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# P6_6 Interstellar Space Pirates: Design Decisions

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**Abstract**

The authors present in the following paper an analysis of how the journey time of a typical pirate ship with mass $1.270 \times 10^5$ kg travelling from Earth to Proxima Centauri, varies with solar sail area. Also presented is the analysis of the journey time as a function of area-mass ratio to investigate whether there is a point of diminishing returns. Lastly, a comparison between the journey duration profiles when using aluminium, silver or gold is presented, in which it is concluded that using silver would result in the shortest journey time, albeit not by a large amount.

## Introduction

In our previous paper, an initial calculation of the journey time for a typical pirate ship from Earth to our nearest stellar neighbour, Proxima Centauri, was performed, if it were to use a solar sail. The aim of this paper is to expand on the work of the previous paper by analysing the effect of varying the total sail surface area, taking into account the mass of the sail and the reflectance of the sail material. It also aims to provide a brief analysis on the best mirror material to use.

## Assumptions

The ship is assumed to be floating freely, not bound by an orbit around the Earth or Sun. It is also assumed that the mass of the ship is the same as in the first paper: $1.270 \times 10^5$ kg [1], with an initial ship velocity of $0.000\,\text{ms}^{-1}$.

## Method

For this investigation, we first employ the same expression for the journey time found in the previous paper:

$$t = \sqrt{\frac{2(R_2 - R_1)}{a}} \tag{1}$$

where $R_2$ is the distance from the Sun to Proxima Centauri [8], $R_1$ is the distance from the Sun to the Earth [7] and a is the acceleration given by Equation (2):

$$a = \frac{A\sigma}{m} \int_{R_1}^{R_2} 4\frac{G_{sc}}{cR^3} \cos^2(\alpha) dR \tag{2}$$

Where this equation is the same as in the previous paper but with an extra coefficient $\sigma$ which represents the average reflectance of the sail material. These were coded into R, and this model was used to analyse firstly how the area of the sail affects the journey duration and secondly, how the area-to-mass ratio affects the journey duration. For the mass term $m$ in Equation (2), the area is incorporated to account for the increase in mass of the sail due to the increased area of material:

$$m = A\left(d_{sub}\rho_{sub} + d_m\rho_m\right) + m_{ship} \tag{3}$$

where $d_{sub}$ is the thickness of the substrate layer in m, on which the reflective layer is placed, $\rho_{sub}$ is the density of the substrate in $\text{kg/m}^3$, $d_m$ and $\rho_m$ correspond to the same parameters but for the reflective metal layer. $m_{ship}$ is the mass of the ship in kg and $A$ is the sail area in $\text{m}^2$.

For this analysis, the substrate we will be using is called CP-1, which has a mass density of $1540\,\text{kg/m}^3$ [2]. Initially, we select aluminium as the reflective layer, which has a density of $2712\,\text{kg/m}^3$ [3].The purpose of plotting journey time with the area-to-mass ratio means we can investigate whether there is a ratio beyond which you get diminishing returns. The journey time profiles for three different metals are plotted for comparison. To compare three highly reflective metals: aluminium; silver and gold, their average reflectance over a range of wavelengths from 200 nm, 400 nm, 650 nm − 20 µm respectively, was calculated for each [4][5][6]. These reflectances are represented by $\sigma$ in Equation (2).

## Results

The results for a CP-1-aluminium based solar sail can be seen below:

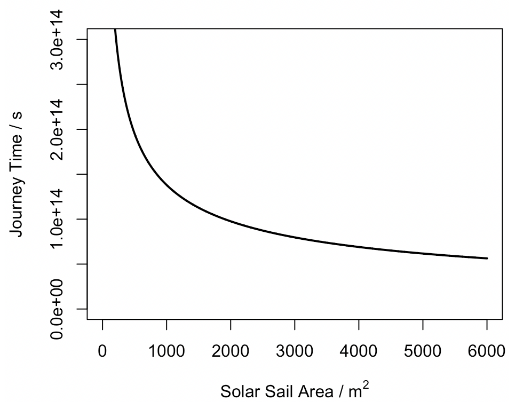


Figure 1: Graph showing how the journey time varies with sail area.

Figure 1 shows the sharp exponential decrease in journey time from an area of $0 - 3000\,\mathrm{m}^2$.

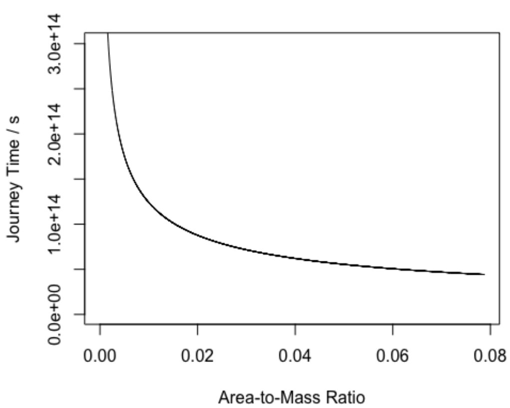


Figure 2: A clear exponential decrease in journey time as a function of area-to-mass ratio for the solar sail.

Figure 2 shows a sharp decrease in journey time between an area-to-mass ratio of 0 - 0.04, beyond which the journey time does not decrease as rapidly. Finally, a comparison of three highly reflective metals: aluminium, silver and gold and their journey times is displayed in Figure 3:

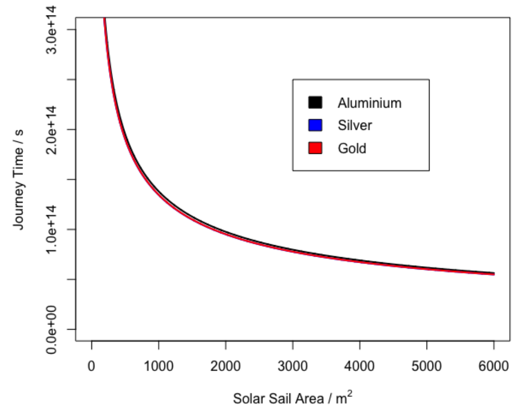


Figure 3: Comparison of the journey time profiles for aluminium (black), silver (blue) and gold (red). The profiles for silver and gold are almost identical, though the silver profile (blue) is marginally lower.

Figure 3 demonstrates that while the journey time profiles are very similar, the silver and gold profiles indicate a slightly reduced duration. Though difficult to see, the silver profile, denoted by the blue line, is marginally lower than the gold profile (red line). This was distinguished by looking at the average reflectance for gold and silver, which are 97.68% and 97.98% respectively [6][5].

## Conclusion

In conclusion, Figure 1 demonstrates that while journey time does decrease sharply between $0 - 3000\,\mathrm{m}^2$, the overall journey duration is still very long, likely due to the limiting factor that is the mass of the ship. From Figure 2, we can conclude that for the case of our ship, an area-to-mass ratio beyond 0.04 (including the mass of the ship), the journey time does not decrease significantly, thus the utilisation of a larger area-to-mass ratio would be almost negligible beyond this. From Figure 3, we can conclude that whilst the three have very similar journey time profiles, using silver as your mirror material would result greatest reduction in duration for any sail area.

## References


[1] `shorturl.at/jlzY9`[Accessed 30/11/21]

[2] `shorturl.at/wxBVY`[Accessed 30/11/21]

[3] `shorturl.at/irFHU`[Accessed 30/11/21]

[4] `shorturl.at/bjzA2`[Accessed 30/11/21]

[5] `shorturl.at/hlnB8`[Accessed 30/11/21]

[6] `shorturl.at/aswAD`[Accessed 30/11/21]

[7] `shorturl.at/djzC5` [Accessed 29/11/21]

[8] `shorturl.at/fyNPR` [Accessed 29/11/21]