# Aerospace Europe Conference 2023
# Joint 10$^{th}$ EUCASS – 9$^{th}$ CEAS Conference

Abstract #XXX *(to be filled by the organizers)*
Preferred Topics: REUSSA / REUSYS / FDGNCAV
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Type: Oral
Status of corresponding author: Regular

## Title
# ReFEx: Reusability Flight Experiment – Architecture and Algorithmic Design of the GNC Subsystem

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## Abstract
One of the main objectives of the mission ReFEx is to demonstrate GNC capabilities for an aerodynamically controlled RLV stage. The GNC subsystem steers the vehicle to reach a target state, crossing from the supersonic to the subsonic flight regime. This objective is achieved by: 1) planning a feasible trajectory from the current state to the target (Guidance), 2) estimating the current state from the sensor measurements (Navigation) and 3) tracking the attitude commanded by the guidance while stabilizing the vehicle using the actuators (Control). This paper provides an overview of the algorithms of these modules, their integration into the GNC architecture and their performance.
The Guidance module implements two functionalities: updating the trajectory and commanding the reference attitude. The initial trajectory update compensates state dispersion at separation from the launcher. Minor updates at a fixed rate compensate modelling inaccuracies and tracking error throughout the re-entry phase. These updates are conducted solving an unconstrained non-linear optimization problem that results from parameterizing the control profile.
The Navigation module estimates the variables required by Guidance and Control in two stages. First the kinematic variables, position, velocity and attitude, are estimated using a Kalman filter that is obtained from an automated design procedure, which merges the information provided by measurements from a 4-axis IMU, a GNSS receiver, and four Sun sensors. Second, aerodynamic variables, such as Angle of Attack, and Mach number, are estimated using a second Kalman filter, which combines the outcome of the first filter with the measurements of a Flush Air Data Sensing system.
The Control system consists of the controller, which computes a torque based on guidance and navigation inputs, and the control allocation, which converts this torque into actuator commands. During the exoatmospheric flight, a PD-controller with feedback linearization is used, calculating the desired attitude trajectory using spherical linear interpolation and polynomial progression. The command is allocated to cold gas thrusters using a pulse modulation method. For the atmospheric phase, a cascaded linear controller based on incremental nonlinear dynamic inversion (INDI) is used. Local control effectiveness gradients augmented by a constrained damped Least-Squares method are used to allocate the torque to aerodynamic actuators.
These algorithms were implemented and tested in a 6-dof closed loop simulation. This environment allows to conduct automatically Monte Carlo campaigns, simulating the uncertainties in the vehicle (including in sensors and actuators) and the environment.