Great Lakes Maritime Research Institute

A University of Wisconsin - Superior and University of Minnesota Duluth Consortium

MICHIGAN

Seaway-Sized Bulk Carrier Model for Hydrodynamic Optimization of Ballast-Free Ship Design

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Goal: construct a scale model needed to investigate the optimization of the discharge from the ballast-free trunks to eliminate or minimize any propulsion power penalty associated with the use of the Ballast-Free Ship concept

New IMO Requirements

- A 95% volumetric ballast exchange (@ 200 nm, 200 m) - effectiveness is still being debated, but, phasing out by 2012
- Flow-through exchange for three volumes "shall be considered" to meet this standard
- All ships shall remove and dispose of sediments in ballast spaces
- Management standard for non exchange: less that 10 viable organisms/m^3 above 50 μm and 10 between 50 and 10 μm
- Indicator microbes limited: E. coli, Vibrio cholerae, intestinal Enterococci

re: *International Convention for the Control and Management of Ships' Ballast Water and Sediments, IMO, Feb. 13, 2004*

The Ballast-Free Ship Concept

Its origin:

Question from biologists/ecologists on the National Research Council's Ships' Ballast Water Operations Committee (1998) deliberations:

"Why not just eliminate the use of water ballast?"

MGP's Response: "Water ballast is necessary in the light cargo condition to ensure:

- Transverse stability
- Bow submergence
- Propeller submergence
- Reduce windage for adequate maneuverability, …"

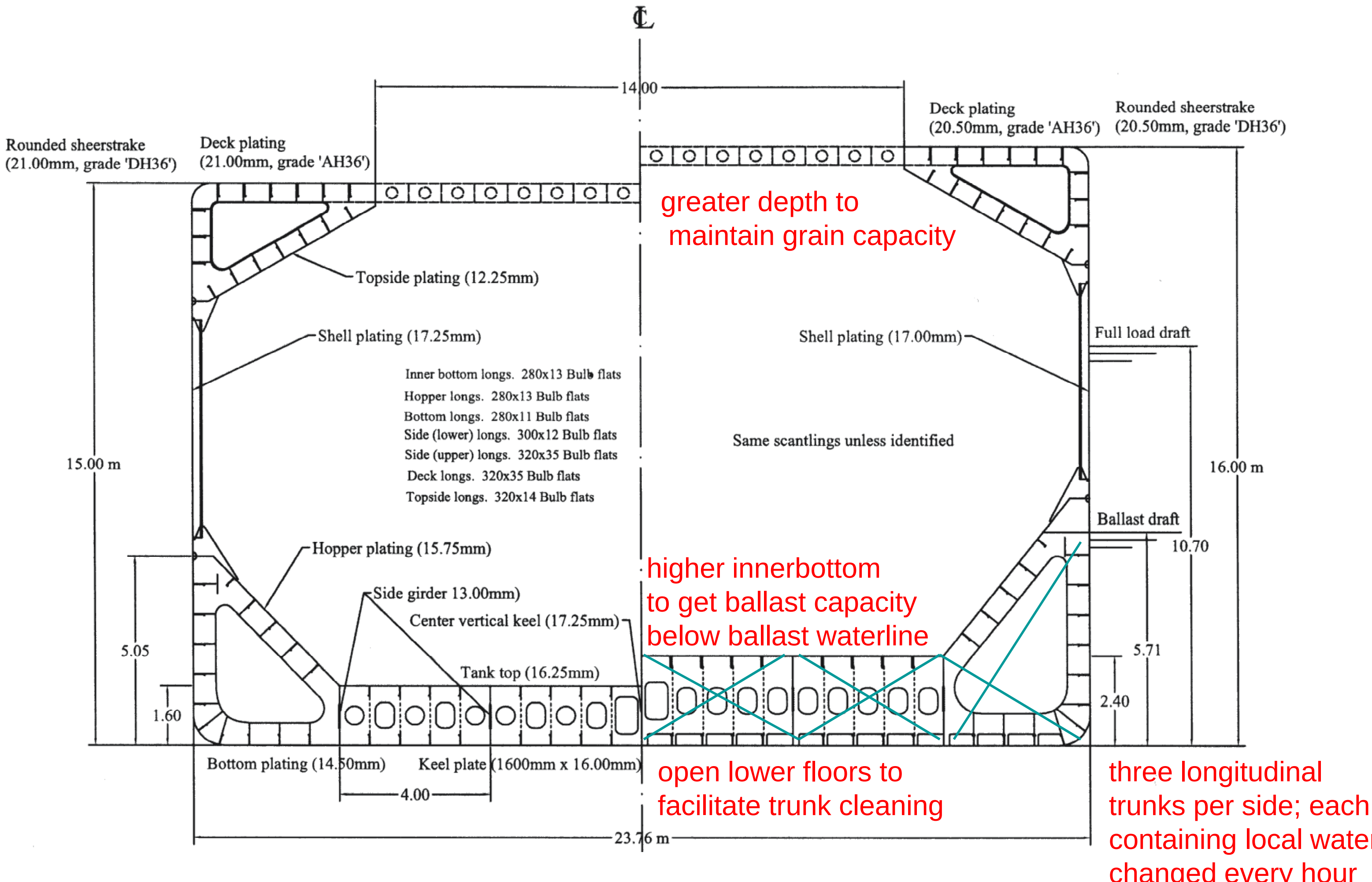
The Ballast-Free Ship Concept

- Traditional approach: Add water ballast to increase vessel weight in the light cargo condition
- Paradigm shift: instead of thinking add weight, reduce buoyancy
- "Foreign" Ballast-Free Ship concept principles:
  - Replace traditional ballast tanks by longitudinal, structural ballast trunks that extend beneath the cargo region below the ballast waterline.
  - Connect trunks to the sea through a plenum at the bow and another at the stern. Trunks flooded in ballast condition. Pumped when finished.
  - The natural hydrodynamic pressure differential between the bow and the stern region induces a slow flow in the ballast trunks.
  - Trunks are, therefore, always filled with "local seawater".
- US Patent #6694908, 2004

GLMRI Ballast-Free Ship Concept Project

- Concept advantages:
  - Ship only carries local water – no foreign ballast
  - Eliminates the need for costly ballast water treatment equipment
  - Effective approach even for transport of biota smaller than 50 microns; e.g. Vibrio cholerae
- Current GLMRI project research
  - Early work demonstrated concept feasibility (available pressure differential, trunk flow will develop, overall ship redesign).
  - Resistance and propulsion assessment showed serious cost disadvantage
  - Long-term goal is the computational fluid dynamics (CFD) study and hydrodynamic testing to minimize propulsion impact
  - This research requires the long-lead time and costly scale model for a Seaway-sized Ballast Free bulk carrier

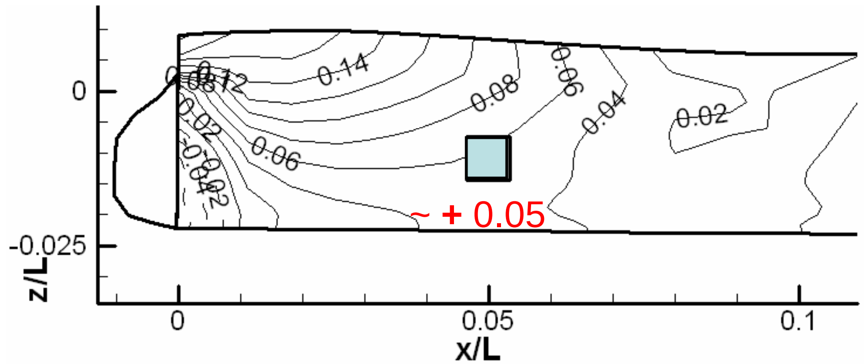
Comparison of Midship Sections



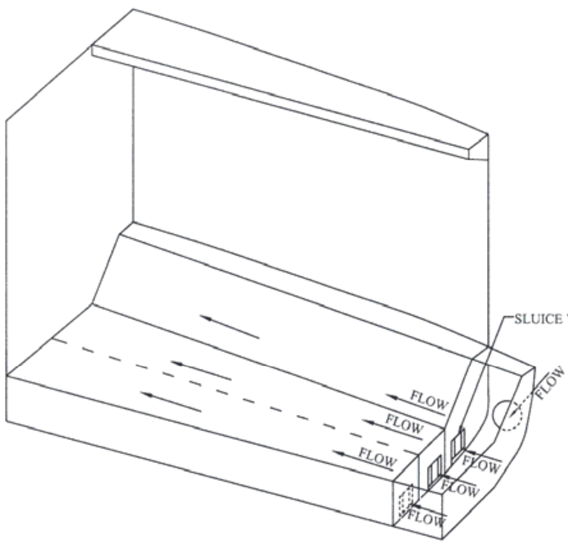
Typical Salty
Bulkcarrier

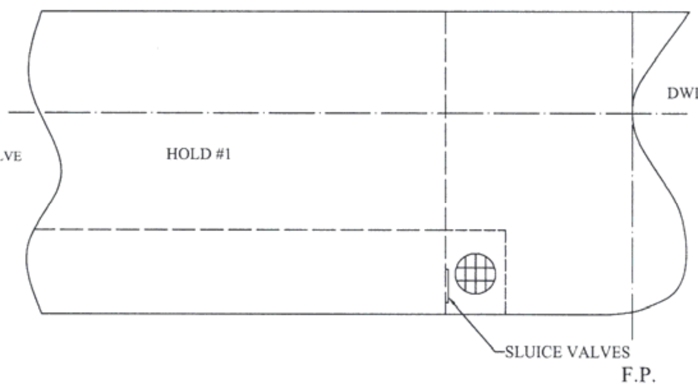
Ballast-Free
Ship Design

Schematic Bow Plenum

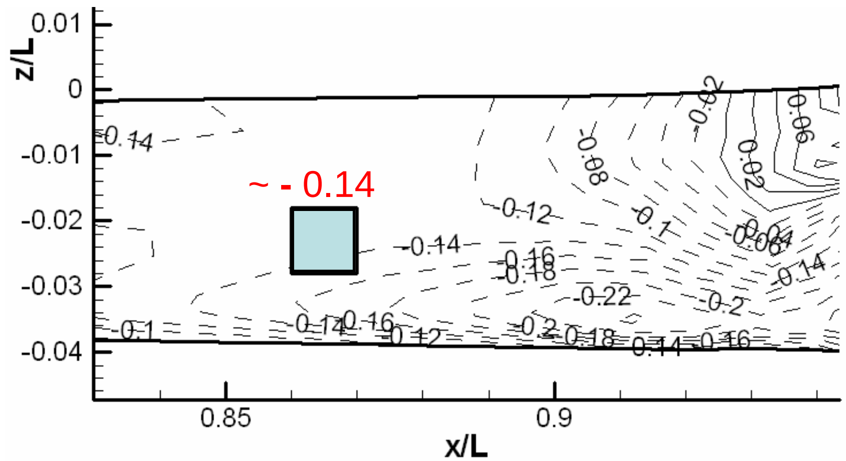


Nondimensional pressure coefficient $C_p > 0$

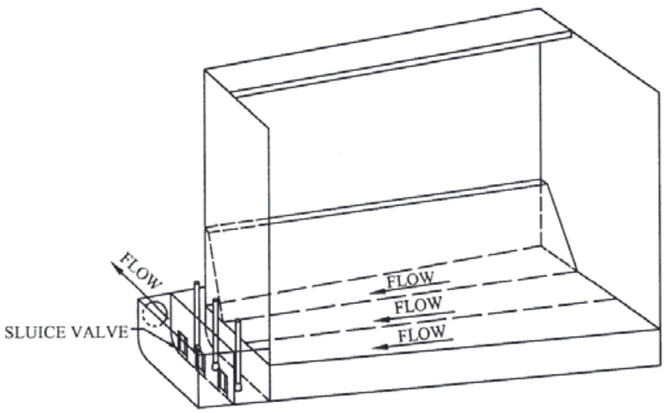


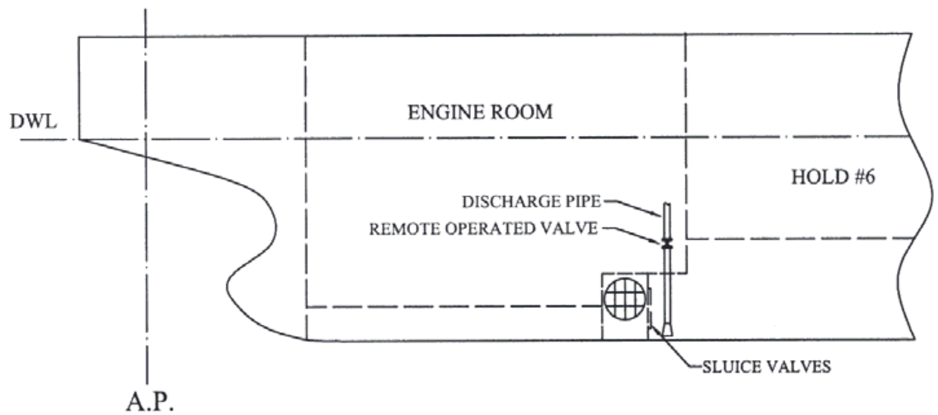


Schematic Aft Plenum



Nondimensional pressure coefficient $C_p < 0$





Initial Hydrodynamic Test Result

(for faster available LASH ship design not Seaway-sized bulk carrier)

Resistance Increase at Service Speed (22kn)

Full-Scale Ballast Exchange time (min)	Percent change relative to baseline
120 min.	2.2%
90 min.	2.7%
60 min.	4.0%

Required Shaft Power Increase at Service Speed (22kn) with Speed-Dependent Form Factor

Full-Scale Ballast Exchange Time (min)	Percent change relative to baseline
120 min.	7.4%
90 min.	16.6%
60 min.	32.5%

Initial Economic Comparison

	Typical bulk carrier	Ballast-Free bulk carrier
Installed engine Nominal MCR (hp)	11,640	
Block coefficient	0.838	0.844
Required service MCR (hp)	10,451	11,248
Hull steel weight (tons)	5,553	5,767
CRF (i = 10%, 20 yrs.)	0.1175	
Case 1: Engine size a continuous variable		
Net capital cost change ($)	- 96,900	
Net operating cost change per annum ($)	+ 42,700	
Change in RFR ($/ton)	**+ 0.133**	
Case 2: Same engine size		
Net capital cost change ($)	- 409,900	
Net operating cost change per annum ($)	+ 42,700 fuel penalty	
Change in RFR ($/ton)	**- 0.023**	

RFR = Required Freight Rate needed to make a profit

Goals of Current GLMRI Effort

- Design Ballast-Free ship Seaway-sized bulk carrier
- Build model ($$) for use in subsequent hydrodynamic tests which will attempt to,
- Optimize the location and details of the plena openings, particularly aft to,
- Minimize or reduce the 7.4% propulsion penalty found initially and used in economics studies

Seaway-sized Bulk Carrier Hull Form Design

- Design based upon
  Polsteam *Isa*
  design from Jiangnan
- Hull design using Maxsurf
  NURBS modeling program

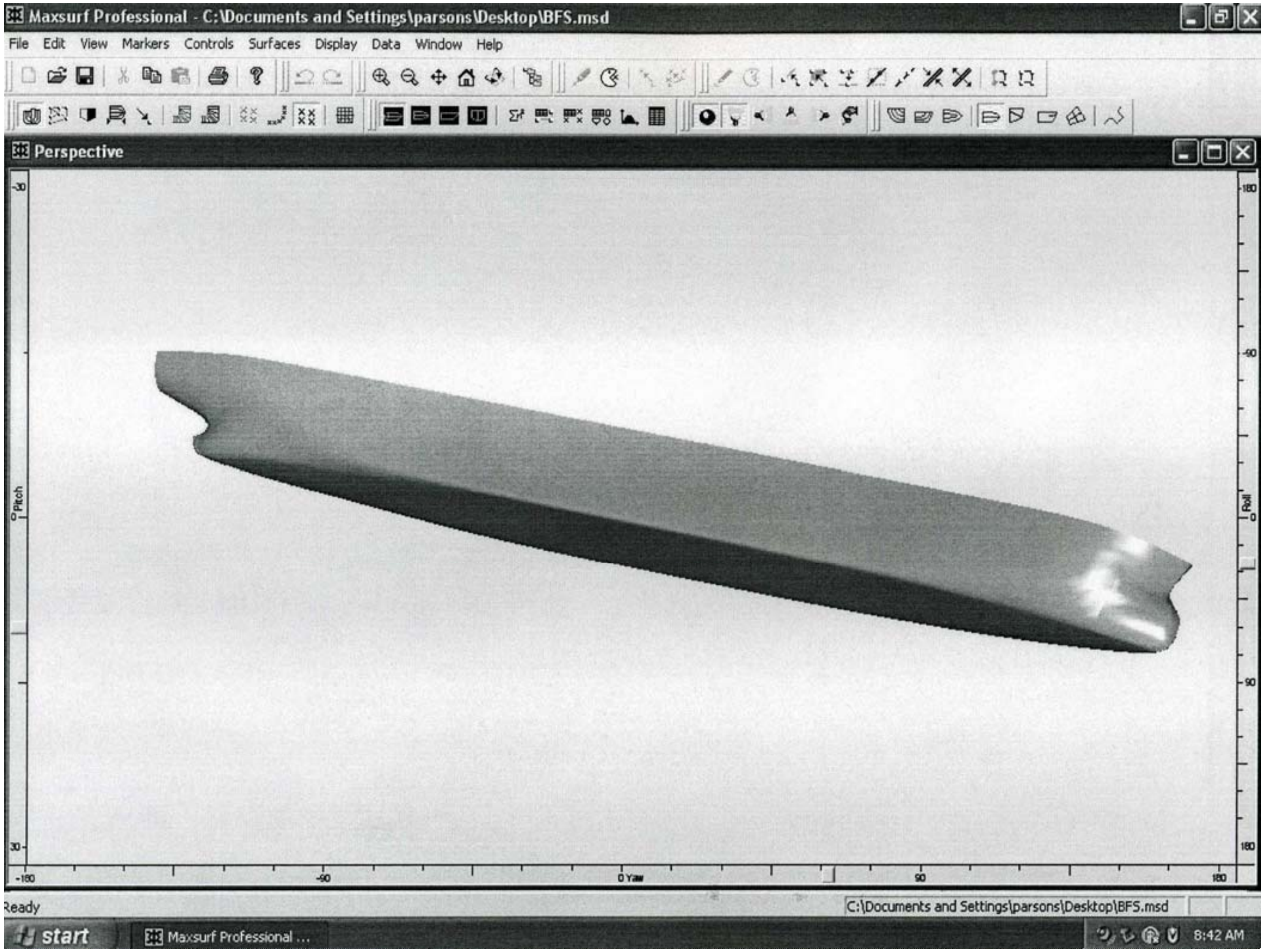
LWL	= 195.5 m
LBP	= 192.0 m
B	= 23.76 m
D	= 16.0 m
T_{FL}	= 10.7 m

Block C_B	= 0.835
Waterplane C_{WP}	= 0.909
Displacement	= 42,546 t

Ballasted to 40% fwd; 70% aft
Speed in ballast = 15.5 knots
Froude number F_n = 0.185

Scale Ratio λ = 37.92 (5 m model)

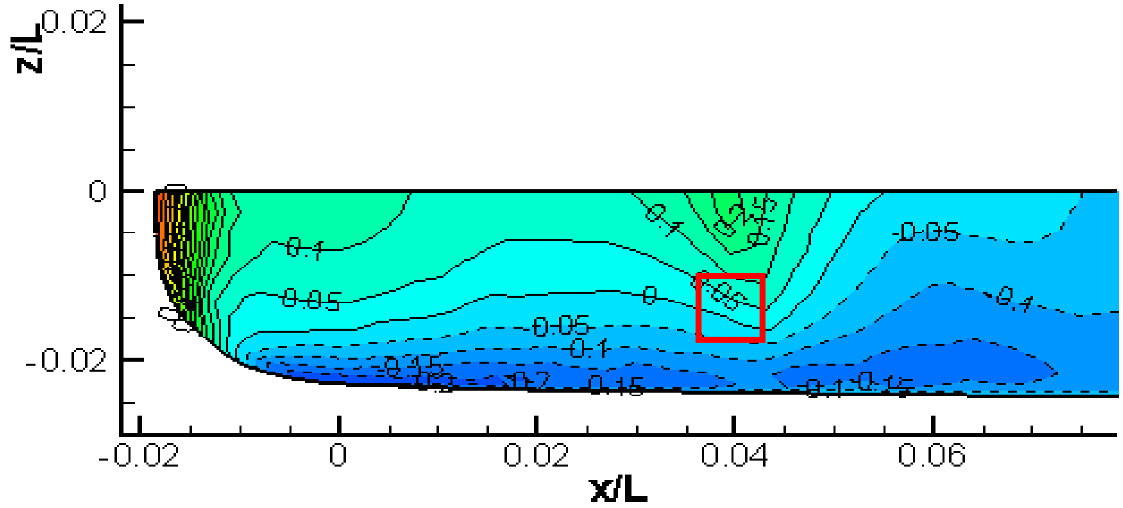
Bulk Carrier Hull Design

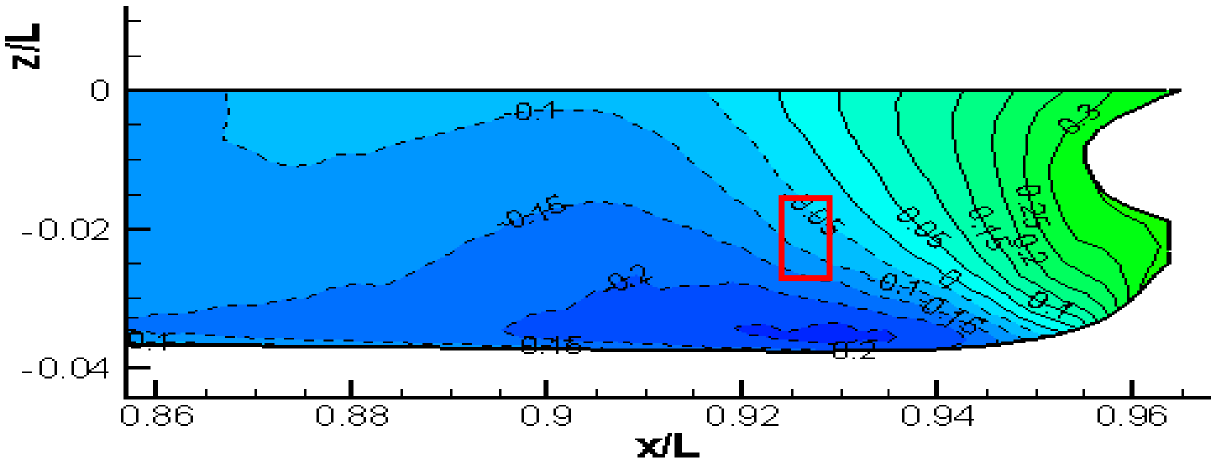


External Flow Studies

- Computational Fluid Dynamics analysis using FLUENT® for pressure differential
- Model-scale ballast condition using Froude scaling
- Using $\kappa - \varepsilon$ turbulence model; wall functions near wall
- Converged model at 1,507,546 cells
- Friction drag within 0.3% of ITTC friction line
- Form drag coefficient k = 0.139

Pressure Contours in Ballast



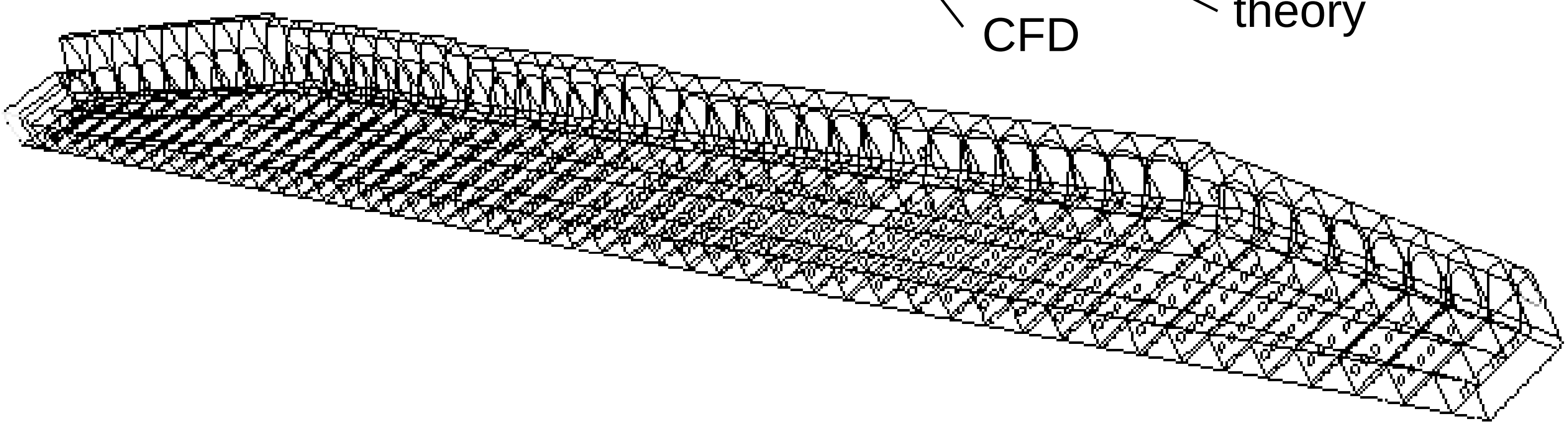


Internal Flow Simulation

- Computational Fluid Dynamics analysis using FLUENT®
- Cells 705,915 in model; three trunks per half ship
- Boundary conditions from external study
- Confirmed initial model scaling law derived theoretically

$$Q_m = Q_s \lambda^{-(2.52 \sim 5/2)}$$

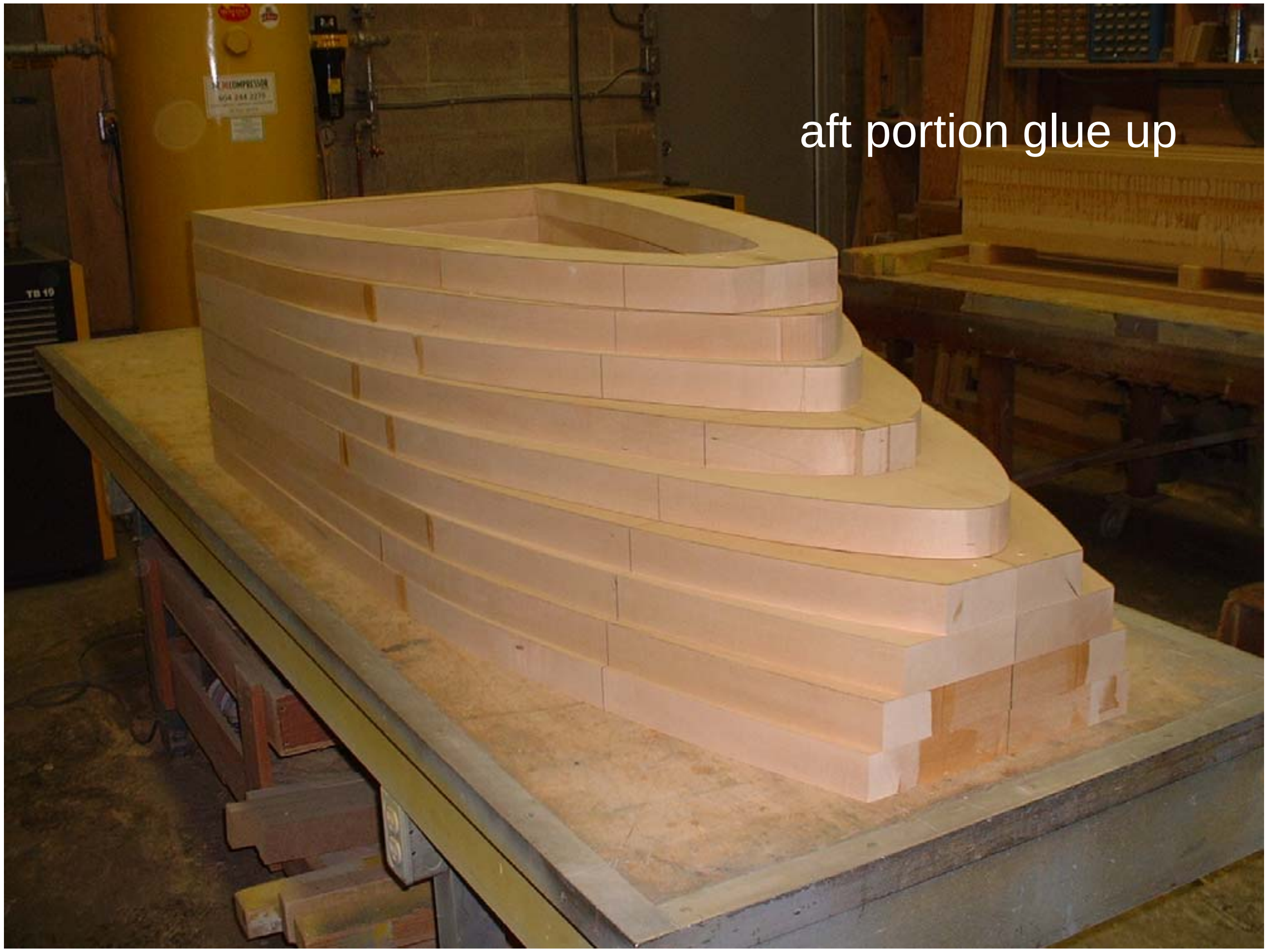
CFD (2.52) — theory (5/2)



The Future – What's Next

- Model is now under construction at
  F.M. Pattern Works, North Vancouver, BC
- Model delivery expected near end of October 2006
- Seeking funding for hydrodynamic testing
  (pending GLMRI proposal)
- Optimize plena locations and details first using CFD
- Confirm/refine optimum locations and details in model test
- Expect to eliminate most of the 7.4% propulsion penalty
- At no penalty, the ΔCFR would then be -0.20 $/ton
  relative to a filtration and UV treatment installation

Model Construction Underway in BC



5 m = 16'5" model at pattern maker's precision

New FY 07 Proposals from University of Michigan

- Short-Sea Shipping Opportunities for the Great Lakes: An economic analysis for the waterborne transportation of containerized cargo
  A. N. Perakis, NAME
- Hydrodynamic Optimization Testing of Ballast-Free Ship Design
  M. G. Parsons, NAME
- A Review of Great Lakes Shipbuilding and Repair Capability
  – Past, Present and Future
  Parsons as placeholder for D. J. Singer (new July 2006), NAME
  with T. Lamb (retired NAME, UM June 2006)
- Conceptual Design of a Family of Small, Economical, General-Purpose *Green Future* Class Ships for the Great Lakes Trade
  Parsons, NAME