Proposal for Forming an IAA Study Group SG 3.32

Title of Study:
Autonomous Dynamic Trajectory Optimal Control of Launch Vehicles

Proposer(s):
(Must be member(s) of the Academy M or CM)
Zhengyu Song, M2, China Academy of Launch Vehicle Technology, China, IAA Member.

Primary IAA Commission Preference:
(From Commission 1 to Commission 6)

Commission 3: Space Technology & Systems Development

Secondary IAA Commission Interests:
(From Commission 1 to Commission 6)

Commission 4: Space System Operation & Utilization

Members of Study Team

Chair(s):
(Must be member(s) of the Academy, M or CM)
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Co-Chair(s):
Jean-Marc ASTORG, CM2, Director of Launchers Directorate, CNES, France

Secretary:
Danjun Zhao, Head, School of Aeronautics and Astronautics, Central South University, China

Other Members:
(Open to members and non- members of the Academy)
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Short Description of Scope of Study

Failed launches due to reduced engine thrust have occurred, but advanced guidance and control techniques have the potential to save missions. Dynamic optimization methods are studied for launch vehicle flights. To reduce the risk of mission failure, trajectories and controls are reconstructed online to satisfy the requirements of autonomous flight control under faults and various uncertain conditions. The model-based embedded optimization algorithms are developed, which has abilities for rapid iterations and engineering application. The key is to address the real-time computation and convergence problems of online optimization and control.

Overall Goal:

(Expected scientific or practical benefit of the study group's efforts)

Multitasking, reusability and pinpoint landing technology can greatly reduce the cost of launch vehicles and bring new challenges to the control technology of launch vehicles. First, if particular cases occur (e.g., reduced engine thrust) in the ascending phase, the shift conditions between the flight phases are no longer satisfied. The remaining carrying capacity is fully utilized through autonomous re-planning, to maximize the capability to finish the original mission, or insert into optimal parking orbits, thereby improving the reliability of the mission and reducing the loss under the fault. Second, the initial conditions of powered vertical landing are difficult to accurately control, and the powered landing phase is under wind disturbances and atmospheric uncertainties. The pinpoint powered landing needs to be realized by autonomous trajectory re-planning. For the first scenario, all space missions face the need for "end-to-end" global optimization compared to traditional serial sequential optimization. For the second scenario, common needs exist for landing on any celestial body with an atmosphere. With the improvement of highly-efficient algorithms, embedded hardware and software, the model-based optimization and control have become the focus of future research. The traditional real-time optimization and control methods are mainly for unconstrained or simply constrained tasks. The model-based real-time optimization and control methods can deal with complex constraints to address the mentioned new challenges. This study requires multi-disciplinary optimization of ballistics, guidance, control, aerodynamics, payload, etc. It also needs to refer to dynamic optimization investigations in other industrial fields. The developed algorithms should be highly real-time and adaptive to satisfy the requirements of online flight control.

Intermediate Goals:

- Study the method of real-time assessment of the remaining carrying capacity of rockets, and explore the definition of parking (rescue) orbits under different remaining carrying capacities and the modeling of the corresponding optimization problem;
- Analyze models of each flight phase of reusable rockets (tasks, trajectories and attitudes), and establish multi-level optimization and control problems;
- Analyze the effect of uncertainties on the trajectory and attitude control of the landing phase of the vertical recovery process, and explore the feasibility of relaxing the optimization and control constraints to reduce the requirements of engine throttling under the condition of large thrust-to-weight ratio;
- Establish the computational framework for solving optimization problems in autonomous flight control; evaluate the efficiency of solving the optimal control problem and the convergence of the algorithm; and study the trust region of the optimal solution, the fast initial value guess algorithm, the termination criteria of optimization calculation and the validity of the corresponding solution;
- Customize autonomous optimization and control algorithms for engineering application according to specific mission characteristics.

Methodology:

(Email works, workshops, stand alone conferences, interim publications, etc.)
- Regular e-mail communication and webinars;
- Special workshops;
- Collaboration to be held in the course of international meetings (including the separated sessions or roundtables):
• IAC and IAA meetings, such as IAA Conference on Dynamics and Control of Space Systems, etc;
• Annual IAA Academy Day (China);
• Annual AIAA and IEEE Aerospace Conference.
- Benchmark models and open solving / simulation platform.

Time Line:
(Cannot exceed three years)
1st Meeting, at IAA 2019 Spring meeting, to identify study items and members;
2nd Meeting, at IAC 2019 Autumn meeting, to discuss the materials, models, goals, emphasis and assignments;
3rd Meeting, at IAA 2020 Spring meeting, to discuss the solution proposals;
4th Meeting, at IAA 2020 Academy Day (China), to discuss the interim results, follow-on work, future challenges;
5th Meeting, at IAC 2021 Autumn meeting, to summarize achievements, conclusions and recommendations;
6th Meeting, at IAA 2022 Spring meeting, to present the Academy Report.

Final Product (Report, Publication, etc.):
- Study Report.
- Publications of report information in appropriate journals.
- Publications of study result in appropriate Publishing House.

Target Community:
- Scientific and engineering aerospace organizations.

Support Needed:
Reservation of rooms for meeting during IAC, IAA Academy Day. Publications in Acta Astronautica.

Potential Sponsors:
Chinese Society of Astronautics (CSA)
China Academy of Launch Vehicle Technology (CALT)

To be returned to the IAA Secretary General Paris *by fax: 33 1 47 23 82 16 or*
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