USE OF SCILAB FOR SPACE MISSION ANALYSIS AND FLIGHT DYNAMICS ACTIVITIES

Thierry Martin

CNES

Use of Scilab in CNES

⇨ **Scilab is now widely used in CNES, in various engineering fields, such as Telecommunications, RF analysis, Navigation, Attitude Control System analysis,…**

⇨ **This presentation explains how Scilab is used for Flight Dynamics activities, with selected examples in:**

- Mission analysis
  - ➔ Mission analysis for advanced studies (PASO activities)
  - ➔ Operational mission analysis (Automated Transfer Vehicle (ATV) mission opportunities)
- Development of new algorithms
- Flight dynamics operational systems
  - ➔ Operations for early orbit acquisition
  - ➔ Debris conjunction analysis in ATV-CC

Scilab for Mission Analysis

2 examples:

- ⇨ Mission analysis for advanced studies
- ⇨ ATV rendezvous opportunities

CNES process for advanced studies (phase 0)

⇨ **Advanced studies are carried out by a dedicated organization (PASO: "Plateau d'Architecture des Systèmes Orbitaux") through a concurrent design process using its associated Concurrent Design Facility.**

⇨ **Based on users needs (Science, Earth observation, Security / Defence,..) and after a selection process, the Paso study plan (about ten advanced projects per year) is established annually.**

⇨ **Output of an advanced study:**

- Clear and structured user needs
- Comprehensive assessment of system concepts (constraints identification)
- Mission design and system optimisation,
  - ➔ Orbit design based on mission requirements
  - ➔ Orbit analysis to assess impacts on satellite (power, thermal control, fuel budget,…)
- Analyse different options of partnership and their impacts on cost or system definition
- Propose a development rationale and R&D action plan (technologies evaluation)

Mission analysis for advanced studies

Mission needs — Mission analysis iterations ⟷ Orbital solutions

Mission needs

⇨ **Geometry during observations**
- Constant Sun aspect angle
- Fixed ground tracks
- Inertial orbit or required orbital regression rate

⇨ **Earth coverage**

⇨ **Constant altitude**

⇨ **Revisit time**

⇨ **Data access (volume, frequency,..)**

⇨ **Mission orbit acquisition (interplanetary,…)**

⇨ **Orbit maintenance**

Orbital solutions

⇨ **Sun synchronous orbit**

⇨ **Repeat orbits**

⇨ **Inclination (equatorial / polar)**

⇨ **Orbit excentricity**

⇨ **Constellation (number of satellite, number of orbital plans,..)**

⇨ **Ground stations network**

⇨ **Maneuver strategy with propellant assessment**

Why Scilab for advanced studies mission analysis ?

Phase 0 studies general features

- ⇨Duration: a few weeks ➔ a few months
- ⇨About ten advanced studies per year
- ⇨High level of innovation
- ⇨Orders of magnitude needed
- ⇨Parametric / sensibility studies needed
- ⇨Balance between accurate analysis and order of magnitude evaluation
- ⇨Trade-offs
- ⇨No strict framework ➔proposals welcome

Tool desired qualities

- ⇨Rapid development of scripts
- ⇨Add-ons or tailoring of Flight Dynamics (FD) software needed
- ⇨SciLab scripts have to work in conjunction with other software
- ⇨SciLab applications with MMI for recurrent problems
- ⇨Toolbox developments for easy reuse
- ⇨Flexibility
- ⇨Easy interface

Mission Analysis Tool boxes

Celestlab

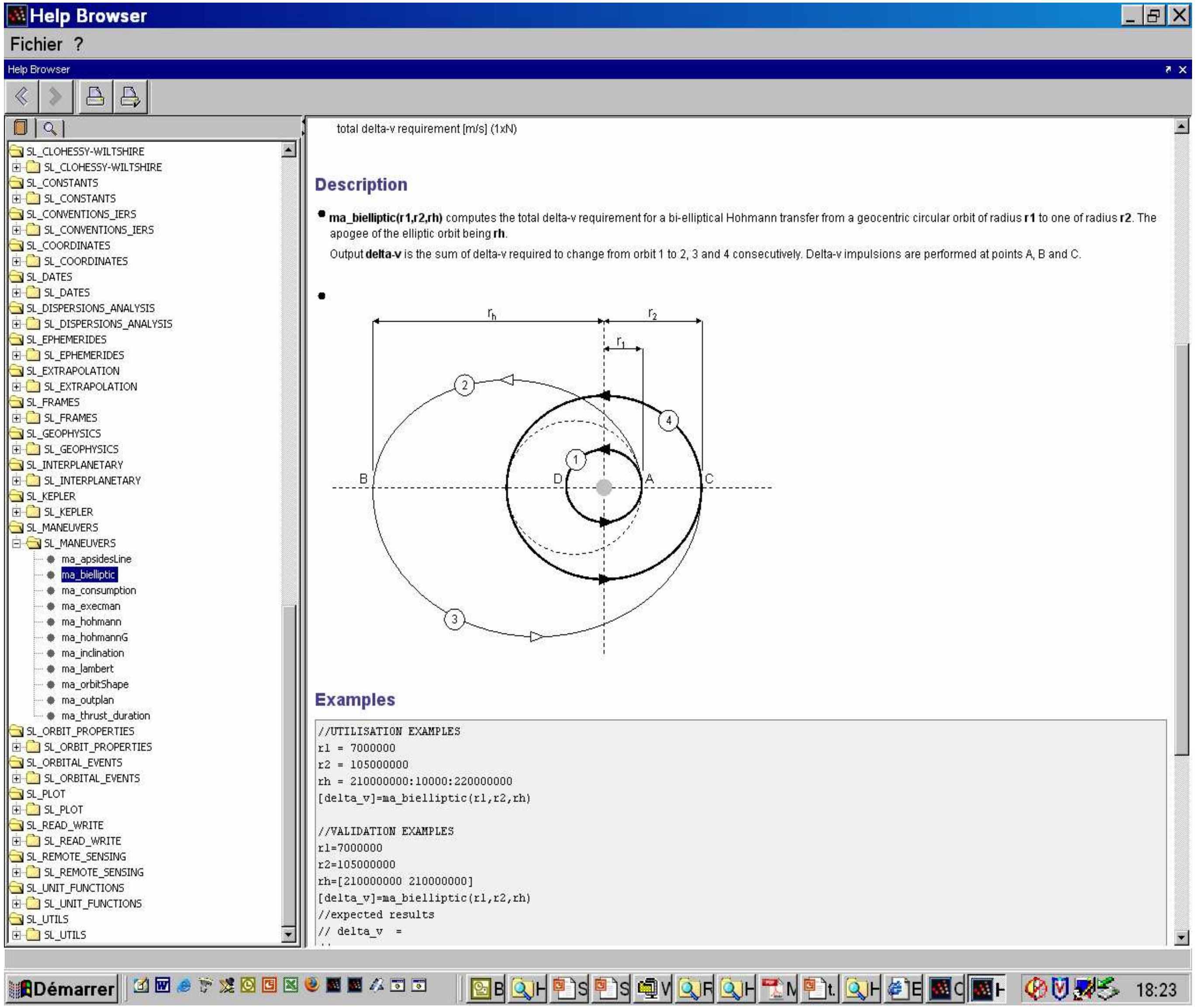
- ⇨ Based on previous library *SpaceLab*
- ⇨ New design in order to be a SciLab Associated External Module
- ⇨ Modular Flight Dynamics library
- ⇨ Validated against CNES legacy software
- ⇨ All functions written in SciLab so far
- ⇨ Comprehensive documentation including sketches and bibliography
- ⇨ Conventions for naming
  - CL_iersMeanObliquity (functions)
  - %CL_mu (constants)

Skitos

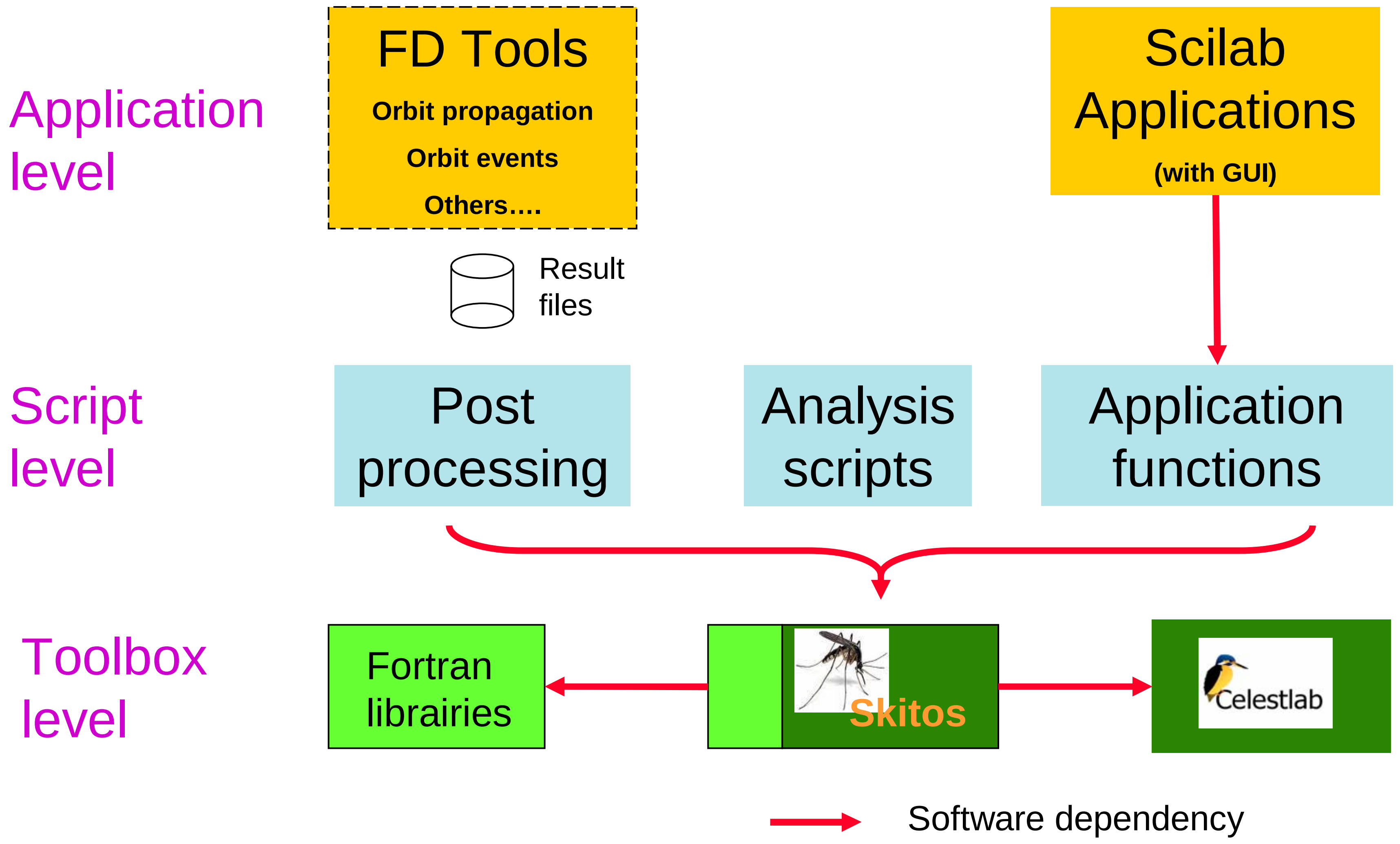
- ⇨ SciLab KIT for Orbit Studies
- ⇨ Follow toolbox guidelines
- ⇨ Extension of CelestLab
- ⇨ Depends on CelestLab
- ⇨ For CNES internal use
- ⇨ Functions that may migrate to CelestLab (functions under evaluation)
- ⇨ Functions that depend on other libraries (FORTRAN) ➔ OS dependent

Celestlab : a mission analysis toolbox

- ⇨ Coordinates & Frames
- ⇨ Trajectory & Maneuvers
- ⇨ Orbit properties
- ⇨ Interplanetary
- ⇨ Geometry and Events
- ⇨ Relative motion
- ⇨ Models
- ⇨ Orbutils

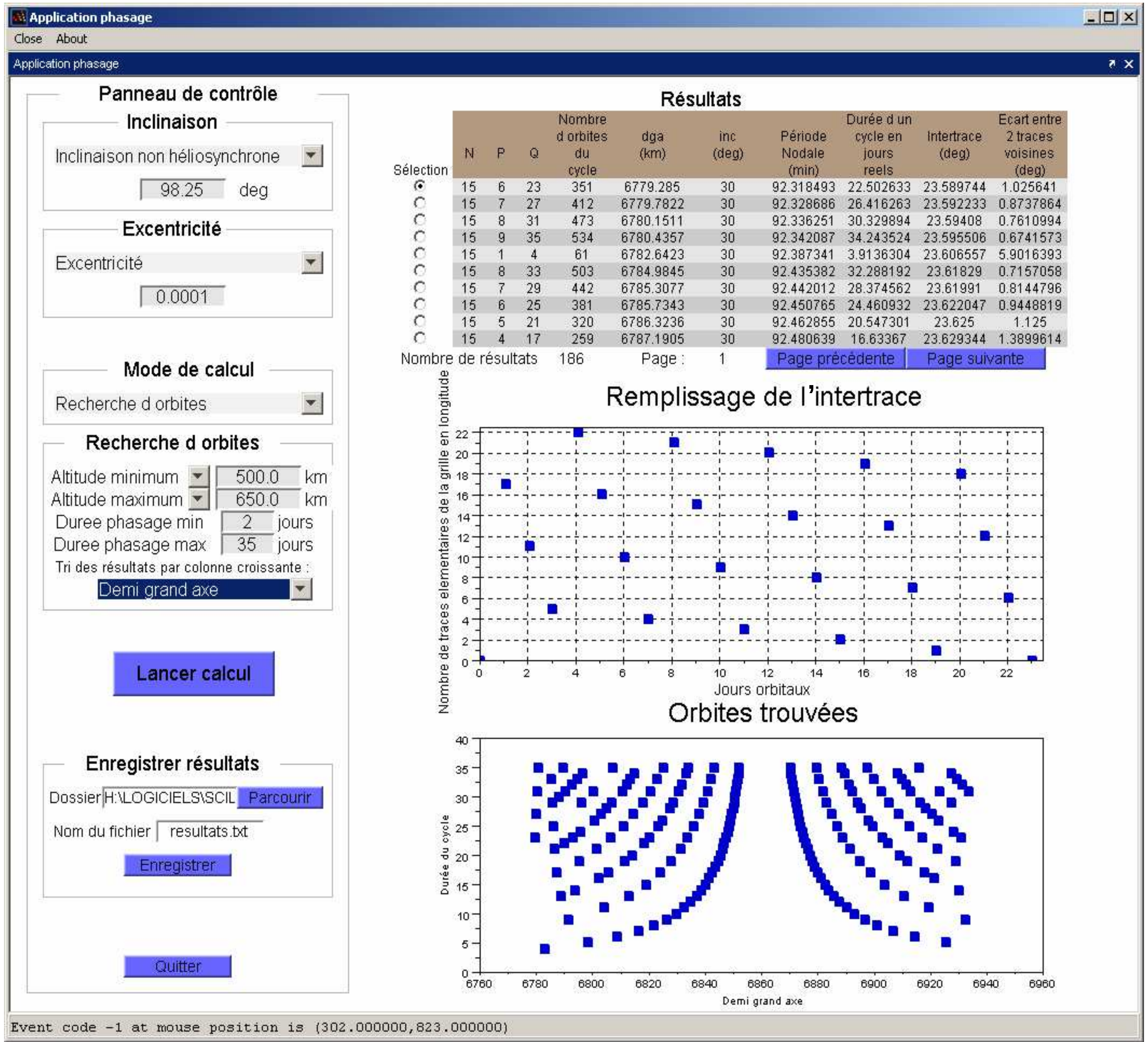


Scilab within the tool Mission Analysis environment



Example of Scilab application with GUI (1)

- ⇨**Example of application: Computation of repeat orbits characteristics**
- ⇨**GUI allows easy use of the tools**
- ⇨**Interface (functions) available for parametric studies**
- ⇨**Low level functions available in CelestLab**

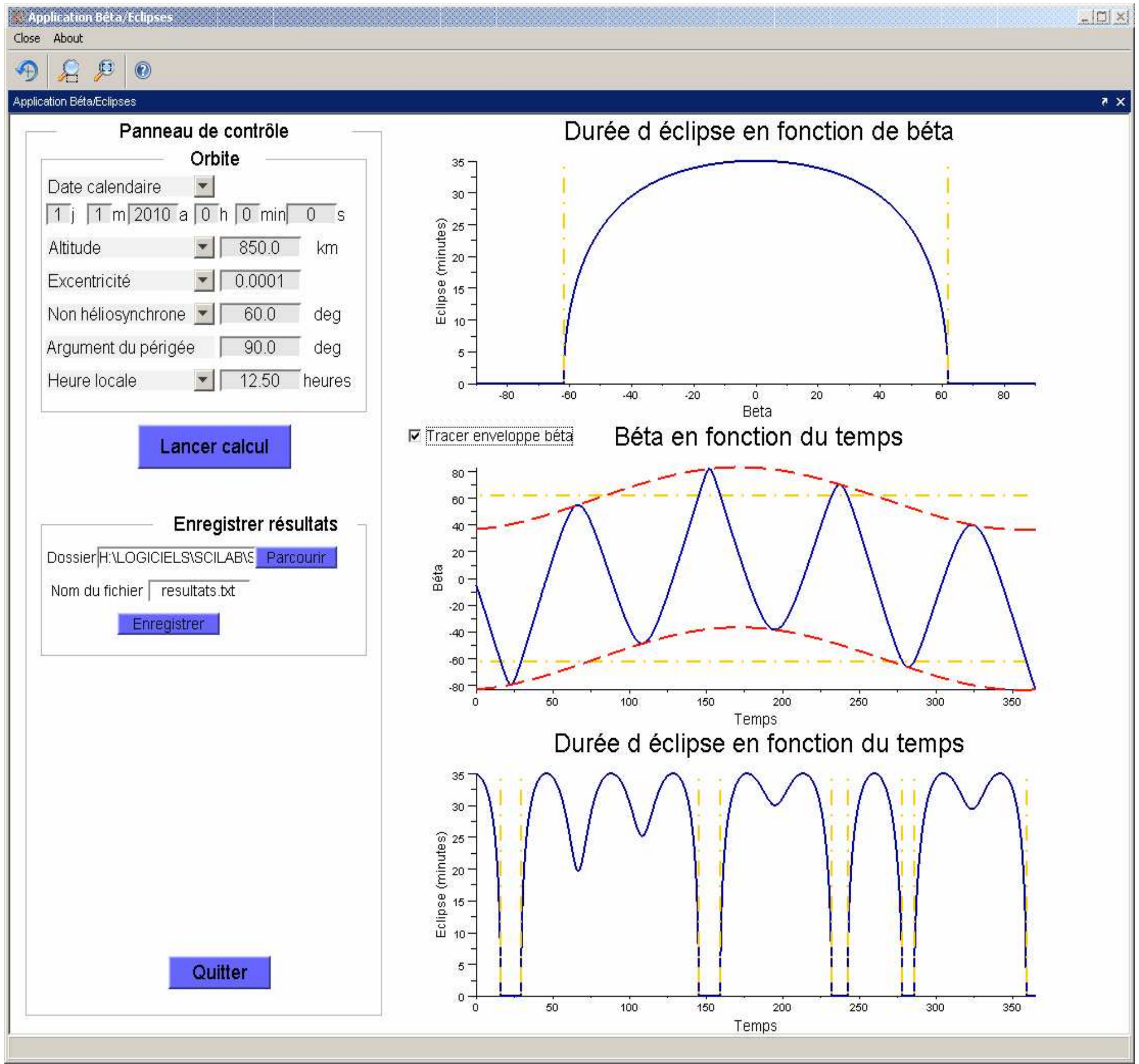


Example of Scilab application with GUI (2)

⇨**Application for sun / orbit geometry analysis**

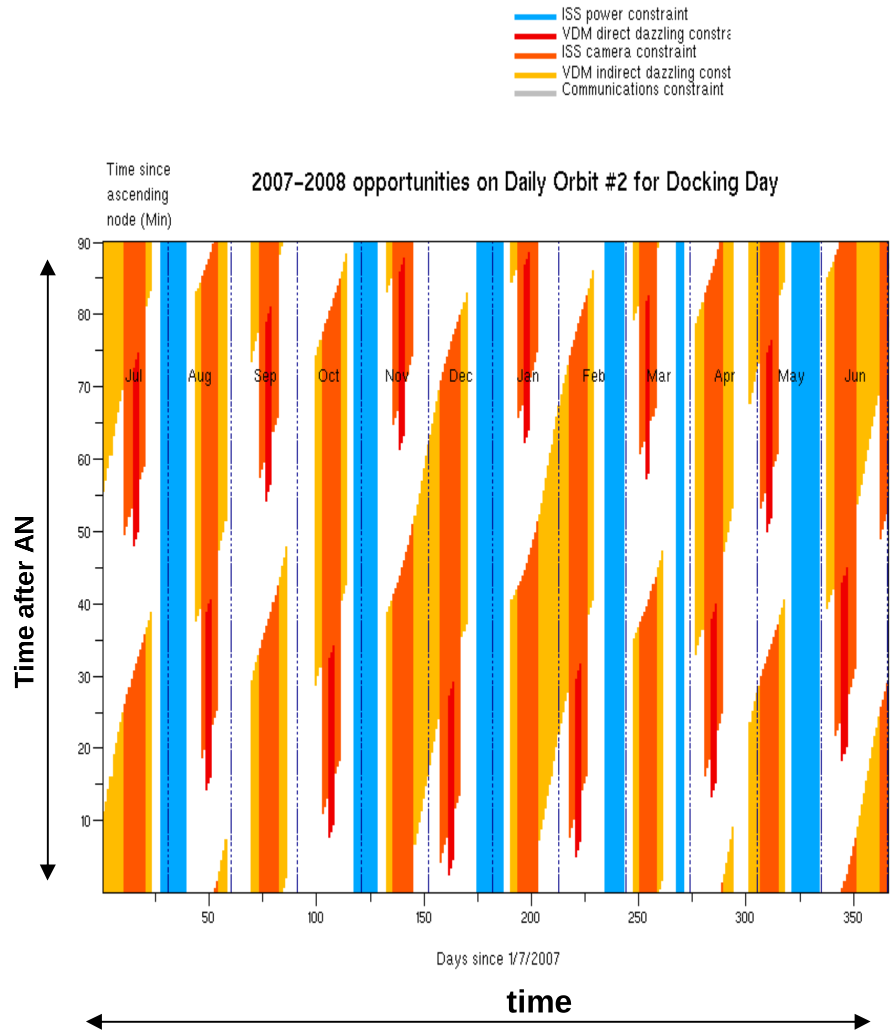
⇨**Computes:**

- Sun elevation wrt orbit plane (beta angle)
- Eclipse duration



Operational mission analysis (ATV rendezvous opportunities)

- ⇨ **Numerous scripts were developed for the ATV mission analysis (orbital events analysis)**
- ⇨ **Need to establish a firm base for the scripts used for this analysis ➔ Motivation for starting SpaceLab**
- ⇨ **Scripts based on SpaceLab used to compute rendezvous opportunities over a period of time**
- ⇨ **Due to operational complexity, constraints were quite changing**
- ⇨ **It was decided to keep this application written in SciLab for flexibility purpose**



CENTRE NATIONAL D'ÉTUDES SPATIALES

Design and evaluation of new algorithms

Design and evaluation of orbit control algorithms

⇨ **Scilab has been used to design and validate (relative) orbit control algorithms**

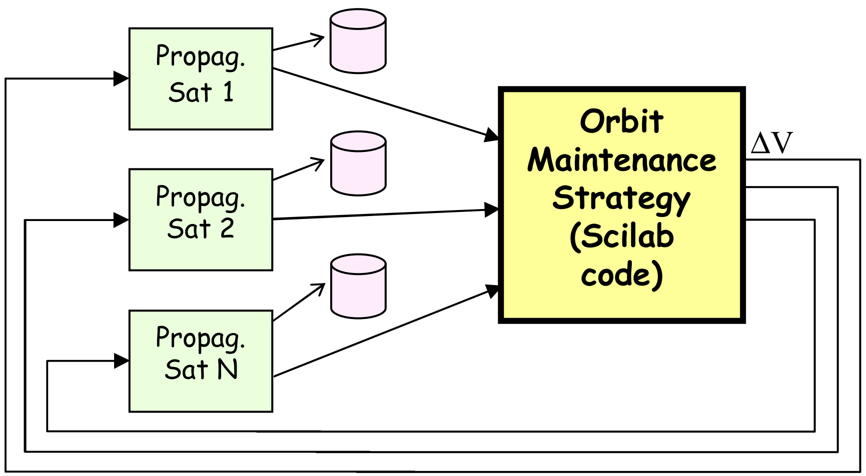
⇨ **Advantage of using Scilab: has offered enough flexibility to easily evaluate variants to the algorithms**

⇨ **The simulator is run in non interactive mode, except exceptionally for debugging purposes**

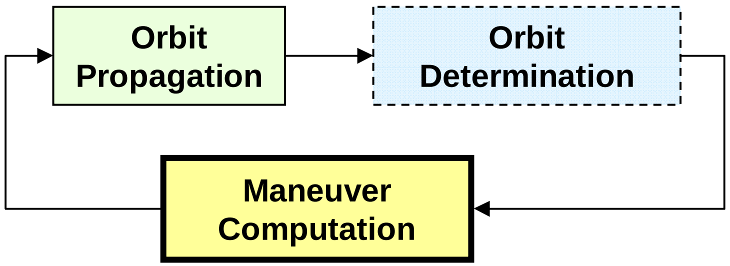
⇨ **The SciLab program is embedded in a larger software structure where several (validated) tools (i.e. binaries) exchange relevant information.**

⇨ **CNES "SIMBAD" data exchange (socket based) library is used (written in C, Scilab API added)**

Multiple satellite simulation environment



Typical orbit control loop



USE OF SCILAB IN FLIGHT DYNAMICS OPERATIONAL SYSTEMS

2 examples

- ⇨ **Debris conjunction analysis in ATV-CC Jules Verne**
- ⇨ **Operations for early orbit acquisition**

Debris conjunction analysis in ATV-CC Flight dynamics

⇨ **Script installed in ATV-Control Center for Jules Verne**

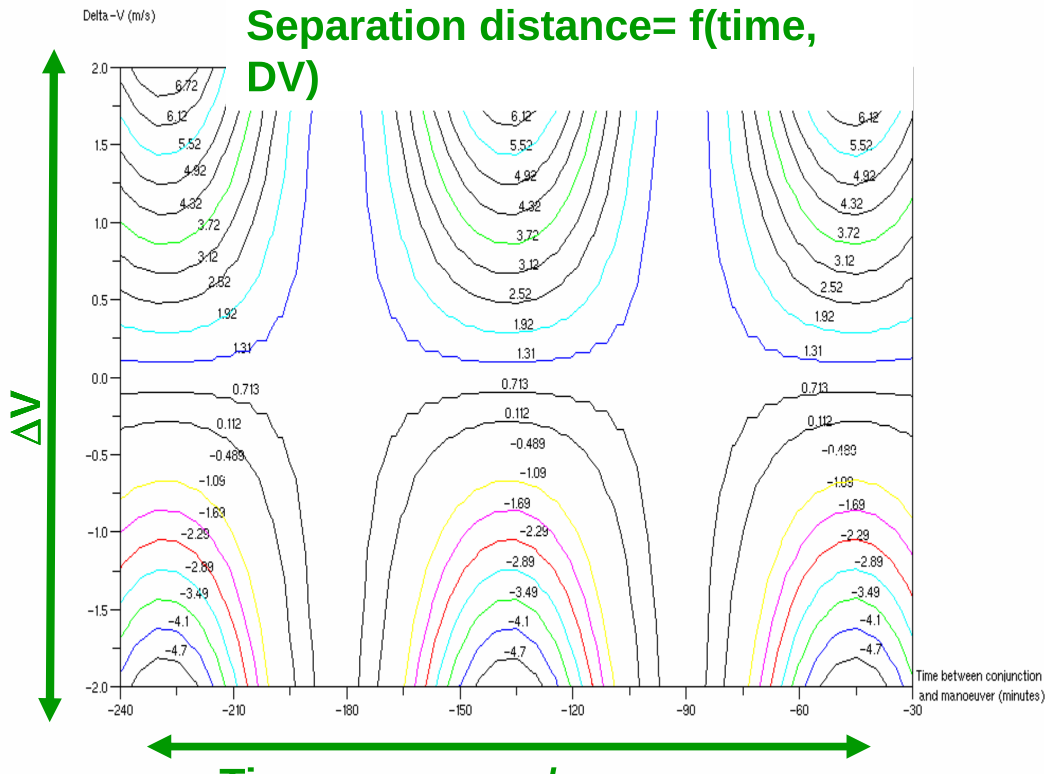
⇨ **This script works in conjunction with other operation software and is used for situation analysis and investigation**

⇨ **Computes the efficiency of an avoiding maneuver as a function of time before the conjunction and the size of the maneuver**

⇨ **Used to create "dynamical abaci"**

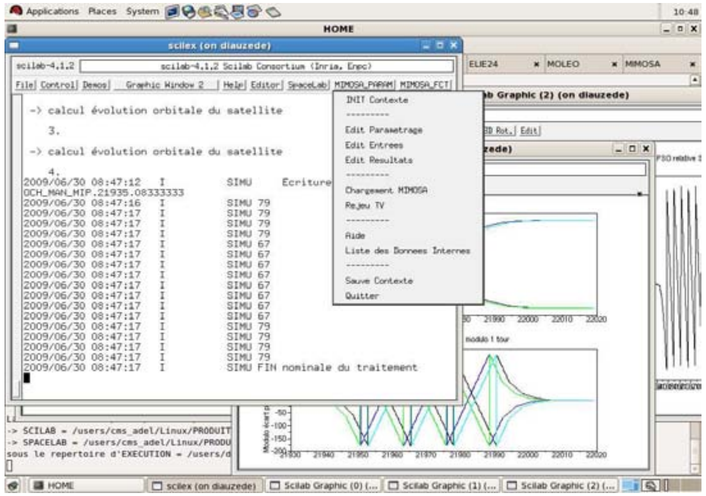
⇨ **Not an operational software**

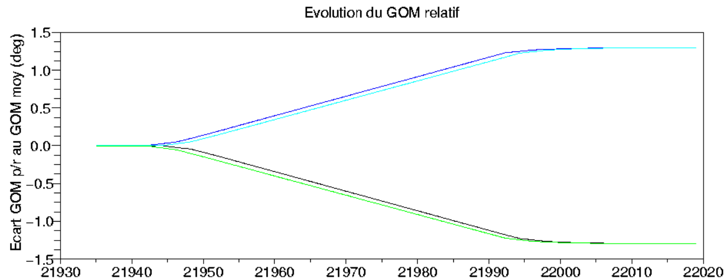
⇨ **The solution is simulated with operational software**

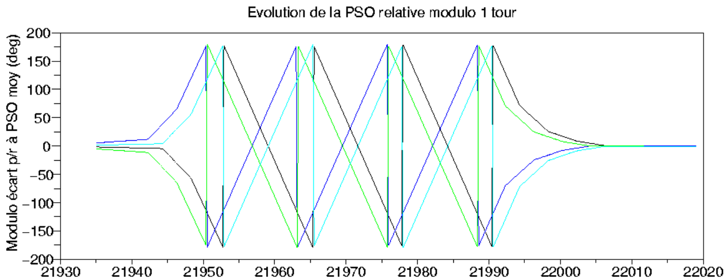


Operations for early orbit acquisition

- Software used for operations (orbit acquisition of a cluster of 4 satellites)
- About 40 scripts, 120 functions, 5000 lines of code (including comments)
- Computes the orbit maneuver strategy from injection by launcher to beginning of operational phase
- Interfaces added to access the control center data (non Scilab GUI means used)
- Calculations activated by simple menus (no command-line nominally needed)
- But access to low level functions and algorithms possible, if (really) required.







Some difficulties

⇨ **Computing time**

- **Avoiding loops is sometimes difficult (for orbit simulation for instance)**

⇨ **Working with vectors**

- Sometimes increases complexity of development
- Readability is difficult
  - ➔Improved with the use of functions
  - ➔Code has to be highly commented

⇨ **Scilab 5.x not available for Unix OS**

⇨ **Link with FORTRAN 90**

- Requires interface functions
- Programs must be compiled for various OS
- Difficulty to re-use existing FORTRAN libraries

CNES
CENTRE NATIONAL D'ÉTUDES SPATIALES

Conclusions

⇨**Scilab is widely used within the CNES flight dynamics departments**

⇨**The mission analysis toolkit which is used for advanced studies is growing based (in particular) on:**

- Scilab libraries (CelestLab, Skitos)
- Scilab specialized applications (MMI, associated toolbox)

⇨**A first version of CelestLab will be delivered as a SciLab external associated module. CelestLab provides functions for mission / flight dynamics analysis on:**

- Orbit propagation,
- Orbit geometry,
- Reference frames and models,
- etc…