A kinematic description of locomotion in the marine polychaete genus *Tomopteris*

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Introduction

Tomopterids are a family of highly motile holopelagic polychaete worms with global distributions and approximately 60 described species. Despite the lack of chetae (bristles) and internal septa which distinguish them from other polychaetes, *Tomopteris* has been observed to swim with a high degree of maneuverability and minimal disturbance to its midwater surroundings. Tomopterids generate thrust by combining metachronal rowing of their parapodial appendages with the propagation of a body wave travelling from tail to head.

This project sought to provide a basic kinematic description of forward swimming in *Tomopteris* with a focus on the stroking action of the parapodia and the initial generation of the body wave. The ultimate goal is to place *Tomopteris* in a comparative context with previous studies of neridiform polychaetes (Clark and Tritton 1970, Hesselberg 2007, Yang 2012) and to develop an understanding of more complex turning, reversal, and backwards swimming behaviors exhibited by tomopterids.

Fig 1. *Tomopteris* specimen

Methods

NMNH and MBARI researchers collected specimens of *Tomopteris* in August 2015 and June 2016 using the remotely operated vehicle (ROV) *Doc Ricketts* from the Monterey Submarine Canyon off the Californian coast. We placed the animals in a photo tank and filmed them using a high-speed Photron FASTCAM Mini AX50 camera. The video clips of swimming were recorded at frame rates ranging from 250-1000 fps for lengths of 500-3000 frames. We selected 10 videos with a clear dorsal view of swimming featuring 3 different animals for digitization and kinematic analysis in this first stage of the project.

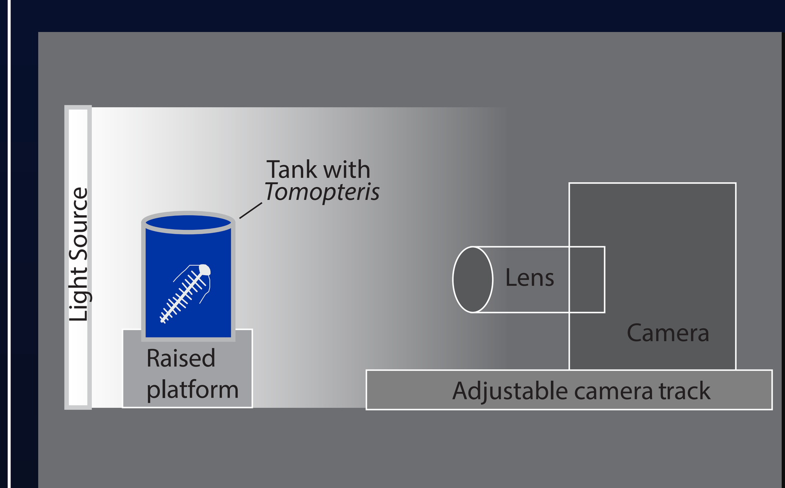

Fig 2. Setup for *Tomopteris* filming

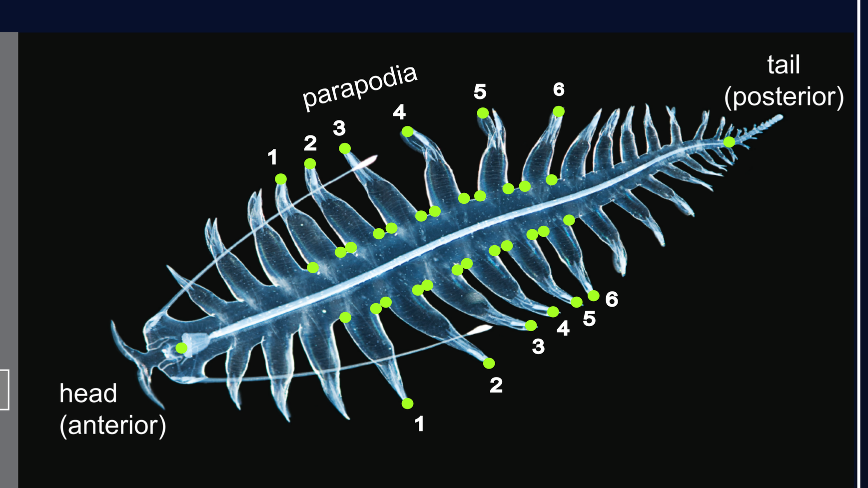

Fig 3. Diagram of *Tomopteris*, body points used for digitization shown in green

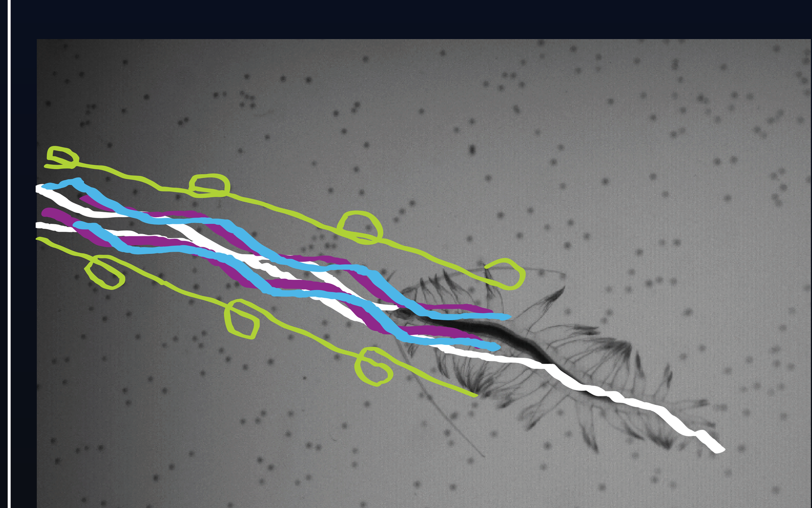

Fig 4. Illustrated path of selected body points: head/tail (white), anterior parapodial base points (purple), posterior parapodial base points (blue), parapodial tips (green)

We used the DLTdv5 software package developed by Hedrick (2008) in MATLAB R2016a to track the positions of forty 2-D body points on the head, tail, acicular cirri, and parapodial bases/tips. We tracked six adjacent parapodia from the middle section of the body. We calculated and graphed several kinematic parameters from these points including the animal's swimming velocity, body wave speed, and the angular motion of the parapodial tips with respect to their bases.

Results and Discussion

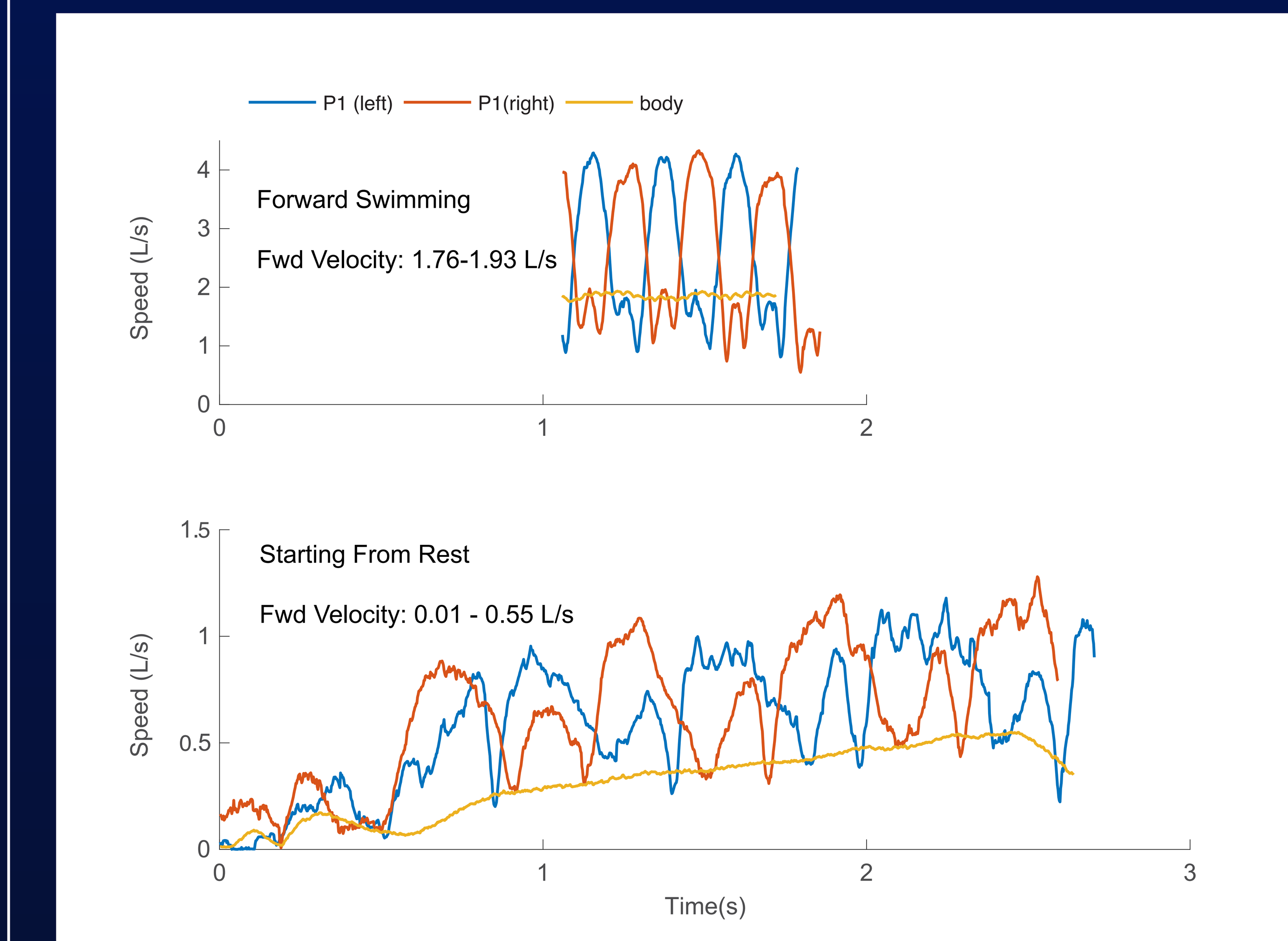

Fig 5. Speed of tips of a pair of parapodia corresponding to the same segment on left/right sides in two animals exhibiting different behaviors

Within a segment pair, the speed of one parapodium during power stroke is nearly equal to that of its partner's recovery stroke indicating that despite a lack of septa, *Tomopteris* segments work in a concerted fashion.

Consistent local peak is observed during recovery stroke, this can possibly be explained by the motion of the pinnules which are drawn inward to decrease drag during recovery stroke.

When animal starts to swim these local maxima are large, resulting in a pattern of almost overlapping velocity peaks, but shrink as animal settles into regular motion. The action of the parapodial tips and pinnules during these transitional phases merits further investigation.

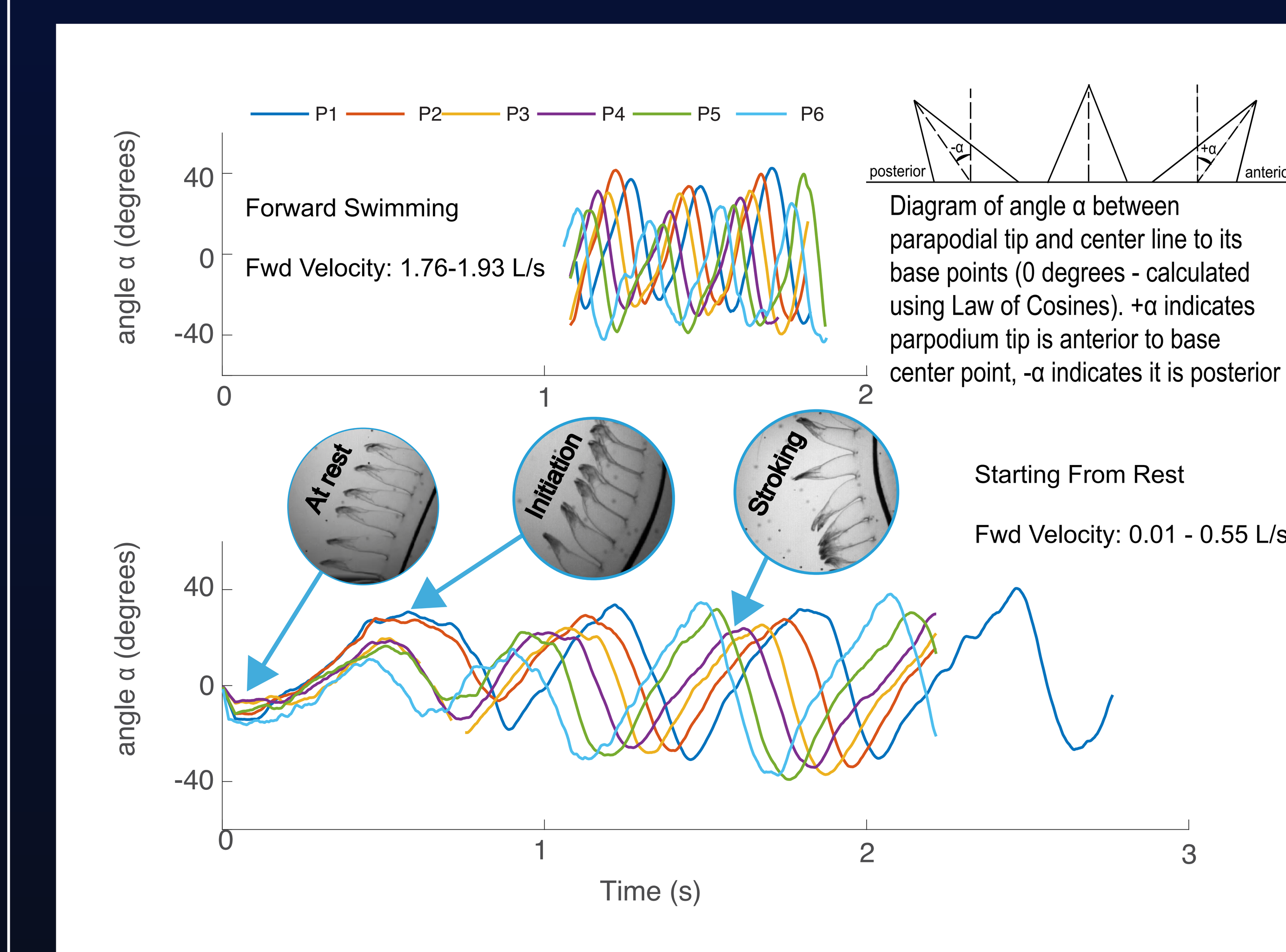

Fig 6. Angular motion of 6 adjacent parapodial tips (labeled 1-6 ant. to post.) on left side of animals swimming and passing through stages of rest, initiation of body wave, and normal parapodial stroking motion.

During straight swimming, adjacent parapodia are phase shifted in their strokes generating a metachronal wave. However, during the initial movements of wave propagation, parapodia stroke together in the same direction before separating. The period of each full stroke is also larger than during normal swimming.

Relative location of an appendage on the body appears to affect the range of angles through which it moves. More anterior appendages stroke more degrees forward and fewer degrees backwards than posterior appendages. A possible explanation is that more posterior appendages are shorter and must stroke farther backwards (more negatively) to generate powerful thrust.

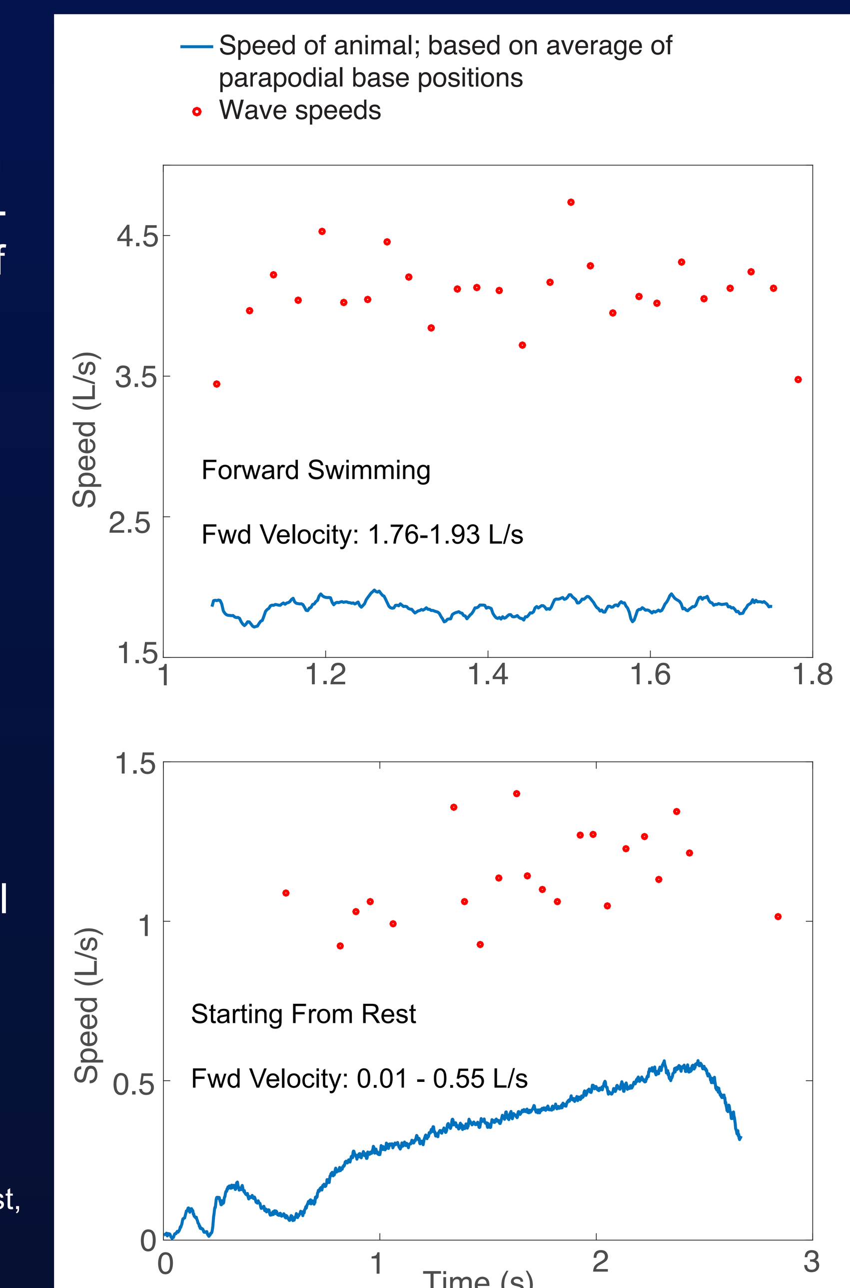

Fig 7. Average speed in body lengths/sec (L/s) of animal position and body wave peaks travelling posterior-to-anteriorly during straight swimming and initiation of motion. Body lengths of animal: 1.36 cm, 9.09 cm.

The body wave consistently propagates along the body faster than the speed of the animal through the water. The ratio of average wave speed to average body speed, though consistent during different behaviors by the same animal, varied from 2.2 to 5.6 among the 3 specimens.

Wave speed increases with animal speed but the relationship is not one-to-one implying that the body wave is not solely responsible for generating forward thrust.

Next Steps

- Examine behavior of most anterior and most posterior parapodia to understand why stroke amplitude is not constant and symmetric, taking parapodial length into account
- Expand data set to include larger number of individuals exhibiting turning, reversals, and backwards swimming behaviors
- Separate and quantify relative contributions of parapodial power stroke vs body wave undulation to net forward thrust of animal
- Use particle image velocimetry (PIV) to evaluate fluid flow around animal

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