

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



⇒ **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**

⇒ **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



- ⇒ 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)

- ⇒ 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

- ⇒ Coordinates & Frames
- ⇒ Trajectory & Maneuvers
- ⇒ Orbit properties
- ⇒ Interplanetary
- ⇒ Geometry and Events
- ⇒ Relative motion
- ⇒ Models
- ⇒ Orbitals

Help Browser

Fichier ?

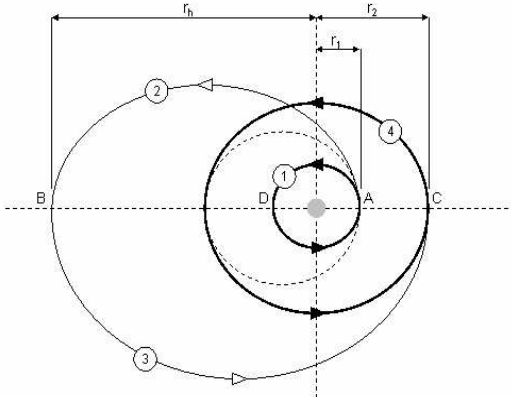
Help Browser

- SL_CLOHESSY-WILTSHIRE
- SL_CONSTANTS
- SL_CONVENTIONS_IERS
- SL_COORDINATES
- SL_DATES
- SL_DISPERSIONS_ANALYSIS
- SL_EPHEMERIDES
- SL_EXTRAPOLATION
- SL_FRAMES
- SL_GEOPHYSICS
- SL_INTERPLANETARY
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 - ma_apsidesLine
 - ma_bielliptic**
 - ma_consumption
 - ma_execman
 - ma_hohmann
 - ma_hohmannG
 - ma_inclination
 - ma_Jambert
 - ma_orbitShape
 - ma_outplan
 - ma_thrust_duration
- SL_ORBIT_PROPERTIES
- SL_ORBITAL_EVENTS
- SL_PLOT
- SL_READ_WRITE
- SL_REMOTE_SENSING
- SL_UNIT_FUNCTIONS
- SL_UTILS

total delta-v requirement [m/s] (1xN)

Description

- **ma_bielliptic(r1,r2,rh)** computes the total delta-v requirement for a bi-elliptic Hohmann transfer from a geocentric circular orbit of radius **r1** to one of radius **r2**. The apogee of the elliptic orbit being **rh**.
- Output **delta_v** is the sum of delta-v required to change from orbit 1 to 2, 3 and 4 consecutively. Delta-v impulses are performed at points A, B and C.

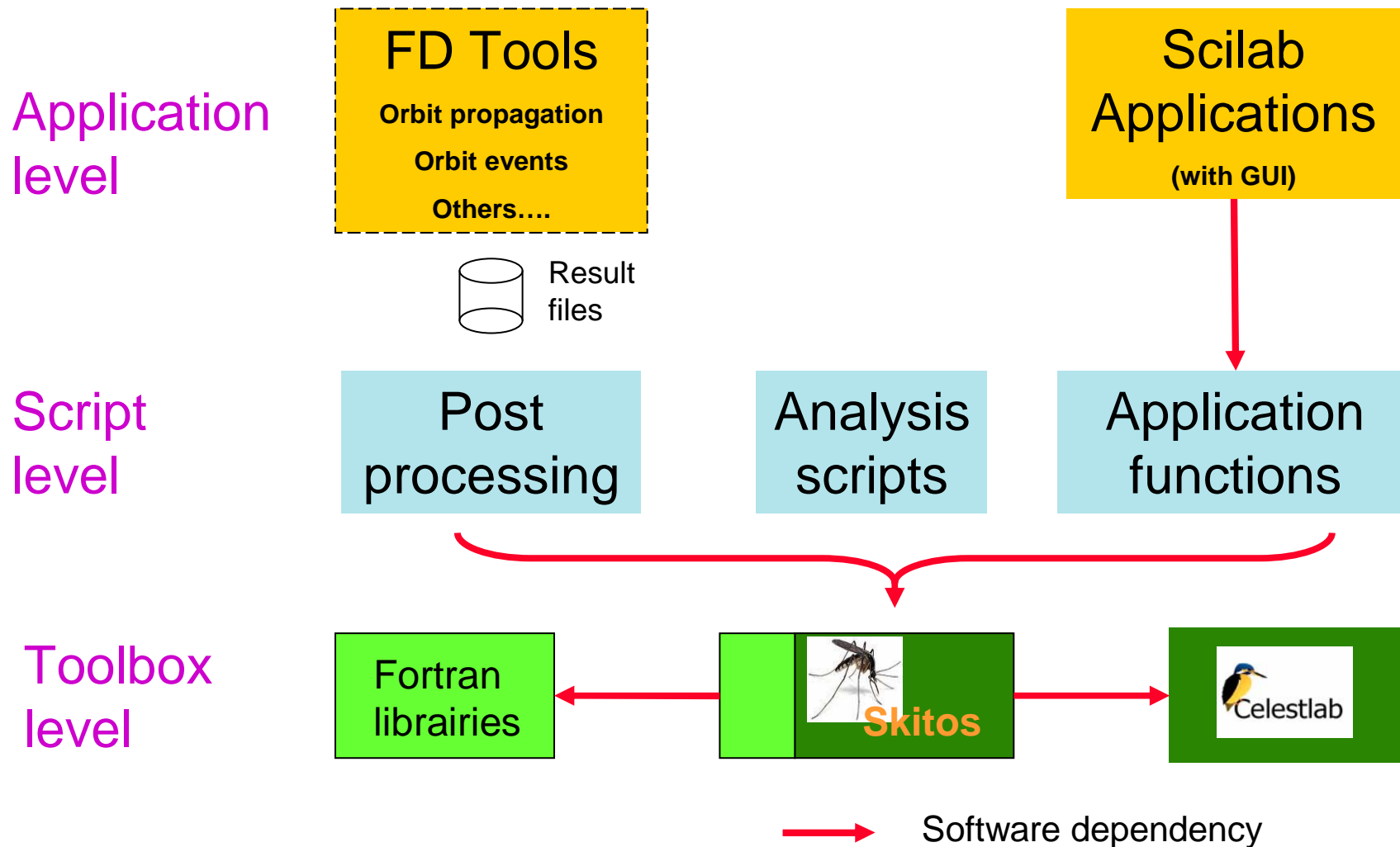


Examples

```
//UTILISATION EXAMPLES
r1 = 7000000
r2 = 105000000
rh = 210000000:10000:220000000
[delta_v]=ma_bielliptic(r1,r2,rh)

//VALIDATION EXAMPLES
r1=7000000
r2=105000000
rh=[210000000 210000000]
[delta_v]=ma_bielliptic(r1,r2,rh)
//expected results
// delta_v =
```


Scilab within the tool Mission Analysis environment



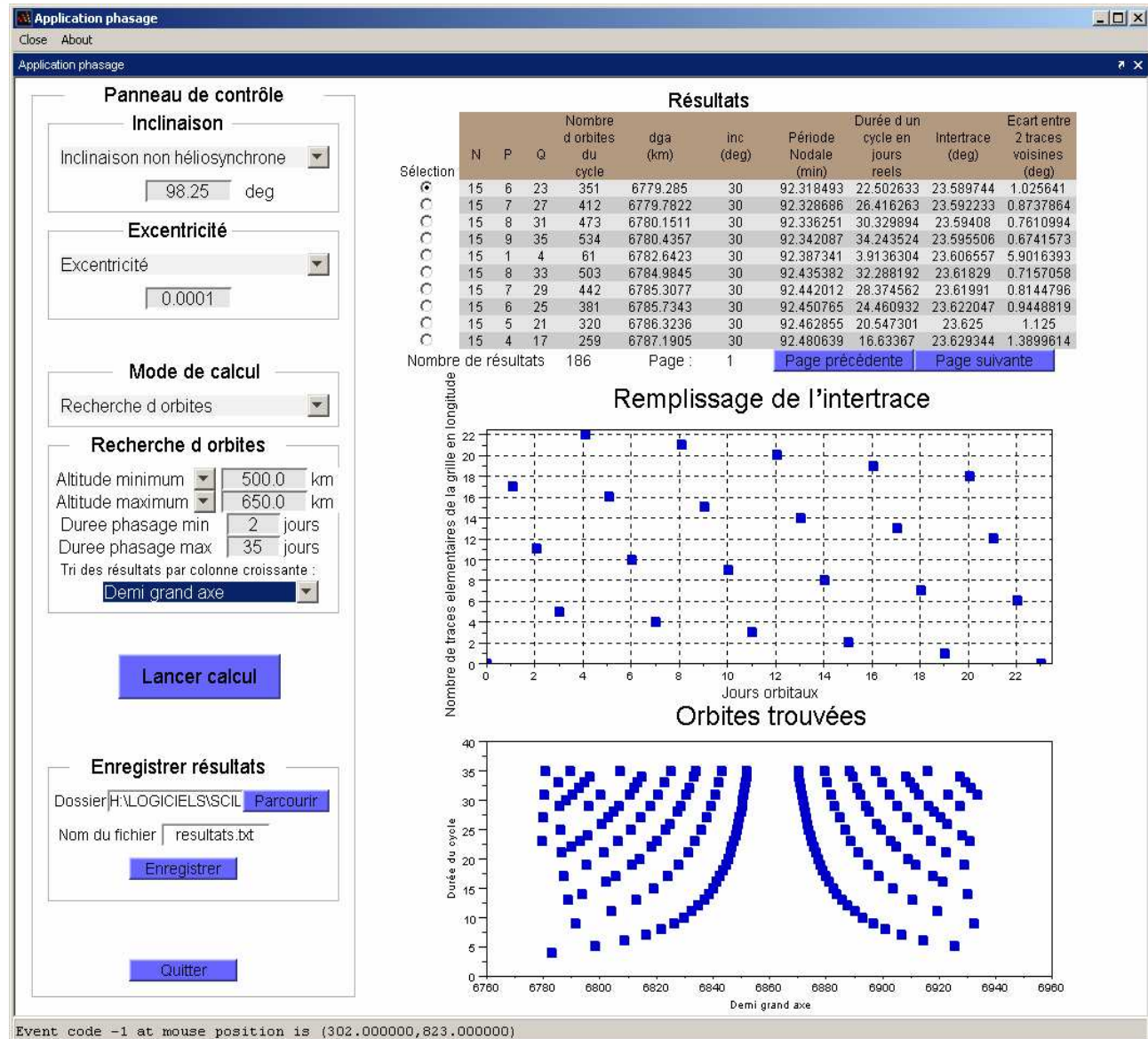
Example of Scilab application with GUI (1)

⇒ 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



Panneau de contrôle

Inclinaison
Inclinaison non héliosynchrone
98.25 deg

Excentricité
Excentricité
0.0001

Mode de calcul
Recherche d'orbites

Recherche d'orbites
Altitude minimum: 500.0 km
Altitude maximum: 650.0 km
Duree phasage min: 2 jours
Duree phasage max: 35 jours
Tri des résultats par colonne croissante: Demi grand axe

Lancer calcul

Enregistrer résultats
Dossier: H:\LOGICIELS\SCILAB Parcourir
Nom du fichier: resultats.txt
Enregistrer

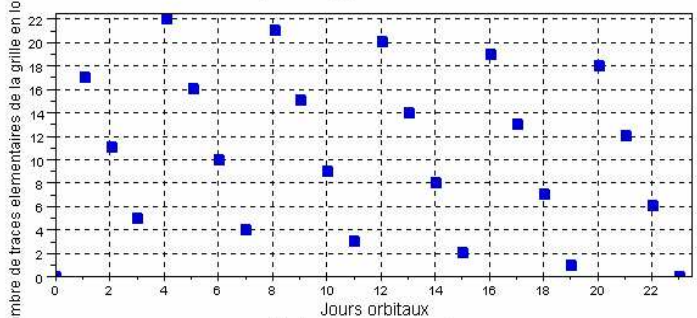
Quitter

Résultats

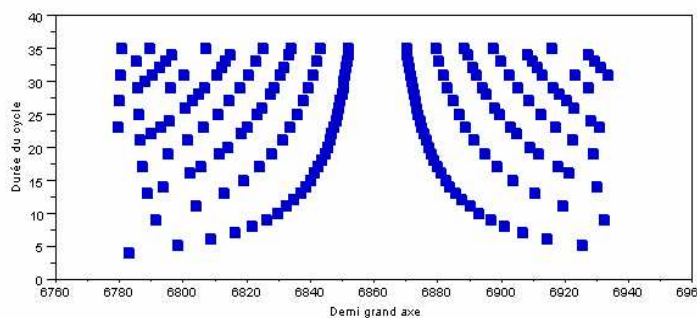
N	P	Q	Nombre d'orbites du cycle	dga (km)	inc (deg)	Période Nodale (min)	Durée d'un cycle en jours reels	Intertrace (deg)	Ecart entre 2 traces voisines (deg)
15	6	23	351	6779.285	30	92.318493	22.502633	23.589744	1.025641
15	7	27	412	6779.7822	30	92.328686	26.416263	23.592233	0.8737864
15	8	31	473	6780.1511	30	92.336251	30.329894	23.59408	0.7610994
15	9	35	534	6780.4357	30	92.342087	34.243524	23.595506	0.6741573
15	1	4	61	6782.6423	30	92.387341	3.9136304	23.606557	5.9016393
15	8	33	503	6784.9845	30	92.435382	32.288192	23.61829	0.7157058
15	7	29	442	6785.3077	30	92.442012	28.374562	23.61991	0.8144796
15	6	25	381	6785.7343	30	92.450765	24.460932	23.622047	0.9448819
15	5	21	320	6786.3236	30	92.462855	20.547301	23.625	1.125
15	4	17	259	6787.1905	30	92.480639	16.63367	23.629344	1.3899614

Nombre de résultats: 186 Page: 1 Page précédente Page suivante

Remplissage de l'intertrace



Orbites trouvées



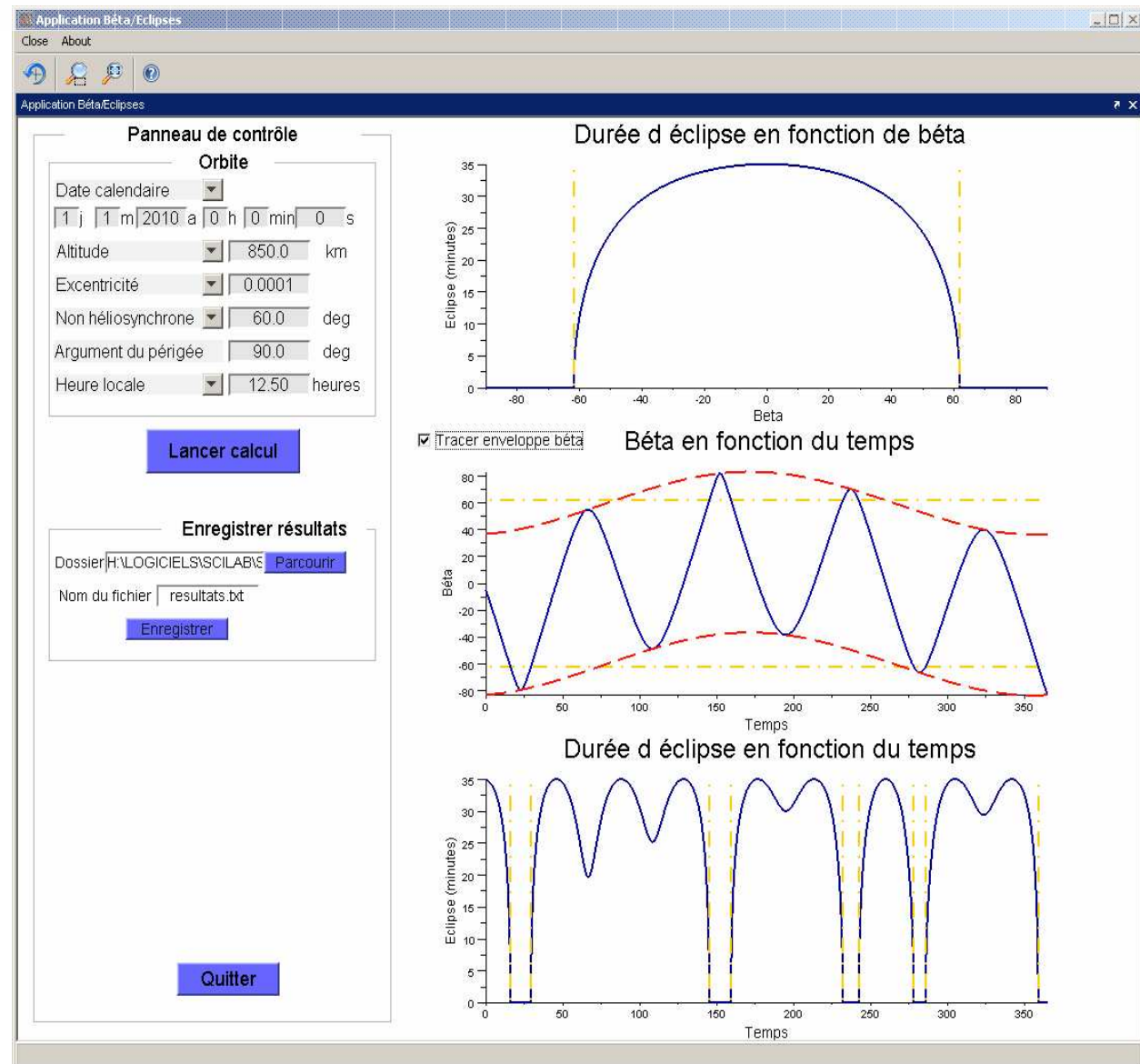
Event code -1 at mouse position is (302.000000,823.000000)

Example of Scilab application with GUI (2)

⇒ Application for sun / orbit geometry analysis

⇒ Computes:

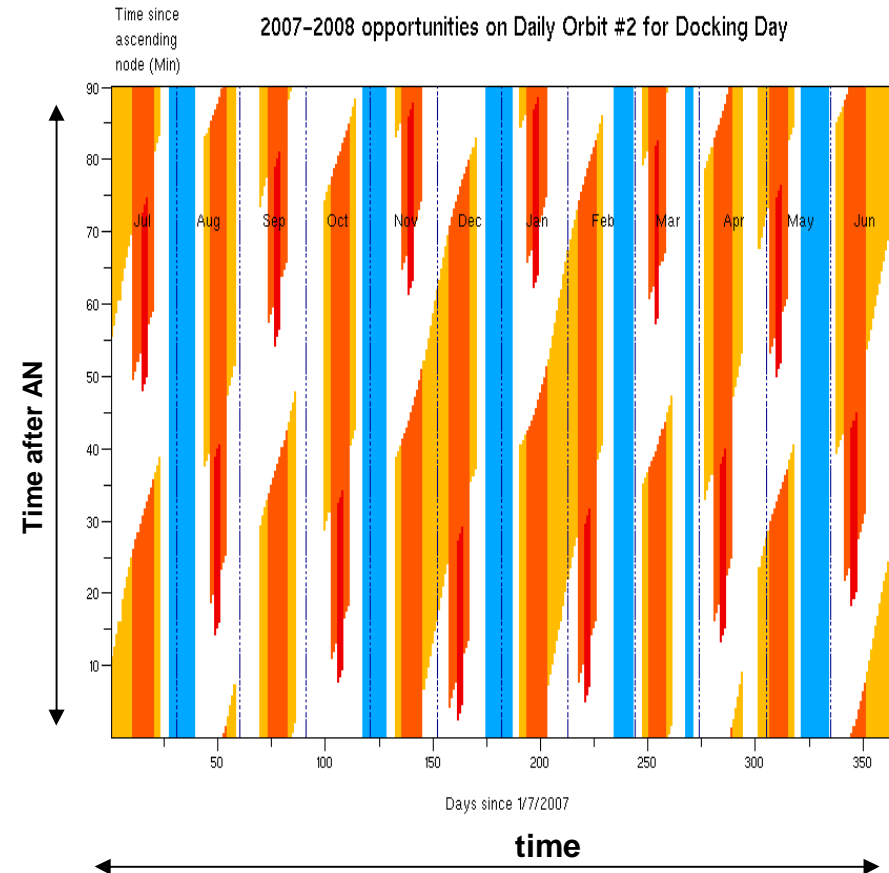
- Sun elevation wrt orbit plane (beta angle)
- Eclipse duration



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

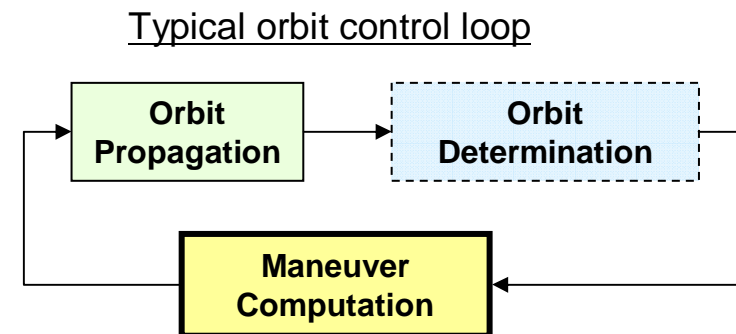
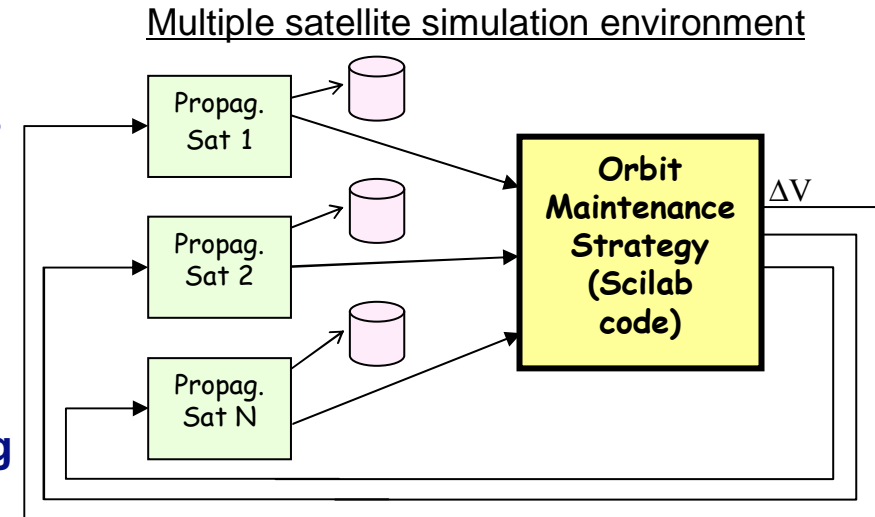
█ ISS power constraint
█ VDM direct dazzling constr
█ ISS camera constraint
█ VDM indirect dazzling const
█ Communications constraint



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)**



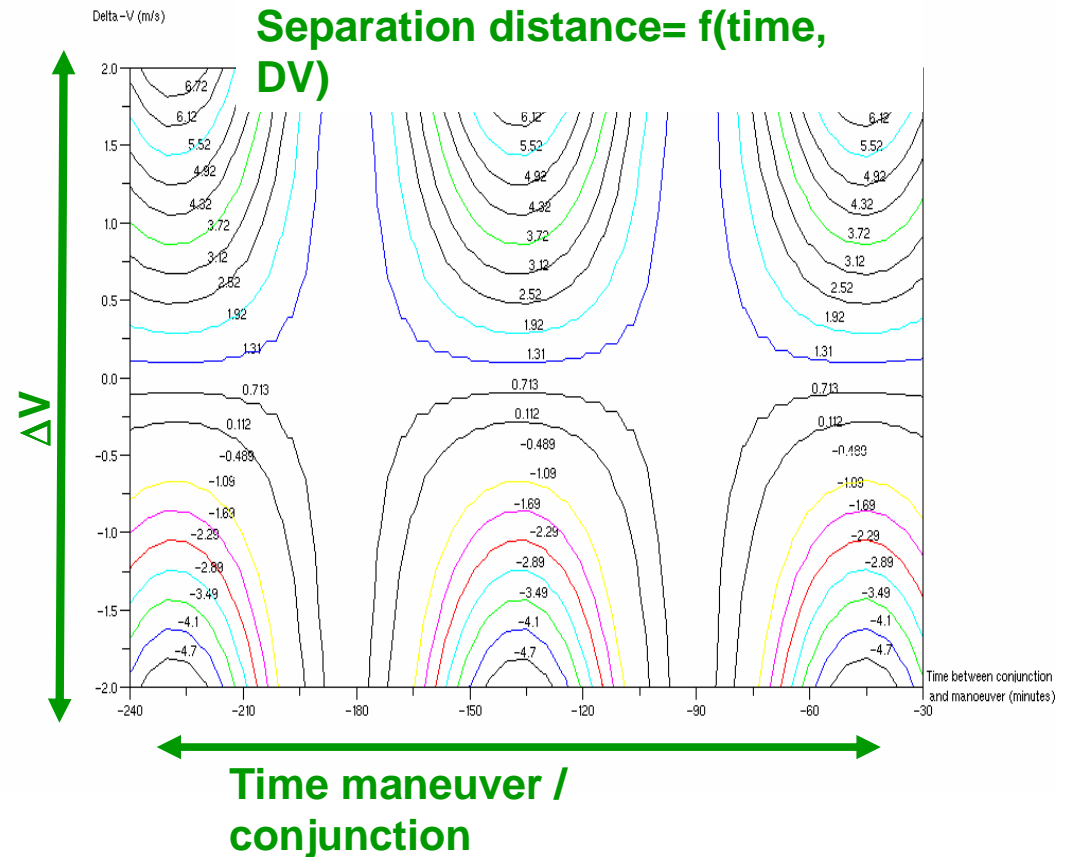
USE OF SCILAB IN FLIGHT DYNAMICS OPERATIONAL SYSTEMS

2 examples

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

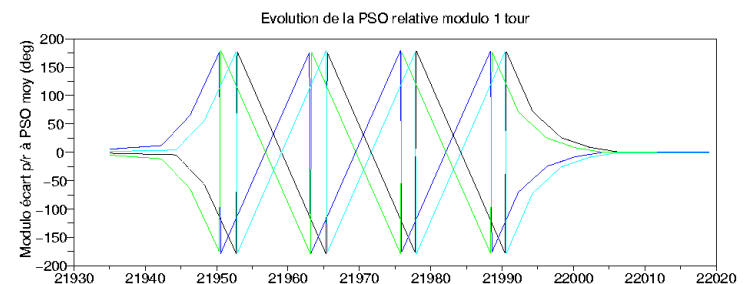
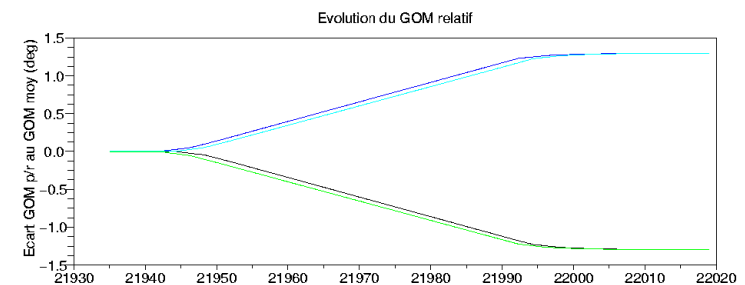
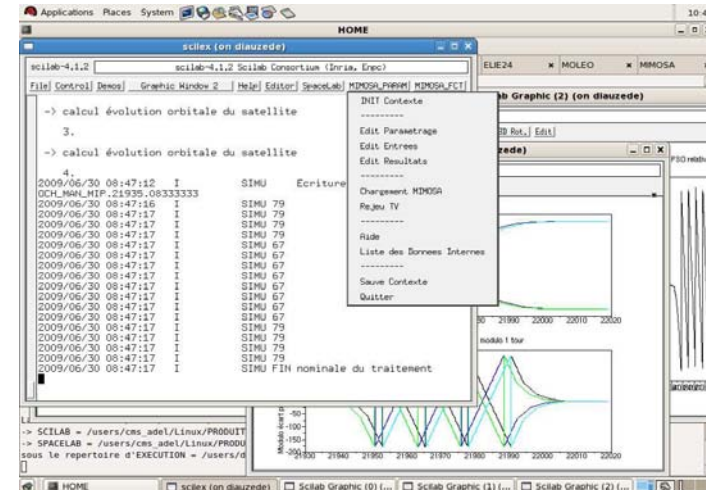
Debris conjunction analysis in ATV-CC Flight dynamics

- ⇒ 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

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...