5TH INTERNATIONAL CONFERENCE ON SPACECRAFT FORMATION FLYING MISSIONS AND TECHNOLOGIES

The Design of the Formation Flying Navigation for Proba-3

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INNOVATING SOLUTIONS

INTRODUCTION

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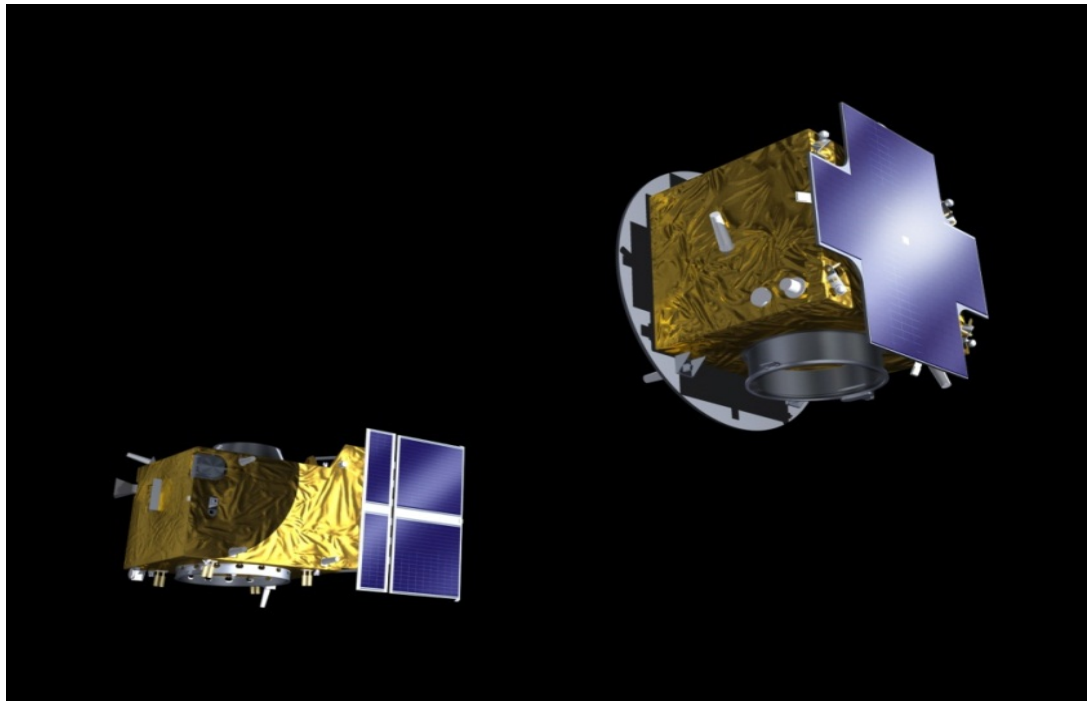
- Performance

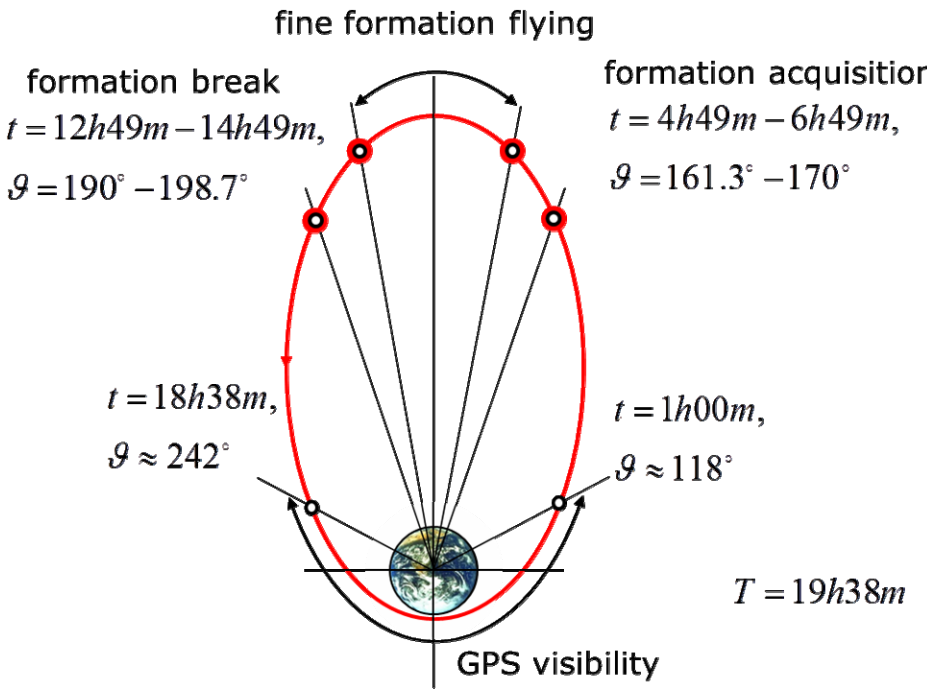


SENER NGC Aérospatiale Ltée NGC Aerospace Ltd

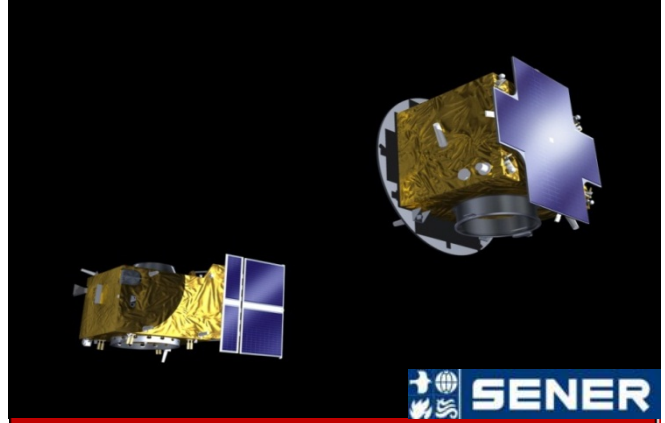
PROBA3 - Mission

- Formation flying in elliptical orbit
  - Science: Solar Coronagraphy
  - Demonstration of Formation Flying
- Occulter SC and Coronograph SC launched in stack configuration and afterwards separated
- Inter-Satellite Distance of 150m during apogee
- High elliptical orbit around Earth
- Nominal routine:
  - 6h of Formation Flying experiments around apogee
  - Formation break
  - Perigee Pass without manoeuvres
  - Formation reacquisition

Parameter	Value
Perigee height	600 km
Apogee height	60530 km
Semi-major axis	36943 km
Eccentricity	0.8111 -
Inclination	59°
RAAN	84°
AoP	188°
Orbital period	19h38m



PROBA3 - Spacecraft



Parameter	OSC	CSC
Area [m2]	1.77	3.34
Wet mass [kg]	211	339
Dry mass [kg]	190	327
SRP coefficient [-]	1.9 (1.5)	1.29
Thrust per thruster [mN]	10	1000

- Actuation
  - **1N** thrusters on **CSC**
  - **10mN** thrusters on **OSC** (CGT)
  - Reaction wheels

- Sensors:
  - STR, Sun sensors, Gyros (both SC)
  - **Formation Flying Metrology:**

    Relative GPS (only available around perigee)

    Coarse Lateral Sensor (CSC, only available around apogee)

    Fine Lateral and Longitudinal Sensor (CSC, only available around apogee)

- SC GNC (NGC Aérospatiale Ltée / NGC Aerospace Ltd) – provides estimates of attitude and absolute position and velocity
- Actuation Manager – provides estimates of actuation levels
- Inter-Satellite Link (both SC)

  not current baseline for FF NAV:
  - Visual Based System (OSC)
  - Shadow Position Sensor (CSC)

FF NAV – Drivers (1)

- **OSC** In nominal operations OSC commands the formation - commands own fine actuation and issues impulsive guidance commands for perigee pass to CSC. However **fine metrology is located in CSC**.

- **Absolute Attitude** - to process measurements and actuation, it is necessary to know the absolute attitude of both vehicles. Sent through ISL.

- **Metrology Acquisition and Handover** - Relative metrology doesn't always allow building a relative state

- **CLS** – FOV ± 5 deg , accuracy 12 arcsec
  FLLS – FOV ±50 arcsec , accuracy 0.04 arcsec (lat), 20.8 micron (lon)

- Synchronization - The necessary data to process a measurement at OSC FF NAV lags approximately 4 seconds behind the time at which the solution is requested.

- The **dynamic environment** is well known (relative motion in elliptical orbits around a spherical central body, plus corrections for SRP).

- **RGPS integration -** solution provided to the FF NAV is the result of a filtering and processing of RGPS data using orbital dynamics. It is not a raw measurement subject to uncorrelated noise.

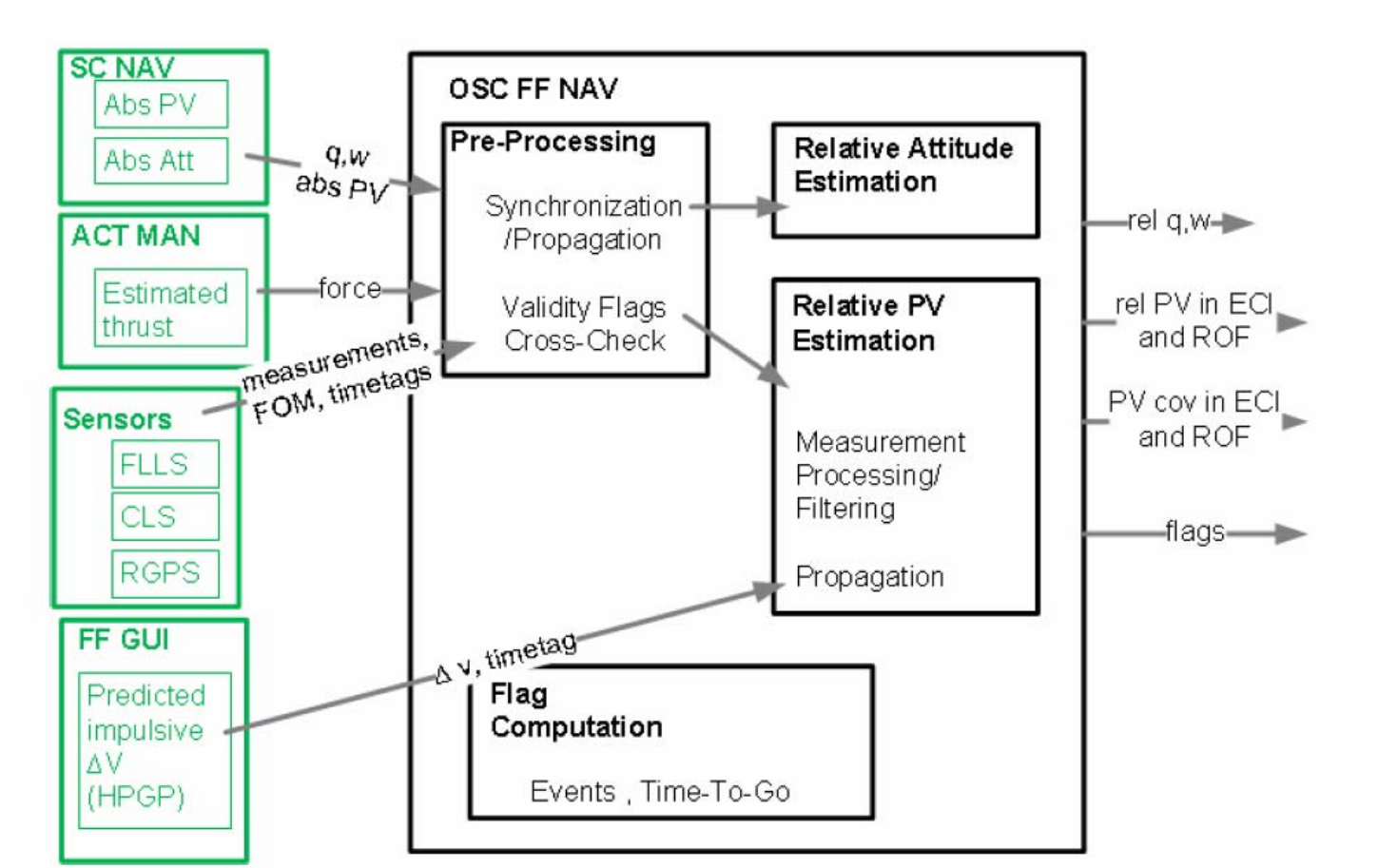
FF NAV – Drivers (2)

Objectives

- **FF Sensor** Data acquisition, pre filtering, synchronization, calibration, cross check
- **Absolute Navigation Data** acquisition, pre filtering, synchronization, cross check
- Transform the measurements and absolute navigation solution into a **common relative reference frame**
- Process and **incorporate measurements**, absolute navigation, and commands, filter them **through a dynamic model** and compute the navigation solution.
- Output filtered relative attitude/rate , PV, associated covariance matrices validity/accuracy flags
- Propagate solution to the required times of interest
- Provide Navigation Solution at 1 Hz

FF NAV – Design (1)

The synchronization and processing of measurements from **a high number of sources**, with different **levels of accuracy**, misalignment, bias and **latencies**, and whose **availability varies with flight phase**; the processing of these measurements concurrently in two spacecraft **that communicate through an Inter-Satellite Link** which introduces significant latency; and their filtering in **a local reference frame**, through a **model of natural and forced relative** dynamics in a highly elliptical orbit.



FF NAV – Design (2)

Concept

- The design choice was thus to have a **Kalman filter the core of the system,** where states are **relative position and velocity in the LVLH reference** frame.
  - The propagation-correction cycle runs up to **a cycle correction time**, which is an adjusted measurement timetag (virtual if no measurement is available).

- The correction step uses **all the available relative measurements** that it has to improve the solution – CLS , CLS(lat) + FLLS (long) or FLLS

- **Pre-processing block** verifies (cross checks), synchronizes (propagates/backpropagates) all the buffered SC GNC and actuation data to the cycle correction time

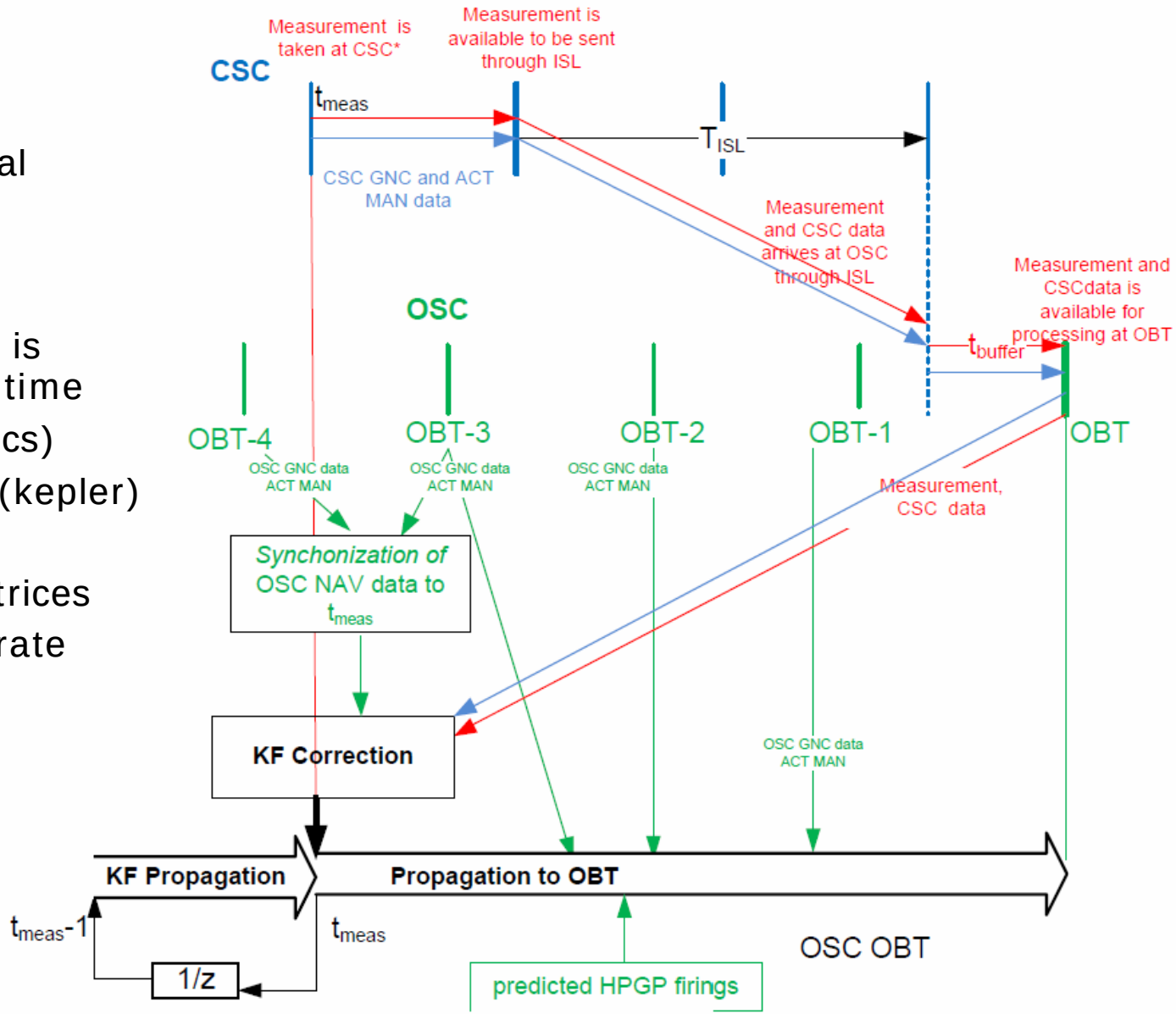
- **Outer propagation function**. This function makes use of the buffered knowledge of Cold Gas and HPGP actuation from SC actuation manager and also of predicted.

- **Reseting –** RGPS solution replaces current solution

FF NAV – Design (3) - Synchronization

Key Concepts:

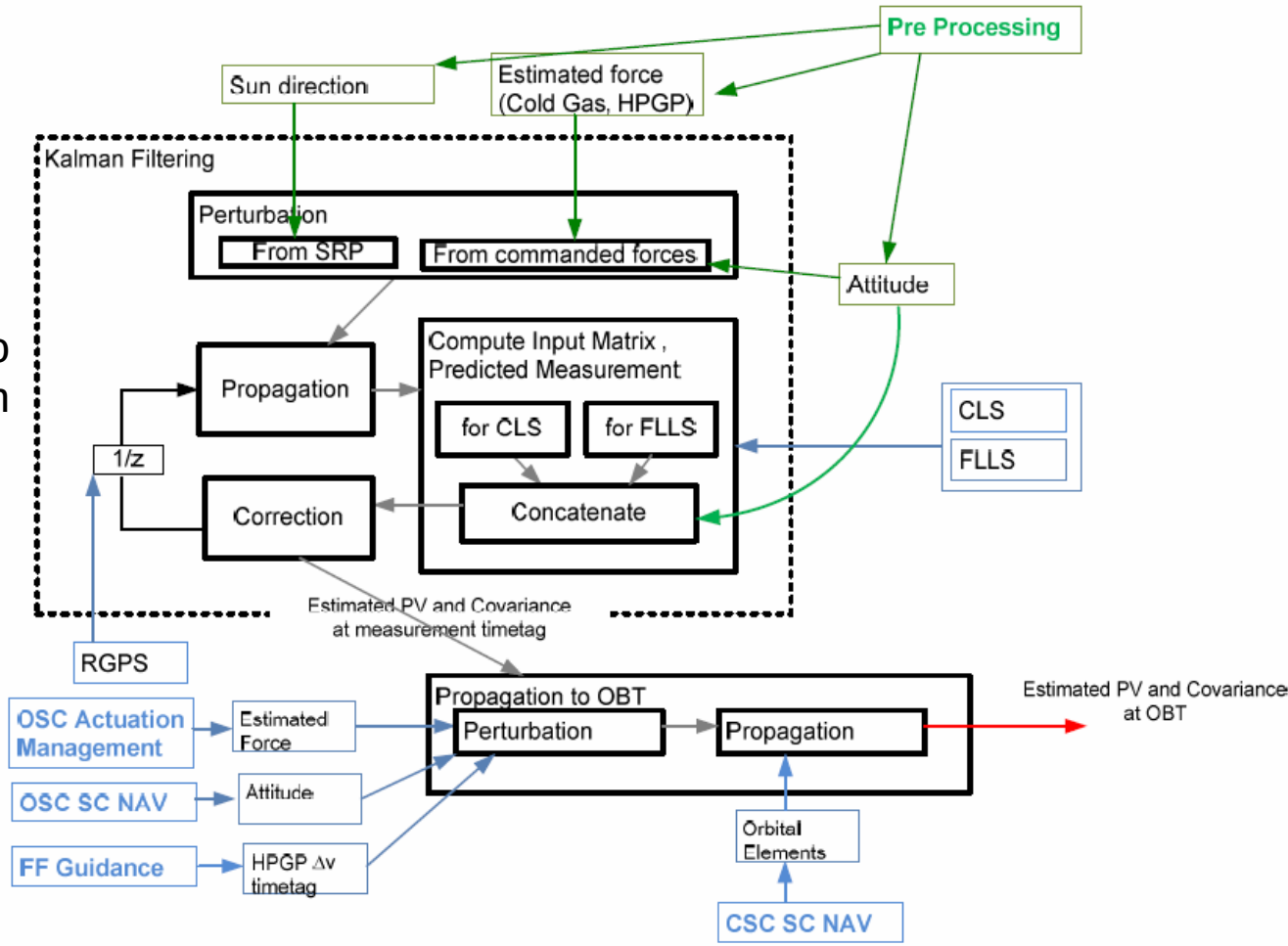
- At OSC, due to several sources of latency, measurements lag
- Buffered data at OSC is adjusted to correction time
  - Attitude (kinematics)
  - Absolute position (kepler)
- KF measurement matrices are be built to incorporate measurements
- Propagation
- Post Propagation



FF NAV – Design (3) - Filtering

- Yamanaka-Ankersen
- SRP
- Forced motion

- Attitude and unactuated sc absolute state used to build conversion/rotation Measurement Matrices



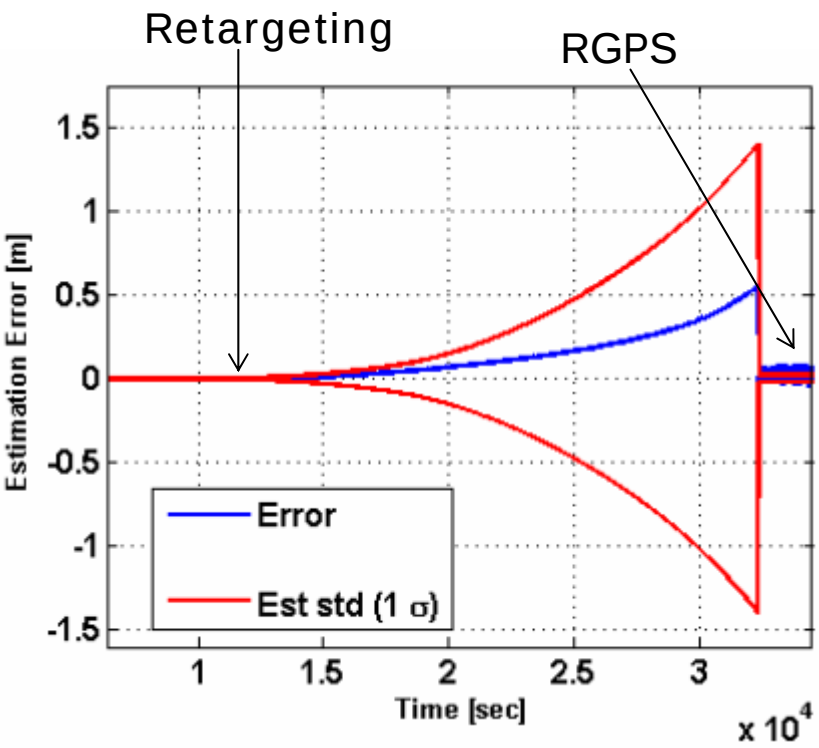
Performances (1)

Test results in the Proba3 Functional Engineering Simulator

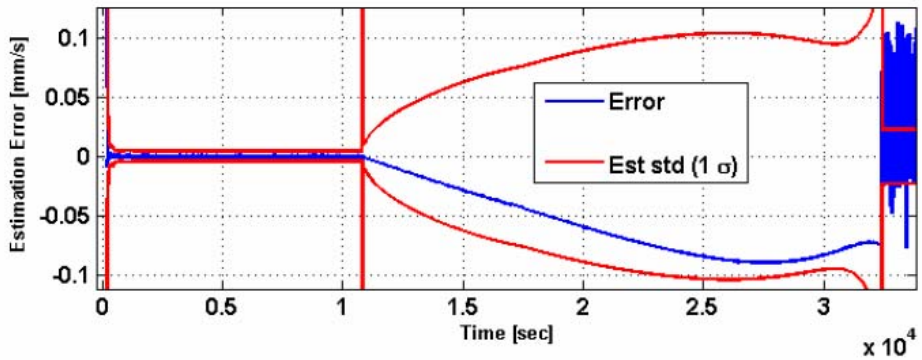
Tuning and preliminary performance assessment was performed taking in account nominal performances of sensors, actuation and SC GNC NAV performances.

Overview – from formation acquisition (apogee -3 hours) to perigee

Position

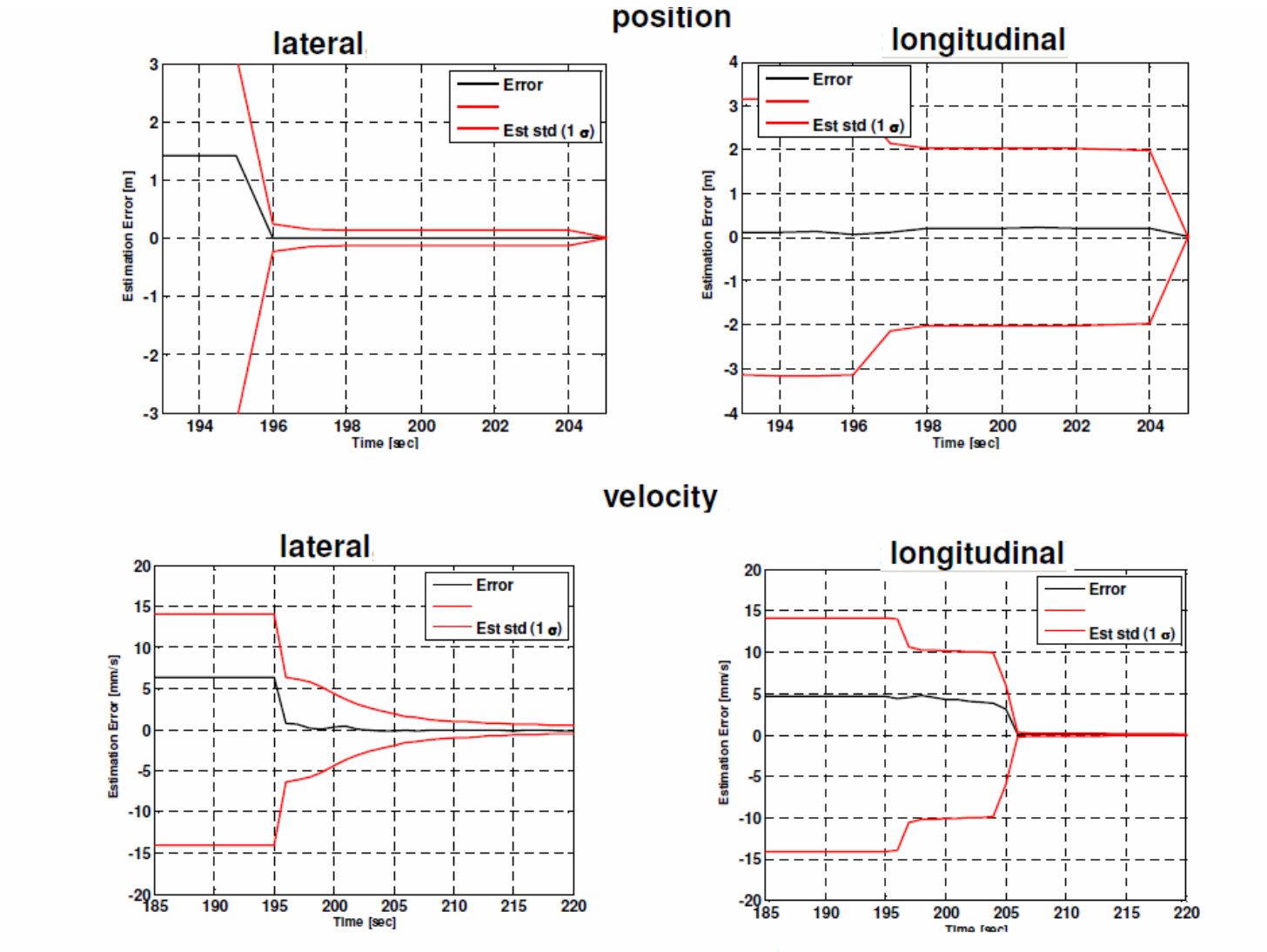


Velocity



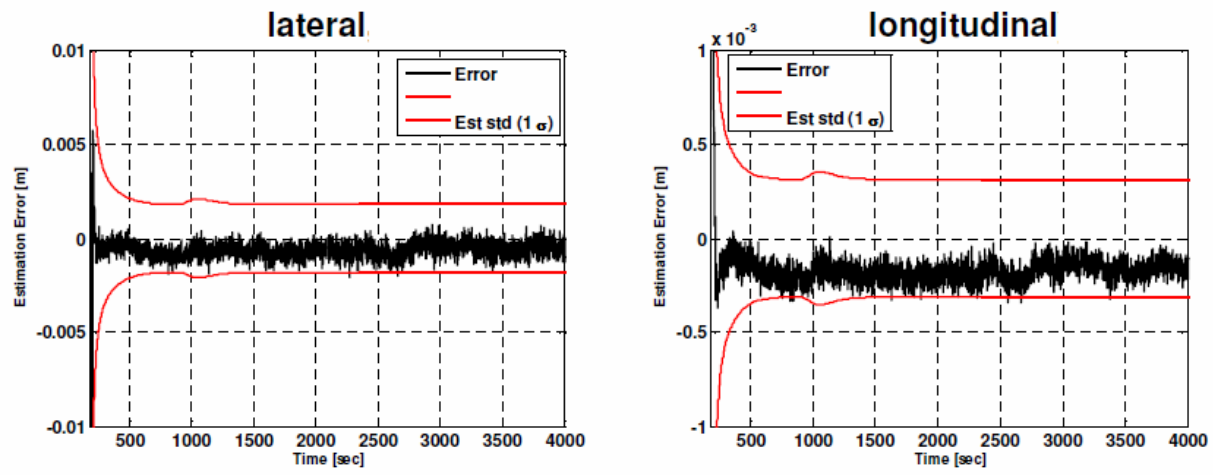
Performances (2)

CLS acquisition



Performances (3)

FLLS acquisition (position)



FLLS accuracy <0.1 arcsec is one order of magnitude better than absolute attitude determination - Error is governed by the later.

Single test performances	Long Pos [mm]	Lat Pos [mm]	Long Vel [mm/s]	Long Vel [mm/s]
CLS	**	25	5	0.5
FLLS	0.3	1	0.0015	0.002
Perigee Pass (before rGPS)	1250	510	0.12	0.075
RGPS*	100		0.1	

Conclusion

- Formation Flying algorithms tackle multiple sources of information, accuracies, latencies, in formation flying
- Successful handover through metrology chain to ~mm accuracy

- Successful prototyping, autocoding of the algorithms as parte of the FF SW software
- Tested in Functional Engineering Simulator
- Preliminary design review held late 2012
- Successful demonstrated nominal operations
- Phase C to start

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RGPS*	100		0.1	

Thank you

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