NASA TECH BRIEF

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Optimized Braking of Landing Vehicles with Atmospheric Drag

The landing maneuver of a space vehicle on a distant planet or on Earth requires in its early stages a deceleration so that the terminal velocity will permit a landing. During the final deceleration maneuver, however, propulsive retrothrust devices must be used to ensure that the surface is approached with a velocity that permits a soft landing.

The program of application of retrothrust must be determined carefully and in such a way as to conserve fuel, especially when it is necessary to consider the cost of transferring one pound of mass from the Earth to another planet (and, eventually, back to Earth). Accordingly, a study was made of the determination and specification of a control law that assures minimum fuel consumption and minimum expenditure of time during the propulsive braking of a landing vehicle subjected to atmospheric drag and following a vertical or a gravity-turn ballistic trajectory.

The distinctive dynamical feature in the solutions of the optimal control problems is that the retrothrust acts in the same dynamical sense as the atmospheric drag. Thus, the drag is a gratis braking force. The drag, however, is a strongly state-dependent (velocity- and altitude-dependent) force. During a propulsive soft-landing maneuver on an atmosphere-bearing planet, the typical dynamical situation is as follows: decreased altitude implies increased drag; decreased velocity implies decreased drag; the retrothrust decreases the vehicle's velocity and, at the same time, retards the vehicle's descent to denser atmospheric regions. Hence, the retrothrust reduces the decelerating effect of the atmospheric drag. Reduction of the (gratis) decelerating effect of the atmospheric drag, however, implies increased integrated retrothrust effort (= mass expenditure) to achieve a soft landing. Therefore, the minimum fuel consumption (= minimum mass expenditure) burning program for the retrorocket will necessarily imply the maximization of the available decelerating effect of the drag since the burning program of the retrorocket implicitly also "controls" the time history of the atmospheric drag that affects the descending vehicle.

Solution to the problem assumes that as the vehicle descends through the atmosphere, at a certain time t_0 the vehicle's altitude, velocity, and path angle relative to the surface are known. The vehicle is equipped with a retrorocket having a maximum thrust level T_{max}. The program of computation then determines $t_1 > t_0$ when the retrorocket is turned on and maximum thrust is maintained until the terminal time τ when the vehicle reaches zero velocity at essentially zero altitude and the rocket thrust is terminated. The optimization can be performed for a vertical or for a ballistic descent in which the landing time is minimized. The fuel consumed for the maneuver is readily computed.

Note:

Requests for further information may be directed to:

Technology Utilization Officer
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(continued overleaf)

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No patent action is contemplated by NASA.

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