Augmented Spacecraft Formation-Flying Using Low Thrust Propulsion

Callum Arnot\(^1\), Colin McInnes\(^2\)

\(^1\)PhD Student, Advanced Space Concepts Laboratory, University of Strathclyde, callum.arnot@strath.ac.uk
\(^2\)James Watt Chair, Professor of Engineering Science, School of Engineering, University of Glasgow, colin.mcinnes@glasgow.ac.uk

The Concept

Although ballistic spacecraft formation-flying is well understood, it is limited to a comparatively small set of relative motion trajectories. However, rich new families of formation-flying trajectories can be generated by the addition of continuous low thrust. Such a modified problem provides potentially useful alternatives to the classical ballistic formation-flying problem. Using the Clohessy-Wiltshire approximation of relative motion, families of forced, non-Keplerian relative orbits are generated and explored, presenting new concepts for leader-follower spacecraft formations in geostationary Earth orbit.

The Model

The Clohessy-Wiltshire equations, which provide a linear approximation of motion in a rotating frame, can be augmented by the addition of thrust terms:

\[
\begin{align*}
\dot{x} &= 3x^2 + 2ny + a_x \\
\dot{y} &= -2nx + a_y \\
\dot{z} &= -n^2z + a_z
\end{align*}
\]

This allows the effect of thrust on close-range relative trajectories to be analysed. All following examples consider a leader spacecraft which is in a circular geostationary orbit around the Earth.

The Orbits

By applying different thrust commands, we can:
- Change the period of the follower’s (decoupled) z-axis motion, producing the non-Keplerian Modified Z-Period Orbit (MZPO)

- Force the follower spacecraft to trace a circular relative orbit around the leader, with any desired period and orientation, in the Forced Circular Relative Orbit (FCRO)

- Combine the MZPO and FCRO to force the follower to constantly track the Sun vector about the leader, in the Sun Vector Tracking Orbit (SVTO)

The Applications

The ability to track the Sun vector about a spacecraft in orbit has several potential uses, chief among them being the ability to provide constant aspect-angle, bright illumination of the leader spacecraft for visual inspection by the follower. With the advent of highly efficient and controllable electrostatic microthrusters, it can be envisaged that a small camera-equipped spacecraft could be used to examine the condition of geostationary satellites in orbit – providing highly valuable information about spacecraft conditions as a possible precursor to on-orbit servicing. Uses for the FCRO and MZPO include the deployment of distributed sensors and fractionated spacecraft – permitting, at once, more complex and less expensive mission architectures than currently exist.