What GPS really costs: implications for the development of a lunar navigation satellite system

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Introduction

By providing external position, navigation, and timing (PNT) information, lunar satellite navigation systems could provide needed navigation information to missions enabling them to reduce or remove custom-built PNT hardware. The removal of hardware could potentially reduce mission cost and enable room for other payloads. However, for this cost reduction to occur, paying for a lunar navigation satellite system (LNSS) service must be less expensive than paying to include the custom navigation hardware and supporting software. Terrestrially, the Global Positioning Service (GPS) service is "free", it is financed by the United States government via tax revenues. However, a commercially-provided LNSS service, if not government financed, will need to charge users. What might such an LNSS cost to build and operate? To begin addressing this question, we examined the costs and economic benefits of the United States Global Positioning System (GPS). The analysis shows that a subscription-based commercial PNT solution is likely to take a very different form from the ubiquitous GPS service available terrestrially.

Fig 1: Artistic rendering of a GPS Block III satellite vehicle. From Lockheed Martin GPS III/IIIF Photo Gallery. (https://www.flickr.com/photos/lockheedmartin/albums/72157625171465765

Methods

GPS financial data were extracted from [1] and [2] to generate the numbers provided in Tables 1 and 2. Data were linearly scaled from a 30 satellite system [3] to a 24 satellite system [4] in effort to better represent lunar goals. However, it is also reasonable to expect that early satellite systems will have even fewer satellites and perhaps be more similar to the 5 satellite system proposed by [5] and depicted in Figure 2. We caveat our comparisons by noting that a linear scaling of satellite number to operational cost is unlikely.

GPS Program Budget

Fiscal Year	GPS Program Annual Budget (Millions USD)	GPS Operating Budget (Millions USD)	Lunar Scaled Operation Cost (Millions USD)
2018	$1,182.706	$510.938	$408.750
2019	$1,424.584	$526.716	$421.373
2020	$1,713.24	$476.232	$380.986
2021	$1,791.217	$482.435	$385.948
2022	$2,028.074	$402.971	$322.377

Table 1: GPS costs are as published on https://www.gps.gov/. The annual budget is presented as well as an operating budget that excludes ground segment and R&D costs. Operating costs were then linearly scaled from 30 satellites to 24 satellites for the lunar environment.

GPS Block III Satellite Cost Deconstruction

	Program Acquisition Unit Cost (Millions USD)	Average Production Unit Cost (Millions USD)	GPS Block III Contract Cost (Millions USD)
2008 Plan (8 satellites)	$397.488	$190.567	$3,179.9
2019 Update (10 satellites)	$528.520	$287.912	$5,285.2

Table 2: GPS Block III program and satellite costs. Program acquisition unit costs include research and development plus other fees, while average production unit cost only represents procurement costs. All costs in this table are found in [2] which was current as of fiscal year 2019.

When assessed from an economic perspective, a commercial lunar satellite navigation system is likely to be markedly different from GPS.

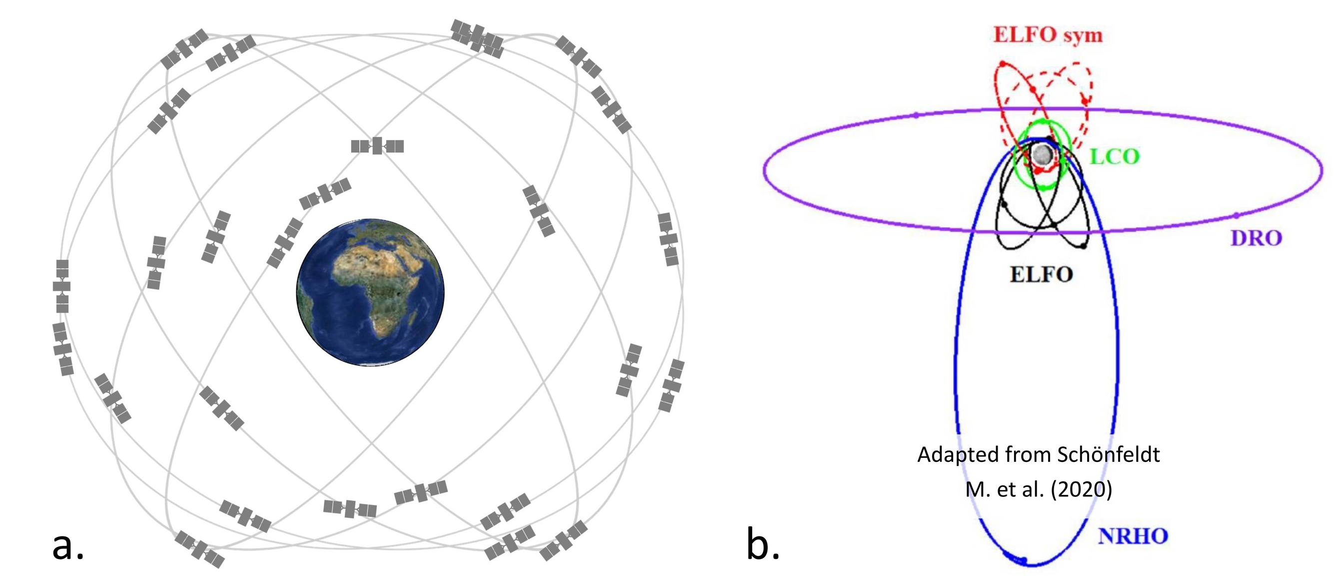

Fig 2: Comparison between GPS orbital design and lunar navigation satellite system orbital design. a) GPS orbits as defined by the 2020 standard positioning service performance standard (image modified from https://www.gps.gov/systems/gps/space/). b) Lunar navigation satellite system orbital design as defined by [3] (figure adapted from their figure 1).

Discussion

The government cost to provide GPS fidelity PNT information is high, roughly 290 million USD per satellite with an annual operating cost of approximately 480 million. In the case of GPS, the economic gains are modeled to exceed these costs. In 2011, the economic gain from GPS was modeled to exceed 67.6 billion annually [6]. The smaller market, and therefore, smaller economic base supporting an LNSS means it is unlikely we will recreate GPS at the Moon, at least not initially. However, other satellite navigation options exist and are in development that could help fulfill lunar mission needs. Recall, the first satellite navigation system, called Transit, used different technology than GPS. More frequent timing updates, or accepting a reduction in positioning accuracy, could enable use of less expensive technologies such as chip-scale atomic clocks (CSACs). In the end, creative thinking about LNSS may bring new and better ways of providing satellite navigation services.

References

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