GAIA: TRAJECTORY DESIGN WITH TIGHTENING CONSTRAINTS

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This paper will describe the updated mission analysis for Gaia and the required changes in the transfer design and mitigation strategies due to additional constraints that appeared after the S/C had been built.

Gaia's primary objective is to survey one thousand million (one billion) stars in our Galaxy and local galactic neighbourhood in order to build the a 3D map of the Milky Way one hundred times more precise than earlier efforts, and answer questions about the Milky Way's origin and evolution. The mission's secondary objectives reveal Gaia as the ultimate discovery machine. It is expected to find up to ten thousand planets beyond our Solar System and hundreds of thousands of asteroids and comets within it. The mission will also reveal tens of thousands of failed stars and supernovae, and will even test Einstein's theory of General Relativity.

The operational orbit is a small size Lissajous orbit around the Sun-Earth Libration Point 2 (SEL2). The launch system is Soyuz-Fregat from Kourou. For the transfer the Soyuz rocket lifts the Fregat upper stage together with Gaia in a sub-orbital trajectory. A first burn of the Fregat upper-stage injects the stack consisting of Fregat and Gaia in a circular parking orbit with an inclination of 15 Deg. This allows to drift towards the required argument of perigee for an injection towards SEL2. At the correct argument of perigee a second Fregat burn lifts the Fregat-Gaia stack into a transfer orbit with an apogee altitude of about 1 Million km. After a launch day dependant transfer duration of 14-28 days libration point insertion manoeuvre is executed, which shall place Gaia into its operational orbit.

The transfer is subject to several constraints:

- Only two Soyuz-Fregat flight programs are available defining the apogee altitude and the argument of perigee
- The S/C attitude (Solar array sun aspect angle) is constrained prior to TCM#1 and fixed after TCM#1 to achieve thermal stability
- Due to the propulsion system design Gaia cannot be decelerated after launch and thus all transfer correction manoeuvres must have a DeltaV vector directed into the anti-sun direction. This results in the fact that some manoeuvre error directions cannot be compensated by the S/C
- Time critical correction of deviations from required perigee velocity (deterministic and stochastic)
- During the transfer and while on the operational orbit Gaia must maintain a Sun-S/C-Earth angle of less than 15 Deg at all times to ensure communication with the phases array antenna in all S/C attitudes
- The transfer and operational orbit shall remain free of Earth eclipses for at least 5.5 years
- The eclipses may not exceed 20% during the transfer phase

The constraints listed above were the input to the mission analysis and were used to define the launch opportunities for Gaia. However, within the final year prior to launch several other problems surface, which required a re-design of the transfer strategy:

- With the S/C being built the propellant budget was fixed
- The translation between required DeltaV, manoeuvre efficiency and propellant allocation was erroneous
- The S/C showed unacceptably larger directional errors for the libration point insertion manoeuvre

These items did not allow for a launch with the previously calculated transfer trajectories and mitigation measures had to be found, but were in many cases disregarded due to financial or scheduling implications:

- The root cause for the large directional error could be identified by Mission Analysis and confirmed by the manufacturer and a prediction of the deterministic part of the directional error was established – However, due to contractual reasons the results could not be applied
- The identification of the root cause allowed to define thrust azimuth angles with a low expected directional error. The transfer trajectories were re-designed to take the additional constraint on the allowed manoeuvre directions into account. This causes an increase in the required DeltaV due to sub-optimal manoeuvre directions, which could partially compensated by choosing appropriate Fregat flight programs with different apogee altitudes
- The insertion manoeuvre was further split into two parts to allow a for easy corrections of directional errors in an efficient manoeuvre direction
- The S/C design would have allowed to carry extra propellant due to existing margins on the launcher payload mass, however, the S/C mechanical qualification had been performed with a specified propellant load and a re-qualification would have been required to add additional fuel
- Manoeuvre decomposition by changing the S/C attitude was introduced in order to achieve a better manoeuvre efficiency

In addition to the changes in the nominal trajectory design new methods in case of contingencies had to be developed to still reach an operational orbit with the given propellant, but with a more complex transfer trajectory design.

In the end a feasible mission design could be found, proving the value of strong mission analysis involvement in phase C/D/E.