ANNUAL REPORT 2007

UIUC, June 12, 2007

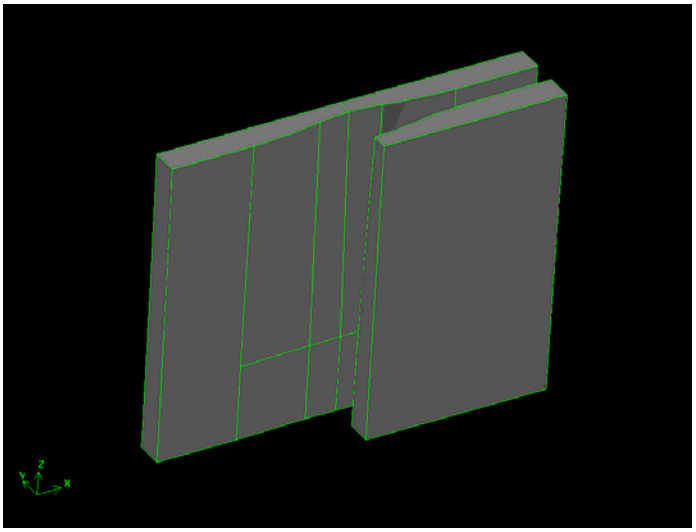
Flow in a Funnel Mold

Bret Rietow (MS Student) &
Brian G. Thomas

Department of Mechanical Science and Engineering
University of Illinois at Urbana-Champaign

Objectives

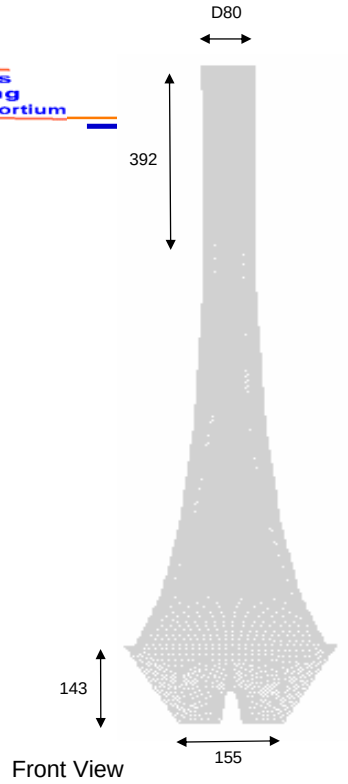
- Model fluid flow in a funnel mold caster
- Compare steel flow with water models
- Investigate the effect of casting speed



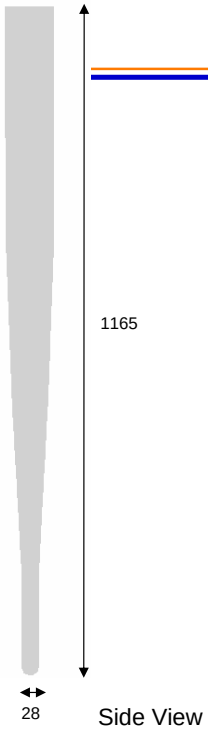
Dimensions:

Narrow Face: 90 mm
Wide Face: 1450 mm
Mold Length: 1200 mm
Max. Funnel Width: 170 mm
SEN Submergence: 265 mm

Nozzle 2: Geometry and Operating Conditions



Front View



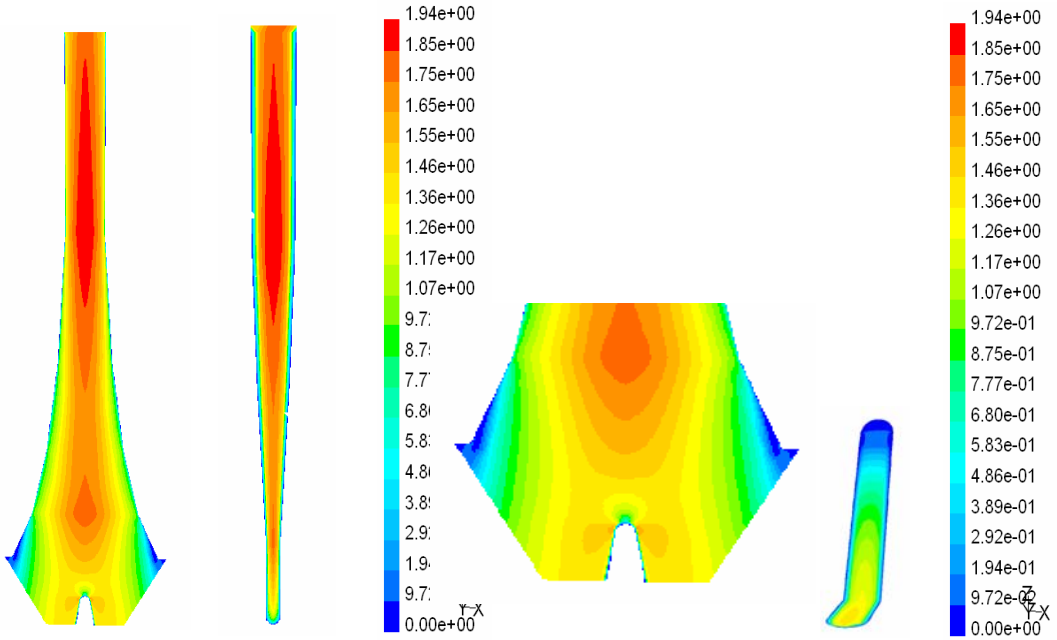
Side View

Casting Speed = 3.6 m/min
(slab size = 90x1450 mm)

Inlet velocity (F.S.) = 1.56 m/s
Steel density = 7000 Kg / m3
Steel viscosity = 0.006Kg/m.s

All Dimensions are in mm

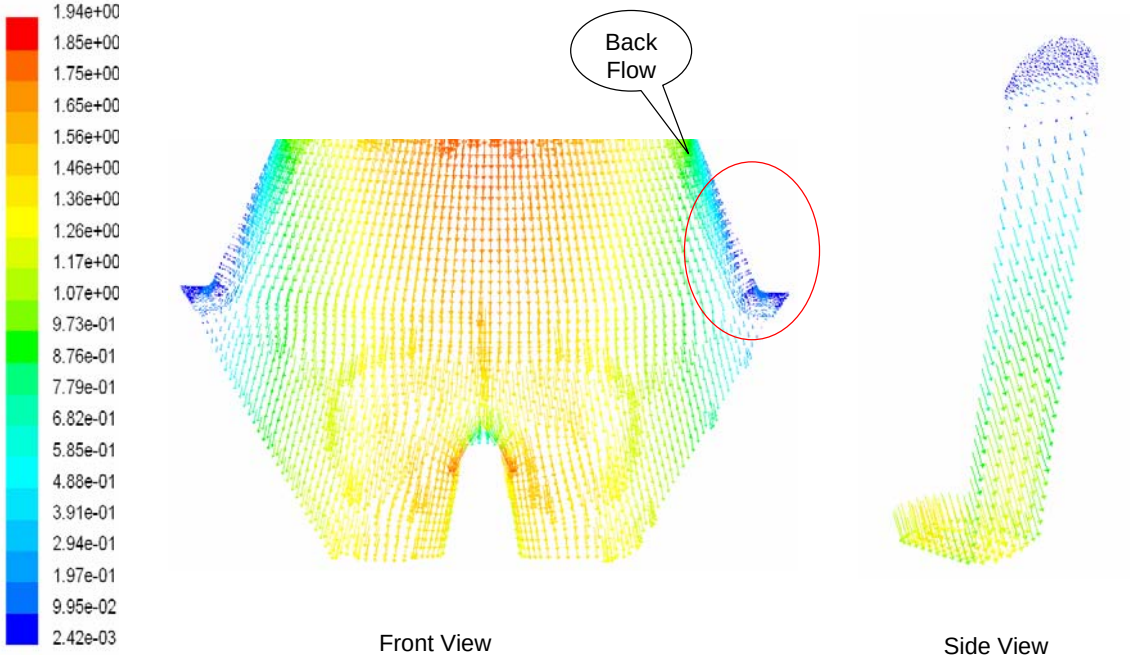
Velocity in nozzle



Front View

Side View

Port outlet velocity



Jet Characteristics

Casting Speed (m/min)	**3.6**
Jet Speed (m/s)	**1.14**
Vertical Jet Angle (degrees)	**79.4**
Port-to-bore Ratio	**1.62**
Back Flow Zone Percentage	**<4%**

Good uniform spread of flow leaving ports despite a large port to bore ratio.

Steep downward jet, resulting in a slower flow on the top fluid surface.

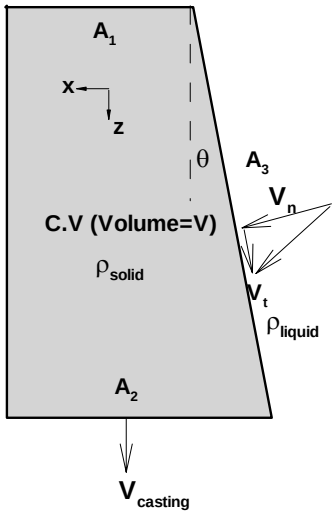
A high casting speed can be run with this nozzle without EMBR.

Model Formulation: including steel shell

- CON1D used to predict shell thickness
- Mass and momentum "sinks" used at fluid boundaries to simulate solidification
  - Sinks are a function of shell curvature

$$MassSink = \frac{-\rho * V_c * v_z}{C.V.}$$

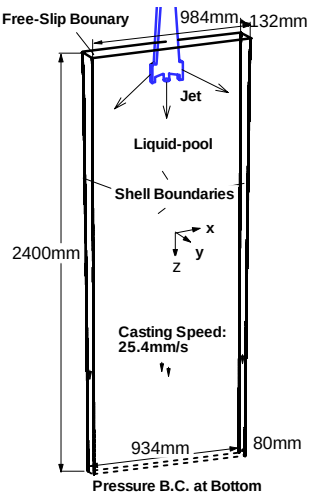
$$MomentumSink = \frac{-\rho * V_c * v_z}{C.V.} * V_i$$



- Standard k-epsilon turbulence model
- FLUENT solves N.S. equations for steady, single phase flow

Model Validation

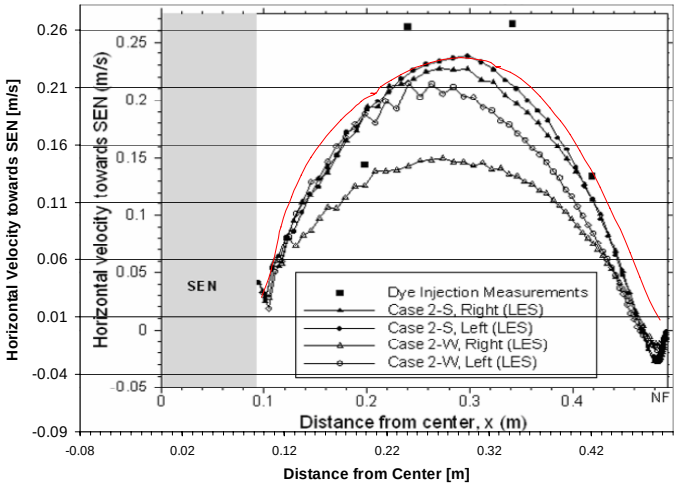
- Comparison to previous work performed by Quan Yuan on a parallel mold thin-slab caster



Parameter/Property	*Case 2-S*
Mold Width (mm)	984
Mold Thickness (mm)	132
Mold Length (mm)	1200
Domain Width (mm)	984 (top) 934.04 (domain bottom)
Domain Thickness (mm)	132 (top) 79.48 (domain bottom)
Domain Length (mm)	2400
Nozzle Port Height × Thickness (mm × mm)	75 × 32 (inner bore)
Bottom nozzle Port Diameter (mm)	32
SEN Submergence Depth (mm)	127
Casting Speed (mm/s)	25.4
Fluid Kinematic Viscosity (m^2/s)	7.98×10^{-7}

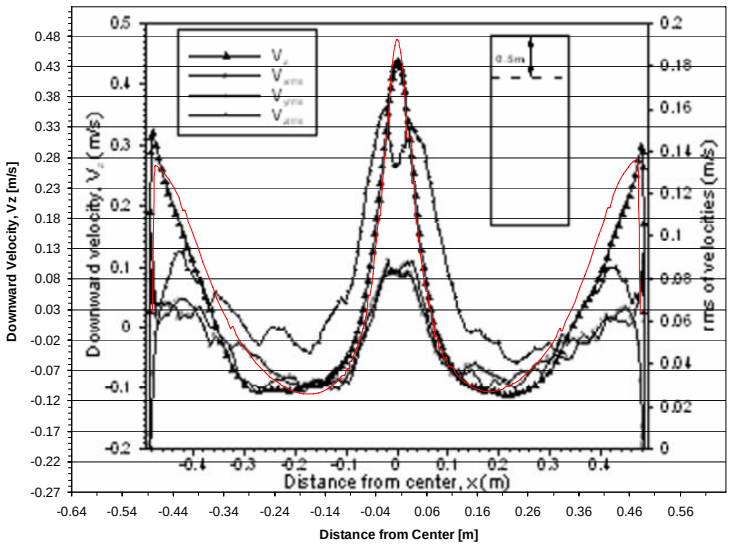
Model Validation (top surface velocity)

- Horizontal Velocity at Top Surface WF Centerline

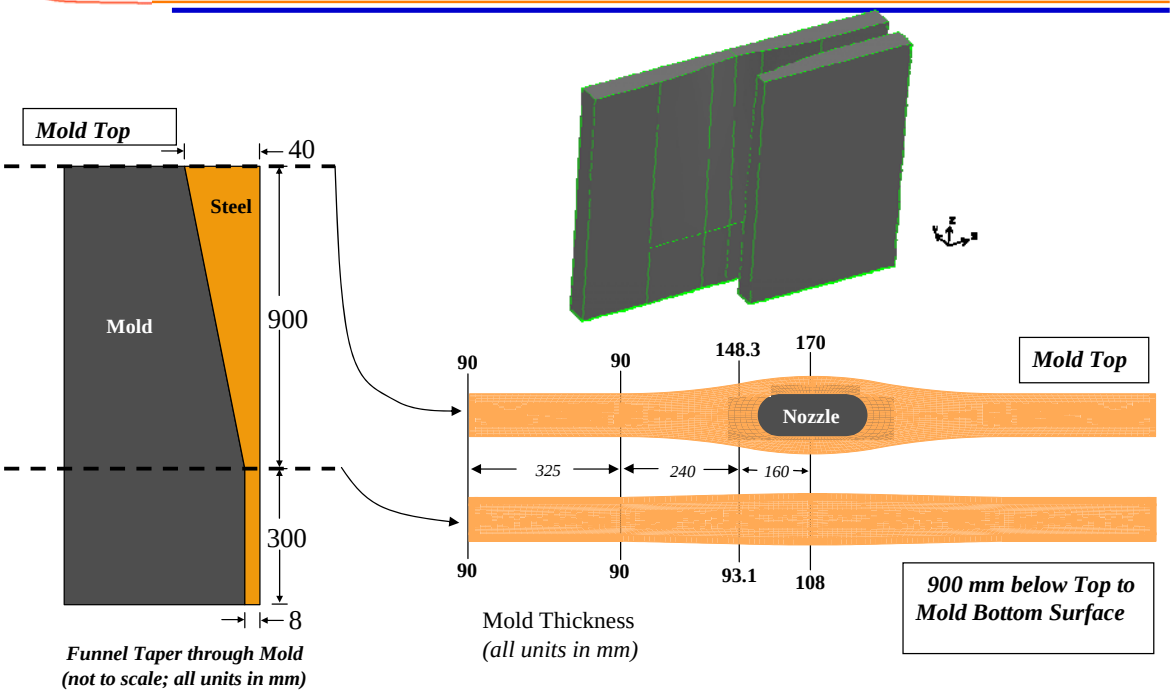


Model Validation (cont.)

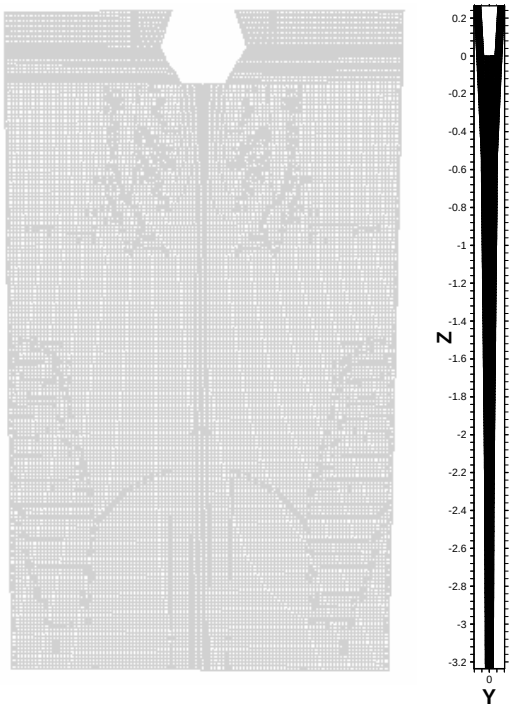
- Downward Velocity along WF Centerline, 0.5m from top surface



Funnel Mold Design



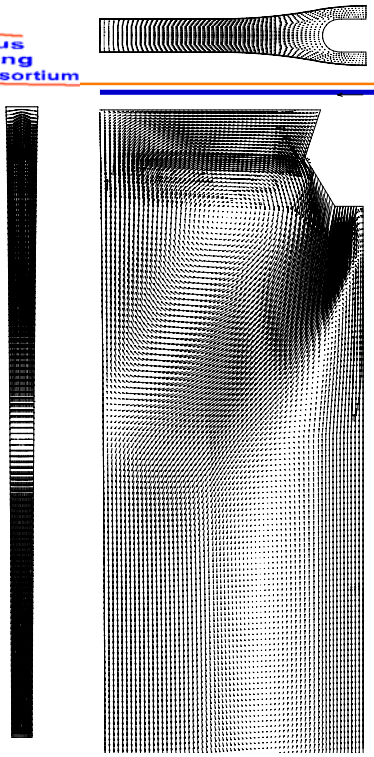
Funnel Mold Model



Solidifying steel shell greatly affects shape of liquid pool

Casting Speed	*3.6 m/min*
Mold Width (mm)	1450
Mold Thickness in top funnel region (mm)	170
Mold Thickness at narrow face (mm)	90
Mold Length (mm)	1200
Domain Width (mm)	1450 (top) 1414 (domain bottom)
Domain Thickness (mm)	90 (top) 50.84 (domain bottom)
Domain Length (mm)	2500
Nozzle 2: Port Effective Height × Thickness (mm × mm)	201.53 × 28
SEN Submergence Depth (mm)	265
Casting Speed (m/min)	3.6
Fluid Kinematic Viscosity (m^2/s)	8.57×10^{-7}

Flow Pattern details

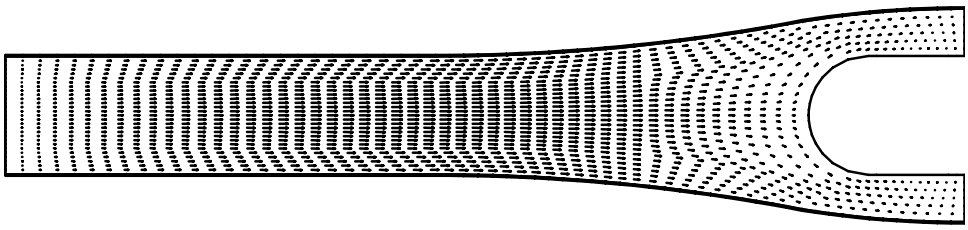


3.6m/min steel caster

Centerline

Surface velocity details

3.6m/min steel caster



Uniform flow towards SEN (idealized symmetric steady flow pattern)

Rounded SEN allows smooth streamlined flow and penetration into gap between SEN and WF

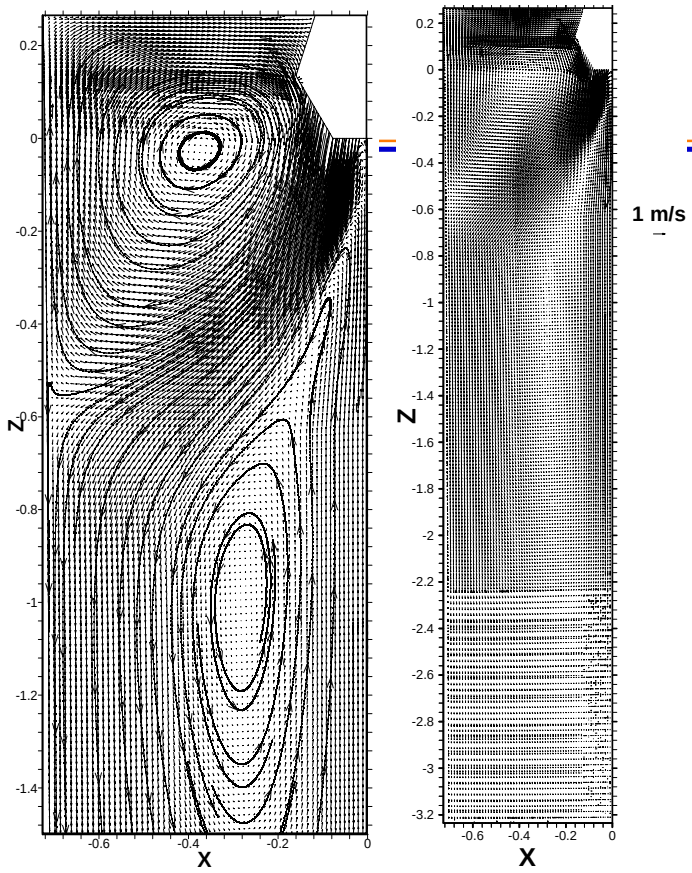
Funnel effect is small (flow behavior similar to parallel mold)

Flow Pattern details

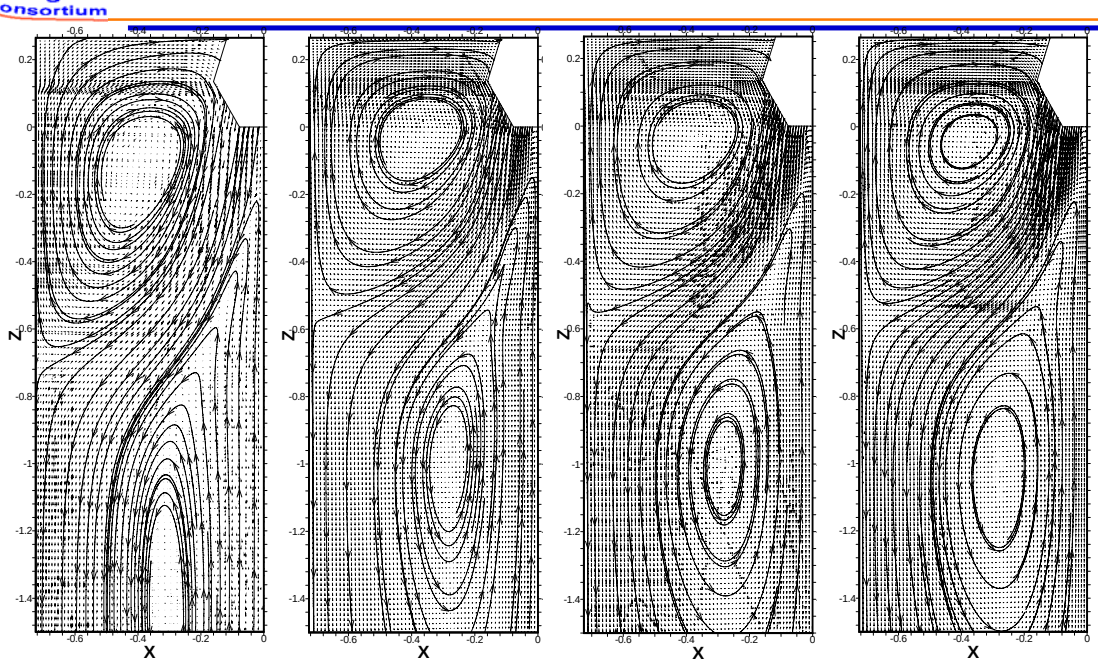
Velicity vectors and streamlines in WF Centerline

3.6m/min steel caster

Note: Lower recirculation zone extends deep into caster



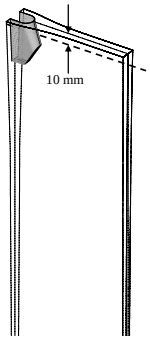
Overall Flow Pattern (CL comparison)

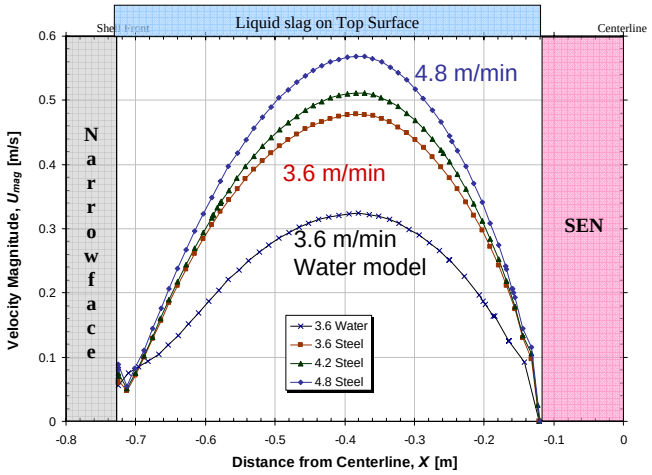


3.6m/min Water model | 3.6 m/min | 4.2m/min | 4.8 m/min

Qualitatively similar flow patterns (water model has lower NF impingement)

Surface velocity
(towards SEN, across width near top surface)

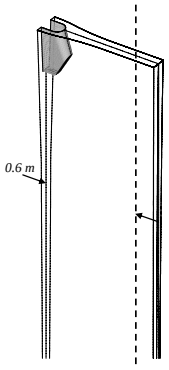


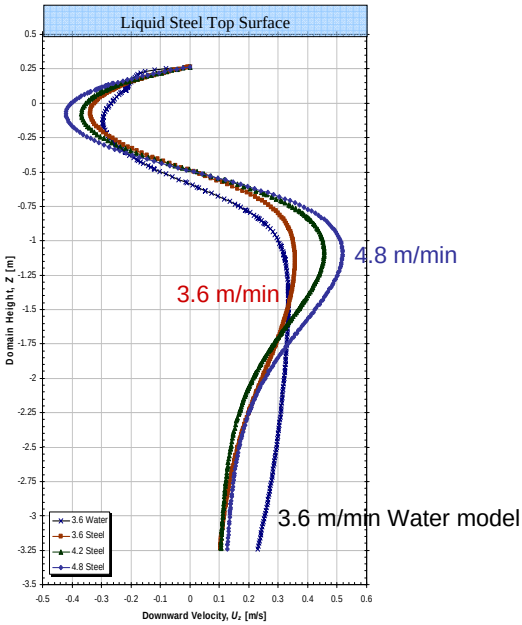


Increasing casting speed linearly increases surface velocity

Water model produces much lower surface speeds

Downward velocity
(down centerline near NF)

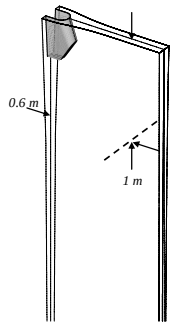


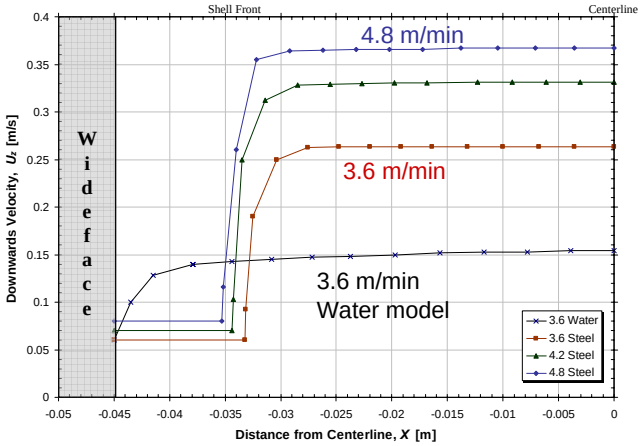


Increasing casting speed increases velocity more towards end of lower recirculation region

Water model produces excessive speeds low in caster

Downward velocity
(through thickness 1m below meniscus)

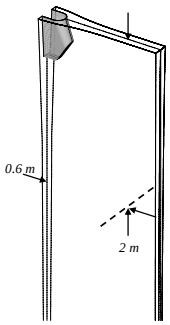


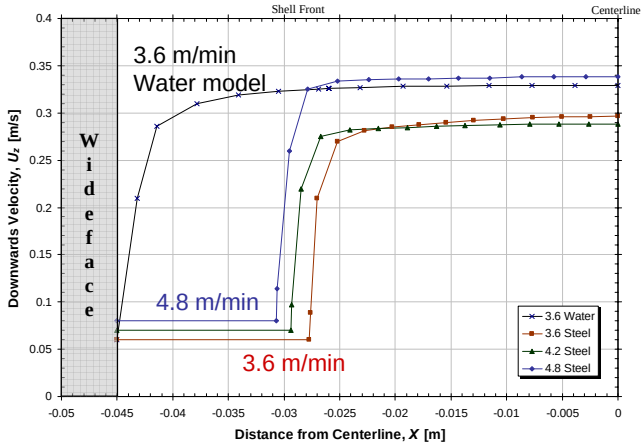


Water model under-predicts speed in upper recirculation region
(lack of shell resistance to push flow upwards)

Increasing casting speed linearly increases velocity

Downward velocity
(through thickness 2m below meniscus)

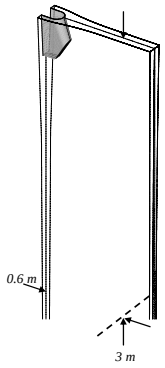


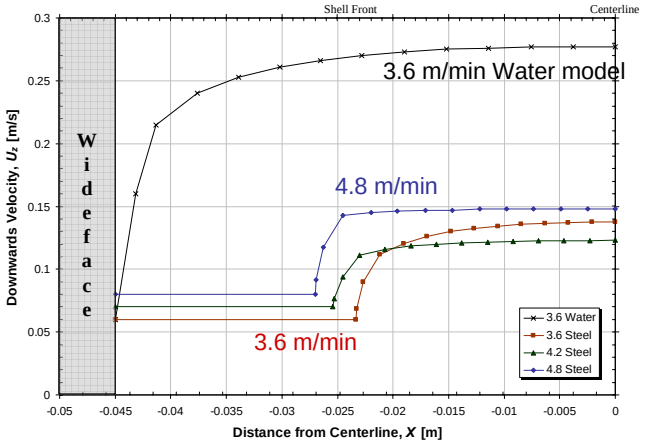


Increasing casting speed linearly increases velocity

Water model produces higher speed estimates in lower recirculation region

Downward velocity
(through thickness near NF)

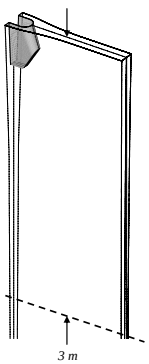


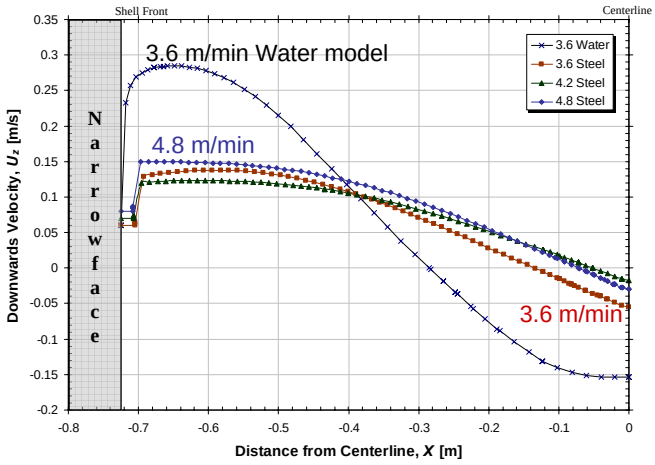


Increasing casting speed increases velocity linearly

Water model produces excessive speeds low in caster (missing shell)

Downward velocity
(across width 3m below meniscus)





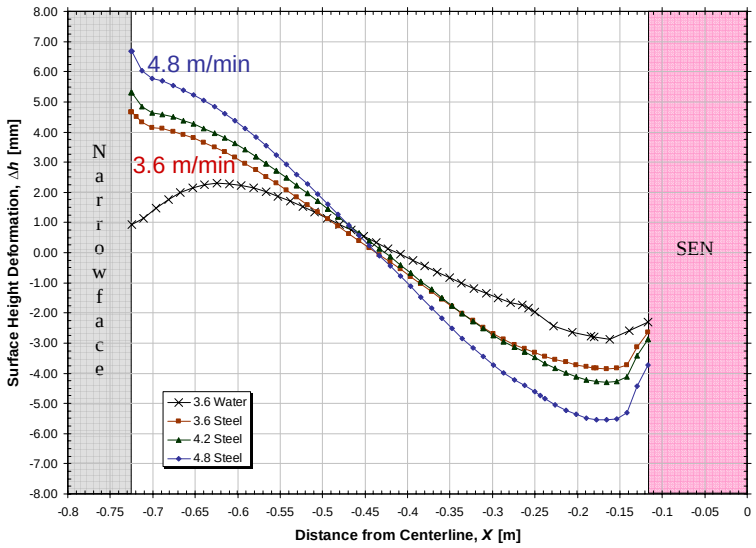
Increasing casting speed increases velocity linearly

Water model produces excessive speeds low in caster (missing shell)

Top-Surface Standing Wave Profile

$$height = \frac{p - p_{mean}}{(\rho_{steel} - \rho_{flux}) * g}$$

Higher standing waves in steel than water model



Steel-slag interface height along wideface centerline approximated using fixed surface pressures

Conclusions: Steel Caster / Water Model

- Water model and steel both have generally similar classic double-roll flow patterns. The funnel effect is small.
- Water model underpredicts velocity in upper mold, including 32% low top surface velocity (0.34 vs 0.48 m/s), and less surface turbulence.
- Steel shell provides resistance to flow (~50% drop in cross section area), so "pushes" more fluid to the surface, increasing recirculation velocities.
- Water jet penetrates deeper than steel jet, impinging ~0.13m lower on NF, due to lack of shell taper restricting downward flow.
- Far below top surface, downward steel flow is nearly uniform (at the casting speed), so all particles penetrating this far are eventually trapped. Water model sends flow disturbances far into strand: producing more eddies in low-velocity regions and extending lower recirculation zone.

Conclusions: Effect of Casting Speed

- Increasing casting speed has little effect on single-phase flow pattern and jet impingement location (-0.835 m below the top surface). Lower recirculation region is extended further down the strand.
- Velocity increases almost linearly with casting speed. Maximum surface velocity increases with casting speed, from 0.48 m/s (3.6 m/min) to 0.57m/s (4.8 m/min)
- Increasing casting speed produces *quadratically* increasing top surface wave height and profile
- The highest point of the standing wave occurs near the meniscus and slopes downward to the SEN.

Acknowledgements

- Continuous Casting Consortium Members (Algoma, Baosteel, Corus, Delavan, Labein, LWB Refractories, Mittal Riverdale, Nucor, Postech, Steel Dynamics)
- National Science Foundation
  - GOALI DMI 05-00453 (Online)
- National Center for Supercomputing Applications (NCSA) at UIUC
- Fluent, Inc.
- Former UIUC researchers: L. Zhang and J. Aoki