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# FINITE-THRUST OPTIMIZATION OF INTERPLANETARY TRANSFERS OF SPACE VEHICLE WITH BIMODAL NUCLEAR THERMAL PROPULSION

**Abstract**

The nuclear thermal propulsion (NTP) is one of the leading candidate technologies for primary space propulsion for manned exploration of the solar system. High specific impulse capability and sufficiently high thrust-to-weight ratio of NTP cause the effectiveness of this type of propulsion for the piloted missions, especially for the piloted missions to Mars. The other benefit of NTP is it's possible bimodal design when nuclear reactor is used for generation of jet thrust in a high-thrust mode and (with appropriate power conversion system) as a source of electric power to supply the payload and the electric engines in a low-thrust mode. Considering NTP as a propulsion system of bounded both power and exhaust velocity, the model of the NTP thrust control has been developed. For the proposed model controlling of the high-thrust nuclear rocket engine (NRE) thrust value is accomplished by the regulation of reactor thermal power and propellant mass flow rate. The problem of optimization of both the combination of high- and low-thrust arcs and the mass parameters of NRE and nuclear electric propulsion (NEP) subsystems has been considered for the interplanetary transfers of the vehicles with bimodal NTP. The interplanetary trajectory of the space vehicle is formed by the high-thrust NRE burns, which define planetocentric maneuvers and by the low-thrust heliocentric arcs where NEP is used. The high-thrust arcs have been analyzed using finite-thrust approach. The motion of corresponding dynamical system is realized in three phase spaces concerned with the starting planetocentric maneuver by means of high-thrust NRE propulsion, the low-thrust NEP heliocentric maneuver and the approach high-thrust NRE planetocentric maneuver. The phase coordinates are related at the time instants of the change of phase spaces due to relations between space vehicle masses. The optimal control analysis is performed using Pontryagin's maximum principle. Proper transversality and jump conditions have been obtained. The analytical solution for the low-thrust heliocentric arc has been developed using transporting trajectory method. The numerical results are analyzed for full high-thrust Earth-Mars transfer with the jettisoning of the first stage and for the transfer with using of low-thrust NEP at the heliocentric arc. The optimal distribution of $\Delta$v ( $\Delta$v is velocity change) budget between high and low-thrust maneuvers and optimal values of the parameters that define the masses of NRE and NEP subsystems have been derived and analyzed. The possibilities of the application of proposed approaches are discussed.