LOW THRUST AUGMENTED SPACECRAFT FORMATION-FLYING

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Abstract: Although ballistic spacecraft formation-flying with zero thrust has great utility, it is limited to a comparatively small set of relative trajectories. However, rich new families of formation-flying trajectories can be generated by the addition of continuous low-thrust. This new and novel problem provides a wide range of potentially useful alternatives to natural ballistic formation-flying. In this paper, the standard Clohessy-Wiltshire approximation of spacecraft motion in a rotating frame is used to investigate the motion of a ‘chase’ spacecraft about a ‘target’ spacecraft which is in a circular geostationary Earth orbit. Families of non-Keplerian relative motion are systematically explored, generating analytical representations of the relative motion trajectories and the required thrust commands for both simple static formations and more complex new forced relative orbits.

The first such concept, the Modified Z-Period Orbit (MZPO), uses thrust to modify the period of the out-of-plane relative motion of the chase spacecraft, and is an extension of the statically displaced non-Keplerian orbit concept to generate complex periodic relative orbits. Second, the thrust commands are generated for Forced Circular Relative Orbits (FCRO) of the chase spacecraft relative to the target. The MZPO and FCRO concepts find joint application in the development of the Sun Vector Tracking (SVT) formation, in which the chase spacecraft orbits the target spacecraft with an in-plane period of one solar day and an out-of-plane period of one year, with the aim of matching the daily and yearly cycle of the Sun about the target spacecraft. Transfers between relative orbits are also analysed, and it is shown that both forced low-thrust manoeuvres and ballistic zero-thrust manoeuvres can be used to efficiently patch between displaced non-Keplerian orbits, and indeed Keplerian orbits, in the rotating frame.

It is shown that the applications of the new families of formation-flying trajectories are diverse. For example, the SVT spacecraft formation can facilitate constant-angle illumination of a target spacecraft for visual inspection by a chase spacecraft. The FCRO general-case thrust commands allow for a range of distributed sensing missions, and the rotating-frame orbit patching method permits on-orbit spacecraft inspection trajectories which are not disruptive to the geostationary satellite service, through the avoidance of sensor and communications interference zones nearby the target spacecraft.

Proceeding from the analysis, an exhaustive taxonomy of formation-flying relative orbits in geostationary orbit is generated, extensively cataloguing new and novel spacecraft formations according to thrust requirements. Finally, an assessment of the potential uses, advantages, and disadvantages of available thrust technologies within the context of spacecraft formation-flying is presented, including electrostatic thrusters and solar sails. For electric propulsion it is found that propellant requirements are modest when appropriate thruster technology is selected, and therefore that the concept of low-thrust augmented spacecraft formation-flying in geostationary Earth orbit is deliverable in the near term.

Keywords: Spacecraft Formation-Flying, Non-Keplerian Orbits, Rotating Reference Frame, Low Thrust Propulsion, Hybrid Thrust Propulsion.