Efficient Coordinate Transformations in Maritime Co-Simulations

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Coordinate Transformation Techniques for Improved Co-Simulation in the Maritime Industry

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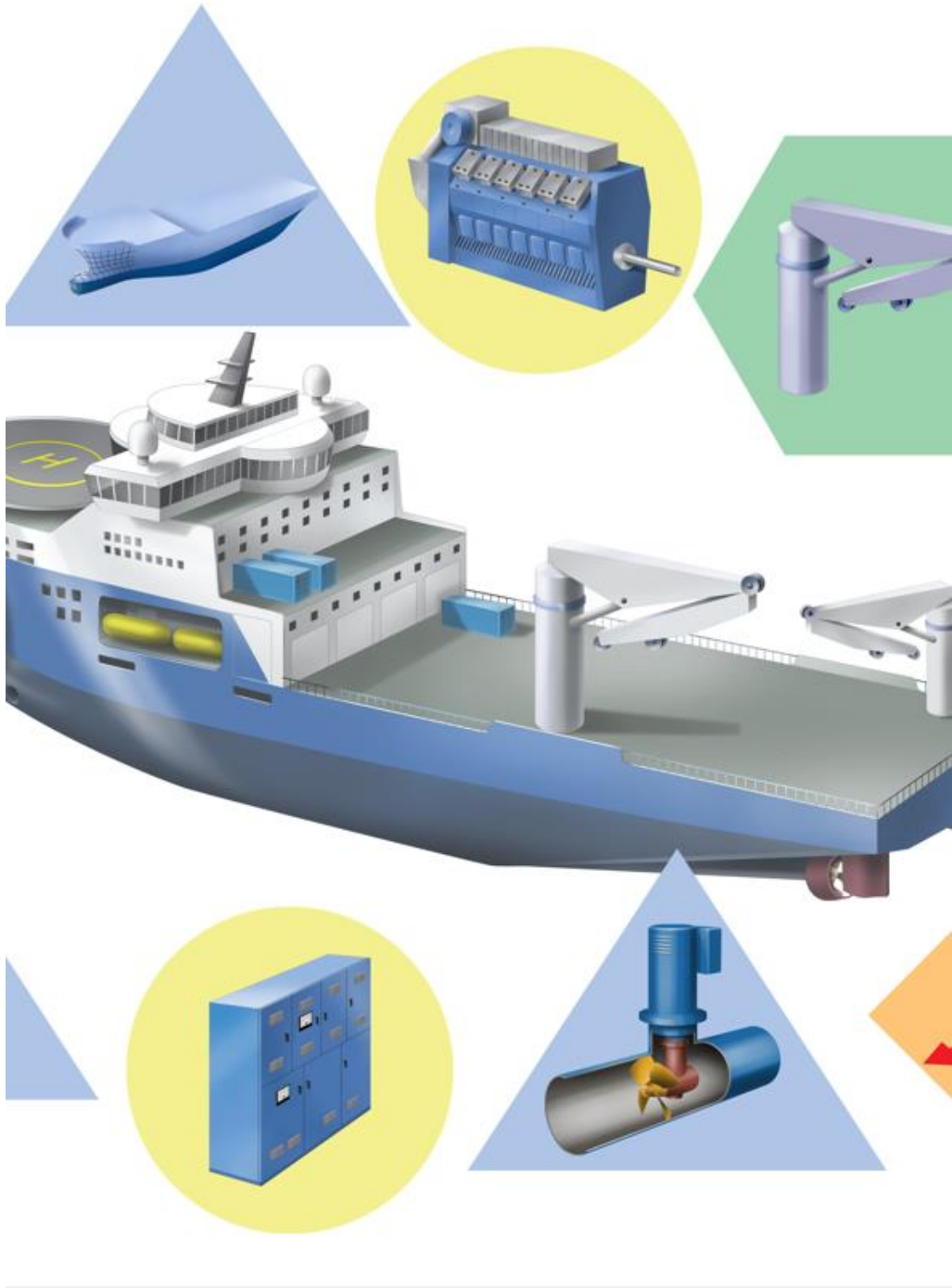
Co-simulation

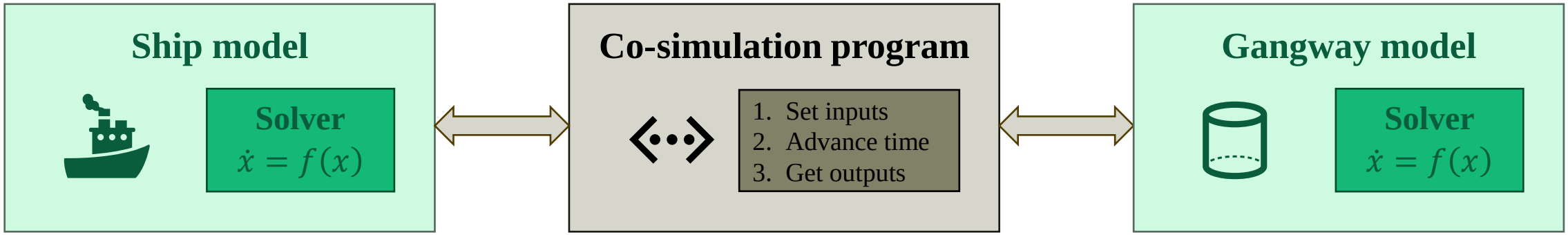
Background

- Simulation as key enabler
  - Virtual prototyping
  - Assess performance up-front
- More complexity and more interconnectivity
  - Anticipate system behavior
  - Collaboration between many stakeholders



Co-simulation

- Method for joint simulation
- Independent simulation models
- Narrow input/output interfaces
- Synchronization at discrete time point



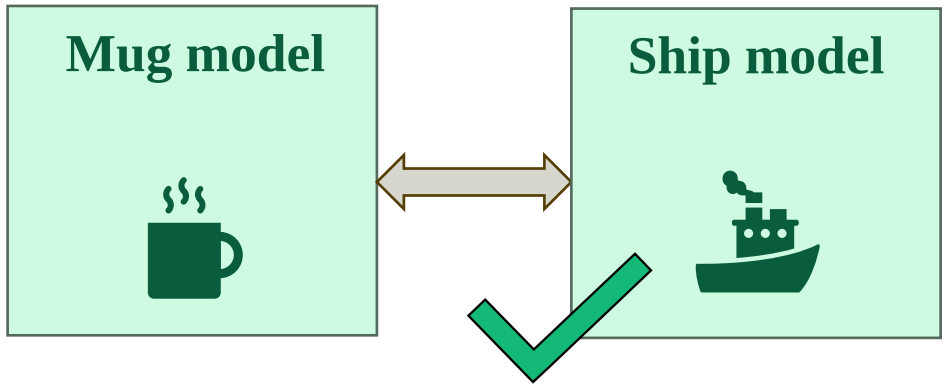
Co-simulation

The Good

- Independent modeling
  - By experts
  - With expert software
- Modularity and reuse of models
- Black-box modeling
  - Protect sensitive internals

The Bad

- Accuracy and stability
- Lack of connection standards



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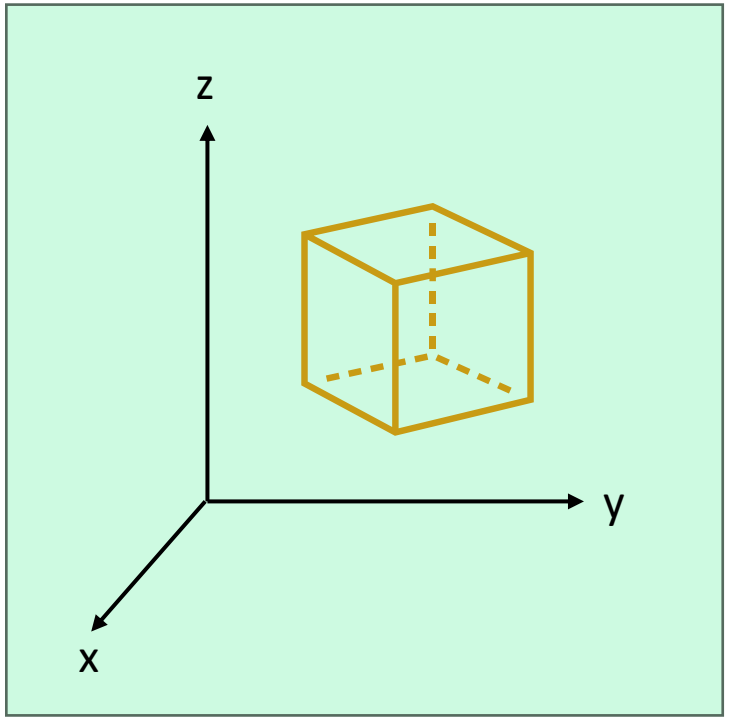
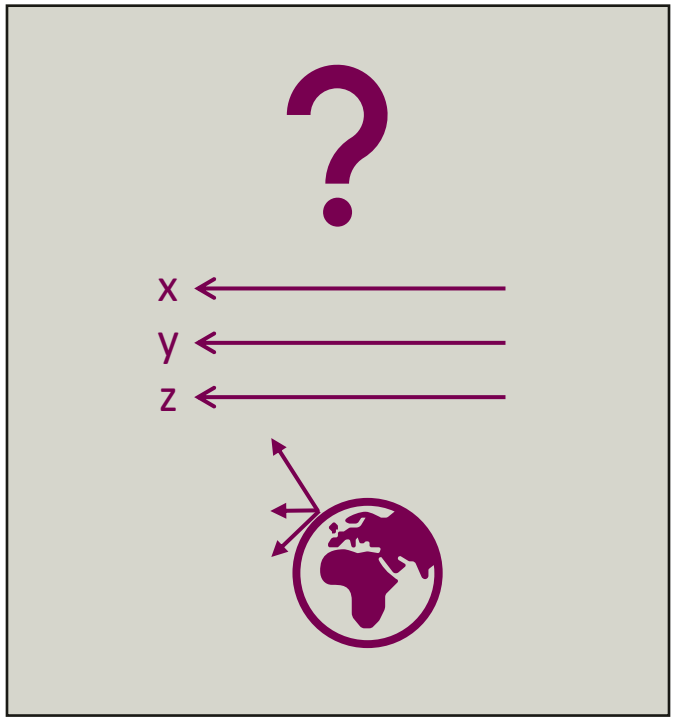
Coordinate systems in co-simulations

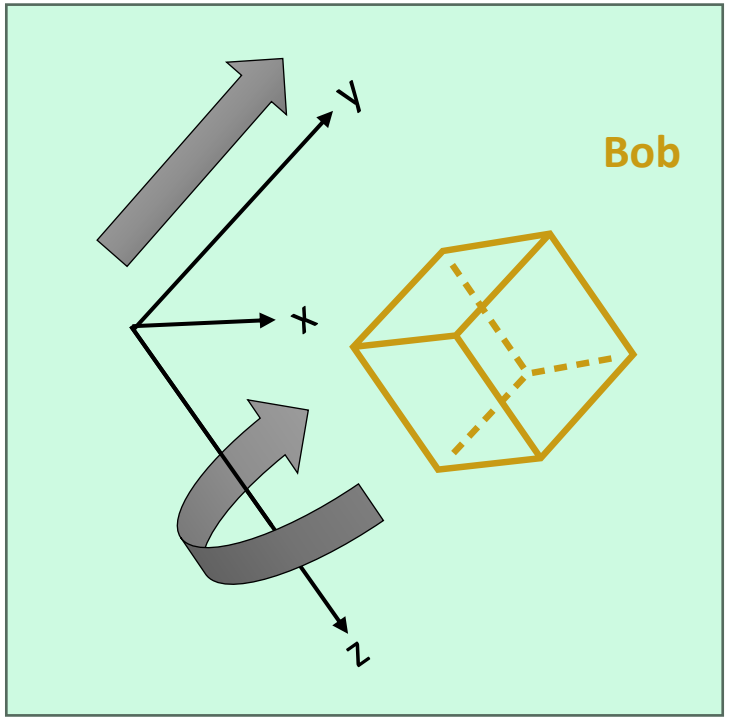
Coordinate systems in co-simulation



Alice's awesome simulation model

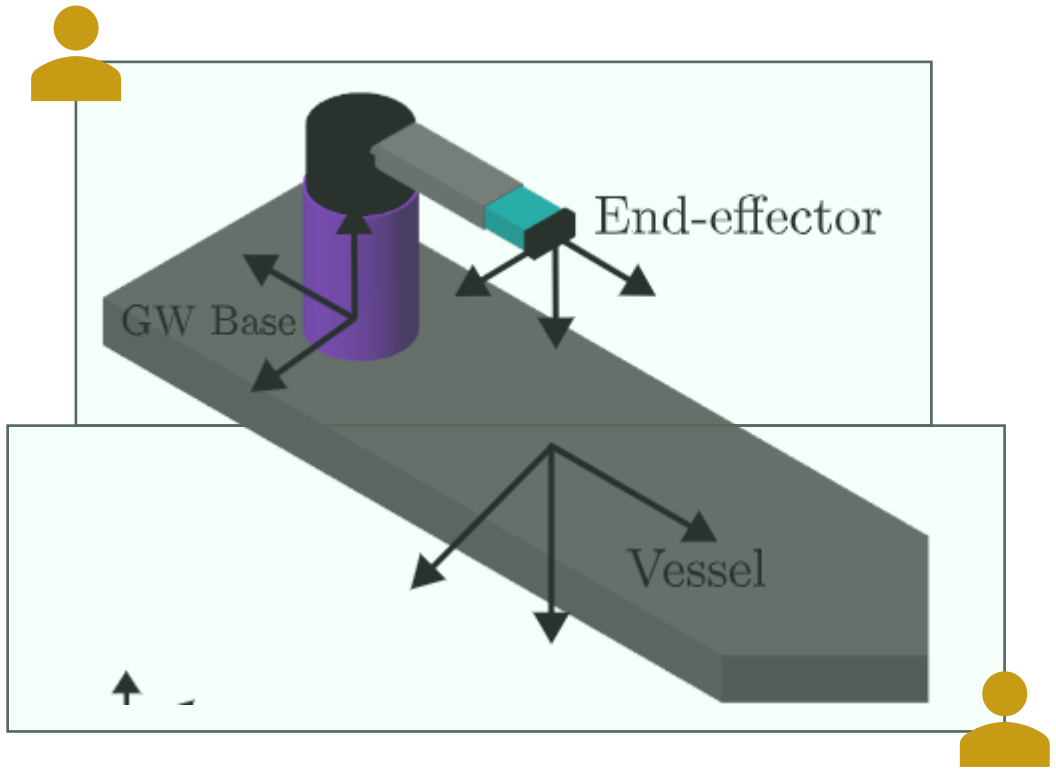


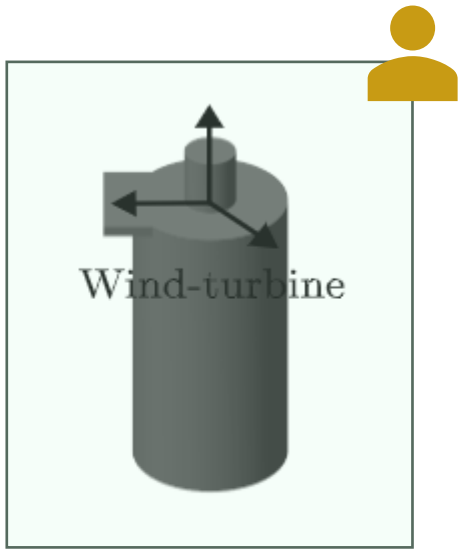
Corey's colossal confusion

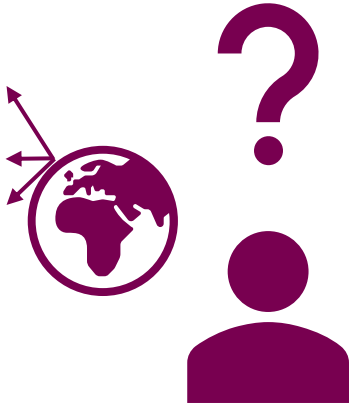


Bob's bombastic simulation model

Case: Gangway—Vessel





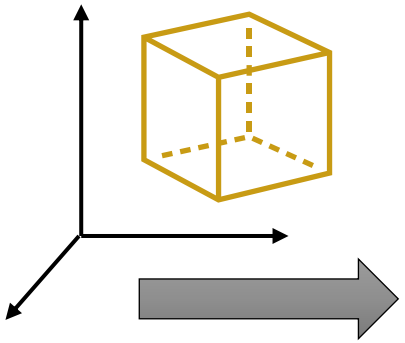


General solution approaches

Inertial and non-inertial reference frames

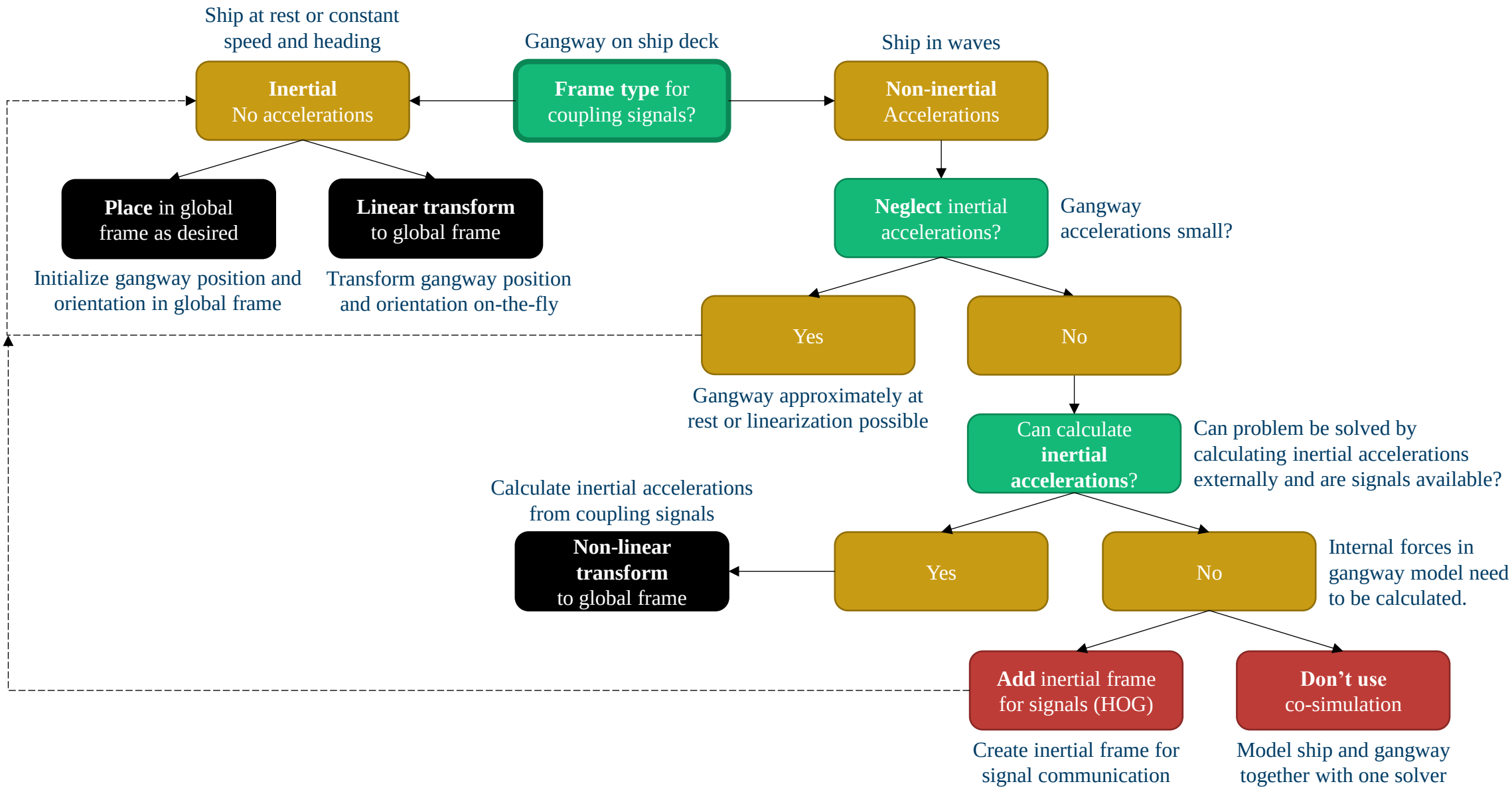
Inertial

- At rest or constant linear motion
- No acceleration / rotation
- **Physics is independent of frame**
- Simple linear transformations

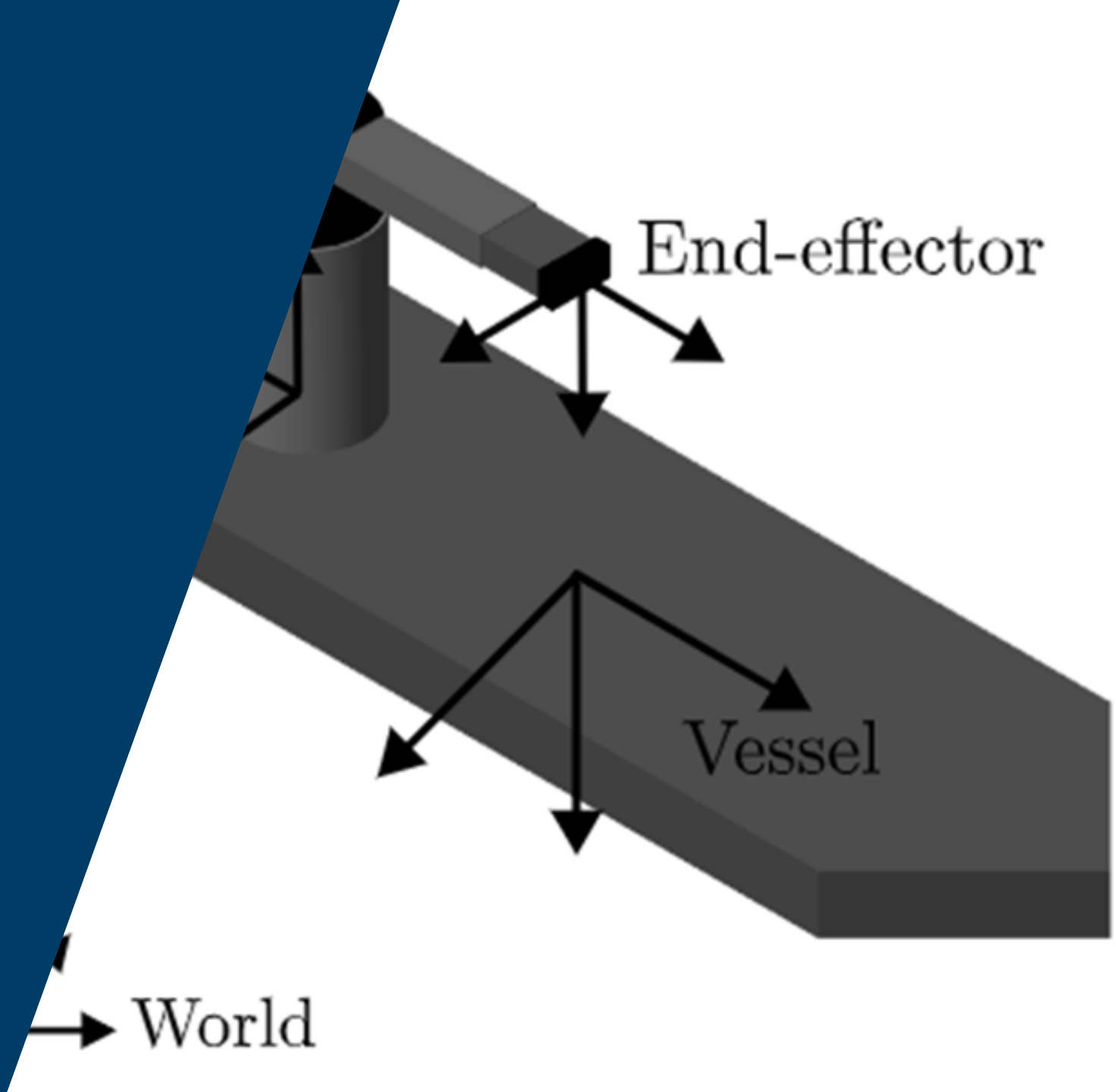


General principles

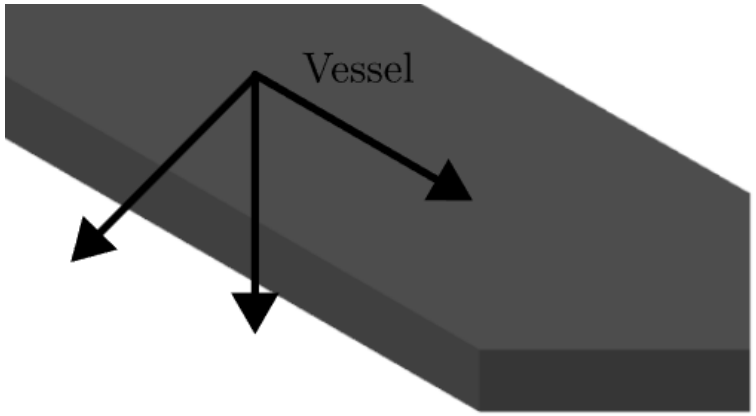
- An **inertial** reference frame is strongly recommended as the global frame on the co-simulation level.
- **Inertial** reference frames are strongly recommended to exchange coupling signals from models.
- If an **inertial** frame is used, it can either be initialized to align with the global frame, or a linear transformation can mediate between the local and the global systems.
- For non-inertial frames, the relevant accelerations can be calculated *if* we have sufficient knowledge about the system used *and* we receive the necessary signals.
- Alternatively, the model has to be adapted to include a local inertial reference frame into which the relevant coupling signals are translated.


Ship at rest or constant speed and heading
Gangway on ship deck
Ship in waves
Inertial
No accelerations
Frame type for coupling signals?
Non-inertial
Accelerations
Place in global frame as desired
Linear transform to global frame
Initialize gangway position and orientation in global frame
Transform gangway position and orientation on-the-fly
Neglect inertial accelerations?
Gangway accelerations small?
Yes
No
Gangway approximately at rest or linearization possible
Can calculate inertial accelerations?
Can problem be solved by calculating inertial accelerations externally and are signals available?
Calculate inertial accelerations from coupling signals
Non-linear transform to global frame
Yes
No
Internal forces in gangway model need to be calculated.
Add inertial frame for signals (HOG)
Don't use co-simulation
Create inertial frame for signal communication
Model ship and gangway together with one solver

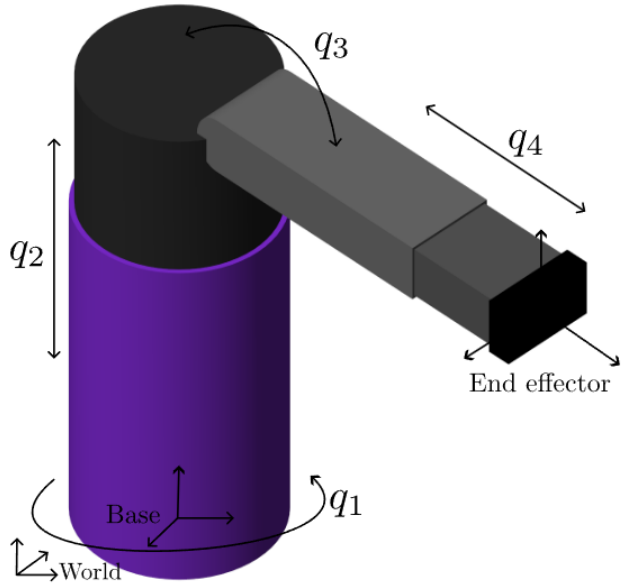
Case: Vessel—gangway



Vessel—gangway

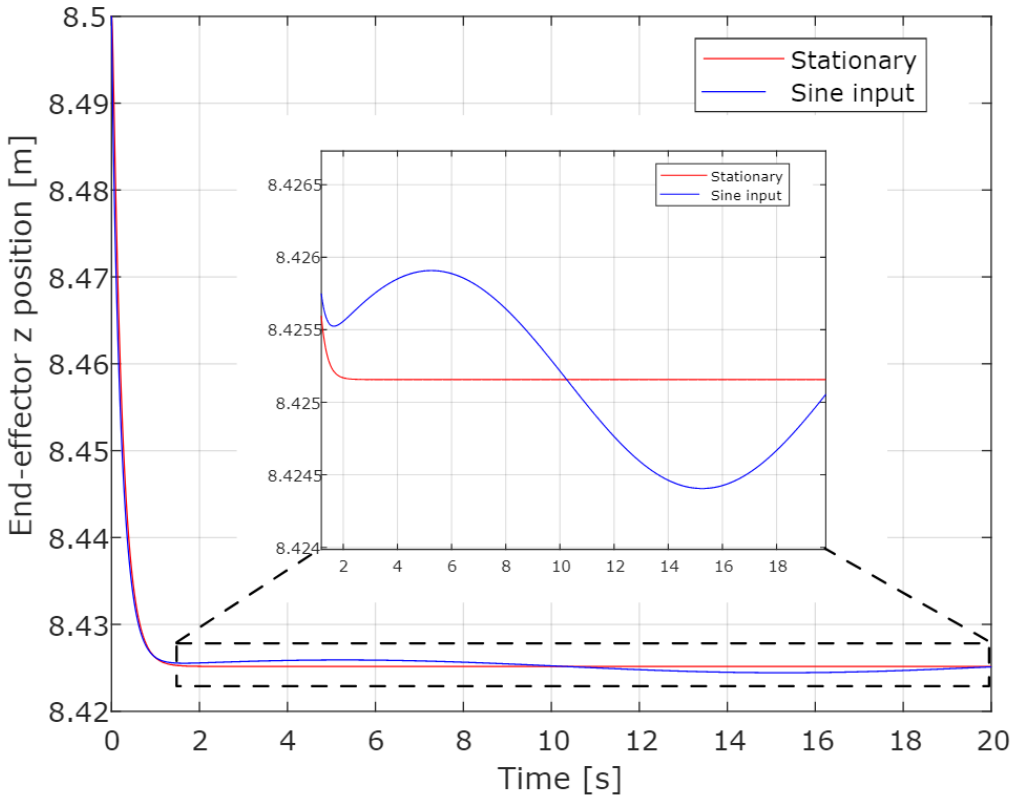


6-DOF
positions and orientations



Interaction errors

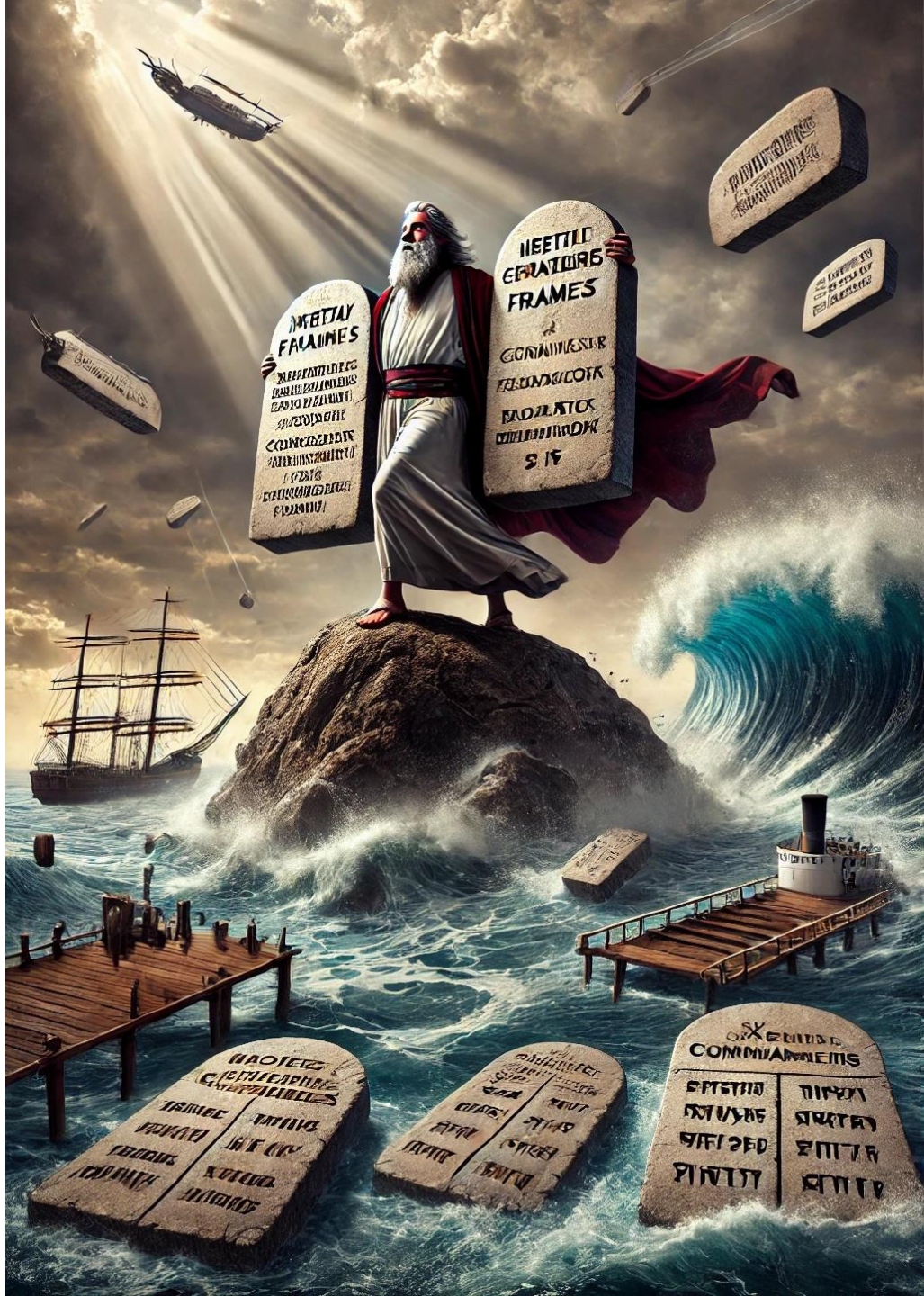
- For simplicity, sinusoidal heave motion of vessel
- Stationary case
  - Gangway base assumed fixed in space
  - End-effector inside model at rest
  - Vessel motion super-imposed
- "Hand of God" case
  - Gangway accepts externally dictated movement
  - End-effect accelerations and forces are correctly modeled



Recommendations and conclusions

The six co-simulation commandments

1. Keep models independent
2. Only use inertial frames for coupling signals
3. Allow for externally dictated motion ("Hand of God")
4. Beware gravity and buoyancy
5. Document your modeling work
6. Visualize



Conclusion

Where we are now:

- Co-simulation is great!
  - For collaborative modeling and simulation of ships and maritime systems
- Correct and efficient handling of coordinate systems
  - Important, but difficult!
- Possible to derive important principles

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