Center for Ocean Engineering
Naval Construction & Engineering Program
Department of Mechanical Engineering

Design and assessment of Wavecutter, a high speed hybrid hydrofoil/ SWATH crew boat

Prepared by: LTJG Vasileios Georgiadis, HN

Advisor: Dr. Stefano Brizzolara

Supervisor: Prof. Chrys Chryssostomidis

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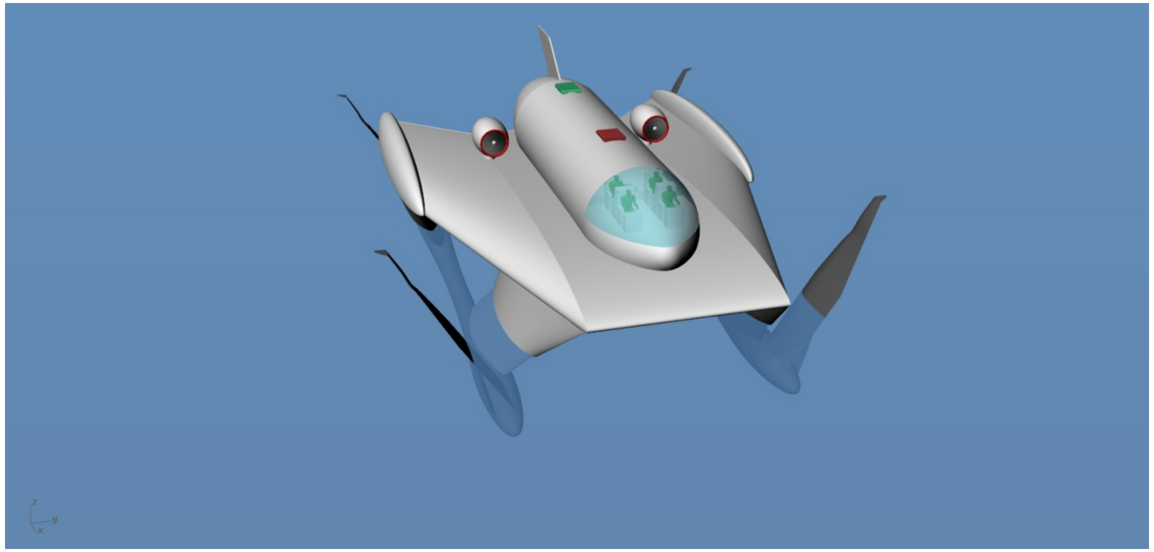
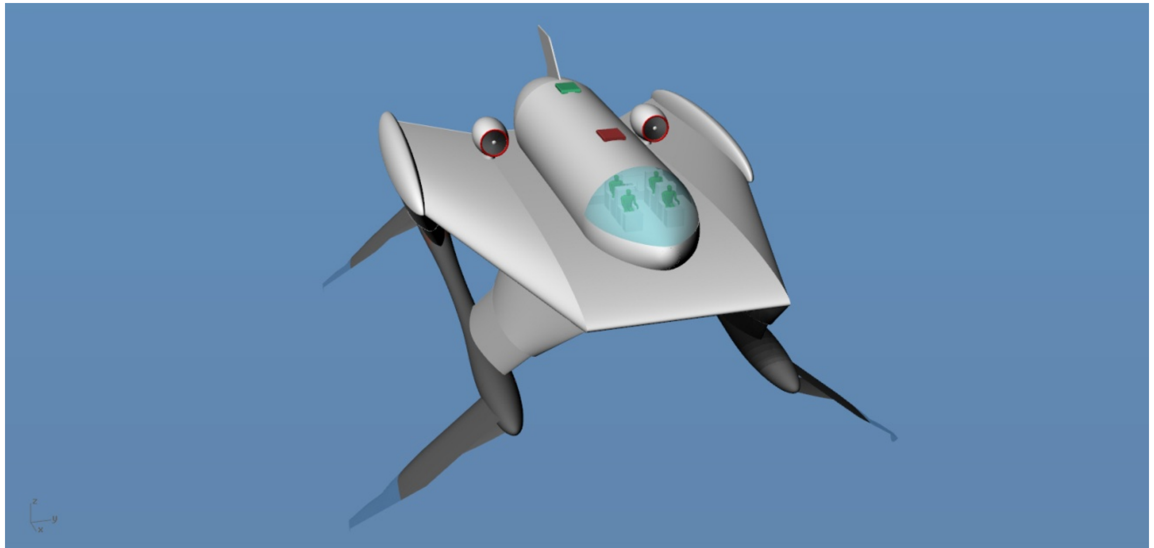
Displacement mode: 0-18 knots



Foil borne mode: 18-85 knots



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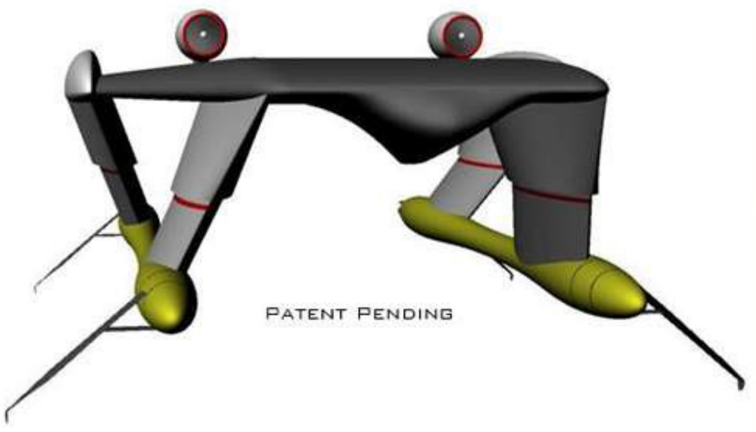
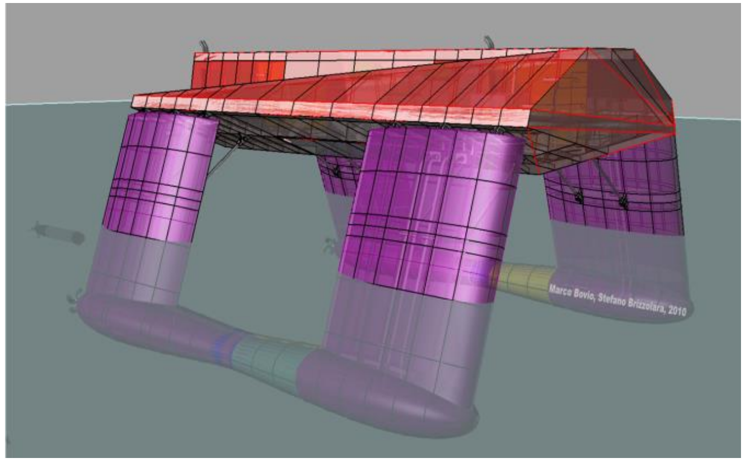
MIT i-Ship lab research on hybrid SWATH vessels

SWATH/hydrofoil design



SWATH/catamaran design



- Family of hybrid SWATH ASVs
- SWATH/hydrofoil design for rapid reaction and intervention missions
  - Maximum speed 120 knots
  - Length 20 m
  - Payload 10 MT
- SWATH/catamaran design for AUV support and transportation
  - Maximum speed 12 knots
  - Length 6 m
  - Payload 200 kg

Mission requirements

Gulf of Mexico map

- Intended function: rapid transportation of crew and cargo to and from offshore installations.
- Example: emergency offshore oil rig evacuation.
- Desired attributes:
  1. travel fast (~85 knots)
  2. endurance (400-600 NM)
  3. operational sea state (4)
  4. passenger payload (20-24)
  5. cargo payload (10-15 MT)
  6. crew (4-6)
- Endurance and sea state are based on Gulf of Mexico distances and sea statistics respectively

State of the art in fast crew transportation

Monohull example: Damen 1605

Length o.a. :	16.55 m
Speed max :	40 kts
Speed range :	25 - 40
Deck area :	14.4 m2
Hull Construction :	Aluminium
Industrial Personnel :	29

Hydrofoil example: Boeing 929-100

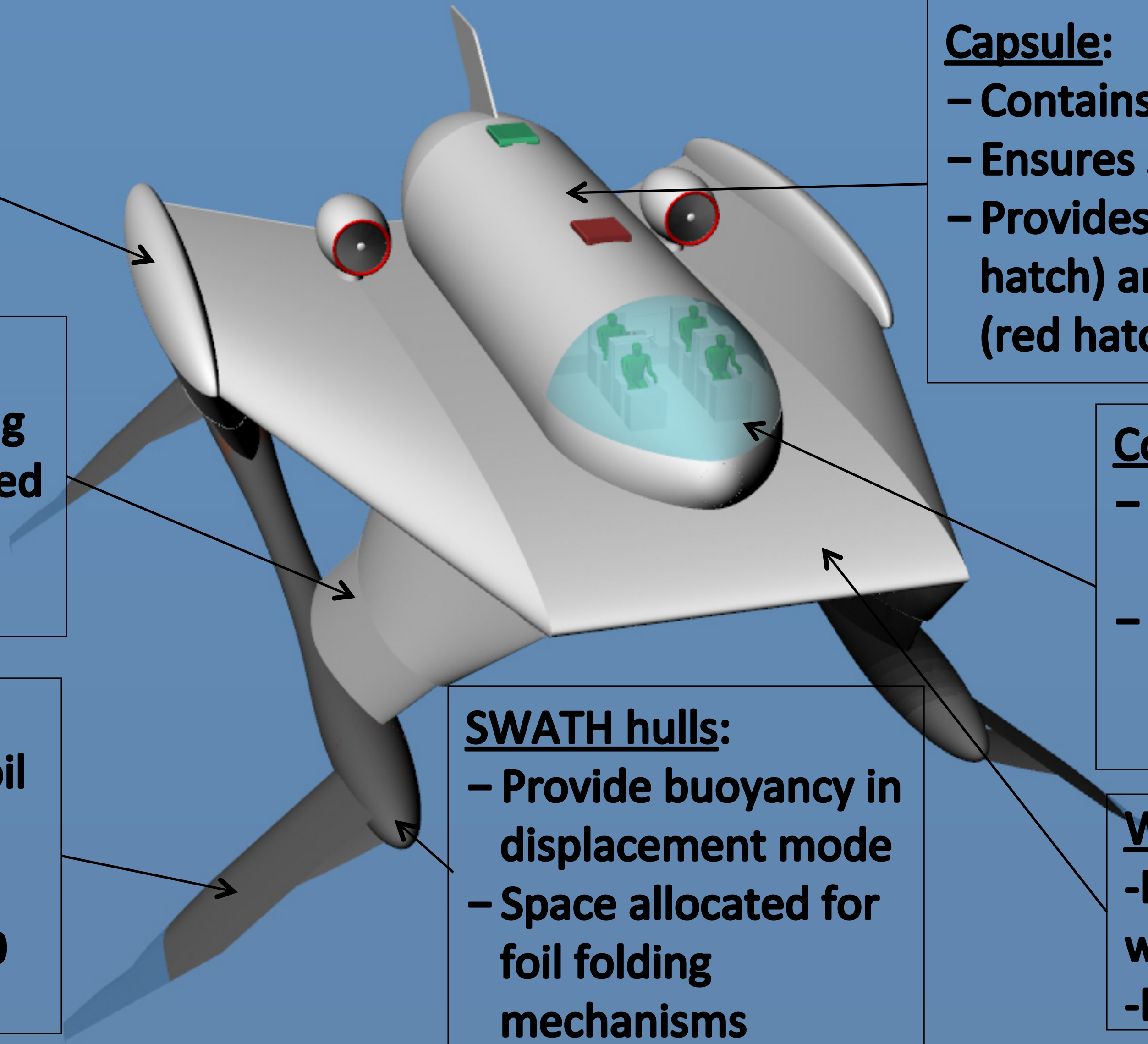
--Length/Width~27.4m/8.53m
--Maximum speed~45 knots
--Propulsion-engine~2 Rolls Royce Allison Model 501-KF Gas Turbine
~Propulsion-waterjet~2 Rockwell Powerjet 20 Propulsion Unit
--Gearbox~2 Rockwell Powerjet 20 Gearbox
--Pasengers~243

Vessel overview

Winglet:
- Eliminates tip vortices
- Increases efficiency

Struts:
- Connect SWATH hulls to wing
- Space inside them was utilized
- Lower struts contain ballast tanks for trim adjustment

Hydrofoils:
- Provide ~90% of the lift in foil borne mode
- Super-cavitating foils (cavitation begins above ~50 knots)



Capsule:
- Contains manned compartments
- Ensures structural integrity
- Provides normal access (green hatch) and emergency access (red hatch)

Control room:
- Design similar to an airplane's cockpit
- All control and monitoring of the vessel is performed here

SWATH hulls:
- Provide buoyancy in displacement mode
- Space allocated for foil folding mechanisms

Wing:

-Lifts 10% of the vessel's weight

-Exploits ground effect

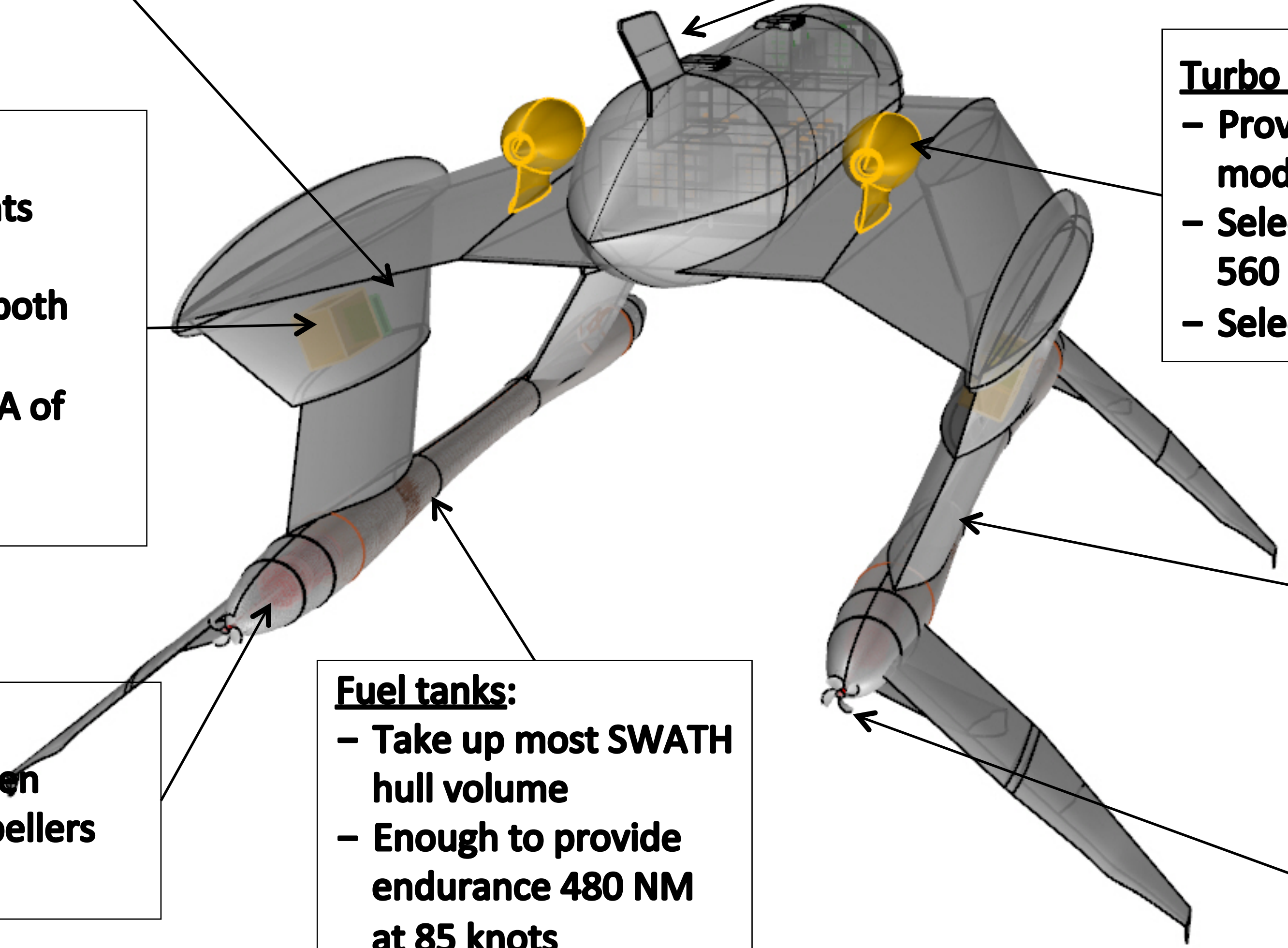
Propulsion system

Generators:
- Convert diesel's mechanical energy to electric

Rudder/stabilizer:
- Acts as rudder/stabilizers in foil borne mode, just like airplane designs

Diesel engines:
- Propulsion in displacements mode (0-18 knots)
- Provide electric power in both modes
- Selected engine type DQCA of Cummings (MTU)
- Selected rating 545 KW

Turbo fans:
- Provide thrust for vessel at foil borne mode (18-85 knots)
- Selected engine type Rolls Royce Trent 560
- Selected rating 267 KN



Ballast tanks:
- Space has been allocated in the lower struts for ballasts tanks
- Used for trim control

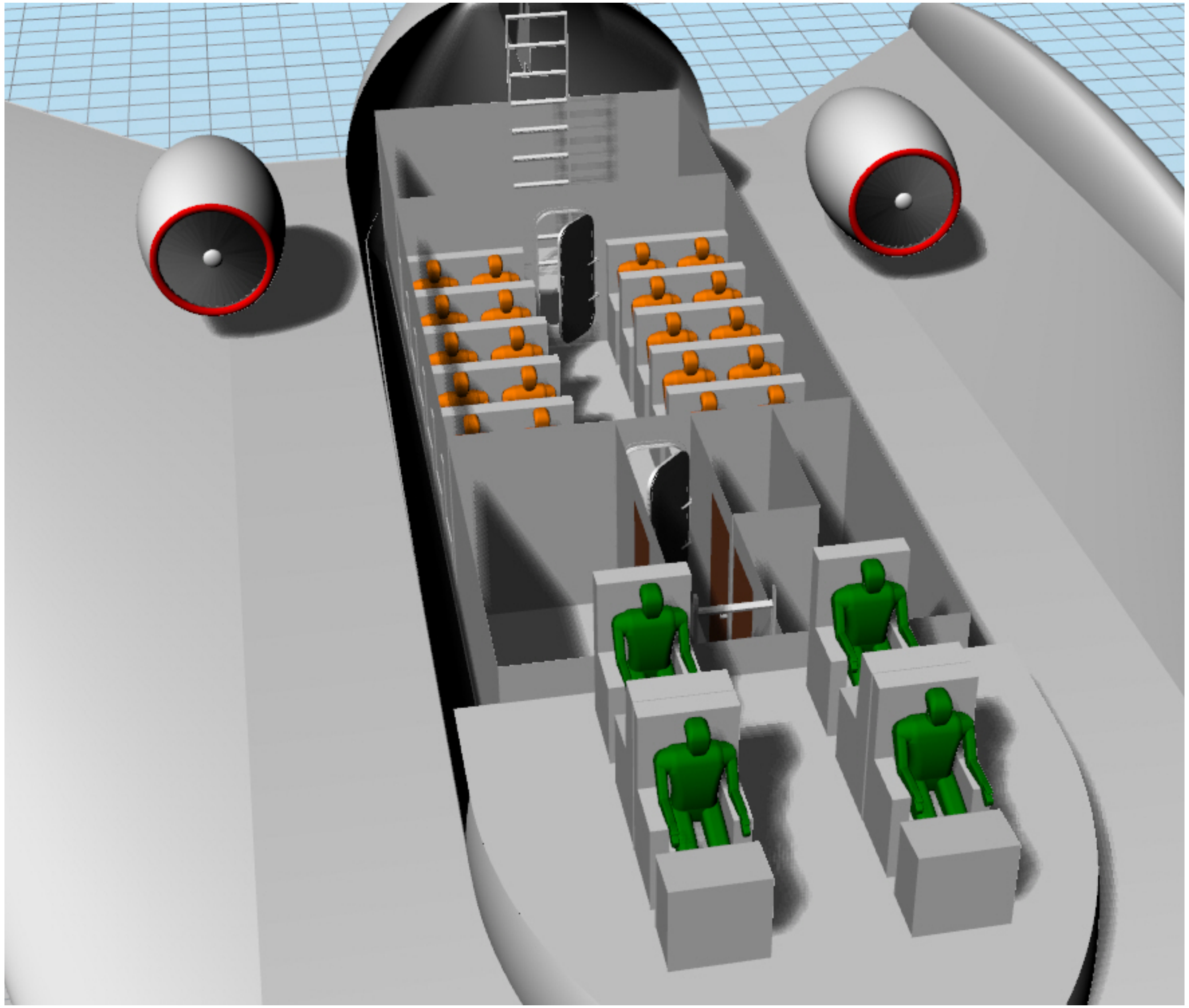
El. Motors:
- Variable frequency driven
- Transfer energy to propellers through shafts

Fuel tanks:
- Take up most SWATH hull volume
- Enough to provide endurance 480 NM at 85 knots

Fixed-pitch Propellers:
- Propel vessel in displacement mode

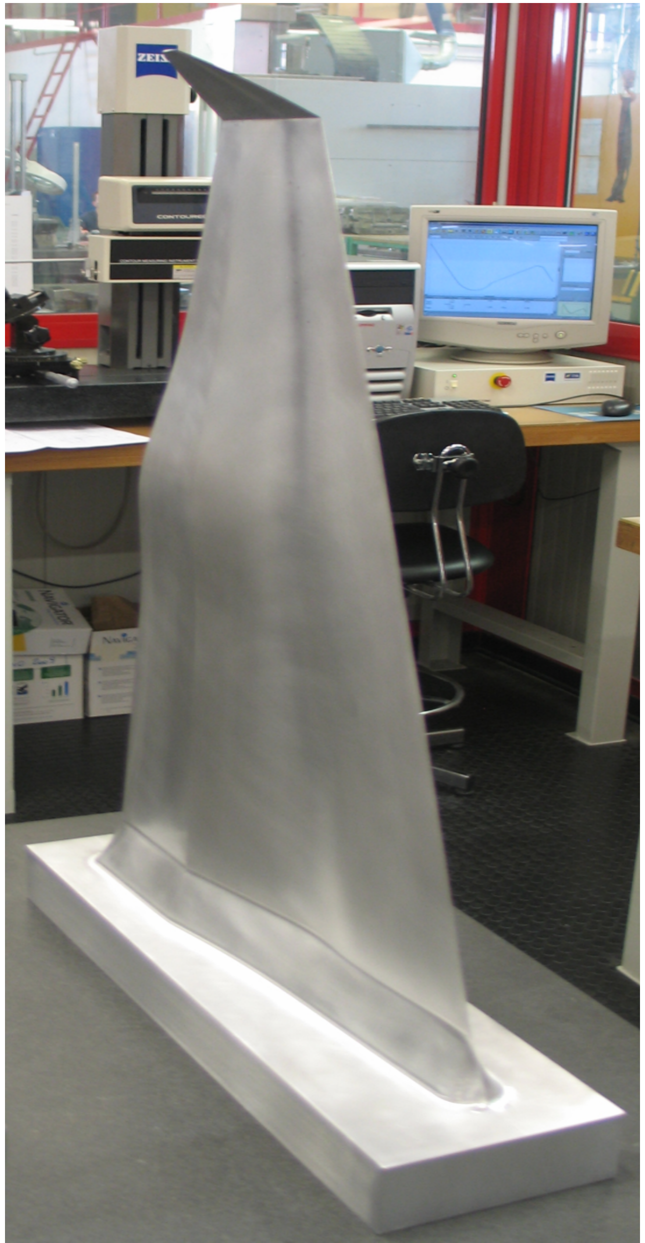
Manned compartments internal arrangements

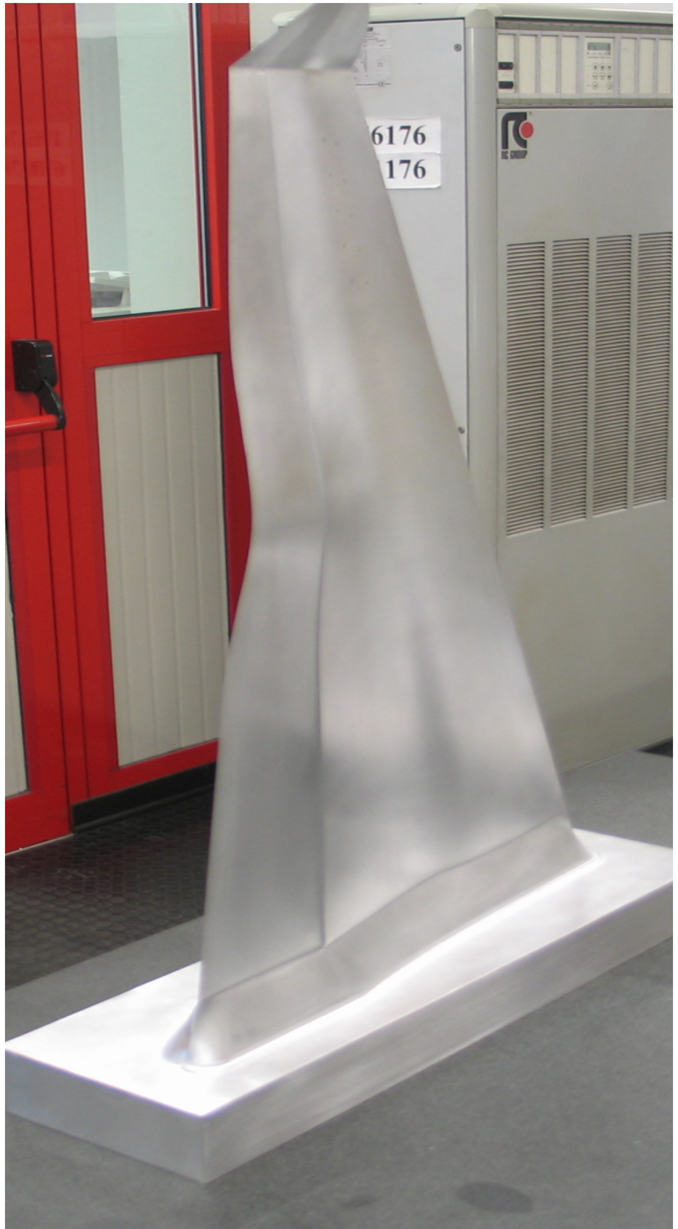
3D view of manned compartments



- Mapped process
- Inferred required attributes
- Control room had to be forward to act as a ‘bridge’
- Crew office, W.C. and emergency medical/berthing are required
- Seats, room height and corridor size were based on average human size with some allowance
- Normal entry/cargo space has enough volume for 15 MT cargo with density of steel

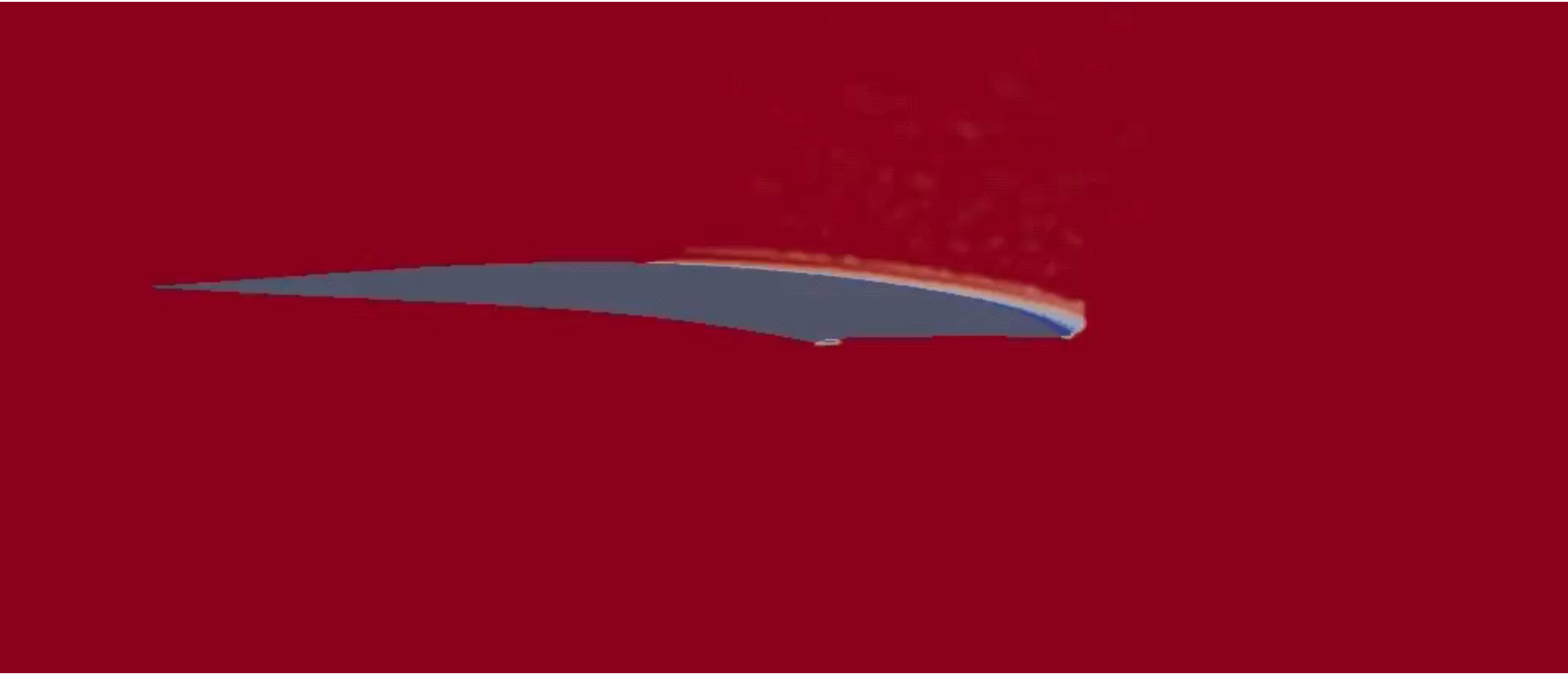
Super cavitating surface piercing foils





- Designed by Dr. Brizzolara
- Improved version: solved unsteady ventilation problem of previous versions
- Wedge serves to ignite cavitation on backward area preventing cavitation in forward area
- Produces increased lift-to-drag ratio (5 to 1)

Unsteady turbulent flow solution



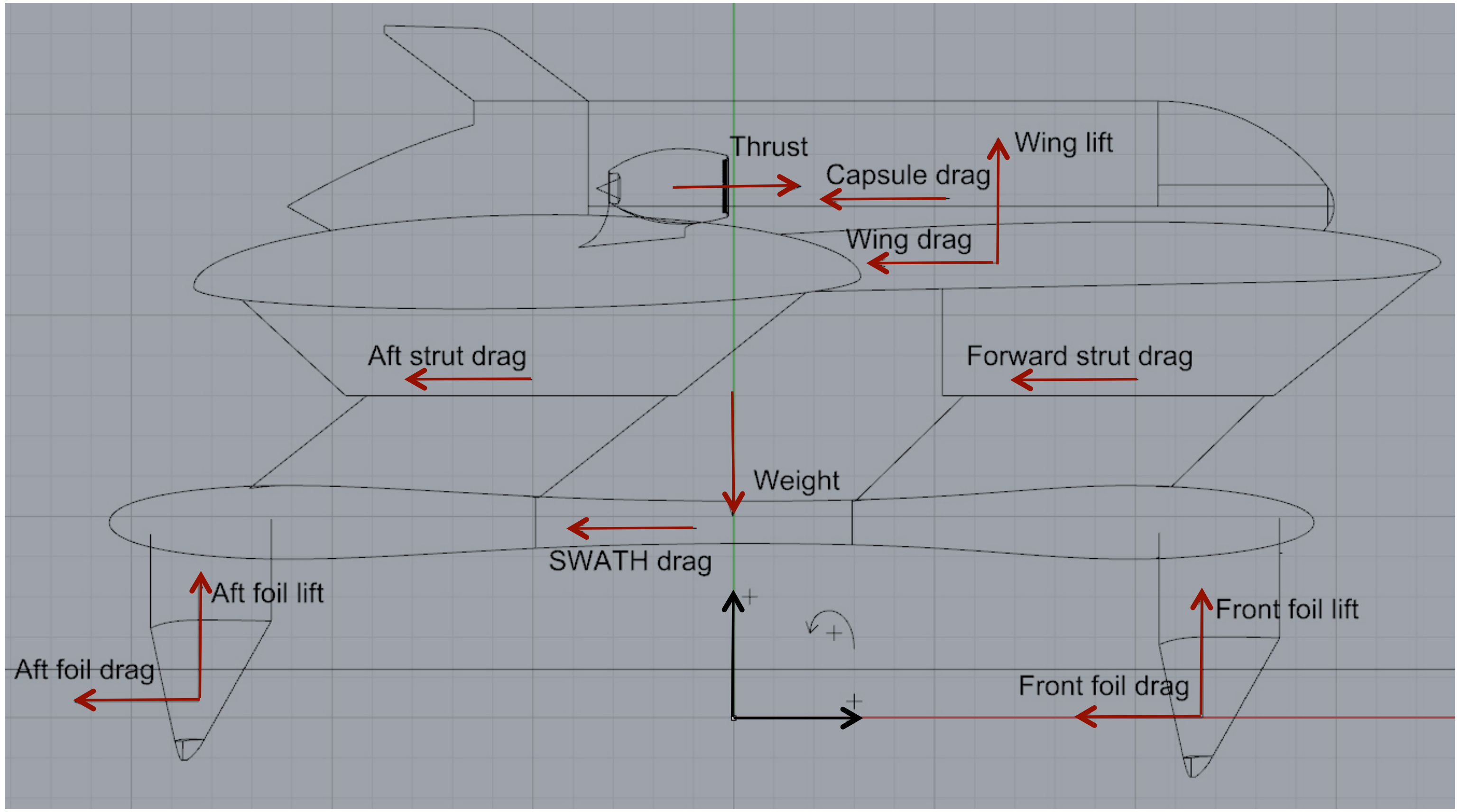
Hydrofoil model experiments

Experimental model

- Cavitation tunnel experiments were performed on a model
- Model is ~10 times smaller
- Data was extracted and used to find force coefficients for the vessel
- Force coefficients were used to calculate foil forces

Hydrofoil sizing criteria

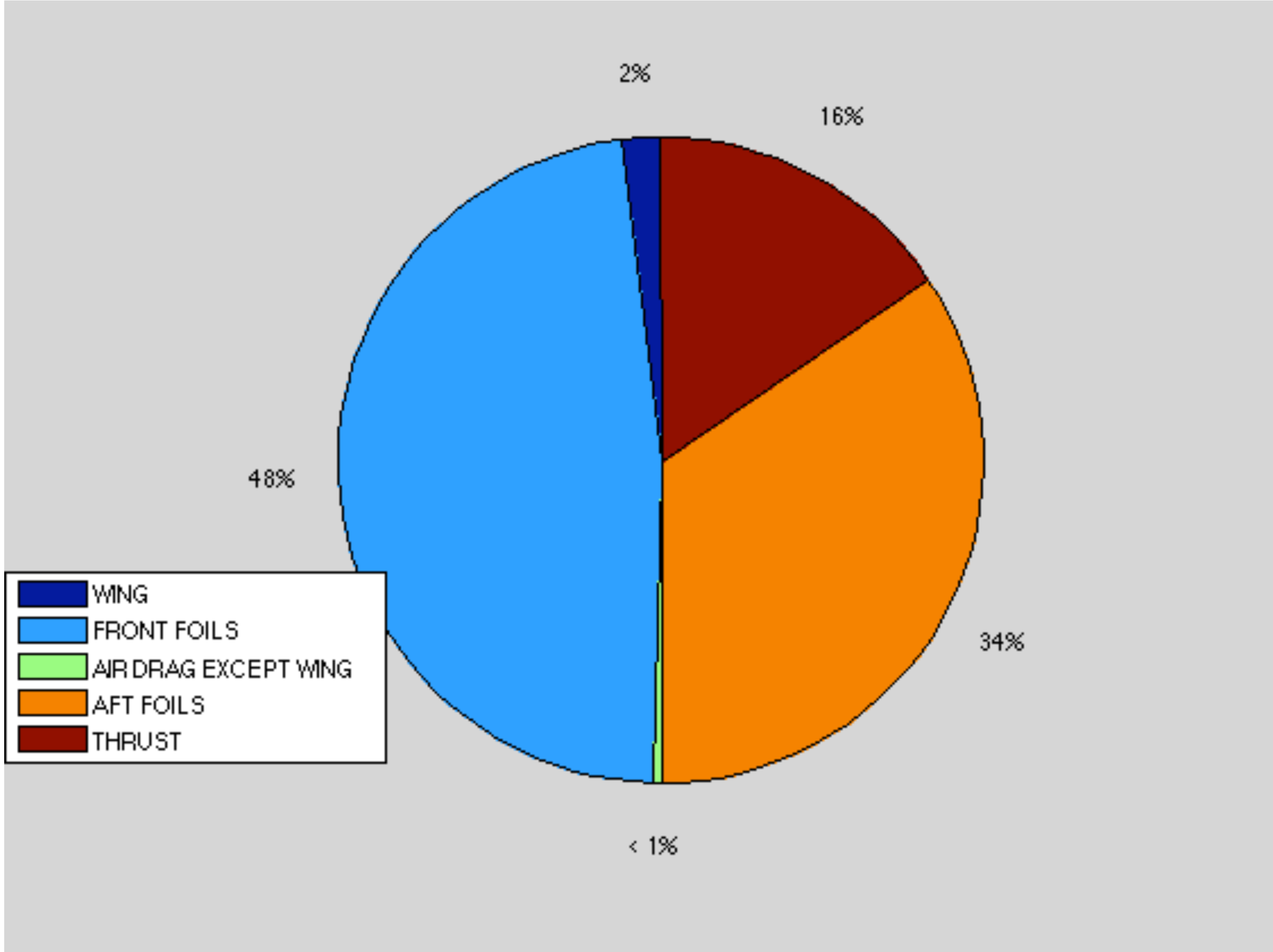
Vertical plane forces drawing



- Goals:
  - Equilibrium at max. speed
  - Zero trim at max. speed
  - Strength!!
- Constraints:
  - Limit on the max. foil longitudinal length (3 m)
  - Required clearance from SWATH hulls (2.75 m)
- Desired:
  - Zero (design) foil a.o.a.

Hydrofoil sizing results

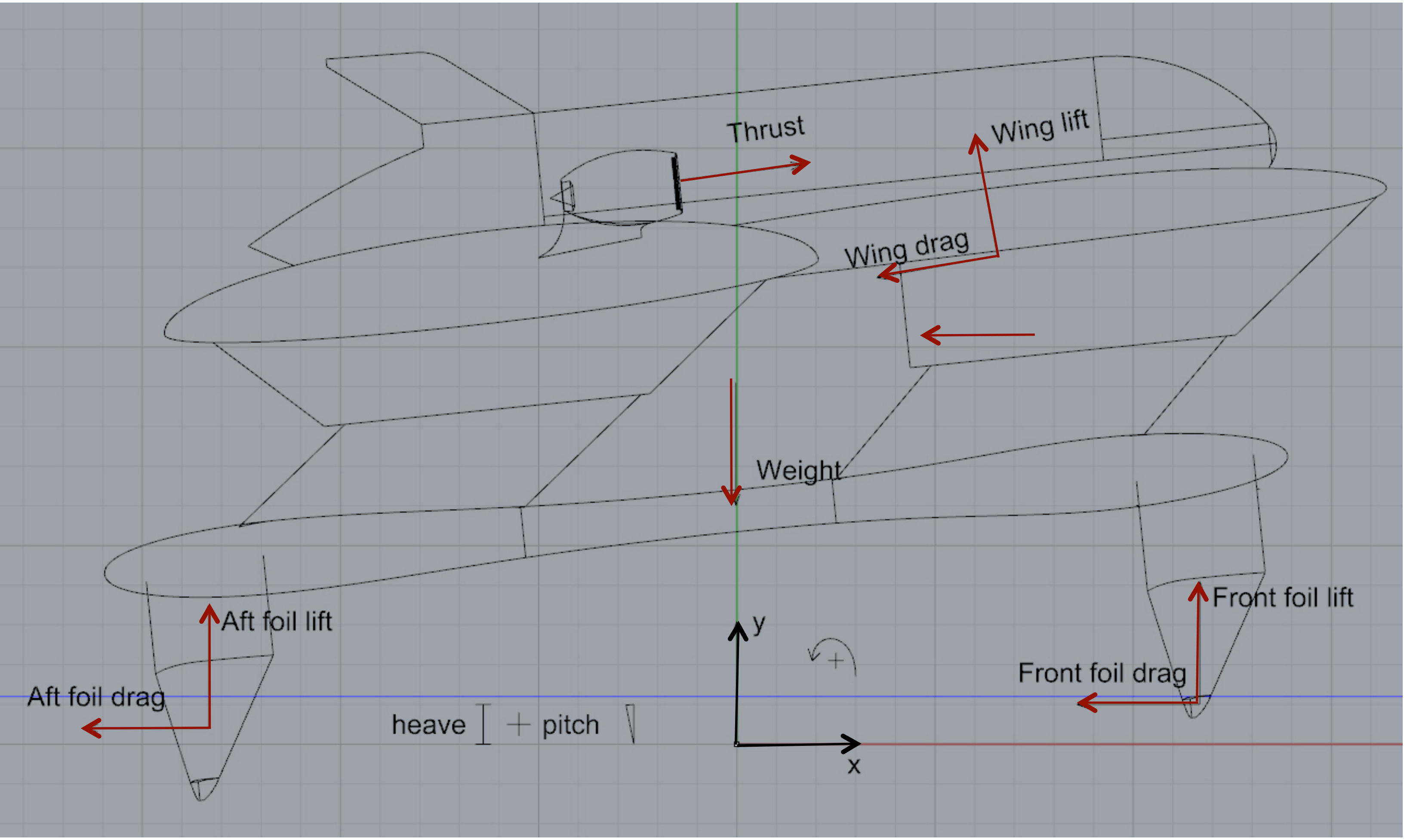
Required moments from front and aft foils



- Thrust force vector is located high up: large moment is produced!
- To counteract this moment, front foil need to be larger than aft foil
- Could have adjusted initial a.o.a. but it was desired they be kept zero
- This phenomenon is also occurs in sailing vessels, where sail force is located high up (see Americas Cup hydrofoil racing sailboats)

Longitudinal stability-foil borne mode (small angles)

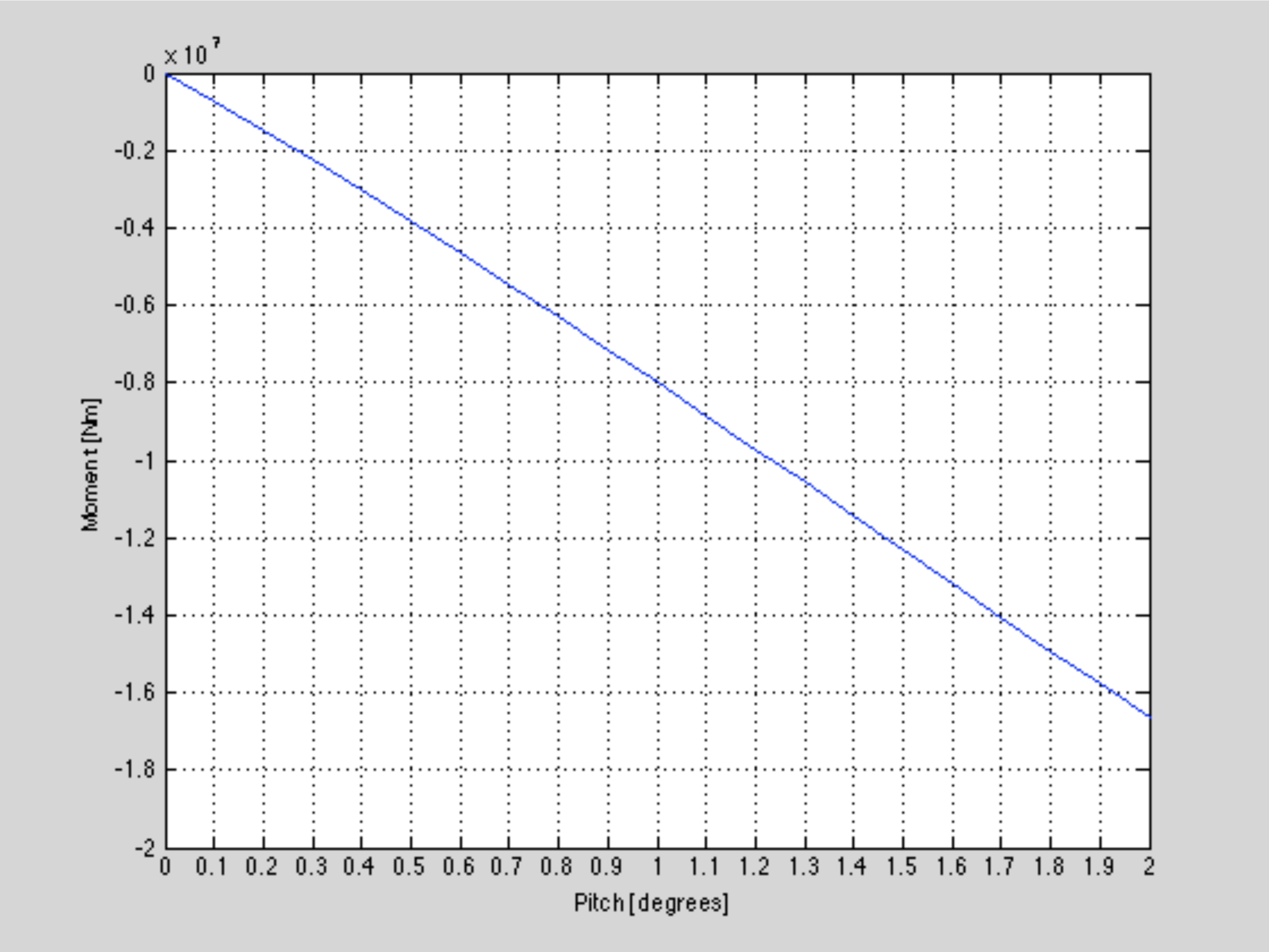
Free body diagram



- To have positive stability, reaction moment must oppose pitch motion
- Required a customized ‘inclining experiment’ type simulation
- Slow pitch rotation followed by heave
- Vessel allowed to heave to reach vertical equilibrium

Longitudinal stability-foil borne mode (small angles)

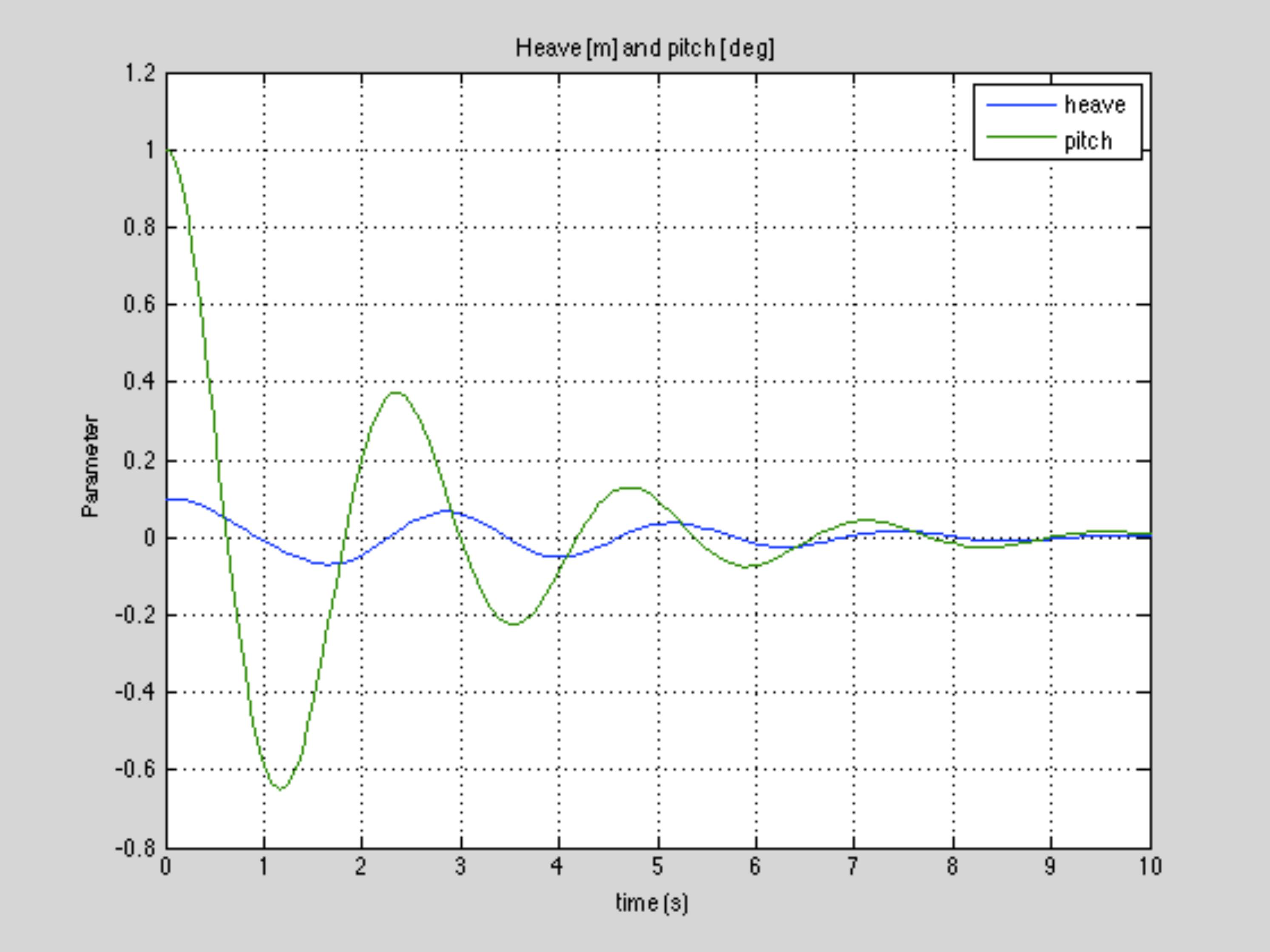
Righting moment graph



- Righting moment found in each position
- Vessel has positive stability: moment is reactive
- Simulation program can be used for predicting wind and high speed turning righting arm curve (future work)

Simulation 1: Dynamic behavior in calm sea

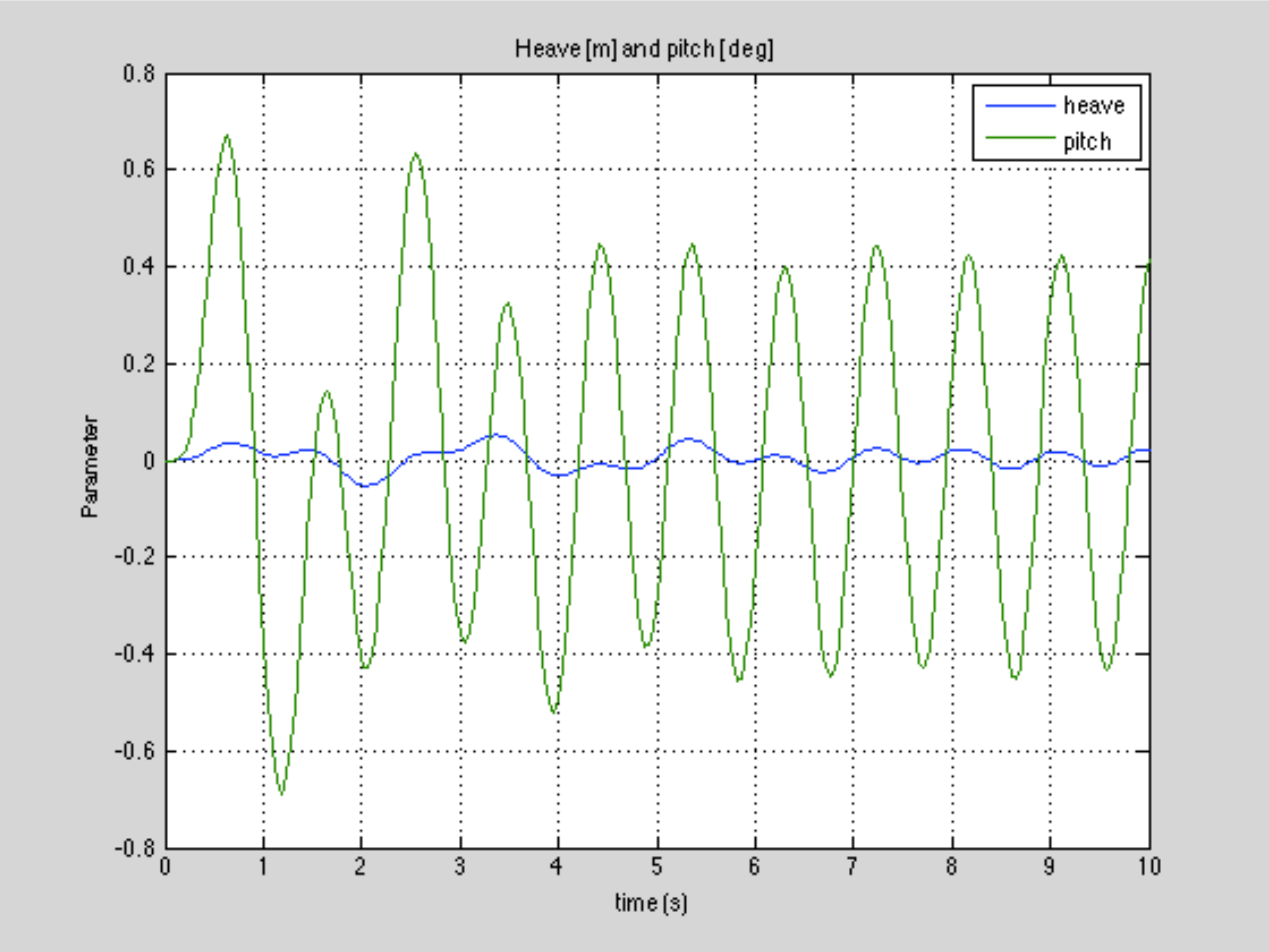
Initial heave (0.1) and pitch (1^0) - calm sea



- Stable dynamic behavior
- Motion damping occurs due to dissipative terms
- System oscillates with its natural frequency

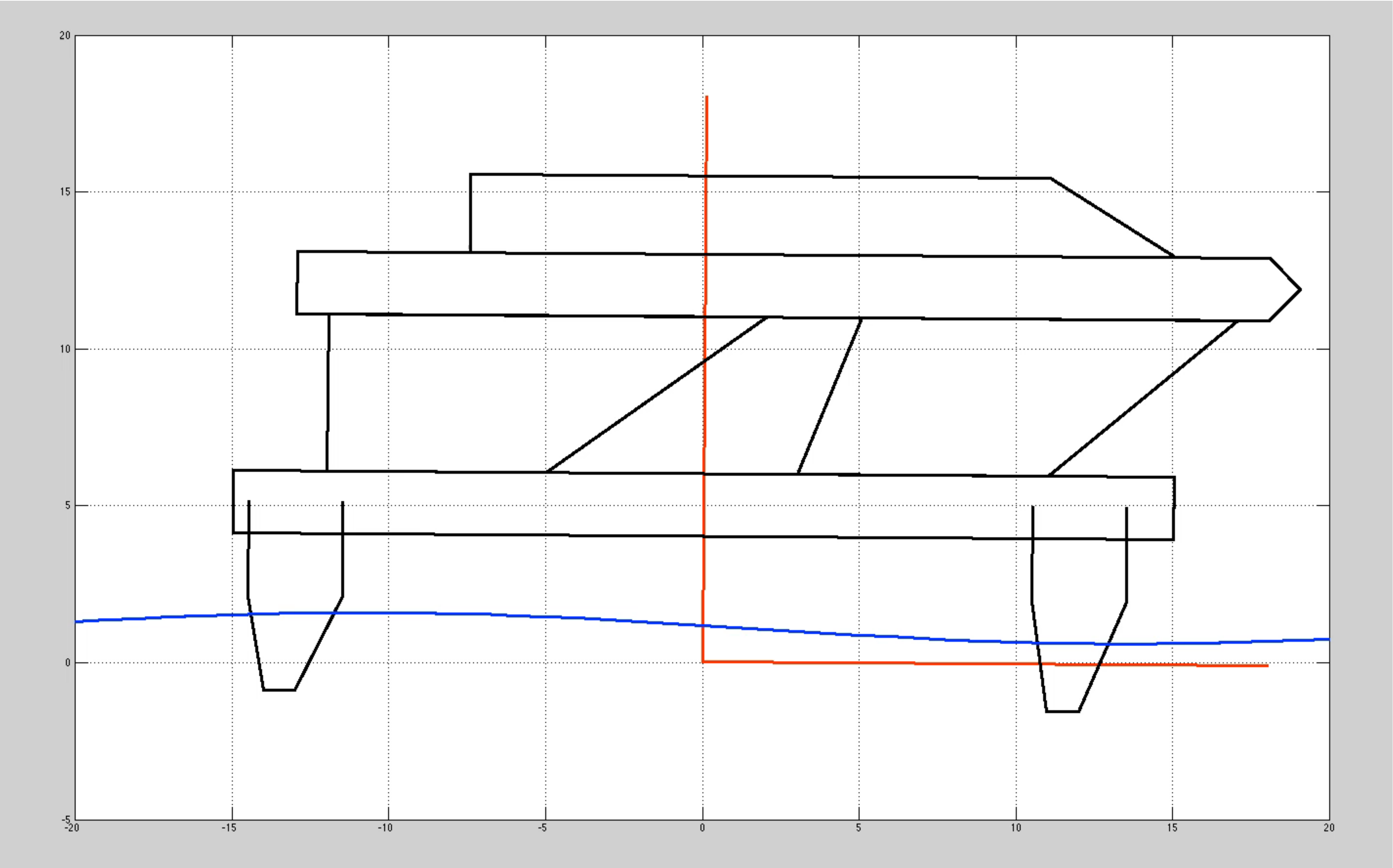
Simulation 2: Dynamic response to sinusoidal wave

Wave length=2*LBF, Wave height=0.5 m



- Initial peak is due to the sudden encounter of the wave
- System reaches stable oscillation in ~8 encounter periods
- Heave magnitude is minimal compared to the magnitude of the incoming wave
- Pitch magnitude is small but noticeable
- Vessel essentially enters into a vibration state in response to head waves

Simulation 2: Visual animation



Future work/recommendations

1. Computational Fluid Dynamics simulation in unsteady conditions will reflect dynamic behavior more accurately
2. Structural design of the vessel + global structural analysis

Questions