IAA Study Group Status Report

Responsible Commission: Commission IV

Study Number and Title: 4.22 Through Optimization of Aerospace Trajectories

Short Study Description (repeat from Study Group Proposal):
The analysis and improvement of advanced methods for elaboration of a rigorous approach to the through optimization of branching trajectories of space transportation systems (STS), including injection into an orbit, interplanetary flights, reentry of separated parts and vehicles, emergency trajectories and probability processes.
The methods are supposed to give the possibility of using adjoint variables as sensitivity functions (one of the basic Pontryagin maximum principle properties). Also the possibility to develop methods for global optimization, in particular to estimate the number of local optimal solutions arising in different aerospace problems. These methods may have both analytic and geometric foundations.
Current trends of broad cooperation among specialized scientific institutions as well as geographical expansion of the aerospace corporations have forced development of the new approaches to integrated and multidisciplinary optimization. The new approaches must allow for combining diverse programs intended for detailed single-discipline investigations into a unified framework.

Progress in past six months:

- The system analysis of safety of spacecraft with air-breathing electric propulsion (ABEP) was considered in conditions of strong variations of density and composition of the atmosphere and orbit parameters. Analytical solutions are obtained for the parameters of the optimal configuration and the minimum ABEP power required to sustain spacecraft in the given circular orbit at a continuous compensation of the aerodynamic drag. An algorithm is proposed for determining the parameters of spacecraft with ABEP, which provides the maximum range of atmospheric characteristics, at which long-term spacecraft can be sustained in very low orbits.

  Reference: A.A. Golikov, O.V. Yanova, Spacecraft Safety in Very Low Earth Orbits, Proceedings of the 69th International Astronautical Congress, Bremen, Germany, 01-05 October 2018, Paper IAC-18-D5.1.5.

- The problem of the aircraft range maximization was considered with taking into account current wind distribution. Analytical solutions based on the Pontryagin maximum principle are obtained for linearized model of wind. The trajectory optimization algorithm was developed on the base of the homotopy method in case of an arbitrary wind distribution. It is shown, that in real atmospheric conditions suggested solutions allow to obtain considerable effect of fuel saving: for example, fuel economy on the obtained optimal trajectory of closed flight Mexico-Rome-Mexico can reach more than 8 % in comparison with the straight-line flight.

Reference: A.E. Sagalakov, A.S. Filatyev, Is there possible the supersonic flight of a subsonic aircraft: the optimization of aircraft trajectories in realistic atmosphere (in Russian), TsAGI Science Journal, 2019 ((in press).

- There was considered the formation flight of four nanosatellites forming a tetrahedron. The main goal of this research was to find the relative orbits of these satellites that, at least in the linear Hill-Clohessy-Wiltshire model, ensure finite relative motion and keep the volume and shape of the tetrahedron configuration. Since real motions of these satellites will differ from the linear ones, especially under the influence of the J2 perturbation, the active control is necessary. In addition, limited size of the satellites does not allow to use a complex 3-axis attitude control system. In this research the passive magnetic attitude control system was considered, and supposed that the thrust direction is always aligned with the local geomagnetic field. In order to increase mission lifetime the control algorithm that minimizes the propellant consumption and keeps the tetrahedron volume and shape was developed.

  Reference: G. V. Smirnov, Y. Mashtakov, M. Ovchinnikov, S. Shestakov, A. F. B. A. Prado, Tetrahedron formation of nanosatellites with single-input control, Astrophysics and Space Science, 363: 180. https://doi.org/10.1007/s10509-018-3400-4.

- The expansion of the capabilities of the space transportation system (STS) for interplanetary flights was analyzed including in interplanetary mission the heliocentric Earth-Earth flight with the subsequent gravitational maneuver at the Earth. The use of spacecraft (SC) with electric propulsion (EP) on the heliocentric trajectory makes it possible to provide a large magnitude of hyperbolic excess velocity (further – a finite hyperbolic excess of velocity (FHEV)) when SC is approaching the Earth. The large magnitude of such FHEV when using the Earth's swingby can provide the wide possibilities of STS. The problem of finding the possible range of the FHEV magnitude was considered.
  Optimization of the characteristics of the heliocentric trajectory Earth-Earth was carried out according to the criterion of the maximum SC mass delivered to the Earth. Three types of extremal trajectories were found. The optimal sequence of active and coasting trajectory sections (the profile of the thrust function) for each extremal type was investigated. It was shown that the considered maneuver makes it possible to significantly expand the range of hyperbolic surpluses of speed when departing from the Earth and substantially increase the SC mass in the departing trajectory. The extremal trajectories of each found type of extremals turn out to be optimal in some range of FHEV.

  Reference: M.S. Konstantinov, Analysis of the Change in the Optimum Thrust Profile as a Function of the Parameters of the Transport System with Electric Propulsion, AIP Conference Proceedings 2046, 020048 (2018); doi: 10.1063/1.5081568. Viewonline: https://doi.org/10.1063/1.5081568.

- The problem of the simultaneous optimization of the low-thrust trajectory of the spacecraft, the main design parameters of its electric propulsion system and power supply system were considered with the spacecraft useful mass as the optimization criterion. The thrust vector orientation program, the thrust switch on/off moments, and trajectory parameters (the launch date, the departure hyperbolic excess velocity direction and value) were being optimized. Alongside with the control program and the trajectory parameters, the main parameters of the electric propulsion system (maximum power consumption, specific impulse) and the power supply system (initial electric power at the heliocentric distance of 1 AU) were being optimized also.

Reference: V.G. Petukhov, Woo Sang Wook, and M.S. Konstantinov, Simultaneous Optimization of the Low-Thrust Trajectory and the Main Design Parameters of the Spacecraft, Advances in the Astronautical Sciences, 161 (2018), p. 639-653.

Website Study Information update: (please give any update regarding Study Group Membership, documents, Study Plan and Schedule):

None

Issues requiring resolution? (recommend approach):

None

Product Deliveries on Schedule? (If modified explain rationale):

Yes

Study Team Member Changes? (List any Study Team Members that you wish to discontinue, and provide names plus contact coordinates of any Members you wish to add on the second page of this Study Update form.) Note: Complete contact information including email, tel. and fax must be provided for all additions. Only Members with complete contact information will be listed and receive formal appointment letters from the IAA Secretariat.)
None

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Status Report Date: 28.02.2019

Study Team Membership Changes

None

Effectivity Date:

Discontinue:

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Current email address

Add:

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Tel.
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