Final Presentation

FASTREC

Fast Reconfiguration Technologies for Recurrent Space Transportation Flight

18/12/2023

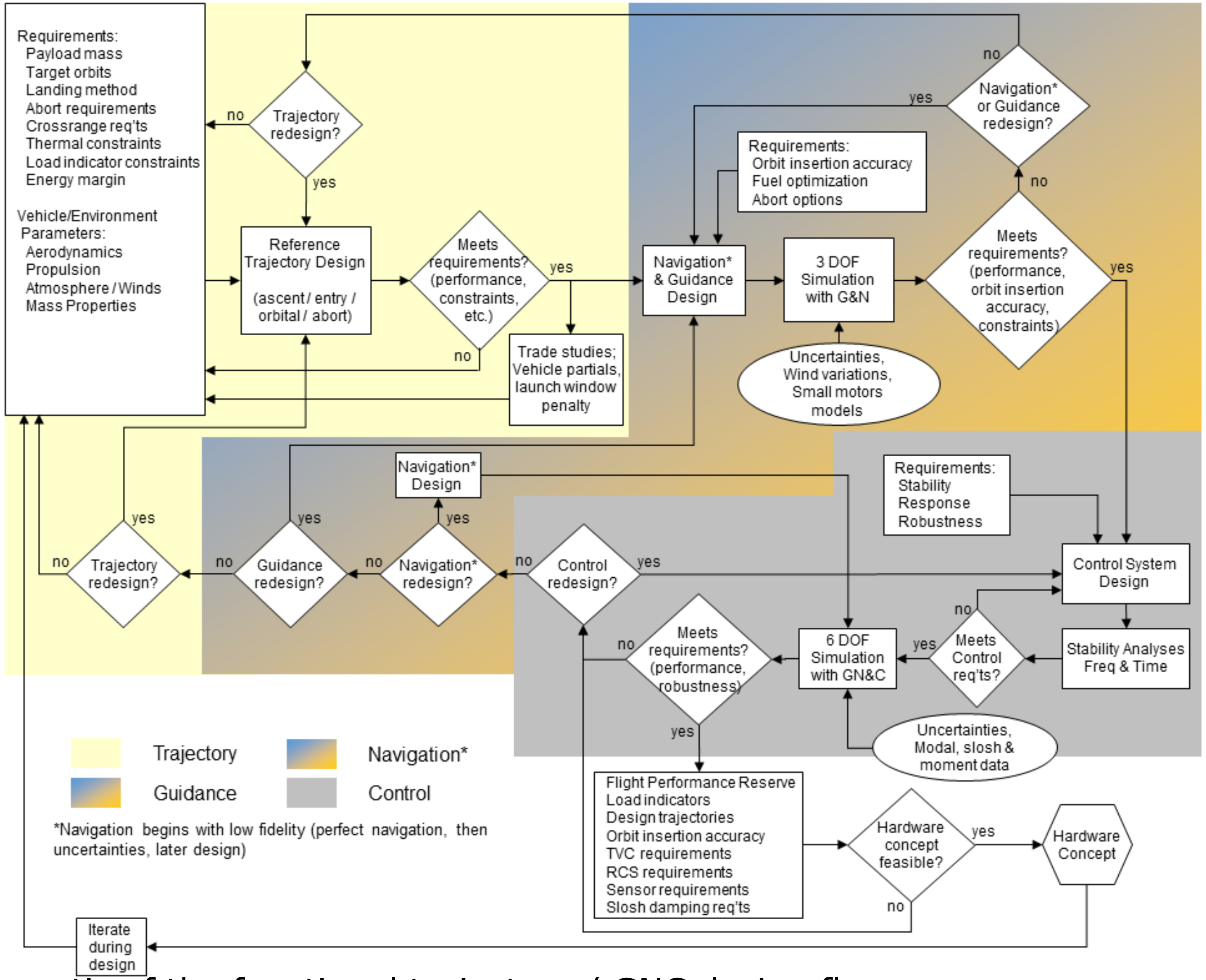
Overview

Context and Background

J. Rakoczy, "Fundamentals of Launch Vehicle Flight Control System Design", NASA Engineering and Safety Center Academy

Today's launch campaigns involve several months of mission preparation for a payload delivery, involving a significant recurrent cost for each mission.

Modern on-board computing and sensor technologies enable a range of improvements in GNC design and performance. Rethinking the launch preparation process using currently available technologies has the potential to make significant improvements, employing an integrated process covering flight physics, flight management, GNC, trajectory optimisation, software, mission customisation, etc., to arrive incrementally at a type of flight management system for rapid access to space.



Schematic of the functional trajectory / GNC design flow

Objectives

Exploit design tools/techniques and advanced GNC algorithms whose application aim for a reduction in the reconfiguration effort and turnaround time of a launch vehicle while increasing the operational availability and safety

Adoption of advanced guidance, navigation and control techniques

Replacing disconnected manual processes with integrated tools can make the mission preparation process more reliable and more efficient

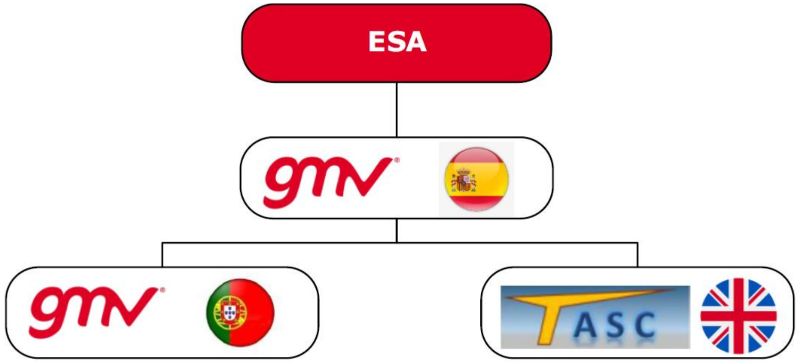
Consortium and Work Logic

ESA: Joris Belhadj and David Riley.

GMV Aerospace and Defence S.A.U (GMV-ES) acting as prime contractor.

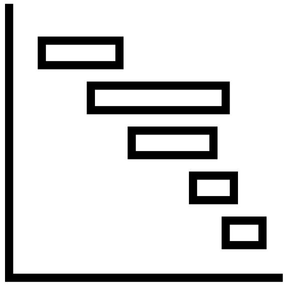
GMVIS SKYSOFT S.A (GMV-PT) acting as subcontractor.

Technology for AeroSpace Control Ltd (TASC) acting as subcontractor.



Task ID	Task Name	Objective	Main responsible
Task 1	Requirement and Improvement Areas definition	Critical review of the industrial GNC mission preparation process with detailed analysis of the GNC functions.	GMV-ES TASC
Task 2	Trade-off solutions, implementation plan and preliminary design	Study of possible solutions to each of the *Improvement Areas* (IAs) identified in task 1, and their trade-off. Define the development plan for the actual set of IAs with preliminary design of the various solutions.	GMV-ES GMV-POR
Task 3	Detailed design and development	Detailed design and development of the solutions to the IAs based on the preliminary design defined in task 2.	GMV-ES TASC
Task 4	Testing and validation	Testing and validation of the developed design. Use the updated SW infrastructure developed within task 2 for the V&V.	GMV-POR TASC
Task 5	Comparison and synthesis	Assess achievements quantitatively by a critical comparative analysis according to the metrics developed, comparing the improved process against the baseline. Critical analysis and recommendation of further work required to put the improvements into industrial practise.	GMV-ES TASC

Development Approach



- Continuous collaborative approach
  - Monthly working sessions involving ESA and all partners
  - Around 23 meetings were arranged
  - Demos were prepared to showcase the status and capabilities of the missionisation tooling at different points in time. This allowed to receive feedback continuously

a critical review of the current end-to-end GNC mission preparation, execution and validation process was performed

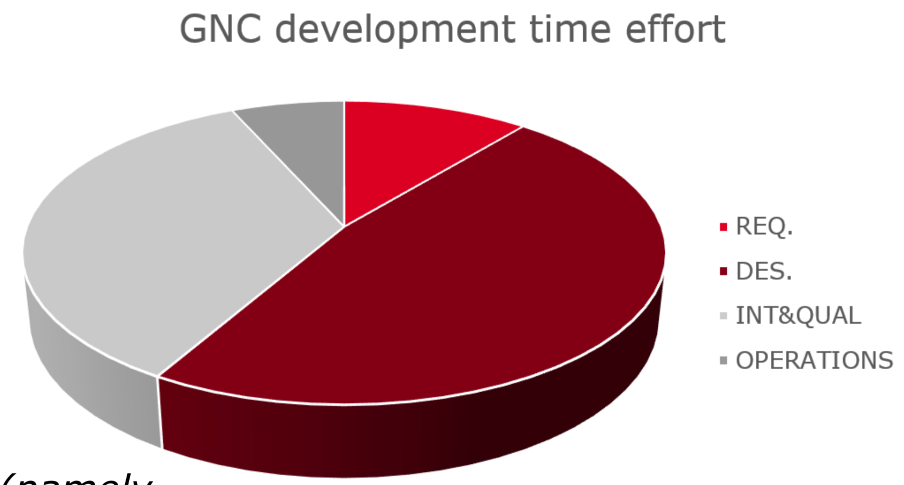
The work was divided into:

- The **mission requirements and improvement areas definition**, presenting a review of the current Mission Preparation Process, and a set of Improvement Areas stemmed from the considerations made
- **Preliminary design of the solution of the IAs**
- Subsystem level strategies designed for advanced and versatile guidance and control strategies to meet responsive mission configuration objectives. It provides the **detailed design of the solutions** needed to solve the IAs
- Results of the defined test plan needed to **validate the algorithms implemented**
- **Critical comparative analysis**: improved process against the baseline

Project Achievements and Results 1/6

COST AND TIMESCALE DRIVERS

Trajectory generation; Mission timeline; Control Synthesis; Dispersion analysis; Iterative nature of the GNC Final Studies; Documentation



Allocation of the time effort among phases during a GNC development

*In the case of a recurrent flight, where most of the infrastructure (namely the trajectory optimization tool, the simulator and the GNC architecture) is already present, a **shift of the effort from the Design phase to the Operation (retuning) is expected**. For the Integration & Qualification phase, however, if the process is not automatized, most of the effort would need to be repeated. An important improvement is expected if the **consistency between the mission data and the requirements** is automatically guaranteed throughout all the Final Studies, and if the **V&V tests are automatized** as much as possible.*

Project Achievements and Results 2/6

IMPROVEMENT AREA 1: TASKS AUTOMATION

common environment across the process and connecting information flow

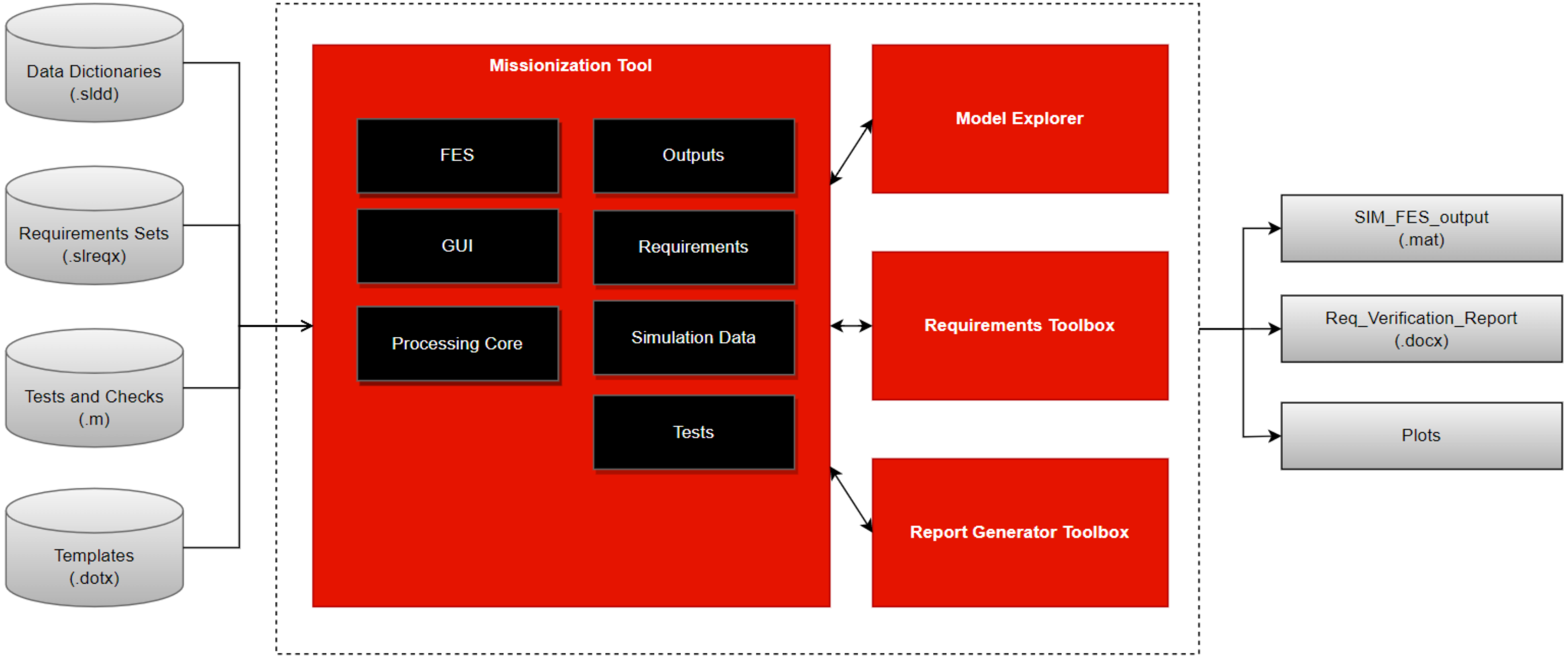
continuous checks

configuration management

model-driven approach

report generation

simulation test execution



streamlining requirement management

Data Dictionaries (DD): An important novelty of the Missionization tool was the inclusion of DDs as main data management tool due to their advantages related with e.g. - *Model Linkage, Version Control, Entry comparison, Data grouping, Unified Interface, and Connectivity with MathWorks Toolboxes*

Project Achievements and Results 3/6

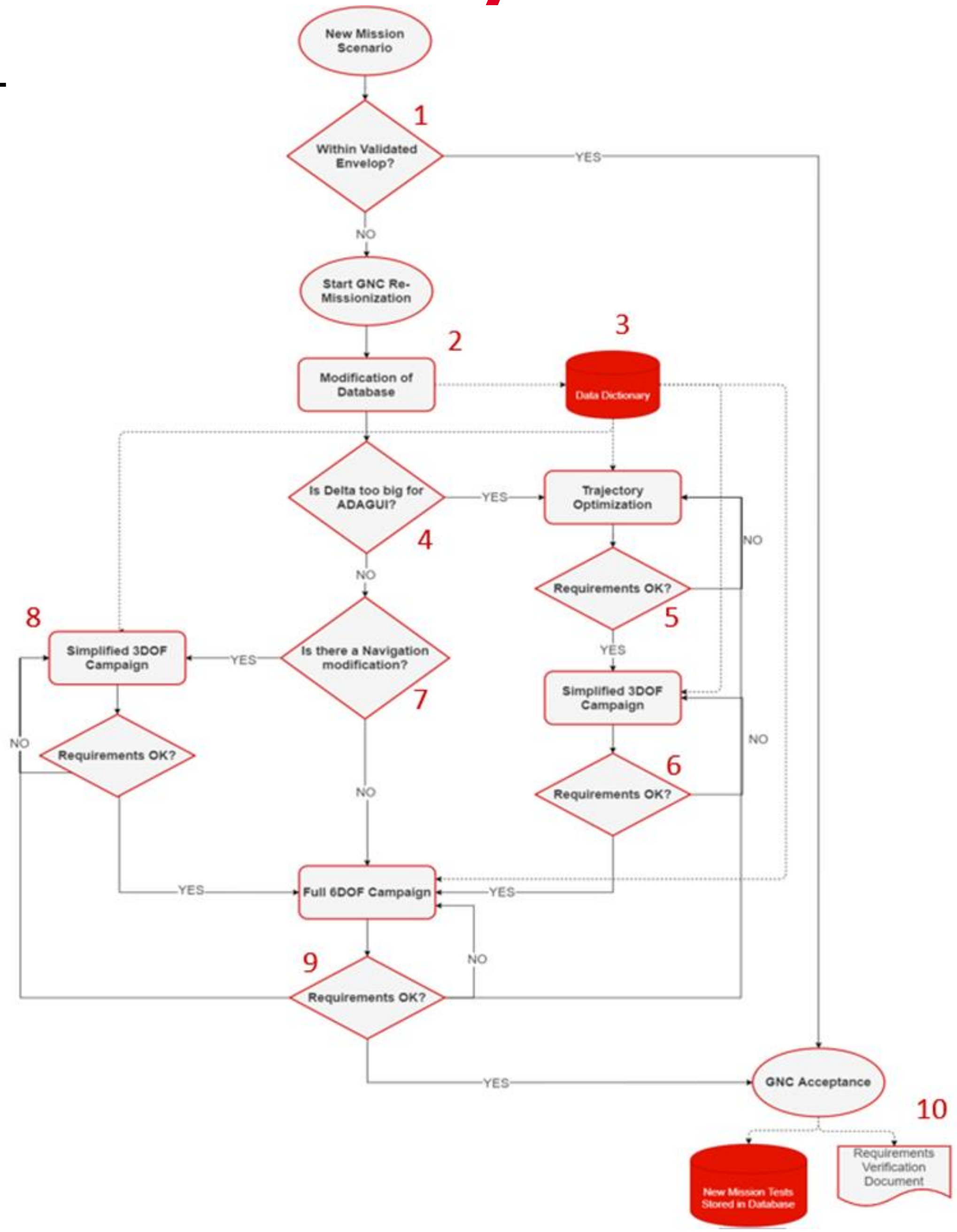
IMPROVEMENT AREA 2: PROCESS IMPROVEMENT

- Integration of several steps into one.
- Capability to avoid steps of the classical approach.
- Feedback from previous missions is in the pipeline.
- Easier requirements management.
- Lighter MC campaigns.

The flexibility of the Guidance and Control algorithms (IA-3 and IA-4) allow for skipping different points of the process that usually take much time

IA-1 helped interconnecting the DD database with all the steps and speeding up each of the steps, the requirement validation, and the documentation generation

GNC expert with knowledge on the Guidance and Controller capabilities will always be a critical asset

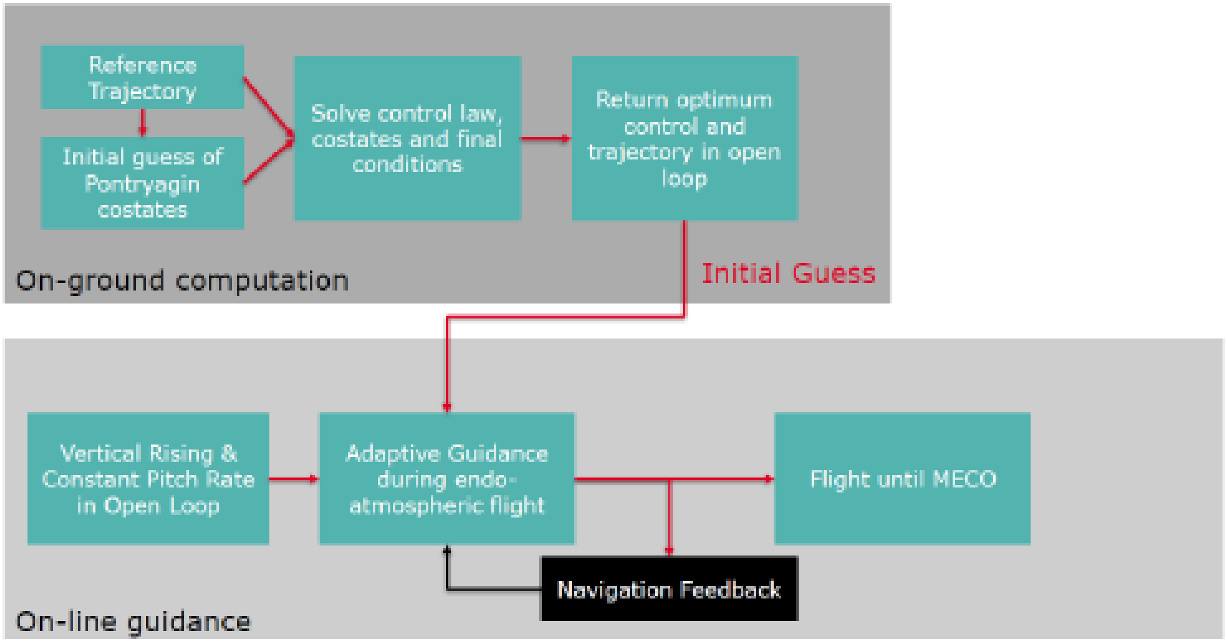


Project Achievements and Results 4/6

IMPROVEMENT AREA 3: ADAPTIVE GUIDANCE

Shorten the V&V missionization process and reduce costs by having an adaptive guidance algorithm that can handle small changes from a reference mission, like payload mass, without the need of repeating the verification or the tuning process.

- Creating trajectories by modifying data of previous ones and the deltas. This speeds the process by automatizing the new scenario instead of requiring iterations and engineering effort.
- It can expand the conditions at which the launcher can fly, it can reduce risks and launching costs by reducing the abort condition caused by GNC.
- Having diverse flying conditions implies having more launch windows. Thus, launch services can occur more often, satisfying the expected growth required by future demands from the market.



The implementation of ADAGUI allows to have two different modes of interoperability between Guidance and Control: one in which the drift is managed only by the Guidance and not fed into the Controller, and one in which the drift is fed into the Controller.

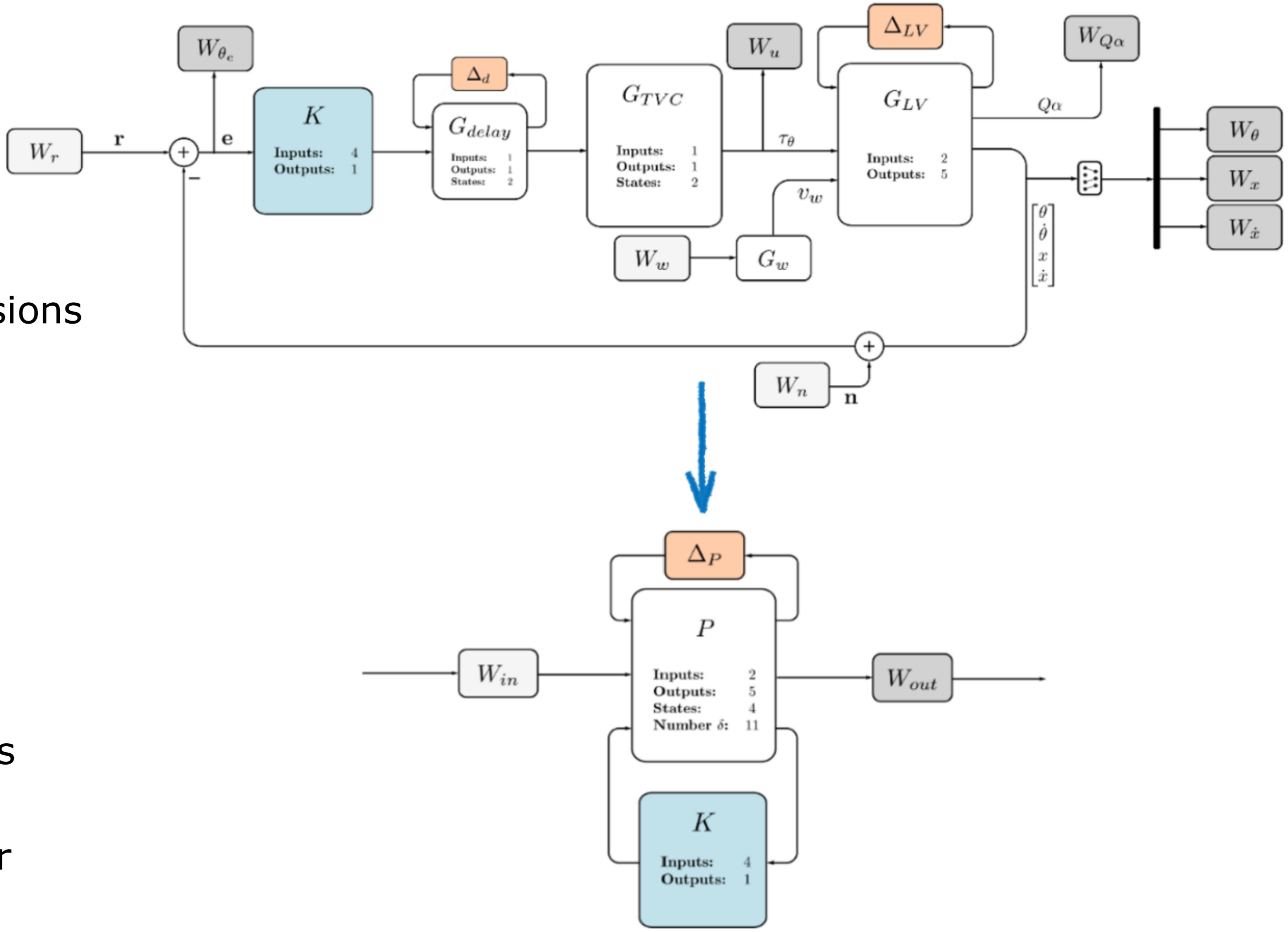
Project Achievements and Results 5/6

IMPROVEMENT AREA 4: ADAPTIVE CONTROL

Advanced control technique that **guarantee by design**:

- Robustness to system uncertainties
- Methodological changes
- Provides a design framework that can cover multiple missions

Shown to be capable to perform **incrementally or jointly** the design of the rigid-body controller and bending filter for the ascent-atmospheric flight



Same framework allows:

- To perform stability analyses via classical stability analysis and via the structured singular value μ approach.
- To evaluate the main performance metrics of the launcher during the atmospheric-ascent flight.
- To evaluate the robustness of the controller against last minute payload mass changes.

Project Achievements and Results 6/6

USE CASE DEFINITION

Compare the traditional guidance methods with Adaptive Guidance, in 3DOF and 6DOF, as well as the Control

The tool improves the complete missionization process and steps can be skipped depending on the deltas

Use case #1 **Launch window shift**	**Wind profile change**
Use case #2 **Commercial changes**	Payload mass change System level interactions: Trajectory
Use case #3 **Different launcher instance**	Slight thrust level change w.r.t. to nominal System level interactions: Trajectory, Propulsion
Use case #4 **Launch sites**	Launch site coordinates System level interactions: Trajectory

If ADAGUI is implemented in the missionization, and the deltas are known before launch, a change in wind, payload mass and thrust can be simulated in the 6DOF scenario directly without the need for the trajectory optimization and 3DOF.

Having implemented the control, it is seen that in general the 3DOF simulation can be skipped and run directly the 6DOF simulation. Only in the case that the 6DOF fails, then performing the 3DOF to check if the failure comes from the guidance or the control.

Trajectory optimization is required if the launch site is changed, in the case that the original launch site and the new one has a difference in latitude larger than 2.5 deg. Launch site longitude does not affect the process.

Also from the Use Cases analysis, it was possible to extract several conclusions from the Guidance and Control algorithms that can be summarized here as:

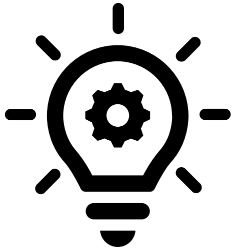
- The Open Loop guidance is more sensitive to changes than ADAGUI with respect to the nominal values, especially in the Q alpha constraint.
- Different wind, turbulence and gust models impact on the Q alpha constraint but not on the dynamics of the 1st stage.
- Payload mass must have at least 50% change with respect to the nominal value to modify the dynamics of the 1st stage.
- Dynamics of the launcher are significantly impacted by a thrust reduction.
- Open Loop guidance cannot recover from a thrust reduction, based on the Q alpha limitation. ADAGUI can, at the cost of not reaching MECO height and a reduced delta v.
- Open Loop with control in the 6DOF fails when changing the launch site latitude, but ADAGUI can withstand up to a delta of ±2.5 deg.
- Open Loop and ADAGUI show similar behaviour (with respect to themselves) when the trajectory optimization process was re-run for a different Launch Site.
- In all cases, it is seen that the Robust Control makes ADAGUI to be less sensitive in the Q alpha.
- There are no significant differences in the TVC effort between ADAGUI implementations. However, it is seen that the general trend is that ADAGUI without drift shows lower values.
- Pitch and Yaw drift is significantly reduced when using ADAGUI.

Conclusions

IAs IMPACT (not exhaustive)

- Ease iterations between steps, assuring consistency.
- Accelerate the transition from each step to the next.
- Minimize the need for retuning of the G&C algorithms.
- Going directly to the 6DOF analysis drastically reduces the time. However, as guidance and control are tested together, in case of non-compliance, the re-tuning time could be higher.
- Trajectory Optimization step: only used if the scenario modifications are very drastic.
- DDs interconnecting all the steps, requirement validation, documentation generation, reducing the time for tasks not directly related with the algorithms.

ADAGUI is more robust than the traditional methods when the dispersion is applied in wind and turbulence profiles, mass and inertia, and thrust



A control designer can effectively use the robust structured-Hinfinity to incrementally or jointly obtain a full valid rigid+flexible design

Way Forward

***Control** related*

Robust Modelling: It is suggested to continue development towards an automated modeling process for launchers.

Robust Control: A potentially semi-automated process can be envisioned that allows the designer to automatically obtain an optimal controller for a given plant using design templates.

Robust Analysis: An automated analysis process can be developed connected to the robust modeling suggestion as well as the suggestion of design templates.

***Guidance** related*

Complete implementation in a software tool for automatic trajectory computation and validation in the mission design process: Definition of inputs and outputs for the final user; Creation of interaction interface with the user.

ADAGUI implementation in an onboard computer and its preparation for flight software e.g.: Adaptation to be compatible with a real navigation and control; Definition to consider more path constraints; Implementation in the onboard computer; Exploration the trust region.

***GUI and tool** related*

User Guidance	Implementing more tooltips or even a guided tour within the GUI to provide information about the various functionalities.
Real-time Feedback	Enhancing the GUI to display real-time progress indicators during lengthy operations like test execution.
Error Handling and Reporting	Strengthen the error-handling mechanism by providing more descriptive error messages.
Responsive Design for Devices	Ensure that the GUI is responsive and adaptable to various screen sizes.
Interaction with Tools	Enhance the GUI tool's capabilities for interaction with Simulink.
Accessibility and Usability	Incorporate accessibility features into the GUI design to ensure it is usable by individuals with disabilities.
Extend Toolbox support	Start the design phase of the GNC using System Composer and Simulink Test on top of the other toolboxes already used.
PIL and HIL	It would be interesting to extend the Missionization tool capabilities to include also the PIL and HIL activities that would include the Code Generation Toolbox.

Thank you

FASTREC TEAM