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CANDELA P·12


ZERO
100% Electric
Hydrofoiling Passenger Vessel
Research & Development
CANDELA P-12

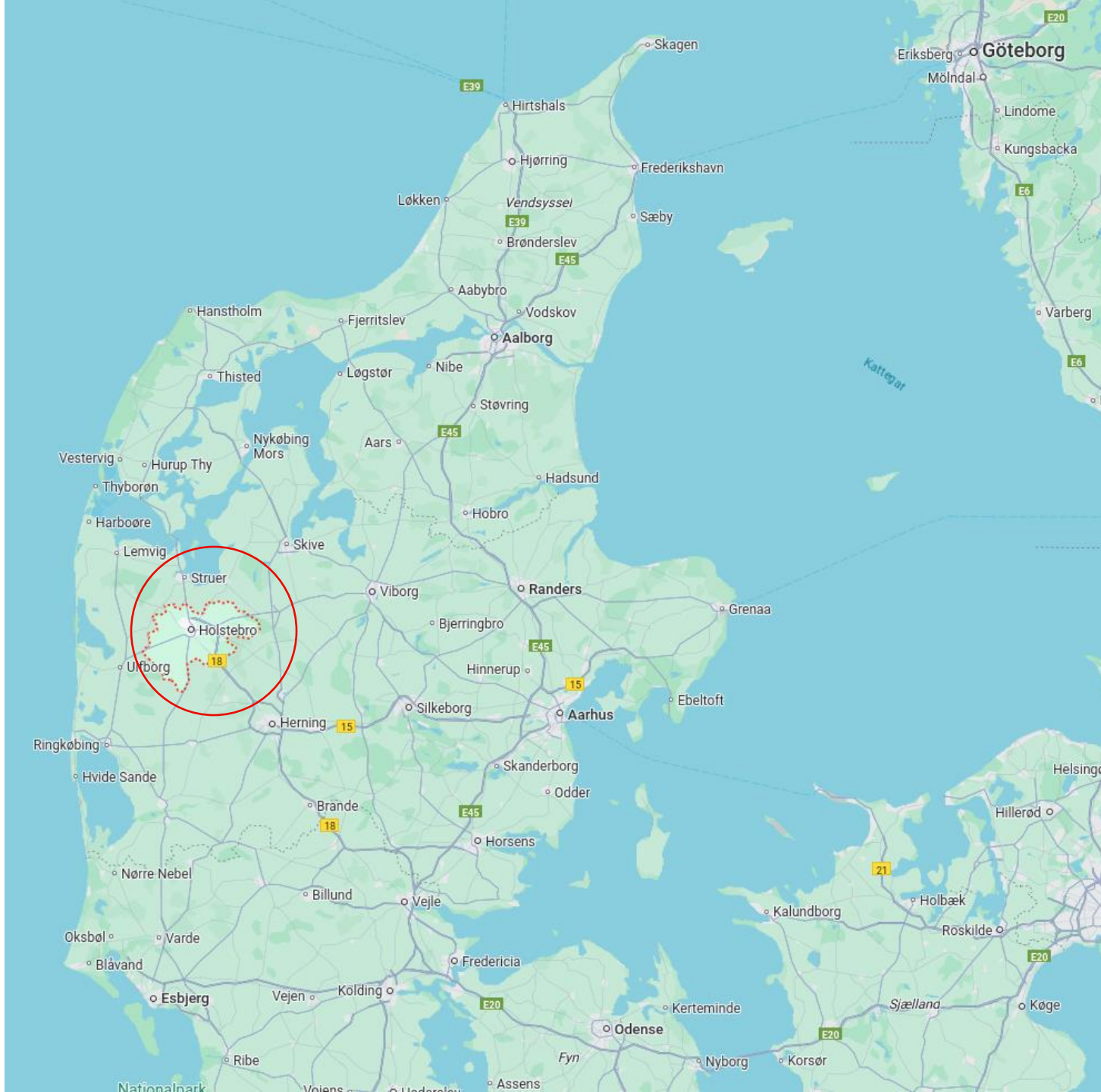
Agenda

- Personal background
- Candela history
- Boat models
- Details



Background

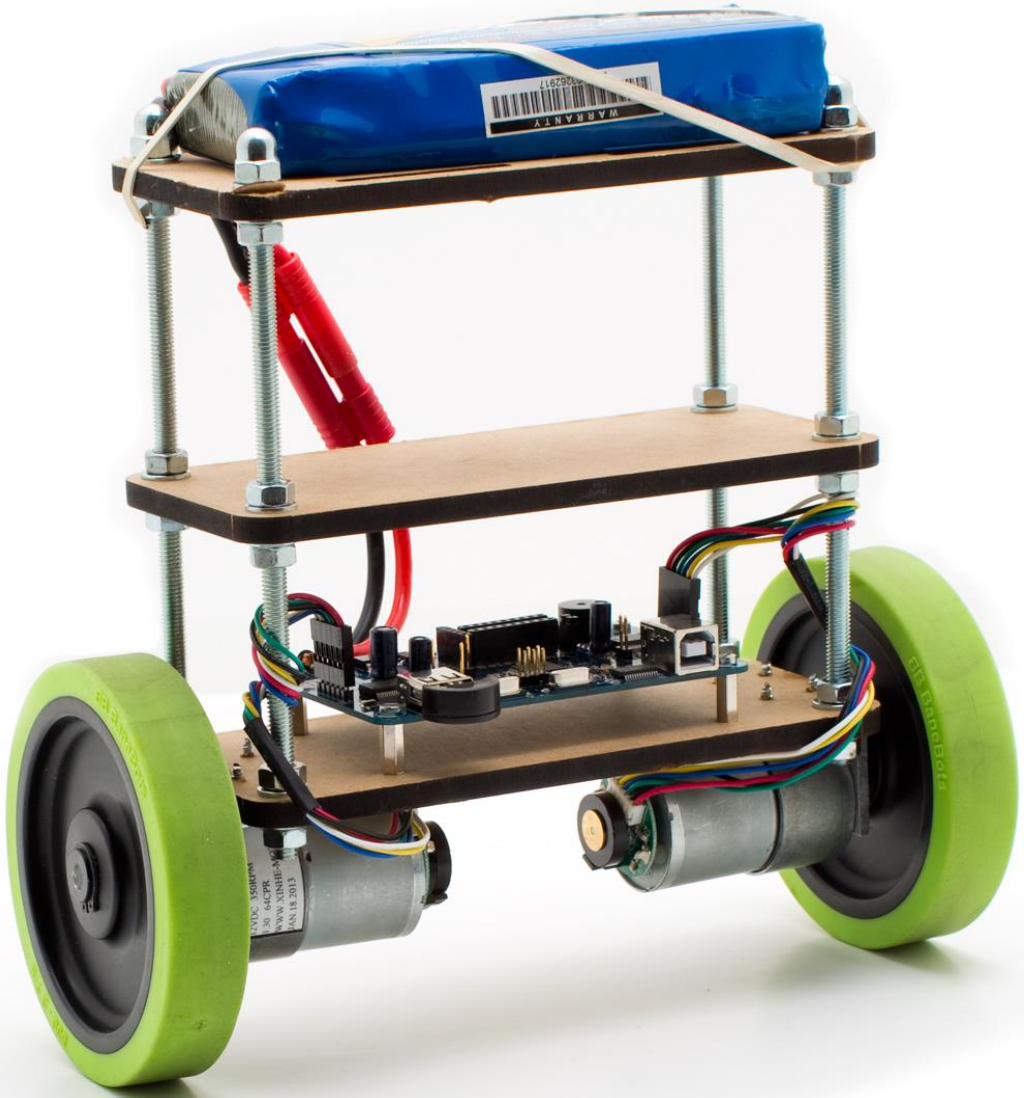
- Kristian Sloth Lauszus
  - 32 years old
- Holstebro, Denmark
- Wanted to be an EE since childhood
  - Science, LEGO Mindstorms



Gymnasium

- Started for real in HS/Gymnasium
  - Learned electronics + SW
- Goal to control segway with PS3 controller
  - USB host
  - Bluetooth
  - Embedded
  - Sensor fusion





University

- Electrical Engineering
  - Control system
- Technical University of Denmark (DTU)
  - 2012-2027
- San Francisco State University
  - Fall, 2014
- University of Illinois Urbana-Champaign (UIUC)
  - Fall, 2016



University

- Consultant
- EE, SW
  - USB host
  - Observers
  - Controllers
  - GitHub
- Projects
  - Segway
  - Flight controller





Candela's history

- Stockholm late 2014
- Joined May 2015
- First 2 years as a consultant
- Flying first time Spring 2017



Timeline

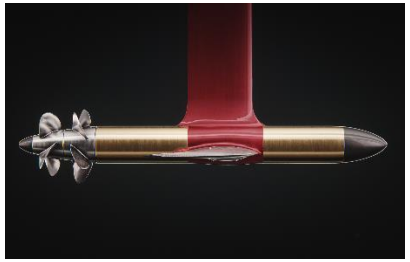


C-7 – Serial production
32 made and sold to 10 countries

2014 – 2019

Candela was founded with the mission to:

"Speed up the transition to fossil fuel-free lakes and oceans"



Advanced R&D and production
Launch of the C-8
Series B round

2021



C-8 hit the water, 100+ boats sold
5 x increase of production facilities

2022

Pro-Series launched





Production and commissioning of Candela P-12 Shuttle

2023 – 2024

Ferries in commercial traffic



C-7

- First serial production
- Hand built in Gåshaga
- Very efficient
  - Light
  - Drive train
  - Foil
- Hydraulics
- Battery, inverter & motor outsources
- UI powered by CM3
  - Connectivity

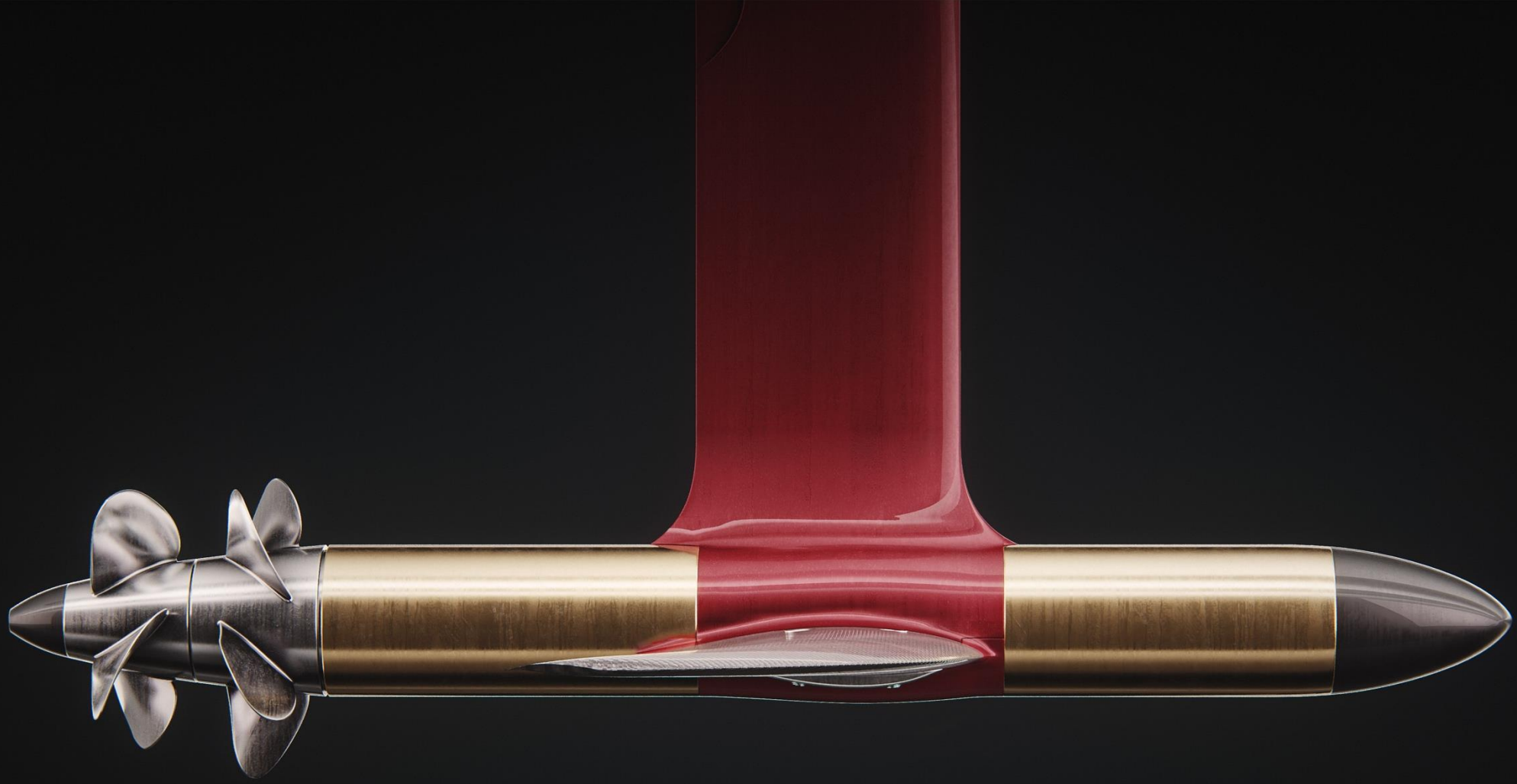




C-8

- Better height sensors
- Faster actuators
- C-POD
  - Less noisy
  - Efficient
- Control of all HW
- Fast UI





C-POD

P-12

- Commercial
- 25-30 people
- Catamaran
- Redundant steering & propulsion



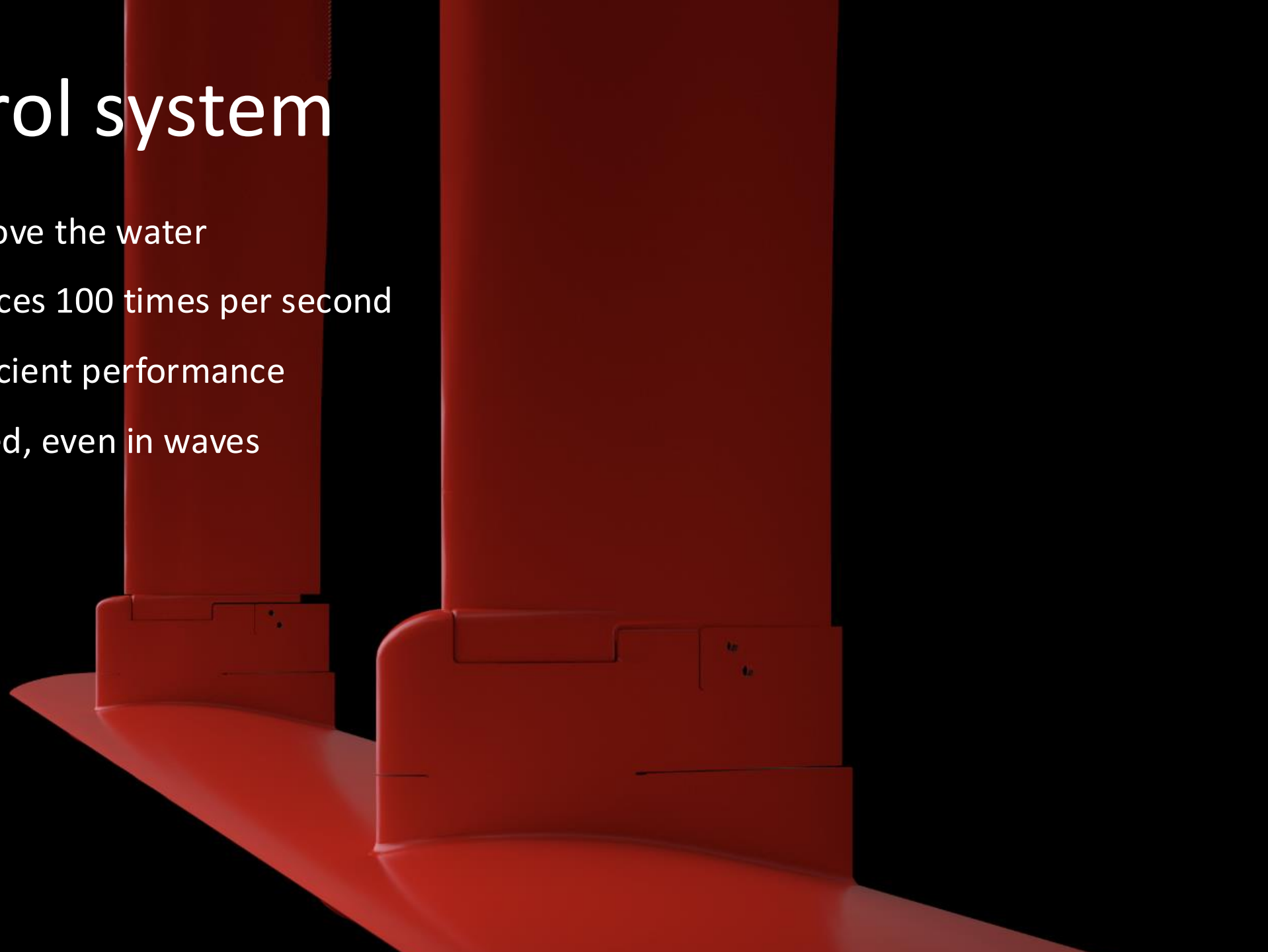
Subsystems

- Retraction
  - AFS & FFS
- Foil system
  - Rake & pushrods
- Propulsion
  - Inverters & motors
- Steering
  - Joystick, throttle, rudder, boarding
- Batteries & DC/DCs
  - BMS, HV DC/DCs, LV DC/DCs
- Thermal system
  - Cooling & heating
- UI
  - Driver's insight into the system
- Computers
  - UI, logger, camera
- Cloud
  - Logged data, VPN



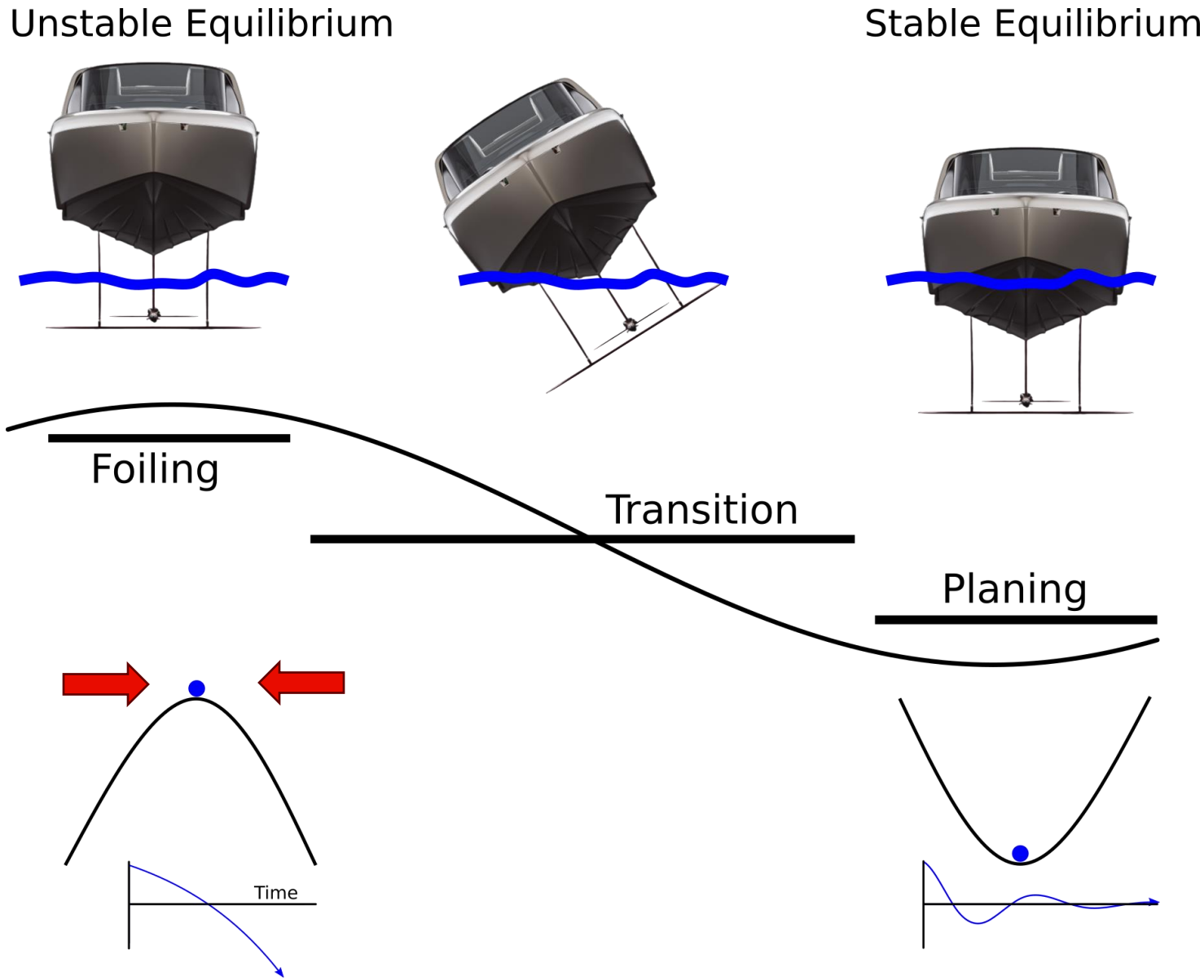
Flight control system

- Keeps boat flying above the water
- Adjusts control surfaces 100 times per second
- Ensures safe and efficient performance
- Comfort at high speed, even in waves



Foiling modes

- The boat has three main operating modes
  - Planing / Displacement
  - Transition
  - Foiling
- The **Flight Controller** keeps the boat in the naturally unstable foiling mode
- **Actuators** coordinate to maintain stability



Unstable states

- Height
  - Keep hull out of water to reduce drag
  - Damp out waves for smoother ride
- Pitch
  - Flat to reduce motion sickness
- Roll
  - Flat when going straight
  - Banks into turns for comfort and agility



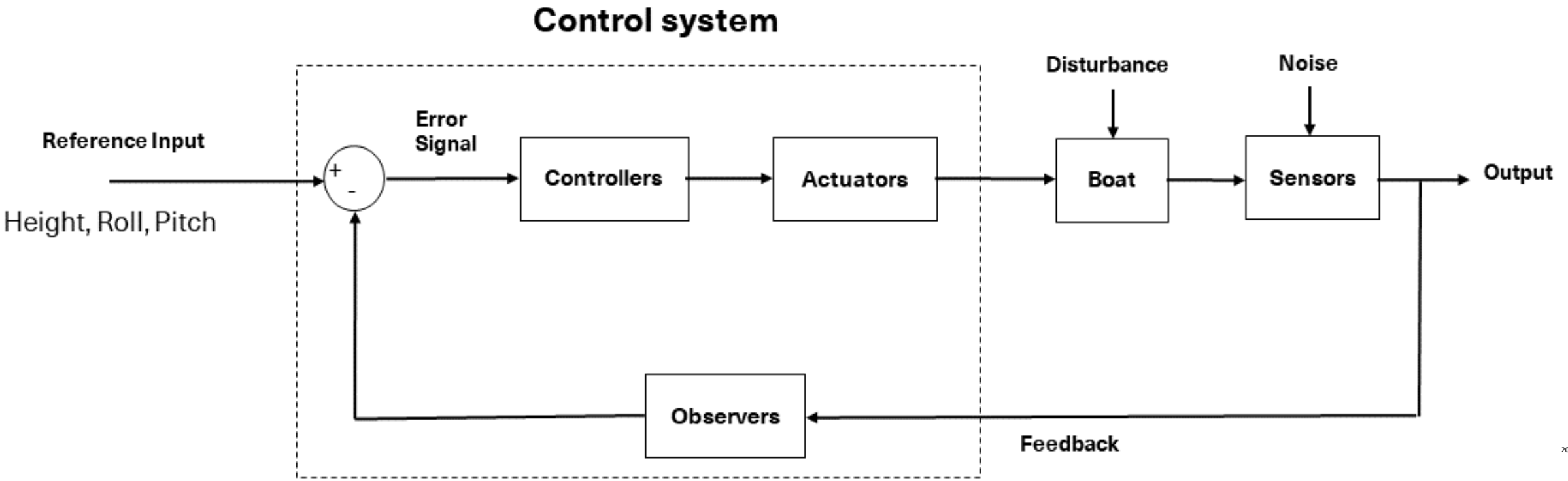
Closed loop

- Feedback loop to push system towards desired state
- Perform 100 actions every second to reject disturbance
- Monitoring and fault handling

Observers : Turn raw data into useful data

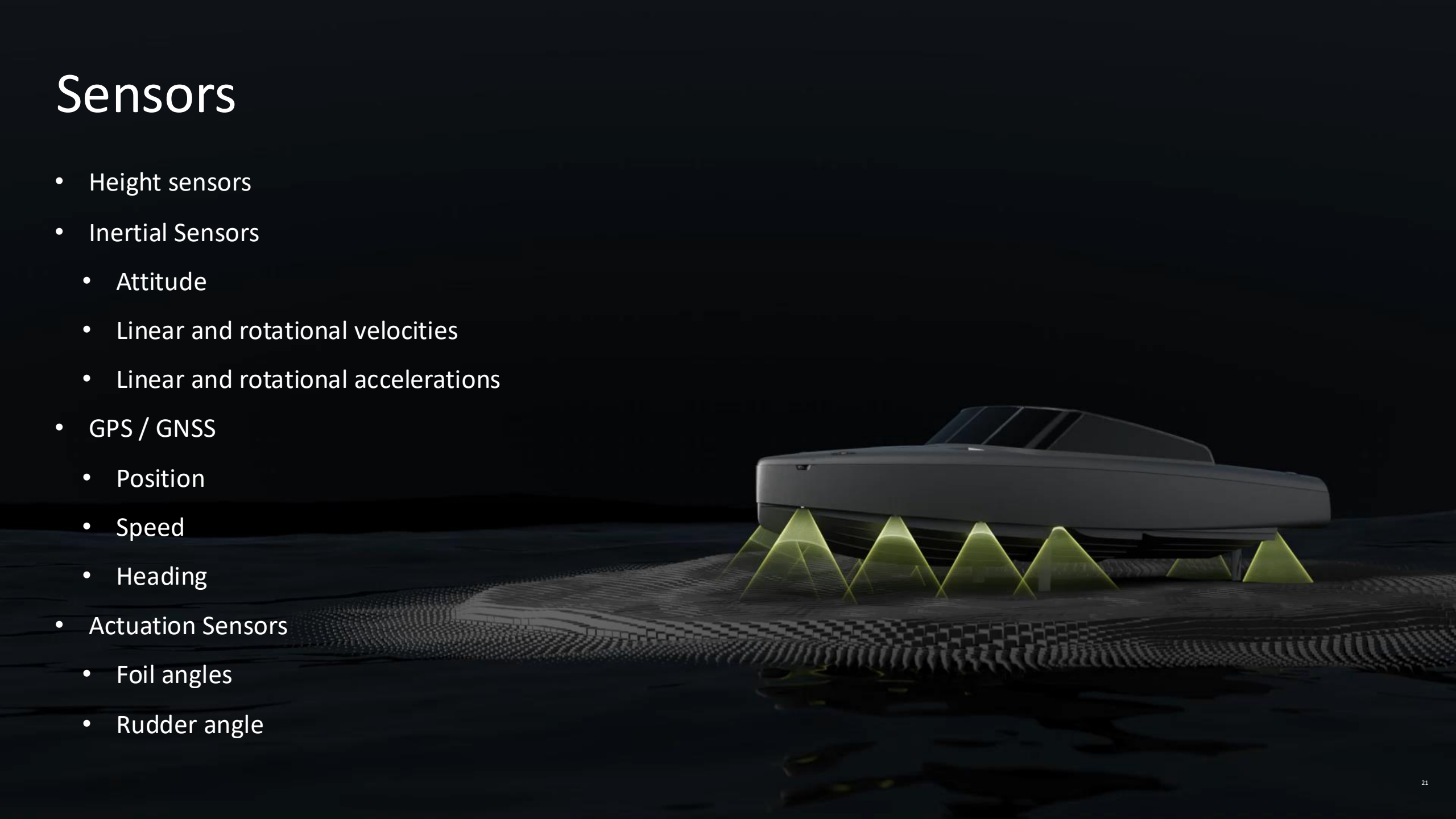
Controller : Decide on action to take

Actuators : Translate action to motor instructions

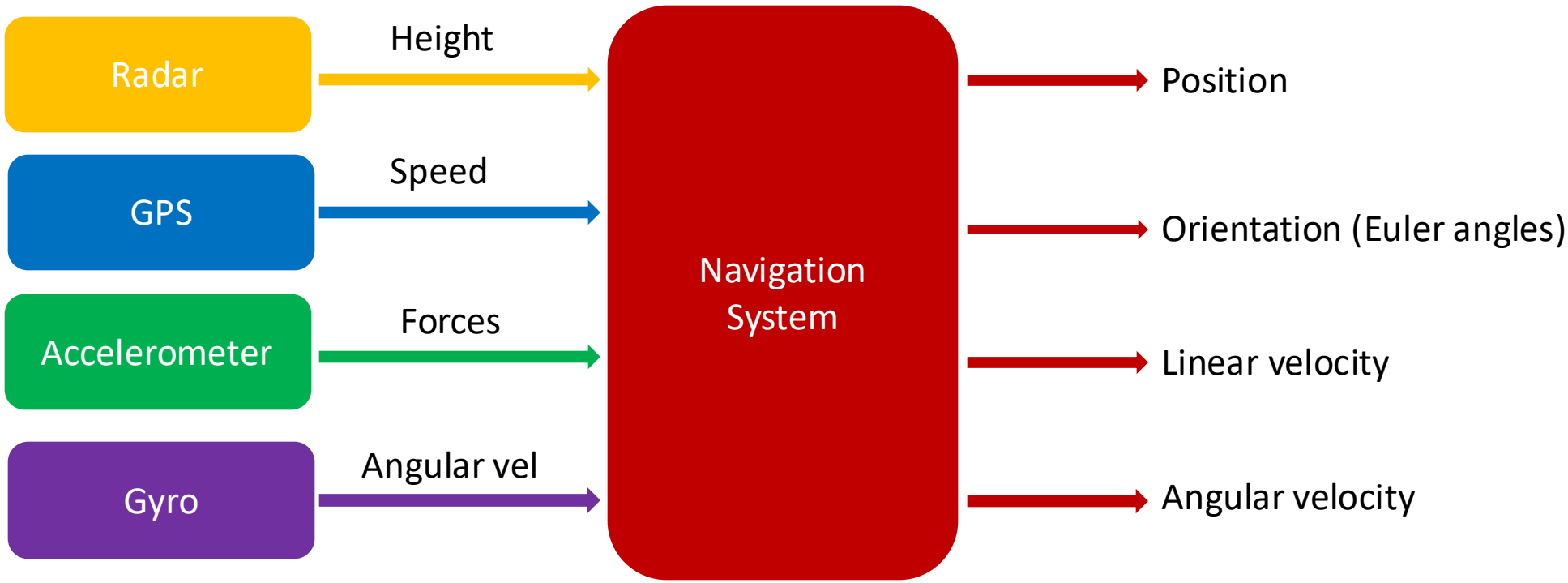


Sensors

- Height sensors
- Inertial Sensors
  - Attitude
  - Linear and rotational velocities
  - Linear and rotational accelerations
- GPS / GNSS
  - Position
  - Speed
  - Heading
- Actuation Sensors
  - Foil angles
  - Rudder angle



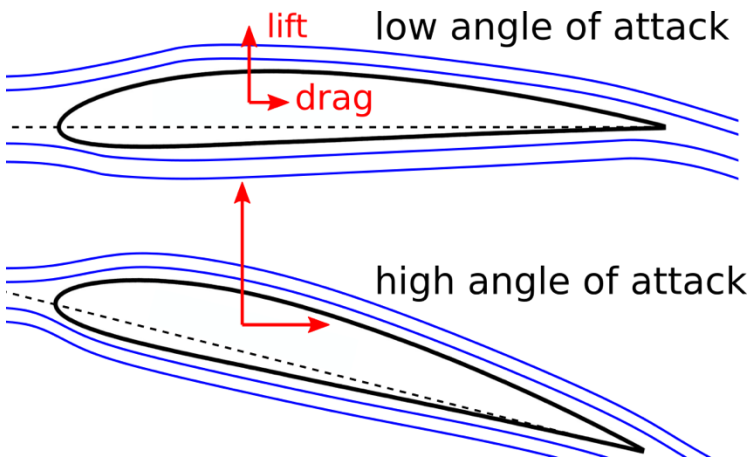
Observers


Radar
GPS
Accelerometer
Gyro
Height
Speed
Forces
Angular vel
Navigation System
Position
Orientation (Euler angles)
Linear velocity
Angular velocity

Actuation

- Front foil
  - Tilts up/down (height & pitch)
  - Difference in AoA (roll)
- Aft foil
  - Tilts up/down (height & pitch)
- Requires minimum speed to fly

$$L = \frac{1}{2} C_L(\alpha) \rho A v^2$$



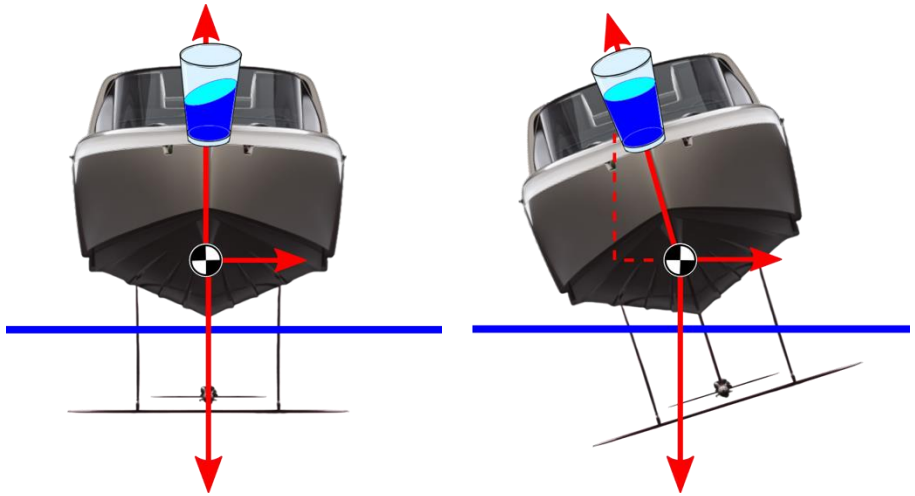




Coordinated turns

- Bank inwards when turning
- Compensate for centripetal force
- Comfort
  - Pushed down into the seat instead of sideways
- Efficiency
  - Less drag and lower forces



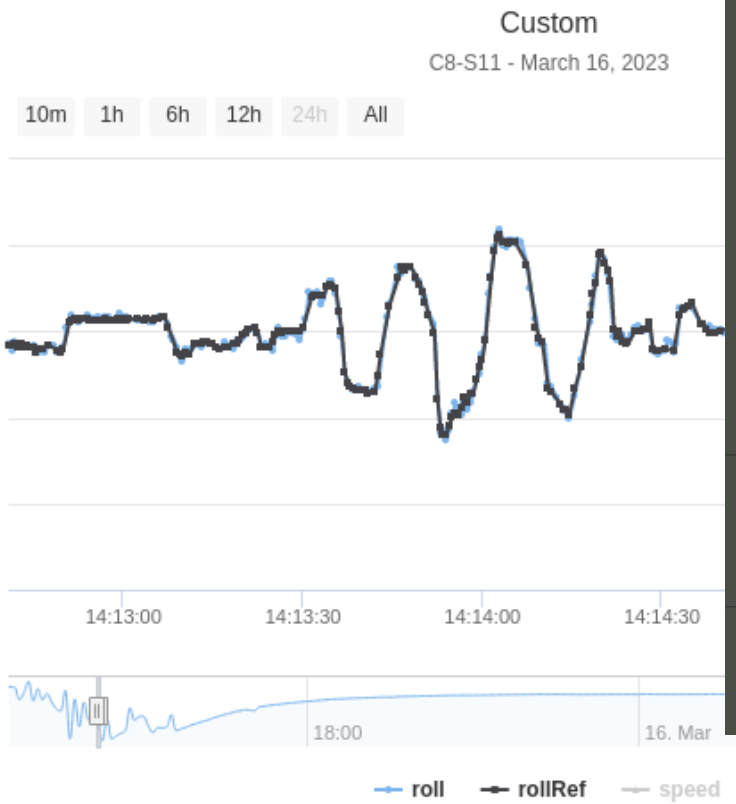


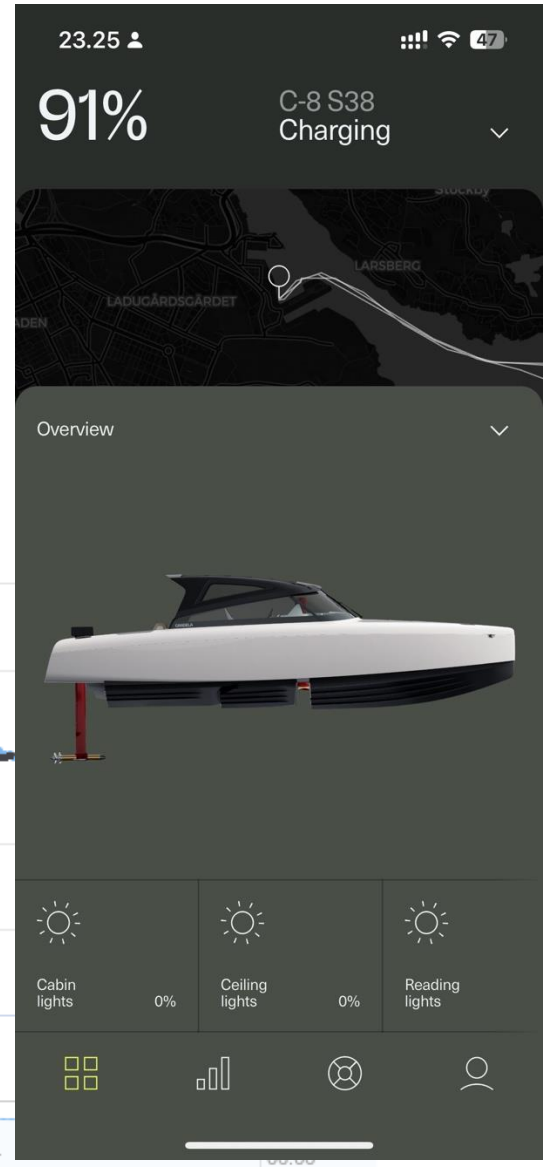
- Banking up to 13 degrees

$$\theta = \tan^{-1}\frac{v\omega}{g}$$

Logging

- Every boat is cloud connected
- For development and diagnostics
- Realtime telemetry





C-8 UI & logger

- Custom navigation system
- Simplicity
- User experience
  - Fully integrated with the boat e.g. retraction
- Modern multi-touch screen
- Custom hardware with built-in connectivity
  - Mobile app
- OTA update and assistance

