Supplementary Information

Tuning the torque speed characteristics of bacterial flagellar motor to enhance the swimming speeds

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1. Attachment of oil-droplet (cargo) on bacteria

A mixture of 200 μl Silicone oil (viscosity '$\eta_{oil} = 100$ cst') and 10 μl of bacteria ($\sim 10^6/$mL) in aqueous medium ('$\eta_w = 1$ cst') is shaken using a vortex shaker to form water (containing bacteria) in oil emulsion (Fig. 3(a)). The emulsion is then sonicated in a water bath at a frequency of 40 kHz (BRANSON 2800) for $30-45$ sec, which facilitates the attachment of oil droplets onto bacteria [1]. Thereafter, water in oil emulsion is centrifuged at 2000 rpm for 1 min resulting in water droplet to settle at the bottom as they are denser (1 gm/ml) than Silicone oil (0.96 gm/ml). The settled water droplet at the bottom consist of bacteria, oil droplets and small oil droplets (~ 1 μm) attached to the bacteria. The droplets attached to the bacteria act as a seed where other oil droplets condense resulting in loaded bacteria of various possible configurations in about $8-9$ hrs. The oil droplet loaded bacteria is realised in dilute PBS solution (0.5 mM PBS + 50 μM $MgCl_2.6H_2O$ + 10 μM EDTA) [2] instead of commonly used Berg's motility medium [3]. This is because, at high salt concentrations, these emulsions are unstable resulting in phase separation due to rapid coalescence of oil droplet [4]. The images of oil droplet loaded bacteria were captured using an Olympus upright microscope (BX51M) simultaneously in DIC and fluorescent modes. A monochrome camera (Olympus – XM10) used with a 20x objective provided a spatial magnification of 0.51 μm per pixel in the imaging plane.

2. Effect of parameters on variation of swim-speed with cargo size

The speed of a wild-type swimming bacteria is largely immune with the change in various parameters such as geometry scale factor ($\lambda = 1$), maximum torque ($\tau_{max} = 1260$ pN.nm) and knee frequency ($\Omega_m^c = 600$ rad/s) as shown in Fig. S1(a), S1(b) and S1(c) respectively. The geometry scaling is done as $A_o, D_o, A, B, D \rightarrow A_o\lambda, D_o\lambda^3, A\lambda, B\lambda^2, D\lambda^3$ by keeping all the other parameters same as used in the main text to model Speed vs. Cargo Diameter plot shown in Fig. S1. The knee frequency and maximum torque too is varied similarly by keeping other parameters fixed.

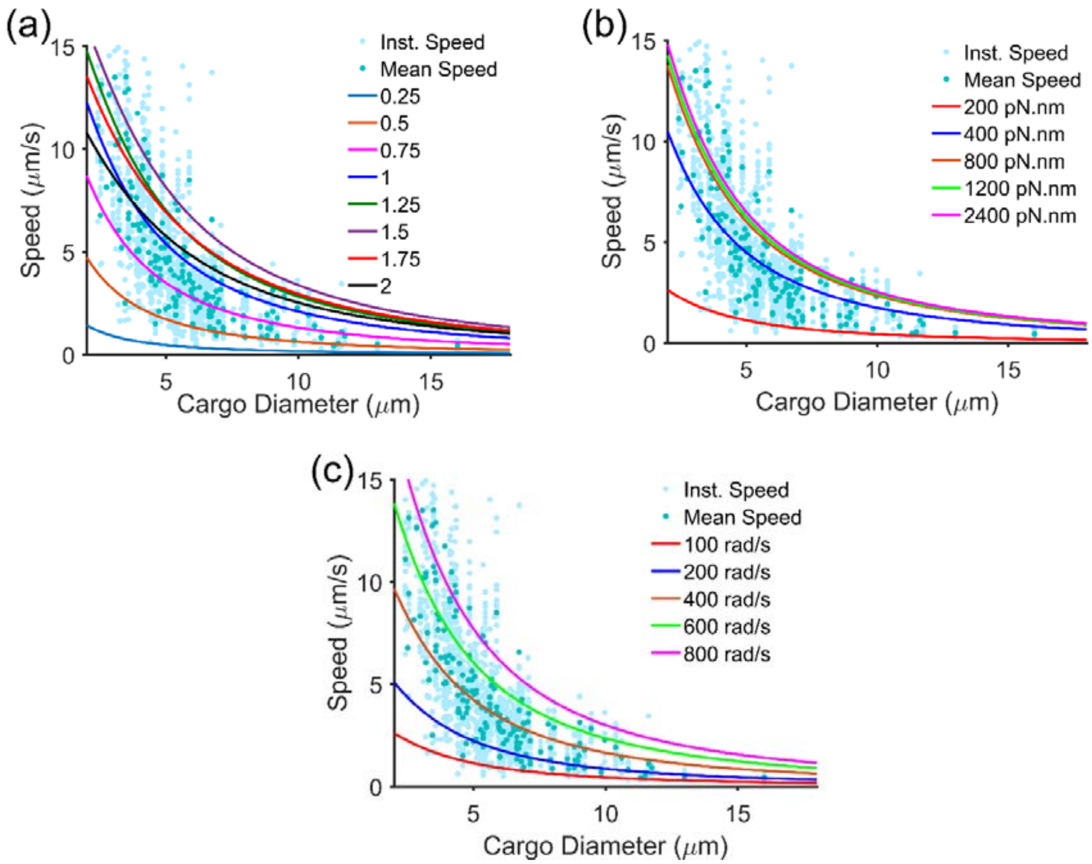

Figure S1: Speed as a function of cargo diameter at various parameters. (a) The speed attains maxima at $\lambda = 1.5$ and then drops. (b) Increase in speed saturates around a maximum torque of $800\ \mathrm{pN.nm}$. (c) Speed of bacteria is of the similar order and explains the experimental data for motor speed $400 - 800\ \mathrm{rad/s}$.

3. Description of the SI Movie

SI Video: Manually tracked video (DIC mode) of cargo loaded bacteria (frame rate = 4x). Initially, multiple trajectories of cargo loaded bacteria is shown. At 20 sec single trajectory of cargo loaded bacteria shown.

References:

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