# STUDIES ABOUT A SHALLOW RE-ENTRY FOR ATV-5

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## ABSTRACT

After five successful missions, the Automated Transfer Vehicle (ATV) program ended last February with the ATV-5 “Georges Lemaitre” re-entry in the South Pacific Ocean in an uninhabited area. The role of the ATV was to provide supplies to International Space Station (ISS) with propellant, water, gas, dry cargo and remove ISS waste. ISS cargo and liquid waste is destroyed during the atmospheric re-entry, as the vehicle itself. ATV provided also a propulsive support to ISS for attitude control, re-boost and debris avoidance. ATV was a project funded by ESA and the spacecraft was developed by AIRBUS-DS as prime contractor. CNES has developed the ATV Control Centre (ATV-CC) under ESA contract and has been responsible for the operations of the five ATV missions.

The ATV-5 re-entry was performed according to the principles of the generic deorbitation mission analysis: one minute after the separation with the ISS, a departure maneuver takes away the ATV from ISS and after 24 hours of free-flight the deorbitation is performed by means of two deorbitation maneuvers lowering the perigee. This kind of deorbitation can be described as “steep” because the apogee of the reentry arc is roughly at the ISS altitude (around 400 km) and the targeted perigee is at the geocentric altitude of 0km or -70km. The targeted perigee altitude depends on the remaining propellant loading in the ATV tanks after the last deorbitation boost. During the ATV-5 attached phase, the ISS did not use as much propulsion support as initially planned, so the remaining propellant in ATV tanks implied to target a perigee at -70km.

But this “steep” reentry profile differs from the initially planned scenario for the ATV-5 re-entry. Indeed in 2013, NASA ISS program requested the ATV Control Center (ATV-CC) to perform with the ATV-5 an experimental reentry observation to characterize the ISS reentry environment and fragmentation models prior to the ISS end of life. Therefore, to be as close as possible to the ISS re-entry conditions, we had to change the generic ATV “steep” re-entry strategy into a new ATV “shallow” re-entry strategy. Many studies were then performed to design an acceptable (science and safety wise) “shallow” re-entry strategy for ATV-5 with the following constraints: the re-entry arc apogee had to be at the geodetic altitude of 190 km and the targeted perigee altitude as high as possible. The limit for the perigee altitude had to allow the re-entry into the atmosphere few minutes after the last deorbitation maneuver and this re-entry had to be safe with regards to the ground population casualty risk: the probability that a debris, resulting of the ATV fragmentation due to atmospheric re-entry, impacts a dry land had to be lower than $10^{-5}$.

Another new feature of the ATV-5 “shallow” re-entry was the attitude after the last deorbitation maneuver. For all of the four previous ATV missions, the vehicle was put in a tumbling attitude after

the last deorbitation maneuver. But, in order to improve the observation of aerothermodynamics phenomenon expected in an ATV and ISS “shallow” reentry, a fixed orbital Earth Pointing attitude was initially planned to be achieved after the last deorbitation maneuver and held down to 125km geodetic altitude.
The fragmentation had also to be observable from the ISS, as it was done for ATV-4 and ATV-1.

An ATV “shallow” re-entry strategy phased with ISS had been finalized with all the ATV operational products adapted to support it. The ATV-CC teams were fully trained to this new strategy. Unfortunately, one week before the undocking, this strategy had to be cancelled due to a failure onboard ATV leading to the isolation of one of the four power chains. In these conditions, ATV was still one fault tolerance to another failure on power, however in order to limit the risk of another critical failure, the planned date for reentry was advanced to the earliest opportunity after undocking. Due to the large amount of unused propellant left onboard ATV, only a “steep re-entry” allowed to meet the safety objectives with regards to the ISS and the ground population. The short time between ATV undocking and reentry did not allow planning enough ATV maneuvers for burning propellant in excess as required by a shallow reentry, nor even for the phasing with ISS as required for ATV fragmentation observation.

The paper will present the studies performed during ATV mission analysis to define a safe “shallow” re-entry trajectory profile satisfying the constraints induced by the ATV reentry observation experiments for the date and location of the re-entry and by the ISS visiting vehicles traffic for the ATV undocking date. The paper will focus in particular on the last deorbitation phase (deorbitation maneuvers and re-entry) but it will also provide an overview of the whole maneuver strategy from undocking to re-entry.