# Dynamic stiffening of the flagellar hook

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# Software overview

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We provide here the source code at the base of the analysis described in our work. Two example experimental traces are also provided to test the output of the code.

**<u>Content</u>**

```
file2000res.npy                  Two experimental data traces
Drag/DragRotatingBead.py         Scripts to calculate the drag coefficient of
Drag/DragTranslationBead.py          a rotating and translating sphere
filters.py                       Signal processing, filtering, smoothing
fitEllipse.py                    Fit ellipse to x,y data
noise_bfm.py                     Main analysis
openTDMS.py                      Read .tdms files (not used in the examples)
PSpectrum.py                     Power Spectral Density of a signal
utils.py                         Various
```

**<u>Dependencies</u>**

The code has been tested on a PC running Debian Linux (4.19.0-17-amd64 #1 SMP Debian 4.19.194-2 (2021-06-21) x86_64 GNU/Linux), with 8 Intel Xeon CPU E5-1620 v2 (3.70 GHz).
The code runs in Python 3.7.11, and we used the `ipython (7.26.0)` console. The following imports are necessary:

```
matplotlib 3.4.2
numpy 1.20.3
scipy 1.6.2
```

## Accessing the example data

The content of the example file can be accessed by

```
    data = load('file2000res.npy', allow_pickle=1).item()
```

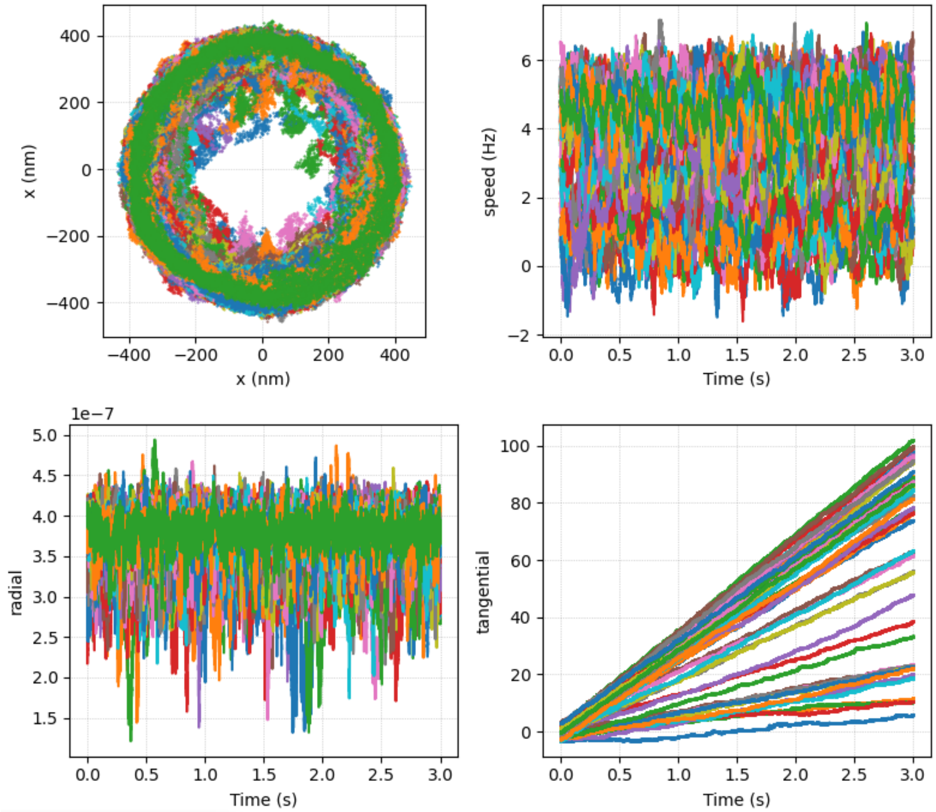
The object `data` is a dictionary with keys `(20, 29)`. The value of each key is again a dictionary, corresponding to one measurement on an individual motor and bead. Its keys are

```
'strain'           strain name
'cellnum'          measurement number
FPS                Frames Per Second of the camera
'x', 'y'           x,y position of the bead center in each time point, in pixel units
'stator'           type of stator (WT: wild type)
'nm_per_px'        pixel size conversion factor
```

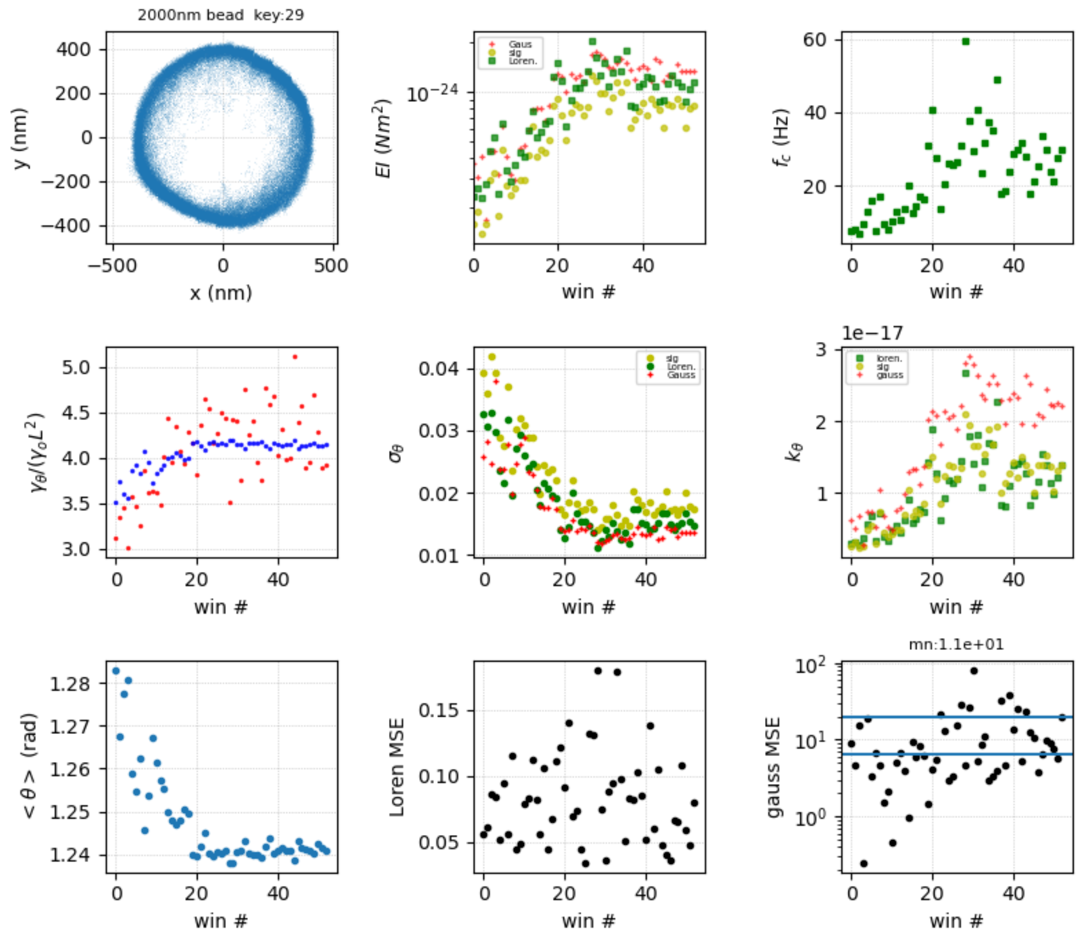
The content of `data` is

```
{20: {'strain': 'MT03',
  'cellnum': 'CL_180828_183950_xythetaROI0',
  'FPS': 10000.0,
  'dbead_nm': 2000,
  'x': array([5.60051109, 5.5774342 , 5.60936609, ..., 2.3257502 , 2.34367477,
         2.35231171]),
  'y': array([1.78207918, 1.79937524, 1.73658298, ..., 2.72624579, 2.7821482 ,
         2.80057767]),
  'stator': 'WT',
  'nm_per_pix': 98.0},
 29: {'x': array([34.90380243, 34.85262809, 34.90295628, ..., 32.3905964 ,
         32.37766435, 32.40861705]),
  'y': array([67.12387766, 67.19290839, 67.17724887, ..., 65.54918043,
         65.51845002, 65.4972709 ]),
  'z': array([1304.75636848, 1304.75636848, 1308.55277878, ..., 1330.53968112,
         1330.01458466, 1327.79936427]),
  'FPS': 10000,
  'cellnum': 'CL_200627_191532_ROI1',
  'strain': 'MT03',
  'stator': 'WT',
  'dbead_nm': 2000,
  'nm_per_pix': 91.3}}
```

For the 1$^{st}$ file, the command above will produce in few minutes the plots shown in the following pages

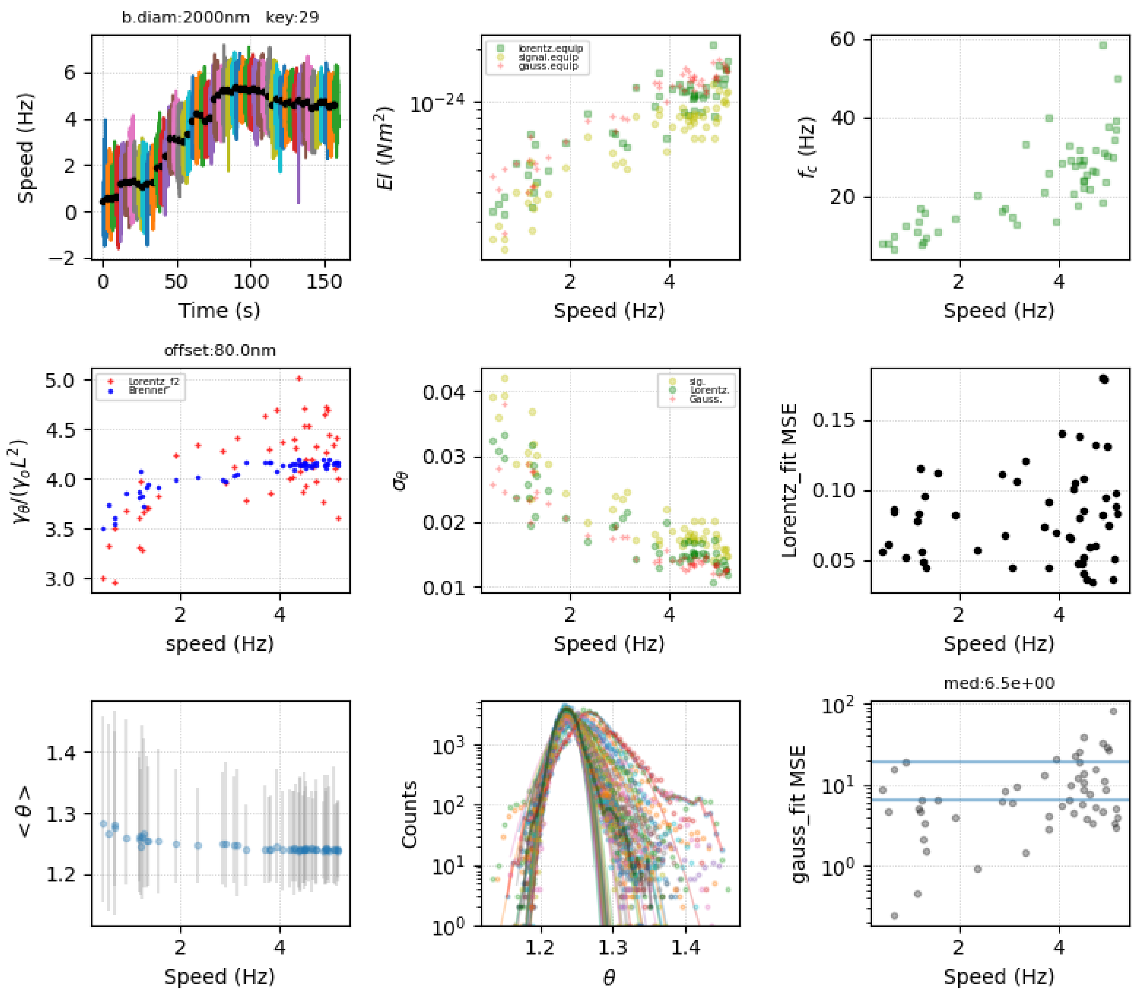



The x,y trace is divided in contiguous windows of `win_s=3` seconds. The panels show all the windows in the trace, shown in different colors.
**subplot(221)** : x,y trajectory
**subplot(222)** : angular speed of the bead in time
**subplot(223)** : radial distance (meters) in time
**subplot(224)** : angle phi (radians) in time




Analysis in each window along the trace.

**subplot(331)** : all x,y points of the trace
**subplot(332)** : bending stiffness *EI* calculated in each window, from the Gaussian fit (red), raw signal (yellow), and Loretzian fit (green), as described in the SI.
**subplot(333)** : Corner frequency obtained from the Lorentzian fit of the PSD.
**subplot(334)** : Relative drag coefficient in each window. Red points: values obtained from the Lorentzian fit of the PSD of theta. Blue points: theoretical value obtained imposing the parameter `offset=80e-9` (meters). The best value of `offset` is automatically determined by the optimization procedure described in the main text and SI.
**subplot(335)** : standard deviation of theta in each window, obtained from the raw signal (yellow), Lorentzian fit (green), and Gaussian fit (red).
**subplot(336)** : Stiffness of the potential for the angle theta, calculated from the equipartition theorem and the variance of the data (`KT/var(thetavar_sig_arr)`, yellow points), from the variance of the Gaussian fit (`KT/theta_stds_gaus**2`, red points), and from the Lorentzian fit (`gamma_loren_f2_pts*freq_c*2*np.pi`, green points)
**subplot(337)** : mean angle theta
**subplot(338), subplot(339)** : Mean Square Error of the Lorentzian and Gaussian fit, respectively.




Analysis as a function of median speed in each time window.

**subplot(331)** : Angular speed omega in time, where the time windows are highlighted by colors. Black dots indicate the median speed value in each window.

**subplot(332)** : Same as subplot(332) in the previous figure, here *EI* is plot as a function of speed in the time window.

**subplot(333)** : Same as subplot(333) in the previous figure, `f_c` is plot as a function of speed in the time window.

**subplot(334)** : Same as subplot(334) in the previous figure, the drag is plot as a function of speed in the time window.

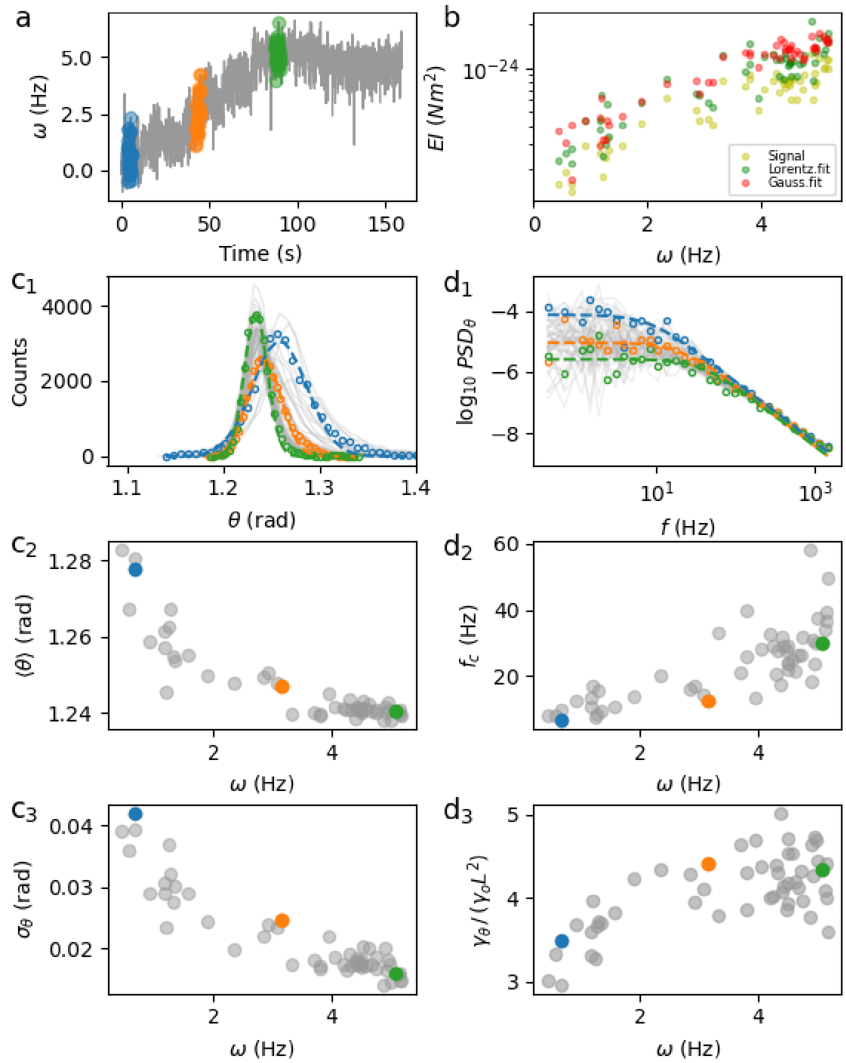
**subplot(335)** : Same as subplot(335) in the previous figure, the std.dev. of theta is plot as a function of speed in the time window.

**subplot(336)** : Same as subplot(336) in the previous figure, the MSE is plot as a function of speed in the time window.

**subplot(337)** : Same as subplot(337) in the previous figure, the mean angle theta is plot as a function of speed in the time window.

**subplot(338)** : Probability distributions of the angle theta (rad) in each window.

**subplot(339)** : Same as subplot(339) in the previous figure, the MSE is plot as a function of speed in the time window.




As for fig.3 of the main text, this figure recapitulates the main analysis shown before.

**a)** Speed omega in time. The three windows at different speeds highlighted by color correspond to the points marked in each plot of the figure.
**b)** Resulting values of the bending stiffness *EI* (see previous figures).
**c1)** Distribution of the measured angle theta in each window.
**c2)** Mean of the angle theta in each window as a function of angular speed.
**c3)** Standard deviation of theta in each window as a function of angular speed.
**d1)** PSD_theta in each windows, the Lorentzian fit (dashed lines) is shown for the three highlighted windows.
**d2)** Corner frequency of the Lorentzian fit in d1, as a function of angular speed.
**d3)** Relative drag coefficient measured, as a function of angular speed.