# RTCA Special Committee 186

## Working Group 4B

## Airborne Surveillance and Separation Assurance Processing

## Meeting #15

**RTCA, Washington, D.C.**
**May 15-18, 2007**

# EXCERPT FOR SELECT TIS-B REQUIREMENTS
## Provided to ASSAP MOPS Group

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**MITRE / CAASD**

The attached document is an excerpt of requirements for the TIS-B uplink service being procured by FAA. While there are major differences in objectives between ASSAP functions and the functions needed of a radar tracking system used to generate TIS-B reports, this material is offered to show the basic requirements philosophy. Of particular interest may be the test approach and the fact that a highly specified test stimulus is also included.

# U.S. Department of Transportation

# Federal Aviation Administration

# Surveillance and Broadcast Services Program

# Traffic Information Service – Broadcast (TIS-B) /Flight Information Service - Broadcast (FIS-B) Essential Services Specification

EXCERPT FOR SELECT TIS-B REQUIREMENTS
Provided to ASSAP MOPS Group
14 May 2007

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# 1 Introduction

# 2 Applicable Documents

# 3 Requirements

## 3.1 Definitions

## 3.2 Functional Requirements

## 3.3 Performance Requirements

### 3.3.1 General Requirements

### 3.3.2 TIS-B Service

#### 3.3.2.1 xxx

#### 3.3.2.2 xxx

#### 3.3.2.3 xxx

#### 3.3.2.4 xxx

#### 3.3.2.5 xxx

#### 3.3.2.6 xxx

#### 3.3.2.7 xxx

#### 3.3.2.8 xxx

#### 3.3.2.9 xxx

#### 3.3.2.10 Broadcast Services Processing

##### 3.3.2.10.1 TIS-B Track Initiation

a. The TIS-B Service **shall [E166]** have a TIS-B track initiation delay that is less than or equal to 2 measurements for ADS-B and multilateration targets; 3 measurements for discrete beacon-reinforced targets (95%); 5 measurements for non-discrete beacon-reinforced targets (95%); and 5 measurements for beacon-only without 2nd-sensor confirmation (95%).

***Notes:***

1. *This effectively puts a bounding constraint on the track initiation time period. The Probability of Detection (Pd) is assumed to be 1 for all sensors used in the scenarios with which this requirement will be tested.*

2. *Beacon-reinforced targets may not be real. It is quite possible for beacon false-targets to have radar reinforcement via radar clutter.*

#### 3.3.2.10.2 TIS-B Track Accuracy

The TIS-B Service performance requirements for airborne track accuracy (i.e., for position, heading, speed, and altitude) have been derived from operational FAA tracking systems.

The airborne accuracy requirements are specified for two principal sensor configurations of three sensors, four types of simulation flight paths (radial, tangential, turning, and linearly accelerating), four speeds, and different ranges from the central sensor. The sensor types selected for these requirements are long and short range radars with ATCBI-5 with error characteristics as shown in Appendix A, Table A-3-3.

Table 3-1 contains the performance requirements for both the short range and long range cases.

In Table 3-1, when two values are provided in a cell, the requirement must be interpreted as follows. The value in parentheses represents the requirements for the track when multiple sensors contribute to the track. The value outside the parentheses is the requirement for the single sensor track. Under the “range” column the case number provided in parentheses indicates which flight scenario, defined in Appendix A, Figures A-3 and A-4, provided the multisensor track requirements. The case numbers are assigned to the radials with respect to the central sensor and are used (sometimes in conjunction with the range parameter) to identify a specific flight scenario within each figure.

**Table 3-1. Requirements for Track Accuracy**

| Central Sensor | Flight Path | Speed (kts) | Rng. (nm) | Position Error (nm) | | Heading Error (°) | | Speed Error (kts) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Peak RMS Position Error | Mean Position Error | Peak RMS Heading Error | Mean RMS Heading Error | Peak RMS Speed error | Mean RMS Speed error |
| Short Range Sensor (ATCBI-5) | Linear Acceleration† | 650->250->650 | Center | 0.4 | | 13 | | 37 | |
| | | | All | 0.6 | | 19 | | 60 | |
| | 180° | 100 | 48 | 0.4+ | | 97 (70+) | | 20 (10+) | |
| | | 250-700 | (case 3) | 0.4+ | | 32 (30+) | | 20 (10+) | |
| | Radial | 100 | (case 2) | | 0.1# | | 7 (2#) | | 5 (4#) |
| | Tangential | 100 | | | 0.1# | | 5 (5#) | | 9 (7#) |
| Long Range Sensor (ATCBI-5) | Linear Acceleration† | 650->250->650 | n/a | 0.5 | | 13 | | 60 | |
| | 90° turn | 100-700 | 84 | 1.1 (0.4+) | | 70 (38+) | | 60+ | |
| | Radial | 100-700 | 100 | | 0.5 | | | | 11 |
| | Tangential | 100-700 | | | 0.4 | | 7 | | 15 |

***Notes for Table 3-1:***

1. *Table symbology:*

   *† These scenarios were generated and the values in this table are based on best engineering judgment.*

   *+ These multisensor cases use existing scenarios (because they are not spatially distributed).*

   *# These multisensor cases use a single target path from existing scenarios and are run multiple times through the standalone filter algorithm, with independent noise generated each time (i.e., run Monte Carlo iterations).*

2. *All sensor measurements include a 0.1 measurement standard deviation uncorrected registration error in both range and azimuth (e.g., for sensor with range accuracy, $\sigma_r$ = 125 feet the bias in range, $b_r$, would be 12.5 feet, and bearing accuracy, $\sigma_\theta$ =0.25 degrees, the bias in azimuth, $b_\theta$, would be 0.025 degrees). The bias error can be either added to the truth data as is done for the random error range and azimuth.*

### 3.3.2.10.2.1 Horizontal Position

a. The TIS-B Service **shall [E167]** provide target data with horizontal position accuracy better than 30 meters (98 feet) with a 95% probability for aircraft on the airport surface.

b. The TIS-B Service **shall [E168]** achieve steady state position accuracy for targets according to the requirements in Table 3-1 under the “mean position error” column for the specified tangential and radial scenarios.

c. The TIS-B Service **shall [E169]** achieve a turn/linear acceleration maneuver position accuracy for targets according to the requirements in Table 3-1 under the "peak rms position error" for the specified linear acceleration/turn scenarios.

#### 3.3.2.10.2.2 Horizontal Velocity

a. The TIS-B Service **shall [E170]** generate and maintain tracks for all targets at a range of speed spanning at least 20 to 700 knots.

b. The TIS-B Service **shall [E171]** achieve steady state speed accuracy for targets according to the requirements in Table 3-1 under the "rms speed error" column for the specified tangential and radial scenarios.

***Note:*** *In a multisensor environment, it is assumed that at least one contributing sensor is meeting the required accuracy prior to and including the sampling interval.*

c. The TIS-B Service **shall [E172]** achieve a turn/linear acceleration maneuver speed accuracy for targets according to the requirements in Table 3-1 under the "peak rms velocity error" for the specified linear acceleration/turn scenarios.

#### 3.3.2.10.2.3 Heading/Ground Track

a. The TIS-B Service **shall [E173]** achieve a steady state ground track heading accuracy for targets according to the requirements in Table 3-1 under the "rms heading error" column for the specified tangential and radial scenarios.

***Note:*** *In a multisensor environment, it is assumed that at least one contributing sensor is meeting the required accuracy prior to and including the sampling interval.*

b. The TIS-B Service **shall [E174]** achieve a turn/linear acceleration maneuver ground track (heading) accuracy for targets according to the requirements in Table 3-1 under the "peak rms heading error" for the specified linear acceleration/turn scenarios.

#### 3.3.2.10.2.4 Vertical Position

a. The TIS-B Service **shall [E175]** provide target data with altitude accuracy of 45 meters (147.6 feet) with a 95% probability in either straight and level flight or in an altitude maneuver.

#### 3.3.2.10.2.5 Vertical Velocity

a. The TIS-B Service **shall [E176]** achieve altitude speed accuracies for beacon targets in straight and level flight of <=387 feet/minute.

b. The TIS-B Service **shall [E177]** achieve altitude speed accuracies for beacon targets in an altitude maneuver of <=422 feet/minute.

c. The TIS-B Service **shall [E178] not** use altitude data resulting in the altitude speed exceeding 6000 feet/minute.

### 3.3.2.10.3 TIS-B Track Reliability

#### 3.3.2.10.3.1 False Track Rate

False tracks are characterized by dual tracks, split tracks, swap tracks or clutter tracks, which are defined in §3.1. The following requirements characterize the false target performance for the TIS-B Service.

a. The TIS-B Service **shall [E179]** generate less than 0.1% dual tracks of all targets being tracked.

b. The TIS-B Service **shall [E180]** detect and remove dual tracks within 30 seconds 90% of the time.

c. The TIS-B Service **shall [E181]** output fewer clutter or split track reports than clutter or split measurements received.

d. The TIS-B Service **shall [E182]** maintain a track swap rate in accordance with Table 3-2 in the environment of the scenarios specified in Appendix A, §A.3.1.

**Table 3-2. Track Swap Requirements**

| Aircraft/Vehicle Equipment | 100 kt Overtake | Head-on Approach | Crossing (30 deg) |
|---|---|---|---|
| Non-Discrete Code vs. Non-Discrete Code (same code, no Mode C) | 0% | 0% | 1.1% |
| Discrete Code Track vs. Discrete Code (different code) Track* | 0% | 0% | 0% |
| Discrete Code Track vs. Non-Discrete Code Track* | 0% | 0% | 0% |

** Includes beacon garble*

***<u>Notes for Table 3-2:</u>***

1. *Requirements assume a clutter-free environment and no beacon garble, unless other wise indicated.*

2. *Aircraft speeds are 300 knots and 400 knots for 100 knots overtake, 300 knots for 30 degrees crossing, and 200 knots for head-on approach.*

3. *The sensor characteristics to be used in conjunction with track swap scenarios are those specified in Table 3-1 and Appendix A.*

4. *Requirements apply to a tracker using inputs from one or multiple radars when the radar closest to the aircraft is a short-range radar.*

5. *Beacon-reinforced targets need not necessarily be real. It is quite possible for beacon false-targets to have radar reinforcement via radar clutter.*

6. *False targets (beacon or radar) tend to form in clusters. They are not accurately modeled by a uniform random distribution.*

### 3.3.2.10.3.2 Track Continuity Rate

a. The TIS-B Service **shall [E183]** maintain a track continuity rate that is better than 99.9%.

***Notes:***

1. *This requirement refers to how often tracks are inadvertently dropped rather than dropped due to the target leaving coverage nor does it include the period during track initiation.*

2. *The track continuity rate is defined as:*

$$\frac{\text{(actual time in track)}}{\text{(expected time to be in track)}}$$

3. *As an example, for a simple ND consecutive missed detection rule for track termination, the probability of track continuity, Pc, is given by*

$$P_c = 1 - q^{N_D}$$

*where q is the probability of a missed detection.*

*For ND =5, a continuity rate of 99.9% can be achieved for a detection probability, PD, of 0.75.*

*0.999 = 1 - q5*

*q~0.25, and PD=1-q=0.75*

*For ND=3, the detection probability would be equal to or better than 0.9 to achieve 99.9 percent track continuity.*

b. The TIS-B Service **shall [E184]** maintain track on a target maneuvering at magnitudes of acceleration of up to 1.5 g.

### 3.3.2.10.3.3 Track Loss Rate

Track loss probability is the probability that a track is lost under various conditions based on aircraft maneuvers and data types. A track is considered lost if there is no correlation of the track's 4096 identification code with the correct sensor data for ten consecutive track update opportunities. These requirements were derived from existing FAA tracking systems.

a. The TIS-B Service **shall [E185]** maintain a track loss rate of 0% in the discrete code versus discrete code and discrete code versus non-discrete code environment of the scenarios specified in Appendix A, §A.4.

# Appendix A

## TIS-B Performance Scenarios

This appendix provides the accuracy and track reliability requirement verification scenarios for the TIS-B Service. The scenarios in this appendix pertain to the performance requirements in 3.3.2.10.

### A.1 Accuracy Requirement Verification Scenarios for Position, Heading and Speed

The radars used in the requirements verification have the characteristics in Table A-3-3.

**Table A-3-3. Sensor Characteristics for Test Scenarios**

| | Sensor Channel | |
|---|---|---|
| | ATCRBS | Primary |
| **Long-Range Radars** | | |
| Scan time | 10–12 secs | 10–12 secs |
| False reports | Less than 1/scan | Less than 350/scan |
| Blip/Scan | 95% | 90% |
| Azimuth standard deviation | 0.23 deg | 0.18 deg |
| Azimuth quantization | 0.0879 deg | 0.0879 deg |
| Range standard deviation | 0.12 nmi. | 0.08 nmi. |
| Range quantization | 0.125 nmi. | 0.125 nmi. |
| Altitude standard deviation* | 50 ft | - |
| Altitude quantization | 100 ft | - |
| Maximum radar bias | | |
| Range | 0.5 nmi. | 0.5 nmi. |
| Azimuth | 0.176 deg | 0.176 deg |
| **Short-Range Radars** | | |
| Scan time | 4–5 sec | 4–5 sec |
| False reports | Less than 1/scan | Less than 350/scan |
| Blip/Scan | 95% | 90% |
| Azimuth standard deviation | 0.23 deg | 0.18 deg |
| Azimuth quantization | 0.0879 deg | 0.0879 deg |
| Range standard deviation | 0.04 nmi. | 0.04 nmi. |
| Range quantization | 0.0156 nmi. | 0.0156 nmi. |
| Altitude standard deviation* | 50 ft | - |
| Altitude quantization | 100 ft | - |
| Maximum radar bias | | |
| Range | 0.125 nmi. | 0.125 nmi. |
| Azimuth | 0.176 deg | 0.176 deg |

* Includes altitude quantization

### A.1.1 Scenarios for Position, Heading, Speed Accuracy Performance Verification

In this section flight paths are identified for performance evaluation in the following areas:

- steady state (i.e., straight line flight) track quality,
- transient state (i.e., maneuver and linear acceleration) track quality,
- single versus multi-sensor track quality.

Verification of the requirements is based on government furnished scenarios for AAS performance requirements presented in [3]. For the multi-sensor runs, two types of configurations of three sensors are provided. The first configuration consists of three long range radars, shown in Figure A-1, and the second configuration consists of two short range radars and one long range radar, shown in Figure A-2. In each configuration, the central sensor is located at (0,0). Additional sensor 1 is at the radial 315 at the range of 40 NM from the central sensor (when the central sensor is a short range sensor) and at a range of 100 NM (when the central sensor is a long range sensor). Additional sensor 2 is at radial 180 degrees at a range of 100 NM from the central sensor and is always a long range sensor.

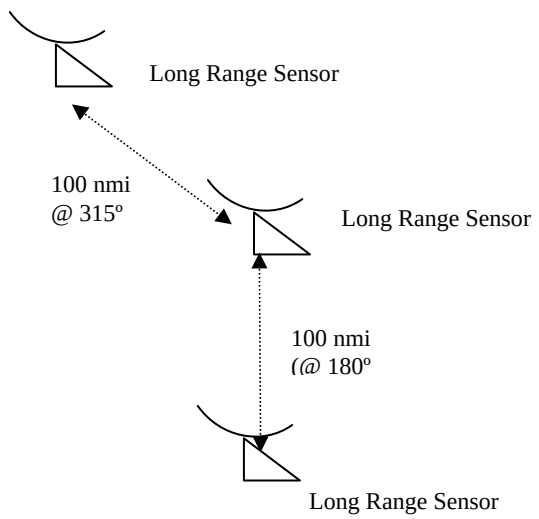


**Figure A-3-1. Configuration of Three Long Range Sensors**

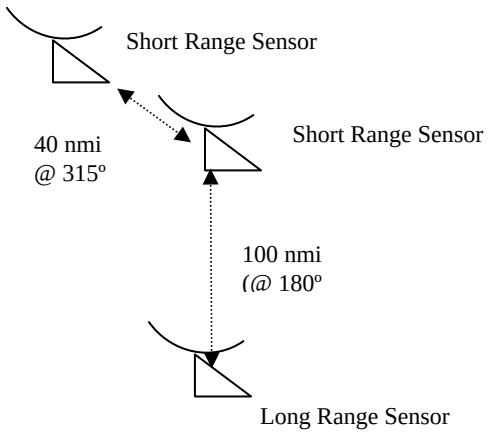


**Figure A-3-2. Configuration of Two Short Range Sensors and One Long Range Sensor**

Figure A-3-3 illustrates the flight scenarios for the configuration where the central sensor is a short range radar and the additional sensors are one short and one long range radar. The flight paths are shown with respect to the central sensor. Figure A-3-4 illustrates the flight scenarios for the configuration where all the sensors are long range radars.

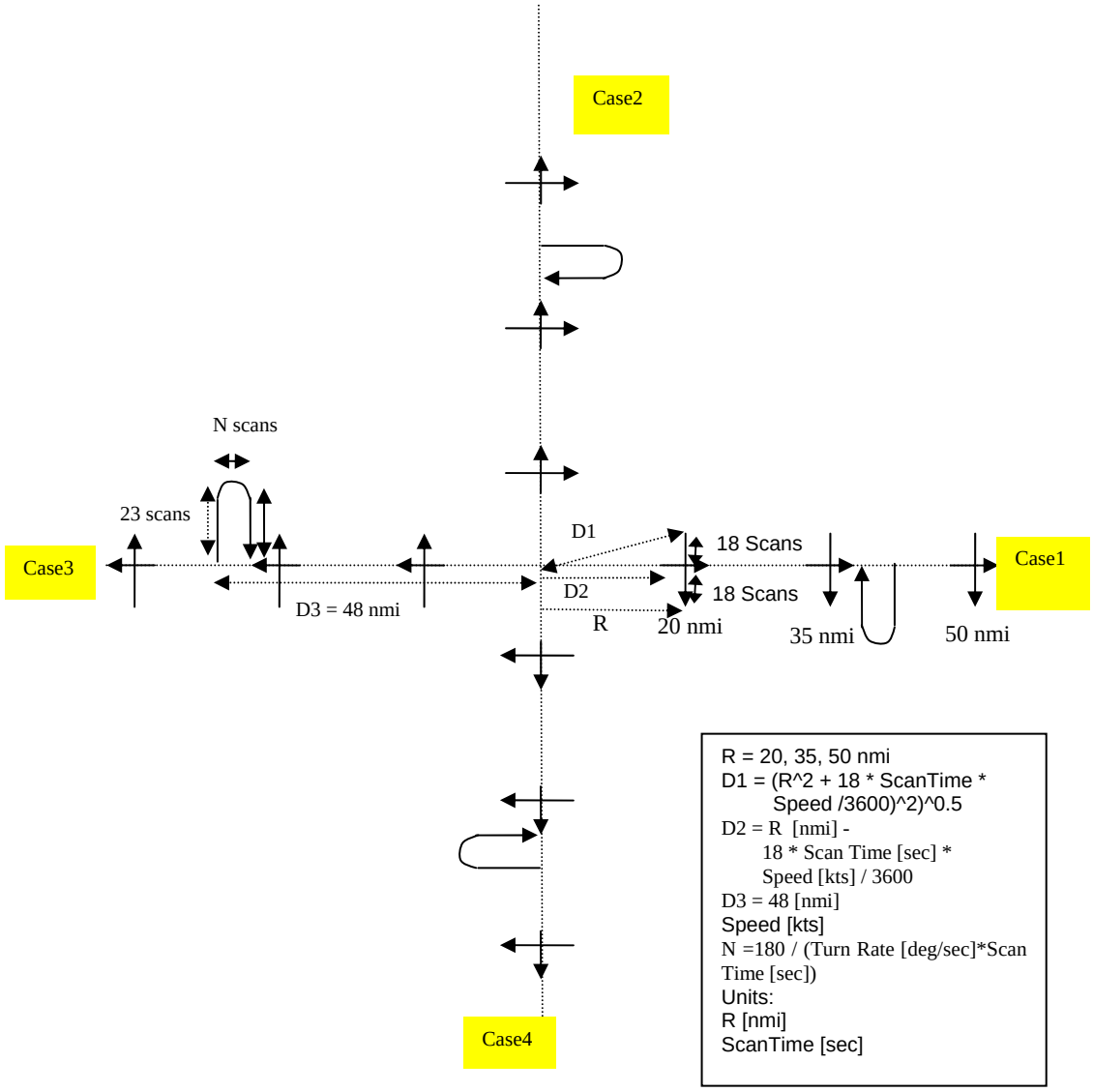


**Figure A-3-3. Scenario for Configuration with Two Short Range Sensors and One Long Range Sensor**

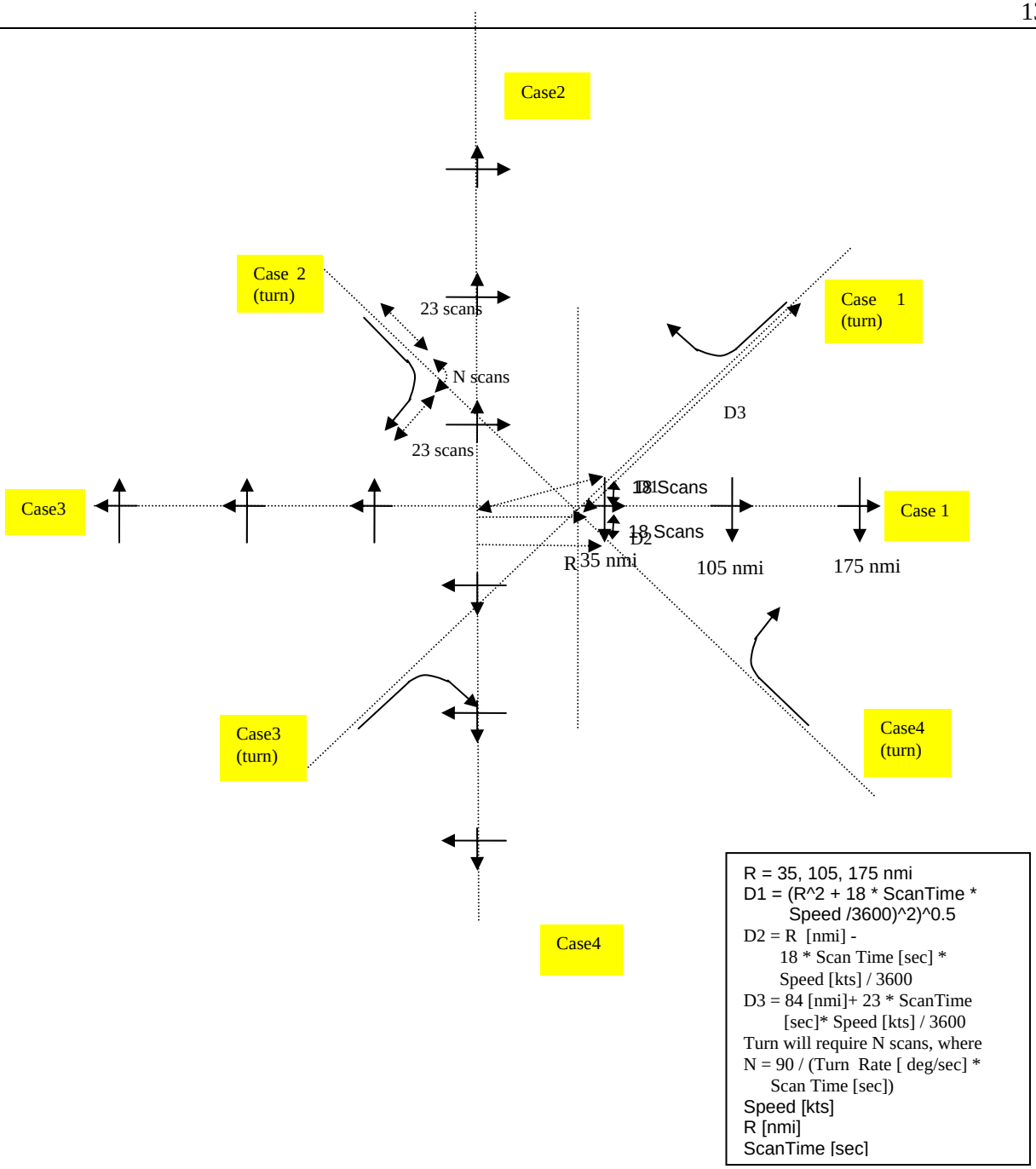


**Figure A-3-4. Scenario for Configuration with Three Long Range Sensors**

Since the tracking performance test results are statistical measures, it is important that they not be sensitive to sample size. The performance parameters in the existing documents were computed by running 100 Monte Carlo iterations. There are a number of approaches to generating an input file that does not require running 100 cases sequentially. One approach would be to generate for each flight path case (referenced in Table 3-1) 100 flight paths with identical characteristics except for 500 feet separation in altitude. However, due to the possibility of exceeding the maximum loading constraints of the tracker (i.e., target density within a beamwidth), two techniques were adopted: (1)

distributing the 100 flight paths over 360 degrees or (2) staggering the 100 flight paths in time by up to six scans.

To validate the requirements associated with single sensor accuracies, 50 radial and tangential flight paths are distributed over 360 degrees, separated by 7.2 degrees, and the scenario is run twice to generate the requisite 100 flight paths. The plots of these radial and tangential scenarios are shown in Figures A-5 and A-6 for the short range radar and long range radar configurations, respectively. The FAA Multi-Sensor Surveillance Simulator (MSSS) is used to generate these scenarios. The MSSS Player will be made available to the service provider to provide scenario data for testing purposes.

To validate the requirements associated with the multi-sensor accuracies (the values shown in parentheses in Table 3-1), the 100 flight paths are staggered in time by up to six scans. Figures A-7 and A-8 depict the multi-sensor scenarios for radial, tangential, turning and linear acceleration for the short range and long range configurations, respectively. The straight legs of the turning scenarios serve dual purposes, i.e., they are used for computing radial or tangential accuracies when appropriate. In the long range configuration, the 90 degree turn is not only used to compute the accuracies during the turn, but also to compute the accuracies during the radial leg (before the turn) and tangential leg (after achieving steady state) of the turn as shown in Figure A-8. This is a compromise because the flight paths for the multi-sensor radial and tangential accuracies in Table 3-1 were referenced to “case 3” in Figure A-4; this is at a different location than the turning flight path of Figure A-8. In the short range configuration, the straight leg before the 180 degree turn can be used for computing the tangential accuracies. Its location, shown in Figure A-7, is very close (off by 2 miles) to the location specified in Table 3-1 (case 3 of Figure A-3). However, the 180 degree turn does not provide an opportunity for computing radial accuracies.

To validate the requirements associated with linear acceleration/deceleration, 100 flight paths are staggered in time by 30 seconds; with targets starting at the maximum range south-west of the central radar and traveling east along a parallel line 20 nautical miles south of the central sensor (see Figures A-7 and A-8 for the short range and the long range configurations, respectively). For the first 23 scans, the initial speed of the targets is 250 knots. Afterwards, the targets accelerate at 1 knot/sec for 400 seconds to reach 650 knots, after which the targets maintain constant speed for another 23 scans. This is followed by a deceleration at 1 knot/sec for 400 sec to reach 250 knots after which the speed is held constant for another 23 scans. The scenario takes 18 minutes and 38 seconds for each of the 100 staggered targets. Data collection to verify the accuracy requirements will begin after the first 23 scans.

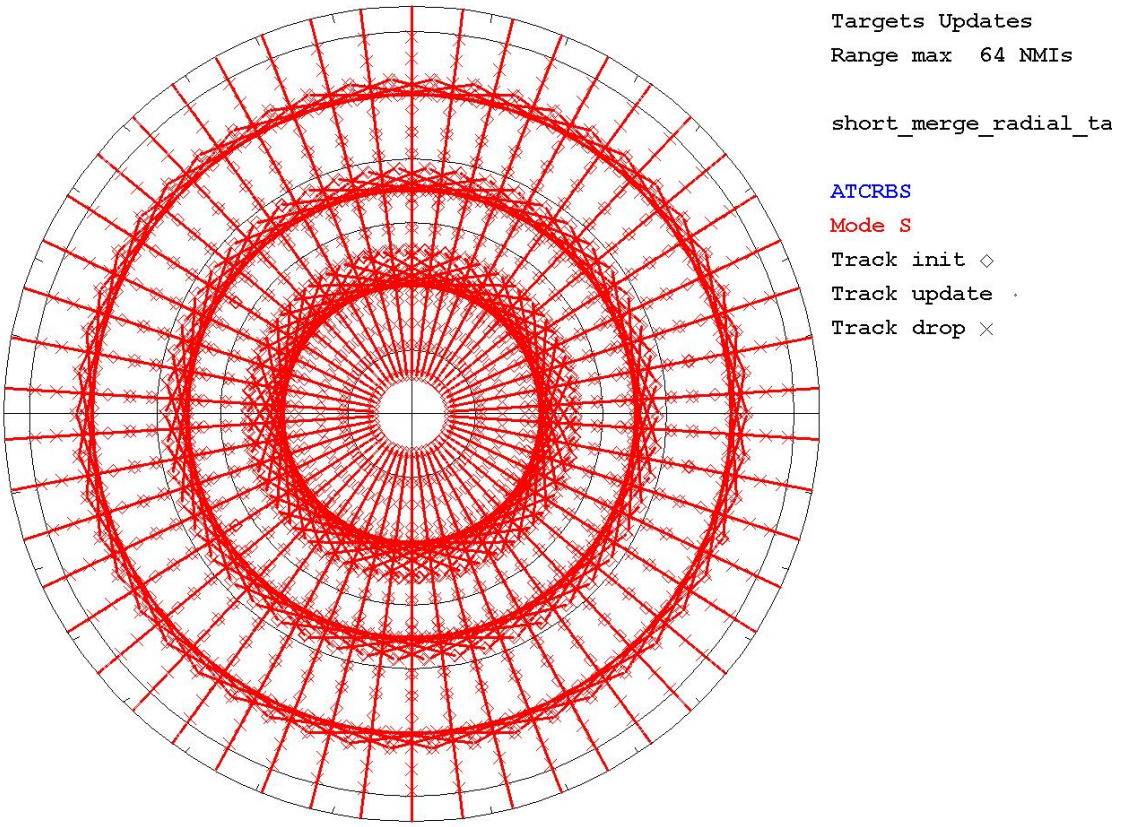


**Figure A-3-5. Radial and Tangential Flight Paths for Computing Single Sensor Accuracies for the Short-Range Radar**

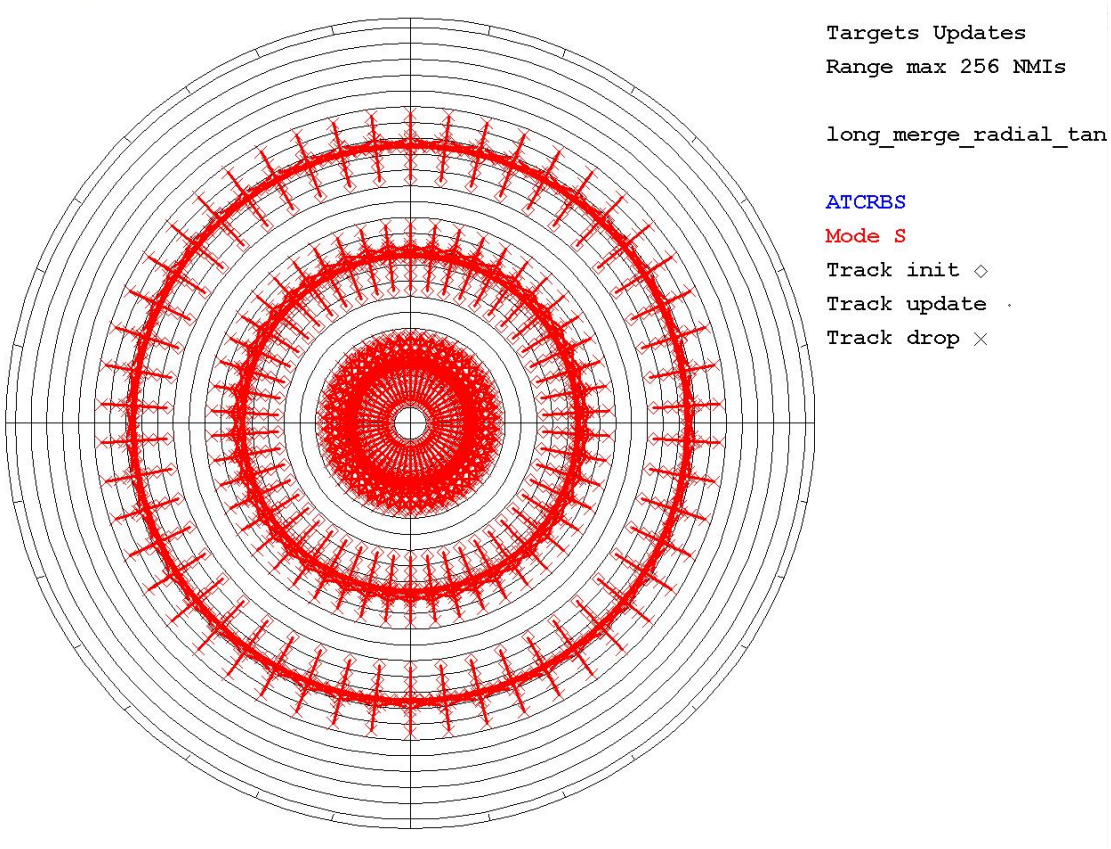


**Figure A-3-6. Radial and Tangential Flight Paths for Computing Single Sensor Accuracies for the Long Range Radar**

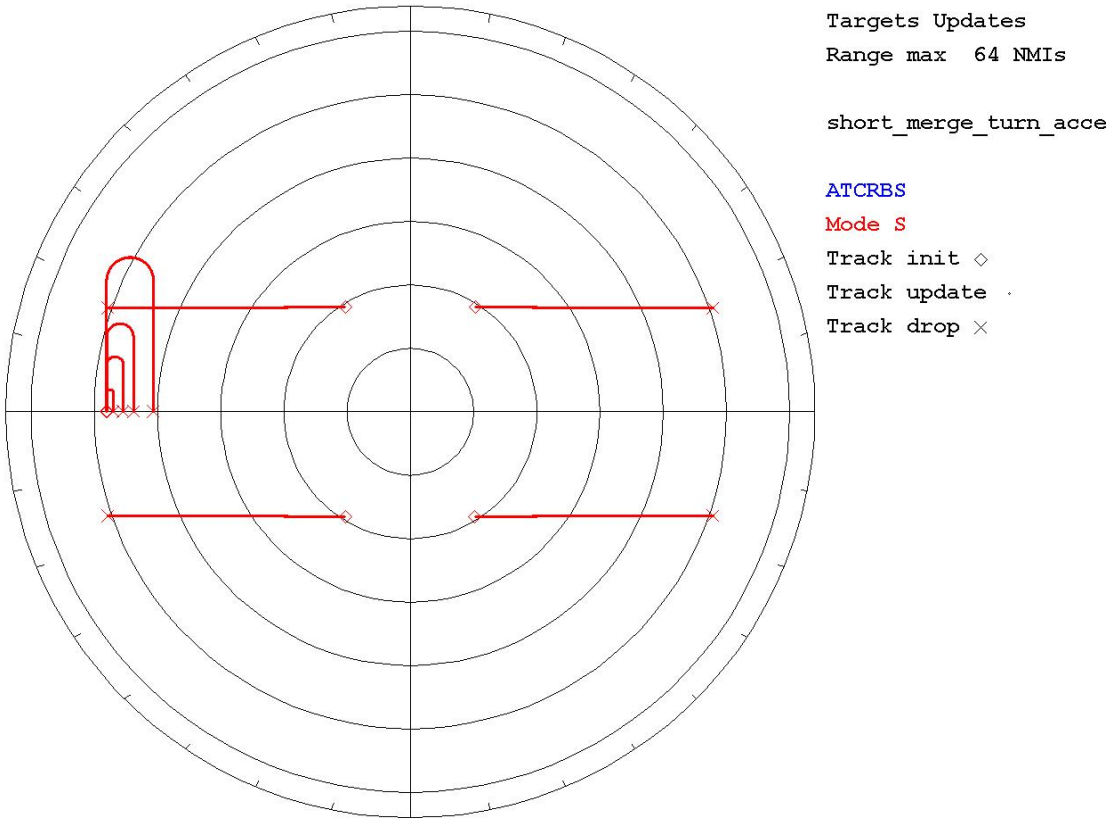


**Figure A-3-7. Multi-Sensor Scenarios for Computing Turning, Tangential and Linearly Accelerating Accuracies for the Short-Range Radar Configuration**

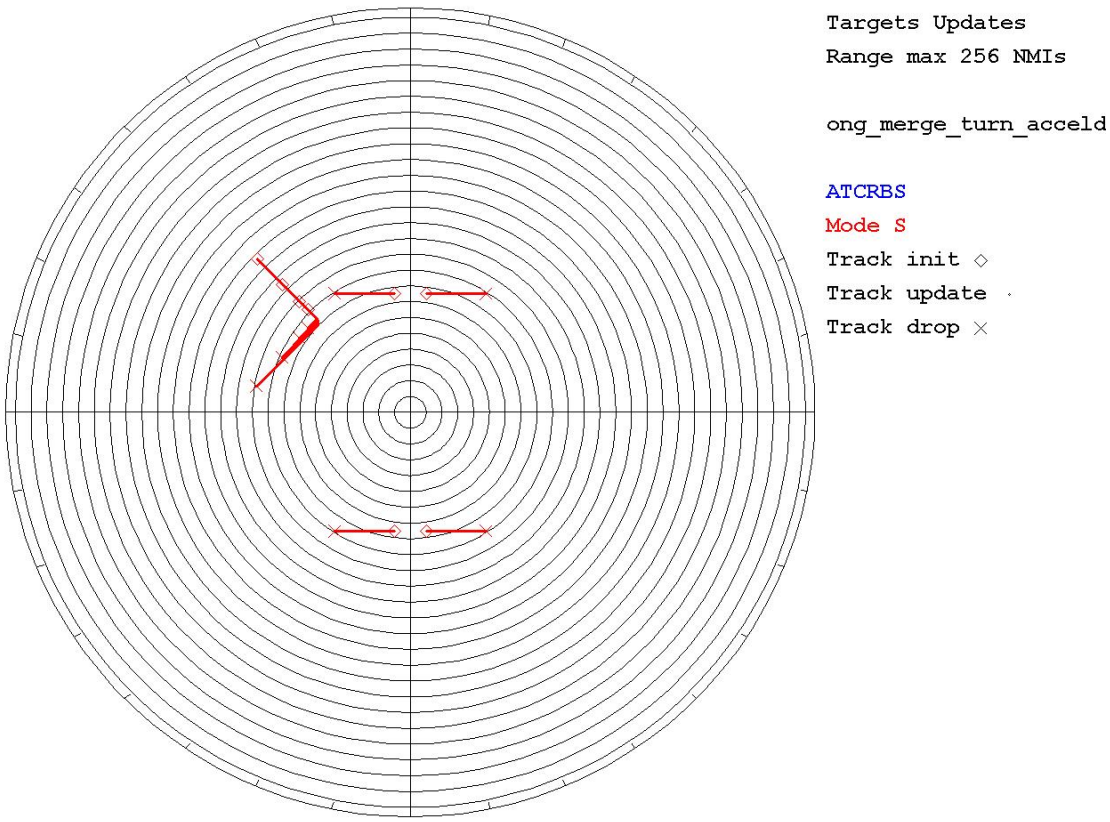


**Figure A-3-8. Multi-Sensor Scenarios for Computing Turning, Tangential, Radial and Linearly Accelerating Accuracies for the Long-Range Radar Configuration**

## A.2 Accuracy Requirements for Altitude and Altitude Velocity

### A.2.1 Scenarios for Altitude and Altitude Velocity Accuracy Performance Verification

As was the case in §A.1 for the position, heading and speed accuracy performance requirements, the altitude and altitude velocity accuracy requirements are defined specific scenarios. In this case, the two scenarios are called Straight Flight and Altitude Maneuver. Each scenario has targets within an area 400 x 400 nautical miles that is centered within a Surveillance Coverage Volume of 1000 x 1000 nautical miles. Within the Surveillance Coverage Volume are 64 radars, 19 short-range radars (nominal coverage is 60 NM) and 45 long-range radars (nominal coverage is 250 NM). The layout of the radars is shown in Figure A-9. Each radar has a blip/scan ratio of 98%. Each target is reported by no more than four radars.

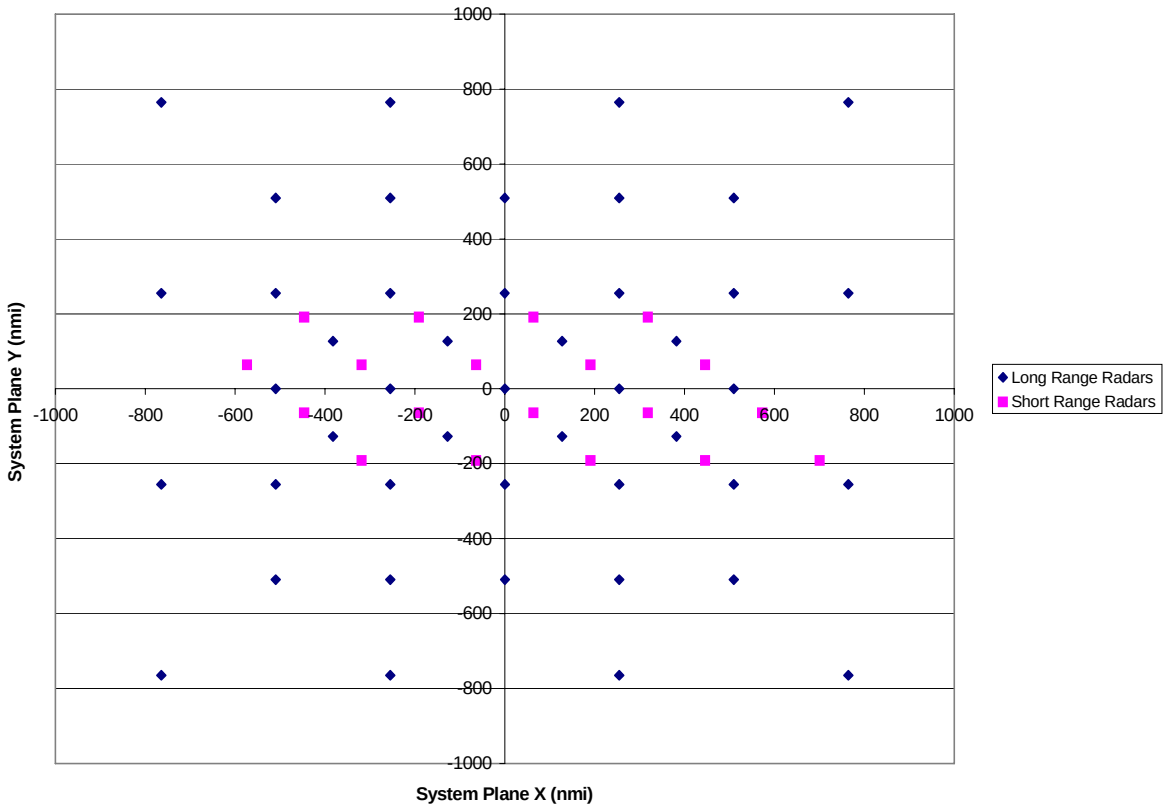


**Figure A-3-9. Radar Locations for Altitude and Altitude Velocity Scenarios**

In straight and level flight, each target will fly at a constant speed, between 250 and 500 knots, a constant heading, and a constant altitude, between 10,000 and 20,000 feet. This scenario duration is 10 minutes. Data collection to verify the accuracy requirements will begin at the start of the second minute of scenario time.

In altitude maneuvering flight, for the first minute of scenario time, the targets will fly at a constant speed between 250 and 500 knots, a constant heading and a constant altitude of 20,000 feet. Afterwards, half of the targets will ascend and half will descend for three minutes, after which the scenario ends. The absolute altitude change rate for each target will be constant (randomly determined within a range of 0 to 3,000 feet/min). This scenario duration is four minutes. Data collection to verify the accuracy requirements will begin at the start of the second minute of scenario time.

## A.3 Track Reliability

In this section, the track swap and track loss requirements with appropriate scenarios are provided. These requirements are taken from the STARS functional requirements [2].

### A.3.1 Track Swap Requirements

Track swap probability is the probability that a track ceases to correlate with the correct target and instead tracks a proximate target after a swap opportunity. A track swap occurs if it results in a persistent misidentification (five scans) or a track loss after a swap

opportunity. The track swap requirements are base upon the following assumptions. Two aircraft tracked with beacon-only reports should not swap if the codes are different. This applies to the discrete code track vs. discrete code track (different codes) and discrete code track vs. non-discrete code track environments. An aircraft that is tracked with non-discrete beacon-only reports should not swap with an aircraft that is tracked with search-only reports.

Scenarios depicted in Figures A-10 to A-12 consist of 16 pairs of targets of discrete coded targets in straight and level flight [1]. The scenarios are each run six times, each time under different radar noise situations. The six runs create 192 discrete tracks. Discrete Track Swap probability is computed by dividing the total number of swaps by the total number of swap pairs (96) and expressing the result as a percentage.

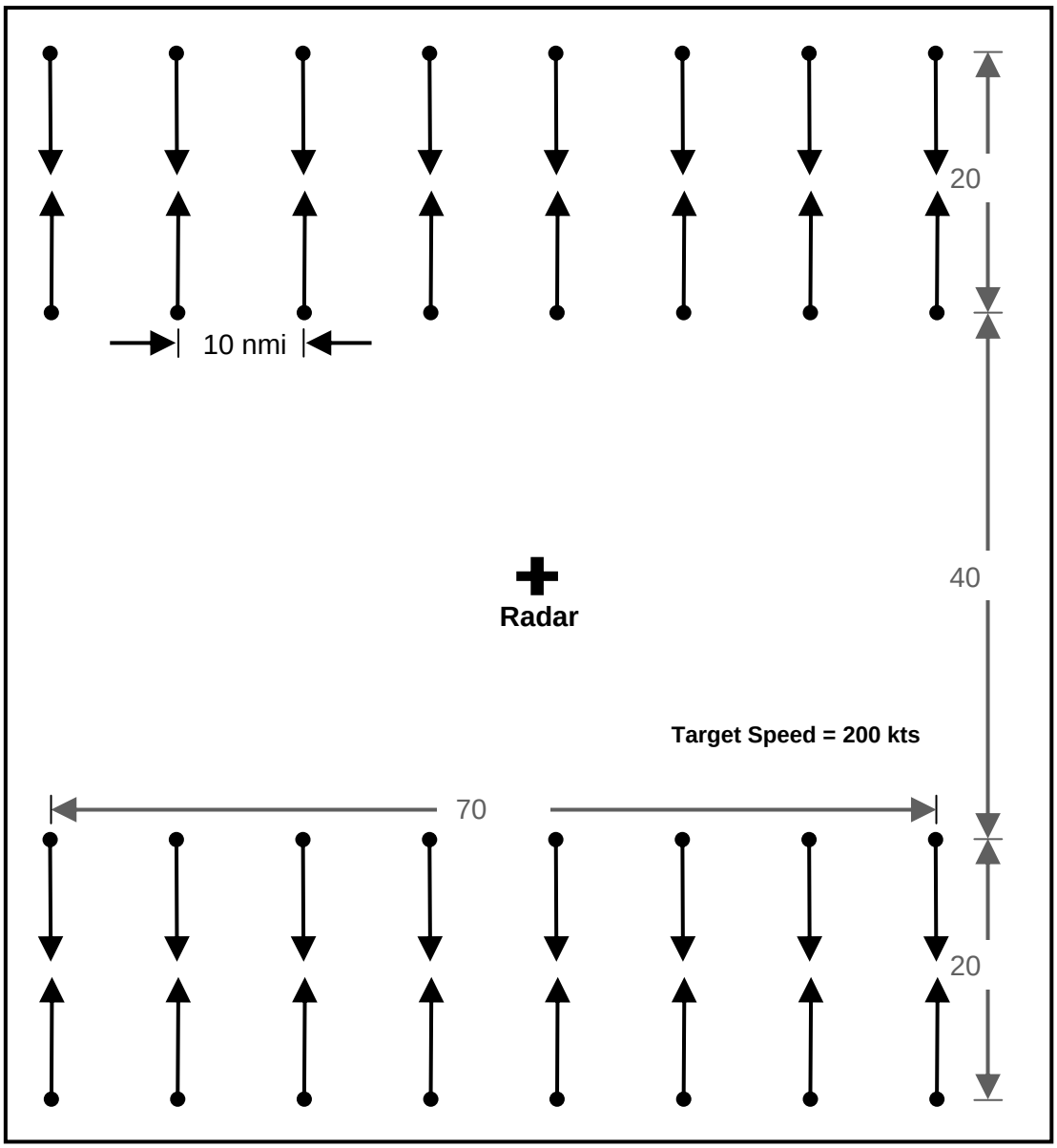

**Figure A-3-10. Head-On Approach Scenario**

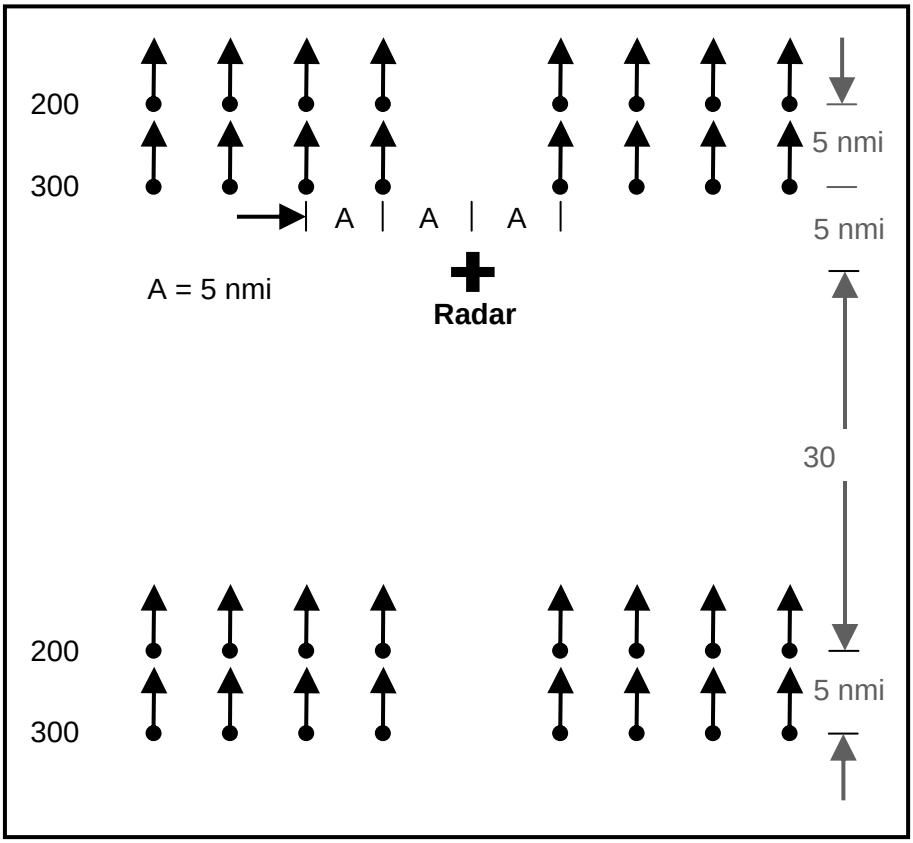


**Figure A-3-11. 100 kt Overtake Scenario**

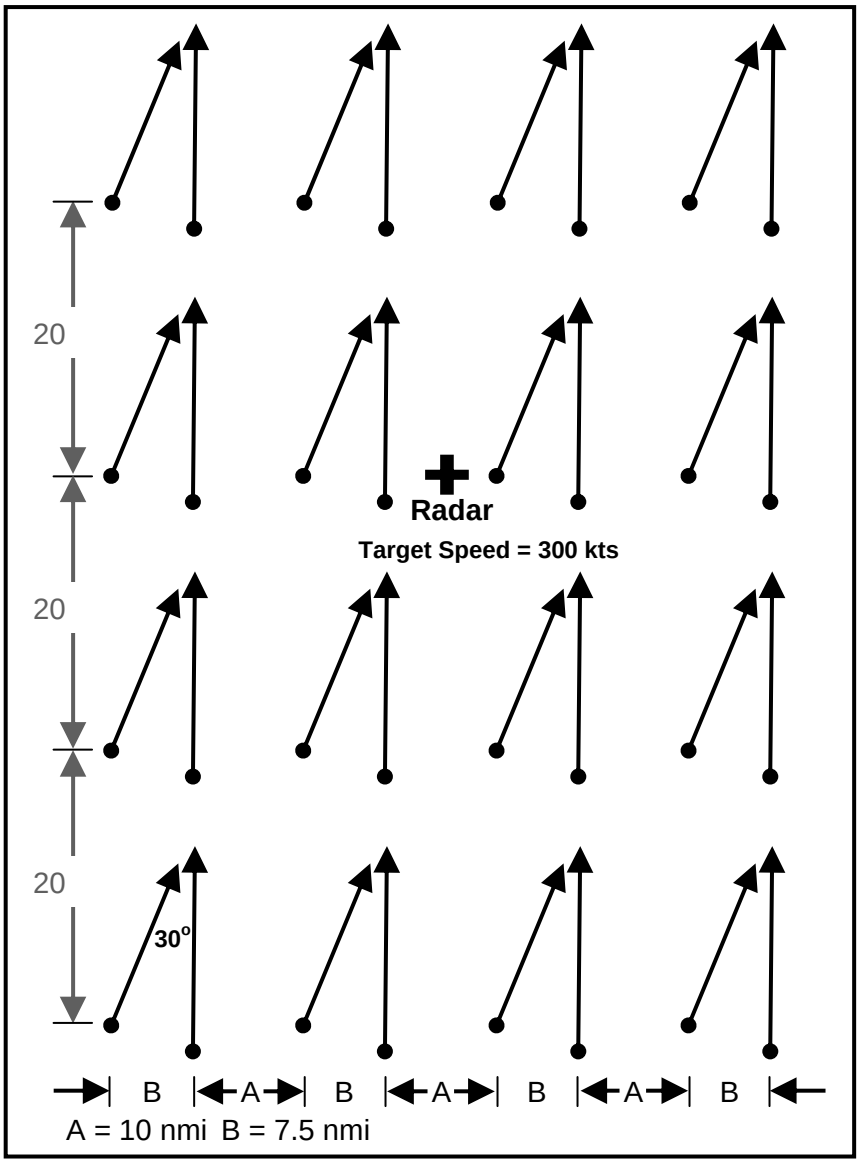


**Figure A-3-12. 30° Crossing Scenario**

## A.4 Track Loss Scenario

The Track Loss scenario consists of 16 pairs of discrete coded targets in straight and level flight in 30 degree crossing situations as shown in Figure A-12. The scenario is run six times, each under different radar noise situations. The six runs create 192 discrete tracks. The scenario in Figure A-12 is run again, this time one target in each pair has a discrete code and the other target has a non-discrete code. The scenario is run six times, each time under different noise situations and with different aircraft identifications. The six runs create 96 discrete coded tracks.

Discrete track loss probability is computed by dividing the total number of losses by the total number of discrete tracks (192+96=288 tracks) and expressing the result as a percentage.

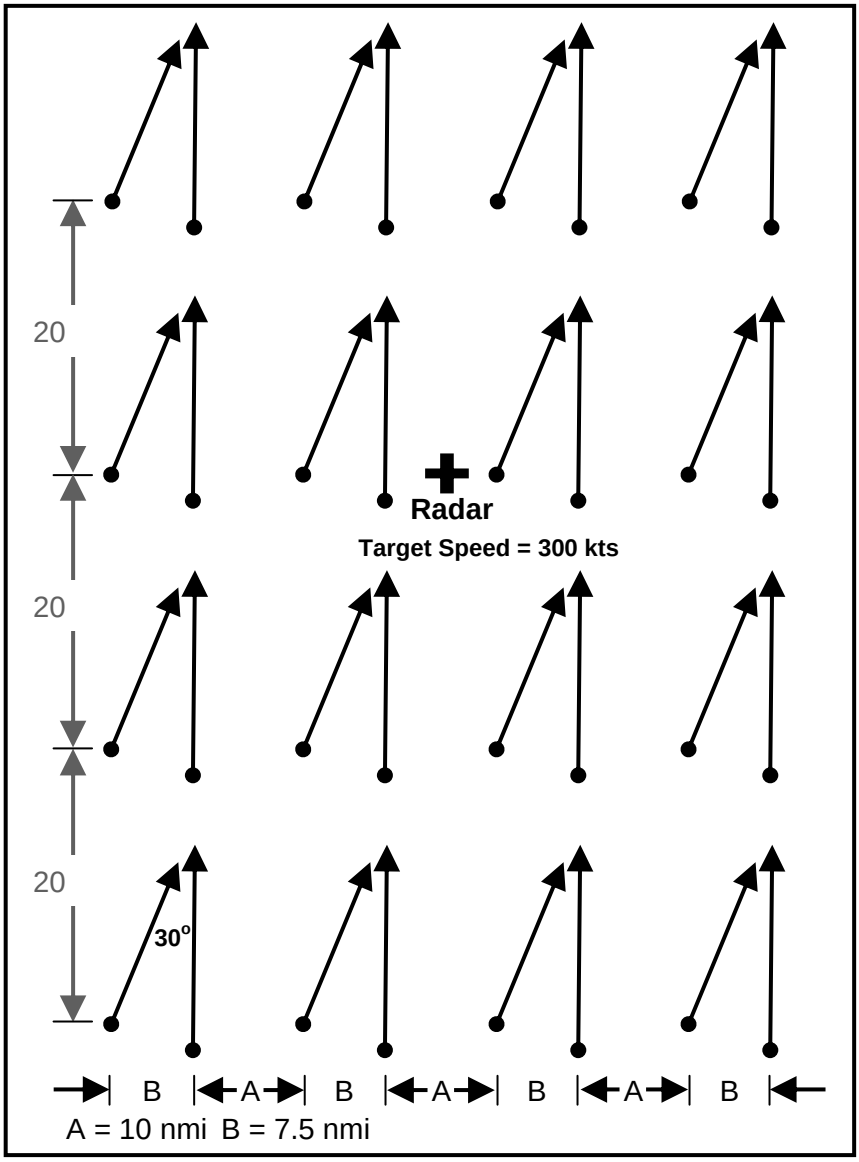


**Figure A-13. Track Loss Performance Scenario**

## A.5 References for this Appendix

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