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Orbit Determination Sensitivity Analysis for the Planned Europa Multiple Flyby Mission

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Agenda

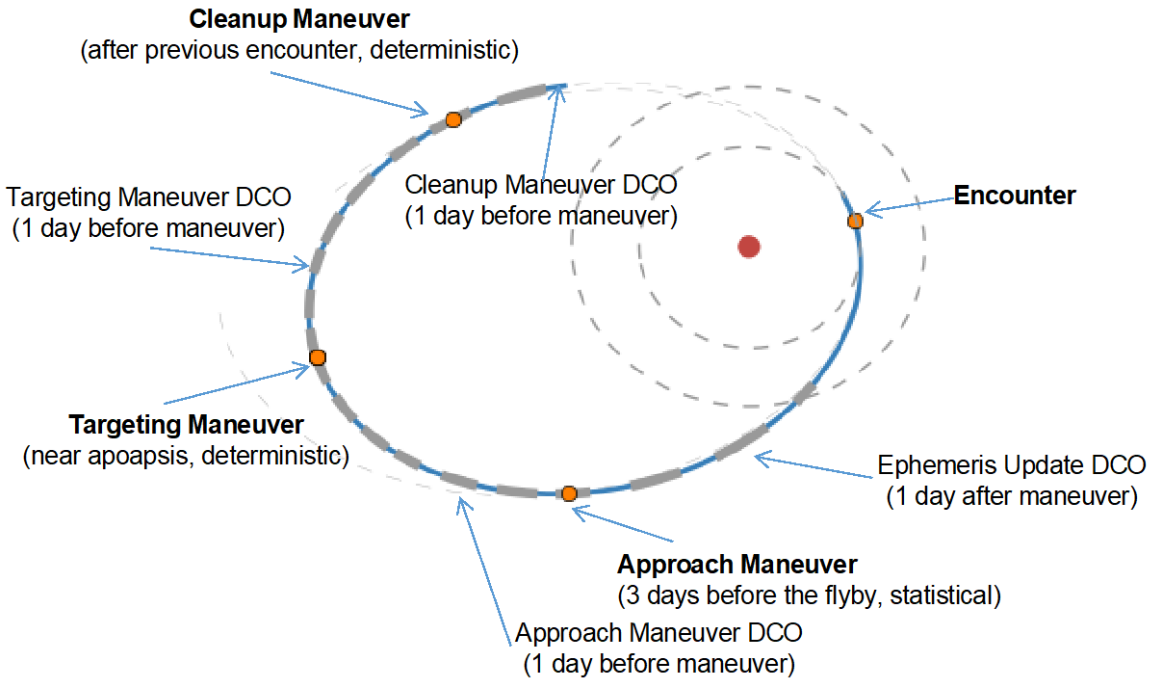
- Planned Europa Mission Background
- Navigation Concept
- OD Sensitivity Study
- Orbit Determination Setup
- Maneuver Analysis
- Covariance Analysis
- Baseline Case OD Mappings
- OD Sensitivities
  - Delivery and Encounter-2 days update
  - Filter and Execution Error Variations
- Summary

Planned Europa Mission Background

- Planetary Science Decadal Survey 2011: Europa most likely solar system body to harbor life
  - Initially studied as JIMO/JEO orbiter concepts
  - De-scoped to orbiter, multiple flyby, lander options
- Multiple flyby mission selected, now Phase A
  - Instrument payload selections made
  - Magnetometer, imaging spectrometer, radar, thermal emission, dust analyzer
  - Instruments point nadir at Europa close approach
  - Still developing flight system

Navigation Concept

- Direct launch via Space Launch System
- 2022 launch, 2025 arrival at Jupiter
- 42 Europa flybys baselined
- Three maneuvers between flybys (generally)



OD Sensitivity Study

- Determine sensitivity of orbit determination delivery and knowledge uncertainties through parametric variation of baseline tour navigation strategy
- Covariance analysis to determine orbit determination uncertainties (linear)
- Monte Carlo maneuver analysis to compute distribution of potential executed maneuvers (nonlinear)
- Iterate between the two starting with no OD errors

Orbit Determination Setup

- Processing assumptions
  - Arc: epoch near apojove, encompasses two flybys
  - Doppler and range data every other 8 hours
  - CU/TRG/APR maneuver each arc
  - Uncorrelated stochastic white noise for mis-modeled small forces

Table 1. Baseline Orbit Determination Assumptions

Tracking Data	2-way Doppler and range collected every other 8 hour pass
Doppler data weight	0.1 mm/s per 60-sec integration for SEP $> 15°$ 1 mm/s for $7.5° <$SEP$< 15°$ 5 mm/s for SEP $<7.5°$, no data SEP $<3°$
Range data weight	3 m for SEP angles $> 7.5°$, no data SEP $< 7.5°$
Tracking exclusion near Europa flybys	no data from 12 hours before to 12 hours after flyby
Un-modeled accelerations	4.5 x 10^{-6} mm/s per axis stochastic white noise, 8 hour batches
Nominal data cutoff for maneuvers	1 day before maneuver execution time

Orbit Determination Setup

- Filter setup
  - Estimated parameters have a priori uncertainty reduced in filter
  - Considered parameters only contribute uncertainty

Table 2. Filter parameter arc setup

Parameter	Unit	Estimated/Considered	a priori σ
Epoch state S/C position - X/Y/Z	km	Estimated	15
Epoch state S/C velocity - X/Y/Z	cm/s	Estimated	5
Jupiter Ephemeris Set III parameters	-	Estimated	de430 covariance
Jupiter Satellite States pos/vel	km & km/s	Estimated	jup310 covariance
Jupiter Harmonics and Pole	-	Estimated	jup310 covariance
Jupiter and Satellite GMs	km^3/sec^2	Estimated	jup310 covariance
Earth polar motion - X/Y	arcsec	Considered	3E-04
UT1 bias	sec	Considered	4.25E-05
DSN station locations	cm/arcsec	Considered	3 / 1E-03
Troposphere path delay - wet/dry	cm	Considered	1/1
Ionosphere path delay - day/night	cm	Considered	55/15

Maneuver Analysis

- Monte Carlo simulation of trajectories
  - Execution error based on designed maneuver
  - Produces maneuver covariance
  - Iterated with OD covariance analysis
- Gates Error model for maneuver execution
  - Fixed and proportional errors for each burn
  - Magnitude and pointing error components
  - 8x22N configuration for magnitudes > 0.21 m/s

Table 3. Gates Model for Tour Maneuver Execution Errors (1σ)

	Error Component (per axis)	8x22N configuration	4x22N configuration
Magnitude	Fixed Error (mm/s)	4.67	4.67
	Proportional Error	0.33%	1.00%
Pointing	Fixed Error (mm/s)	3.33	3.33
	Proportional Error (mrad)	6.67	6.67

Maneuver Analysis

- Largest increase: scale satellite covariance x5
  - Largest effects in beginning of tour
- Largest decreases:
  - ½ all Gates Model errors and telemtry cases

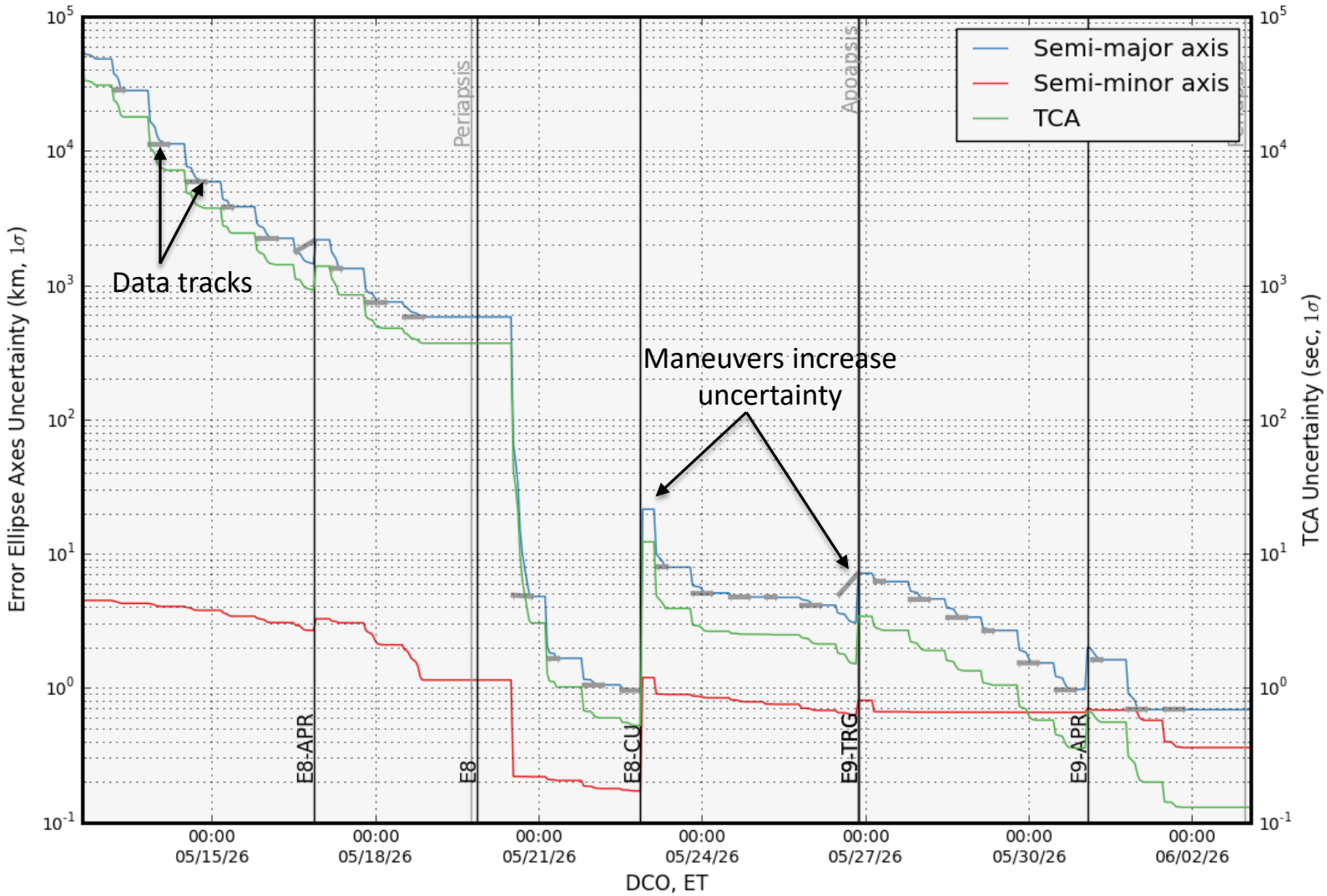
Table 4. Tour ΔV Performance Case Statistics

Case	Mean (m/s)	Sigma (m/s)	ΔV99 (m/s)
Baseline	1309.508	19.056	1358.494
APR-2.5day	1298.568	15.182	1338.688
APR-3.5day	1315.538	16.782	1359.378
16hr DCO margin	1319.184	16.894	1362.763
CU/TRG telemetry	1289.015	12.800	1322.026
CU/TRG/APR telemetry	1288.911	12.804	1321.979
No satellite estimation	1300.370	14.058	1336.974
jup310 cov scaled x5	1356.182	57.271	1514.770
jup230 cov	1305.321	15.596	1346.217
2x all Gates errors	1375.536	30.986	1464.708
1/2x all Gates errors	1275.263	10.937	1302.513

Covariance Analysis

- Determines expected level of error at flybys and maneuver design DCOs
- Simulated Doppler and range observables processed in least-squares navigation filter
- Uncertainty represented as B-plane ellipse or Radial, Along-track, Cross-track coordinates
- Maneuver execution error applied stochastically at maneuver times

Covariance Analysis

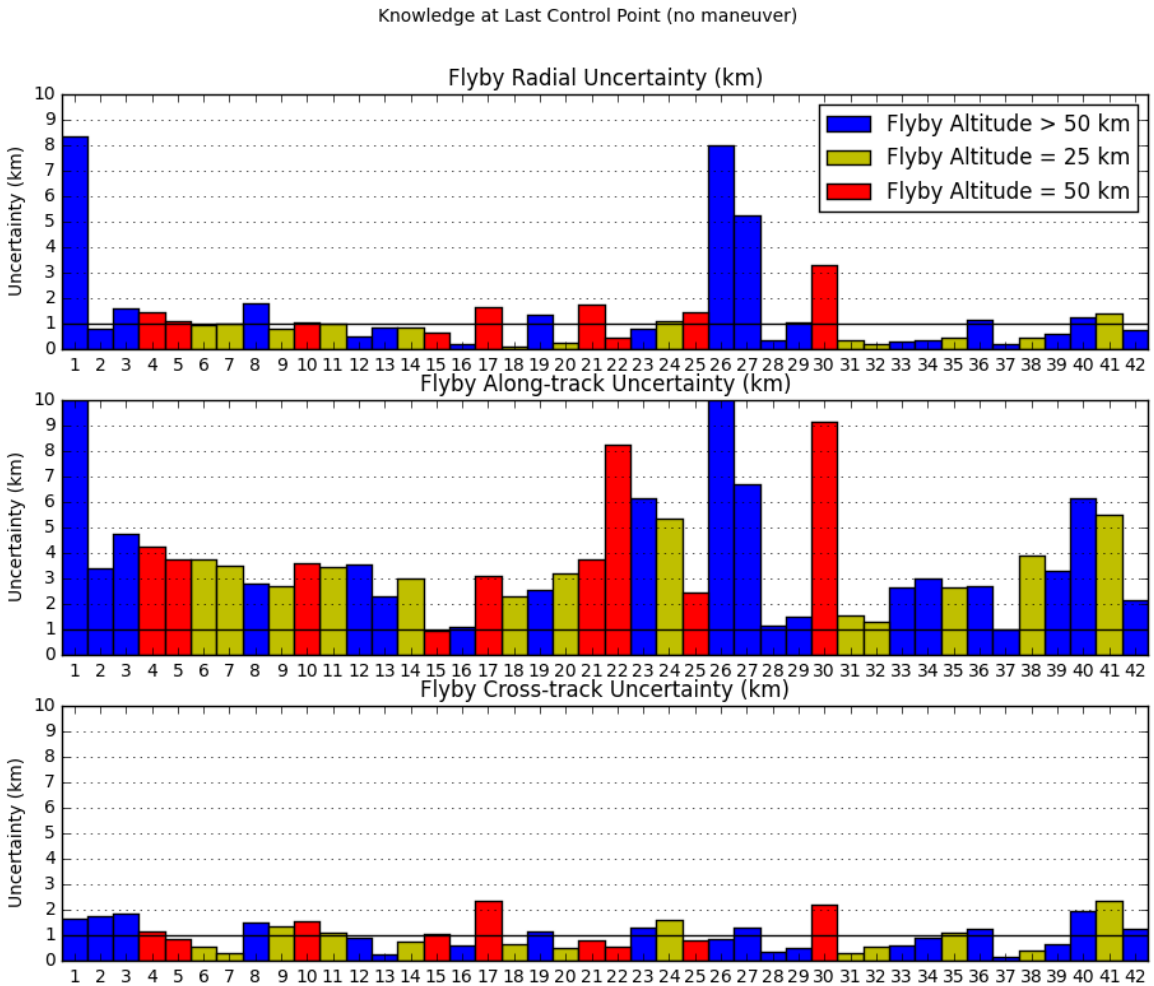


Baseline OD Mappings

- Knowledge at Last Control Point
  - OD knowledge at design DCO of APR maneuver, Encounter-4 days
  - Does not include execution error of APR maneuver
- Delivery from Approach Maneuver
  - Encounter-3 days
  - Includes APR maneuver execution error
- Delivery Knowledge Update
  - Encounter-2 days
  - Accumulates an additional data track

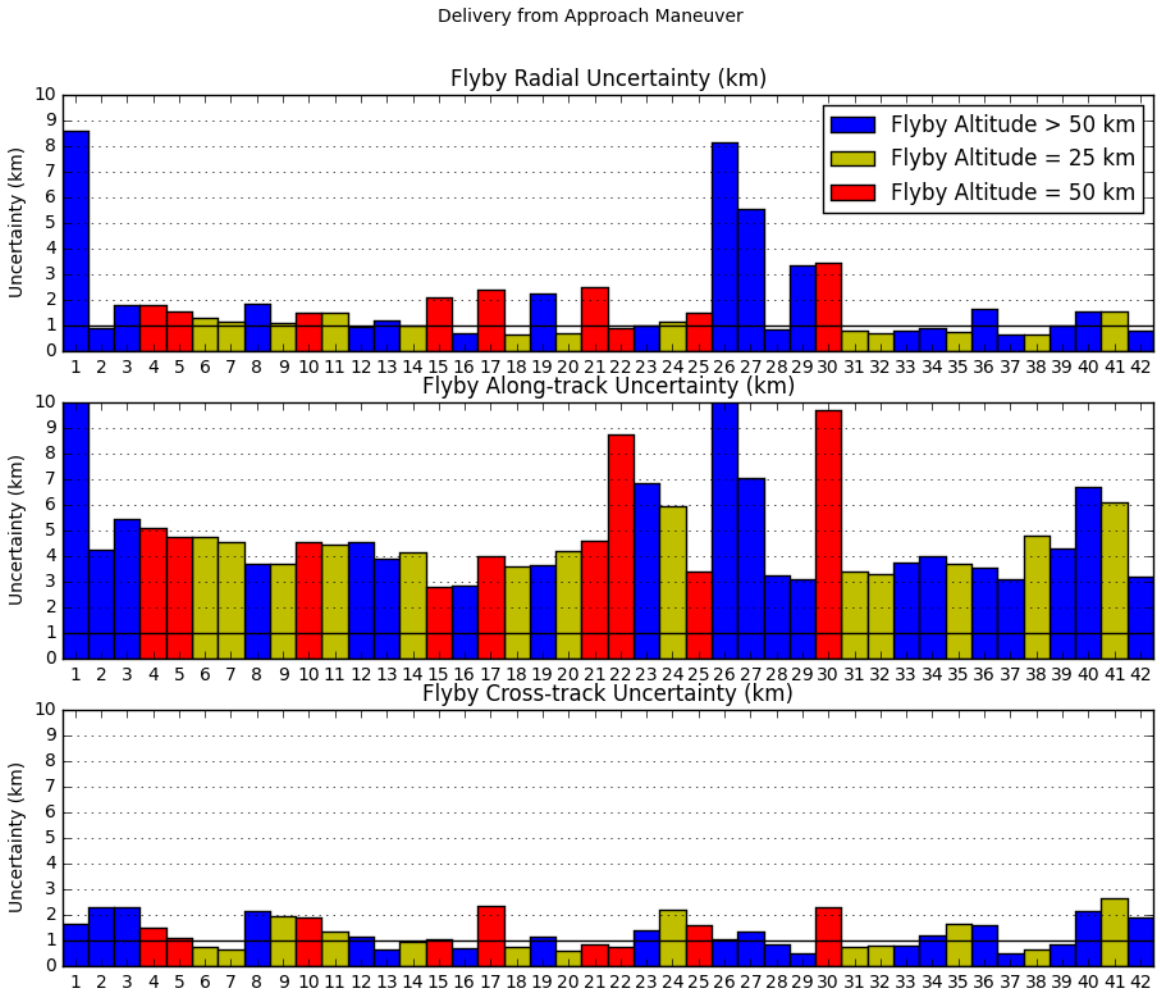
Baseline OD Mappings

- Knowledge: Approach Maneuver Design (1σ)



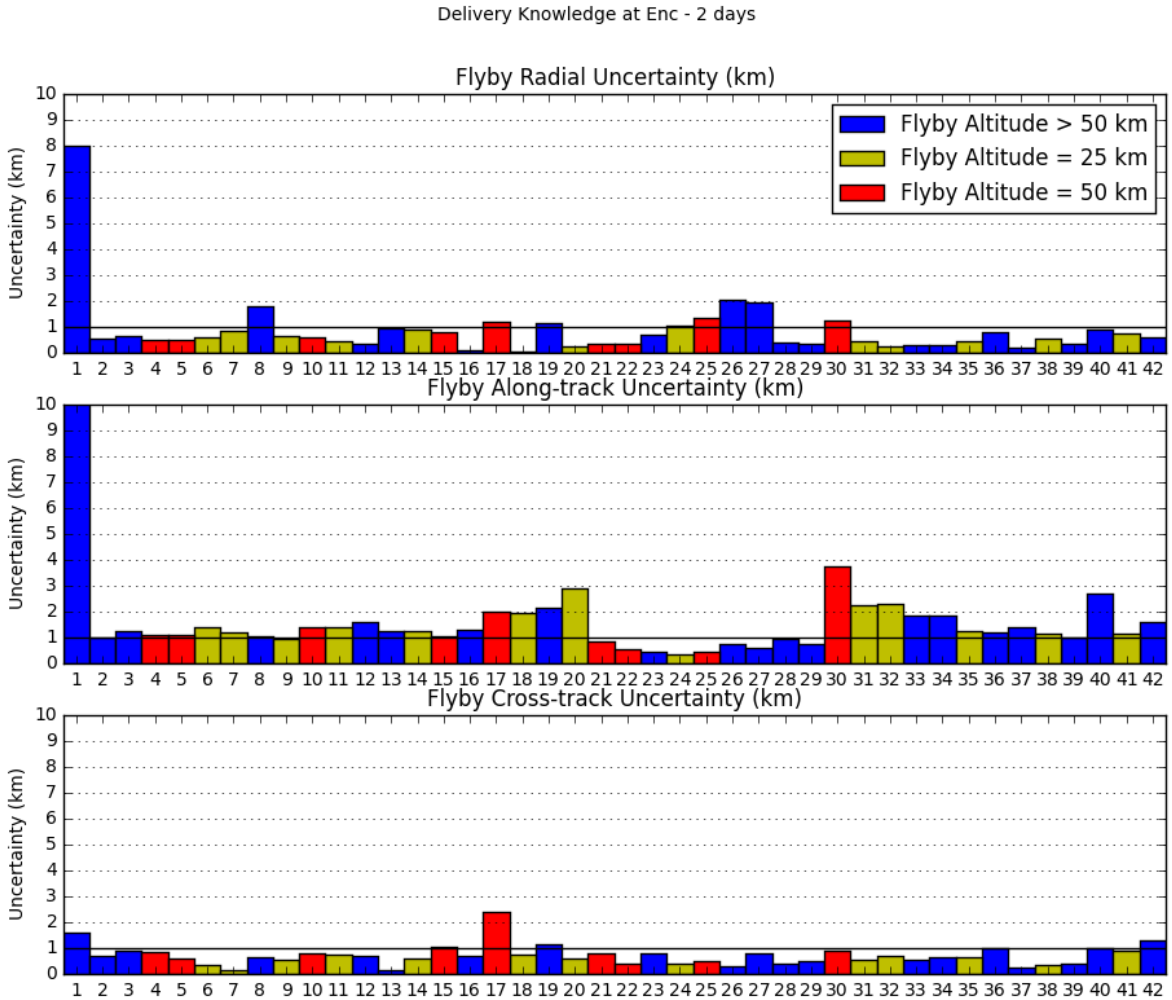
Baseline OD Mappings

- Delivery: Approach Maneuver Execution (1σ)

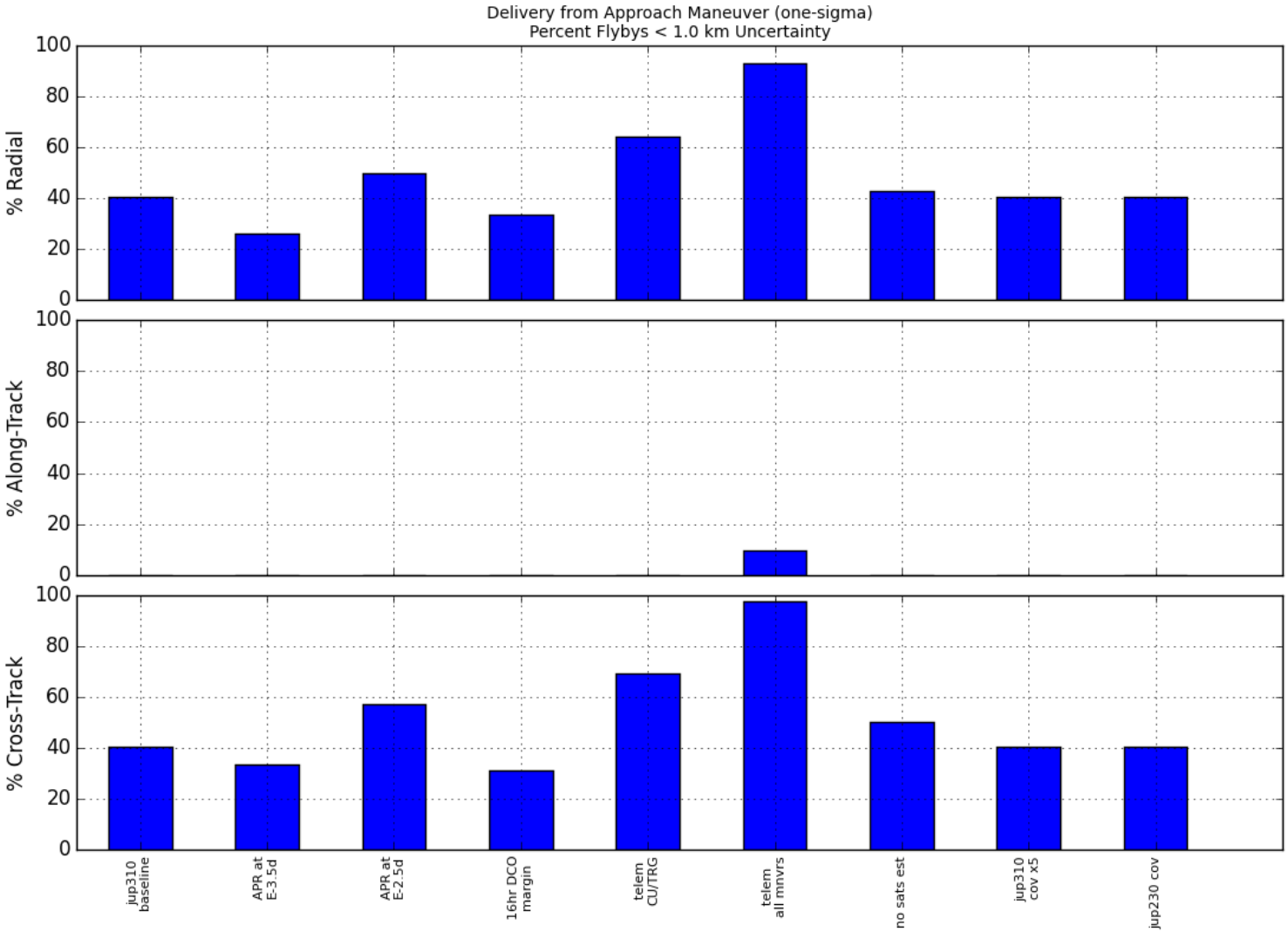


Baseline OD Mappings

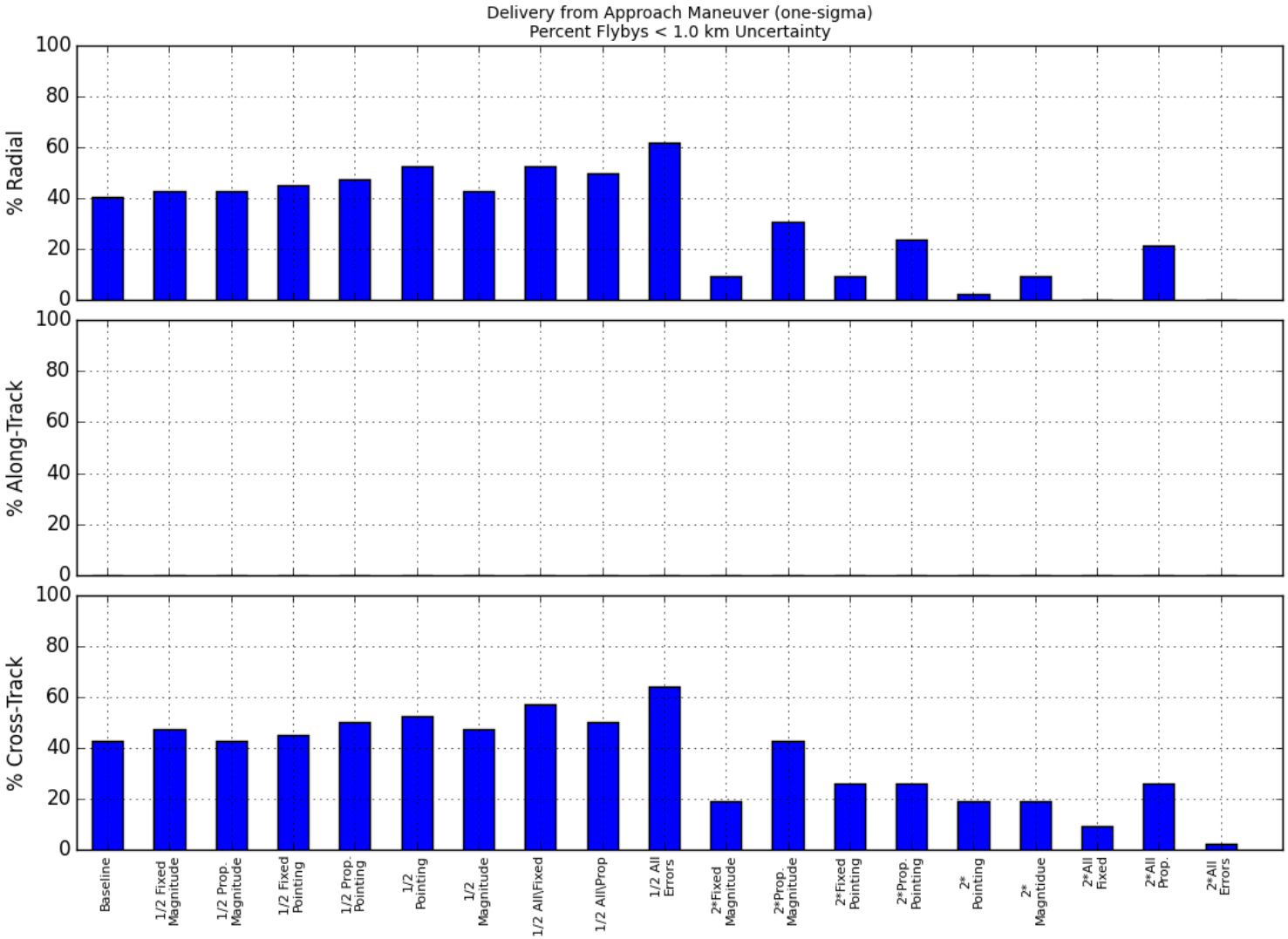
- Delivery: Knowledge Update at E-2 days (1σ)



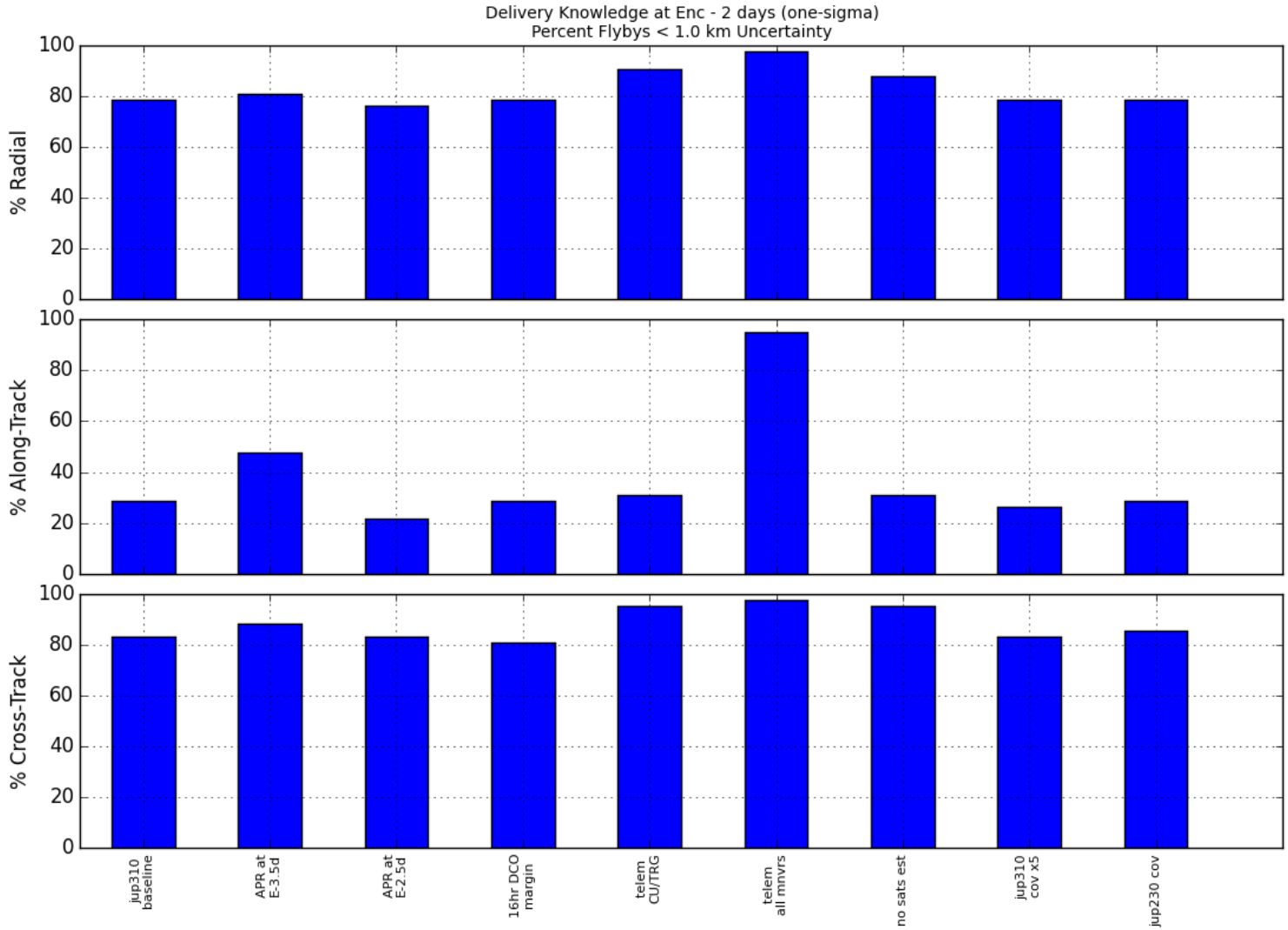
OD Sensitivities – Delivery Filter Variations



OD Sensitivities – Delivery Execution Error Variations



OD Sensitivities – E-2 Update Filter Variations



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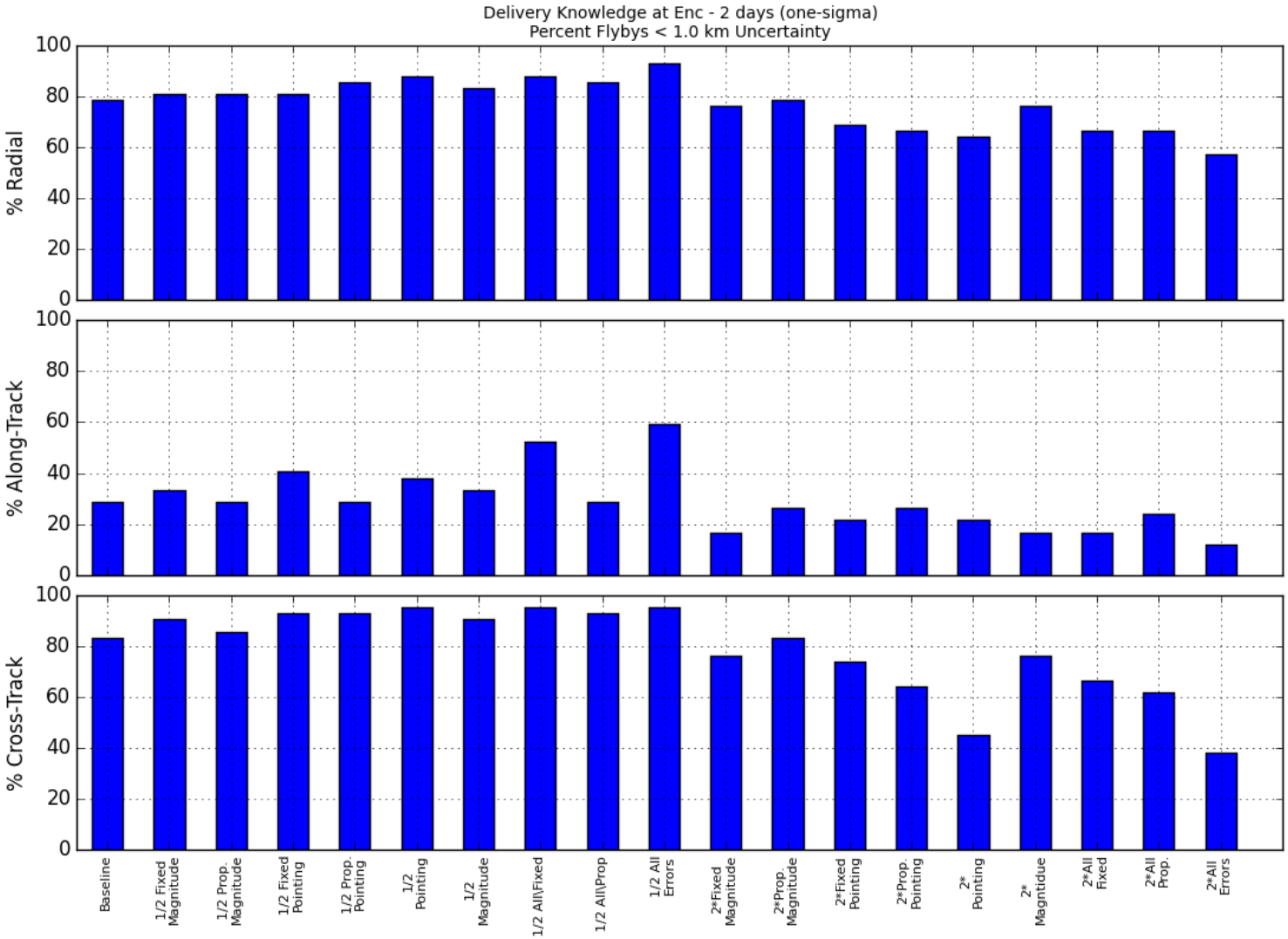
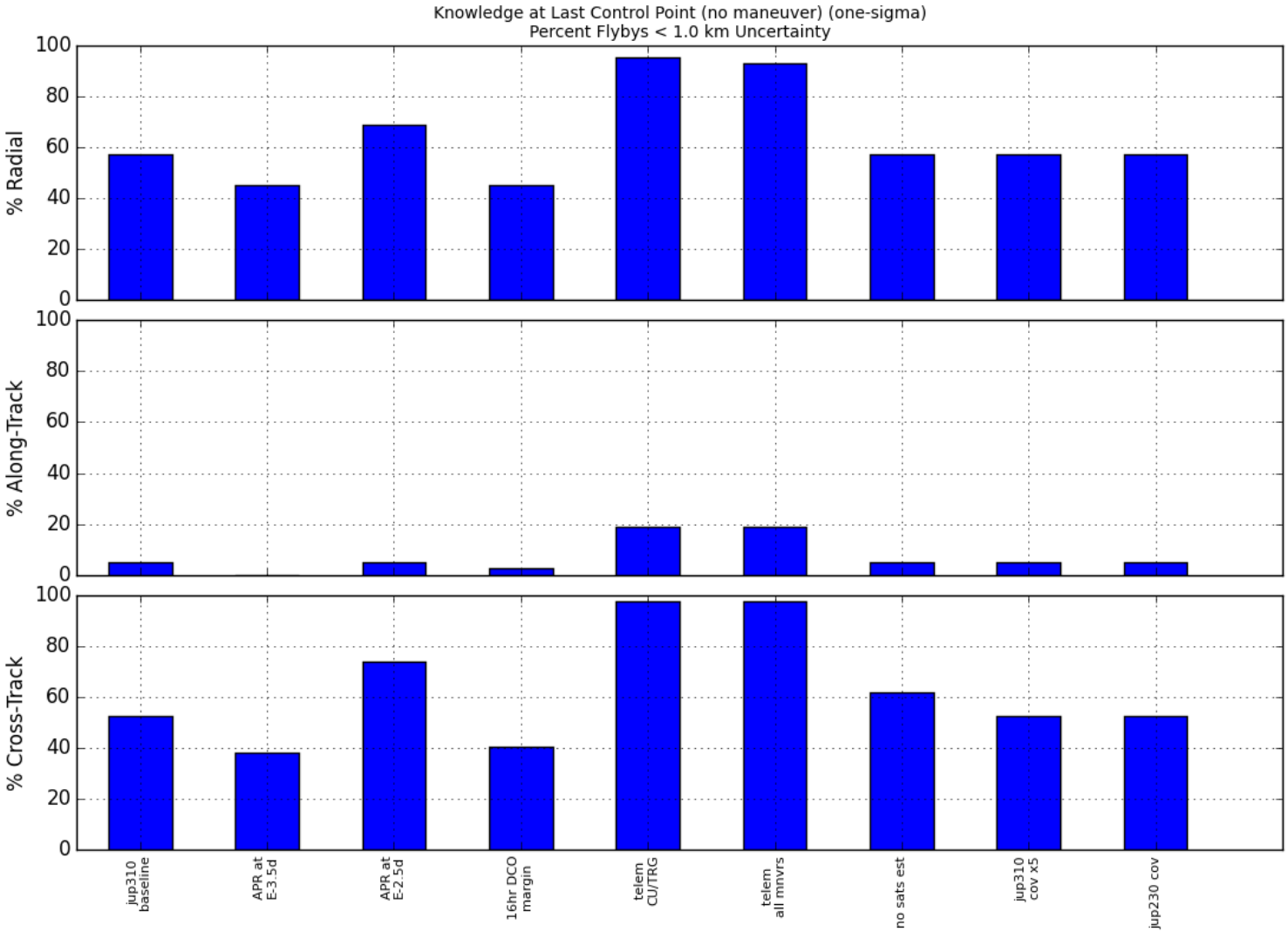
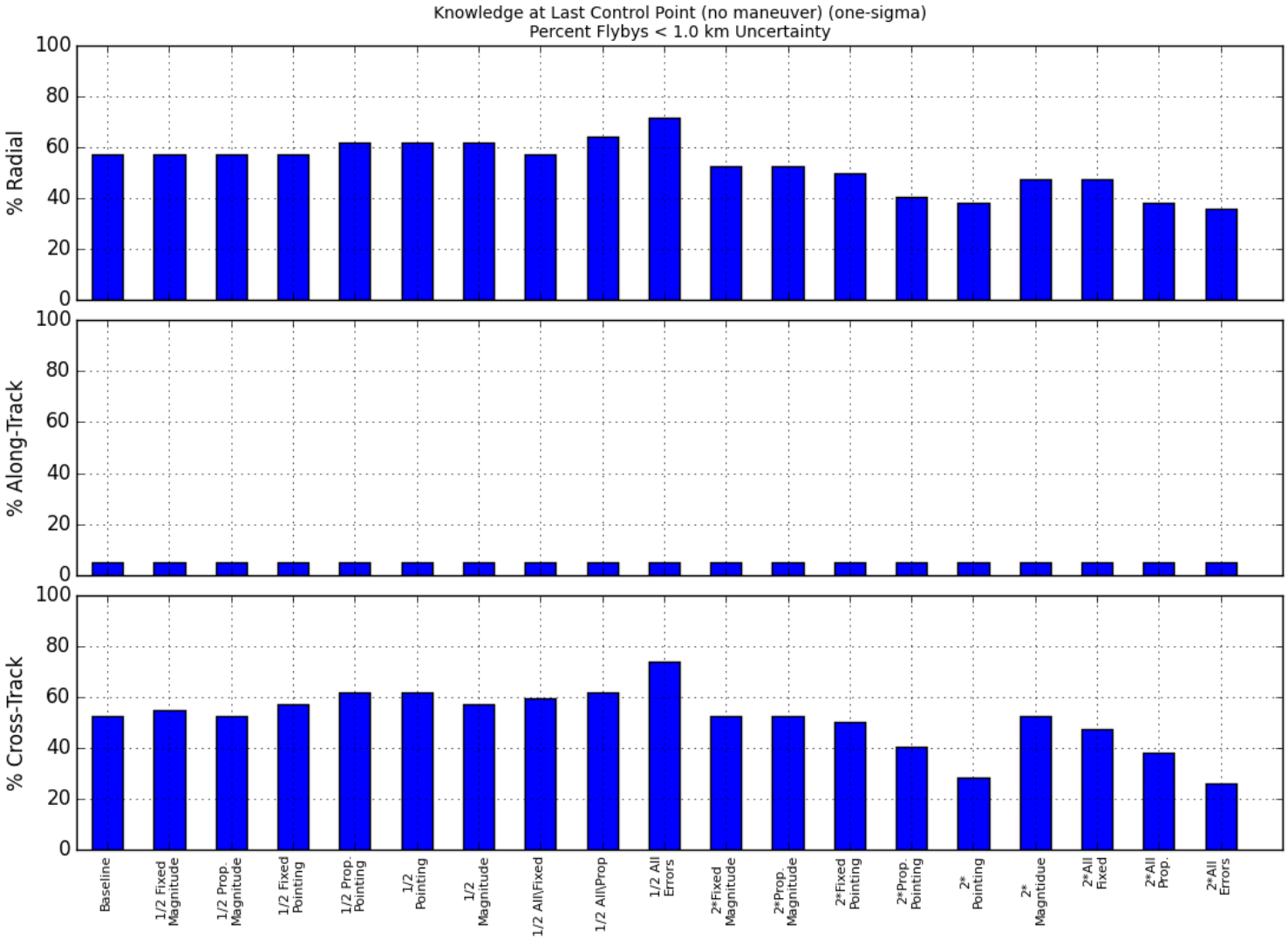


Summary

- 50% (1σ) of flybys with < 1km radial uncertainty baseline
- Increases to 80% of flybys < 1km radial uncertainty with Encounter-2 days update
- Post-maneuver telemetry and halving Gates Model errors both achieve 90% of flybys with < 1 km radial uncertainty
  - Majority of telemetry improvement from CU/TRG
  - Majority of Gates Model improvement from halving fixed errors
- Δ V99 most sensitive to Gates Error model
- Δ V99 sensitive to a priori satellite covariance, due to dispersions early in tour

BACKUP SLIDES

OD Sensitivities – LCntrlPt Filter Variations



OD Sensitivities – LCntrlPt Execution Error Variations