4 years of successful INTEGRAL operations without thruster firing

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Abstract

In May 2020 INTEGRAL suffered a major anomaly in the propulsion system. The performance of the thrusters became unpredictable, and no more propellant was usable. A new observing strategy (z-flip strategy) was developed by the Flight Dynamics team at ESOC to redistribute the accumulated angular momentum between the reaction wheels and reduce their speeds by flipping the spacecraft by 180° around its z-axis.
This new observing strategy was implemented at ISOC and we have been using it since June 2020. We present an overview of the strategy and its application to science operations. Despite some limitations in the observing strategy, we have been able to resume full operational efficiency with no impact in the scientific programme.

Z-flip strategy

Following the May 2020 anomaly and with the thrusters no longer reliable, a new way of operating based on angular momentum conservation was put in place (see Kuulkers et al. 2021).

The main cause of accumulation of angular momentum on the reaction wheels is the Sun radiation on the spacecraft solar arrays. The Sun radiation creates a torque on the spacecraft and an increase in the reaction wheels speed that needs to be balanced. This is done by pointing INTEGRAL to opposite directions in the sky across the Sun constraint during roughly equal amounts of time, so that the torque created by pointing to a direction in the sky is compensated while pointing in the opposite direction (see Fig. 1).

The strategy was implemented at ISOC in June 2020 and has become part of routine science operations. INTEGRAL mission planning now includes the assessment of the angular momentum evolution in every revolution using tools developed by Flight Dynamics. Most of the times the z-flip strategy is implemented in one revolution, but when required by the scientific programme we perform one orbit long observations, and the compensation of angular momentum takes place over two or more revolutions.
In addition to the Sun radiation, the Earth gravity gradient torque also affects the angular momentum close to perigee. We take this effect into account by selecting an optimal perigee entry attitude to continue lowering the angular momentum during perigee passage.

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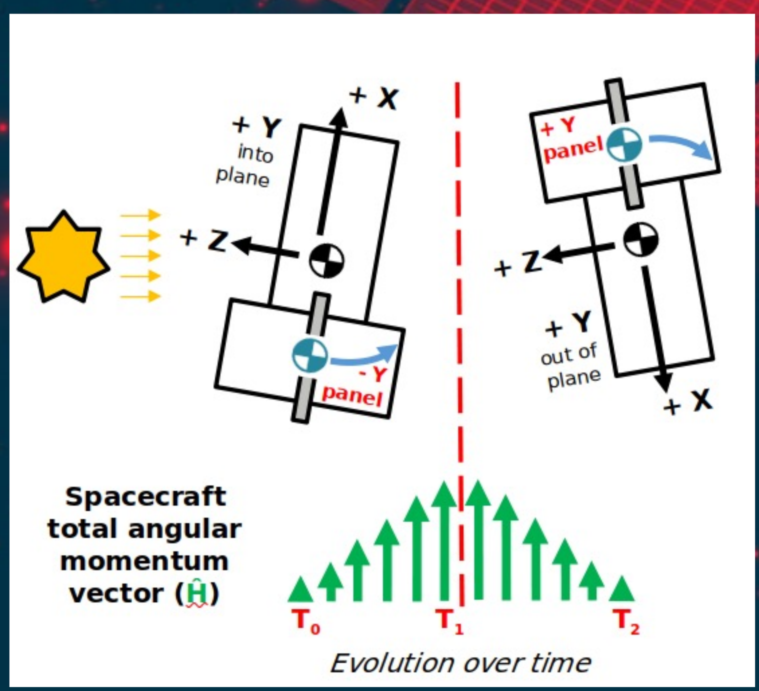

Fig. 1: Illustration of z-flip strategy (D. Salt, ESOC)

Mission planning example using the z-flip strategy

We show an example of mission planning using the z-flip strategy in revolution 2656. The z-flip was performed using two targets (M31 and Cen A, Fig. 1 left) located at ~172° from each other. We evaluated the angular momentum and wheel speeds evolution over the revolution. The compensation of the wheel speeds and angular momentum can be seen in Fig. 2 (middle and right). We always make sure that the angular momentum and wheel speeds do not exceed critical values set by Flight Dynamics. With the selection of an optimal perigee entry attitude, combining the effects of the gravity torque and the radiation pressure, the angular momentum and wheel speeds decrease during perigee passage as well.

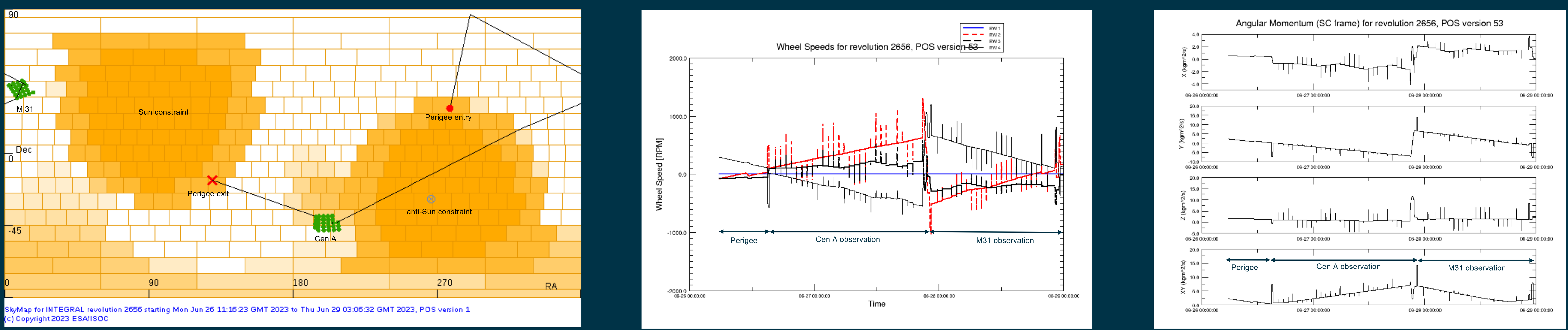

Fig. 2: Left: Sky map of revolution 2656 in equatorial coordinates showing the M31 and Cen A observations. The orange/yellow areas represent the observation constraints. Middle: predicted wheel speeds evolution during the revolution. Right: predicted spacecraft angular momentum evolution in different axis during the revolution.

Conclusions and outlook

The z-flip strategy has been the default planning strategy since June 2020 with full operational efficiency. It is limited by the available targets in the scientific programme and requires a proper selection of the targets in each revolution. In routine planning we try to keep the angular momentum and wheel speeds as low as possible to have bandwidth to accommodate ToOs, orbit long observations or not favorable targets to the z-flip strategy when needed. In such cases, when targets are not favorable, we sometimes need a few revolutions to reach low levels of angular momentum/wheel speeds again. If the accumulated angular momentum is too high and we approach critical limits, we can always perform one auxiliary observation at an appropriate attitude to make the angular momentum go down, however this has so far never been required.

The z-flip strategy could be applied to existing missions to reduce fuel consumption and thus extend their lifetime, or to missions in development to optimize the thrusters' usage and fuel consumption.

References:
Kuulkers, E. et al., NewAR, 9301629K, 2021

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