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TDWR Scan Strategy Requirements

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16. Abstract

This report describes the requirements for the scan strategy to be employed in the Terminal Doppler Weather Radar (TDWR). The report is divided into three main sections: rationale, example scan strategy and requirements. The rationale for the TDWR scan strategy is presented in terms of 1) detection of meteorological phenomena, and 2) minimization of range and velocity folding effects. Next, an example is provided based on an experimental scan strategy used in Denver during the summer of 1987. Finally, the requirements for the TDWR scan strategy are presented based on the preceding discussion. Also, an appendix is included describing the proposed criteria for switching between scan modes.

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Contents

	Page
1.0 Introduction	1
2.0 Rationale	1
2.1 Detection of Meteorological Phenomena	1
2.1.1 Microbursts	1
2.1.1.1 Surface Divergence	1
2.1.1.2 Features Aloft	2
2.1.2 Gust Fronts	3
2.1.2.1 Surface Convergence	3
2.1.2.2 Wind Shift Estimation	4
2.2 Minimization of Range and Velocity Folding	4
2.2.1 Range Unfolding	4
2.2.2 Velocity Dealiasing	4
3.0 Example Scan Strategy	5
3.1 Monitoring Mode	5
3.2 Hazardous Weather Detection Modes	5
3.2.1 Off-airport Scan	8
3.2.2 On-airport Scan	11
4.0 Requirements	11
4.1 Scan Sequencing Capabilities	11
4.2 Monitoring Mode	11
4.3 Off-airport Hazardous Weather Detection Mode	14
4.4 On-airport Hazardous Weather Detection Mode	14
4.5 Timing Tolerances	14
5.0 Summary	14

Contents (con't)

	Page
References	15
Appendix A. Proposed Scan Mode Selection Criteria	16

Illustrations

		Page
Figure 3-1.	FL-2 sector scan for Stapleton airport (Denver).	6
Figure 3-2.	Scans aloft for FL-2 off-airport hazardous weather detection mode.	10
Figure 3-3.	Scans aloft for FL-2 on-airport hazardous weather detection mode.	13

Tables

Table 3-1.	FL-2 Monitoring Mode.	7
Table 3-2.	FL-2 off-airport hazardous weather detection mode.	9
Table 3-3.	FL-2 on-airport hazardous weather detection mode.	12

TDWR Scan Strategy Requirements

1.0 Introduction

The report describes the requirements for the scan strategy to be employed in the Terminal Doppler Weather Radar (TDWR). The report is divided into three main sections: rationale, example scan strategy and requirements. The rationale for the TDWR scan strategy is presented in terms of 1) detection of meteorological phenomena, and 2) minimization of range and velocity folding effects. Next, an example is provided based on an experimental scan strategy used in Denver during the summer of 1987. Finally, the requirements for the TDWR scan strategy are presented based on the preceding discussion. Also, an appendix is included describing the proposed criteria for switching between scan modes.

2.0 Rationale

The TDWR scan strategy must be designed to accomplish two objectives. The first objective is to detect hazardous meteorological phenomena, and the second objective is the minimization of range and velocity folding effects. The impact of these objectives on scan strategy will now be explored. Two TDWR siting options will be considered: on-airport and off-airport. On-airport siting requires the use of 360 degree scans only, while off-airport siting allows the primary use of sector scans.

2.1 Detection of Meteorological Phenomena

The TDWR is required to detect the meteorological phenomena of microbursts and gust fronts. the different requirements on the scan strategy that emerge for each phenomenon will be described.

2.1.1 Microbursts

Microbursts are rapidly developing, short-lived events characterized by divergent wind shears near the surface. The primary requirement for TDWR with respect to microbursts is the reliable and timely detection of these surface outflows. A secondary requirement is the detection of features aloft to aid detection reliability and timeliness.

2.1.1.1 Surface Divergence

The TDWR must be able to detect microbursts within the region 6 nm (11 km) from the airport reference point (ARP), as specified in the TDWR System Requirements Statement [1]. In particular, all microburst outflows below 1500 ft (500 m) must be detected within this region. This requirement is also compatible with the recommendations of the TDWR User Working Group [2].

In order to scan the surface outflow adequately, the vertical beam size should be no larger than 300 m at the limit of the coverage region. For a vertical beamwidth of 0.5 degrees, this implies that the far edge of the coverage region should be no more than 34 km from the radar. Thus, for the off-airport option the radar should be located no further than 23 km from the airport reference point.

For the purposes of subsequent discussion, it will be assumed that the off-airport location is 18 km from the ARP, so that the limits of the coverage region are 7 km to 29 km range. If a 1 km buffer region is assumed at each edge of the sector scan, then the minimum size of sector scan covering the terminal region is approximately 90 degrees (2 x arc sin 13/18).

Microburst outflows evolve rapidly, so it is necessary to perform frequent surface scans. Since microbursts typically reach maximum intensity within 5 minutes from the onset of surface outflow, the surface scans should be repeated once per minute in order to capture the peak outflow and to allow trend computation.

2.1.1.2 Features Aloft

In addition to surface outflow detection, it is also desirable to scan aloft for microburst features. It has been shown for Denver microbursts that features develop aloft prior to the onset of surface outflow [3]. The kinds of features aloft observed depend on the type of microburst event and its stage of development. Denver microbursts have been classified as low, moderate and high reflectivity events, and conceptual models for the evolution of each type of event have been developed [4]. Field experience with microbursts recorded in the Southeast has been generally compatible with the Denver models for moderate and high reflectivity events.

Based on these observations, it has been found that microburst features aloft develop prior to the onset of surface outflow. In a typical scenario for a moderate reflectivity event, a reflectivity core develops in a storm cell at the 6 km level. Concurrently, convergence develops at about the same altitude. In the next stage, the reflectivity core begins to descend, and convergence and/or rotation may develop near the 3 km level. In initial, weak surface outflow may now be observed at this stage. In the third stage, the reflectivity core reaches the surface and the surface outflow reaches peak intensity. The outflow then subsequently declines in intensity and dissipates within the next five minutes.

Microburst features aloft typically precede the initial surface outflow by about 10 minutes. The presence of microburst features aloft can be used in two ways to improve microburst detection. First, detection of a microburst feature aloft such as a descending core accompanied by convergence or rotation aloft can be used to provide an early declaration of the microburst hazard while the surface outflow is still in the early, weak stage of development.

Second, the detection of features aloft can be used to increase the reliability of microburst detection. The presence of features such as storm cells, reflectivity cores, convergence aloft, rotation aloft and divergent tops can be used to determine whether a marginal surface divergence signature represents an actual microburst outflow.

An additional reason for performing scans for features aloft is to facilitate automated scan mode selection. The ability to detect features aloft such as precipitation cells is necessary for automatic switching between scan modes for monitoring and hazardous weather detection to be discussed later.

In order to reliably detect microburst features aloft, the TDWR thus should scan to the 6 km level over the entire terminal area. Also, in order to ensure that features do not fall between the elevation scans, the worstcase scan-to-scan vertical spacing should not exceed 1 km. Furthermore, the update rate for completing a sequence of scans aloft should be such that a descending reflectivity core can be reliably detected. It has been found empirically that reflectivity cores descend at a rate which does not normally exceed 1 km/minute. A reflectivity core descending from the 5 km level would therefore require about 5 minutes to reach the surface. Thus, a scan sequence aloft which repeated in 2.5 minutes should scan a descending core twice before it reached the surface.

Note that the sequence of scans aloft should be performed in order of increasing elevation angle. Ordering the scans aloft in this fashion ensures that a descending reflectivity core will be unambiguously detected. A scan using decreasing elevation angles could potentially miss a descending core for an entire cycle by scanning just below the core as it descended.

2.1.2 Gust Fronts

Gust fronts are large scale, low reflectivity events associated with a line-like convergence signature extending to about 1.5 km above the surface [5]. The gust front convergence is often associated with a substantial shift in the environmental winds. These wind shifts can have a major impact on airport operations [6,7].

The key considerations for gust fronts are the detection of the surface convergence signature, and estimating the wind shift magnitude and time of arrival in the terminal area.

2.1.2.1 Surface Convergence

Since gust fronts are large scale events, often tens of kilometers in length it is necessary to use 360 degree scans to detect them. Also, it has been found that reliable gust front detection requires the use of two scans at different elevation angles, typically 0.5 and 1.0 degrees. The convergence signatures from the two elevation scans are correlated vertically to help reject spurious signatures.

2.1.2.2 Wind Shift Estimation

Once a gust front is recognized, it is tracked on subsequent volume scans so that the arrival time in the terminal area can be predicted. The TDWR is required to generate a 20 minute warning of impending wind shifts. In order to do this, the TDWR must begin tracking the gust front at a sufficient distance such that the warning can be generated in time.

Assume that gust front move at a maximum speed of 20 m/s (72 km/hr), the gust front scans are repeated every five minutes and that the gust front must be recognized twice in order to establish a reliable arrival estimate. Under these assumptions, the gust front will travel 6 km between the first and second detections, and 24 km in the next 20 minutes to reach the terminal area. The total distance traveled in 25 minutes is therefore 30 km.

Thus, the gust front must be detected at a range of 30 km for the on-airport option and at 59 km for the off-airport option (assuming the worst-case of the gust front on the far edge of the terminal region, i.e. at 29 km range).

2.2 Minimization of Range and Velocity Folding

The scan strategy must also make provision for techniques to minimize range and velocity ambiguities.

2.2.1 Range Unfolding

The TDWR must minimize range folding and be able to flag radar returns which are range folded. An algorithm has been developed which selects a PRF value which minimizes range aliasing [8]. The algorithm employs a 360 degree scan performed at a low PRF to obtain a large unambiguous range. By comparing the returns from this low PRF scan with other scans, an optimum PRF can be selected to minimize range aliased returns. Any folded returns which remain after application of the optimum PRF are flagged. Different PRF values are computed for the microburst surface outflow and gust front scans. At present, it appears that the low PRF scan should be repeated once every five minutes.

2.2.2 Velocity Dealiasing

The TDWR must provide unambiguous velocity measurements over the range from +40 m/s to -40 m/s. This wide range of velocities is required to account for microburst outflows with differential velocities as large as 75 m/s. Since no simple selection of radar parameters can achieve this velocity range, it may be necessary to make measurements for surface scans at more than one PRF, and use the redundancy of these measurements to estimate the true velocity. Scan time has therefore been allotted to perform each surface scan twice, to allow for this possibility.

3.0 Example Scan Strategy

A specific example of an experimental scan strategy will now be presented. This scan strategy was implemented for operation by the FL-2 radar at Denver, CO during the summer of 1987. The FL-2 radar is an S-band radar located in an off-airport configuration approximately 15 km to the southeast of Stapleton International airport, shown in Fig. 3-1. As seen in the figure, the microburst detection region was considered to be the area between 7 km and 23 km range. The gust front detection region was considered to be the region within 72 km of the radar.

Three scan modes will be described. The monitoring mode was used when no significant weather returns were present within 30 km range from the radar. The off-airport hazardous weather detection mode was used when weather returns were present within 30 km range. The on-airport hazardous weather detection mode was used for microburst events within 6 km from the radar.

3.1 Monitoring Mode

The monitoring mode is modified NEXRAD scan sequence lasting five minutes. The only modification was to append a low PRF scan to the end of the sequence. This mode consists entirely of 360 degree scans operating in the same direction (clockwise or counter-clockwise) in order to minimize acceleration forces on the pedestal. The scan sequence is shown in Table 3-1.

The decision to use full 360 degree azimuthal scans is based on the desire to minimize the accelerations required by the antenna pedestal, and to allow the same surveillance scanning program to be used in both on-airport and off-airport scenarios. Note that the primary purpose of the information collected in the surveillance mode is to detect the onset of significant precipitation in the terminal area.

3.2 Hazardous Weather Detection Modes

The FL-2 radar is operated primarily in the off-airport hazardous weather detection mode to provide surveillance of Stapleton airport. The on-airport mode was used when microburst events approached within 6 km of the radar.

The assumptions used in designing the hazardous weather detection scans were as follows:

- Azimuthal velocity and acceleration:

  30 deg/s maximum azimuthal velocity

  15 deg/s^2 maximum azimuthal acceleration

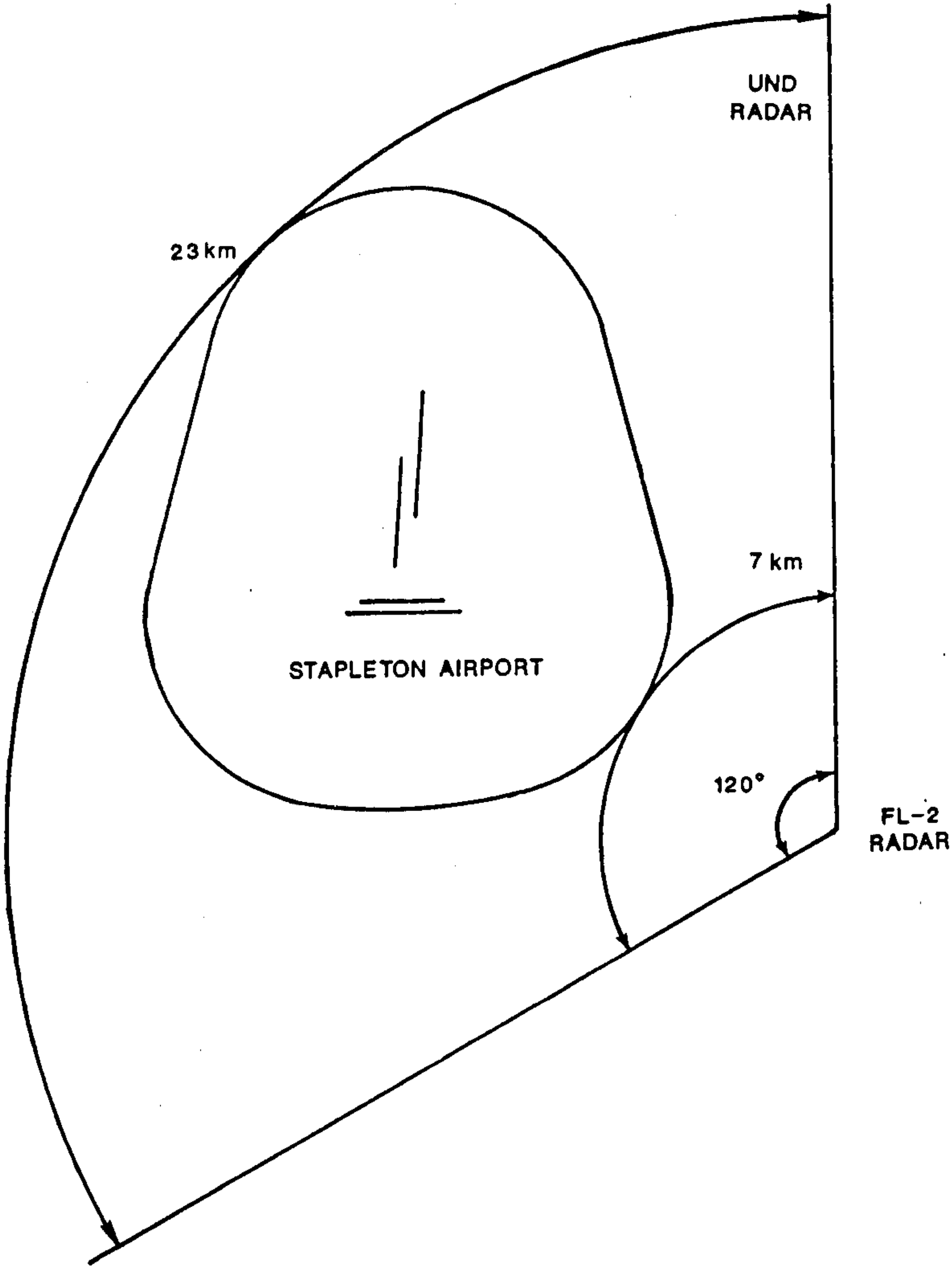

Figure 3-1. FL-2 sector scan for Stapleton Airport (Denver).

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Table 3-1. FL-2 Monitoring Mode.

Tilt	Elev. deg	PRF Hz	Azim. deg	Max. Range km	Speed deg/s	Time sec	Purpose
1	0.5	1000	360	96	14	26	Wind shift/gust front /MB outflow
2	1.2	"	"	"	"	26	Wind shift/gust front
3	2.2	"	"	"	"	26	Precip. detection
4	3.2	"	"	"	15	24	" "
5	4.3	"	"	"	"	24	" "
6	5.4	"	"	"	"	24	" "
7	6.5	"	"	"	"	24	" "
8	7.8	"	"	"	"	24	" "
9	9.1	"	"	"	24	15	" "
10	10.5	"	"	"	"	15	" "
11	12.1	"	"	"	"	15	" "
12	13.8	"	"	"	"	15	" "
13	15.8	"	"	"	"	15	" "
14	18.0	"	"	"	"	15	" "
15	0.4	350	"	432	"	15	Low PRF
	Total					300 sec	

Note: all scans are performed in the same direction (clockwise or counter-clockwise).

- Elevational velocity and acceleration:

  15 deg/s maximum elevational velocity

  15 deg/s^2 maximum elevational acceleration

- Maximum elevation angle: 60 degrees

The FL-2 radar has range gate sizes specifiable in 120 m increments.

3.2.1 Off-airport Scan

The off-airport hazardous weather detection scan was defined as shown in Table 3-2. This scan strategy ws designed to accomplish the following timing goals:

- gust front scans every five minutes
- low PRF scan every five minutes
- scan aloft sequence completed every 2.5 minutes.

Note that the scan sequence assumes that the lower of the two gust front scans is also used as a microburst surface outflow scan. The scan aloft sequence accomplishes a complete scan of the region between 7 km and 26 km up to 6 km altitude with worst-case intertilt spacing of 1 km, as shown in Fig. 3-2. The maximum elevation angle is 40 degrees for the scan sequence.

In order to maximize recording of microburst events, the sector size was 120 degrees rather than the 90 degree minimum size needed to scan the terminal area. Also, the maximum of azimuthal velocity used was 25 deg/sec rather than 30 deg/sec. Accounting for acceleration an deceleration the 120 degree sector takes 6.5 seconds to scan at 25 deg/sec whereas the 105 degree sector takes only 5.5 seconds at 30 deg/sec. Since there are 30 sector scans in the sequence, the total time required would be 30 seconds less over the five minute sequence. There would be an additional reduction in scan time for each of the three 360 degree scans from 16 to 14 seconds. The total time gained would be 36 seconds.

If it were necessary to use the dual-PRF method for scanning the surface scans for microburst detection, the additional time would allow the extra five surface scans to be inserted into the sequence without increasing the total time beyond five minutes. The extra time required would be 36 seconds (14 + 4 x 5.5). If the dual-PRF method is not required, then additional scans aloft could be inserted into the scan sequence to further decrease the interscan spacing.

An important consideration which emerges from the design of the scan sequence is that the scan direction must be controllable for each elevation scan. That is, the usual practice of assuming that the elevation scans will either all be in the same direction or strictly alternating is not adequate for the TDWR application.

Table 3-2. FL-2 Off-airport Hazardous Weather Detection Mode.

Tilt	Elev. deg	PRF Hz	Azim. deg	Max. Range km	Speed deg/s	Time sec	Purpose
1	0.4	1000	360	72	+25.0	16	Wind shift/gust front / MB outflow
2	2.2	"	120	48	+ "	8	Features aloft
3	4.5	"	"	"	- "	8	" "
4	6.7	"	"	"	+ "	8	" "
5	8.8	"	"	"	- "	8	" "
6	11.0	"	"	"	+ "	8	" "
7	13.1	"	"	"	- "	8 (64)	" "
8	0.2	"	"	"	+ "	8	MB outflow
9	1.0	"	360	72	- "	16	Wind shift/gust front
10	15.6	"	120	48	- "	8	Features aloft
11	18.6	"	"	"	+ "	8	" "
12	21.9	"	"	"	- "	8	" "
13	25.8	"	"	"	+ "	9 (57)	" "
14	0.2	"	"	"	- "	9	MB outflow
15	30.1	"	"	"	+ "	8	Features aloft
16	34.8	"	"	"	- "	8	" "
17	39.9	"	"	"	+ "	10	" "
18	2.2	"	"	"	- "	8	" "
19	4.5	"	"	"	+ "	8	" "
20	6.7	"	"	"	- "	8 (59)	" "
21	0.2	1000	120	"	+ "	8	MB outflow
22	0.5	350	360	432	- "	15	Low PRF
23	8.8	1000	120	48	- "	8	Features aloft
24	11.0	"	"	"	+ "	8	" "
25	13.1	"	"	"	- "	8	" "
26	15.6	"	"	"	+ "	9 (56)	" "
27	0.2	"	"	"	- "	9	MB outflow
28	18.6	"	"	"	- "	8	Features aloft
29	21.9	"	"	"	- "	8	" "
30	25.8	"	"	"	+ "	8	" "
31	30.1	"	"	"	- "	8	" "
32	34.8	"	"	"	+ "	8	" "
33	39.9	"	"	"	- "	10 (59)	" "
Total						295 sec	

Notes:

Scan provides 1 km maximum intertilt spacing for 7 to 26 km range.

Direction of scan is indicated by sign (+ = clockwise).

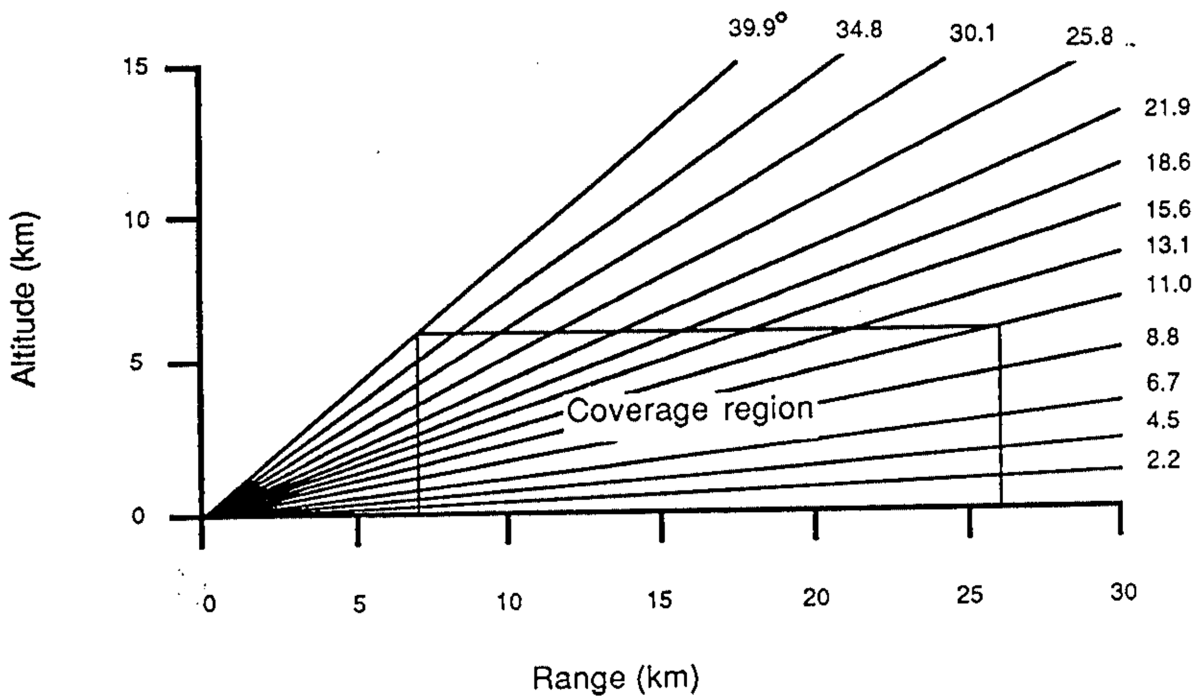

Figure 3-2. Scans aloft for FL-2 off-airport hazardous weather detection mode.

3.2.2 On-airport Scan

The on-airport hazardous weather detection mode for FL-2 is shown in Table 3-3. The rationale for this scan is to provide a worst-case inter-tilt spacing of 1 km below 2.5 km AGL (above ground level) and above 0.5 km AGL between ranges of 1.4 and 11.1 km from the radar, as shown in Fig. 3-3. This scan requires a maximum elevation angle of 60 degrees. Because of this very large elevation angle, the velocity measurements may be difficult to interpret. However, the main reason for using such a high elevation angle is to detect a descending reflectivity core close to the radar.

4.0 Requirements

This section prescribes the TDWR scanning requirements, based on the design rationale and example scan strategy presented in the previous sections.

4.1 Scan Sequencing Capabilites

A number of automatic scanning programs shall be provided. These programs may be dynamically selected by the appropriate scanning strategy procedure. For all scanning programs, the parameters of the program (i.e., scan speed, elevation angles and order of execution within the program) shall be site-adaptable.

The set of scanning programs to be used shall vary with the location of the radar with respect to the airport. A radar installation sites within 5 km of the airport shall be referred to as an ON-AIRPORT site; radars sited further from the airport as OFF-AIRPORT sites.

For each site type, there shall be two primary scanning modes: monitoring mode and hazardous weather detection mode. The monitoring mode shall be used at times when there are no significant weather echoes within 45 km of the airport, otherwise the detection mode shall be used. The selection of the appropriate scanning mode shall be determined based on the proposed criteria described in appendix A.

The general characteristics of the monitoring mode are the same for both types of radar sites, while the hazardous weather detection modes are different. The characteristics of these three different modes are described below.

4.2 Monitoring Mode

In the monitoring mode, the antenna shall perform complete (i.e., 360 degree) azimuthal scans at various elevation angles. Within a scan period of at most 5 minutes, up to 15 azimuthal scans including the base elevation shall be performed at unique elevation angles up to maximum of 60 degrees elevation. Scan speeds shall be chosen at each elevation angle to be compatible with the stated requirements for base product estimate accuracy.

Table 3-3. FL-2 On-airport Hazardous Weather Detection Mode.

Tilt	Elev. deg	PRF Hz	Azim. deg	Max. Range km	Speed deg/s	Time sec	Purpose
1	0.4	1000	360	48	25.0	15	Wind shift/gust front / MB outflow
2	1.2	"	"	"	"	16	Wind shift/gust front
3	7.6	"	"	"	30.0	13	Features aloft
4	12.6	"	"	"	"	14 (58)	" "
5	0.2	"	"	"	25.0	17	MB outflow
6	20.5	"	"	"	30.0	14	Features aloft
7	31.9	"	"	"	"	14	" "
8	46.1	"	"	"	"	16 (61)	" "
9	0.2	"	"	"	25.0	19	MB outflow
10	60.0	"	"	"	30.0	17	Features aloft
11	7.6	"	"	"	"	13	" "
12	12.6	"	"	"	"	14 (63)	" "
13	0.2	"	"	"	25.0	15	MB outflow
14	0.5	350	"	432	"	17	Low PRF
15	20.5	1000	"	48	30.0	14	Features aloft
16	31.9	"	"	"	"	15 (61)	" "
17	0.2	"	"	"	25.0	18	MB outflow
18	46.1	"	"	"	30.0	14	Features aloft
19	60.0	"	"	"	"	15 (47)	" "
	Total					290 sec	

Notes:

Scan provides 1.0 km worst-case intertilt spacing between 0.5 and 2.5 km AGL for ranges from 1.4 to 11.1 km from radar.

All scans are performed in the same direction (clockwise or counterclockwise).

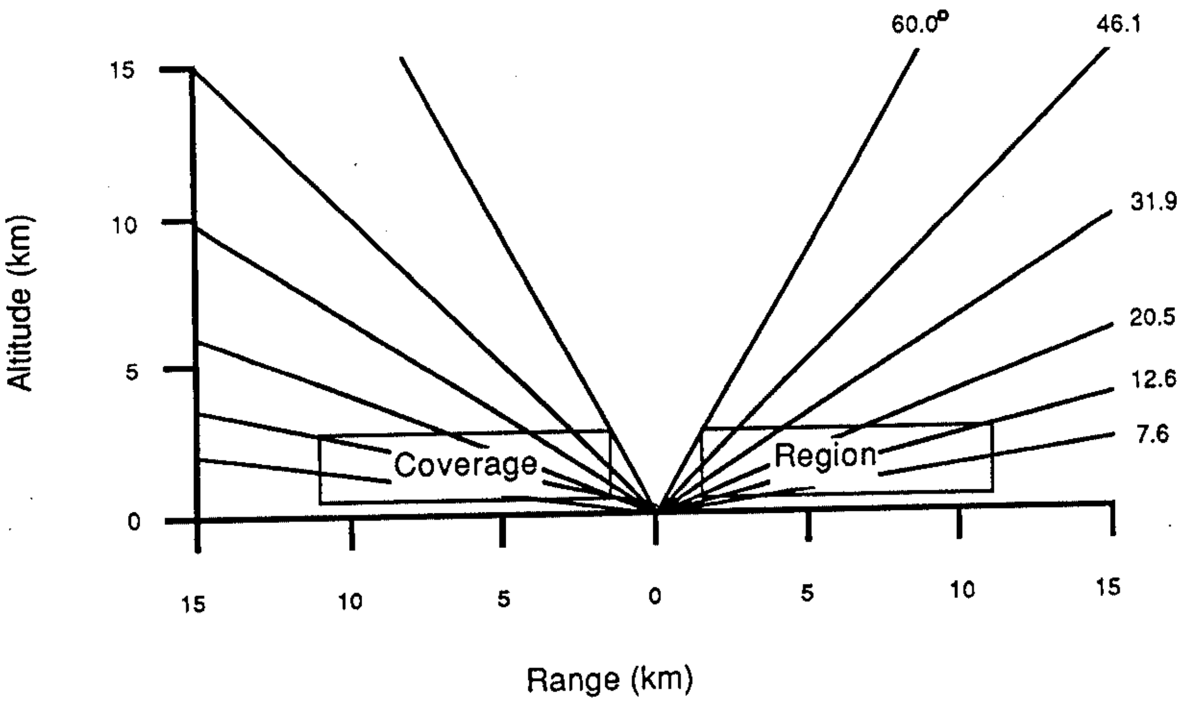

Figure 3-3. Scans aloft for FL-2 on-airport hazardous weather detection mode.

4.3 Off-airport Hazardous Weather Detection Mode

In the off-airport scanning mode, the antenna shall perform a mixture of scan types, designed to optimize the observation of significant meteorological features in the terminal area. Full 360-degree azimuthal scans shall be performed at the surface and at a low elevation angle (e.g., 1.0 degrees) at least once every 5 minutes. An additional 360-degree azimuthal scan at low PRF shall be performed at the surface every 5 minutes.

The remaining azimuthal scans shall be sector scans covering 90 to 120 degree sectors centered on the airport. These sector scans shall be performed in a site-adaptable sequence, and shall contain a surface sector scan at least once every minute, with a total of at least 26 non-surface sector scans performed every 5 minutes. In the event that dual-PRF surface sector scans are necessary to achieve the unambiguous velocity requirements, the maximum sector size may be limited to 105 degrees. The elevation angles for azimuthal sector scans aloft shall be site-adaptable, and will provide coverage to a maximum of 40 degrees elevation.

4.4 On-airport Hazardous Weather Detection Mode

In the on-airport scanning mode, the antenna will perform a sequence of full 360 degree azimuthal scans. A total of 19 scans shall be performed in five minutes, with one scan at the surface every minute. One of the remaining scans shall be a surface scan a low PRF and another shall be at a low elevation angle (e.g. 1.0 degrees). The remaining scans shall be site-adaptable and shall be placed at elevation angles up to a maximum of 60 degrees elevation.

4.5 Timing Tolerances

Any five minute interval specified in sections 4.2 - 4.4 is the maximum allowed time. For one minute intervals between surface scans specified in sections 4.3 - 4.4, the time between the ends of surface scans must average 60 seconds or less over the five minute scan period, and adjacent scans must be no less than 54 seconds or no greater than 66 seconds apart.

5.0 Summary

This project report has described the rationale for the scan strategy to be employed by the Terminal Doppler Weather Radar in terms of the meteorological phenomena to be detected and the minimization of range and velocity folding. An example of an experimental scan strategy employed by the FL-2 radar in Denver during the summer of 1987 was then presented. Finally, the requirements for the TDWR scan strategy were presented for off-airport and on-airport sites based on these considerations.

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Appendix A. Proposed Scan Mode Selection Criteria

The TDWR must automatically switch between two scan modes: monitoring mode and hazardous weather detection mode. The monitoring mode is used when there are no significant weather returns within 45 km of the airport, otherwise the hazardous weather detection mode is selected. Because the TDWR is designed for unsupervised operation, the selection of the appropriate scan mode must be an automated procedure based on a set of criteria. A proposed set of scan selection criteria are presented in this appendix.

The criteria for significant weather shall be the presence of one or more of the following, within 45 km from the airport and, for off-airport TDWR sites, within a 120 degree sector centered on the airport:

- a microburst declaration or
- a gust front declaration or
- a reflectivity feature with maximum reflectivity of at least 20 dBZ at or above 2.0 km AGL (above ground level).

Whenever one or more of these criteria are satisfied, then the significant weather condition shall be declared. When the significant weather condition is declared, the scan mode shall switch to hazardous weather detection mode upon completion of the current monitoring scan.

The hazardous weather detection mode shall remain selected until the significant weather condition remains false for one entire hazardous weather detection mode scan. The monitoring mode shall then be selected for scan following the next scan, unless the significant weather condition becomes true during the next scan.