Tito Neri model scale vessel thruster behaviour

Bart Boogmans
b.boogmans@tudelft.nl
ResearchLab Autonomous Shipping
Dept. of Maritime and Transport Technology, 3ME, TUDelft

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For control purposes of vessels, it is highly beneficial to know what behaviour to expect from actuators. This document bundles some measurements on the aft and bow thrusters of the Tito Neri model scale vessel from department of Maritime and Transport Technology, TUDelft. The two main relations are propeller speed versus thrust (aft thrusters) and engine PWM versus thrust (bow thruster, as it has no sensors for feedback and is currently used in feedforward mode)

Feel free to make contact to aquire datasets, images or scripts generating the figures shown in this document.

Figure 1: The light-blue Tito Neri operating outside. (photo by Casper Cromjongh)

1 Aft thruster

The current setup involves an incremental optical encoder around the engine shaft, having signal digitalized by an arduino and passed along to Matlab-Simulink. Firstly, the encoder signal is compared to signal from an oscilloscope , hooked up to the sensor. The oscilloscope had the signal period read from the screen (Fig. 3) (estimated error around 10%), which was later converted to axle rps to yield datapoints in Fig. 2.

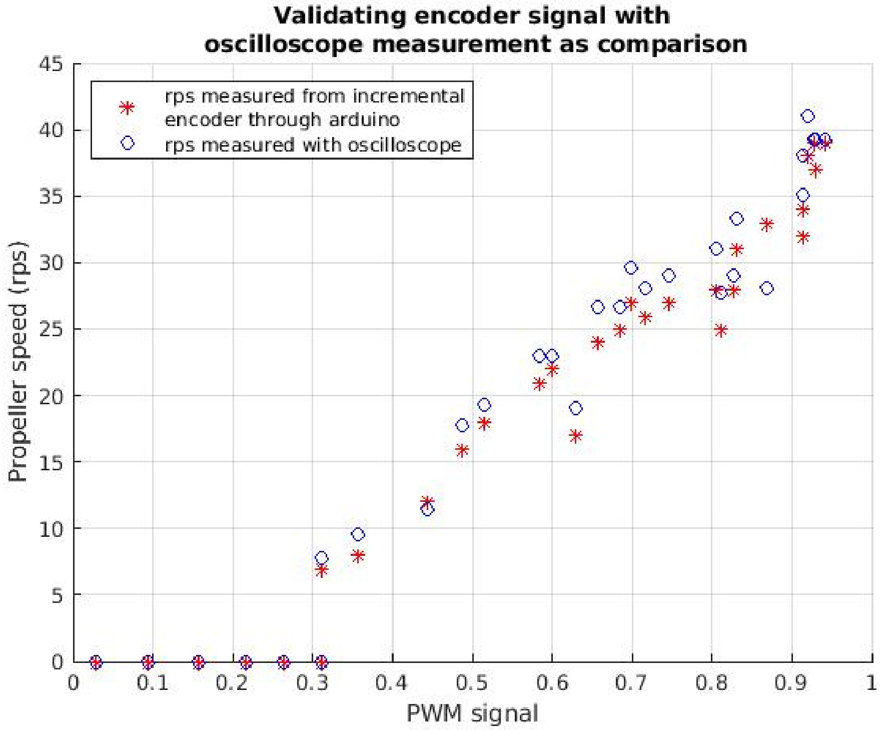

Figure 2: PWM vs propeller speed of aft thruster (Purple ship, portside, azimuth facing backwards/neutral position, waterborne)

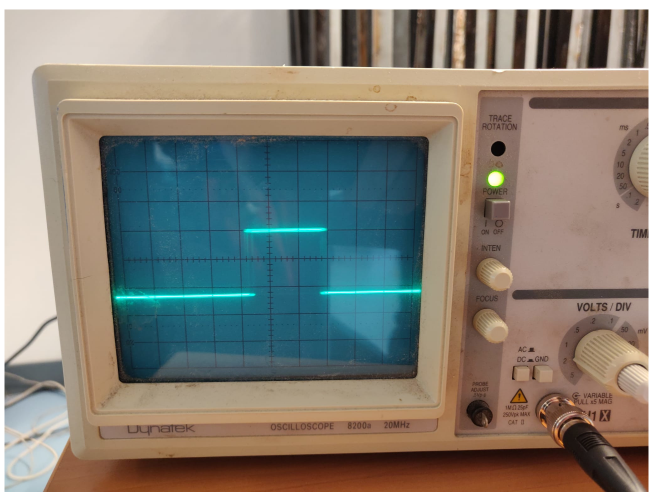

Figure 3: Returned signal from incremental encoder shown on oscilloscope, showing a rather clean step function when the sensor passes a hole. x-grid-scale = 1ms, y-grid-scale = 2V.

Both sensors yield approximately the same values, which indicates that the arduino's signal is reasonable. Furthermore the dead zone near zero speed operation can be clearly seen, as the axle does not turn for PWM values below 0.3.

Aft thruster behaviour is mapped for the purple Tito Neri on the portside thruster while operating in water. The thruster faced backwards in this experiment (as you would point it to move forward).

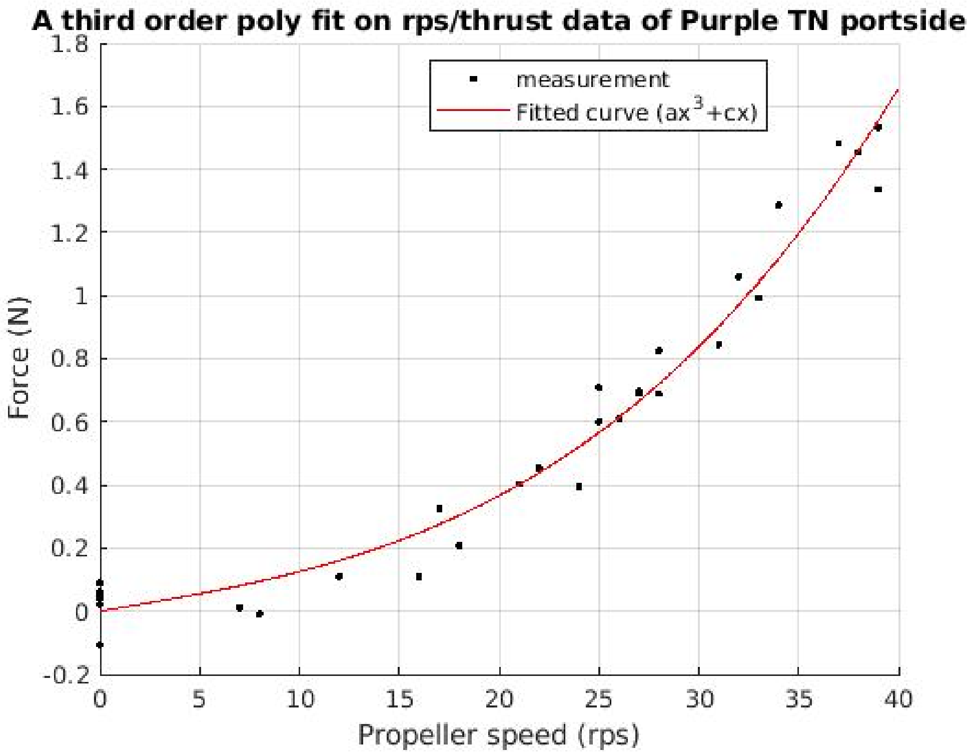

Figure 4: Collected dataset on aft propeller thrust in positive direction only.

Fig. 4 shows collected datapoints of the relation between engine speed and resultant force ad an advance ration of 0 (standstill, no forward speed/current). The speed in this figure pertains engine speed, at the position of the encoder, which needs conversion with the gearbox ratio ($rps_{prop} * 3.0 = rps_{engine}$) to find the actual propeller speed. Force was measured with a weight being lifted from a scale by means of a rope and pulley connected to the vessel, which is converted to newtons in this figure. An optional curve fit to this dataset is shown, although this form is by no means argued as ideal. ($a = 1.925e - 05$,$c = 0.01061$ in this fit).

Behaviour of the propeller in reversed direction has not been measured in this experiment. It will give slightly different characteristics in that direction, albeit with comparable shape and order of magnitudes. Neglecting differences and mirroring forward behavior to represent also reversed operation yields the following relation in Fig. 5.

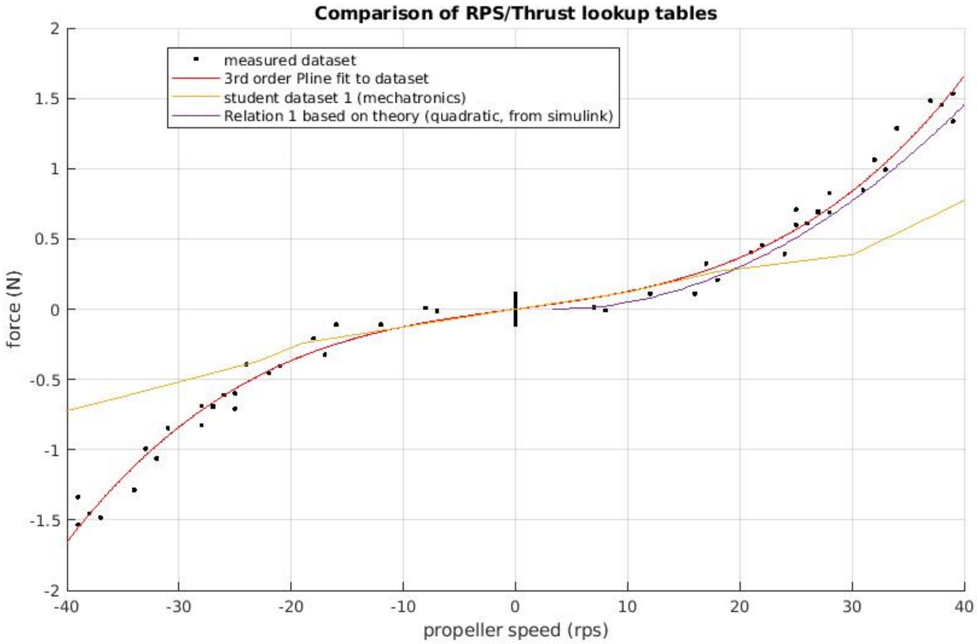

Figure 5: Full operational range of aft thrusters. Measured dataset was mirrored to represent reversed operation, on which the 3rd order polynomial fit was made.

The shown 3rd order polynomial fit has $a = 1.925e - 05$, $c = 0.01061$. The earlier made relation based on theory is quadratic ($rps = 3.0 * sqrt(F/(0.75 * 1000 * 0.06^4)) + (200/60)$ from simulink). One somewhat crude dataset gathered by students is also shown, which shows some errors, but sensible shape and magnitudes.

The conclusion that can be drawn from this is that the theoretic relation between thrust and rps is sensible, as it seems very close to the measured data. Although there will be some differences between ships and propellers, this quantification is aimed to increase knowlede on the force/propellerspeed relations that we currently have. What shape is best suited for control purposes (e.g. the shown 3rd order fit, the quadratic theoretic one, or others) is up for discussion. The third order polynomial fits both the positive and the negative region quite well, although the current fit has a nonzero slope at the origin, where the 2nd order theoretic approach seems to match slightly better.

2 Bow thruster

The bow thruster has no means of getting a feedback signal, and is thus currently operated in a feedforward fashion. The relation between PWM input and resultant thrust was rather crude, consisting of only four datapoints. Furthermore this relation is asymmetrical, which is strange, as the bow thrusters are symmetrical to port and starboard side. Gathered datapoints of various pwm settings are shown in Fig. 6, gathered from the dark-blue Tito Neri in march 2022.

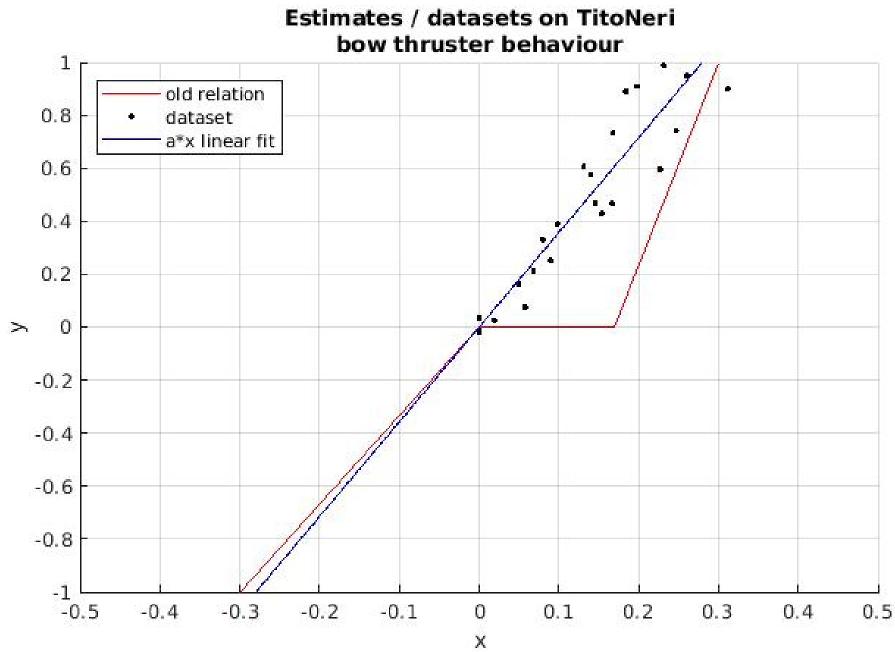

Figure 6: Bow thruster pwm force relation (dark-blue TitoNeri, waterborne)

The old relation shows some form of dead zone behaviour on one side, but not on the opposite. From this dataset it was noted that the bow thruster could realize quite low forces aswell, as it is concluded that the dead zone is quite small. Hence we opt for a linear relationship, also shown in Fig. 6, with $a = 3.575$. The lowest PWM signal to turn the bowthruster was found to be around 0.05, significantly lower than the earlier relation deadzone represents.

Note that the bow thrusters are less sensitive to battery potential changes, as they are powered trough and intermediate step down regulator from 12V to around 8.0V. Resistance or wear can cause other ships to have different responses, although we hope this can function as a reference.