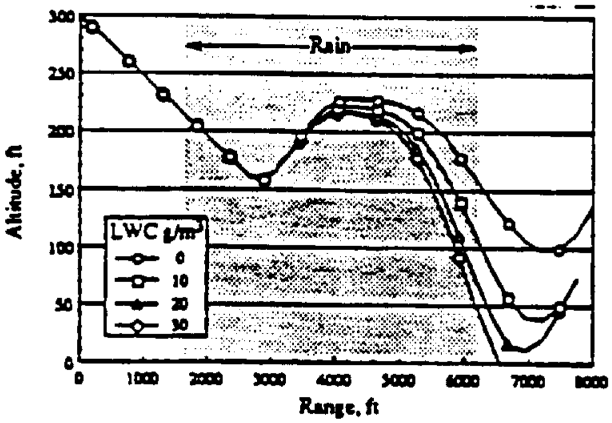

Fig. 21 Effect of heavy rain on wind shear escape performance in a landing configuration.

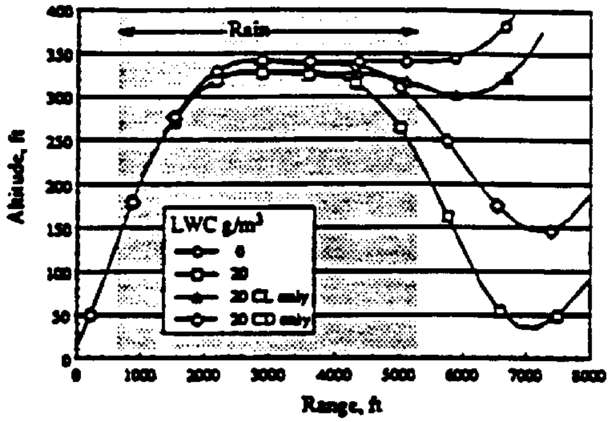

Fig. 22 Sensitivity of lift and drag on wind shear escape performance in a take-off configuration.

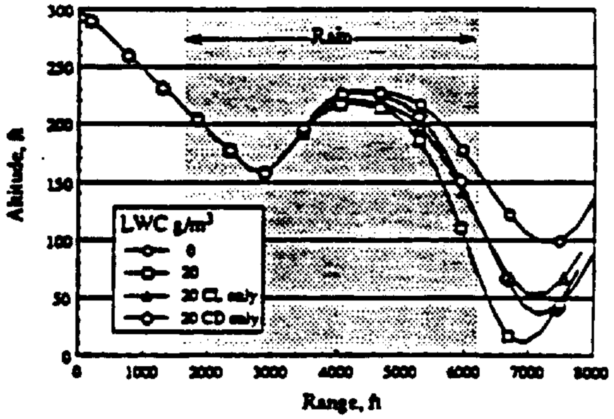

Fig. 23 Sensitivity of lift and drag on wind shear escape performance in a landing configuration.