Docket No. SA-509

Exhibit No. 5-I

NATIONAL TRANSPORTATION SAFETY BOARD

Washington D.C.

NASA Weather Study

INVESTIGATION OF MICROBURST WINDSHEAR ASSOCIATED WITH THE CHARLOTTE 1994 ACCIDENT USING A METEOROLOGICAL NUMERICAL MODEL

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OUTLINE

I. OBSERVED CHARACTERISTICS OF MICROBURST EVENT

II. TASS MODEL

III. SOUNDING AND INITIAL CONDITIONS FOR SIMULATION

IV. COMPARISON OF RESULTS WITH OBSERVATIONS

V. RECONSTRUCTION OF FLIGHT PROFILE

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VII. SCENARIO FOR METEOROLOGY NEAR TIME OF ACCIDENT

VIII. SUMMARY AND CONCLUSIONS

Charlotte, 2 July 1994, Microburst

MICROBURST CHARACTERISTICS

- Large Velocity Change (>35 m/s)
- Velocity Change Over Small Scale (~ 1 km)
- Extremely Hazardous Shear (1-km F-Factor ~ 0.3)
- Moderate to Heavy Rainfall
  - Precipitation Shaft Observed Visually as a Wall of Water
  - Aircraft Radar Observed Shaft as 1.5 to 5 Km (1-3 miles) diameter with High Reflectivity
- Generated from Thunderstorm with Top less than 30,000 ft (10 km)
- Encountered by USAIR 1016 Probably Early in Microburst Lifetime
- Most Intense Microburst that we have Numerically Simulated From Any Case Study to Date

TERMINAL AREA SIMULATION SYSTEM (TASS)

- Atmospheric Simulation Model For Cloud and Microscale Phenomena

- Meteorological Framework -- Includes Microphysics for Rain, Snow, Hail/Graupel, Cloud Ice, and Cloud Droplets

- Ambient Conditions Initialized with Vertical Profile of Pressure, Temperature, Dew Point, and Wind Velocity

- Model Applied and Validated Against a Wide Range of Atmospheric Phenomena -- History of FAA Acceptance, used in Windshear Certification

- Model Used to Reconstruct Previous Windshear Encounters.
    1. 1985 DFW Microburst Accident (Delta)[3,4]
    2. Denver, 11 July 1988, Microburst Incident (UAL)[6,8]
    3. Denver, 8 July 1989, Microburst Incident (Continental)[10,12]
    4. 20 June 1991, Orlando Microburst (NASA Field Program)[9]

Significant Papers Regarding the Study of Microbursts

1. Proctor, F. H., 1987: The Terminal Area Simulation System. Volume I: Theoretical formulation. NASA Contractor Rep. 4046, NASA, Washington, DC, 176 pp.

2. Proctor, F. H., 1987: The Terminal Area Simulation System. Volume II: Verification Experiments. NASA Contractor Rep. 4047, NASA, Washington, DC, 112 pp.

3. Proctor, F. H., 1988: Numerical simulations of an isolated microburst. Part I: Dynamics and structure. J. Atmos. Sci., 45, 3137-3160.

4. Proctor, F. H., 1988: Numerical simulation of the 2 August 1985 DFW microburst with the three-dimensional Terminal Area Simulation System. Preprints Joint Session of 15th Conf. on Severe Local Storms and Eighth Conf. on Numerical Weather Prediction, Baltimore, Amer. Meteor. Soc., J99-J102.

5. Proctor, F. H., 1989: Numerical simulations of an isolated microburst. Part II: Sensitivity experiments. J. Atmos. Sci., 46, 2143-2165.

6. Proctor, F. H., and R. L. Bowles, 1989: Investigation of the Denver 11 July 1988 microburst storm with the three-dimensional NASA-Langley Windshear Model. Appendix 2 of Windshear Case Study: Denver, Colorado, July 11, 1988 -- Final Report, DOT/FAA/DS-89/19, Federal Aviation Administration Final Report, Washington, DC.

7. Proctor, F. H., 1990: Three-dimensional numerical simulation of a Florida microburst: The 7 July 1990 Orlando event. Airborne Wind Shear Detection and Warning Systems, Third Combined Manufacturers' and Technologists' Airborne Wind Shear Review Meeting, Hampton, VA, NASA CP-10060, Part I, 81-103.

8. Proctor, F. H., and R. L. Bowles, 1992: Three-dimensional simulation of the Denver 11 July 1988 microburst-producing storm. Meteorol. and Atmos. Phys., 49, 107-124.

9. Proctor, F. H., 1992: Three-dimensional numerical simulation of the 20 June 1991, Orlando Microburst. Fourth Combined Manufacturers' and Technologists' Airborne Wind Shear Review Meeting, Williamsburg, VA, 214-242.

10. Proctor, F. H., 1993: Case study of a low-reflectivity pulsating microburst: numerical simulation of the Denver, 8 July 1989, storm. Preprints, 17th Conf. on Severe Local Storms, St. Louis, Missouri, Amer. Meteor. Soc., 677-680.

11. Switzer, G. F., F. H. Proctor, D. A. Hinton and J. V. Aanstoos, 1993: Windshear database for forward-looking systems certification. NASA TM -109012, 133 pp.

12. Proctor, F. H., 1994: Numerical simulation of a pulsating, low-reflectivity microburst event. Airborne Windshear Detection and Warning Systems, Fifth and Final Combined Manufacturers' and Technologists' Conference, Hampton, VA, NASA CP-10139, Part I, Hampton, VA, 199-215.

13. Proctor, F. H., 1994: Influence of low-level environmental shear on microburst structure: numerical sensitivity study. Airborne Windshear Detection and Warning Systems, Fifth and Final Combined Manufacturers' and Technologists' Conference, Hampton, VA, NASA CP-10139, Part-1, 178-198.

14. Switzer, G. F., F. H. Proctor, and D. A. Hinton, 1994: Windshear certification database for forward-look detection systems. Airborne Windshear Detection and Warning Systems, Fifth and Final Combined Manufacturers' and Technologists' Conference, Hampton, VA, NASA CP-10139, Part II, Hampton, VA, 447-462.

Charlotte, 2 July 1994, Microburst

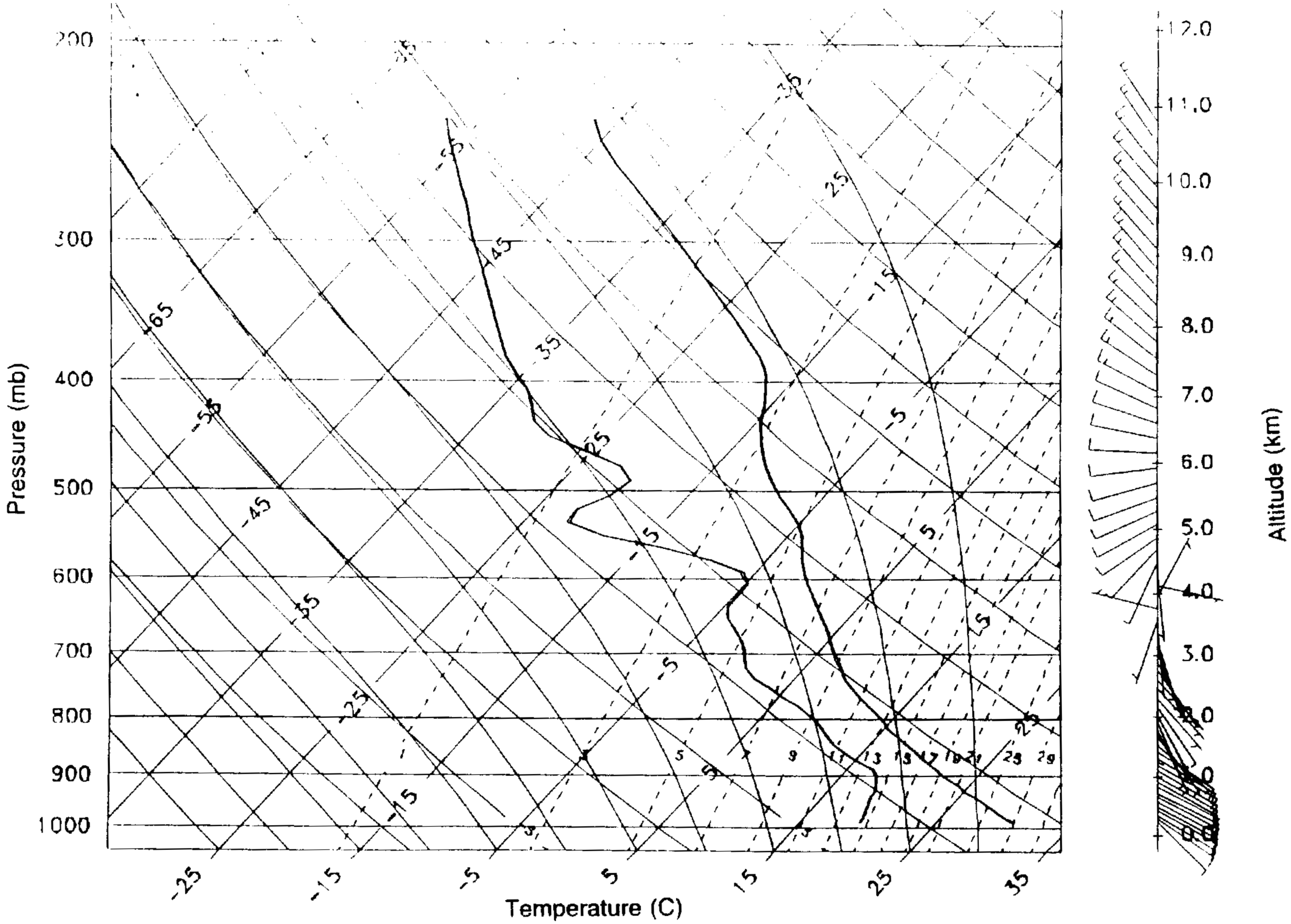
O Vertical Profile of Ambient Temperature, Moisture and Winds -- Representative of the Storm Environment -- Essential for Successful Simulation.

O Model Initialized with Two Sets of Initial Conditions:

Run-1 -- assumes composite sounding -- results appear reasonable when compare to available observations.

Run-2 -- assumes interpolated sounding generated by a NMC Weather Model -- less reasonable comparison, although both soundings produce multicellular storms with very-intense microbursts.

0 Run-1 is Corroborated with Observations and is used to Construct a Scenario for the Meteorological Conditions Around the Time of the Microburst Encounter



Input sounding plotted on Skew-T diagram. Composite sounding for Charlotte (CLT) at 2200 UTC, 2 July 1994; based on observed soundings at Greensboro and Athens, NGM mid-level winds, and surface measurements.

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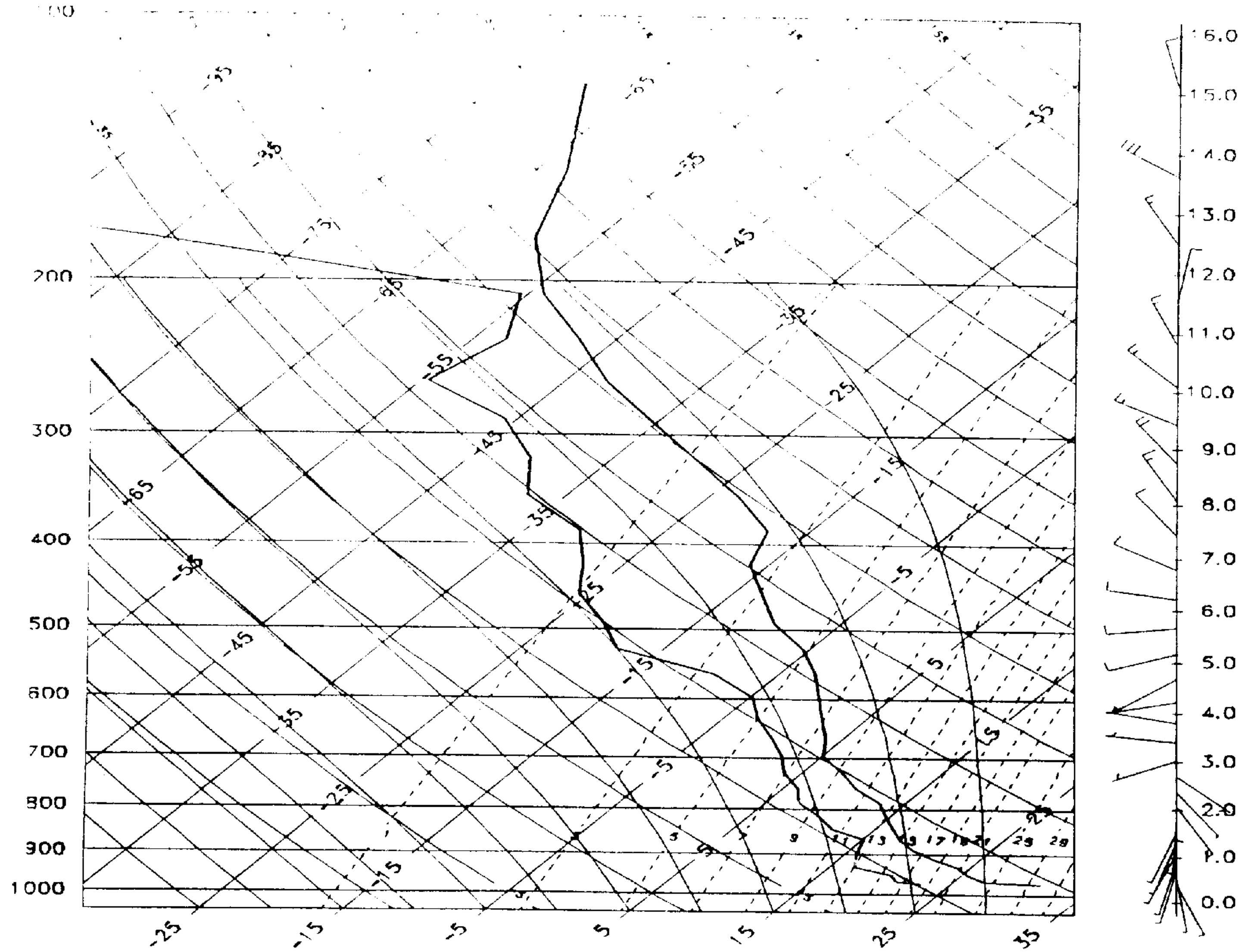


Sounding for Charlotte at 0000 UTC, 3 July 1994, as derived from NMC's ETA model initialization.

Charlotte, 2 July 1994, Microburst Simulation

INPUT DATA / ASSUMPTIONS

PHYSICAL DOMAIN SIZE

- O HORIZONTAL (X,Y): 15.6 KM x 15.6 KM
- O VERTICAL (Z): 11 KM

COMPUTATIONAL RESOLUTION

- O HORIZONTAL - 125 M (125 X 125 GRID POINTS)
  can resolve horizontal scales down to 250 m
- O VERTICAL - 61 M NEAR GROUND STRETCHING TO 300 M AT 11 KM (62 LEVELS)

CONVECTION INITIATED AT MODEL TIME ZERO

- O SPHEROIDAL THERMAL IMPULSE
- O DIMENSIONS - 5 KM HORIZONTAL x 1.5 KM VERTICAL
- O AMPLITUDE - 1.5^{O}

MODEL INPUT SOUNDING

- O COMPOSITE FOR CHARLOTTE -- based on observed rawinsonde soundings at GSO and AHN, mid-level winds from NMC's Nested Grid Model, observed wind, temperature, dewpoint, and cloud-base heights for CLT at 2200 UTC

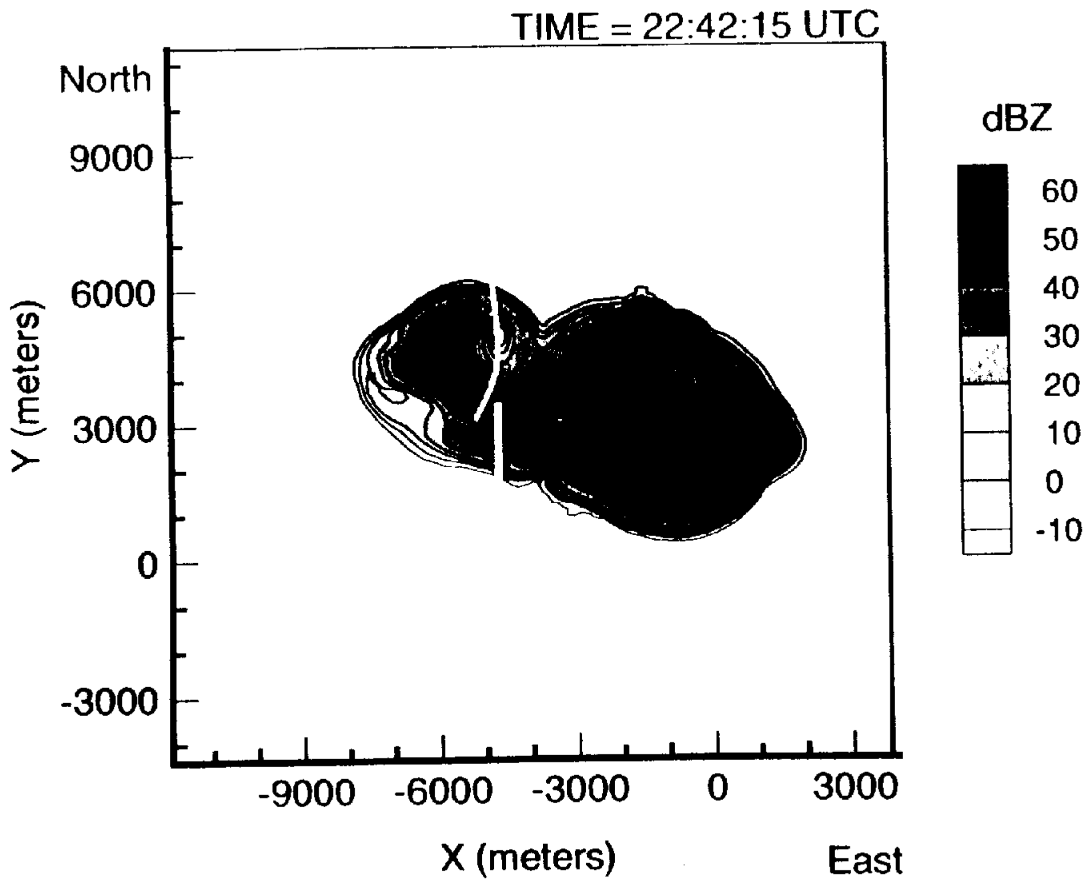
VALIDATION
Charlotte, 2 July 1994, Microburst

COMPARISON OF SIMULATED AND OBSERVED CHARACTERISTICS OF MICROBURST EVENT

	OBSERVED	*SIMULATED*
STORM TOP	7 - 9 Km	8 Km
PEAK RADAR REFLECTIVITY	>60 dBZ	65 dBZ at 3 - 4 Km AGL
STORM TRANSLATION	4.5 M/S from 150^0 (toward NW)	3.8 M/S from 145^0 (toward NW)
RADAR ECHO STRUCTURE AT MID-LEVELS	ELONGATED WNW-ESE	ELONGATED WNW-ESE
ACCUMULATED PRECIPITATION	0.33 INCHES in 15 Minutes	0.25 INCHES in 12 Minutes
DIAMETER OF MICROBURST RAIN SHAFT	ESTIMATED 1.5 to 5 Km	~3.5 Km
MAX TEMPERATURE DROP	$-6^{O}C$ at NWS	-7^0 C
MAX (1-Km AVG) N-S F-FACTOR	~ 0.3 from FDR of USAIR 1016	0.3
PEAK LOW-LEVEL GUST	17.3 M/S - LLWAS 6, (20-25 M/S - estimated by Civilians)	27 M/S
MAX N-S VELOCITY CHANGE (ΔV)	~40 M/S from FDR of USAIR 1016	44 M/S

TASS CLT MICROBURST SIMULATION

RADAR REFLECTIVITY AT 3000 M AGL



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Charlotte, 2 July 1994, Microburst

RECONSTRUCTION OF AIRCRAFT FLIGHT PATH FROM MODEL DATA
COMPARISON WITH FDR DATA

- ADDITIONAL CORROBORATION OF MODEL SIMULATION PROVIDED COMPARING DATA ALONG RECONSTRUCTED FLIGHT PATH

- DATA NOT AVAILABLE FROM FDR, SUCH AS VERTICAL VELOCITY AND LIQUID WATER CONTENT CAN BE PROVIDED ALONG MODEL PROFILE

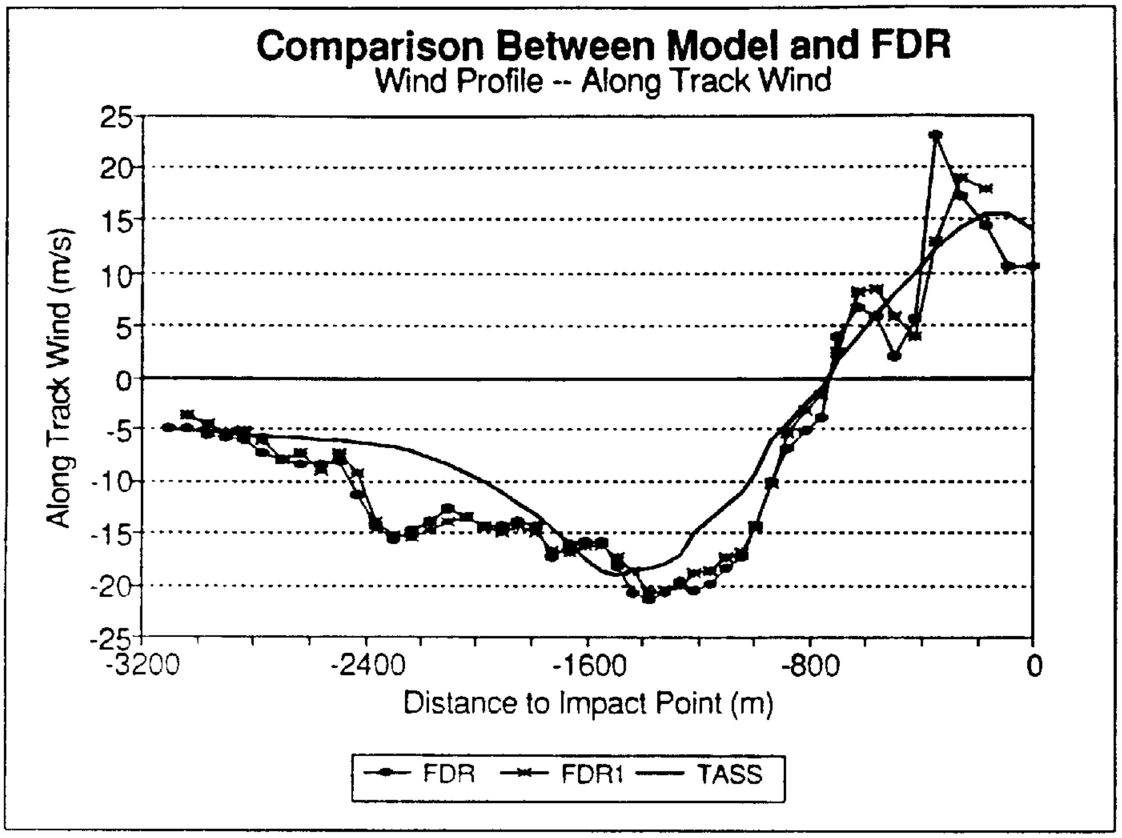
- ALLOWS MATCHING OF TIME AND POSITION OF MODEL COORDINATES WITH ACTUAL COORDINATES (e.g. 24 min simulation time = 2241 UTC; impact point is x=4717 m, y=3428 m in model coordinates)

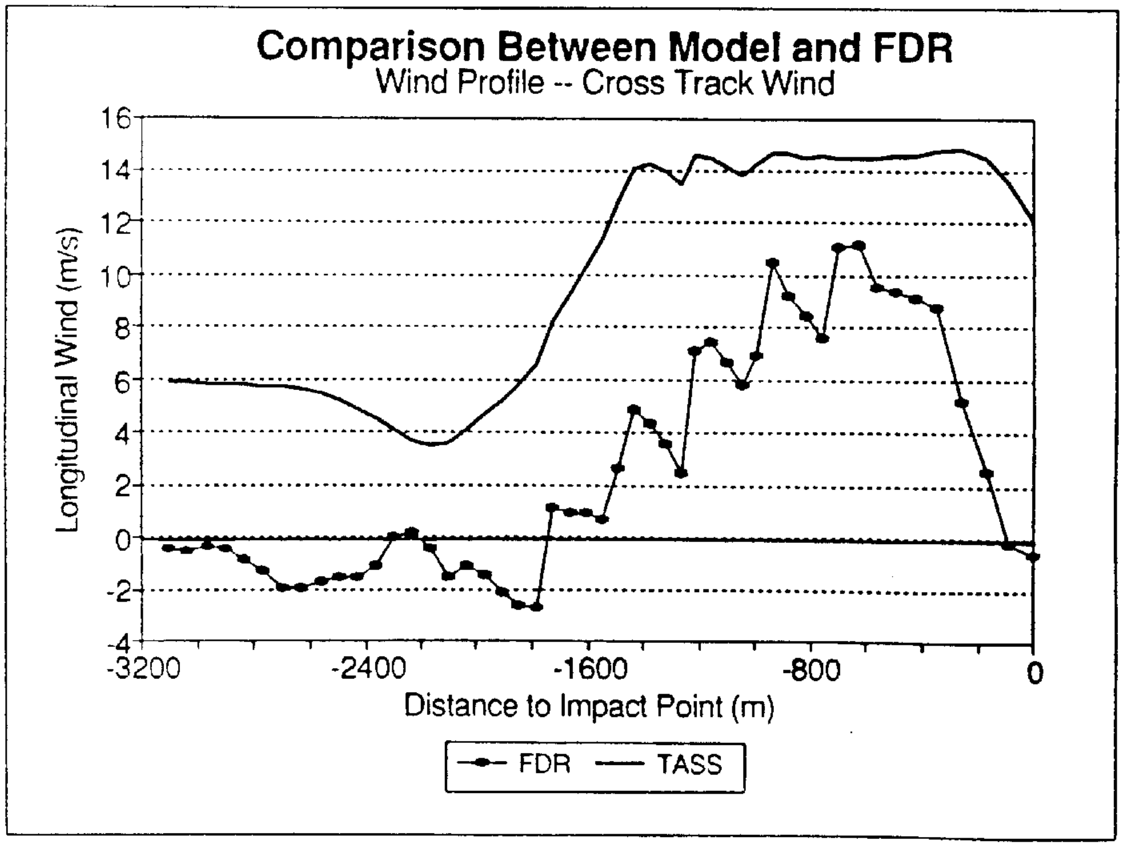
- ALLOWS CONSTRUCTION OF A POSSIBLE SCENARIO OF THE METEOROLOGY NEAR THE TIME OF THE ACCIDENT

FOLLOWING PLOTS SHOW COMPARISON OF ALONG-TRACK WIND, CROSS-TRACK WIND, AND 1-KM AVERAGED F-FACTOR.

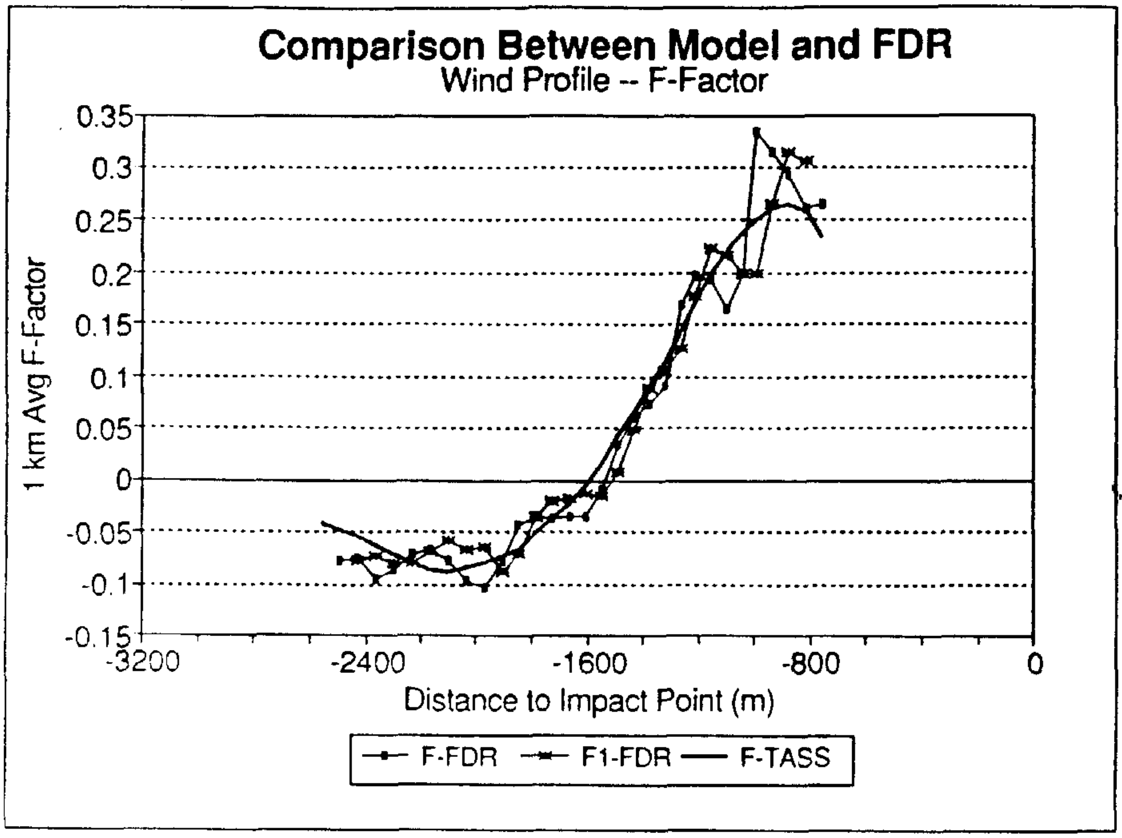
AN F-FACTOR IN EXCESS OF 0.105 IS CONSIDERED BY FAA TO BE HAZARD

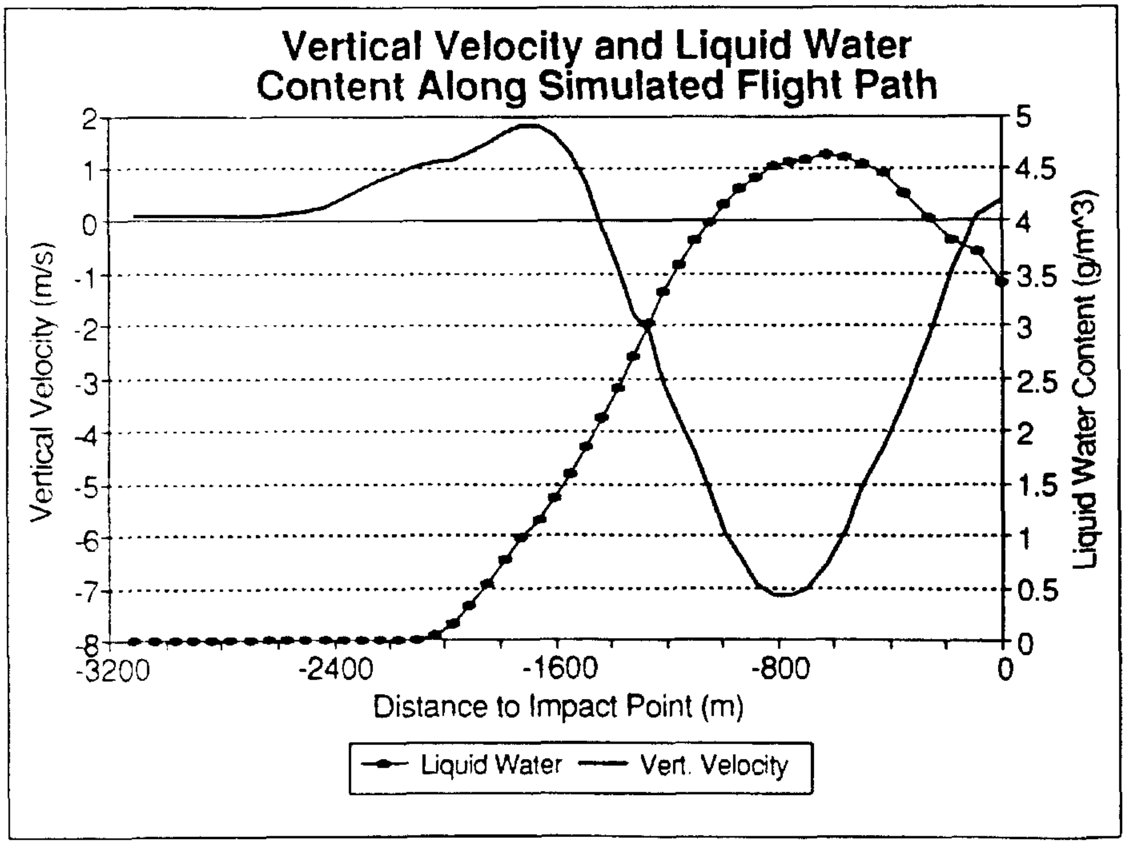
LEGEND:		
	FDR-DATA	WINDS PROVIDED BY NTSB
	FDR1	APPROXIMATION TO ALONG-TRACK WINDS FROM AIR SPEED AND GROUND SPEED
	TASS	WINDS GENERATED ALONG RECONSTRUCTED FLIGHT PATH FROM TASS MODEL
	F-FDR	F-FACTOR COMPUTED FROM FDR-DATA WINDS; INCLUDES ESTIMATION FOR VERTICAL TERM
	F1-FDR	SAME AS ABOVE, BUT FOR FDR1 WINDS
	F-TASS	F-FACTOR FROM TASS WINDS (INCLUDES VERTICAL TERM)


Comparison Between Model and FDR
Wind Profile -- Along Track Wind
Along Track Wind (m/s)
25
20
15
10
5
0
-5
-10
-15
-20
-25
-3200
-2400
-1600
-800
0
Distance to Impact Point (m)
FDR
FDR1
TASS

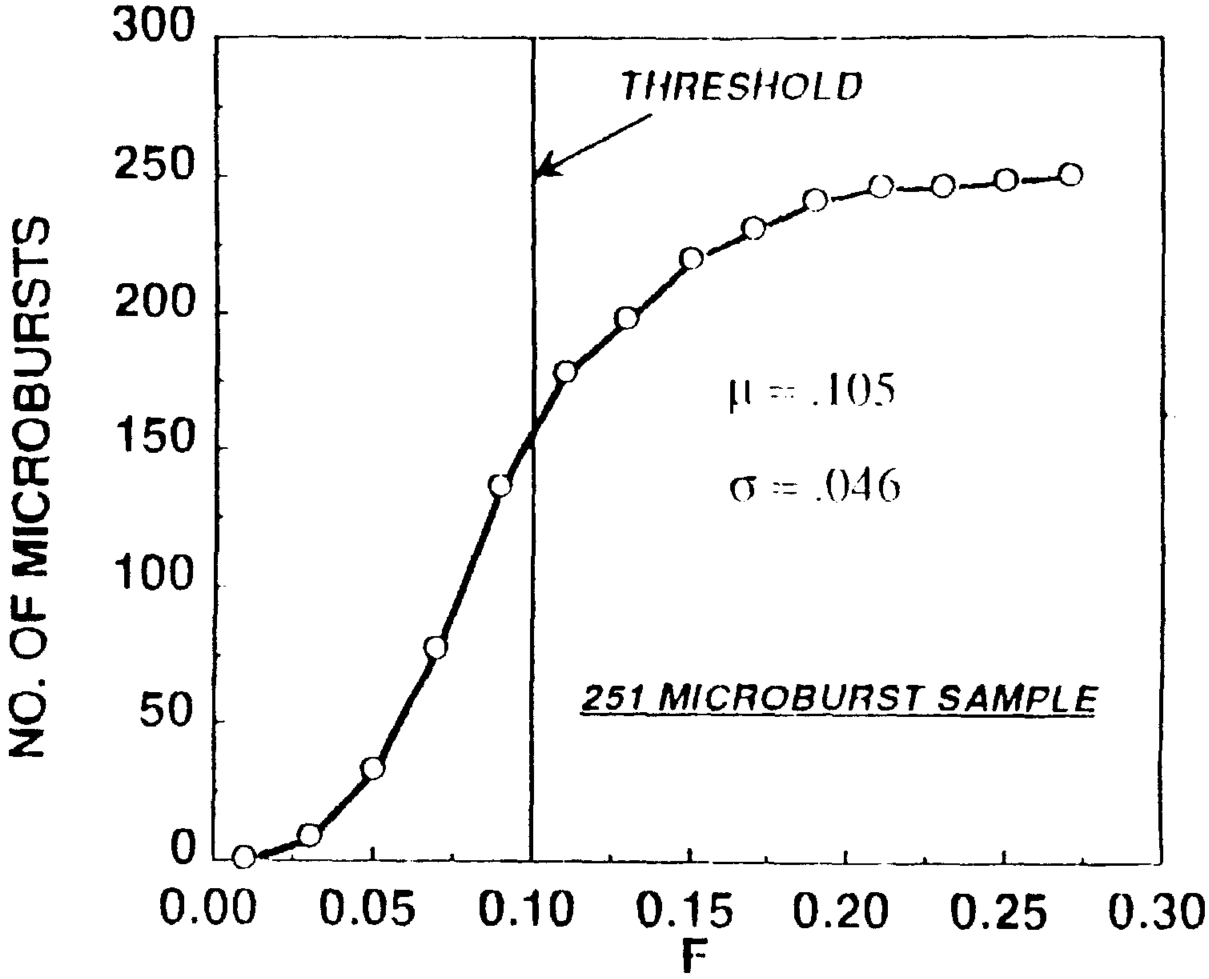

Comparison Between Model and FDR
Wind Profile -- Cross Track Wind
Longitudinal Wind (m/s)
16
14
12
10
8
6
4
2
0
-2
-4
-3200
-2400
-1600
-800
0
Distance to Impact Point (m)
FDR
TASS

16


Comparison Between Model and FDR
Wind Profile -- F-Factor
1 km Avg F-Factor
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-3200
-2400
-1600
-800
0
Distance to Impact Point (m)
F-FDR
F1-FDR
F-TASS


Vertical Velocity and Liquid Water Content Along Simulated Flight Path
Vertical Velocity (m/s)
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
Liquid Water Content (g/m^3)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-3200
-2400
-1600
-800
0
Distance to Impact Point (m)
Liquid Water
Vert. Velocity

17

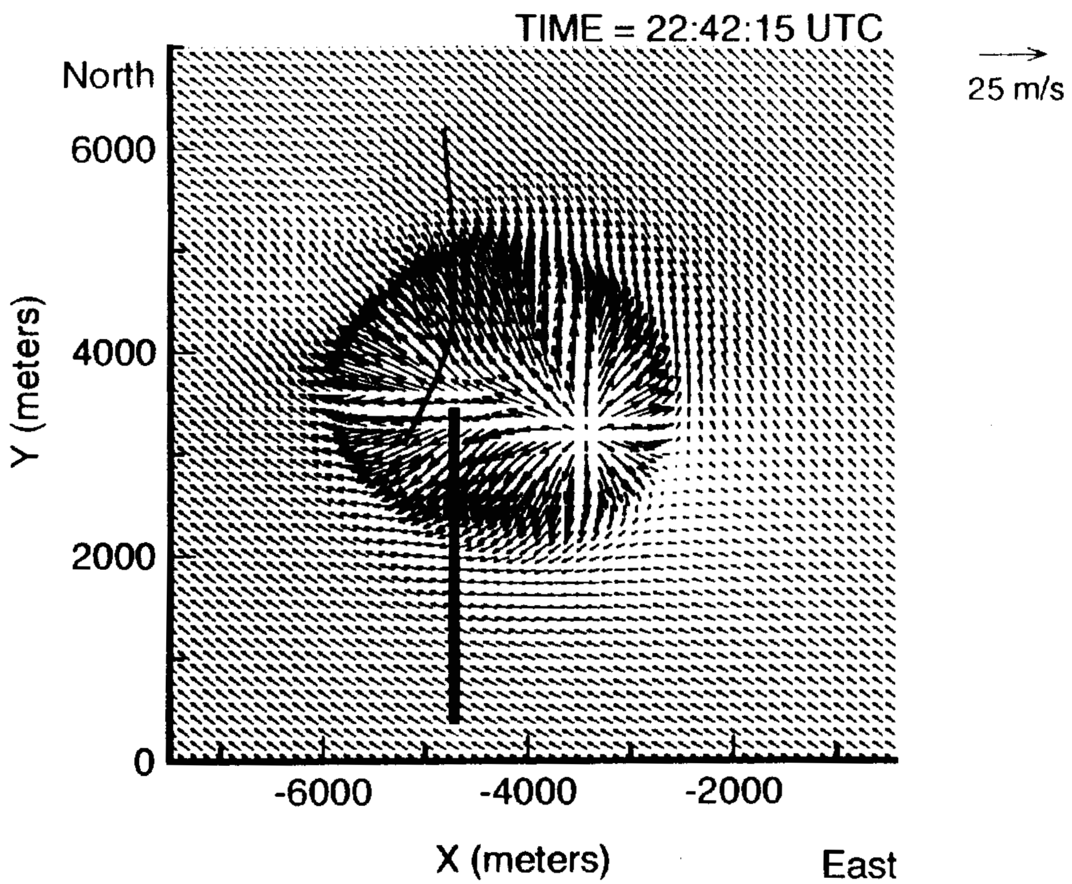


Cumulative number of microburst with peak 1-km averaged F-factor less than or equal to a given abscissa value. Based on 251 microburst sample measured during three field programs. Assumes a 75 m/s airspeed at 100 m AGL. [from "Windshear Detection: Airborne System Perspective," R.L. Bowles, and D.A. Hinton, Windshear -- One Day Conference, Royal Aeronautical Society, London, England, 1990, 25 pp.]

Note: Microbursts with estimated F-factor greater than 0.2 are infrequent and values greater than 0.3 were not measured in the sample.

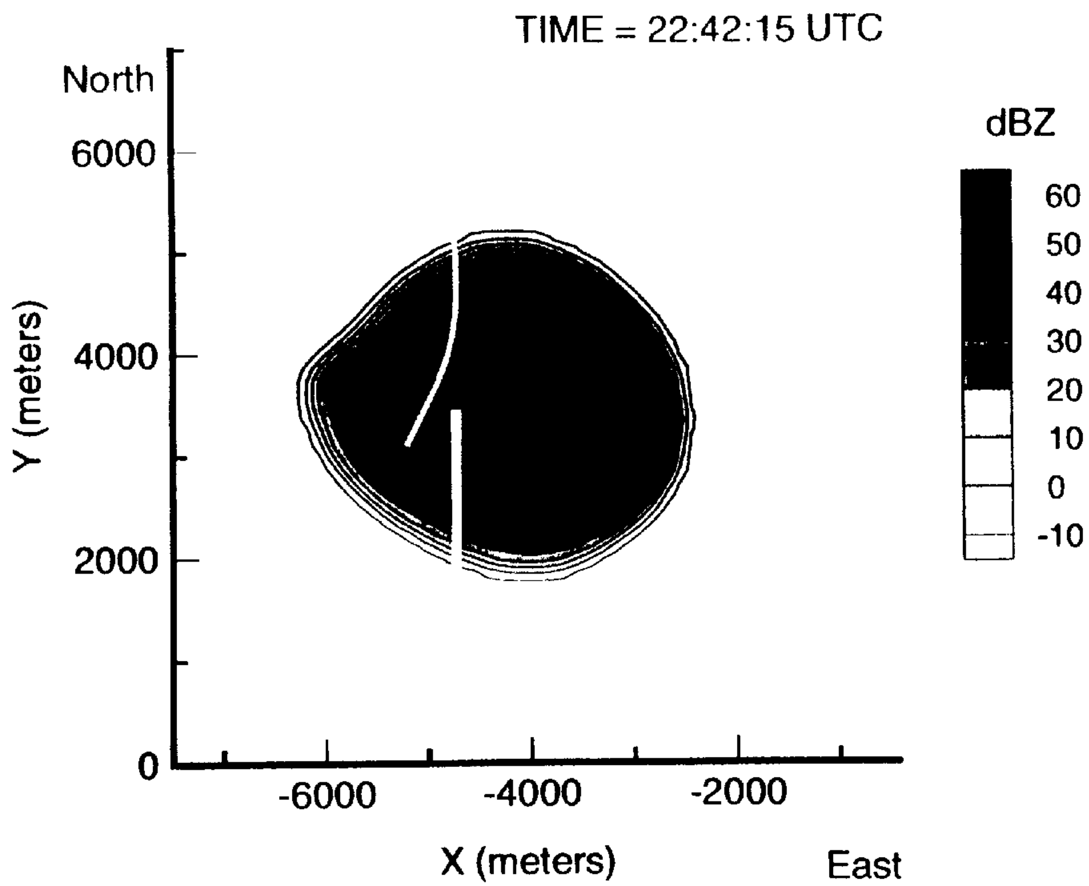
TASS CLT MICROBURST SIMULATION

HORIZONTAL WIND VECTORS AT 90 M AGL



TASS CLT MICROBURST SIMULATION

RADAR REFLECTIVITY AT 160 M AGL



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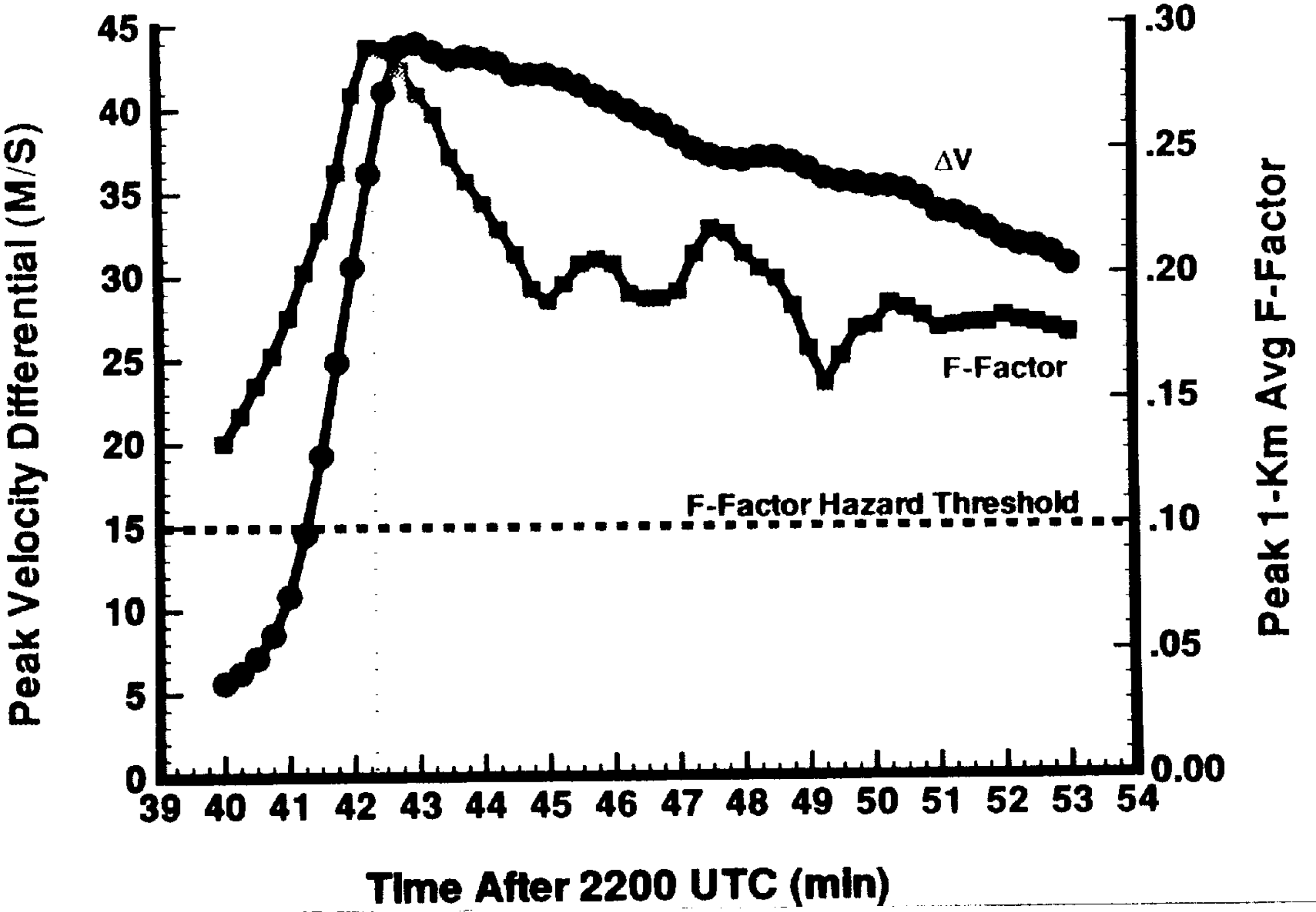
Charlotte, 2 July 1994, Microburst Simulation

ADDITIONAL MICROBURST/STORM CHARACTERISTICS OBTAINED FROM SIMULATION

- MULTICELLULAR STORM WITH NEW CELL GROWTH ON WESTERN END
- MICROBURST MOVEMENT FROM 150° AT 4.7 M/S (toward NW at 9 knots)
- MICROBURST MOST INTENSE DURING EARLY STAGE
- PEAK RAINFALL RATES OF 4.3 INCHES PER HOUR
- MICROBURST OUTFLOW EXPANDS WITH TIME AS IT MOVES NORTHWEST
- EMBEDDED MICROBURSTS DEVELOP DURING LATER STAGES, AND AID IN MAINTAINING HAZARDOUS LEVELS OF WINDSHEAR

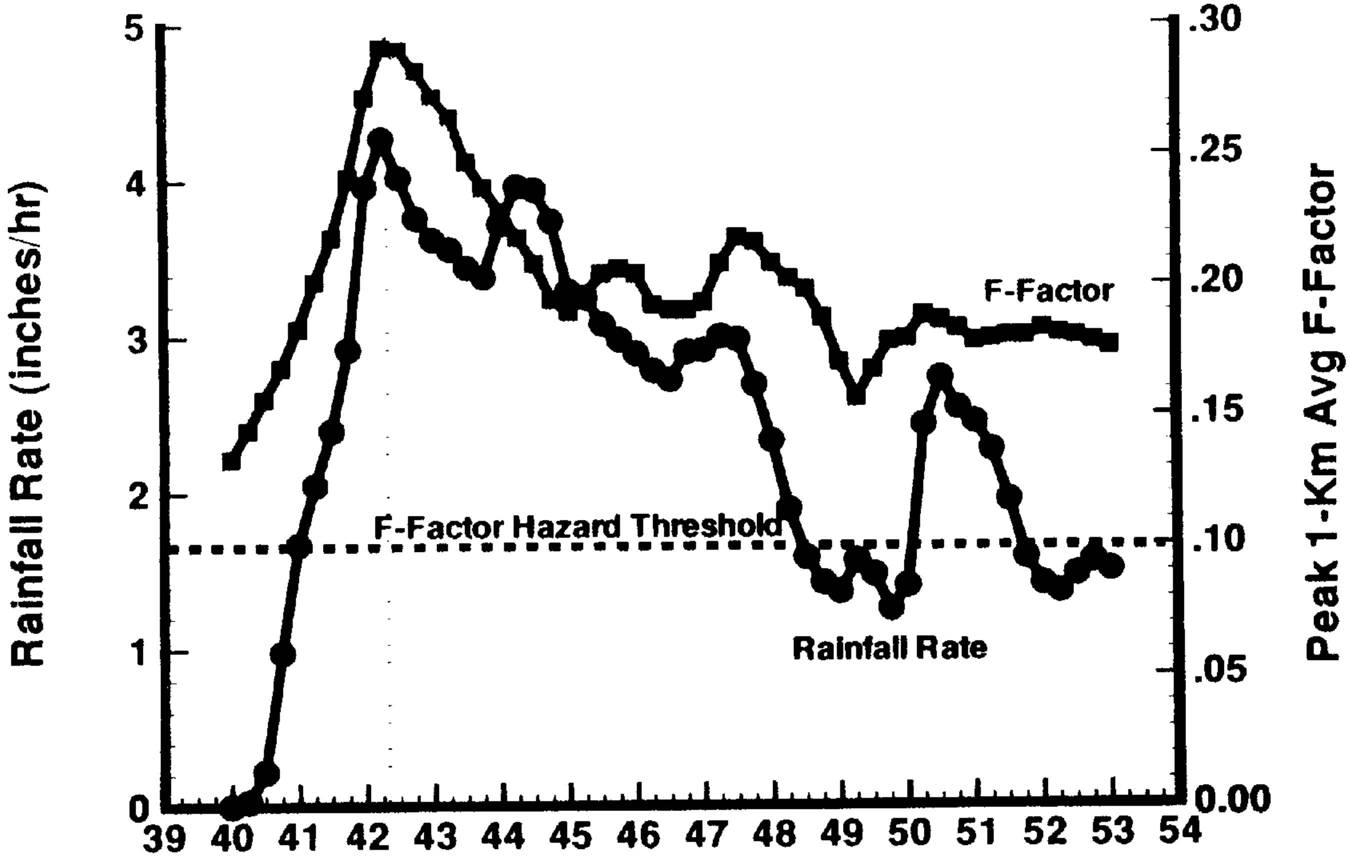
2 July 1994 CLT MICROBURST

N-S Model F-Factor and Velocity Differential vs Time



2 July 1994 CLT MICROBURST

N-S Model F-Factor and Rainfall Rate vs Time

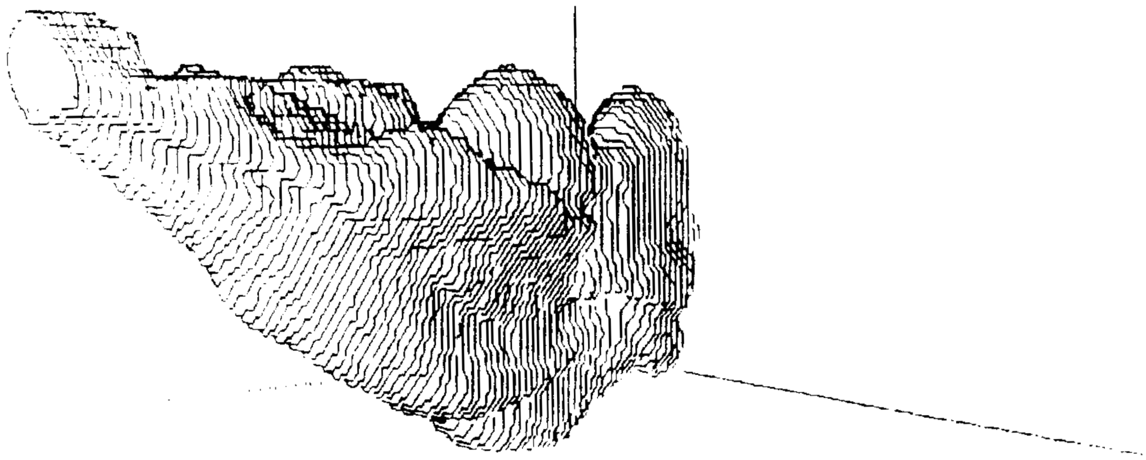


Time After 2200 UTC (min)

22

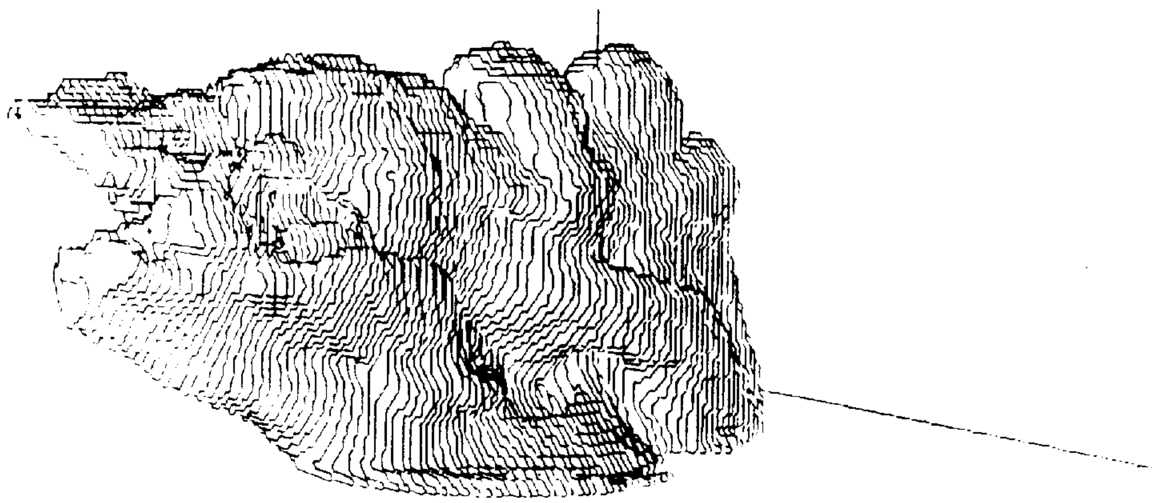
(23)

MODEL STORM AS VIEWED FROM NE AT 2241 UTC (volume encloses Radar Reflectivity greater than 10 dBZ)



CLT 7.3.94
LOOKING SW
RRF AT 24.0 MIN
CONTOUR: 10.0
(200. 250. 50.)

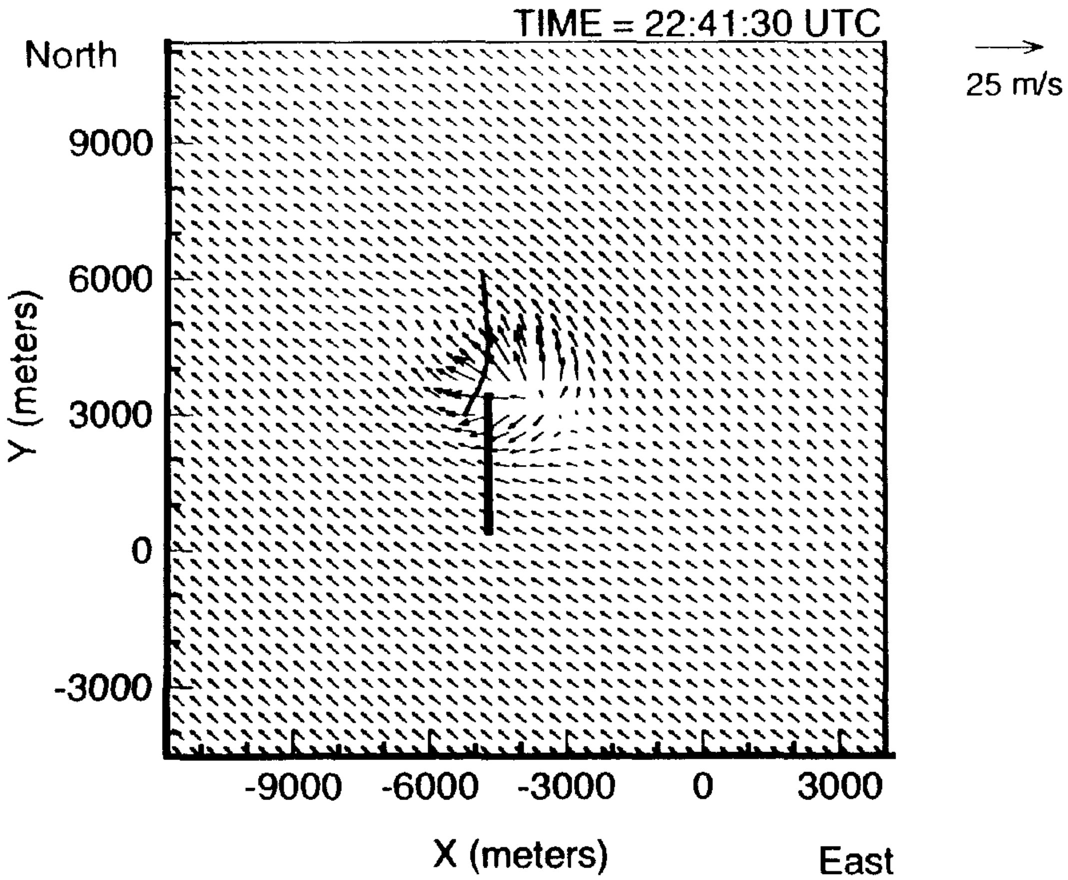
MODEL STORM AS VIEWED FROM NE AT 2247 UTC (volume encloses Radar Reflectivity greater than 10 dBZ)



CLT 7.3.94
LOOKING SW
REF AT 30.Ø MIN
CONTOUR: 1Ø.Ø
(200. 250. 50.)

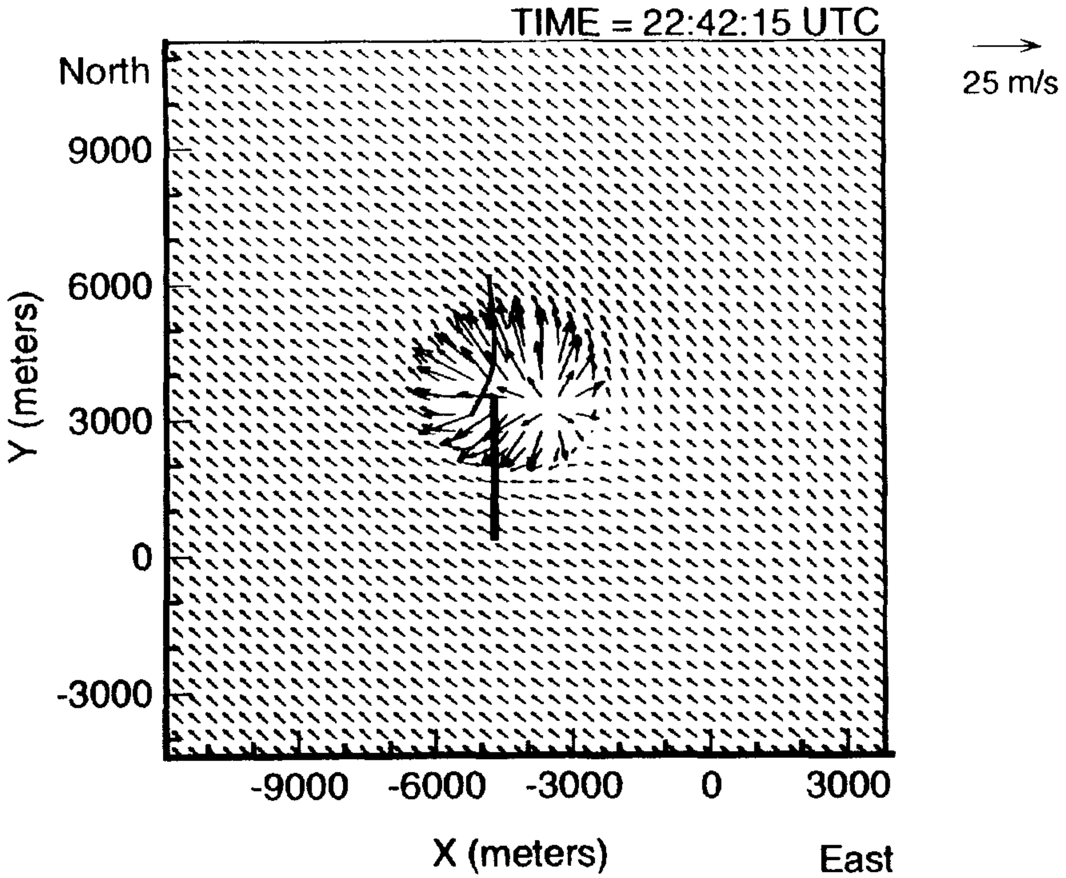
TASS CLT MICROBURST SIMULATION

HORIZONTAL WIND VECTORS AT 90 M AGL



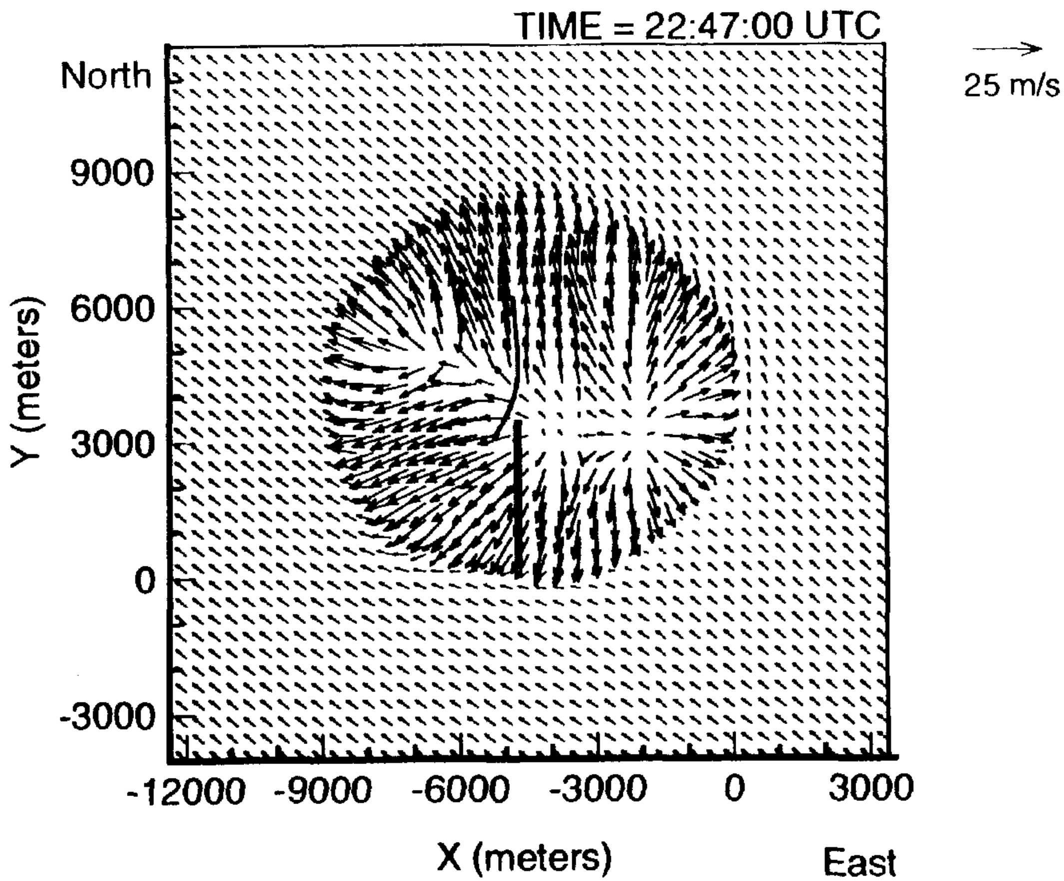
TASS CLT MICROBURST SIMULATION

HORIZONTAL WIND VECTORS AT 90 M AGL



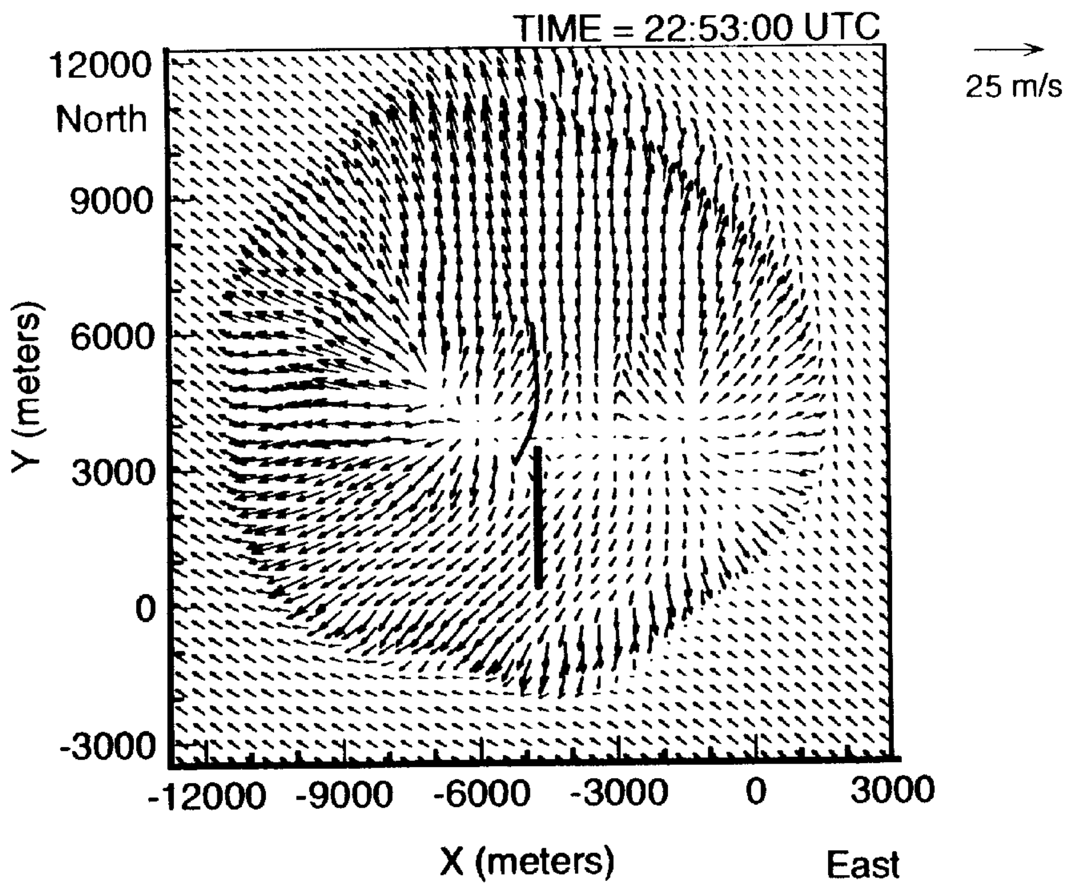
TASS CLT MICROBURST SIMULATION

HORIZONTAL WIND VECTORS AT 90 M AGL



TASS CLT MICROBURST SIMULATION

HORIZONTAL WIND VECTORS AT 90 M AGL



SUMMARY AND CONCLUSIONS

- O RESULTS FROM THE THREE-DIMENSIONAL NUMERICAL SIMULATION OF THE CHARLOTTE MICROBURST SHOW FAVORABLE CORROBORATION WITH OBSERVATIONS AND FLIGHT RECORDER DATA

- O THE NUMERICAL SIMULATION PRODUCES AN UNUSUALLY INTENSE MICROBURST, CHARACTERIZED BY A LARGE VELOCITY CHANGE (~40 M/S) OVER A RELATIVELY SMALL SCALE (~1.5 KM)

- O THE SIMULATED MICROBURST IS DRIVEN BY A SMALL DIAMETER, BUT HIGH REFLECTIVITY, RAIN SHAFT. DIAMETER OF THE SHAFT IS ABOUT 3.5 KM WITH STRONG RADAR REFLECTIVITY GRADIENTS NEAR THE EDGE. THE STORM CELL THAT PRODUCED THE MICROBURST HAD A TOP OF ONLY ABOUT 7.5 KM

- O 1-KM AVERAGED F-FACTORS FROM BOTH THE SIMULATION AND ANALYSIS OF THE USAIR FLIGHT DATA RECORDER ARE ABOUT 0.3. IN THREE WINDSHEAR FIELD PROGRAMS, MICROBURSTS WITH A PEAK AVERAGED F-FACTOR GREATER THAN O.2 WERE INFREQUENT AND NONE EXCEED 0.3.

- O A POSSIBLE SCENARIO CONSTRUCTED FROM THE MODEL SIMULATION INDICATES USAIR 1016 ENCOUNTERED THE MICROBURST EARLY IN ITS LIFETIME AND DURING ITS PERIOD OF GREATEST INTENSITY. FOLLOWING THE ACCIDENT THE MICROBURST OUTFLOW EXPANDED IN SCALE AND SLOWLY MOVED NORTHWESTWARD.

COMPOSITE SOUNDING FOR CHARLOTTE, NC AT 2200 UTC
(used for initializing ambient condtions in model simulation)

30

PRESSURE (MB)	TEMPER-ATURE (C)	DEWPOINT (C)	U (M/S)	V (M/S)
989.00	30.60	19.48		
985.68	30.30	19.43	-3.09	3.12
978.71	29.69	19.31	-4.71	3.26
971.33	29.04	19.19	-5.35	3.18
963.55	28.34	19.06	-5.31	2.98
955.36	27.61	18.93	-5.17	2.79
946.78	26.83	18.78	-5.11	2.66
937.82	26.02	18.63	-5.12	2.59
928.49	25.17	18.45	-5.14	2.58
918.79	24.29	18.22	-5.10	2.62
908.73	23.37	17.93	-5.00	2.67
898.32	22.43	17.53	-4.90	2.71
887.58	21.49	16.87	-4.80	2.73
876.51	20.58	15.79	-4.72	2.74
865.11	19.64	14.47	-4.61	2.78
853.41	18.64	13.30	-4.42	2.89
841.41	17.57	12.25	-3.78	3.27
829.14	16.43	11.35	-2.79	3.69
816.62	15.33	10.40	-1.83	3.74
803.85	14.46	9.43	-1.35	3.29
790.84	13.46	8.34	-1.35	2.68
777.62	12.31	7.00	-1.46	2.16
764.18	11.10	5.41	-1.55	1.82
750.54	9.93	3.70	-1.64	1.71
736.72	8.86	2.08	-1.62	1.77
722.74	7.91	0.84	-1.38	1.92
708.62	7.01	0.04	-0.99	2.02
694.39	6.09	-0.63	-0.68	1.89
680.05	5.14	-1.51	-0.42	1.45
665.61	4.18	-2.69	-0.09	0.87
651.11	3.17	-3.90	0.14	0.40
636.53	2.08	-4.65	0.16	-0.04
621.91	0.94	-4.72	-0.15	-0.28
607.25	-0.22	-4.77	-0.49	0.10
592.57	-1.27	-5.93	-0.12	1.28
577.90	-2.17	-8.87	1.10	2.32
563.24	-2.99	-13.44	2.85	2.93
548.61	-3.94	-18.44	4.52	3.18
534.02	-5.17	-21.77	5.65	3.16
519.47	-6.66	-22.01	6.34	2.94
504.97	-8.26	-20.64	6.78	2.56
490.53	-9.81	-20.16	6.96	1.88
476.17	-11.21	-21.80	6.83	0.84
461.91	-12.46	-25.26	6.43	-0.32
447.77	-13.63	-28.84	6.09	-1.30
433.76	-14.66	-31.00	6.11	-2.05
419.92	-15.51	-32.20	6.39	-2.76
406.25	-16.35	-33.65	6.66	-3.56
392.75	-17.48	-35.51	6.73	-4.43
379.43	-19.09	-37.35	6.66	-5.15
366.27	-21.05	-38.95	6.60	-5.63
353.26	-23.17	-40.47	6.44	-6.00
340.41	-25.30	-42.02	6.11	-6.26

PRESSURE (MB)	TEMPER-ATURE (C)	DEWPOINT (C)	U (M/S)	V (M/S)
327.74	-27.46	-43.60	5.73	-6.32
315.25	-29.71	-45.25	5.45	-6.16
302.95	-32.08	-46.93	5.34	-5.95
290.84	-34.56	-48.61	5.52	-6.08
278.93	-37.10	-50.32	6.02	-6.66
267.22	-39.68	-52.10	6.39	-7.31
255.73	-42.25	-53.98	6.02	-7.49
244.45	-44.85	-55.93	4.96	-7.03
233.43	-46.83	-57.57	4.96	-7.03