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UNIVERSITY OF OREGON

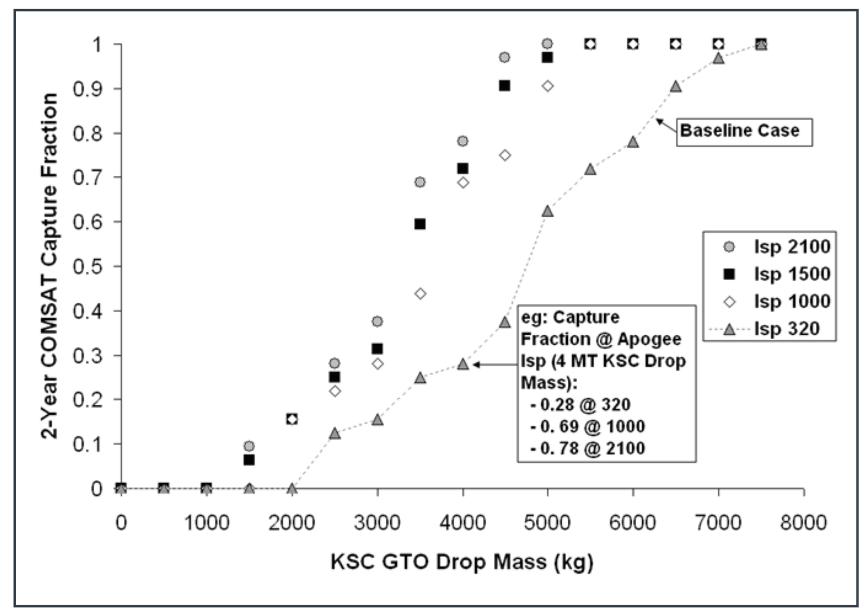
National Aeronautics and Space Administration

The Economics of Advanced In-Space Propulsion

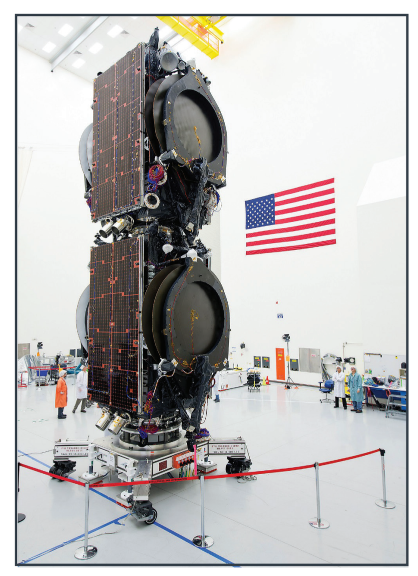
Background

The cost of access to space is the single biggest driver is commercial space sector. NASA continues to invest in both launch technology and in-space propulsion. Low-cost launch systems combined with advanced in-space propulsion offer the greatest potential market capture.[1] Launch market capture is critical to national security and has a significant impact on domestic space sector revenue. NASA typically focuses on pushing the limits on performance. However, the commercial market is driven by maximum net revenue (profits). In order to maximum the infusion of NASA investments, the impact on net revenue must be known.

As demonstrated by Boeing's dual launch, the Falcon 9 combined with all Electric Propulsion (EP) can dramatically shift the launch market from foreign to domestic providers.[2]



Launch market capture for Falcon 9 with Advanced In-Space Propulsion



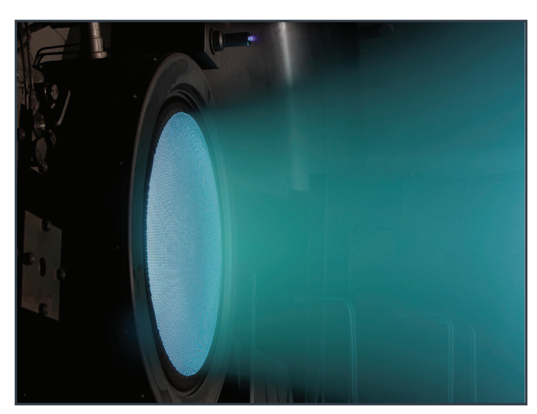
French and Asian spacecraft built and launched by U.S. providers[3]

Example

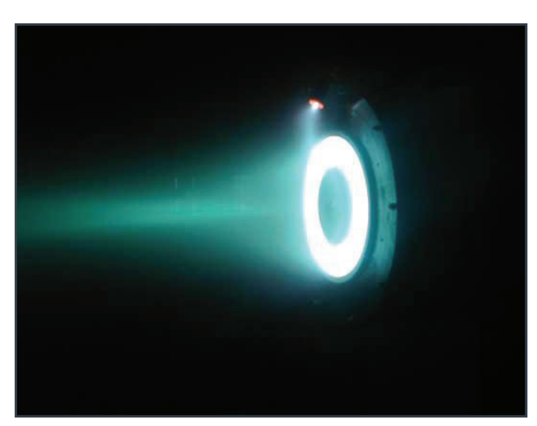
Aerojet developed two thrusters:

1. A high-performance, high specific impulse Gridded Ion Thruster; the most efficient thruster ever developed.
2. A 20% lower efficient, 50% reduced specific impulse Hall Thruster.

The Hall thruster has received more mission capture because it can reduce transfer time. With the time value of money calculation, the Hall thruster provides the highest net revenue despite being the lower performance thruster.



NEXT Gridded Ion Thruster[4]



XR-5 Hall Thruster[5]

Objective

The objective of this research is to guide technology investments for the highest infusion potential through:

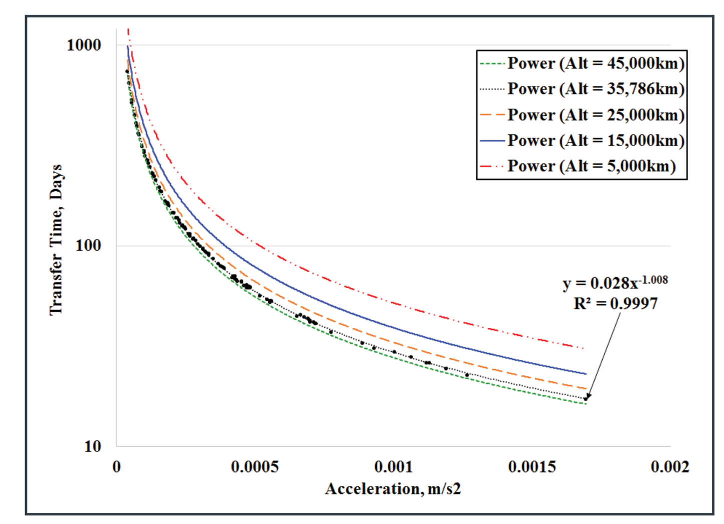
- Understanding the in-space propulsion technology that creates the highest net revenue
- Understanding the sensitivities to the propulsion system cost and performance
  - Efficiency
  - Specific impulse
  - Cost, mass
- Understanding the sensitivities to cost and performance of ancillary systems
  - Solar array performance, mass and cost
  - Launch performance and cost
- Understanding the sensitivities to net revenue factors
  - Insurance costs
  - Rate of return
  - Mission duration

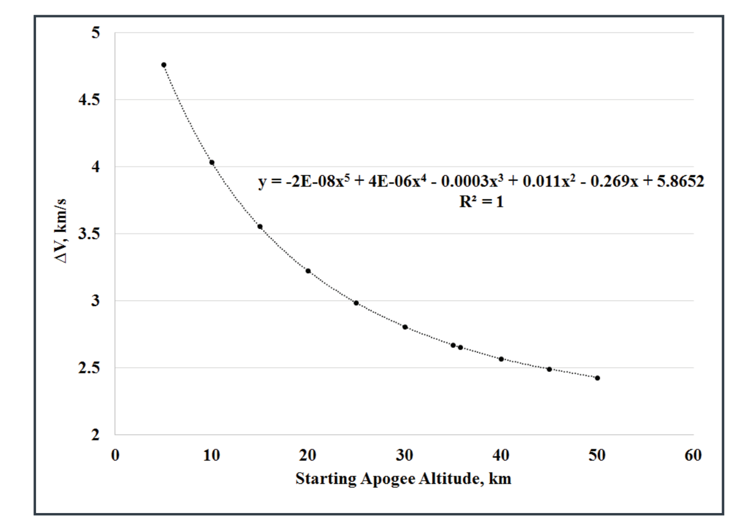
Methodology

- Identify the trajectory performance (ΔV and transfer time) for the propulsion system options
- Identify the cost and revenue drivers for the spacecraft
- Perform parametric time value net revenue calculations
- Perform sensitivity analyses to the revenue drivers
- Identify the near-term, mid-term, and far-term technologies with the highest infusion potential

Results for Trajectory Performance

SEPSPOT[6] is a trajectory optimization program used to determine both delivered mass and transfer time performance as a function of propulsion system characteristics.





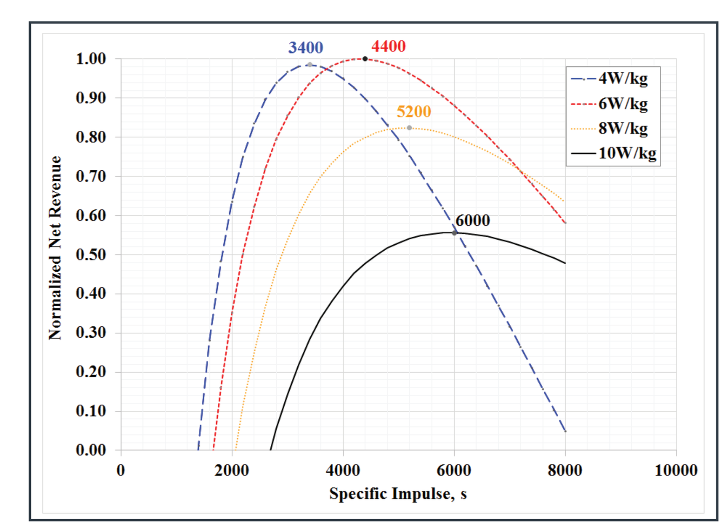
$$a = \frac{2 n P}{M_0 g\, Isp} \Rightarrow t = 0.028 \left(\frac{2 \eta P}{M_0 g\, Isp}\right)^{-1.008}$$

$$M_F = M_0 e^{\frac{-\Delta V}{g\, Isp}}$$

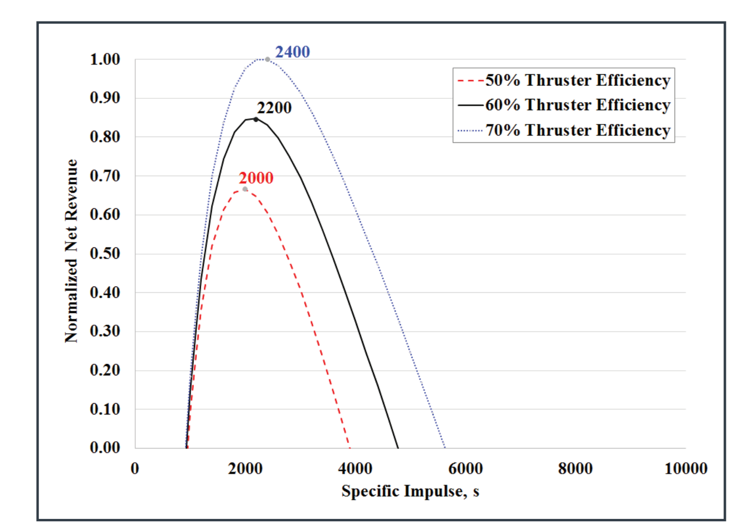
Example Results for Trajectory Performance

The time value calculations are:

$$\int_0^T e^{-rt} = \frac{1}{r(1 - e^{-rT})}$$



Sensitivity to specific power, Falcon 9



Sensitivity to efficiency, Delta IV H

A Subset of Conclusions

- A method has been developed to assess new technology impacts on GEO-space revenues.
- As solar power systems continue to increase in performance, the optimal technology transitions from high thrust-to-power to higher voltage Hall thrusters and then gridded ion systems.
- Efficiency improvements at constant specific impulse yield ~$1M/% benefit per flight.
- Projected reduced launch costs (either through reusable systems or heavy lift) could obviate the benefits of advanced propulsion at high power.

Acknowledgements

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References

[1] Byers, D. and Dankanich, J.W. "Geosynchronous-Earth-Orbit Communication Satellite Deliveries with Integrated Electric Propulsion," Journal of Propulsion and Power, Vol. 24, No. 6, November – December 2008.
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