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EXPANDING THE FRONTIER: A PARAMETRIC LOOK INTO THE DRIVING FORCES OF SPACE TRANSPORTATION BEYOND LEO

Abstract

Background: This paper looks into the driving forces shaping space transportation, with emphasis on US human spaceflight. Space is a frontier and humankind strives to expand it, employing space transportation. Selecting “the best” space transportation system will always involve a trade-off between the dimension of desired physical reach into space and the dimension of transportation economics. The outcome, usually seeing one dimension taking prevalence over the other, determines the “driving force”. This, in turn, shapes space transportation design. The case is made for seeing space transportation simply as a utility supplying energy for transportation tasks. This makes it comparable to terrestrial modes of transportation and allows applying the same, universal performance metrics, replacing previous measures (kg to LEO, $/kg).

Methods: Physical space transportation performance is measured by total (ideal) energy of the payload upon injection into orbit or destination trajectory (in kWh). Economic performance is measured by $/kWh. Using parametric analysis, applying the paradigm of terrestrial public transport, a “tariff zone map” for space transportation is proposed. It shows specific energy cost depending on total energy delivered, which in turn is a function of destination (LEO, cislunar space, Moon, Mars, beyond). Every space transportation system, be it past, present, or future, has its own distinctive footprint when its performance data is plotted on the proposed map. The latter visualizes performance and cost trends with an emphasis on affordability, which helps rational discussion of project options and roadmaps.

Results: The Space Shuttle still is the current benchmark. Over its 31-year service life, it had cost 7000 $/kWh (134-flight average; FY2010 dollars), with an average throughput of 554 MWh/year. Its best year was 1985, with 9 launches and 1.35 GWh/year. The previous Apollo program, mostly relying on the Saturn V launch vehicle, had been driven by physical reach, not economics. In 1969 alone, it had demonstrated a 2.7 GWh throughput at approximately 6500 $/kWh, of which 1500 $/kWh could be attributed to the Saturn V vehicle until trans-lunar injection. The proposed Space Launch System (SLS), “physical”-driven like Apollo, may only undercut 1000 $/kWh in 2030, if ever.

Conclusion: Today, Apollo/Shuttle-era cost levels have become unaffordable, yet there are no signs of cost breakthroughs using Shuttle-derived technology. Air transportation, for comparison, costs no more than 2 $/kWh, so there is much room for improvement. The economics needed for meaningful human exploration beyond LEO, preferably below 500 $/kWh (FY2010 dollars), will need new technologies.