Showcase and Comparison of Three Methods for Visualizing Near-Earth Satellite Conjunction Events

Erick H. White [1] Luis G. Baars [1]

[1]Omitron Inc.

Overview

- Conjunction assessment is a cornerstone of modern space safety
- Reliable visualization of the space environment can benefit operators and analysts alike
- Three new/extended methods provide more robust visualization of unusual conjunction geometries

Motivation

- Current conjunction visualization methods (Figure 1) fail when key probability of collision (P_c) calculation assumptions are violated

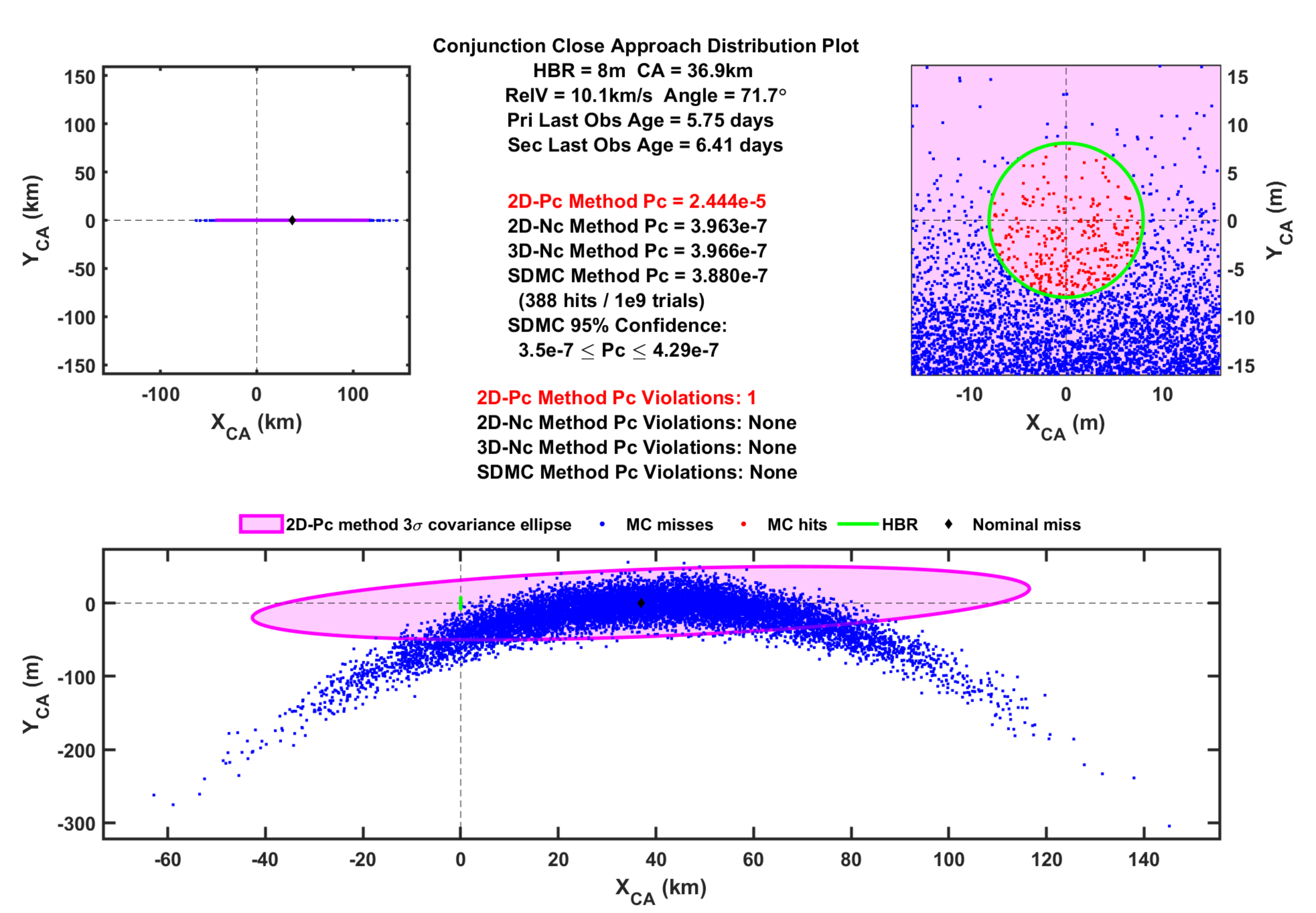

Figure 1. An example of a conjunction plane plot for a case in which it fails to accurately capture the conjunction environment.

Methodology

- Implemented three visualization methods (ellipsoid, bananoid, and point cloud)
- Tested visualization methods against a variety of conjunction geometries to determine best and worst cases for a given method

Results

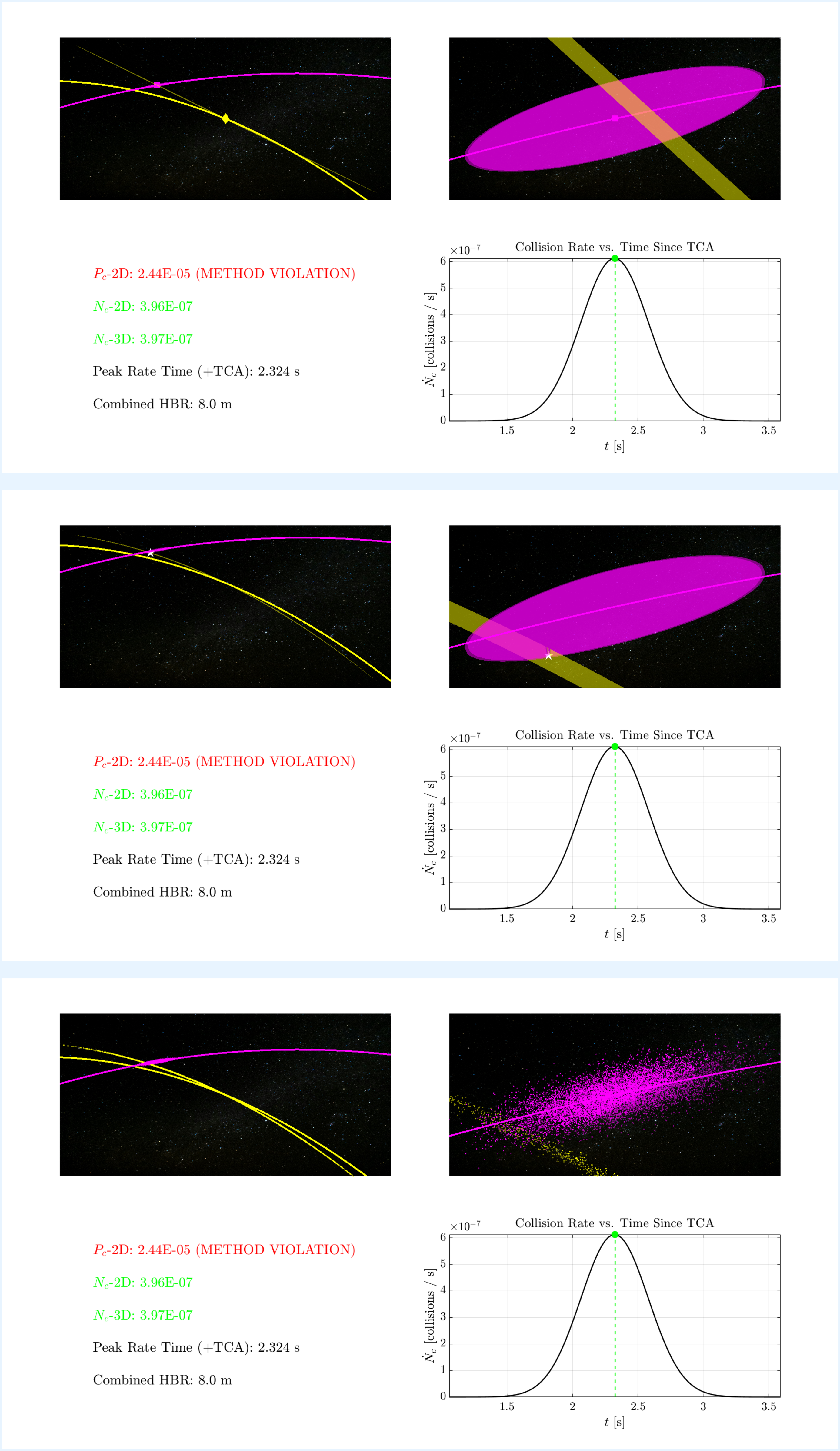

Figure 2. Illustrations of the ellipsoid (top), bananoid (middle), and point cloud (bottom) visualization methods for the conjunction illustrated in Figure 1, which includes a non-rectilinear pass and therefore fails 2D-P_c and the ellipsoidal visualization.

Method Details

Ellipsoid

- Represents uncertainty distributions as shells corresponding to a desired n-σ surface in *Cartesian* space
- Simple to derive and visualize from covariance matrices
- Applicable to typical conjunction geometries

Bananoid

- Represents uncertainty distributions as shells corresponding to a desired n-σ surface in *equinoctial* space
- Moderately computationally intensive, but accurate for conjunctions where rectilinear assumptions are violated

Point Cloud

- Represents uncertainty distributions as a set of samples drawn directly from the underlying distribution in equinoctial space
- Computationally intensive, but free of underlying assumptions used in ellipsoid and bananoid methods

Conclusions

- The bananoid method is versatile and best suited to a wide variety of conjunction geometries
  - Effective for a wide range of relative velocities and clock angles, as well as for extended-duration conjunctions
- Direct visualization provides an advantageous understanding of the three-dimensional conjunction environment
- Visualization methods can accompany P_c calculations to improve understanding of conjunction events

Future Work

- Extension to cislunar and beyond conjunctions
  - Need new formulations that do not depend on equinoctial coordinates
  - New challenges associated with deep-space orbit determination
- Three-dimensional one-surface/one-cloud visualizations
  - Closer analog to CARA's current conjunction plane plots
  - Better parallels some calculations for determining P_c

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