



NTSB National Transportation Safety Board

Crown Princess

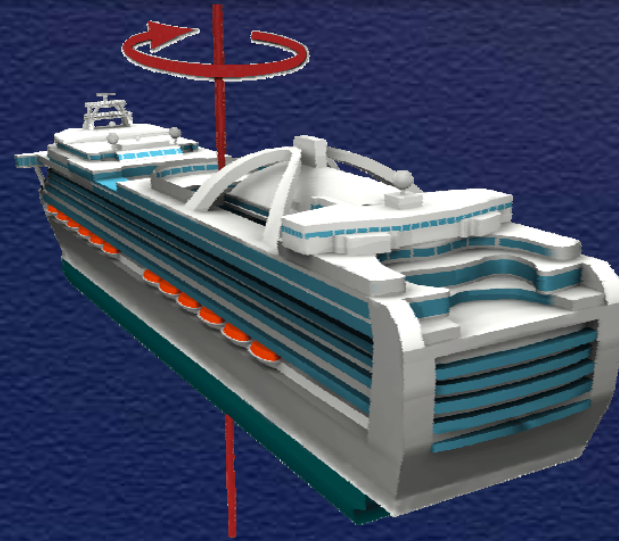
Vessel Dynamics

Overview

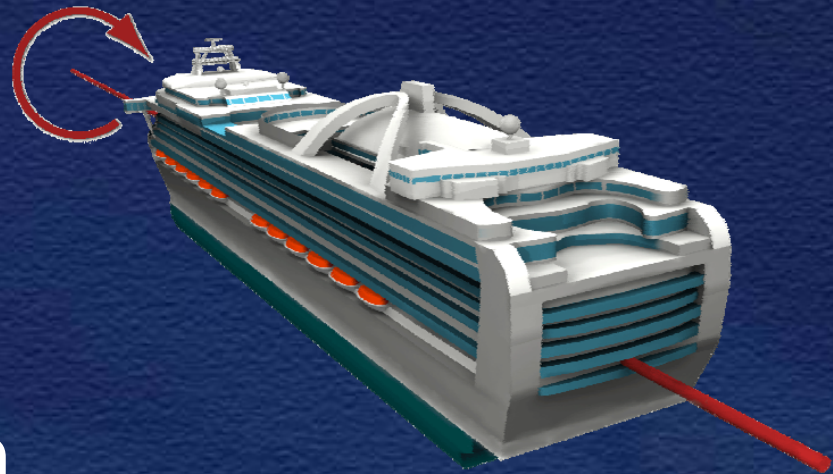
- Ship dynamics under INS
- 2nd officer's manual inputs
- Two opposing heeling responses
- Lag between wheel input and rudder/ship response
- Motion cues

Primary Motion

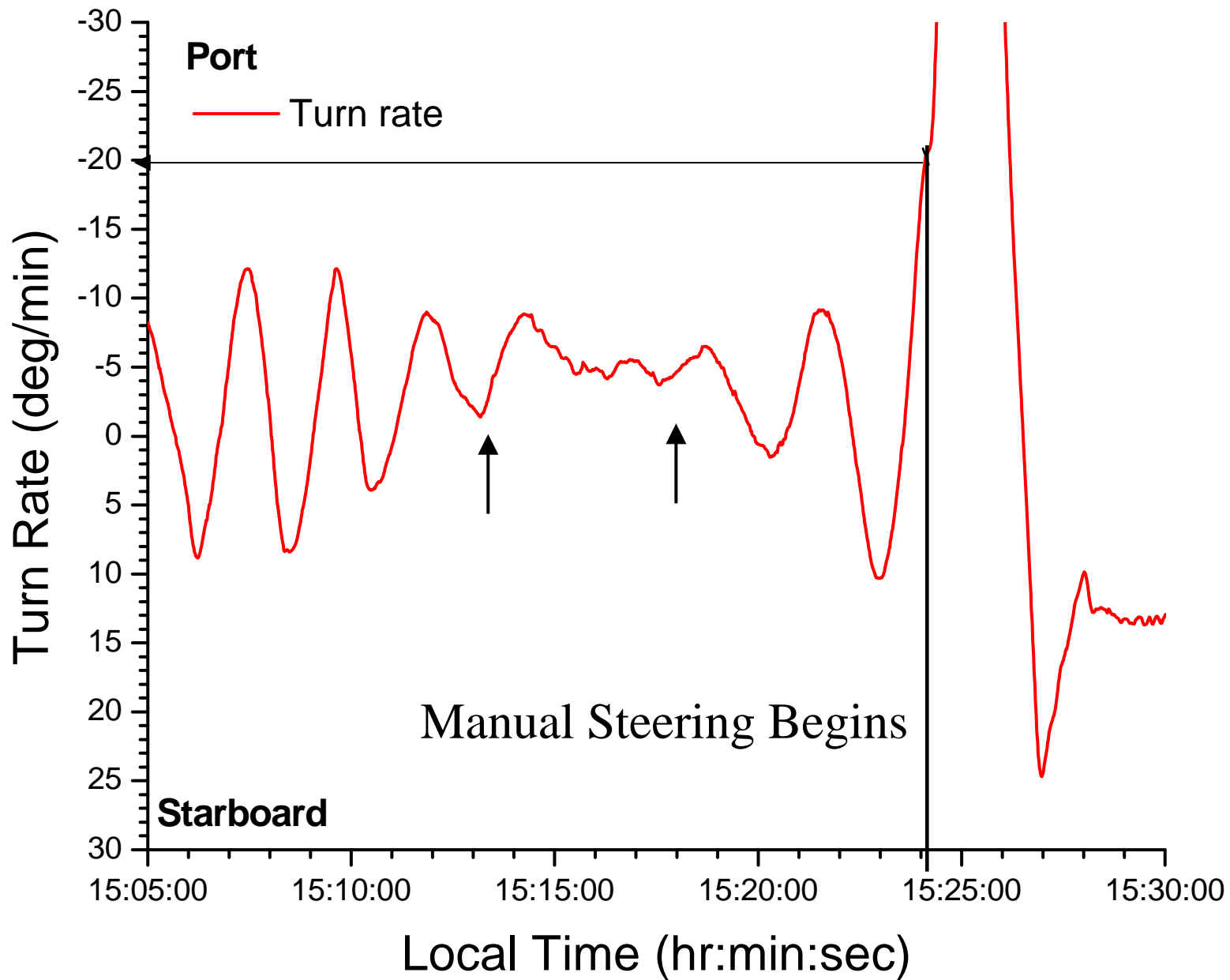
- Yaw Axis
 - Heading
 - Turn rate
 - Turn acceleration

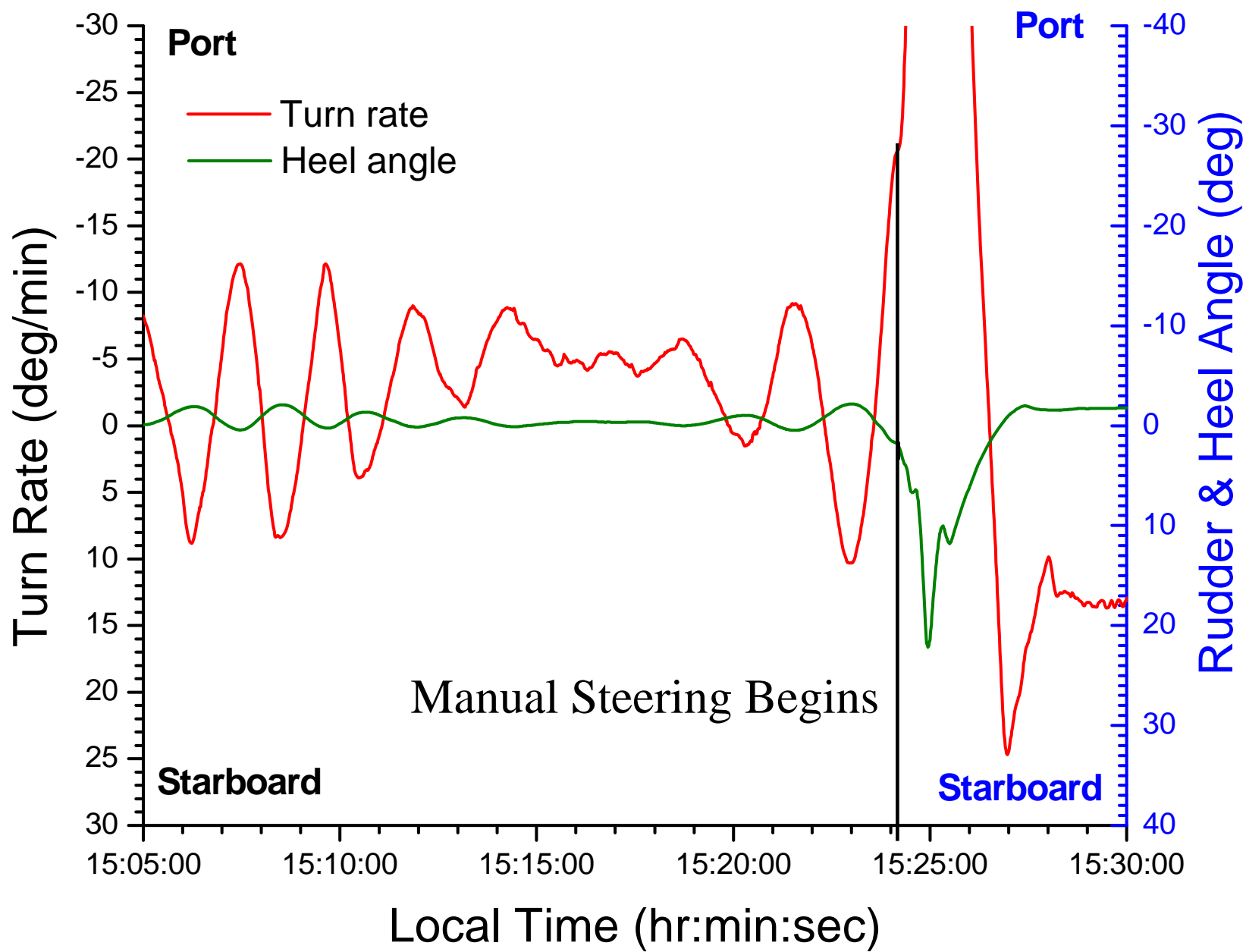


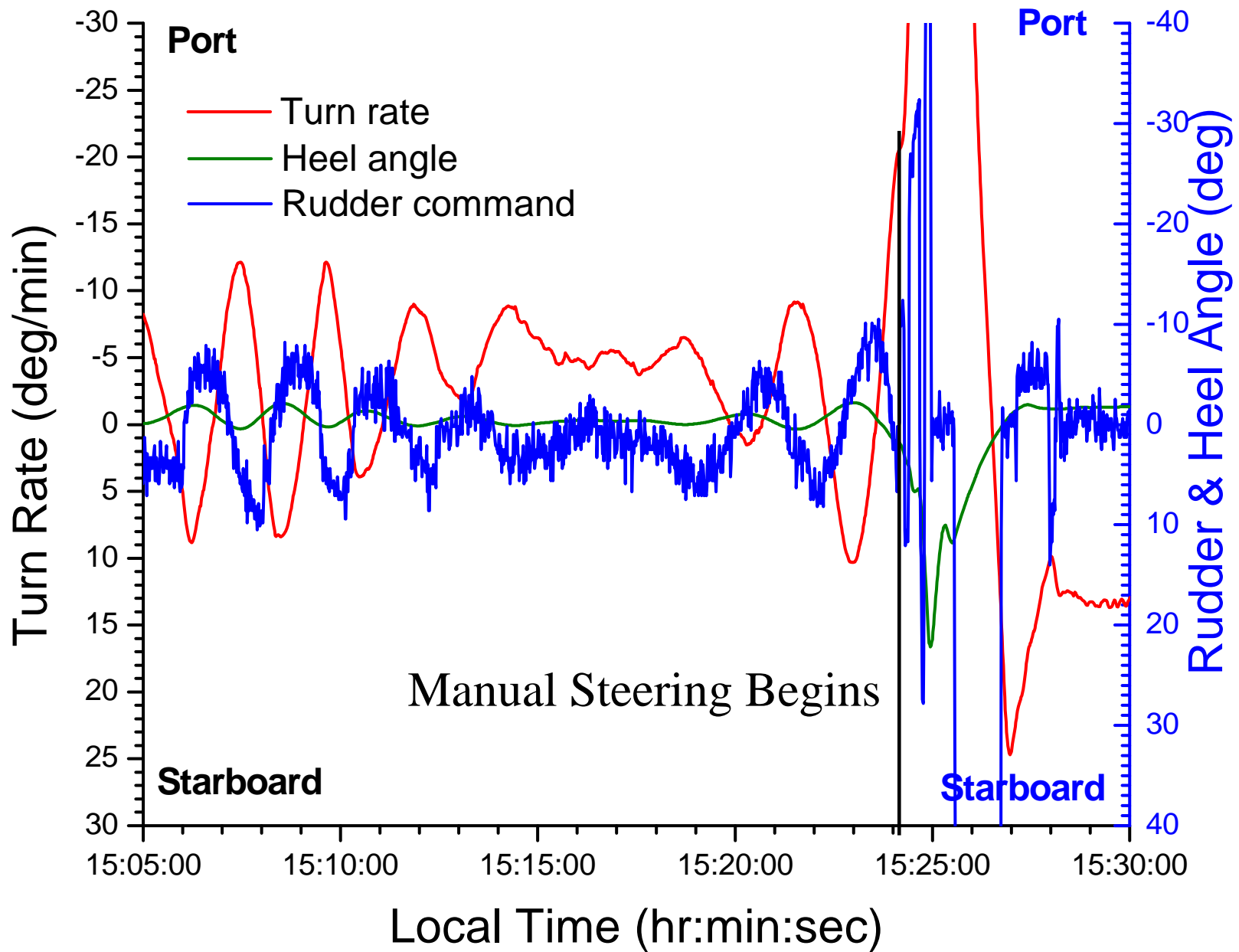
- Roll Axis
 - Heel angle
 - Heel rate
 - Heel acceleration



Recorded Motion

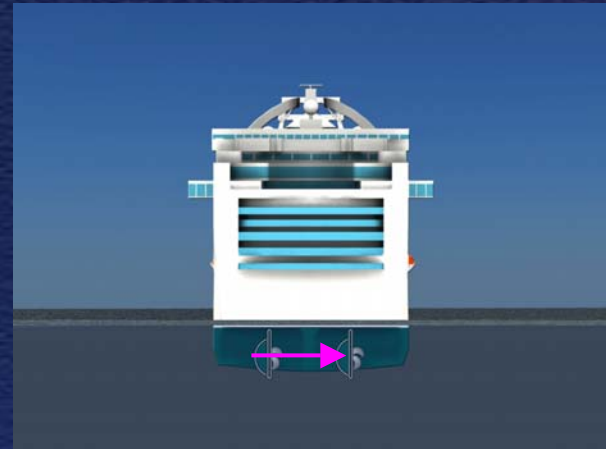




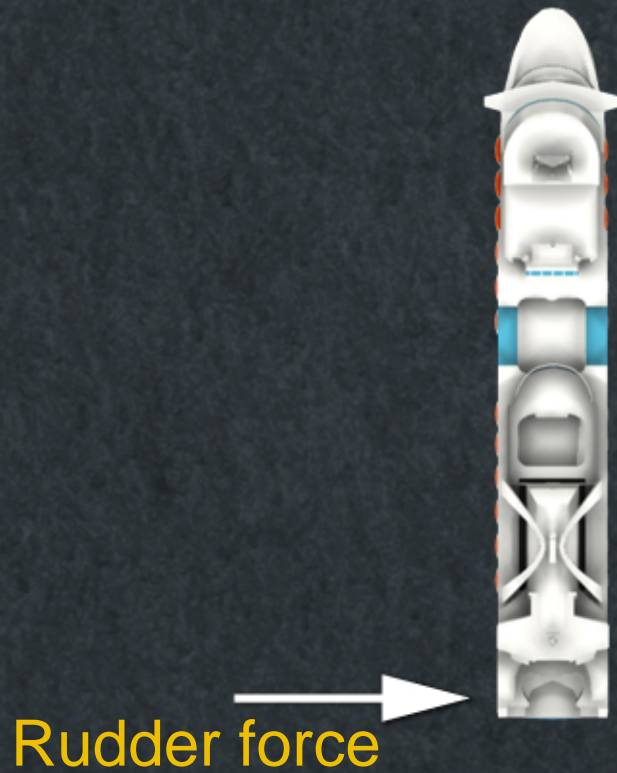


Turning a ship

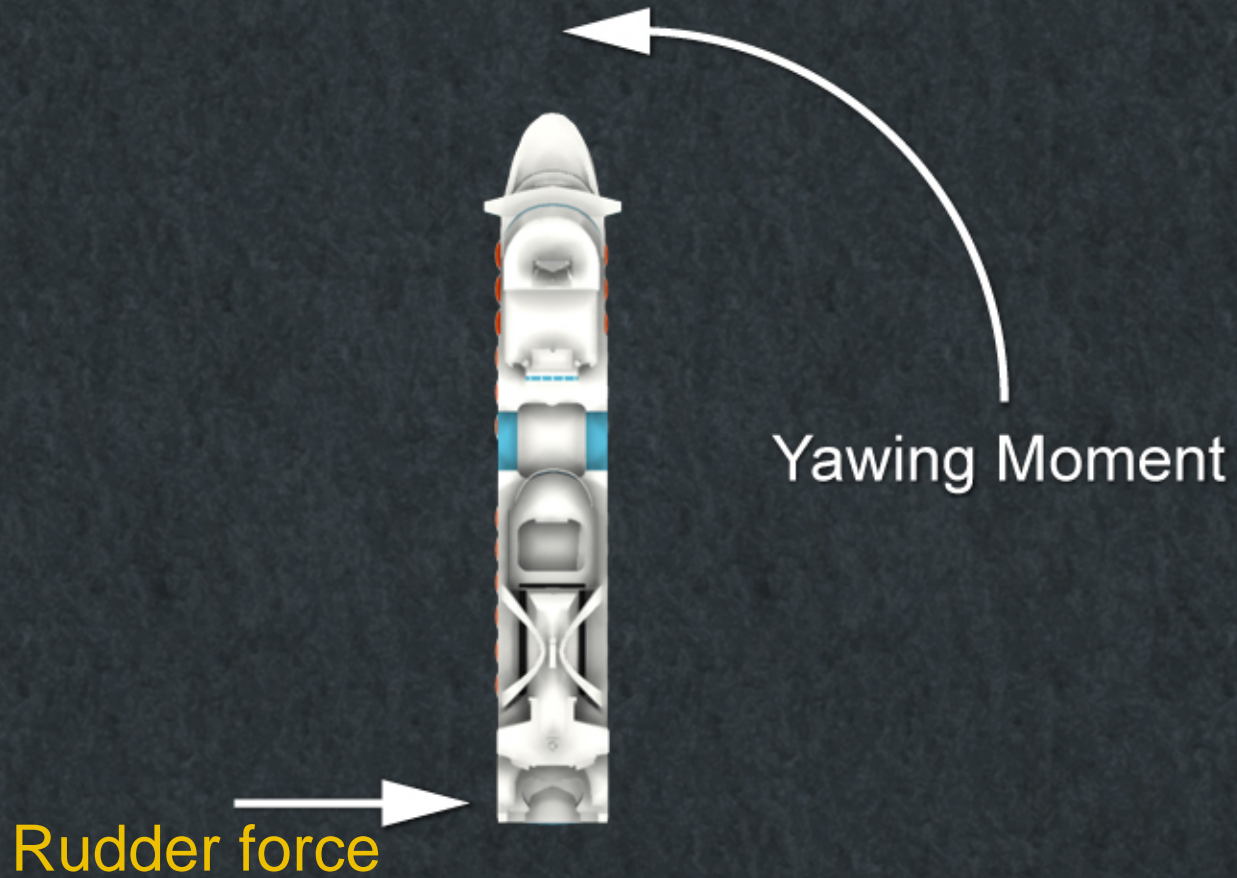
- Wheel command to rudder



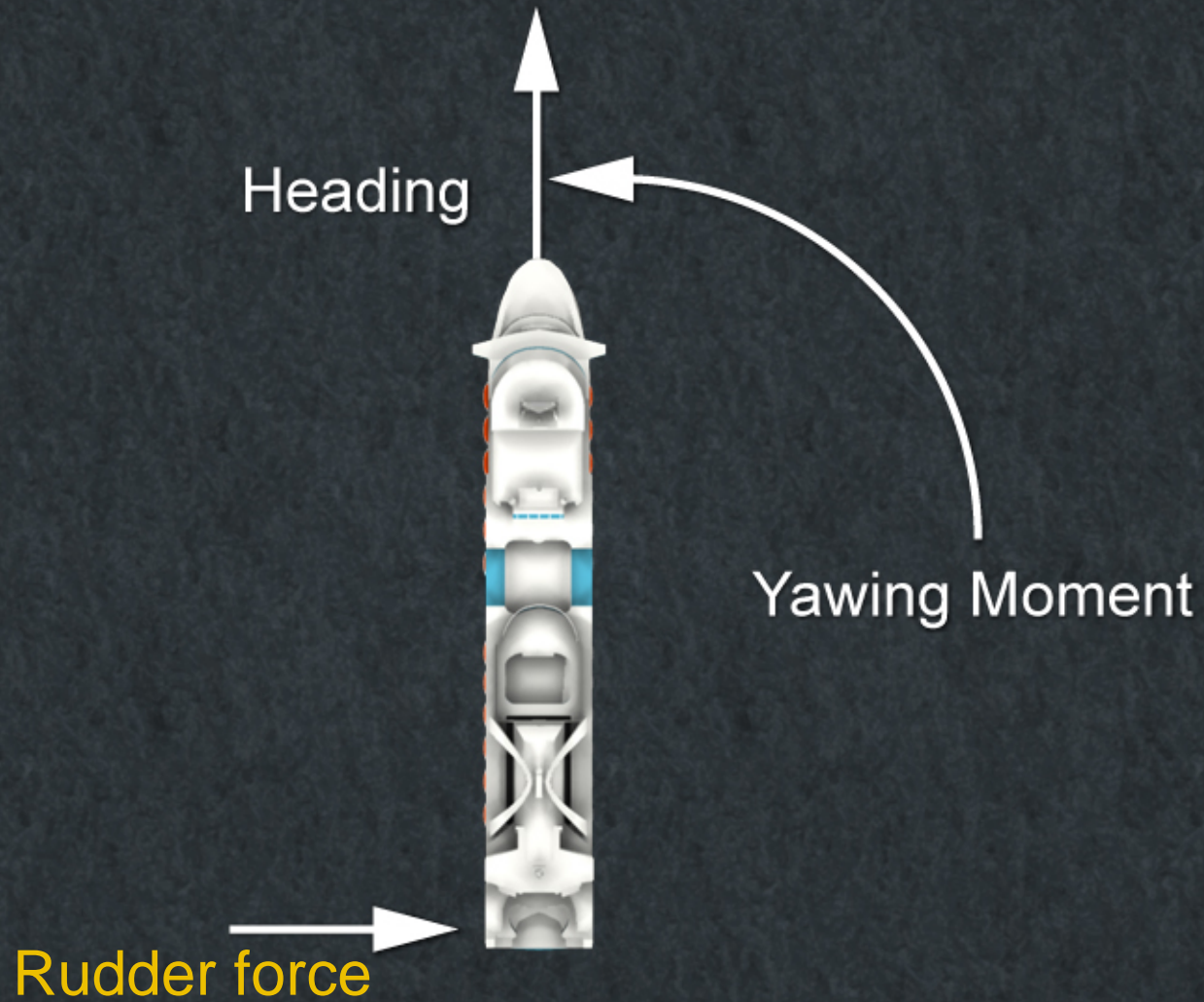
Turning a Ship



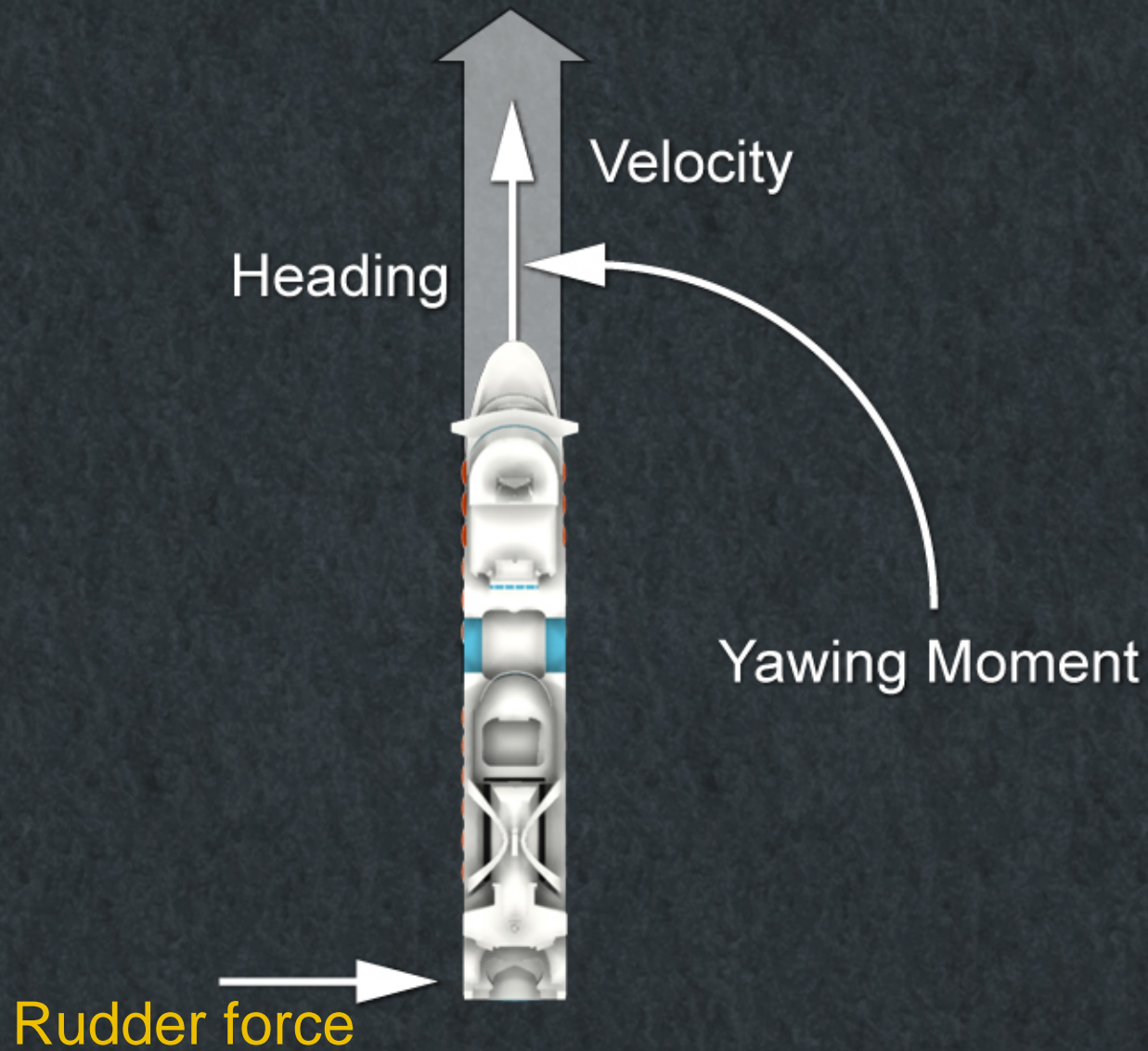
Turning a Ship



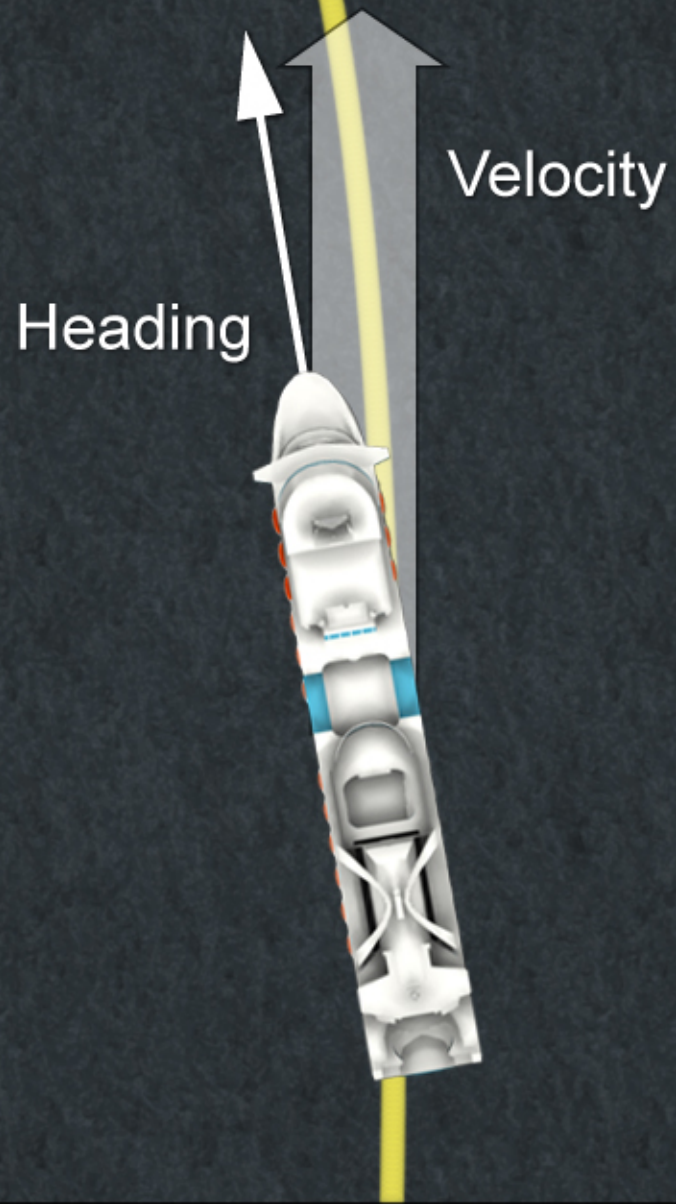
Turning a Ship



Turning a Ship



Sideslip & Side Force



Sideslip & Side Force

Sideslip

Velocity

Heading



Sideslip & Side Force

Sideslip

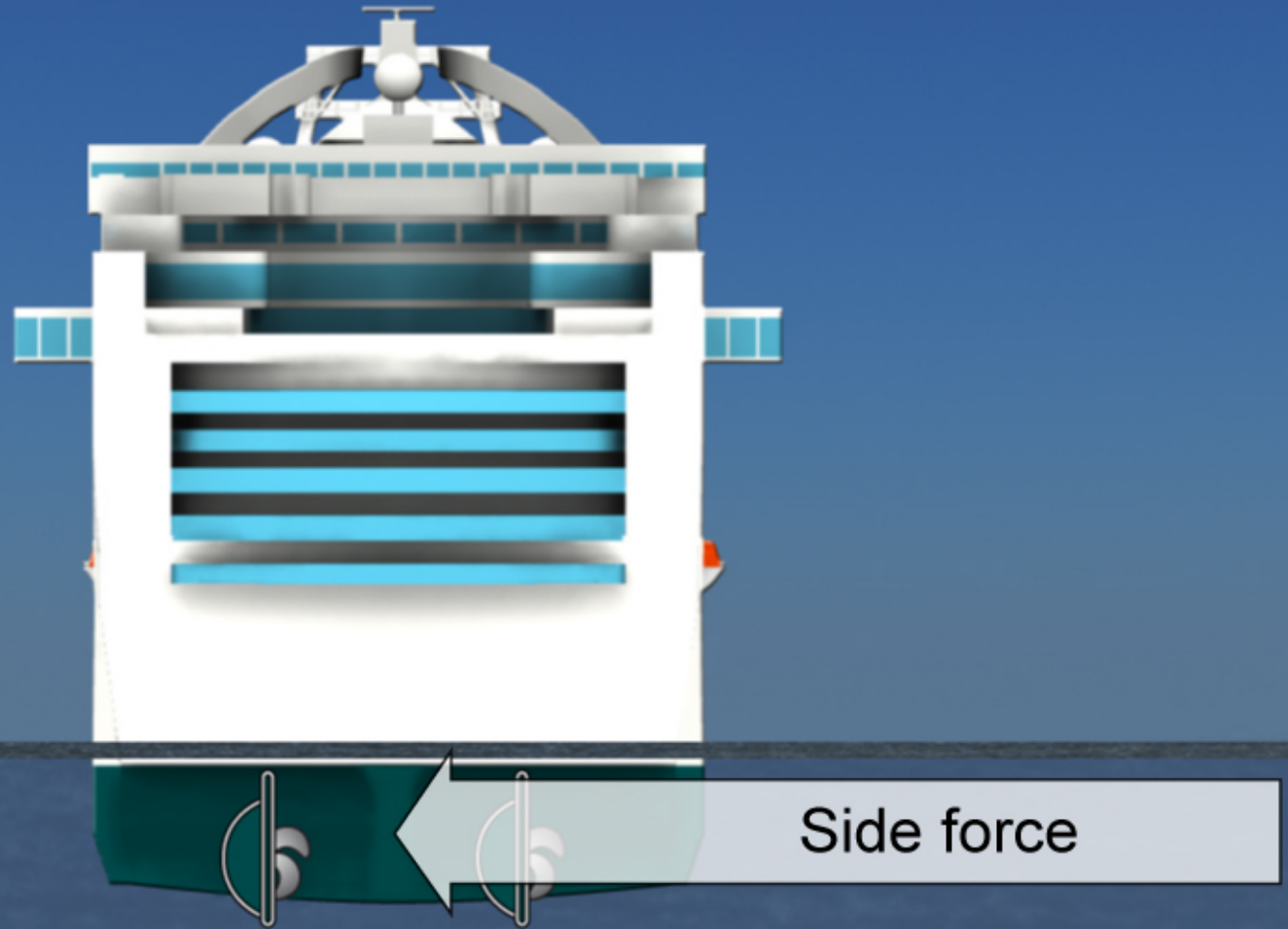
Velocity

Heading

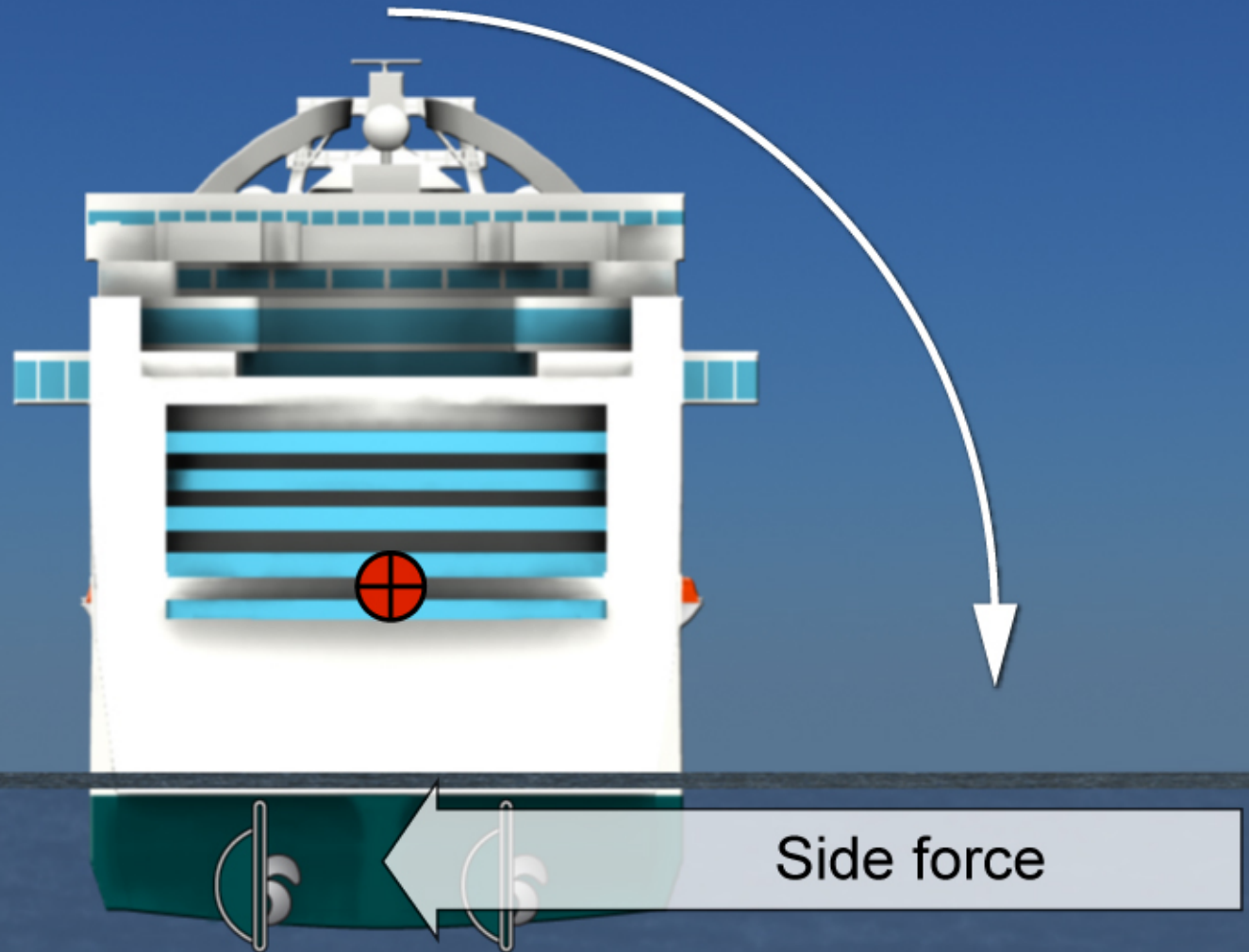
Side force



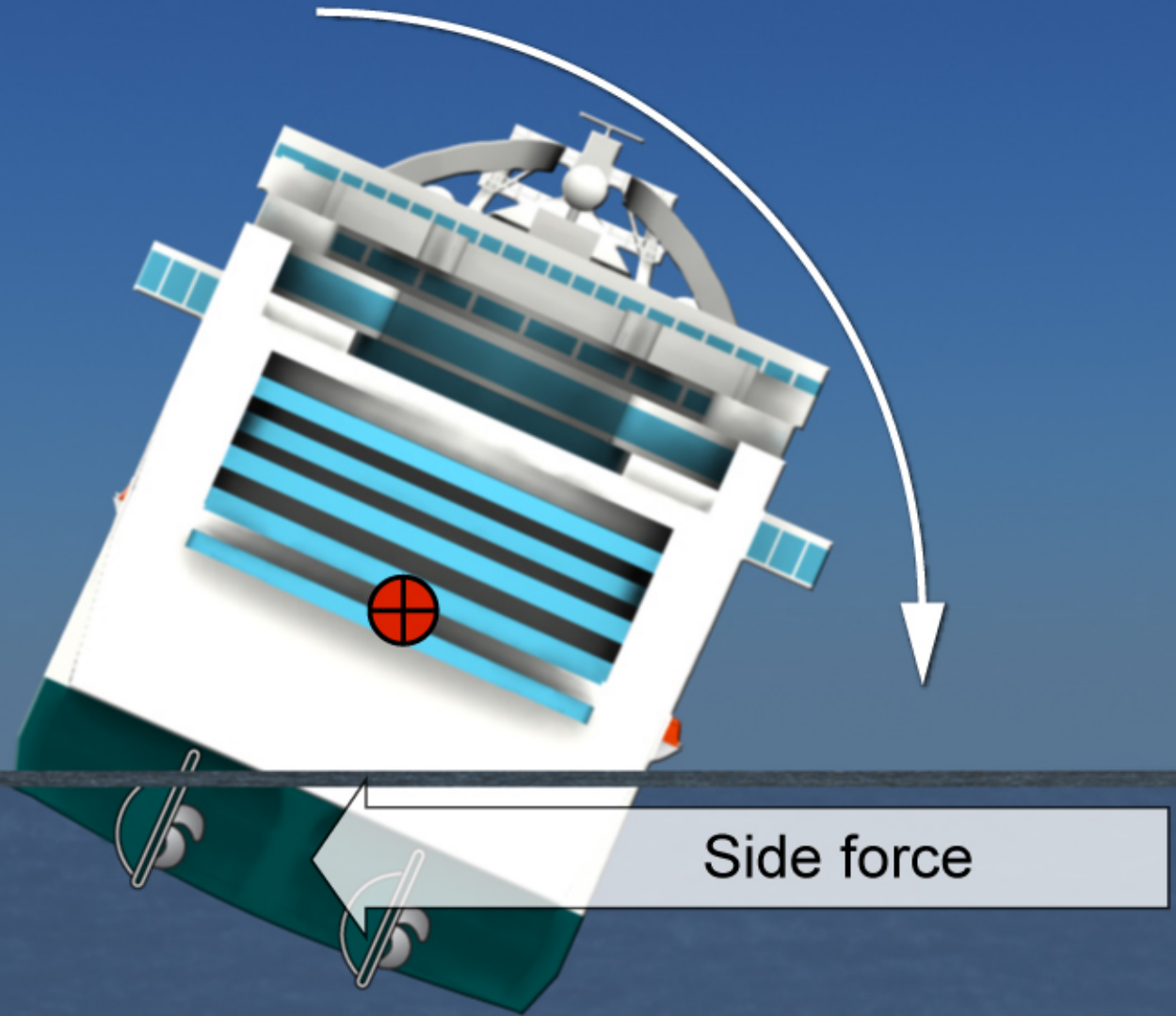
Heeling due to Sideslip



Heeling due to Sideslip



Heeling due to Sideslip



Ship's Response to Rudder

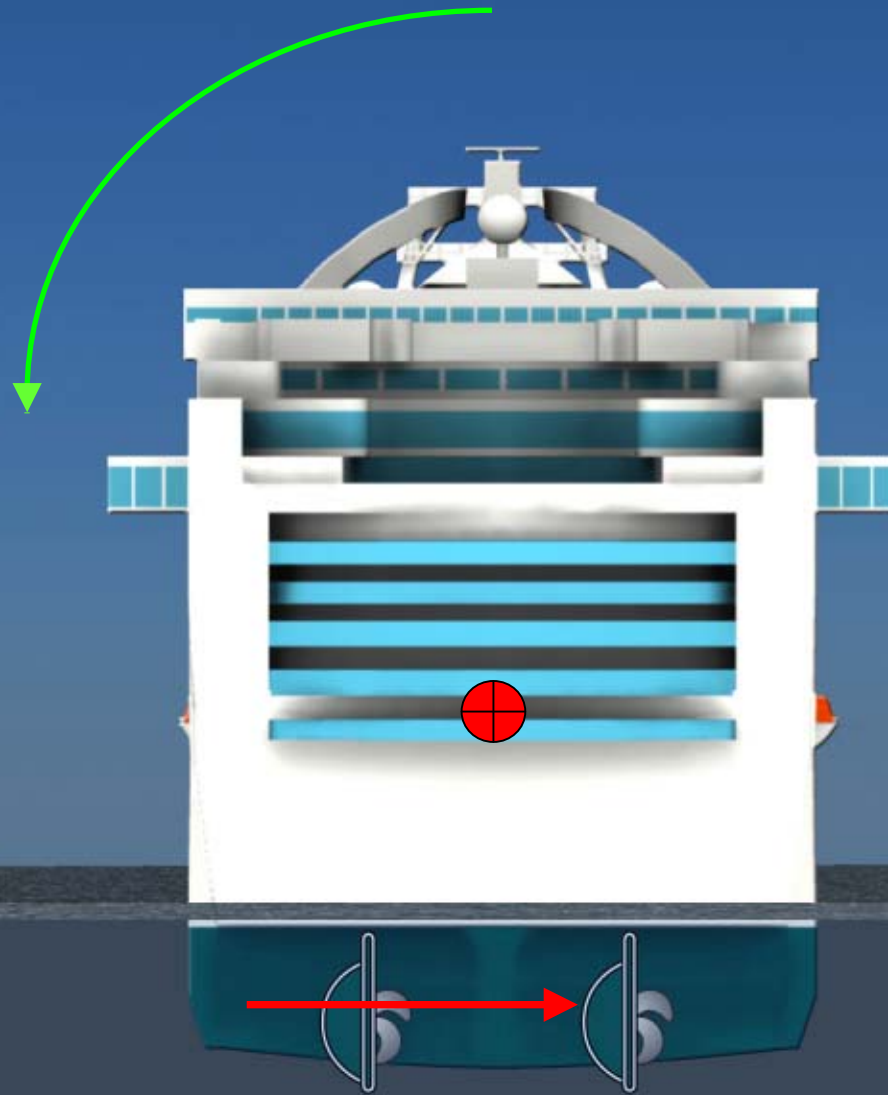
NTSB



Direct Rudder Heeling Moment



Direct Rudder Heeling Moment



Response Lag

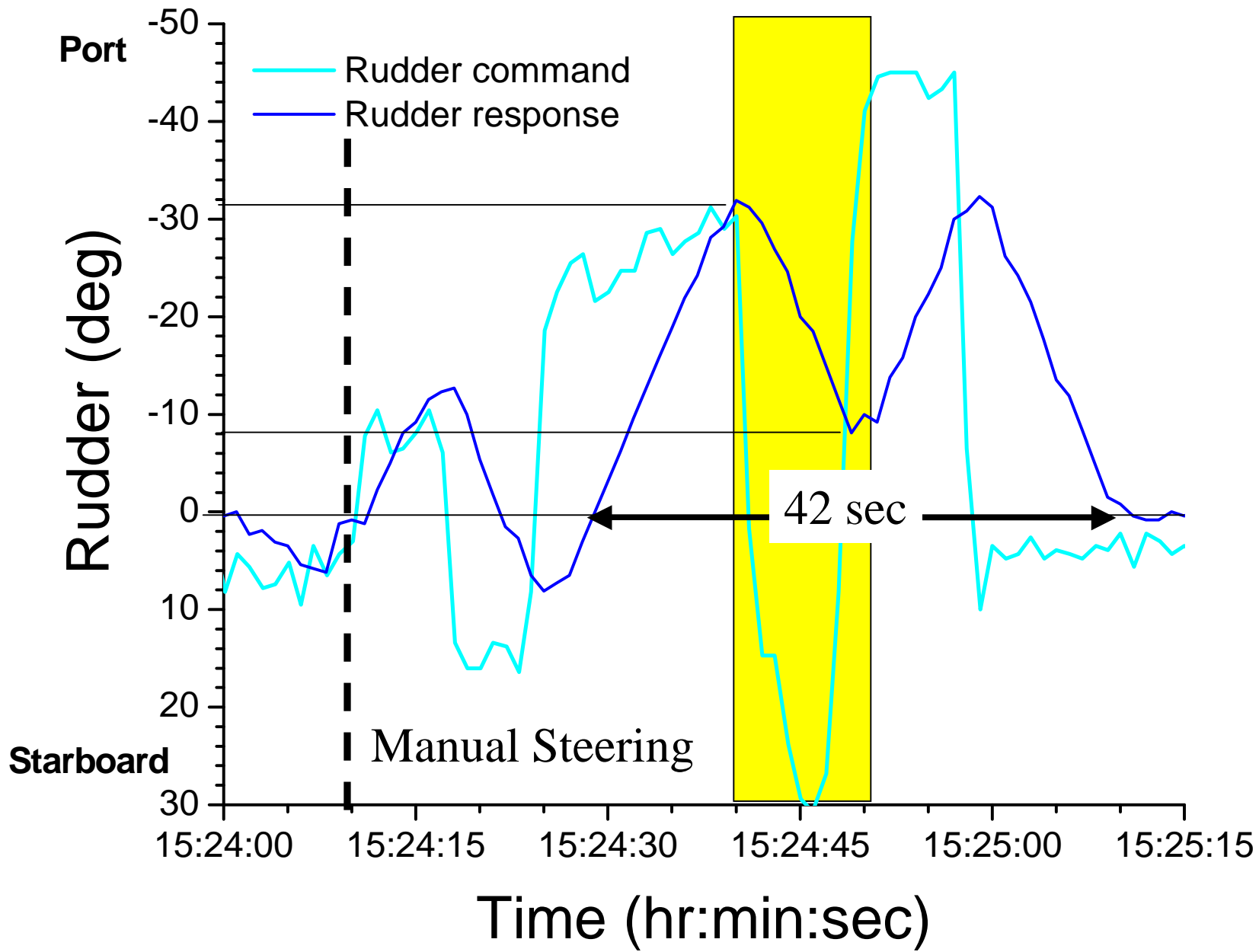
- Direct rudder effect
 - Immediate heel response to rudder
- Sideslip effect
 - Ship must first yaw in response to rudder
 - Takes longer
 - Much stronger



Saturated Rudder

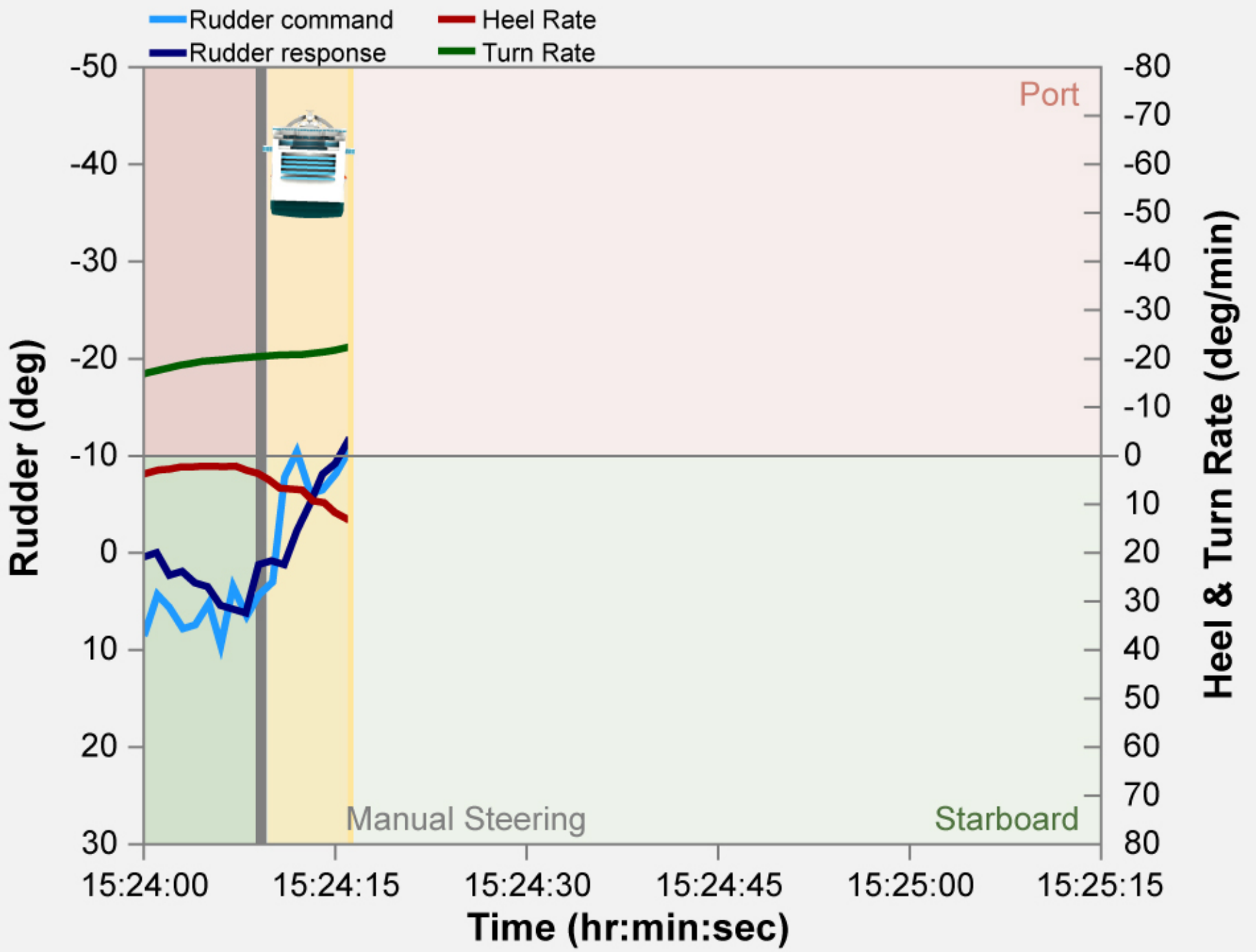
NTSB

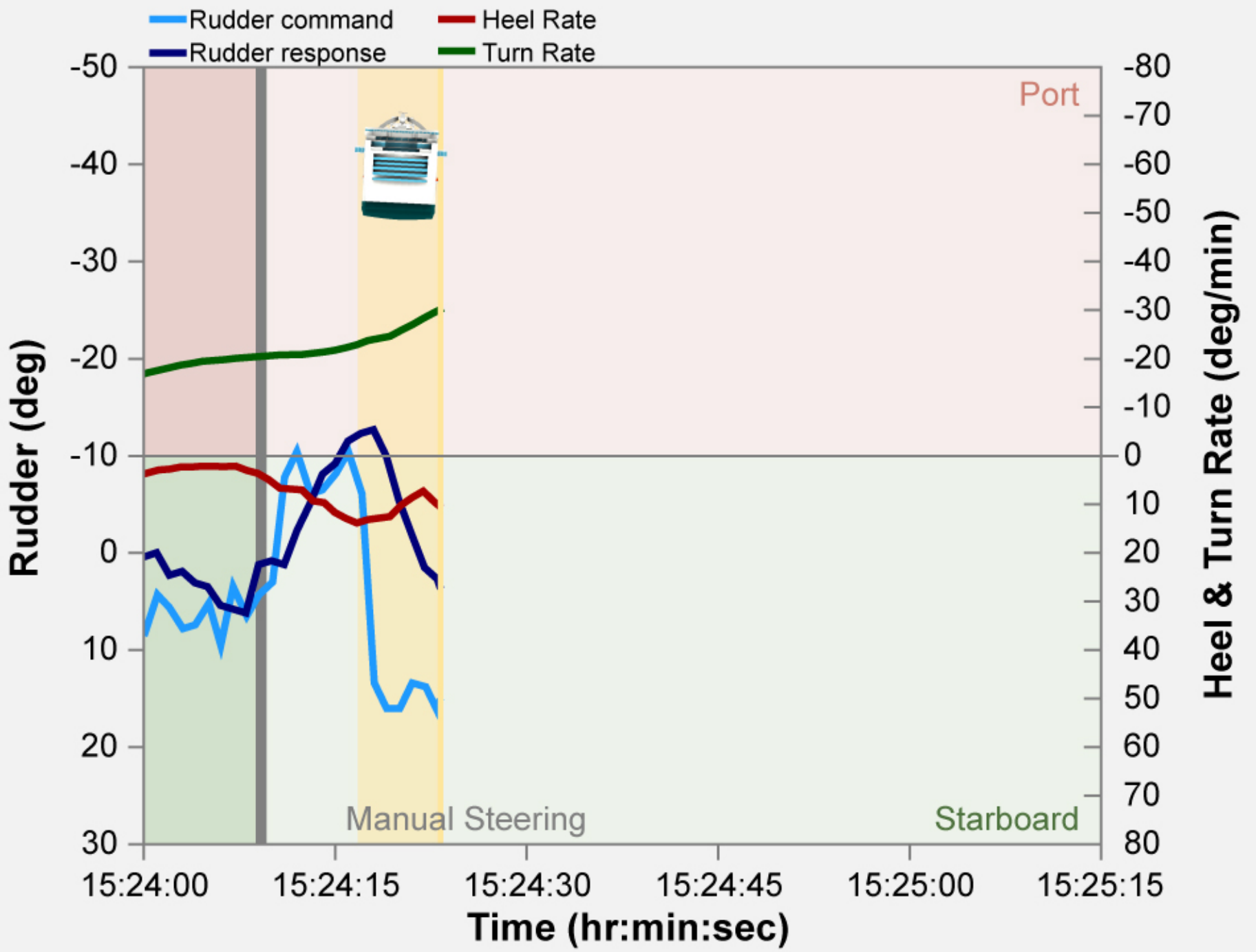


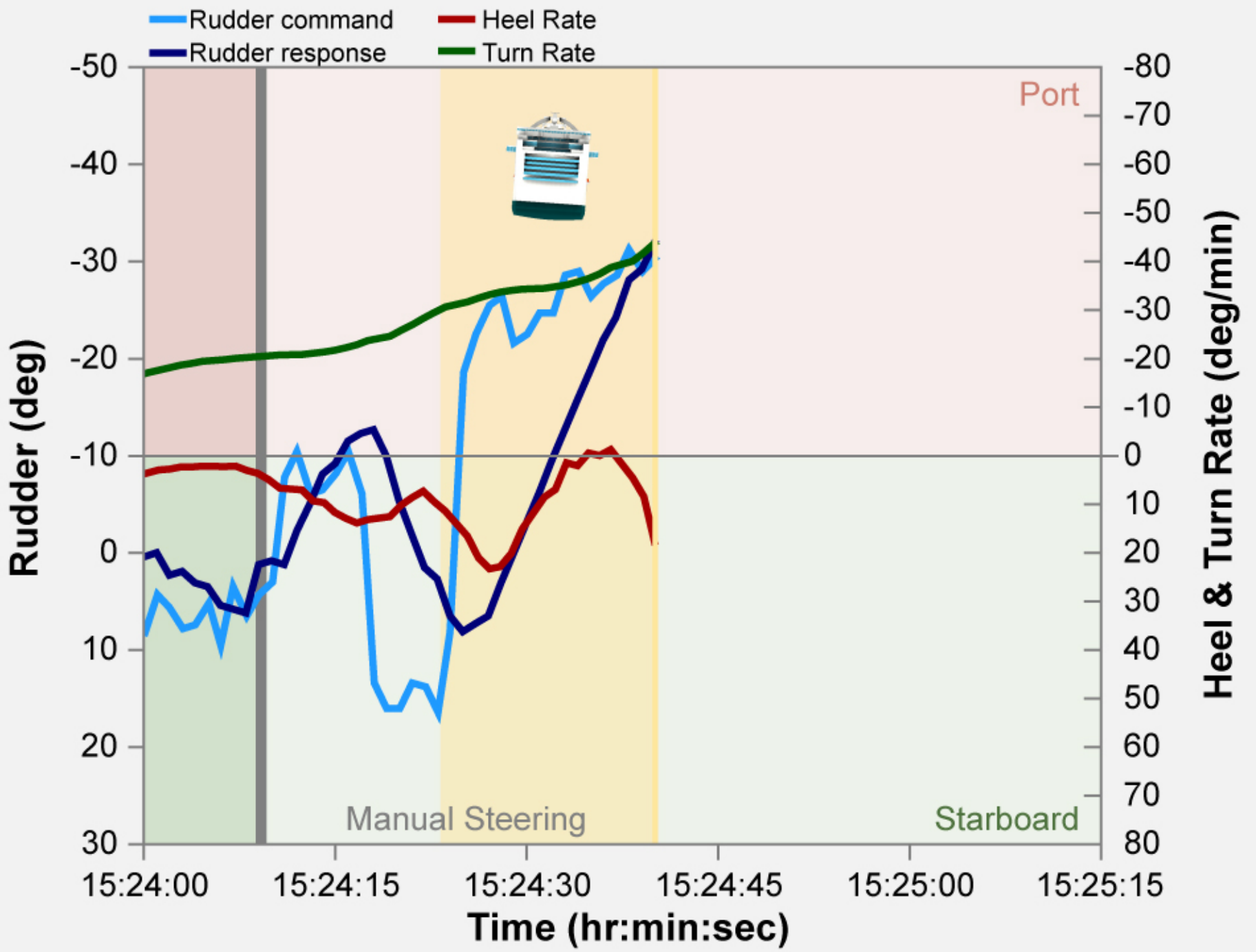


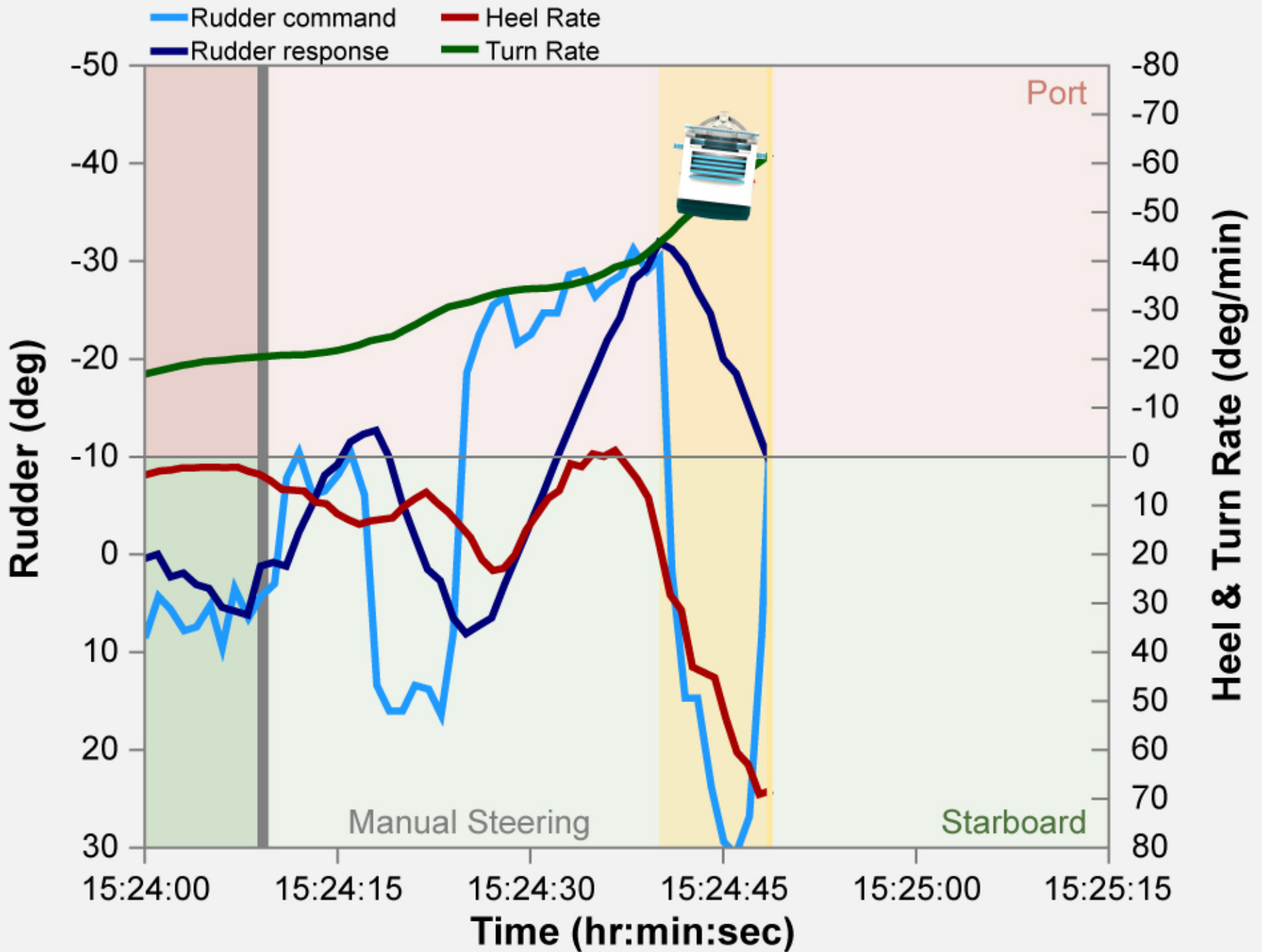
Motion Cues

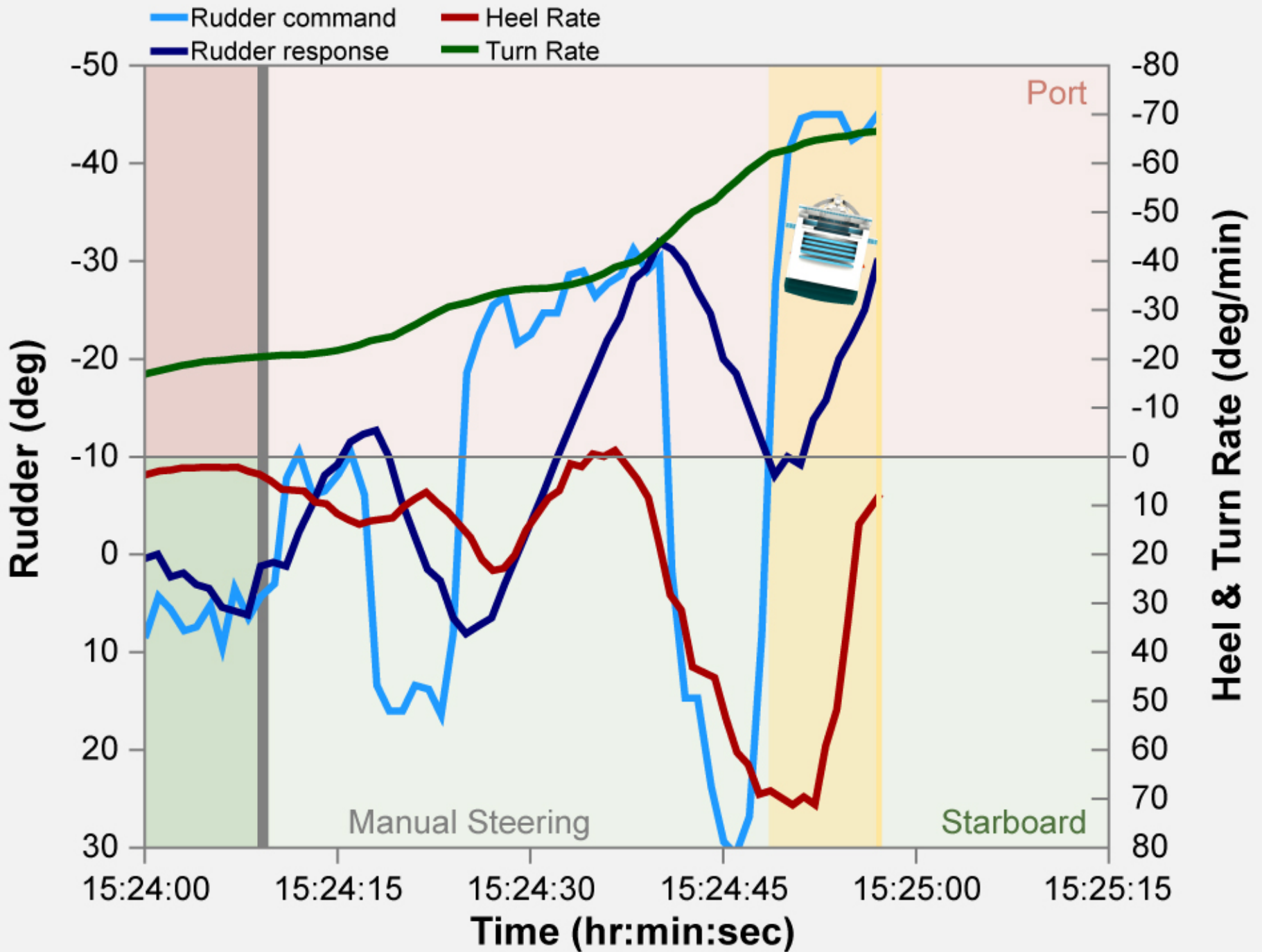
- Positive correlation with:
 - Heel angular acceleration
 - Heel rate

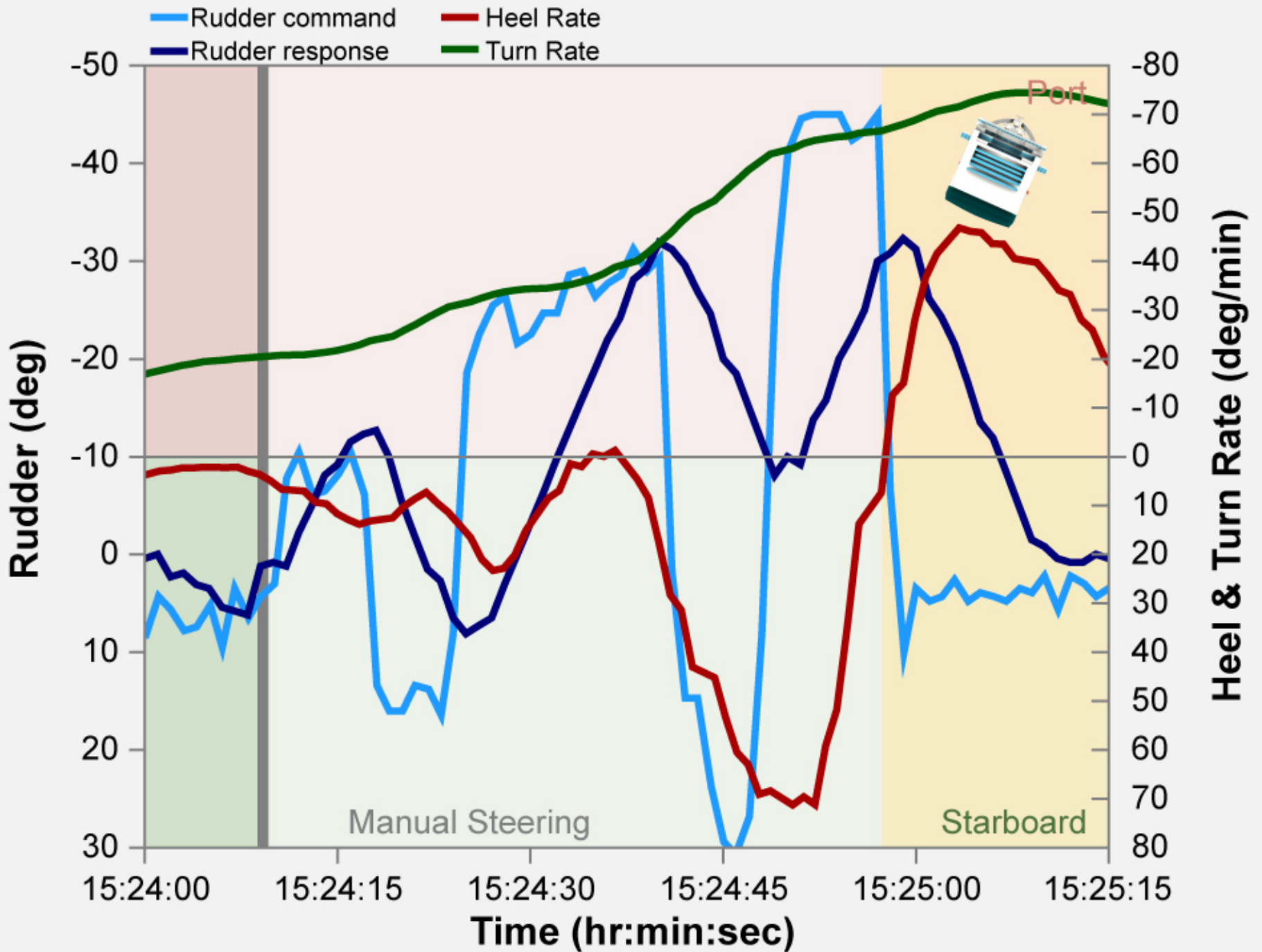












Summary

- The 2nd officer's commanded rudder changes faster than the rudder could respond
 - During a 30 deg starboard rudder command the rudder actually port

Summary (cont.)

- Two effects of rudder on heel
 - Short term direct response in direction of rudder input
 - Longer term more powerful sideslip effect in opposite direction

Summary (cont.)

- Rudder commands modulated heel rate (while turn rate continued to increase)
 - Port rudder initially slowed starboard heel rate
 - But at longer term expense of increased starboard sideslip
- Starboard sideslip overwhelmed direct rudder effect producing starboard heel

Summary (cont.)

- Opposing long term and short term effects complicate the 2nd officer's efforts to control the heel



NTSB