

## Advanced methods of low cost mission design for Jovian moons exploration

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**Keyword :** Adaptive Mission Design, Multi-Tisserand coordinates, TID, Beam of Trajectories

Mission design of DeltaV-low-cost gravity assists tours for the Jovian moons exploration is considered, taking radiation hazard into account. This work is devoted to the description of criteria for creation of optimum scenarios – sequences of passing of celestial bodies with definition of conditions of their execution. Advanced Multi-Tisserand coordinates [1] for this purpose are exploited for the best study of features for the radiation hazard decrease and the spacecraft asymptotic velocity reduction.

One of main problems of the Jovian system mission design (JUICE, Laplas-P) is that the reduction of the asymptotic velocity of the spacecraft with respect to the satellite for the Jovian moon's capture is impossible. A valid reason is in the invariance of Jacobi integral and Tisserand parameter in a restricted three-body model (R3BP). Furthermore, the same-body flybys tour falls into the hazard radiation zone according the Tisserand-Poincaré graph. Formalized 3D beam's algorithm to overcome this "problem of the ballistic destiny" with using full ephemeris model and with several coupled R3BP engaging has been implemented. Withal low-cost reduction of the spacecraft asymptotic velocity for the capture of the moon is required. The corresponding numerical scheme was developed with using Tisserand-Poincaré graph and the simulation of tens of millions of options. The Delta V-low cost searching was utilized also with help of the modeling of the multiple rebounds (cross gravity assists) of the beam of trajectories. The techniques are developed by the authors specifically to the needs of the mission "Laplas P" of Roscosmos.

If we have answers to the questions "what kind of gravity assists", we need answer on the question "when". Advanced 3D modification of multi-Tisserand coordinates [2] for this purpose are introduced. They are Tisserand parameters of SC relative some small bodies in several local R3BP. The Multi-Tisserand graph built based on them. It is shown that the "cross" gravity assists at the early stage of SC orbital energy reduction for TID-comfortable tour are required. As a result, a reasonable increase in the duration of the missions of the Icy Moons exploration can be exchanged on a sharp decline TID and "comfortable" (in TID) tours scenario can be found in the Jovian system (less than 70 Krad for standard SC protection 8-10 mm Al).

### References

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- [2] Grushevskii A. *et al.*, Advanced methods of low cost mission design for outer planets moons'orbiters and landers, *Proceedings 67th International Astronautical Congress – IAC 2016, Guadalajara, Mexico* (2016), IAC-16-C1.4.11