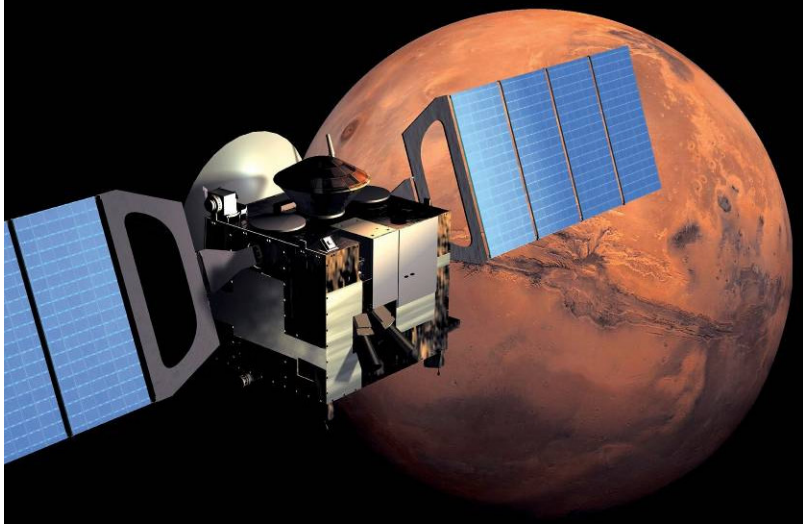
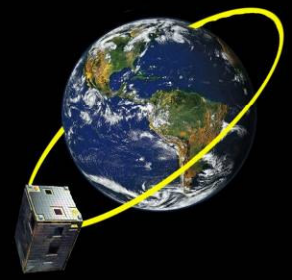
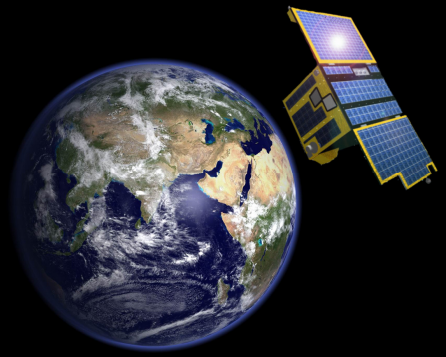
The PROBA Missions – Design Capabilities for Autonomous Guidance, Navigation and Control





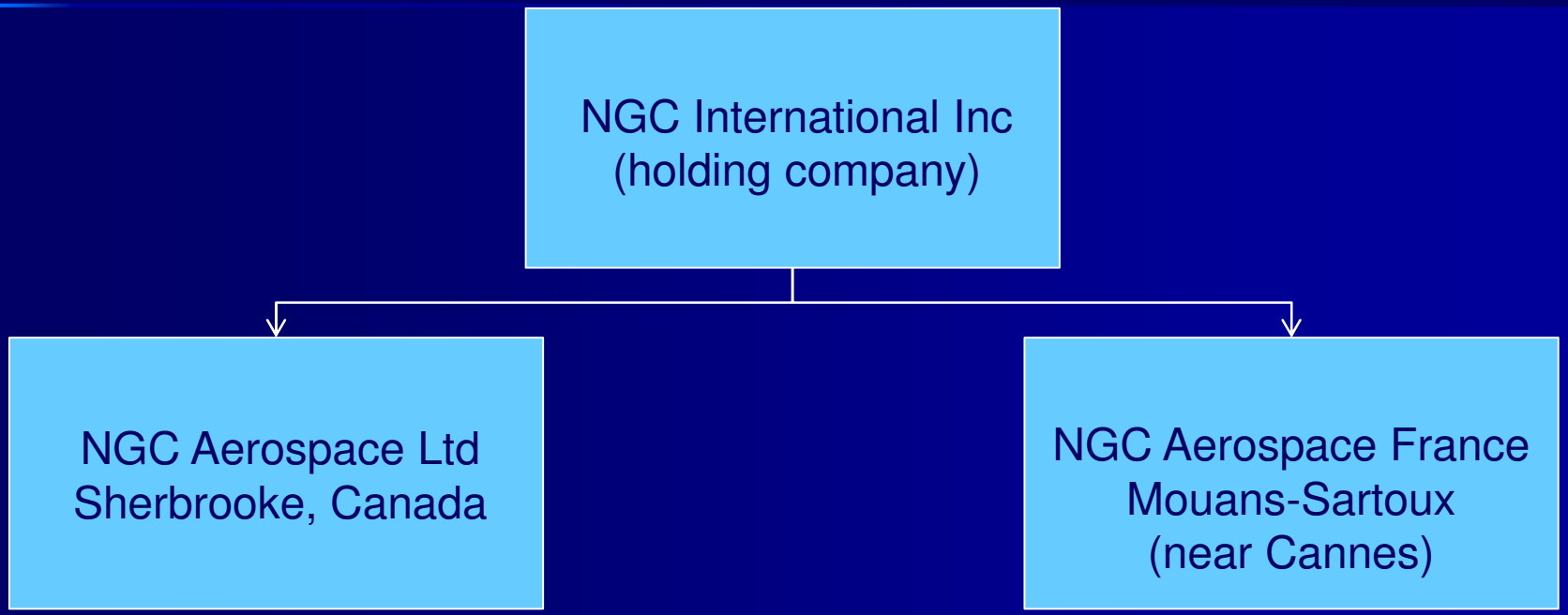
Jean de Lafontaine
President

NGC Aérospatiale Ltée
NGC Aerospace Ltd



Pictures courtesy of ESA

Overview of NGC



- All 100% Canadian-owned
- First company incorporated in 2001, experience in guidance, navigation and control (GNC) software since 1987
- 18 employees (14 eng, 4 admin)
  - 13 at NGC Aerospace Ltd in Sherbrooke
  - 5 at NGC Aerospace France

NGC Aerospace Facilities

- **Main Office** (downtown Sherbrooke)
  - Administration & design activities
- **NGCLAB** (Sherbrooke industrial park)
  - For hardware-in-the-loop verification & validation

LDTF

LABSAT

NGC Mission

- To define space missions and to develop the required analysis tools, simulators and flight software that contribute to the advancement of knowledge, space science and space technology.

- To design guidance, navigation and control subsystems that increase the intelligence, autonomy, performance, reliability and safety of aerospace vehicles while, at the same time, reducing their operational costs.

NGC Products and Services

Three Main Branches

Autonomous GNC for Earth-orbiting satellites

- From requirements to flight to commissioning

Autonomous GNC for planetary exploration

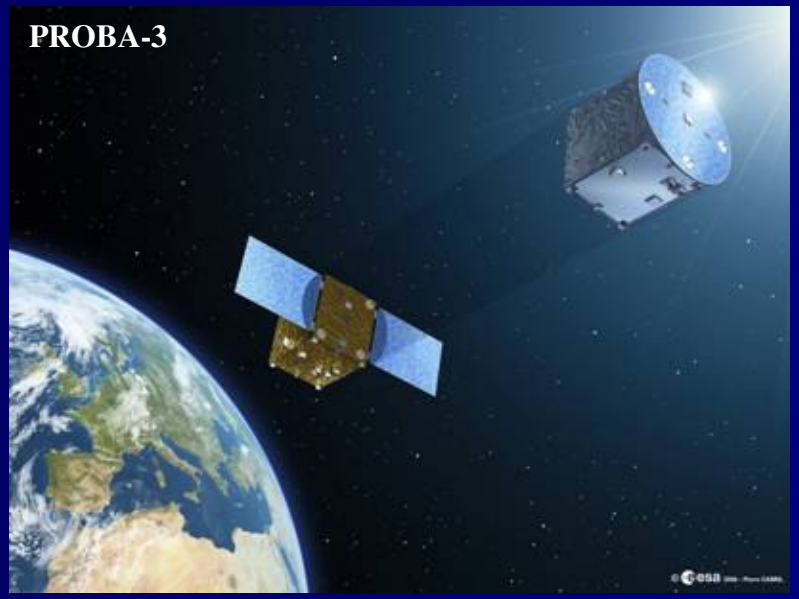
- Autonomous hazard detection and avoidance
- Precision landing

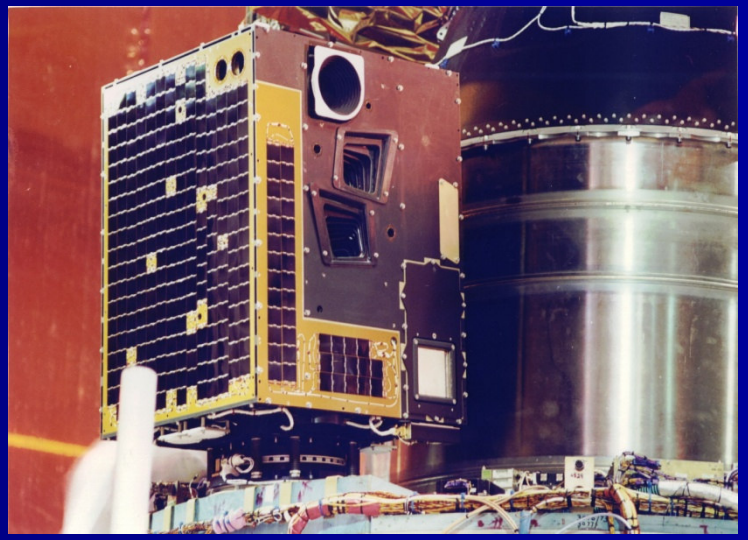
Mission Design & Analysis

- POETE, TICFIRE
- Constellation Analysis

GNC for Autonomous Satellites

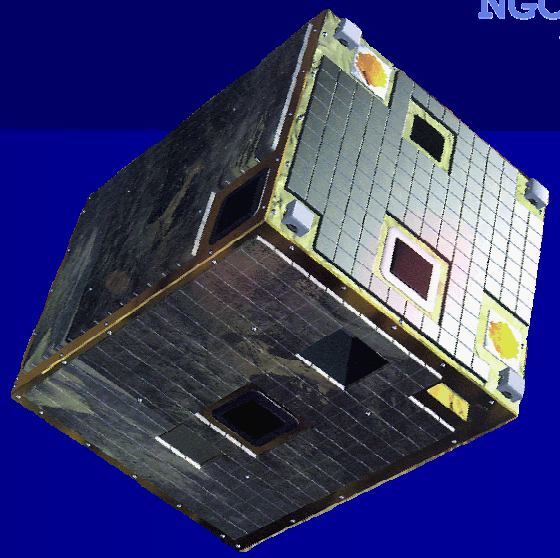
- Intelligent **GNC algorithms**
- Tools for **automatic generation** & **validation** of the flight code
- High-fidelity engineering **simulator**





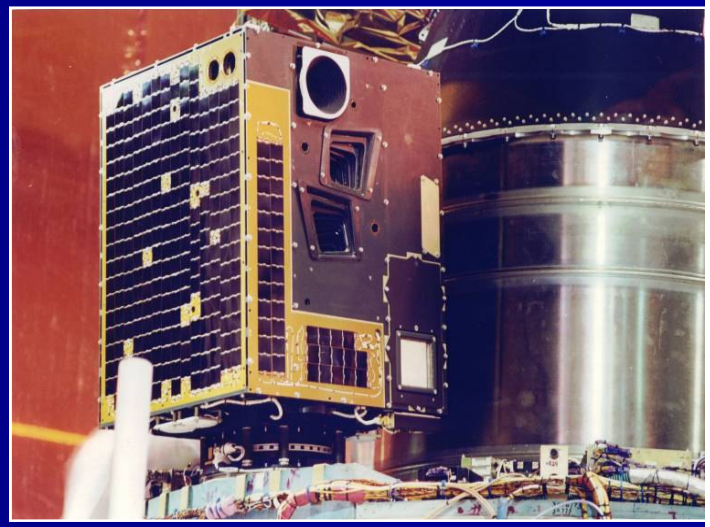
PROBA-1 on the PLSV Launcher

PROBA-1 Success Story



- **PROBA-1**: Earth-Observation Mission
  - launched in October 2001
  - 2-year mission
  - still successfully operating after 8½ years
  - reaction wheels + star tracker + magnetic

- 1st fully autonomous ESA spacecraft
- 1st with automatic flight code generation
- 1st with variable-gain Kalman filter
- 1st with complete on-board guidance
- 1st with quaternion-based multivariable gyroless + sliding-mode controller for large-angle manoeuvres

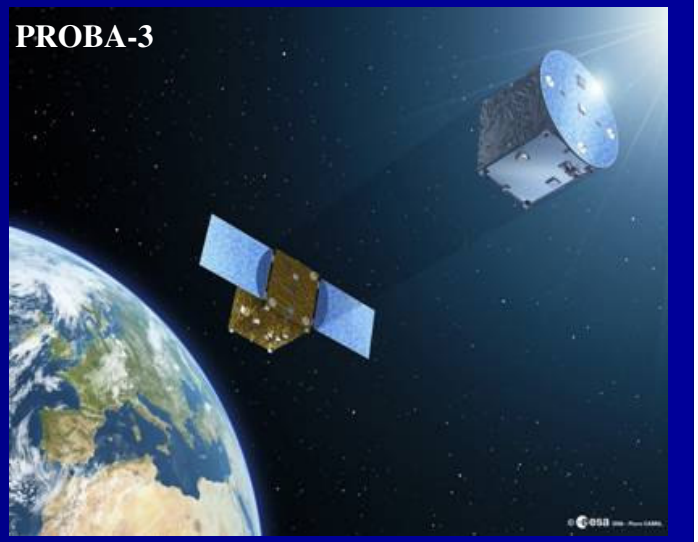


PROBA-1 on the PLSV Launcher

PROBA-2 and PROBA-3 Missions

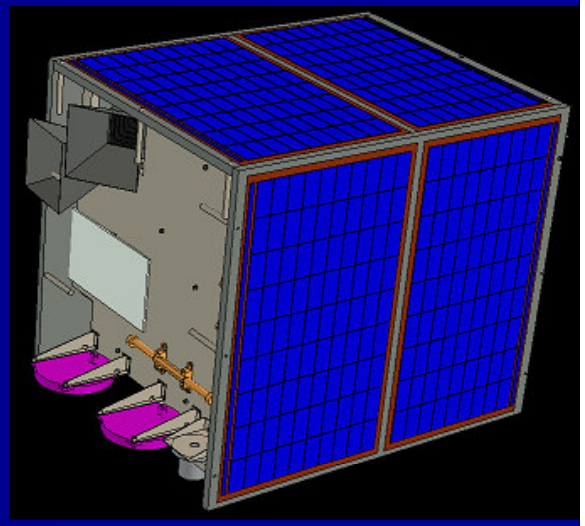
- **PROBA-2**: Sun-Observation Mission
  - launched in November 2009
  - completed commissioning in Feb 2010
  - same autonomy as in PROBA-1
  - 6 GNC technology experiments
  - 3 versions of unscented Kalman Filter incl. a magnetic-based state estimator

- **PROBA-3**: Formation-Flight Mission
  - to be launched in 2013
  - Coronagraph S/C and Occulter S/C on elliptical orbit



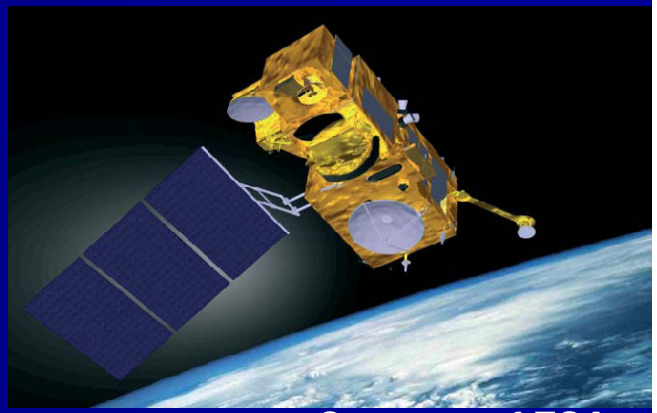
Other Upcoming EO Missions

- **PROBA-V**: EO Vegetation Mission
  - Phase C/D started in February 2010
  - Critical Design Review in April 2010
  - To be launched in early 2012



- **PROBA-Next**: First commercial sale of NGC's flight S/W
  - 3 different commercial clients have selected our technology

- **Sentinel-3**: Design and validation of the normal mode of operation



Courtesy of ESA

Relevance of the PROBA Missions

- Can serve as platform for technology demonstrations
  - 6 GNC technology experiments on PROBA-2
- Experience in GNC can support nanosatellite community
  - low cost GNC system
  - increased autonomy
  - increased performance
  - innovation in GNC techniques and algorithms
- Example: LOCOOS
  LOw-Cost Orbit and Orientation State estimation

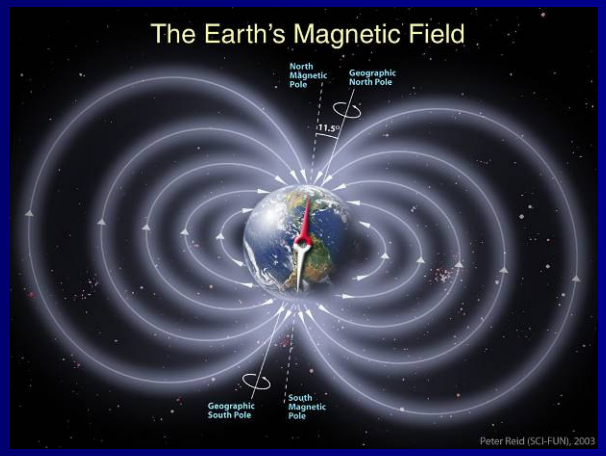
LOCOOS Product

- **Context**
  - Trend toward the use of small spacecraft (nanosatellites)
  - Reduction in mission operation costs → on-board autonomy
  - Reduction in hardware costs → low-cost, simpler hardware

- **Objective: Develop low-cost autonomous navigation system**
  - Based on 'simple', low-cost/mass/power/volume sensors
  - To determine both the orbital states and the attitude states
  - Using the 'natural' environment of a low-Earth orbit

LOCOOS Product

- **Innovation: Combination** of
  - state-of-the-art magnetic-based state estimation
  - state-of-the-art nonlinear unscented-based Kalman filter
  - orbit determination using temperature/light/current sensors



LOCOOS Product

Benefits

- Low-cost **primary navigation system** for:
  - low-Earth small/micro/nano/pico satellites
  - requiring medium-accuracy pointing/position knowledge
- Low-cost **back-up navigation system** for:
  - larger operational satellites
  - requiring knowledge of attitude/position for:
    - degraded mission operation
    - safe-mode operation
    - fast recovery when primary system is back in operation

Current Status

- The LOCOOS navigation software is being integrated into a low-cost flight-proven microcontroller.
- Qualification model is being designed.

LOCOOS Product

Performance

Criteria	PERFORMANCE Magnetometer only	PERFORMANCE + Sun presence
Absolute position determination accuracy (2σ)	< 100 km after 3 orbits	< 15 km after 2 orbits
Absolute attitude determination accuracy (2σ)	< 4.5 deg after 1 orbit	< 3.0 deg after 1 orbit

- Important note: this performance is obtained using medium-accuracy magnetometer with typical biases after delivery
- Algorithms currently flying on-board PROBA-2.