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Efficient design of low lunar orbits based on Kaula recursions

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Preliminary design of artificial satellite missions commonly relays on the use of simplified models that comprise the bulk of the dynamics. In the case of the gravitational potential, the amplitude of long-term oscillations of the orbital parameters is roughly one order of magnitude larger than the short-period oscillations. Because of that, dealing with just the few more relevant zonal harmonics of the potential is generally suitable for the initial steps of the procedure. In addition, the long-term evolution of the orbital parameters is customarily investigated through averaging procedures that remove the higher frequencies of the motion, in this way notably speeding the process of mission design.

However, there are cases in which the use of simplified models is not an option and full zonal potential models must be used instead. The paradigm is provided by the moon, where, due to the irregular character of the moon gravity field, mission designing of low altitude lunar orbits needs to deal with tens of, contrary to just a few, zonal harmonics. The analytical approach is still possible, but the requirement of handling huge expressions formally usually discourages mission planners, who then resort to numerical procedures. Still, useful compact recursions for dealing analytically with the problem exist in the literature since many years ago, yet limited to the equations of the averaged flow.

Based on Kaula's popular work, we re-derive the long-term potential of the zonal problem in closed form and show that Kaula's approach in orbital elements provides much more efficient formulas for the construction of the mean elements potential that recent alternative proposals in the literature. The necessity of having available efficient expressions for the long-term zonal potential, from which the evolution equations of the orbit are directly derived, is illustrated with application to the design of low lunar orbits.

Summary

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