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| Date/date     | 11/2005   | ref./réf. | 1 <sup>st</sup> ACT Competition on Global Trajectory Optimisation | page/page   | 1 / 4 |
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| to/à          | The teams participating to the competition  |           | copy/copie  | Advanced Concepts Team (ESTEC),<br>Ruediger Jehn, Michael Khan, Paolo de Pascale (ESOC) |       |
| Subject/objet | <b>Problem Description for the 1<sup>st</sup> ACT Competition on Global Trajectory Optimisation</b> |           |   |   |       |

**Context:**

Following the announcement of the 1<sup>st</sup> ACT Global Trajectory Optimisation competition, this document describes the trajectory optimisation problem the various teams are asked to solve.

**Introduction:**

The selection of the trajectory optimisation problem for the 1<sup>st</sup> ACT Global Trajectory Optimisation competition was made taking into account the following criteria:

*1. Interest of the problem as a global optimisation problem*

The complexity of a global optimisation problem is closely related to:

- The size of the basin of attraction of the global optimum
- The presence of embedded or isolated global minima
- The number of local minima

A high problem complexity makes global search methods particularly important during the design of the mission trajectory.

**To make the problem interesting from this point of view we selected a very large launch window, a mission that allows considering also fly-by sequences as possible solutions and a low-inclination target orbit**

*2. Originality of the problem*

In order to evaluate the numerical methods used rather than the experience and the ability of the various teams, we tried to find a problem where little help could be acquired by looking at past mission trajectories or by using experience.

**The choice of an unusual objective function and of a relatively unknown celestial body should emphasize the importance of the use of automated global search algorithms.**

*3. The possibility of performing the fairest assessment of the results*

One of our major concerns in preparing the problem description was to assure the possibility, on our side, to give a fair assessment of the results received.

**In order to be able to evaluate and compare the different methods we decided to specify the dynamical models to be used, the values of a number of relevant parameters and the output format of the solution to be returned.**

### ***Problem Description:***

The main objective of the optimisation is to maximise the change in the semi-major axis of the asteroid 2001 TW229 subsequent to the impact of an electric propelled spacecraft.

#### *1-The target*

Consider the asteroid 2001 TW229 and its osculating orbital elements in the *J2000.0 heliocentric ecliptic* reference frame:

| <b><i>Asteroid 2001<br/>TW229</i></b>                   |           |
|---|-----------|
| <i>a</i> (semi-major axis, AU):                         | 2.5897261 |
| <i>e</i> (eccentricity):                                | 0.2734625 |
| <i>i</i> (inclination, deg.):                           | 6.40734   |
| $\omega$ (argument of pericenter, deg.):                | 264.78691 |
| $\Omega$ (Right Ascension of the Ascending Node, deg.): | 128.34711 |
| <i>M</i> (mean anomaly at epoch 53600 MJD, deg.):       | 320.47955 |

#### **Keplerian elements of the asteroid 2001 TW229 as obtained from the Minor Planet Center (<http://cfa-www.harvard.edu/cfa/ps/mpc.html>)**

Consider the asteroid as moving along an unperturbed keplerian orbit.

#### *2-The spacecraft*

Consider a nuclear electric propelled spacecraft with a wet mass of 1500 kg (dry mass can be considered to be zero) and equipped with a thruster with the following capabilities: specific impulse  $I_{sp}=2500$  sec., maximum thrust level  $T=0.04$  N.

#### *3-The mission*

The spacecraft has to be transferred from Earth to the asteroid 2001 TW229 with a launch in [3653-10958] MJD2000 (Modified Julian Date 2000), corresponding to years 2010 to 2030. The maximum time of flight is 30 years. At arrival the quantity  $J = m_f \left| \vec{U}_{rel} \cdot \vec{v}_{ast} \right|$  has to be maximised, where  $m_f$  is the final mass of the spacecraft,  $\vec{U}_{rel}$  is the velocity of the spacecraft relative to the asteroid at arrival and  $\vec{v}_{ast}$  is the heliocentric velocity of the asteroid. The launcher available for the mission is able to provide a 2.5 km/sec escape velocity to the spacecraft with no constraint on the escape asymptote direction. Consider also a constraint on the minimum allowed heliocentric distance of 0.2 AU.

*4-The dynamical models*

Consider only the Sun gravity as an external force acting on the spacecraft. Planets may be used to perform swing-bys, in this case the effect should be modelled as an instantaneous direction change on the spacecraft velocity relative to the planet, subject to a constraint on the angle magnitude (a minimum pericenter radius has to be considered, see table below for details). The planet ephemerides used should have an accuracy equivalent to that of JPL DE405 ephemerides (<http://ssd.jpl.nasa.gov/horizons.html>). Use the numerical values given below and assume the astronomical unit equal to  $AU=1.4959787066e+008$  km, and the Earth standard gravitational acceleration to  $g_0=9.80665$  m/s<sup>2</sup>.

|   | Mercury | Venus  | Earth     | Mars    | Jupiter   | Saturn   | Sun             |
|---|---------|--------|-----------|---------|-----------|----------|-----------------|
| Gravitational Constant, km <sup>3</sup> /sec <sup>2</sup> | 22321   | 324860 | 398601.19 | 42828.3 | 126700000 | 37900000 | 1.32712428e+011 |
| Minimum pericenter radius allowed during fly-by, km       | 2740    | 6351   | 6678      | 3689    | 600000    | 70000    | N/A             |

**Numerical values of some relevant parameters**

***Solution Format***

The best solution found should be sent back to the email address [act@esa.int](mailto:act@esa.int) within the 4<sup>th</sup> of December. The document should contain a brief description of the method used to perform the optimisation and to search the solution space, a summary of the important parameters of the trajectory found (i.e. launch and fly-by dates, thrust duration, mission duration and objective function value reached in  $Kg*Km^2/sec^2$ ) and a visual representation of the trajectory.

In a separate ASCII file the detailed data on the trajectory have to be provided following the format and the units of the example provided ([example.txt](#)). The sampling time between the data points in the file has to be one day and the reference frame for all the quantities provided the *heliocentric ecliptic J2000.0* frame.