

# ON-BOARD SCENARIO GENERATION FOR THE TAEM GUIDANCE OF A WINGED BODY

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The Flight Control team of EADS-ST is in charge of GNC algorithms design, software development and qualification of various systems.

As regards recovery missions, EADS-ST performed the complete design and development for the ARD (Atmospheric Re-entry Demonstrator) program, including the GNC system and notably the guidance algorithm, leading to a successful flight of the capsule in late 1998. Further studies were performed for lifting/winged bodies, on both hypersonic re-entry (from 120 km down to Mach 2 gate) and TAEM flight phase (from Mach 2 gate to Mach 0.5 gate).

When reaching Mach 2 gate, the entry vehicle may be far from the nominal TAEM entry conditions, both in terms of position and velocity. The TAEM guidance shall deal with those offsets, and adapt the real trajectory to the current flight conditions in order to reach the desired conditions at Runway Alignment interface, ensuring a safe auto-landing terminal phase.

An original method was investigated and implemented, inspired by the BURAN Russian shuttle approach for the TAEM problem. The designed guidance scheme is based on a reference trajectory tracking, but involves the in-flight computation of the reference path within a very short time thanks to closed-form analytic formulation and a safe optimisation-less process.

The TAEM flight phase is divided into a set of three predefined sub-phases: starting at the TAEM entry point, an alignment S-turn manoeuvre, at the end of which the vehicle is aligned on the tangent to Heading Alignment Cylinder (HAC), a homing line along this HAC tangent, and eventually when the vehicle has reached the HAC, the HAC tracking phase until reaching the TAEM exit point. In case of over-energetic conditions at the entry point, an initial dissipation S-turn is added prior to the alignment S-turn.

During TAEM phase, the energy management is achieved through the aerodynamic forces control using L/D modulation, enabled by commands in bank angle, angle-of-attack, and according to the vehicle design, speed brake deflections.

The trajectory planner method is based on a natural physical understanding of the TAEM flight phases with some specific assumptions such as flat Earth, equilibrium glide conditions, and piecewise constant L/D

profile. Then, direct link between energy dissipation and downrange enables analytic motion integration and thus expression of both position and velocity conditions at each waypoint defining the outer limits of each TAEM sub-phase. Eventually, knowing the ground length of the trajectory and the altitude loss between entry end exit points, a TAEM reference trajectory can be iteratively derived. In this sense, the generation process may be understood as a dynamic positioning of a fixed-length 3D curve.

Considering a set of 4 predefined HACs, and wind heading on the runway, the trajectory planner keeps only 2 HACs, and consequently one exit point. However, if exit energetic conditions are too high, then up to 4 solutions may be found by adding a dissipation phase at the beginning of the TAEM phase, according to straight-in or overhead conditions.

Because the whole process uses analytical formulation, the generation of a reference trajectory leads to quite limited computational workload requirements: for a typical mission of a re-entry glider, the reference trajectory is built in less than 150 ms of CPU time on a Sun workstation (2000 Specfp index of 166).

A specific guidance scheme is also implemented, based on a reference trajectory tracking logic, both along horizontal (curvilinear abscissa control) and vertical (descent control) command axes. Horizontal logic yields bank angle command from position offsets. Vertical logic yields angle of attack command from offsets on altitude, velocity and flight path angle. Finally, speed brake deflections may be used when available to adjust the current L/D with respect to actual flight conditions.

An updated version of SITHAR simulation tool, formerly developed for the ARD program, was used to test the trajectory planner scheme with the guidance algorithm, for the entry of the ARES-H vehicle down to a landing on Istres runway. The original TAEM generation profile proves its ability to cope with TAEM requirements: off-nominal conditions at Mach 2 gate, due to off-nominal flight conditions during the hypersonic guided re-entry, are eventually set close to zero when reaching the TAEM exit point. Statistical analysis based on Monte-Carlo runs also demonstrates the efficient behaviour of both algorithms in presence of perturbations.

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