

Conjunction Risk Assessment and Avoidance Maneuver Planning Tools

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Introduction

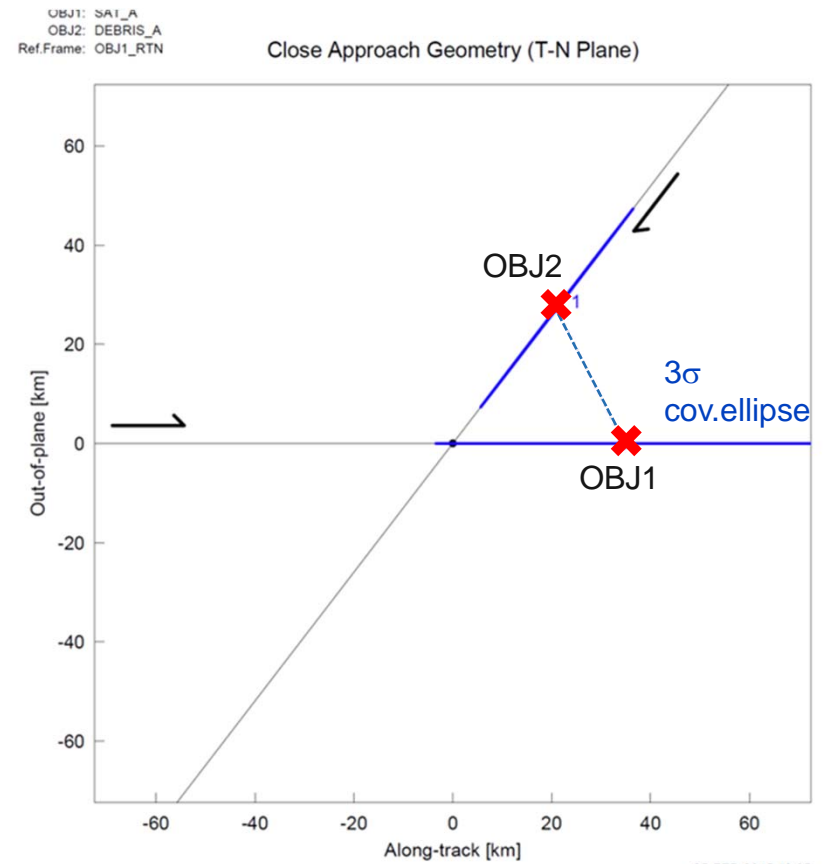
- Collision avoidance operation
 - Conjunction **detection**
 - Conjunction **risk assessment**
 - Conjunction **mitigation**
- Risk assessment
 - Numerous conjunctions are reported
 - If critical, orbit refinement or maneuver planning is required
 - Earlier estimation of **possible critical conjunction** is important
- Avoidance maneuver planning
 - Maneuver decision: ~1.0 day before TCA (LEO)
 - To be considered: risk reduction, timeline, orbit control requirements...
 - Earlier estimation of **possible avoidance maneuver** is important



Conjunction Risk Assessment

Problem:

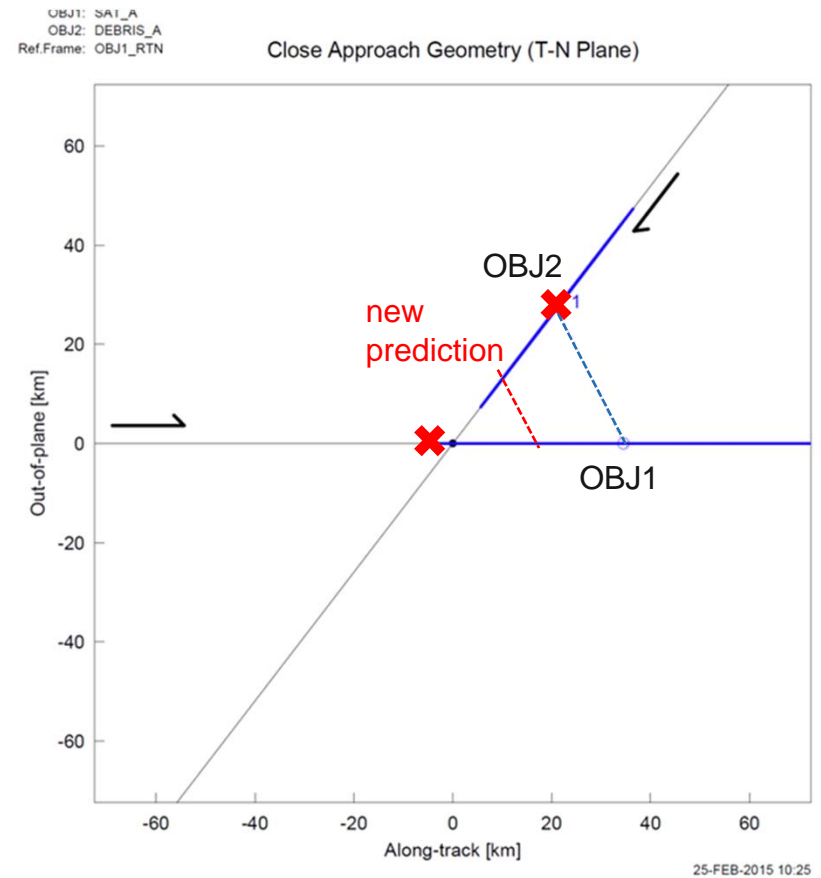
- Prediction changes due to orbit uncertainties especially in along-track
- TCA, conjunction geometry, PoC change accordingly



Conjunction Risk Assessment

Problem:

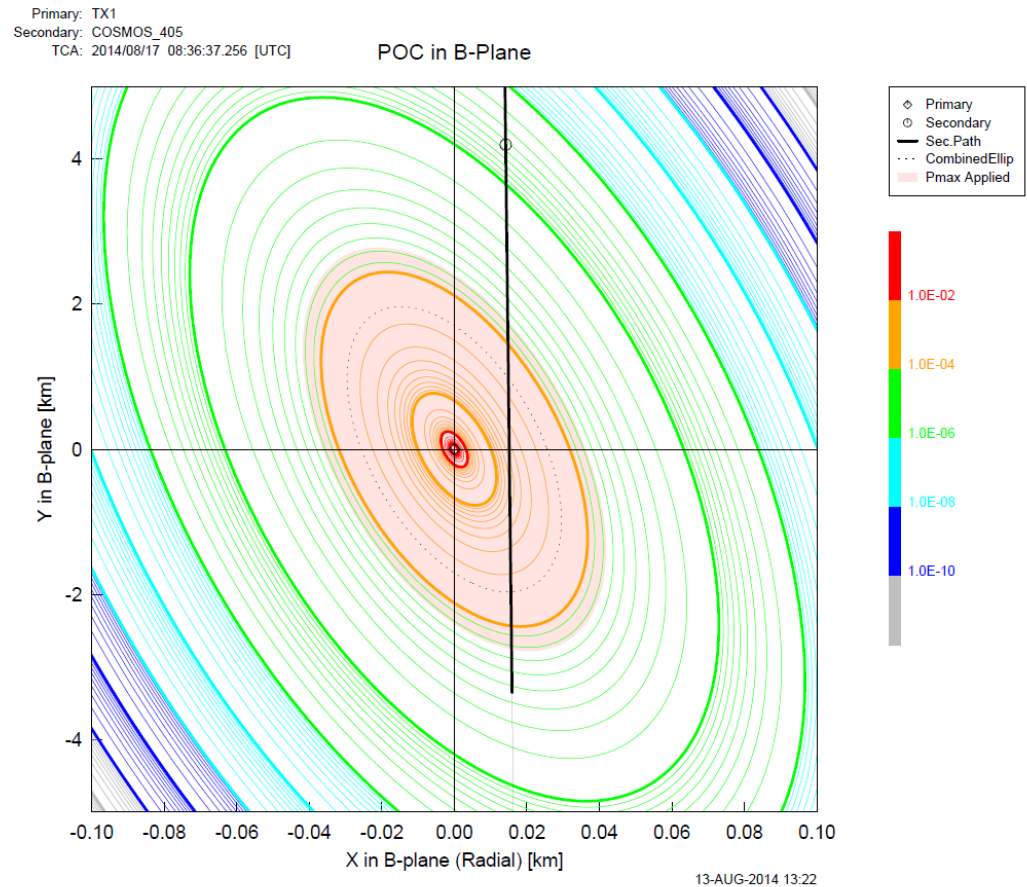
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Collision Probability and Geometry Visualization

Visualization in B-plane

- PoC contour line
- Area where max.PoC is applied
- Object position (total dist., radial dist.)
- Object path due to along-track orbit uncertainties



Avoidance Maneuver Analysis

- Visualization of maneuver effect to conjunction geometry and PoC
 - maneuver options: different size, direction, epoch
 - In-track maneuver is implemented
(easily executable, fuel efficient, easy to come back to original orbit)
- Operator selects a suitable solution considering:
 - risk reduction, timeline, orbit control requirements
- The avoidance maneuver analysis for a single object encounter



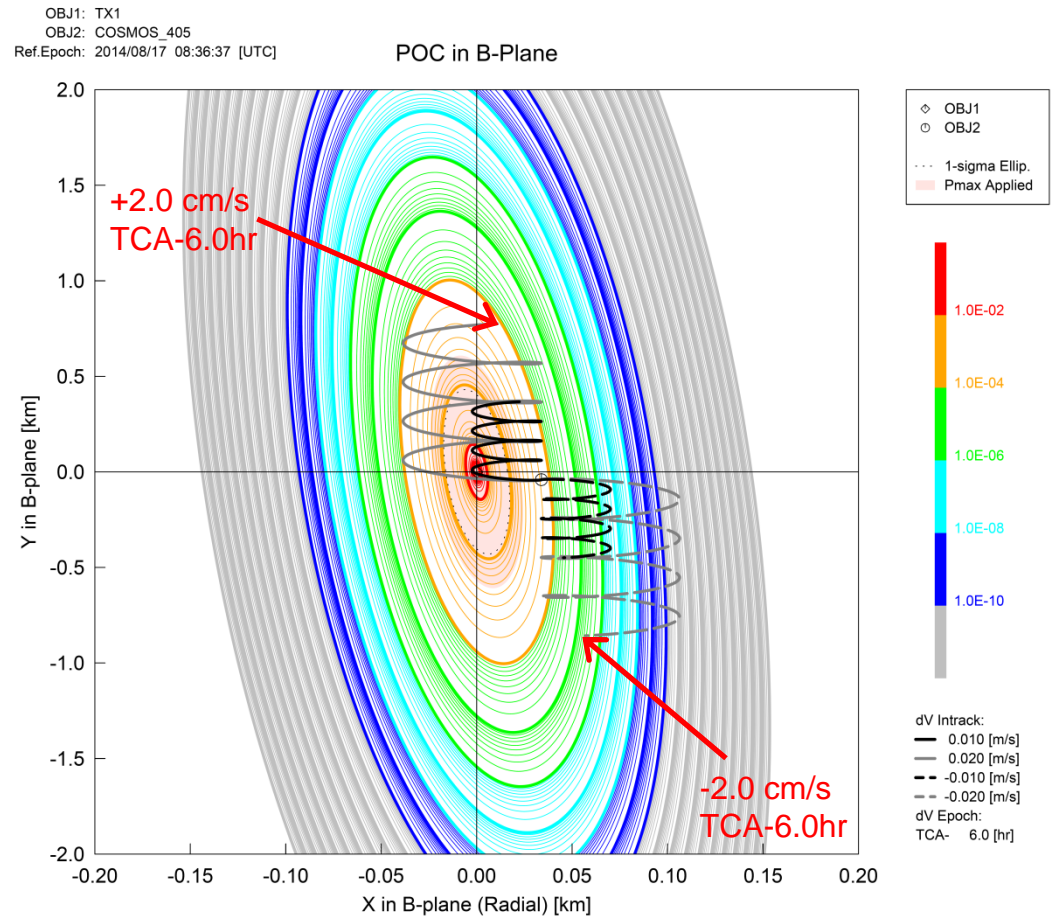
Maneuver Effect Visualization

Visualization in B-plane

- Object trajectories for four man. options starting from TCA-0.0 hr (different size/direction)
- Max.radial separation achieved at TCA-(odd)×(half orb.period)

$$\Delta a = \frac{\Delta D_R}{2} \approx 2 \cdot \frac{\Delta v}{v} \cdot a$$

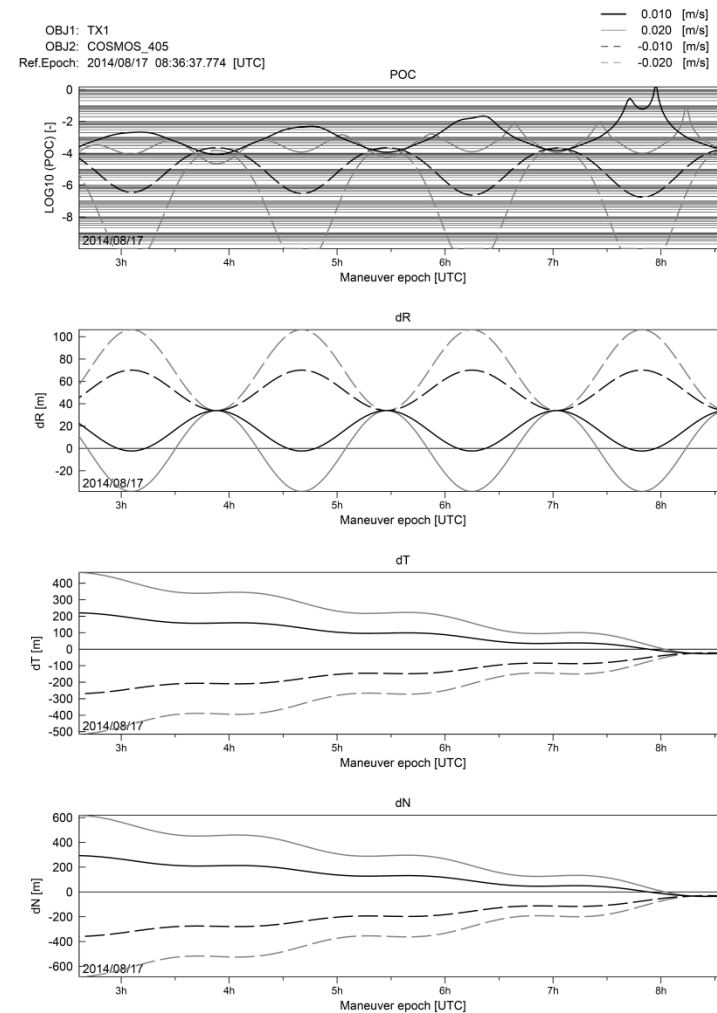
- Rel. position shift along the path line due to tangential shifts



Maneuver Effect w.r.t Maneuver Epoch

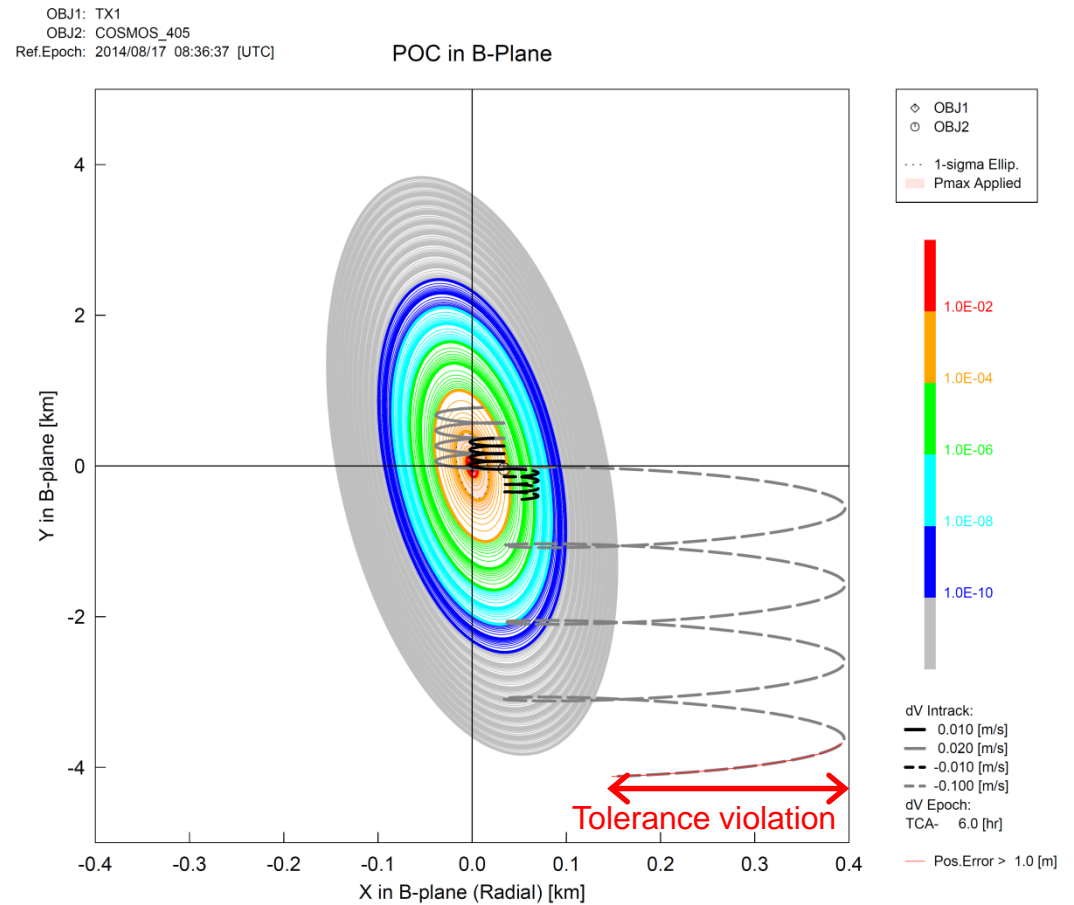
Additional product

- PoC, relative position change according to the maneuver epoch
- Not affected by B-plane difference btwn. original and new TCA







B-plane Error Consideration

- B-plane difference cannot be negligible for:
 - larger man.size
 - man.timing much prior to TCA
- Trajectory is distinguished when resulting rel.position difference exceeds a defined torelance
- For nominal cases, the error is negligible



Application to Operational Process

- Main orbit source for objects: CDM from JSpOC
- E-mail alert for each conjunction
 - Delivered to FD on-call team & project e-mail list
 - E-mail contains:
 - prediction summary and plots,
 - additional plots for maneuver planning and radar tracking (for ,P>5')
- Subject contains:
 - project, object ID, time to TCA,
 - PoC indication (**P>-4** **P>-5** **P>-6**), new event indication (,NEW')

 @ Flight Dynamics Operations	JSpOC warning for AISAT-32371 (TCA-3.2d P>-6)
 @ Flight Dynamics Operations	JSpOC warning for TD1-39134 (TCA-6.5d P>-4)
 @ Flight Dynamics Operations	JSpOC warning for TX1-33679 (TCA-5.6d P>-5)
 @ Flight Dynamics Operations	JSpOC warning for BIR-27115 (TCA-4.3d NEW)

- List of all predicted events



TSX/TDX Conjunction Handling

- TerraSAR-X (2007-) / TanDEM-X (2010-)
 - 514 km altitude
 - TSX: Controlled against a reference orbit inside a tube of 250 m radius
 - TDX: Flying in a close formation with a minimum distance < 300 m



TSX/TDX Conjunction Handling

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 - 514 km altitude
 - TSX: Controlled against a reference orbit inside a tube of 250 m radius
 - TDX: Flying in a close formation with a minimum distance < 300 m
- TSX Collision Avoidance
 - Change execution time/size of regular maneuver, TDX replicates the maneuver
 - TSX perform two maneuvers for collision avoidance and for re-acquisition of reference orbit
 - TDX replicates the maneuvers (fuel-expensive)
 - TDX remains passive → formation has to be re-acquired afterwards (time-consuming)
- TDX Collision Avoidance
 - TDX performs several maneuvers for collision avoidance and formation re-acquisition (TSX remains passive)



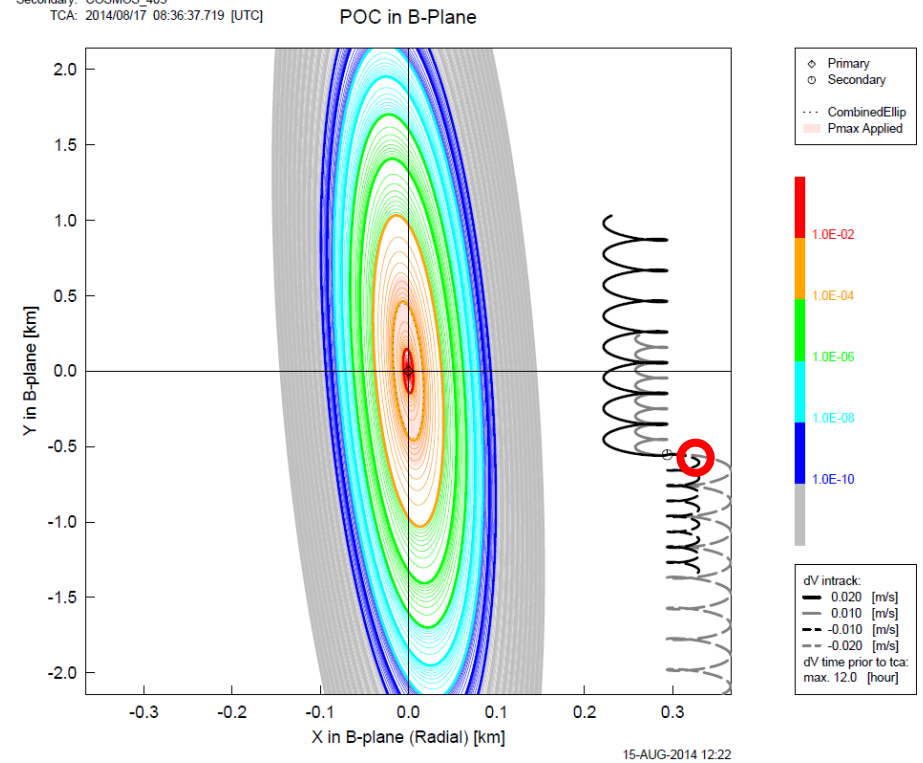
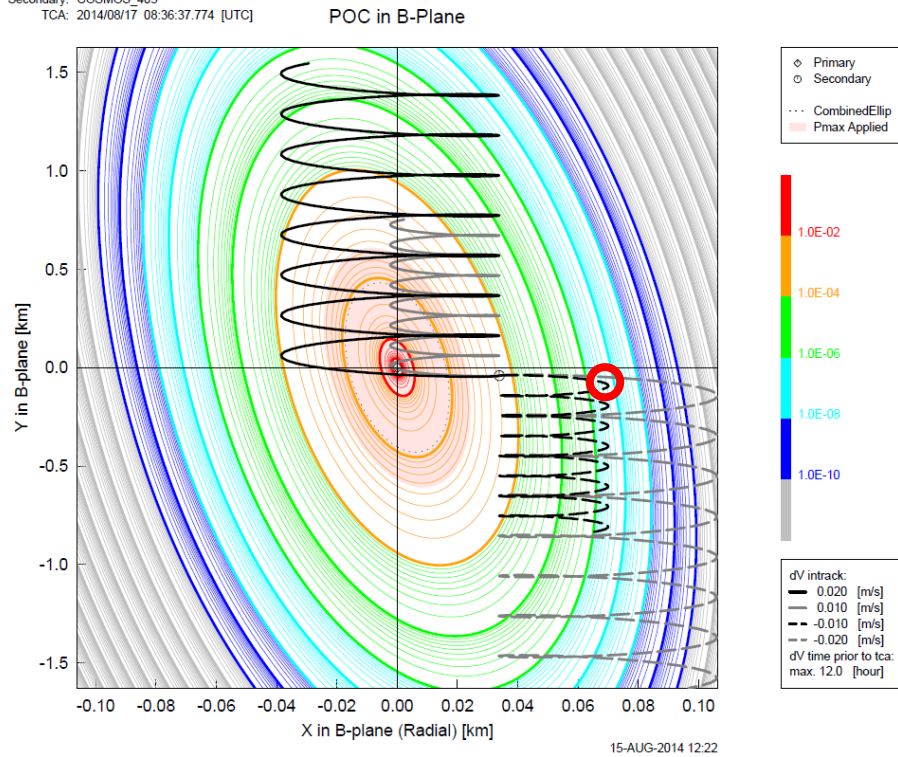
TSX/TDX Avoidance Maneuver Planning

COSMOS 405 encounter to TSX

COSMOS 405 encounter to TDX

Primary: TX1
Secondary: COSMOS_405
TCA: 2014/08/17 08:36:37.774 [UTC]

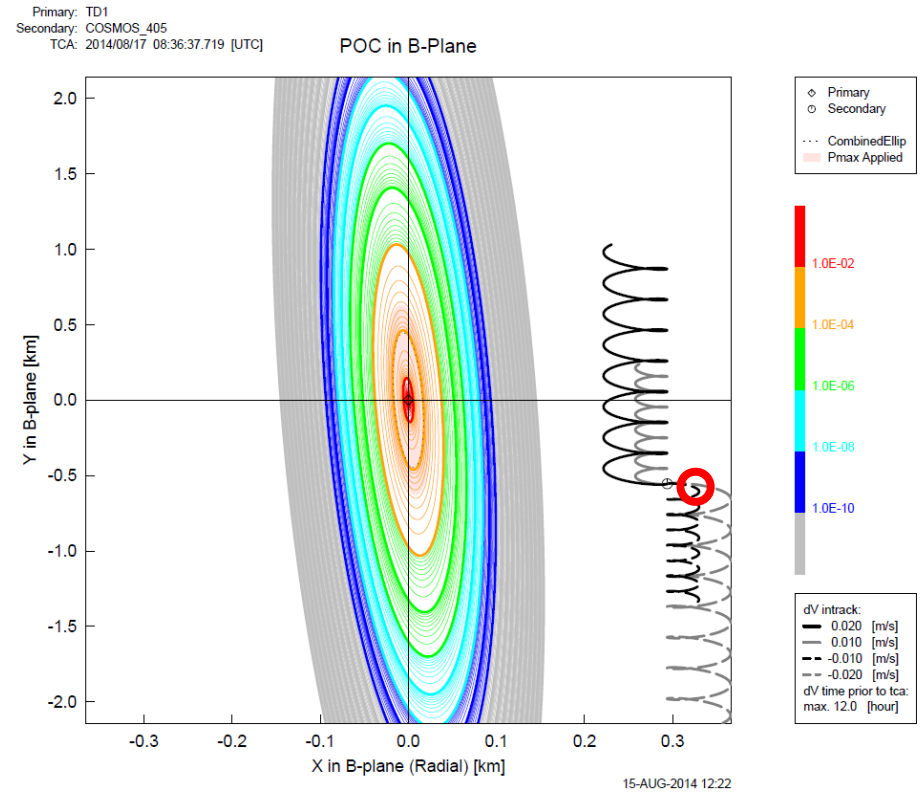
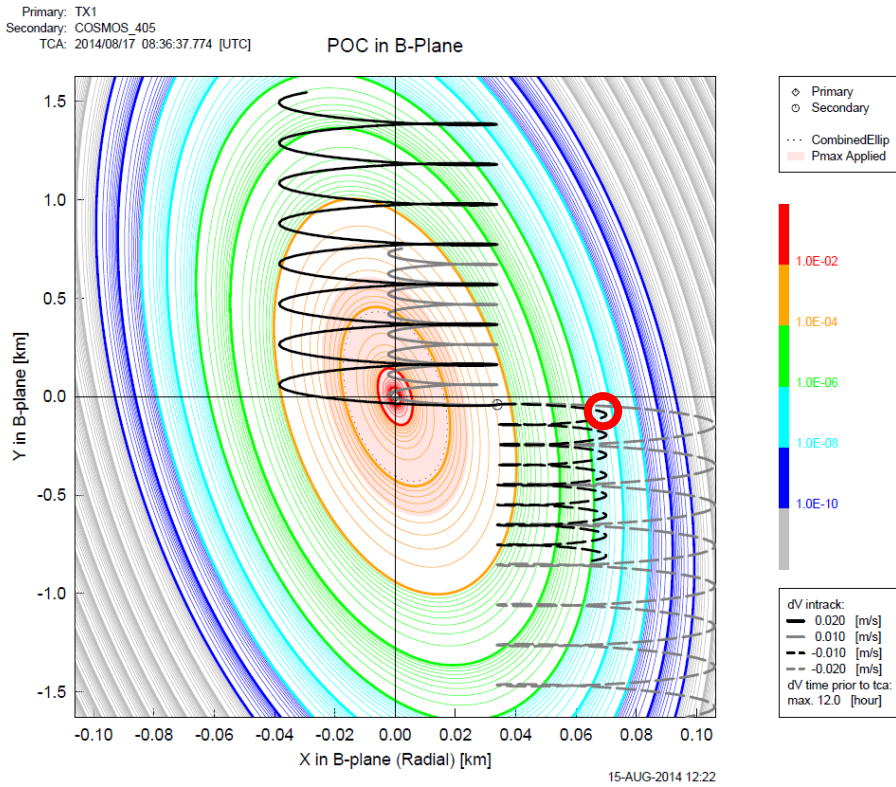
Primary: TD1
Secondary: COSMOS_405
TCA: 2014/08/17 08:36:37.719 [UTC]



TSX/TDX Avoidance Maneuver Planning

COSMOS 405 encounter to TSX

COSMOS 405 encounter to TDX



**CAM of -0.5 cm/s a half orbit before TCA was selected for both satellites
(Control requirements were satisfied → no correction maneuver was necessary)**



Summary

Tools for handling short-term sigle encounters were presented

- Conjunction risk assessment tool
 - Collision probability and geometry visualization in B-plane
 - Object path due to along-track orbit uncertainties

- Avoidance maneuver analysis tool
 - Visualization of maneuver effect to collision probability and geometry
 - Operator selects a suitable solution considering risk reduction and operational requirements
 - B-plane error effect is negligible for nominal encounters

- Application to operational proccess
 - Tools are especially useful for satellites flying in a close formation with high control requirements

