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STRATEGIES FOR RE-USE OF LAUNCH VEHICLE FIRST STAGES

Abstract

Many strategies have been proposed for recovery of launch vehicle first stage components, all of which incur a reduction in payload capacity in an effort to reduce the cost-per-flight. However, there is much debate as to which strategy, if any, can provide sufficient cost savings to justify its associated payload reduction. To clarify the situation, an analysis was performed of the payload penalty and cost of all major first stage recovery strategies under common assumptions. The analyzed strategies include propulsive landing (downrange or at the launch site), winged stages (air-breathing fly-back to the launch site or downrange glider recovery), and engines-only recovery via parachutes.

This paper establishes a general model to compare the payload capacity and cost-per-flight reductions of first stage re-use strategies. The payload capacity model is neatly derived from physical first principles; cost estimation uses analogies to similar systems and the TRANSCOST model. For generality, the models are phrased in terms of dimensionless parameters, and the sensitivity of the results to those parameters is explored. The sensitivity of payload and cost to various technological and operational factors is also assessed.

This study finds that returning the first stage to the launch site by rocket propulsion incurs the highest payload reduction, at about half the payload capacity of an equivalent expendable system. Flying a winged stage back to the launch site under air-breathing propulsion has a smaller payload penalty (15 to 45%), but adding wings and jet engines to the stage increases costs. For downrange recovery, propulsive and glider landing both incur a small payload penalty (10 to 20%). Recovery of the engines alone via parachute incurs almost no payload penalty, but only enables cost-per-flight to be reduced by about half. An order-of-magnitude cost reduction requires re-use of the entire first stage, and optimistic assumptions about refurbishment costs and market demand.

Which strategy is ‘best’ depends on the situation of the launch provider and market. Engine-only parachute recovery is perhaps the easiest to implement, and could quickly offer moderate cost savings if development resources are limited. Despite more difficult development, downrange propulsive landing and downrange glider recovery can both achieve lower cost-per-flight and cost-per-kilogram to orbit. Propulsive landing provides operational flexibility - the same vehicle can also return to the launch site in easier missions. If high enough launch rates are foreseen, the operational convenience of launch site recovery may justify the development of an air-breathing fly-back booster.