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Session X. Airborne Doppler Radar / NASA

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Airborne Radar Simulation Studies of the Denver July 11, 1988 Microburst

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AIRBORNE RADAR SIMULATION STUDIES OF THE DENVER JULY 11, 1988 MICROBURST

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On July 11, 1988 5 United Airline (UAL) aircraft had inadvertent encounters with a microburst that struck Denver Stapleton airport. Four of these aircraft experienced severe wind shear during final approach to 26L&R runways, and had to execute emergency missed approach recovery procedures to escape the hazard, barely avoiding a fatal accident. The question was asked, what would an Airborne Doppler Radar with wind shear detection capability had seen if it had been available on these aircraft. Would the radar have detected the microburst with sufficient warning time to allow the pilot to avoid the severest portion of the microburst. To answer these questions a simulation study was conducted using the Radar simulation program described by C. L. Britt of RTI in the second presentation of this session (SESSION XI AIRBORNE DOPPLER RADAR/NASA). The July 11 microburst data base generated by the NASA Microburst Wind Shear Model (developed by Fred Proctor of MESO INC.) was used in the radar simulation along with the Denver stationary and moving clutter maps described in the first presentation of this session.

In the simulation program a wind shear detection Doppler radar was placed in UAL 395 and 236 aircraft and flown along their landing flight paths. The microburst was placed at the appropriate location and intensity corresponding to each aircraft landing approach time. A baseline set of radar design parameters, which will be described later, were used in the simulation. Output display information and wind shear detection processing was produced as the aircraft approached the microburst. The following charts present information on the results of this simulation study.

DENVER JULY 11 U-BURST AT TIME PERIOD D49 (VELOCITY PLOT)

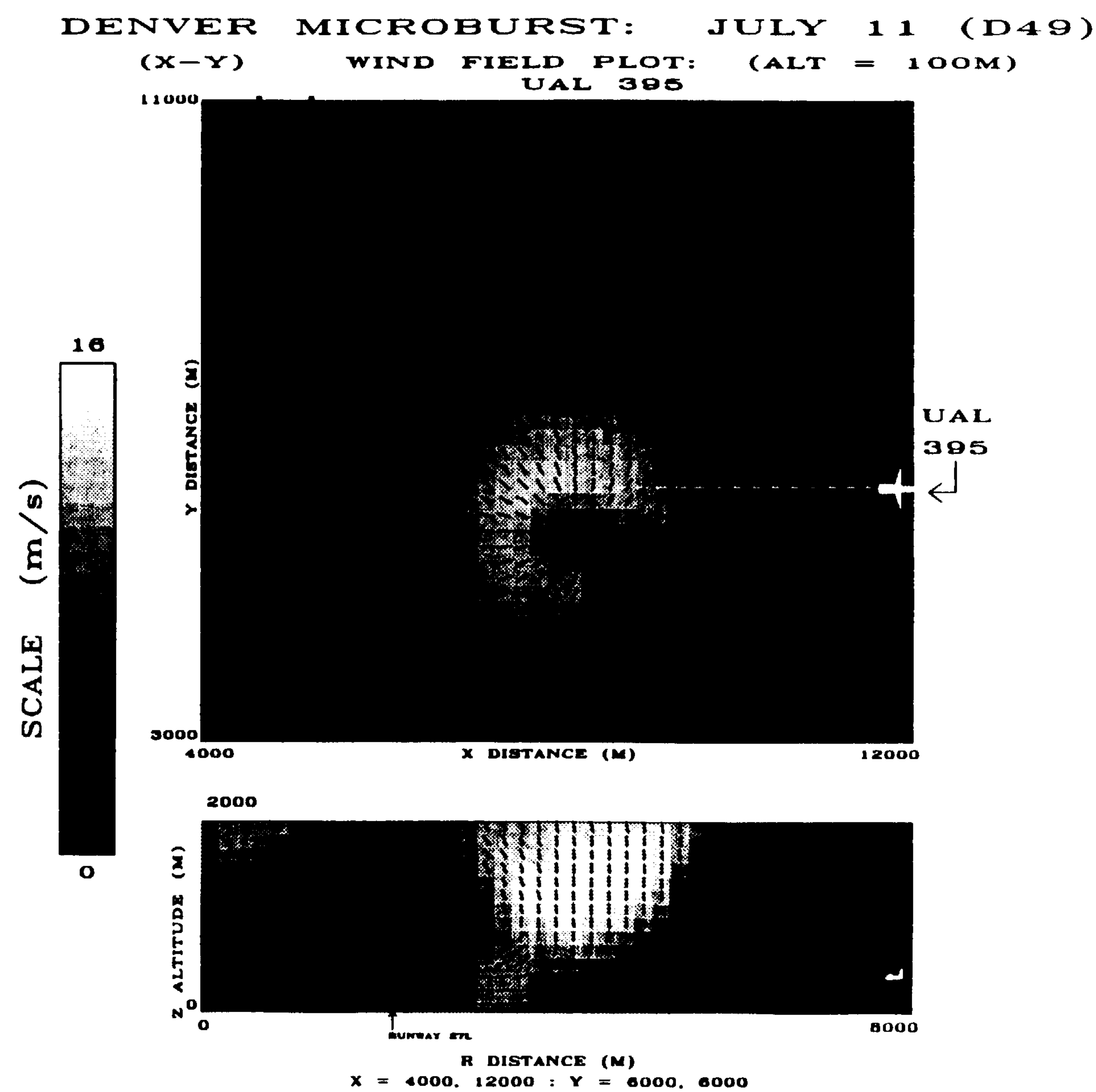
The upper plot shows an X-Y horizontal cross section, at 100 m altitude, of wind vectors for the microburst (U-B) that struck Denver Stapleton airport on July 11 1988. The gray shade contours indicate wind speed (scale on left) in meters per second (m/s), and the arrows show wind direction. The wind direction vectors are shown every 200 m. The Y-axis runs north, the X-axis east. The lower plot shows a vertical cross section (altitude, Z vs X distance) through the U-B along the A/C flight path. The altitude resolution is approximately 80 meters. The down draft wind vectors and divergent outflow wind vectors at low altitude can easily be seen.

The data for this plot was generated by the NASA U-B wind shear model. Actual measured meteorological data prior to the storm are used as inputs to the model. The structure of the storm and wind fields resulting from the model, and shown here, compare very close to the actual U-B that occurred on July 11, as confirmed by ground based Doppler radar, and reconstructed winds using recorder data from the A/C that encountered the storm. This plot is for simulation time D49, corresponding to the actual time associated with the position of UAL flight 395.

The center of the U-B is approximately 2.2 kilometers (KM) (1.2 nautical miles (NM)) east and .5 KM (.25 NM) south of runway 26L. The airport runways are indicated on the figure. The arrows in the U-B show the strong out flow divergence with severe velocity wind shear.

The microburst intensity and location are shown here about a minute after it descended to the ground at about the time UAL 395 was at 1200 feet approaching runway 26L. UAL 395 is shown in the figure as it approaches the storm 7 KM (3.8 NM) from touch down (TD) and 4.8 KM (2.6 NM) from the center of the U-B.

Approximately one minute later UAL 395 was at the center of the storm and came within 75 feet of the ground and .5 miles short of the runway TD before it was able to gain altitude and escape the U-B.



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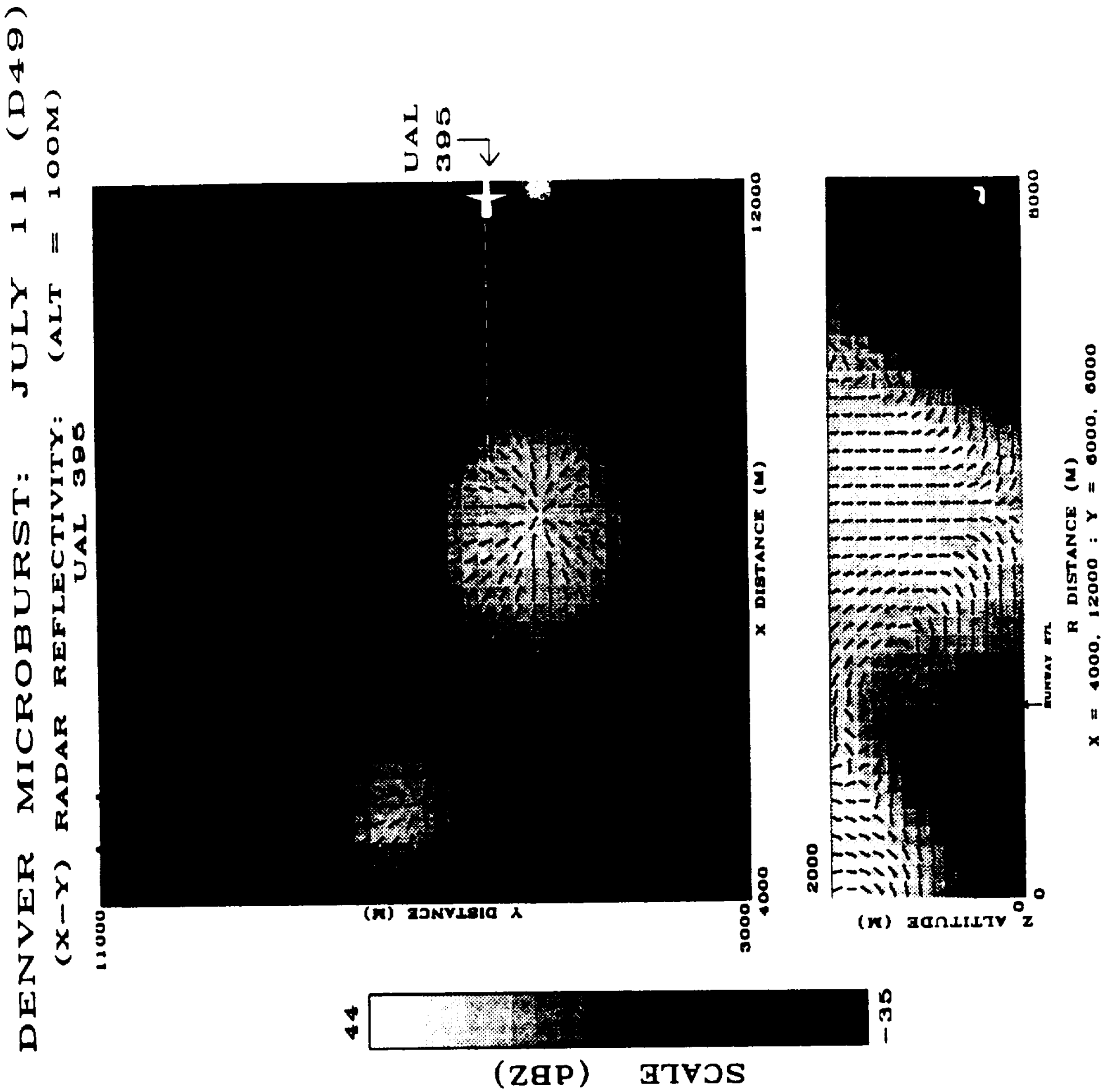
DENVER JULY 11 U-BURST AT TIME PERIOD D49 (REFLECTIVITY PLOT)

This plot is identical to the D49 velocity plot except the gray shade contours indicate the reflectivity levels in Dbz that existed in the microburst. Within the major portion of the microburst outflow region the reflectivity levels range from 0 to 20 Dbz. This microburst is considered a relatively dry microburst. The reflectivity levels are 3 orders of magnitude lower then the levels experienced in the Dallas-Fort Worth microburst of 1985. These lower levels of reflectivity present a more difficult problem for the radar to detect especially in the presents of severe ground clutter.



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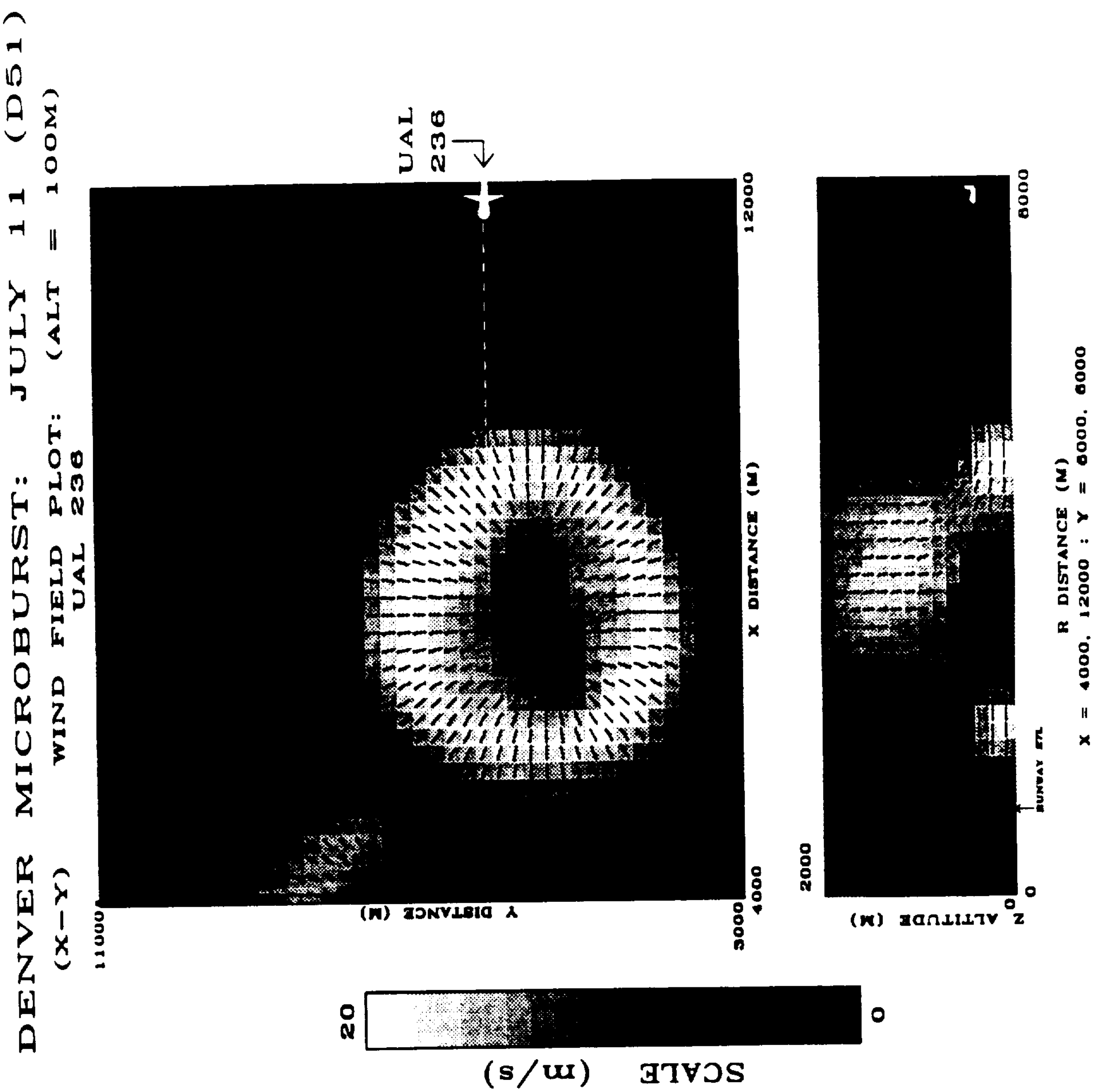
DENVER JULY 11 U-BURST AT TIME PERIOD D51 (VELOCITY PLOT)

This figure shows the velocity contours of the U-B 2 minutes later in its development from time period D49. At this time the storm has grown in size and intensity , as seen in the figure, and has moved slightly east to 2.3 KM (1.2 NM) from the runway. The location of UAL 236 which was following behind UAL 395 is shown in the figure 4.5 KM (2.7 NM) from the U-B. One minute later UAL 236 was located near the center of the U-B approximately 2 KM (1.1 NM) from TD and 150 m (492 ft) above the ground before it began to gain altitude. A portion of a second smaller microburst can be seen NW of the main microburst.



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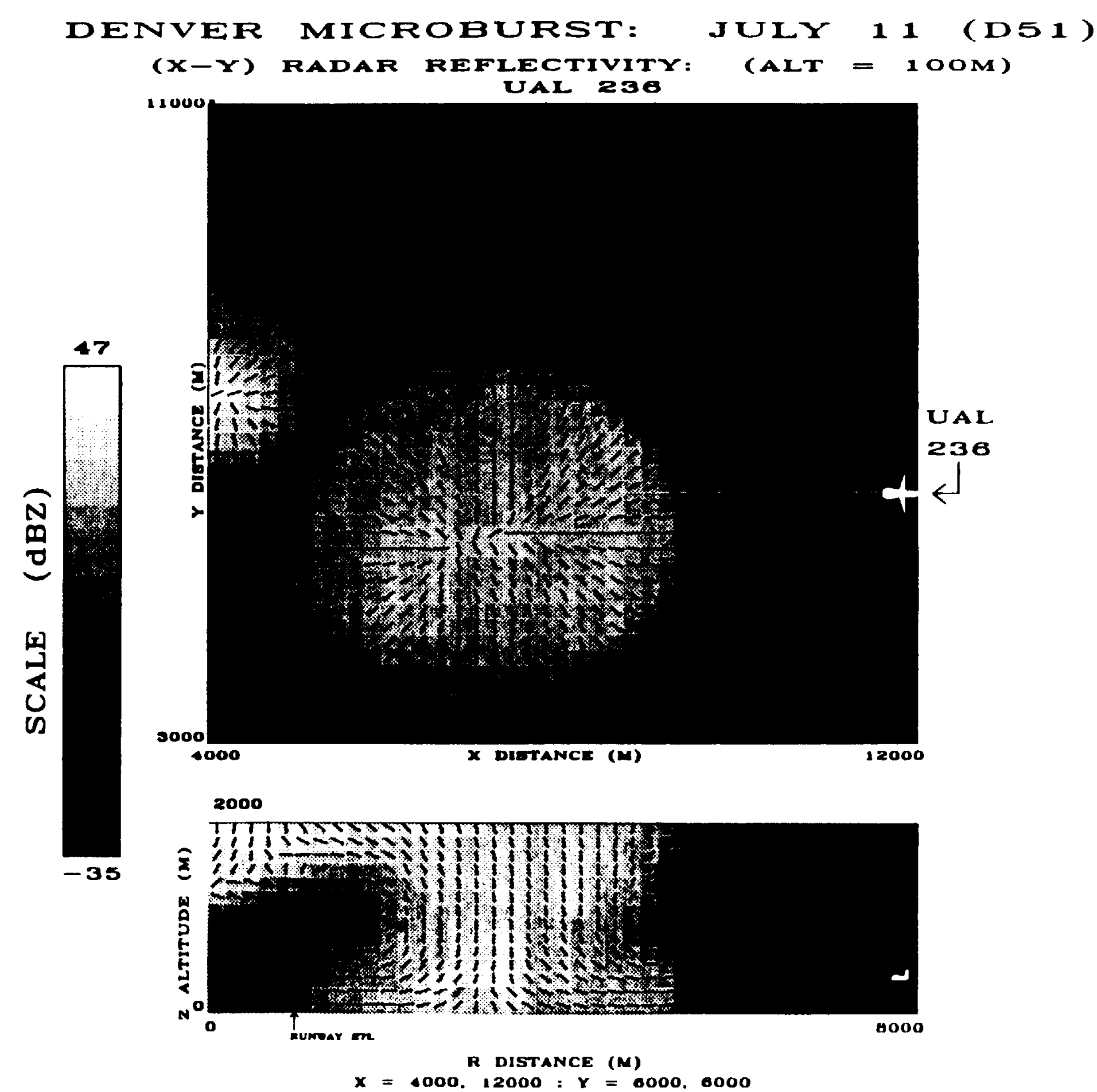
DENVER JULY 11 U-BURST AT TIME PERIOD D51 (REFLECTIVITY PLOT)

This plot is identical to the D51 velocity plot except the gray shade contours indicate the reflectivity levels in Dbz that existed in the microburst. Within the major portion of the microburst outflow region the reflectivity has increased a little to levels ranging from 0 to 23 Dbz.



DENVER MICROBURST: JULY 11 (D51)
(X-Y) RADAR REFLECTIVITY: (ALT = 100M)
UAL 236
11000
3000
Y DISTANCE (M)
4000
X DISTANCE (M)
12000
UAL
236
47
-35
SCALE (dBZ)
2000
Z ALTITUDE (M)
0
0
RUNWAY STL
8000
R DISTANCE (M)
X = 4000, 12000 : Y = 6000, 6000

RADAR BASELINE OPERATING PARAMETERS FOR HAZARD DETECTION

Using the radar simulation program, a set of radar displays of the wind shear hazard that would be seen by a Doppler radar located on board UAL 395 & 236 a/c were produced.

A set of parameters were chosen for the operation of the wind shear detection radar. These parameters are listed on the accompanying chart. The weighted least squares hazard detection and hazard tracking algorithms described in the second presentation of this session were utilized in the simulation runs. In addition a variable antenna tilt was employed to keep the 3 Db point of the main beam hitting the ground 8 km in front of the aircraft. In the simulation program as the aircraft is moved along the glide slope the antenna is scanned over a 42 deg. sector every 3 sec., with the radar sampling a .5 to 5 km range in front of the aircraft. The data is processed to velocity and wind shear information. The horizontal hazard index (F-Factor) is derived and tracked by the radar. If the hazard, area, and alarm thresholds are all exceeded an alarm is sounded to the pilot. The next sets of figures show sample displays of data generated by the radar, illustrating the effects of moving ground clutter and its reduction using antenna tilt.

BASELINE PARAMETERS FOR RADAR HAZARD DETECTION

o FREQUENCY --	X-BAND
o PULSE WIDTH -------------------------------------	.96 usec (144 m)
o PRF --	3755
o TRANSMITTER POWER ---------------------------	200 w
o FLAT PLATE ANTENNA, BEAMWIDTH ---------	3.5 deg
o ANTENNA SECTOR SCAN ---------------------	42 deg
o TIME TO SCAN SECTOR ----------------------	3 sec
o RANGE COVERAGE IN FRONT OF A/C ---------	5 Km (2.7 NM)
o VARIABLE ANT TILT: 3 DB INTERCEPT -----	8 Km
o HORIZONTAL HAZARD INDEX THRESH -------	.07
o HAZARD ALONG TRACK DIMENSION ------	900 m (10 s)
o AREA THRESHOLD ---------------------------	.65 SQ.KM (.2 SQ.MI)
o ALARM THRESHOLD -------------------------	40 sec
o SCANS FOR VALID TRACK ------------------	3

RADAR WIND VELOCITY CONTOUR DISPLAY U-BURST D49; ANTENNA TILT = 0 DEG

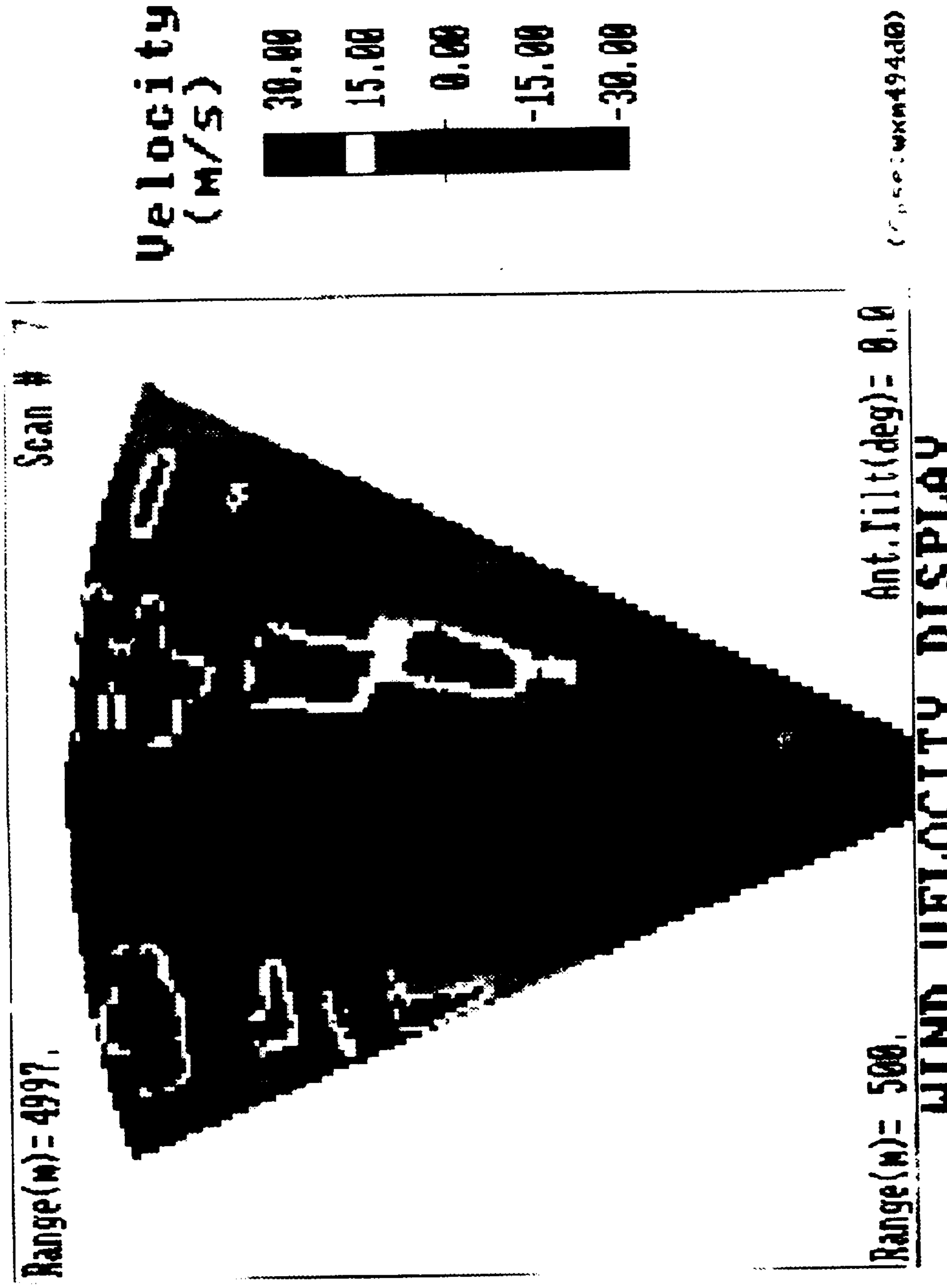
With the A/C approx. 3.3 km (1.8 NM) from the center of the storm a velocity display as shown in this figure was produced.

The radar is scanning +/- 21 degrees in azimuth, and covers a half to 5 km range or approx. 60 sec in front of the A/C. The velocity scale is show on the right in m/s.

The negative velocities, in the dark region approximately 2 km from the a/c, are winds toward the A/C i.e. head winds. These winds correspond to the leading edge of the U-burst, and are about –15 m/s (30 K). At a greater range near the center of the storm the horizontal velocity is zero as shown by the medium gray area. This is followed by the positive velocities corresponding to the outflow on the other side of the u-burst (+12 m/s). These produce tail winds to the A/C. This sudden change in direction of wind flow at these magnitudes will produce a wind shear which will severely effect the performance of the A/C.

The radar can only measure the radial or horizontal outflow velocities from the U-burst. It can not sense the down-flow velocity. This down-flow which is at a maximum at the center of the U-burst also produces a wind shear which effects the performance of the A/C.

Also shown in this display, on either side of the U-B are a significant number of velocity contours produced by clutter returns from moving vehicles on the roads and interstates surrounding Stapleton airport. The antenna in this case was set at a 0 deg. tilt relative to the glide slope. This tilt angle produces the worse case clutter returns. To reduce the clutter the antenna needs to be tilled up. A tilt of three deg. is shown in a later display. However, it is of interest to see how well the weighted least squares hazard algorithm would perform in detecting the U-B hazardous area in the presence of this severe clutter. The next chart shows the results.

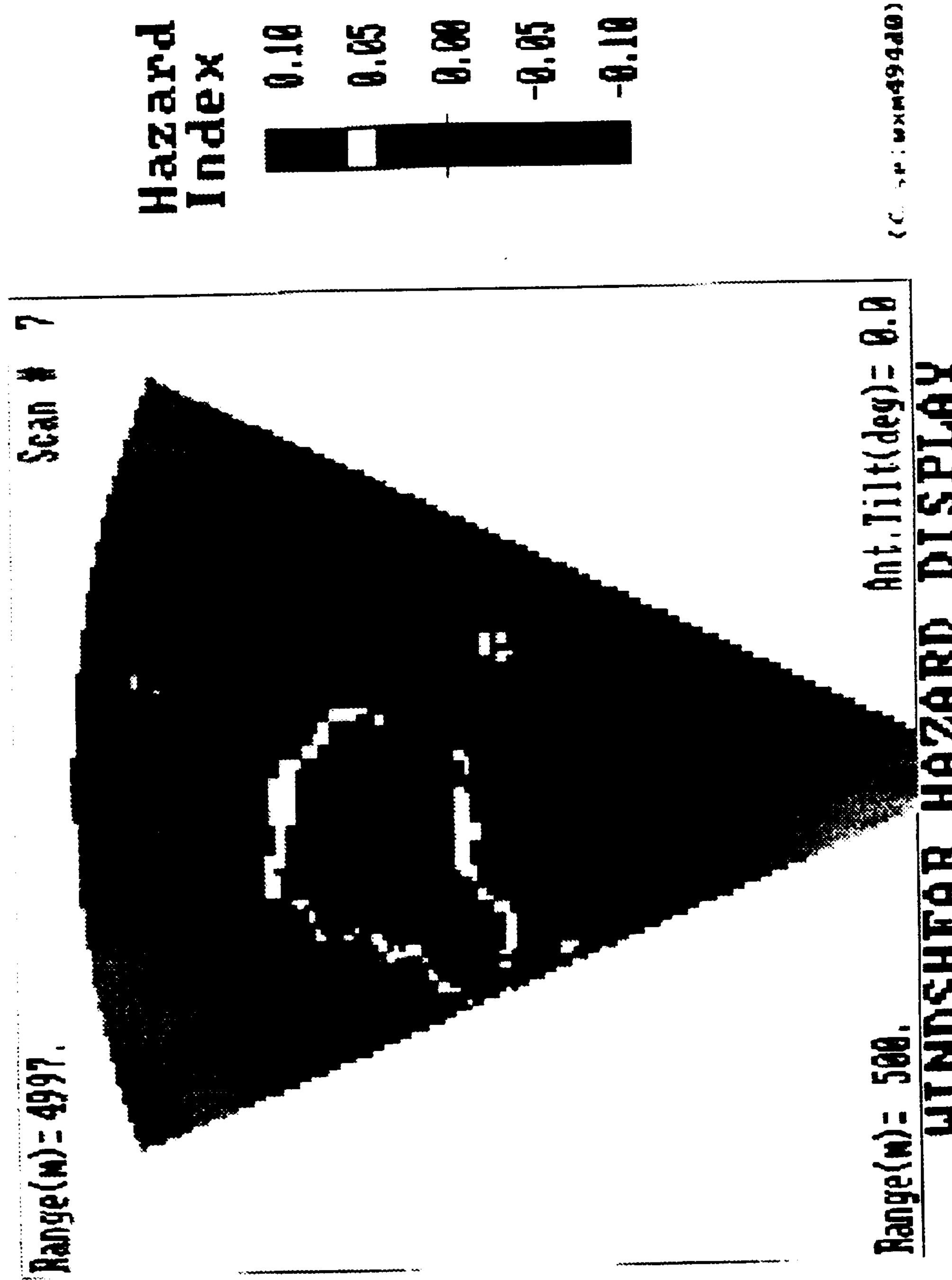

Velocity
(m/s)
30.00
15.00
0.00
-15.00
-30.00
Range(m)= 4997.
Scan #
Range(m)= 500.
Ant.Tilt(deg)= 0.0
WIND VELOCITY DISPLAY

RADAR HAZARD INDEX CONTOUR DISPLAY U-BURST D49; ANTENNA TILT = 0 DEG

Before information is presented to the pilot the radar performs additional data processing to assess the wind shear hazard associated with any wind velocity measurements.

This display shows contours of the horizontal wind shear hazard index associated with the previous wind speed measurements for an antenna tilt of 0 deg. The hazard index relates the effect of wind shear on a loss in A/C performance. It is derived from the spatial rate of change in wind velocity, i.e. wind shear in m/s per m, multiplied by the A/C velocity and divided by the force of gravity. The index is a measure of the spatial wind shear's effect on the A/C performance. Positive indexes indicate a loss of performance on the A/C. Negative indexes will produce a performance increase. If the total index — i.e. sum of the vertical and horizontal component — exceeds a positive .1 over a large area or time interval, severe performance degradation will occur to the A/C and is considered hazardous if encountered at low altitudes. We see from this display, of the horizontal component alone, that a large area of hazardous wind shear exists about 3.3 km in front of the A/C.

It can be noted from the display that very few hazard indexes where generated by the moving ground clutter. The weighted least squares hazard algorithm weighted them out. Unfortunately it also weighted out some of the U-B hazardous area near the center of the U-B. To reduce this problem the antenna must be tilted up. The next two displays show the results of tilting the antenna up by 3 deg.



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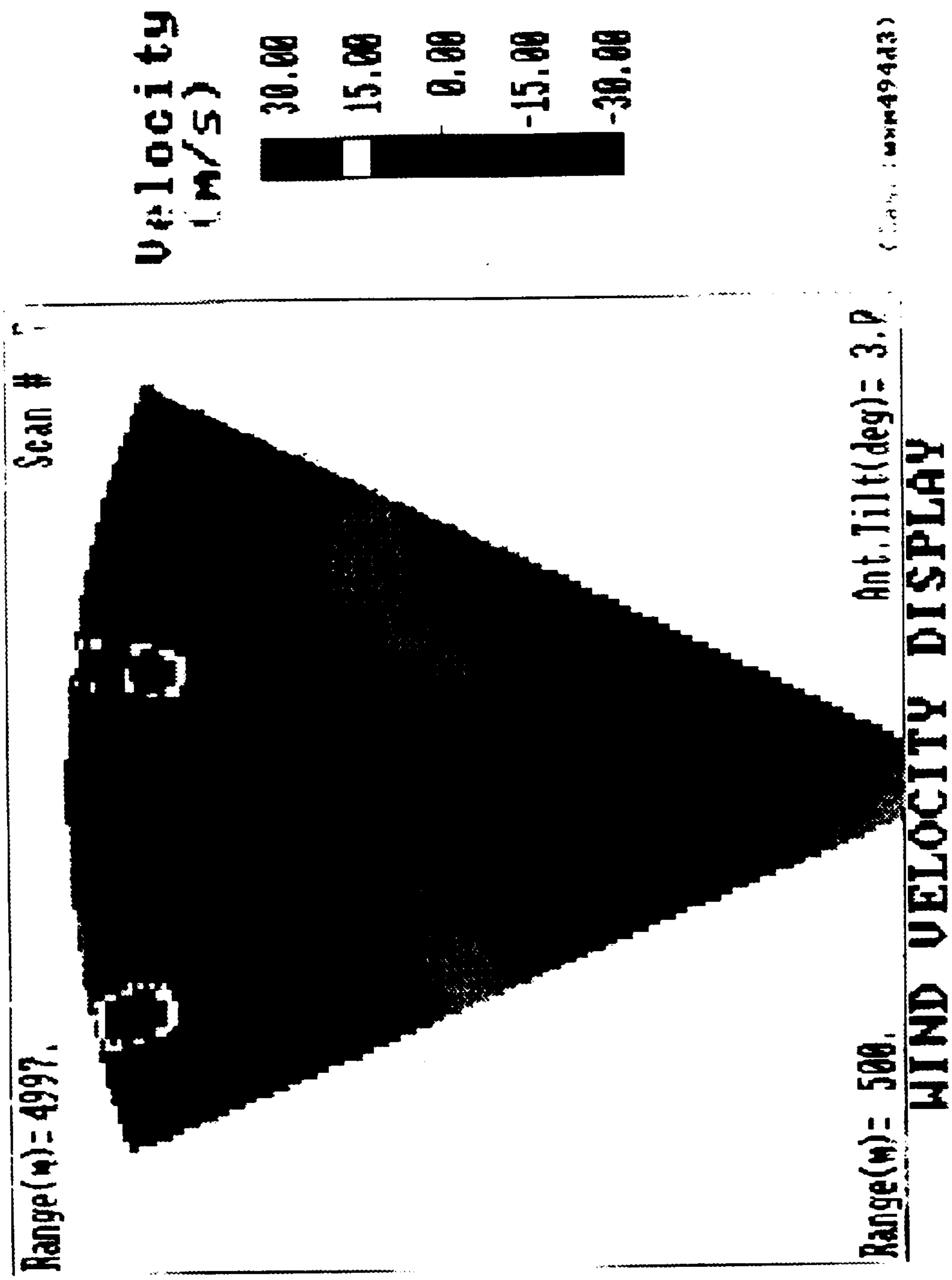
RADAR WIND VELOCITY CONTOUR DISPLAY
U-BURST D49; ANTENNA TILT = 3 DEG

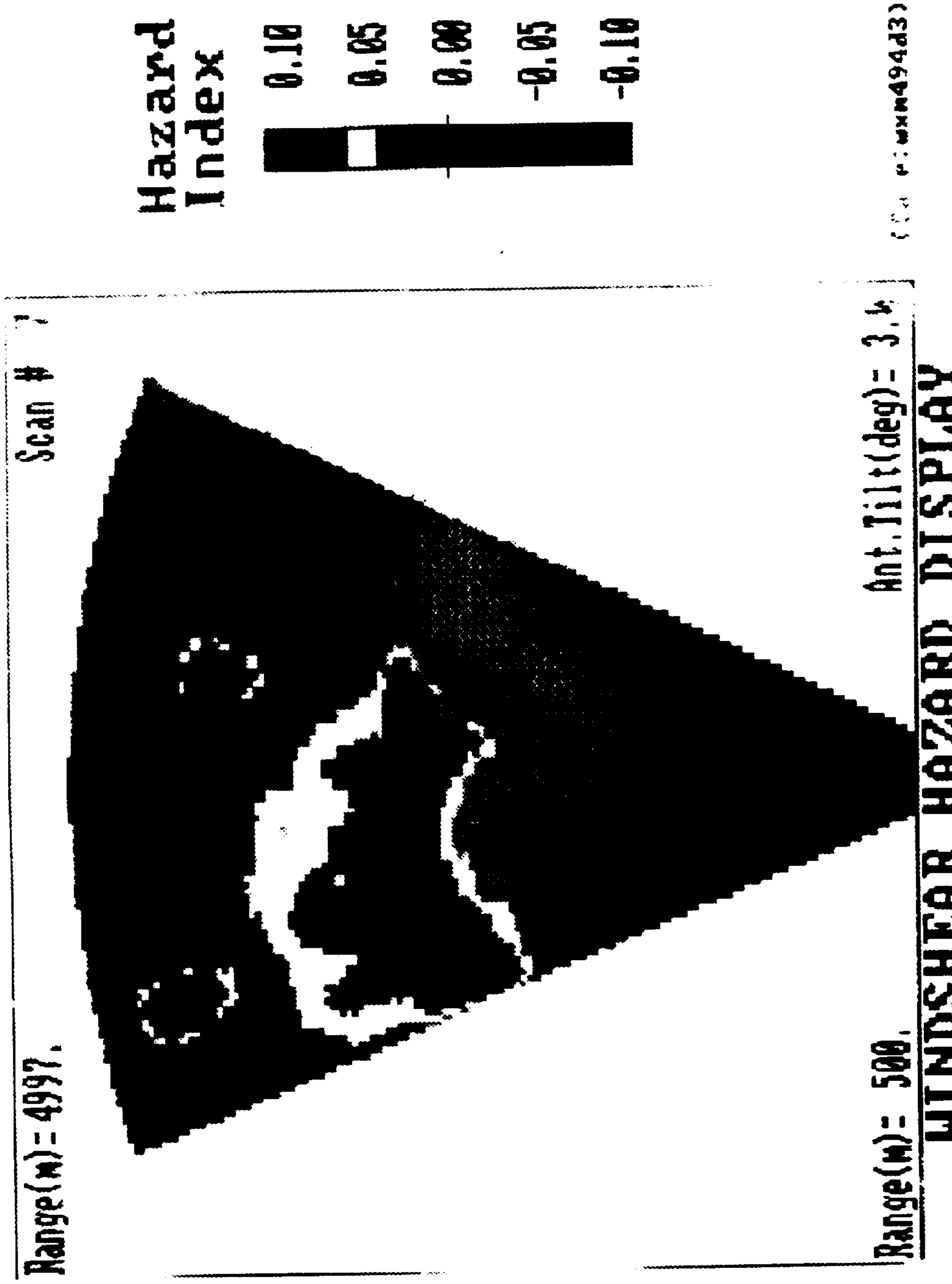
This display shows the velocity contours of U-B D49 at the same time interval as the previous velocity plot. In this case the antenna is tilted 3 deg. above the glide slope. Note, in comparison to the 0 deg tilt case, the significant reduction in the moving ground clutter signatures. Also a larger portion of the U-B velocity signature is discernible. The next figure shows the hazard index display produced by processing this velocity information.


Velocity
(m/s)
30.00
15.00
0.00
-15.00
-30.00
Scan #
Range(m)= 4997.
Range(m)= 500.
WIND VELOCITY DISPLAY

RADAR HAZARD INDEX CONTOUR DISPLAY U-BURST D49; ANTENNA TILT = 3 DEG

This display shows contours of the horizontal wind shear hazard index associated with the previous wind speed measurements for an antenna tilt of 3 deg. In this case a much larger portion of the U-B hazard area is produced. Note that two small hazard areas, near the outer portion of the display, are produced by the moving ground clutter targets that were not removed during the hazard algorithm processing.

After the radar identifies hazardous areas within a scan display it performes additional processing to assesses the size and amplitude of these areas, tracks the hazardous areas, determines if the various thresholds have been exceeded and then provides a shear hazard warning to the pilot. A sample of a shear hazard warning display is shown in the next figure.


Hazard Index
0.10
0.05
0.00
-0.05
-0.10
Scan #
Range(m)= 4997.
Range(m)= 500.
Ant.Tilt(deg)=
WINDSHEAR HAZARD DISPLAY

RADAR SHEAR HAZARD WARNING DISPLAY
U-BURST D49; ANTENNA TILT = VARIABLE

During the simulation run the antenna was continuously scanned as the a/c was progressing along the glide slope. The radar continued to process and evaluate the hazard threat and produced an alarm when the a/c was 40 sec (approx. 3.4 km) in front of the a/c. To minimize the clutter returns the antenna was continuously tilted up from the glide slope, as a function of a/c altitude, keeping the 3 Db point of the main beam hitting the ground 8 km in front of the aircraft.

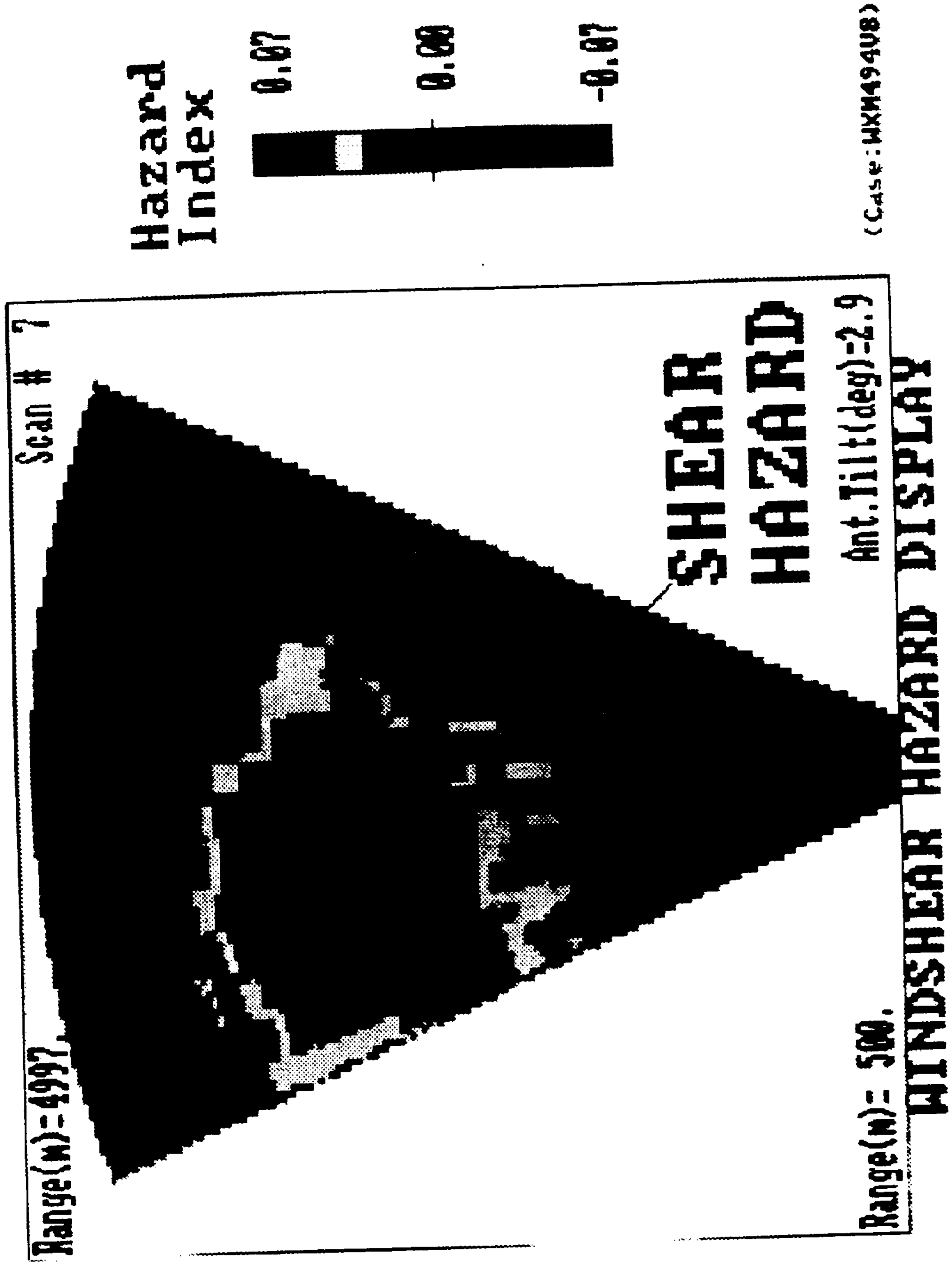
Positive horizontal hazard indices of .07 or larger that occur over an area of .65 square Km (diameter of .9 km or flight time of about 10 seconds) or greater were set as thresholds for defining hazardous areas. The radar tracked the hazardous areas and produced a shear hazard warning display if they occurred within 40 seconds of the A/C's approach.

A sample of this type display is shown in the ajoining figure. The dark gray area in the display, at about 3.3 KM range, with the dark circle indicates a severe hazard area, and a shear hazard warning has been sounded. At this time the pilot should begin his missed approach procedures.

UAL 395 continued its landing approach until it actually entered the U-B before the pilot began his recovery and missed approach procedure. UAL 395 continued descending to 100 ft above ground level before the a/c was able to gain altitude and continue the missed approach procedure.

If UAL 395 had a Doppler radar with wind shear processing capability on board the a/c, the pilot could have executed the missed approach procedure much sooner and avoided the severest part of the storm.

A simuliar set of simulations were conducted on the flight of UAL 236 as it approached U-B D51. A similar warning display was produced by the radar 40 seconds prior to encounter.



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Airborne Radar Simulation Studies of the Denver July 11, 1988 Microburst Questions and Answers

Q: RUSSELL TARG (Lockheed) - At what rain rate does water build up degrade performance of weather radar - red out? How will rain effect wind shear radar?

A: EMEDIO BRACALENTE (NASA Langley) - If the rain rate builds up, of course, we get a much stronger back scatter return signal for the radar to operate on. We also get attenuation, but at these frequencies and over the short ranges we're talking about the back scatter actually increases a little bit faster than we get the attenuation. Over large ranges the attenuation could become critical, if the heavy rain existed over very large portions of the range. When we ran the simulation for the Dallas/Ft. Worth case, which had extremely heavy rains in it, probably in the 8 to 10 inches per hour rate, we saw attenuation which we incorporate in the simulation program. But, it was not sufficient to decrease the back scatter signal. We still had a very strong signal noise ratio. In fact we ran that even up at the KU ban where the attenuation is much heavier and still were able to see through it. So in general, we don't think attenuation of rain rates are going to have an effect. Actually, we prefer to have the rains a little bit heavier because we have a stronger signal to work with. There is the question of heavy rain on the radome and those effects have been addressed off and on. In general the microburst type phenomenon tends to occur in an atmosphere where we're not encountering rain initially. We're looking forward and since we're trying to protect over the 5 to 10 kilometer range we don't think there will be any degradation due to heavy rains. Exactly at what level buildup it would take to completely degrade performance, you're probably talking about extremely heavy rains which probably are up in the tens of inches per hour. They don't usually exist over a very large extent so the attenuation is still going to be small.