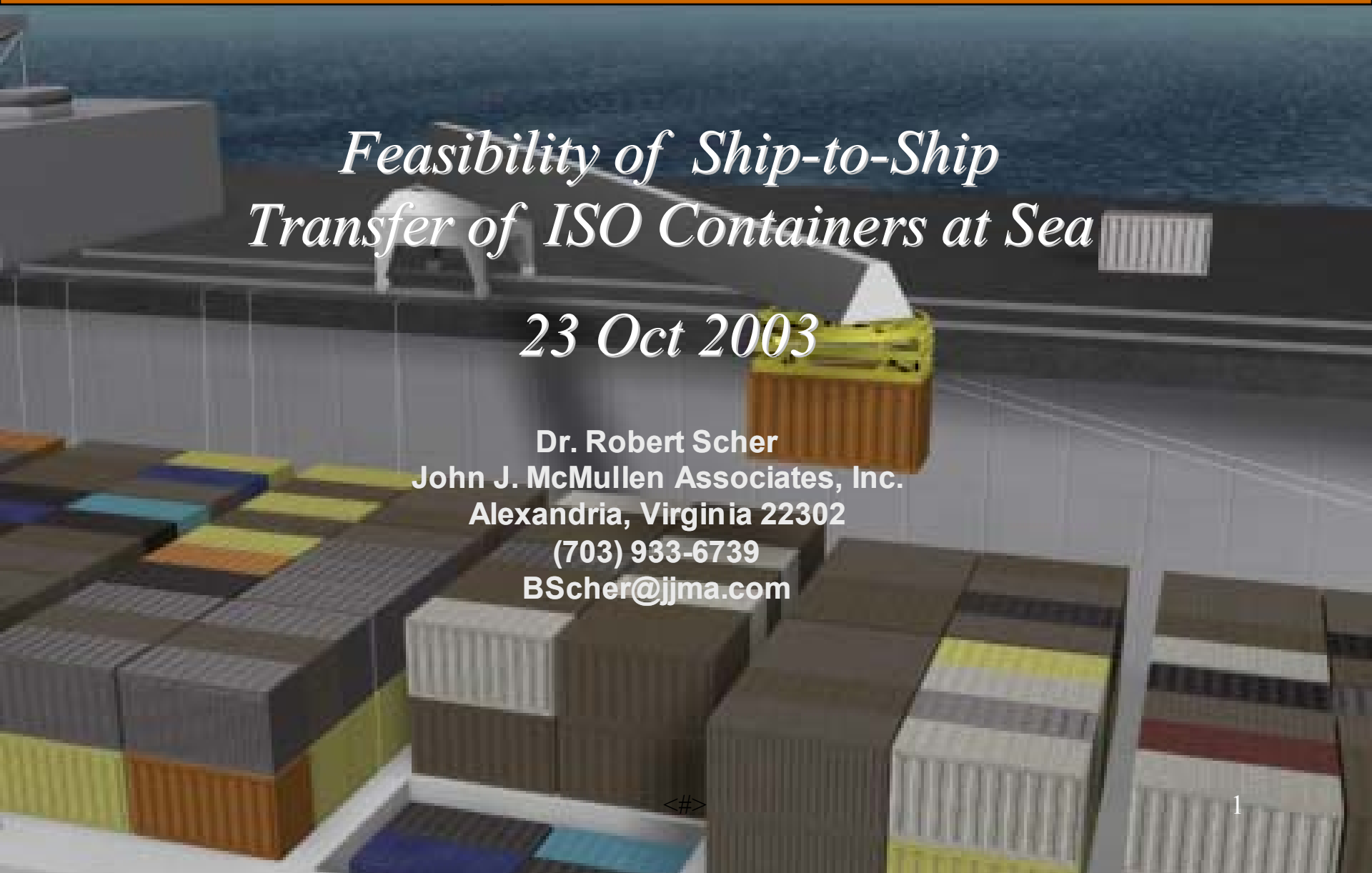

Feasibility of Ship-to-Ship Transfer of ISO Containers at Sea

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Notional Concept of Operations

- Mission – Resupply the Sea Base using ISO containers
- Notional 90,000 ton MPF(F) with equipment to transfer fully-loaded ISO containers to/from unmodified commercial container ships
- Mooring and fendering deployed from MPF(F)

High Capacity Alongside Sea Based Sustainment (HiCASS) Industry Day

What is the logistic pay-off?

CONOPS *with* Skin-to-Skin Container Transfer		CONOPS *without* Skin-to-Skin Transfer
• No special-purpose shuttle ships are required – Direct supply from commercial containerships	⟷	• Uses Navy-owned or chartered CLF shuttle fleet with specialized gear
• Can handle anything on an ISO flat rack or in an ISO container	⟷	• CLF ship handling routes and elevators typically limit load size
• Can Transfer fully loaded containers, 30 – 40 tons per lift	⟷	• Transfers limited to 3 to 6 tons per lift
• Has low replenishment speed reduces risks	⟷	• Replenishment speeds of ~12 kts. is required to maintain rig tension and ship separation

Note: Conventional or Heavy UNREP will still be required for surface combatants and carriers.

Survey of Commercial Experience

- Commercial tanker lightering operations routinely bring 150,000 dwt tanker alongside 300,000 tonner (ULCC)
- Tankers remain alongside in sea state 5 to 6
  - Four 15-ft diameter pneumatic fenders
  - Mooring lines with 50-75 ft nylon grommet (twisted nylon hawser loop for increased elasticity)
  - Mooring winches typically tensioned and locked, reset manually as needed
- Approach speeds typically 3-5 knots
- Lightering tanker then tows ULCC at minimum speed for heading control

Ship Motion Analysis Tools

- ***AQWA (Atkins Quantitative Wave Analysis)*** **– Widely used suite of programs primarily in use by commercial oil industry**
  - **Time-domain multi-body ship-motion and mooring design problems**
  - **Linearized hydrodynamic forces with non-linear mooring forces**
  - **Used for prediction of ship forces and motions, fender and mooring line forces**
- ***ADAMS*** **– Well-known physics-based modeling and analysis tool used for a wide variety of mechanical systems, non-linear dynamics, vehicle and material-handling system design**
  - **Used for prediction of crane responses, power, line loads, evaluation of mooring winch control strategies**

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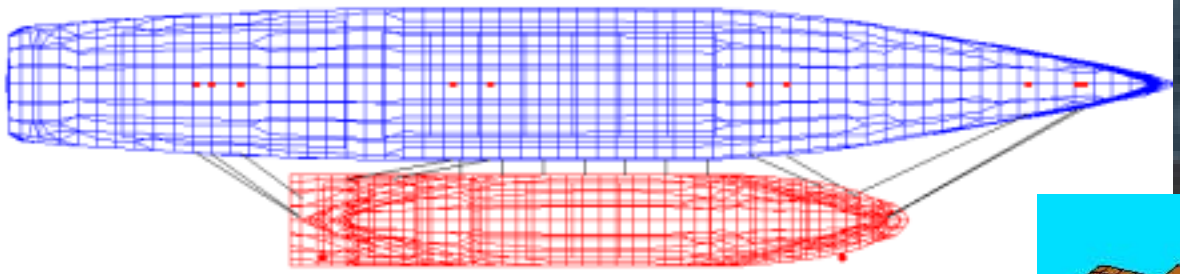

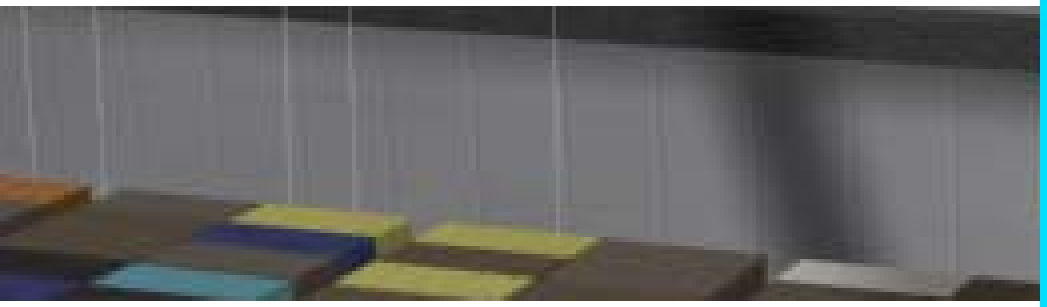

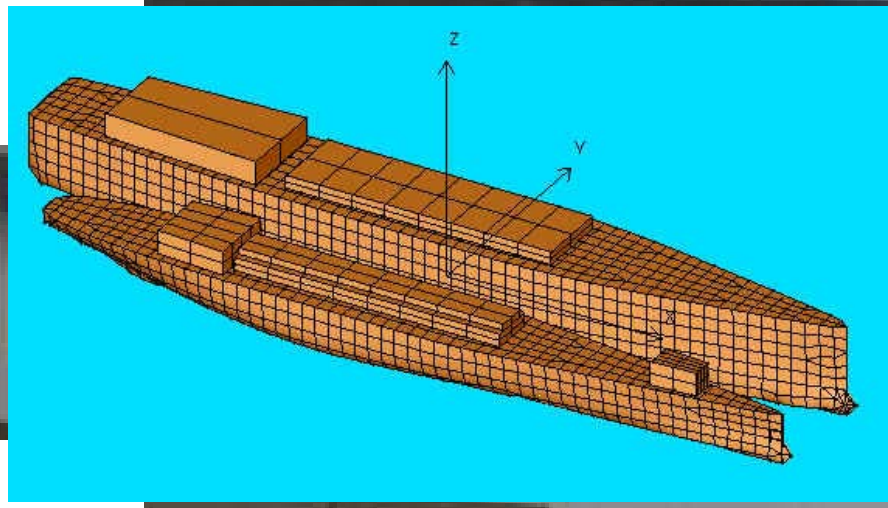

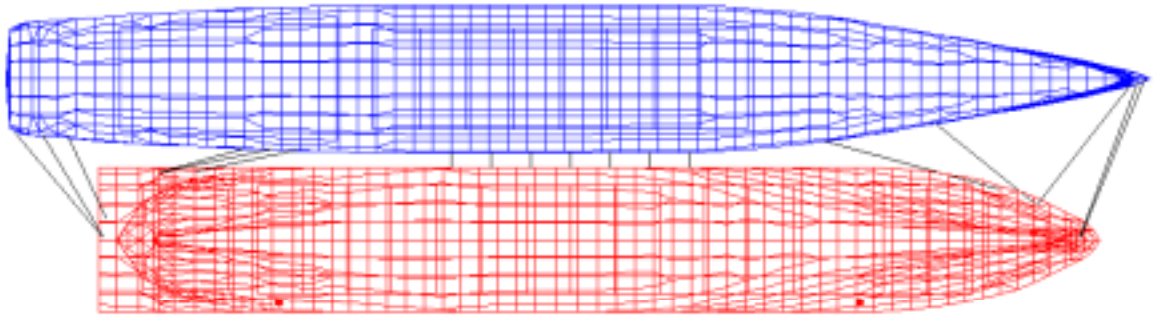

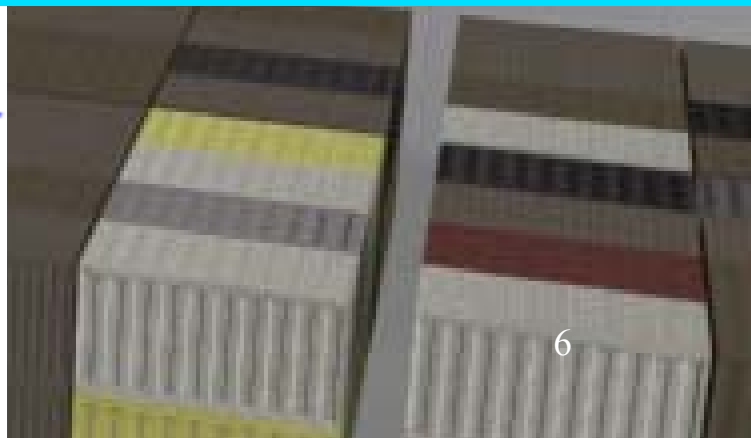

Fendering Studies

- Used 14-ft diameter commercial foam fenders
  - Three fenders positioned high to protect higher freeboard and reduce relative roll
  - Four fenders on the water, as in tanker lightering
- Studied sensitivity to fender stiffness and diameter

Mooring Line Studies

- Conventional mooring lines (with 50-75 ft nylon grommets)
- Studied sensitivity to mooring line orientation, number of lines, and grommet stiffness

Mooring Winch Studies

- Considered constant-tension and locked winches alternatives
- Studied a range of active winch-control strategies
  - Line length and line speed gains

Ship Control during Approach and Separation

- Analytical studies and simulations have not yet been performed
  - Interviewed commercial lightering masters
  - Observed lightering operations
- Key issue for future work
  - Important operational consideration is which ship does the maneuvering during approach
- Judge that approach and separation will be feasible with thrusters and twin screw MPF(F)
  - Major difference from tanker lightering is effect of windage
  - Forward speed interaction forces are less important

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Cargo Transfer Result

- Motion compensation in all six degrees of freedom is required:
  - Roll: max 3.8 deg Crane Ship, 13 deg Target Ship (small containership)
  - Pitch: max 0.7 deg Crane Ship, 1.8 deg Target Ship
  - Relative motions (between crane boom end location and target:
    - » Relative Longitudinal – 5 m
    - » Relative Transverse – 8 m
    - » Relative Vertical – 4 m
  - Relative velocities (between crane boom end location and target:
    - » Relative Longitudinal– 0.8 m/sec
    - » Relative Transverse– 1.1 m/sec
    - » Relative Vertical– 2.0 m/sec
  - Relative accelerations (between crane boom end location and target:
    - » Relative Longitudinal – 0.3 m/sec^2
    - » Relative Transverse – 0.5 m/sec^2
    - » Relative Vertical – 1.5 m/sec^2

Ship Motion Results

- Ships can remain secured alongside in sea state 5 without steel-to-steel contacts
  - Sea state 5
  - Speeds 3 to 6 knots
  - Seas fine on bow or quarter, containership on the sheltered side
- Roll (and associated vertical relative motion between crane boom end and "target" load) dominates crane requirements
  - Clearance under boom
  - Required power
  - Required line speeds

Fender Results

- Existing commercially available fenders are adequate for 90,000 ton MPF(F) with containerships from 1200 to 5500 TEU

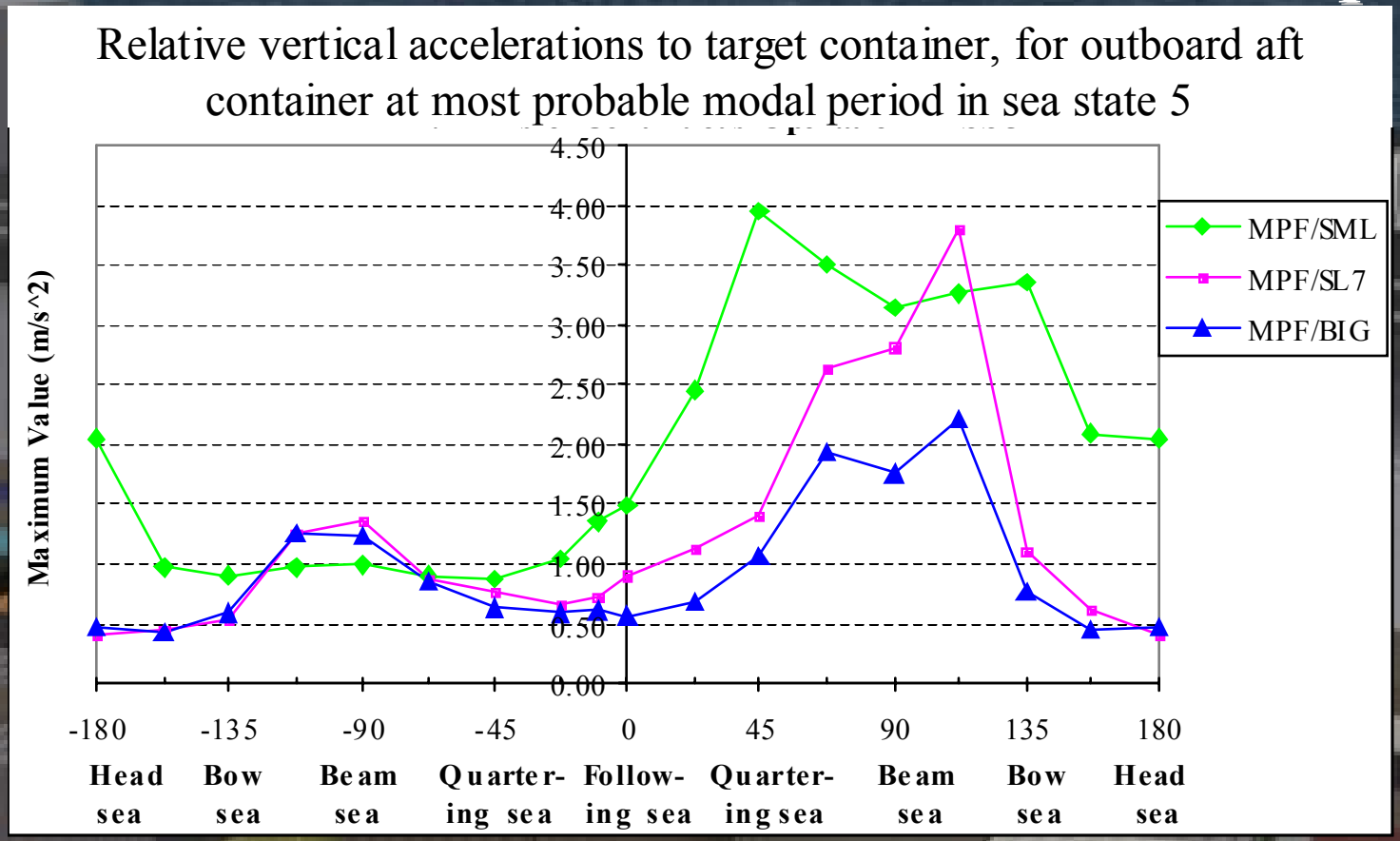
Mooring Line Results

- Existing commercially available nylon grommets are adequate for 90,000 ton MPF(F) with containerships from 1200 to 5500 TEU, when used with CT or actively-controlled winches

Mooring Winch Results

- Locked winches result in overload on mooring lines (or winch-brake slipping)
- Commercial CT winches result in large second-order (slowly varying) yaw, sway, and surge excursions
  - Periods typically 3-5 wave encounter periods
- Active winch-control strategies with appropriate displacement and rate gains efficiently reduce slowly-varying responses

Ship Motion Sensitivities – Container Ship Size



Ship Motion Sensitivities – Effects of Cross Swells

Swell effect on estimated crane power (2 x rms, kW), sea state 5.

Wave/Wind Direction	Swell Height (ft)	Crane Motion Comp Power (2 x rms, kW)			
		MPF/SML		MPF/BIG	
		Working Aft	Working Forward	Working Aft	Working Forward
Bow	0	281	339	149	216
	1	298	358	185	245
	2	353	405	250	295
Quarter	0	349	324	191	229
	1	367	341	216	251
	2	419	397	295	320

Ship Motion Sensitivities – Other studies

- Modal wave periods
- Sea states
- Vessel loading condition
- Fender stiffness
- Mooring winch control

Conclusions

- MPF(F) and containerships of various sizes can remain moored alongside
  - In conditions up to sea state 5
  - Seas fine on the bow or quarter
  - Containership on the sheltered side
- Existing commercial fenders, mooring lines, and winches (with suitable tension settings) are adequate
- An advanced six-degree-of-freedom motion-compensating crane is needed for ISO-container transfer