REAL TIME GUIDANCE for Future Reusable VTVL's DTV – ADAMP - ADAMP II

PhD proposal (can cover more than one PhD student at least 2 to three)

To increase the level of autonomy and responsiveness of future space transportation missions, envisaged scenarios may rely in part on the use of Trajectory design and Guidance strategies based on real-time on-board optimization methods. This proposed approach allows taking into account uncertainties in the mission execution, in such a way that the performance robustness is achieved via the on-board computational capability to resolve a complex optimisation problem in real-time, as opposed to traditional design techniques in which the performance robustness to uncertainties is achieved by the off-line design and tuning of the trajectory and of the Guidance laws.

The current off-line design schemes for the mission analysis and the guidance function of launchers allow developing optimal trajectories based on open-loop guidance for the atmospheric flight and on closed-loop guidance for the orbital flight.

Such off-line schemes have their own limits: in particular, if the real mission deviates too far away from the theoretical design and qualification envelope, then there is no sure way to guarantee the performance robustness of the mission.

Current trends for future launchers include stringent requirements for mission responsiveness, in the sense that the mission and the vehicle shall feature real-time adaptability with respect to fast turn-around time, failures, abort scenarios, modification of target orbits, flexibility in orbital attitude pointing, and more generally any aspect for which real-time re-planning is required.

This might lead to review and adopt new design schemes for Trajectory and Guidance of future launchers, which nevertheless will be required to achieve mission performance robustness with the adequate level of reliability, safety and cost-effectiveness (like any other GNC design scheme).

Within ESA feasibility of potential of guidance algorithms based on real-time on-board convex optimization has been demonstrated as a possible option for operational space vehicles, not only for the ascent/descent phase of launchers, but also for tasks related to mission & vehicle management (MVM) such as slew manoeuvres under pointing constraints.

The objective is to design and assess the mission performance (robustness to uncertainties, performance in case of failure, mission re-planning and divert manoeuvres) of various solutions of autonomous Guidance.

The two benchmark missions are ascent & descent guidance of a recoverable ADAMP and ADAMP II VTVL going from pure retro-propulsive landing to an aero-assisted retro-propulsive landing.

Various real-time on-board real time optimisation schemes are to be studied, in terms of human intervention, mission complexity and environment complexity. The various Guidance systems need to be tested the ADAMP benchmark missions, with the level of physical representativeness of the studied plant dynamics (in particular, environmental disturbances, actuator and sensor models) appropriate for a feasibility study.

The technology shall be developed not only with processor in the loop testing but shall be conducted with flight test it in flight on the DTV/ADAMP family.

Also effort need to be placed in developing the operational methods for designing and validating Guidance systems able to perform autonomous on-board decision-making and mission execution including re-planning.

This effort shall allow to reduce the development risks and to better understand the necessary architecture and functional complexity of an autonomous GNC.

It shall also develop and recommend standard design practices with respect to the existing standards applicable to classical GNC design solutions.

Successive steps raging from detailed design, functional performance verification, software validation, hardware-in-the-loop qualification and in-flight testing, shall be covered by this Real-time Trajectory Optimization Guidance activity.

Objectives

Objective #1: Demonstrate the operational capability of the RealTimeOPT-Guidance Technology in terms of mission planning & execution.

In particular review, trade-off, develop and implement E2E Real time optimisation guidance strategies in order to:

- Assess the level of pre-flight off-line activity necessary for mission preparation, including the subsequent re-preparation work for new mission profiles.
- Assess the capability of the system to manage, on board and in real time, the operational execution of the mission of the launcher, including safety critical aspects such as stage fall-down constraints.

Objective #2: Demonstrate the operational capability of the RealTimeOPT-Guidance Technology in terms of mission adaptation, retargeting and re-planning.

In particular :

- Assess the capability of the system to manage, on board and in real time, in-flight mission retargeting during, such as modification of target orbit or modification of landing site.
- In coordination with the previous bullet, assess the need for manual command and take-over during such in-flight mission retargeting operations.

Objective #3: Demonstrate the operational capability of the RealTimeOPT-Guidance Technology in terms of safe mission execution in degraded off-nominal cases.

In particular :

- Assess the capability of the system to manage, on board and in real time, unforeseen severe off-nominal conditions and system failures within the limits of physical recoverability, with the goal to maintain successful mission completion (as far as possible) or to guarantee a certain level of degraded mission performance (required as a minimum).
- For this purpose, a “safe” back-up mode may have to be designed to cover cases where the on-board optimization process would fail to react to degraded off-nominal situations.

Objective #4: Demonstrate the operational capability of the RealTimeOPT-Guidance Technology in terms of On-Board Computer & SW performance.

In particular :

- Assess the capability of the **RealTimeOPT-Guidance Technology RealTimeOPT-Guidance Technology** to be executed on realistic typical solutions of on-board avionics and computer.
- Evaluate the trade-off between the desired functional performance of the on-board optimization and the physical constraints of its real-time SW implementation onto the on-board hardware.
- Propose recommendations for the on-board hardware & software architecture that would be needed to implement the OBRTTG on a flying test bed.

Objective #5: Evaluate the operational capability of the RealTimeOPT-Guidance Technology in terms of in-flight implementation, testing and demonstration.

In particular :

- Assess the capability of the system to be implemented on-board a flying vehicle (ADAMP, DTV, ADAMP II) and tested in flight for the demonstration of its performance in real flight conditions with real flight hardware. In particular, put the focus on the methodology and the technology for the pre-flight qualification and acceptance of the system prior to the maiden flights.
- Evaluate possible options of existing in-flight test vehicles (DTV, ADAMP, ADAMP II), on which the technology could be incrementally implemented and tested for flight.
- Propose a set of possible test scenarios together with the associated plans and high-level procedures for an incremental in-flight demonstration.
- Incremental approach towards flight testing shall be used to ensure the proper maturation of the HW & SW architecture and the full understanding of the developed real-time code. The test scenarios shall investigate nominal as well as re-targeting strategies.
- In this frame of incremental flight envelope exploration, it is suggested to put the focus on flying test vehicles designed for vertical take-off and landing, existing or under development as precursors of experimental recoverable boosters, with the eventual perspective to test the system on future flying demonstrators of recoverable boosters.

Benchmark Real Time Optimal Trajectory Generation and Guidance for the throtteable powered ascent and descent phases of the mission.

The mission phases to be analysed are the following (see Figure 1) :

- Lift-off of the complete launcher,
- Ascent flight of the complete launcher up to the separation of the recoverable first stage,
- Fly-Back of the recoverable first stage, including powered phases,
- Precision landing of the recoverable first stage at the designated target location.

The major technical aspects to be analysed are :

- Mission analysis including, but not limited to, multi-stage ascent, management of ground safety constraints (stage impact areas) in nominal and off-nominal scenarios,
- Guidance including, but not limited to, powered ascent, descent and landing.

More specifically for the case of a Vertical-Take-off / Vertical-Landing vehicle, the study shall consider the following constraints:

- Load and Dynamic Pressure
- Payload Mass constraints
- Wind Constraints
- Energy efficiency constraints

- Line of sight constraint (visibility from ground stations)
- Glide slope constraint
- General attitude constraints (Aspect angle etc.…)
- Thrust vector angle constraint
- Landing accuracy

Detailed Performance maps (max speed, max-min acceleration, tracking, pin-point landing, retargeting, min fuel, max agility) of the vehicle shall be derived in order to be able to explore the vehicle's flight envelope under various constraints. The resulting system shall be benchmarked against a classical solution. The operational objective is to demonstrate rapid launcher planning strategies and adaptability of the algorithm to various trajectory constraints.

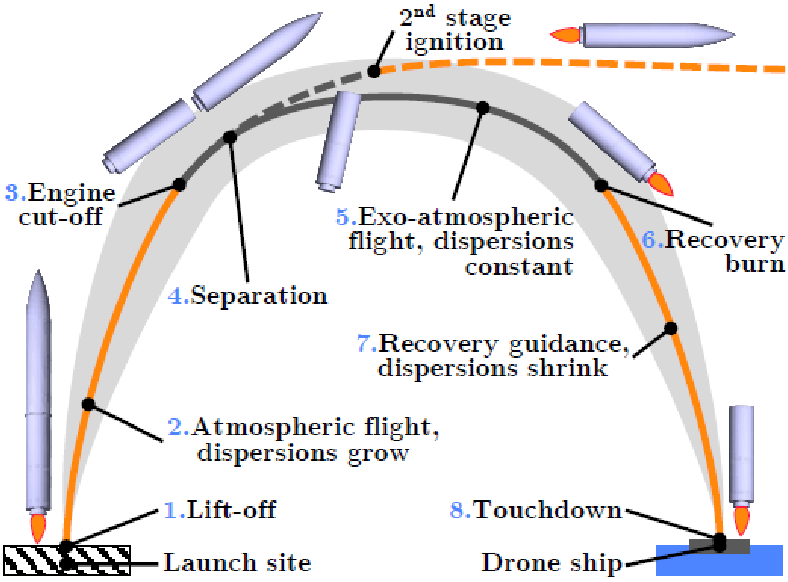

Figure 1 : Recoverable first stage mission scenario

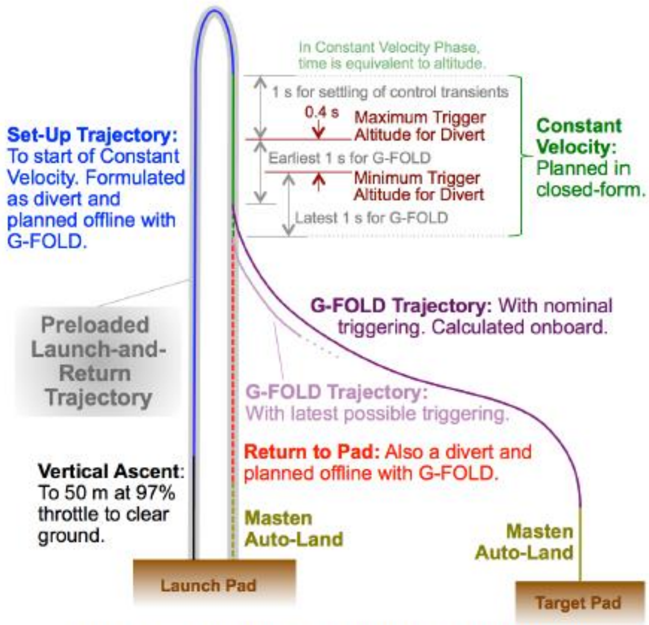

Figure 3 – Schematic of Concept of Operations for Test Flights. Not to scale.

The work to be performed shall be organized according to the following tasks:

- Task 0 : Management, Organization and Project implementation
- Task 1 : Mission Scenario Requirement Consolidation
- Task 2: Review of Real-time Optimisation approaches (Convex etc..)
- Task 3: Trade-off analysis and selection of the various Real Time Guidance Methods
- Task 4: Development of real time design
- Task 5 : Algorithm Detailed Design
- Task 6 : Flight Simulation & SW Validation Infrastructure
- Task 7 : Test Plans for functional verification and for SW validation
- Task 8 : Detailed SW Design, Integration & Coding
- Task 9 : Functional Performance Verification
- Task 10 : SW Testing & Validation
- Task 11: Functional & SW performance Synthesis & Flight Test Plan

Delivery of Thesis

Code and Documentation

The work shall be developed in close collaboration with INCAS under supervision of ESA.

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