Scenarios for Test Section of ASSAP MOPS

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June 20, 2007

Introduction

The ASSAP working group has determined that test scenarios for the following functions should be referenced or specified in the test section of the MOPS:

1. Detection/suppression of TIS-B shadows of ownship.
2. TCAS to ADS-B/ADS-R/TIS-B track-to-track correlation.

Purpose

The purpose of this document is to define and justify worst case scenarios for the functions listed above and to provide algorithms that allow the reader to synthesize these scenarios for bench testing.

Detection/Suppression of TIS-B Shadows of Ownship

This function should be tested in two contexts, one involving a single aircraft and the other involving multiple aircraft:

Case 1: Single Aircraft

Due to unusual circumstances, an ADS-B equipped ownship receives a TIS-B report stream on itself.

- ASSAP shall detect the shadow and suppress it from the CDTI.
- Failure to perform this task may present a hazard to users.
  - Given that ASAS applications are intended for visual meteorological conditions, there is a high likelihood that targets in close proximity to ownship will be visible from the cockpit.
  - If ASSAP fails to detect a shadow of ownship and suppress it from the CDTI, a target will appear on the display in the immediate vicinity of ownship (i.e. 0.5 NM), however, there may be no aircraft visible from the cockpit.
  - There is a risk that the ghost target will be perceived as a grave threat; at the very least it will be a distraction.
- In order to correlate a TIS-B track (with a low update rate) and ownship state (with a high update rate, i.e. derived from GPS), the TIS-B track state must be predicted to time of applicability of ownship state during the periods between TIS-B track updates.
  - Given the information available in TIS-B tracks, straight-line predictions are likely.
  - Significant deviations between ownship positions and predicted TIS-B positions will stress the ASSAP correlation algorithms.

- Thus the ideal test scenario for this case involves ownship completing a 180° turn.
  - In a turning scenario, frequently updated ownship positions must be correlated with a number of predicted TIS-B positions that fan out from the true aircraft trajectory (as pictured in figure 1).

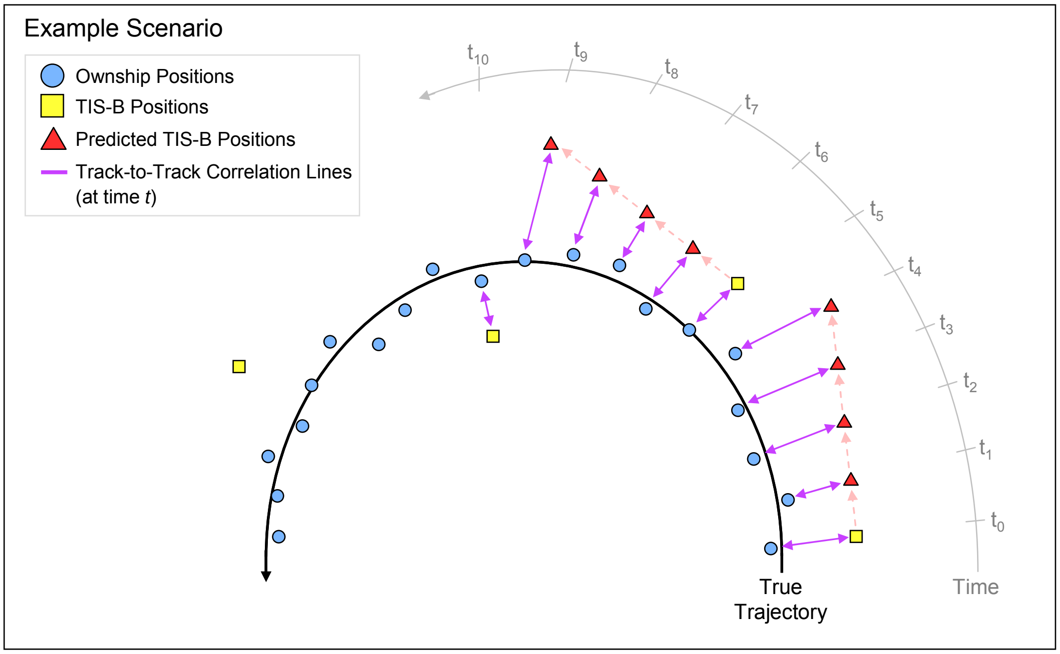

Figure 1. Deviation of Predicted TIS-B Position from True Trajectory.

- Simulating the scenario provides the opportunity to generate the worst case (maximum deviation between ownship and TIS-B positions).
- The truth trajectory can be generated as follows:

$$s = arc\ length$$

$$r = turn\ radius$$

$$\theta = turn\ angle$$

$$s = r\theta$$

$$\dot{\theta} = turn\ rate$$

$$t = time\ required\ \ for\ turn = \frac{\theta}{\dot{\theta}}$$

$$v = aircraft\ speed\ (velocity\ magnitude)$$

$$s = vt = r\theta$$

$$r = \frac{vt}{\theta} = \frac{v\left(\frac{\theta}{\dot{\theta}}\right)}{\theta} = \frac{v}{\dot{\theta}}$$

  - The turn radius is dependent on aircraft speed and turn rate.

- In order to select an appropriate turn rate it is useful to examine the deviations between true positions and predicted positions based on previous true states.
- By holding velocity constant and increasing turn rate, it can be seen that turn radius decreases and the horizontal deviation between predicted position and true trajectory increases (as shown in figure 2).

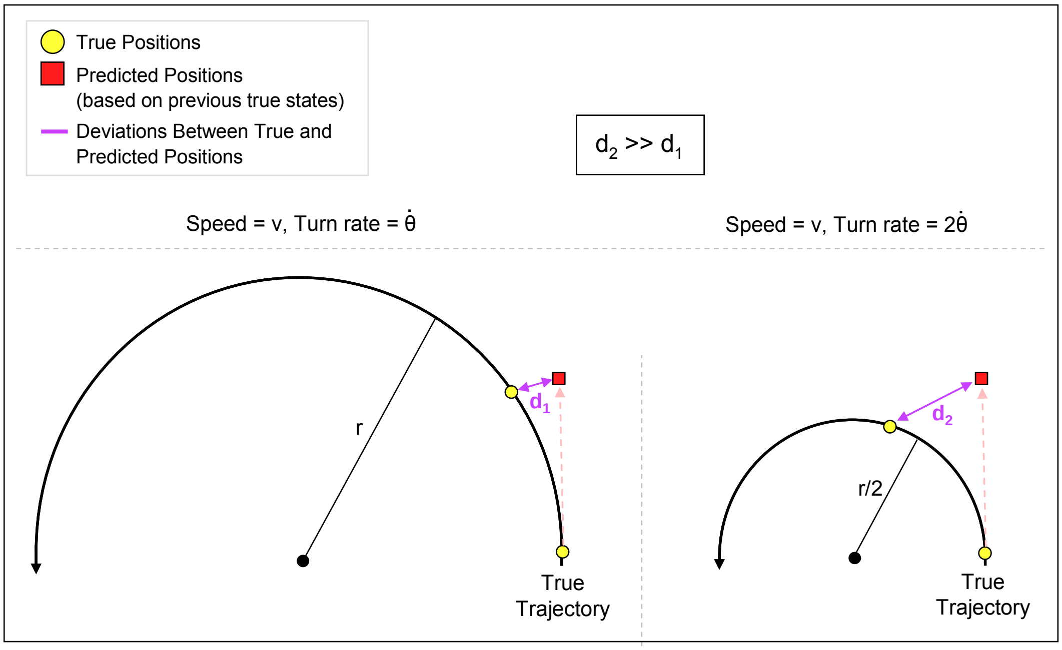

Figure 2. Deviation of Predicted Position from True Trajectory.

- In order to maximize the horizontal deviation between a predicted position and true trajectory, a turn rate of 6^o/s (twice the standard rate) is recommended.
- It is recommended that a speed of 200 knots is used.
    - Most aircraft (i.e. airliners, business jets, general aviation aircraft) are capable of this speed, which enhances the applicability of this scenario.
- Given the recommended turn rate and speed, the turn radius can be calculated:

$6^o/s = (6^o/s)(\pi \text{ rads}/180^o) = 0.10472 \text{ rads/s}$
$200 \text{ kts} = (200 \text{ NM/hr})(1852 \text{ m/NM})(1 \text{ hr}/3600 \text{ s}) = 102.889 \text{ m/s}$

$$r = \frac{v}{\dot{\theta}} = \frac{102.889\, m/s}{0.10472\, rads/s} = 982.515\, m$$

- Given the turn radius, a continuous function for horizontal truth trajectory can be defined using the equation for a circle:

$$x^2 + y^2 = r^2 \; where\; (0,0)\; is\; the\; origin\; and\; 0 \le y \le r$$

- It is highly likely that pressure altitude measurements from ownship will be used to derive ownship and TIS-B altitudes, therefore vertical deviation between ownship and TIS-B positions will be significantly smaller than horizontal deviation.
- A climb or descent contributes little to the scenario unless deviation between vertical positions is large, which is unlikely to be the case.
- It is recommended that true vertical position is held constant at a value consistent with the horizontal procedure (i.e. 10,000 ft):

$$z = 10000\ ft = 3048.78\ m$$

- If desired, discrete points representing the horizontal truth trajectory can be obtained by solving for *x* and inputting *y* from the range *[0, r]* (as shown in figure 3):

$$x = \pm\sqrt{r^2 - y^2}$$

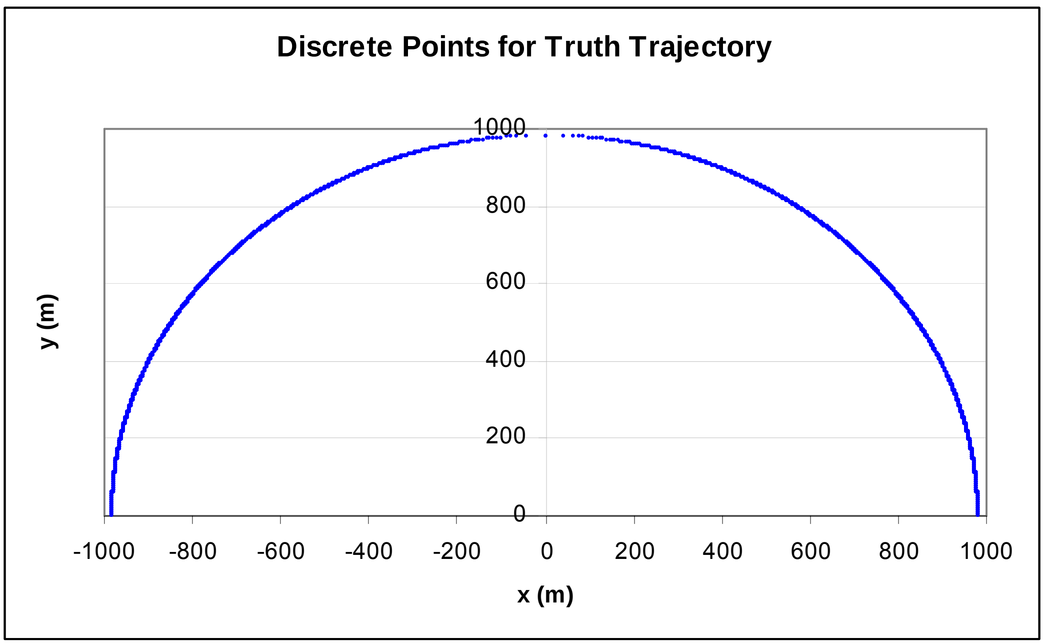

Figure 3. Discrete Points Representing Truth Trajectory.

- Using aircraft speed and a surveillance update rate, truth points can be sampled for a surveillance source.
- To generate a truth sample for terminal TIS-B (4.8 second update rate), the required angle between two truth points is obtained:

$$\Delta s = vt = (102.889\ m/s)(4.8\ s) = 493.867\ m$$

$$\Delta\theta = \frac{\Delta s}{r} = \frac{493.867\ m}{982.515\ m} = 0.50266\ rads$$

- With the required angle between truth points, a loop can be used to generate the sample:

  Point$_1 = (r, 0);$
  $\theta = 0;$
  $\theta_{max} = \pi;$
  $i = 1;$

  While $(\theta \leq \theta_{max})$
  $i = i + 1;$
  $\theta = \theta + \Delta\theta;$
  $x = r\cos(\theta);$
  $y = r\sin(\theta);$
  Point$_i = (x, y);$
  End

  Note: some form of terminator (syntax dependent) should be used to ensure that θ *does not exceed* θ_{max}.

- Truth points sampled once per 4.8 seconds for terminal TIS-B are shown in figure 4.

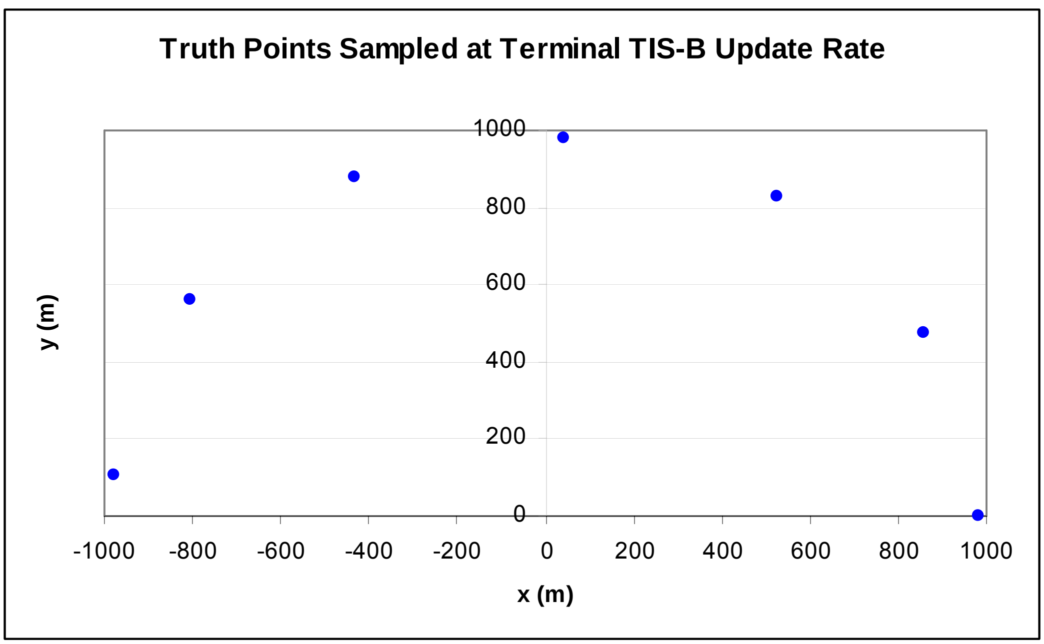

Figure 4. Truth Points Sampled at Terminal TIS-B Update Rate.

- Ownship truth points can be sampled using the same technique.
- It is recommended that ownship truth points are sampled at 1 Hz or greater (at least the same rate as ADS-B).
- Velocities corresponding to sampled positions can be derived from the recommended aircraft speed.

- For any sampled position, the velocity vector will be orthogonal to the ray from the origin through the position, as illustrated by figure 5.

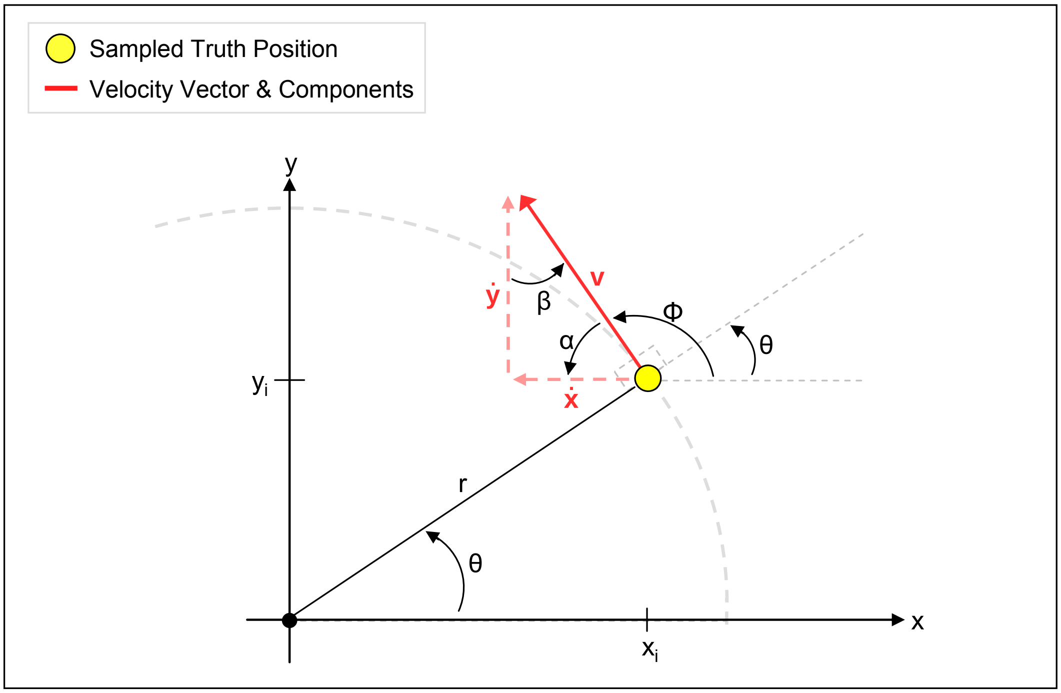

Figure 5. Velocity Vector for Sampled Truth Position.

- True x and y velocities for any sampled position can be calculated as follows:

$$\theta = \cos^{-1}\left(\frac{x}{r}\right)$$

$$\phi = \theta + \frac{\pi}{2}$$

$$\alpha = \pi - \phi = \pi - \left(\theta + \frac{\pi}{2}\right) = \frac{\pi}{2} - \theta$$

$$\beta = \pi - \frac{\pi}{2} - \alpha = \frac{\pi}{2} - \left(\frac{\pi}{2} - \theta\right) = \theta$$

$$\sin\beta = \frac{-\dot{x}}{v}$$

$$\cos\beta = \frac{\dot{y}}{v}$$

$$\dot{x} = -v\sin\beta = -v\sin\theta = -v\sin\left[\cos^{-1}\left(\frac{x}{r}\right)\right]$$

$$\dot{y} = v\cos\beta = v\cos\theta = v\cos\left[\cos^{-1}\left(\frac{x}{r}\right)\right]$$

- Given constant altitude, at any point z-velocity will be zero.
- It is now possible to produce a sample of truth state vectors that conform to a specific update rate (1 Hz for ownship, 1/4.8 Hz for TIS-B).

- To complete the synthesized scenario, position and velocity error must be added to the sampled truth states.

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- There are multiple ways to accomplish this, however, it is unclear which approach offers the best combination of accuracy and ease of implementation.
- The following techniques can be used to add error to sampled state vectors:
  - A Monte Carlo approach with no serial correlation between errors.
    - Random variables are used to generate errors that correspond to the minimal ASSAP application requirements (NACp = 5, NACv = 1, VEPU = 45 m, and some assumed value for vertical velocity uncertainty).
    - Pros: easiest technique to implement, error variance may stress the ASSAP algorithms further.
    - Cons: not necessarily representative of the real world, where surveillance errors have some level of serial correlation (i.e. GPS).
  - A Monte Carlo approach with serial correlation between errors.
    - Random variables are used to generate errors that correspond to the minimal ASSAP application requirements, however, variance is limited by a serial correlation technique.
    - Pros: more representative of real world surveillance error.
    - Cons: harder to implement, may need to perform analysis to identify worst case ranges for seeded random variables (which influence subsequent RVs through the correlation factor).
  - A hybrid approach using Monte Carlo techniques to produce ownship position/velocity errors and a radar tracker simulation to produce TIS-B position/velocity errors.
    - Correlated random variables are used to generate ownship position/velocity errors and a radar tracking simulation is used to generate a sufficiently bad representation of TIS-B errors.
    - Pros: most representative of the real world (i.e. ownship errors due to GPS, additional sources of TIS-B error included, i.e. lag).
    - Cons: most difficult to implement.

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Case 2: Multiple Aircraft

An ADS-B equipped ownship receives TIS-B reports that correspond to another aircraft in close proximity to ownship.

- ASSAP should distinguish the target from ownship and maintain a track for the target.
- Failure to perform this task may present a hazard to users.
  - A TIS-B track will be suppressed from the CDTI if it is mistakenly correlated with ownship.
  - There is a risk that a target in the periphery (or outside) the field of view will become invisible to the flight crew.

NEEDS TO BE COMPLETED