LEOP Mission Analysis System

GMV has developed a new system to support the mission analysis phase and operations of the launch and early phase of the geostationary satellites. The computational layer of the system is based on ESA’s Navigation Package for Earth Orbiting Satellites (NAPEOS). The algorithms and models have been implemented to make the system compliant with the latest recommendations of the International Earth Rotation Service (IERS) standards.

The system integrates the following main tools:

- Transfer design tool: it allows the users to analyse the possible transfer strategies (synchronous or super-synchronous) to be implemented in each specific mission. It performs a check on the mission and satellite constraints that are selected by the user, in example:
  - Maximum total transfer duration
- Ground station visibility in some periods of the transfer orbit (i.e. around the apogee and perigee manoeuvres)
- Maximum duration of the station acquisition phase
- Maximum number of manoeuvres to be executed.

- Apogee/Perigee optimisation software. This program calculates the optimal (in the sense of minimum propellant consumption) manoeuvres that bring the satellite from separation orbit to Near Synchronous orbit (NSO) while (optionally) satisfying the mission constraints.

- Station acquisition module: it provides the sequence of out-of-plane and in-plane manoeuvres to be executed to bring the satellite to its nominal position, it provides also the following functionalities:
  - Initialises first station keeping cycle (targets in eccentricity and inclination vectors can be defined).
  - Takes into account other satellites windows in the path to avoid collisions.

- Geometrical events generation, it computes in example the following events:
  - Orbital events:
    - Station events, it computes also the interference due to colinearity with other geostationary satellites that can be selected from the NORAD TLE database.
  - Sensor and transponder events.

- Launch computation windows, this module computes the launch window for each transfer strategy selected taking into account the specific satellite attitude manoeuvres and satellite constraints.

- Tracking simulation module.

- Orbit determination module. The modelling of the dynamics and data processing used by this module is:
  - Dynamics:
    - Geopotential model configurable to degree and order (e.g. EGM-96, max 70x70)
    - Lunar and solar gravity perturbations (JPL ephemeris)
    - Solid tide perturbations (IERS formulation)
    - Spherical satellite modelling for solar radiation pressure (IERS model).
  - Measurement modelling:
    - Troposphere (Saastamoinen or Hopfield/Yionoulis)
    - Ionosphere (IRI-95 integrated along the ray path)
    - Selective observation processing configurable on density, time interval, source, type, residual level and value range.
Estimated parameters:

- Satellite state vector
- Solar radiation coefficient
- Aerodynamic coefficient
- Measurement biases for each tracking source and type
- Satellite transponder delay
- Maneuver calibration scale factors

The Apogee/perigee optimization problem is mathematically posed as a Constrained Non-linear Local Optimization Problem (Non-linear Programming), and it is stated as:

Minimize $F(x) = x_1, x_2, ..., x_n$

Subject to:

$g_i(x) = 0, \quad i=1, ..., m_e$

$g_i(x) \geq 0, \quad i=m_e+1, ..., m$

Where $x = (x_1, ..., x_n)$ is the array of optimization parameters, $F$ is the objective function or cost function to be minimized (the total propellant mass consumed: $F(x) = \Delta m_{\text{LAEF}} + \Phi(V_a, l_a)$) and $g_i$ are the targets to be achieved and the mission constraints (equality or inequality constraints) to be satisfied. It is assumed that the objective function and the constraints are twice differentiable at the optimum $x^*$, and that the objective function can be evaluated at points which do not satisfy the constraints. Once the problem is formulated in this fashion it can be solved by a standard dedicated optimization subroutine.

Where $\Delta m_{\text{LAEF}}$ is the cost due to the apogee maneuvers and $\Phi(V_a, l_a)$ is the station acquisition cost that depends basically on the orbital parameters after the last apogee maneuver, the on-station longitude and on the maximum duration of the drift orbit.

The optimization variables (vector $x$) are the parameters that define the apogee maneuvers. The parameterization parameterization of a maneuver depends on the thrust steering policy chosen by the user. Currently AEFOS the inertially fixed thrust steering policy, the thrust vector points to a constant inertial direction in the Mean-of-Date frame. Four parameters define each maneuver in this case:

- mid-time
- duration
- Inertial right ascension of thrust vector
- Inertial declination of thrust vector

The optimization software handles any number of maneuvers. Therefore it can be used to optimize the whole sequence of maneuvers from separation to NSO and also to successively re-optimize the remaining maneuvers after the first ones have taken place. It can also be used to calibrate a single maneuver by re-optimising it setting as target a post-maneuver state vector estimated by the orbit determination program. After convergence to a solution, it carries out sensitivity and dispersion analyses. The sensitivity analysis consists of calculating the change in the objective function (mass
penalty) due to a delay in the manoeuvre start time. The dispersion analysis consists of a Monte Carlo simulation in which on each run the initial state vector and the optimization parameters are modified randomly around their nominal values (according to standard deviations specified by the user): the maximum, the minimum, the expected (average) objective function are then calculated and reported.