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COMBINED USE OF RANDOM SEARCH METHODS AND GRADIENT METHODS IN THE OPTIMIZATION OF ROCKET DESIGN PARAMETERS AND CONTROL PROGRAMS

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The aim of this paper is to develop a methodology for optimizing, at the initial design stage, the key characteristics of a rocket with a solid-propellant sustainer engine which can follow a ballistic, an aeroballistic, or a combined trajectory, including the formalization of the combined problem of simultaneous optimization of the rocket design parameters, trajectory parameters, and flight control programs. The problem is formulated as an optimal control problem with imposed equalities and differential constraints. The parameters to be optimized include the rocket design parameters and the parameters of the rocket control programs in different portions of the trajectory. The rocket control programs are proposed to be formed in polynomial form, which allows one to reduce the optimal control problem to a nonlinear programming problem. Optimization methods are overviewed, and random search methods are compared with gradient ones. It is shown that at the first stage it is advisable to use a genetic random search algorithm, which makes a quick and complete examination of the whole of the optimal solution search space and finds the solution closest to the global optimum of the objective functional. At the next stage, it is proposed to use a coordinate gradient descent method in the vicinity of the solution found at the first stage to find the global optimum of the objective functional. The proposed approach to the solution of the formulated problem allows one to determine, to the accuracy required in design studies, the rocket flight control programs optimal in a given class of functions and advisable values of the rocket design parameters. The algorithms for rocket design parameter, trajectory parameter, and control program optimization presented in this paper may be used by design organizations at the initial design stage of rockets of different purposes.

Keywords: *controlled object, solid-propellant sustainer engine, initial design stage, design parameters, motion control programs, objective functional, optimization, random search methods, gradient methods.*

1. *Tarasov V. A.* Flying Vehicle Optimum Design Algorithm (*in Russian*). Moscow: Mashinostroyeniye, 1970. – 364 pp.
2. *Razumev V. F., Kovalev B. K.* Basics of Solid-Propellant Ballistic Rocket Design (*in Russian*). Moscow: Mashinostroyeniye, 1976. – 356 pp.
3. Tewari Ashish. Advanced Control of Aircraft, Spacecraft, and Rockets. Kanpur: John Wiley & Sons, 2011. – 456 pp.
4. *Senkin V. S., Sarychev A. P.* Choice of design parameters and control programs at the initial design stage of launch vehicles (*in Russian*). Tekhnicheskaya Mekhanika. 2014. No. 3. Pp. 33 – 47.
5. *Senkin V. S.* Combined problem of optimization of solid-propellant superlight launch vehicle design parameters and control programs (*in Russian*). Tekhnicheskaya Mekhanika. 2012. No. 2. Pp. 106 – 121.
6. *Krotov V. F., Gurman V. I.* Optimal Control Methods and Problems (*in Russian*). Moscow: Nauka, 1973. – 446 pp.
7. *Alpatov A. P., Senkin V. S.* Combined problem of optimization of the basic design parameters and motion control programs of space rockets (*in Russian*). Tekhnicheskaya Mekhanika. 2011. No. 4. Pp. 98 – 113.
8. *Panteleyev A. V., Letova T. A.* Optimization Methods in Examples and Problems: university textbook (*in Russian*). Moscow: Vysshaya Skola, 2005. – 544 pp.
9. *Russel Stuart, Norvig Peter*. Artificial Intelligence: A Modern Approach (*in Russian, translated from English*) Moscow: Williams Publishing House, 2007. – 1408 pp.

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