ANNUAL REPORT 2007

UIUC, June 12, 2007

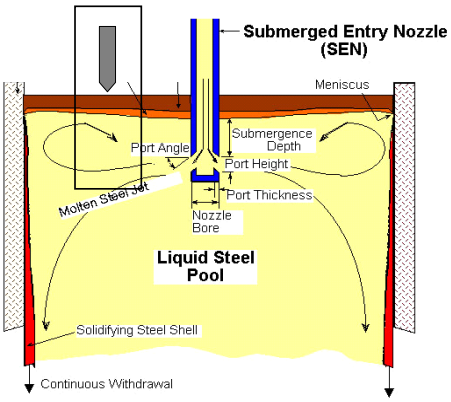
Analysis of Steel Surface Velocity from Nailboard Tests

Bret Rietow (MS Student) &
Brian G. Thomas

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

Objectives

- Quantify Nailboard test as a simple measure of surface velocity in CC mold
  - allow operators to gain fast, inexpensive information about mold flow pattern
  - Model calibration / validation
  - Validate other methods

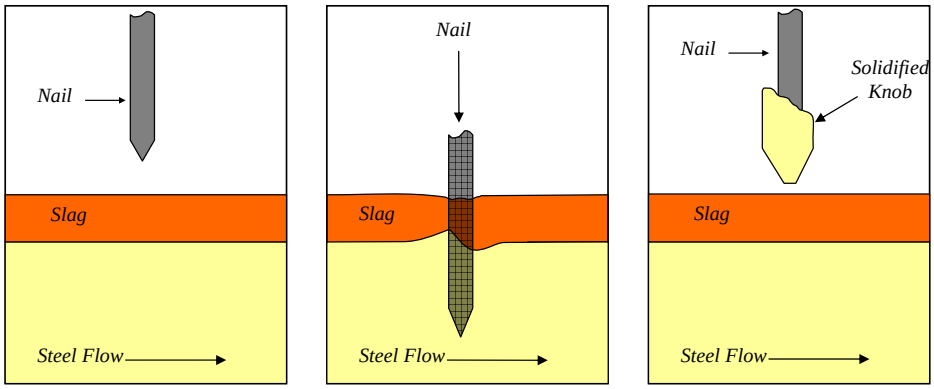


Metal Flow Measuring Devices

- Flow Meters
  - Useless in high-temperature environment of molten steel
- Tracer Techniques
  - May alter composition of metal
  - Flow is not always horizontal
- Pitot Tube
  - Metal solidifies and clogs up inlet
- Visualization Methods
  - Slag layer prevents any optical device from “seeing” the flow surface
- Electromagnetic Devices
  - Have not been shown to transmit through the slag layer
- Strain-measured Probe
  - Requires a solid base
- Vortex-Frequency Probes
  - Expensive
  - Requires a steady base

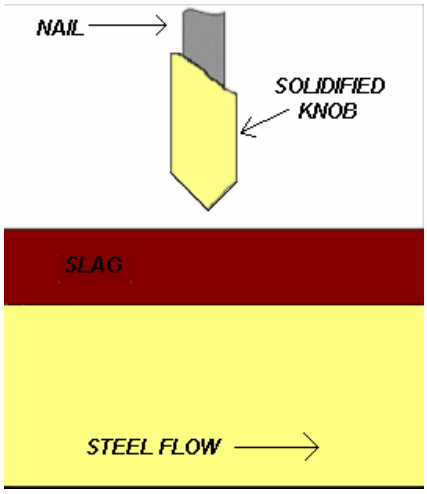
NailBoard Method

1. Nail inserted into surface of flowing steel (3-5s)
2. Fluid builds up on leading edge of nail, and decreases on opposite side and freezes as lump
3. Remove and measure solidified lump



Measure solid lump reveals

– Flow direction (from orientation of lump)
– Flow velocity (from steepness of angle)

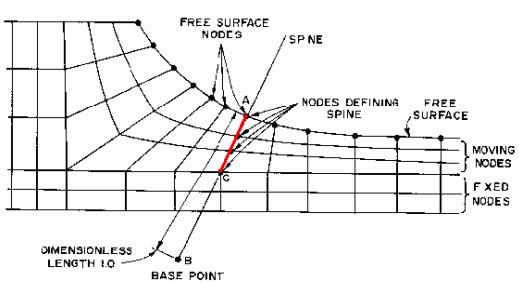


3-D Fluid Flow Model (FIDAP)

- Continuity Equation: $\frac{\partial \overline{u_i}}{\partial x_i} = 0$
- Reynolds-Averaged Navier Stokes equations:

$$\frac{\partial \overline{u_i}}{\partial t} = -\frac{\partial \overline{u_i}\,\overline{u_j}}{\partial x_j} + \frac{\partial}{\partial x_j}\left\{ v\left(\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i} \right) \right\} - \frac{\partial \overline{p}}{\partial x_i} - \frac{\partial \tau_{ij}}{\partial x_j}$$

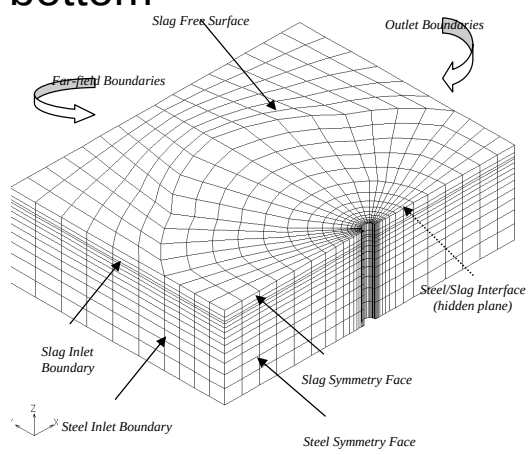
- Track 2 free surfaces: Spines method in FIDAP



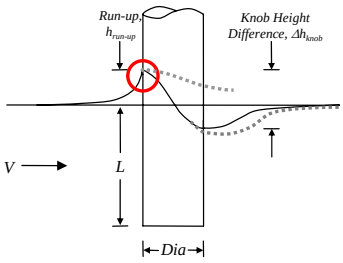
- K-e turbulence model
- Steady State (no waves)
- Isothermal
- Flow field develops faster than lump solidifies

FIDAP Solution Procedure

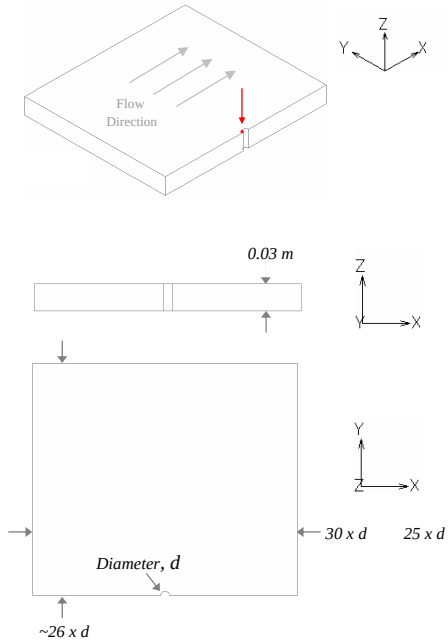
- First step - Steady state, fixed free surface run
- Second step - Transient free surface run
  - results from first run is initial condition
- nail extends to domain bottom
- Boundary Conditions:



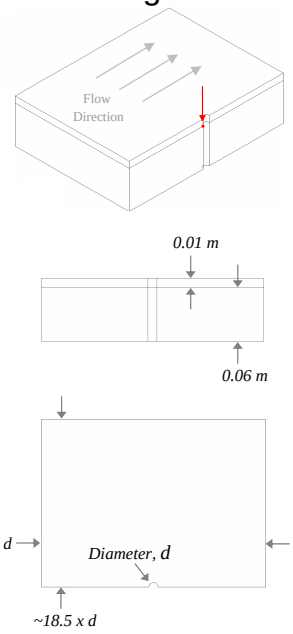
Model Domain



No-slag model

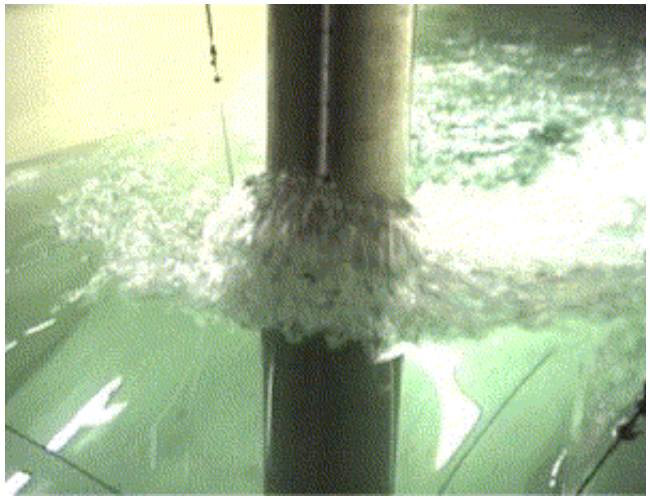


With-slag model



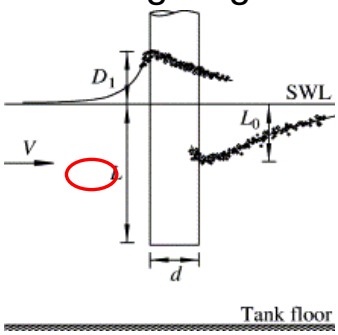
Water model measurements

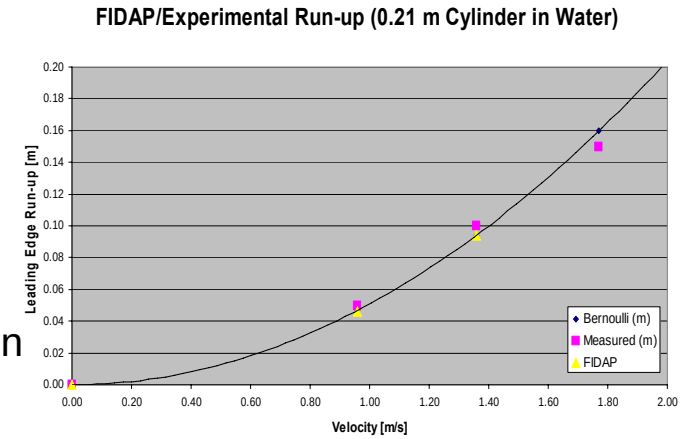
- Chaplin et al (2003)- Steady flow past vertical surface-piercing 0.21m cylinder



Model validation with water model

- Leading Edge Run-up Comparison





Bernouli analytical solution

$$p + \tfrac{1}{2}\rho V^2 + \rho g h = const.$$

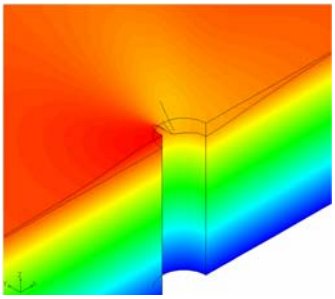
$$Runup = \frac{V^2}{2g}$$

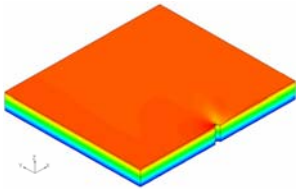
FIDAP IS ACCURATE!

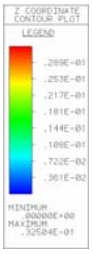
Velocity Results

No-slag model

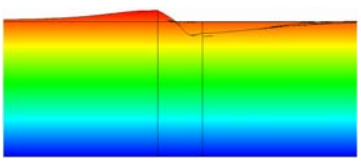
Zoom around Nail





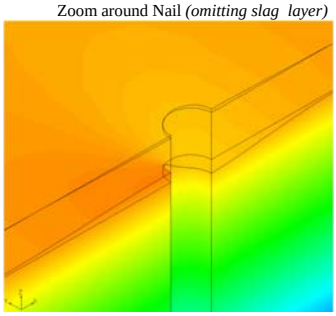


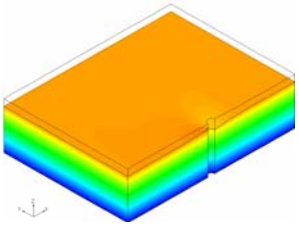
Symmetry Boundary

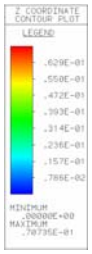


With-slag model

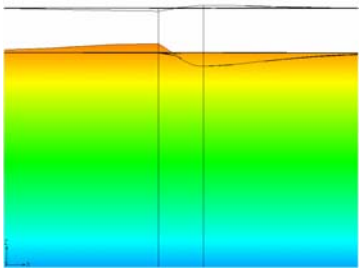
Zoom around Nail *(omitting slag layer)*





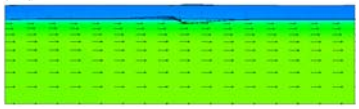


Symmetry Boundary *(omitting slag layer)*

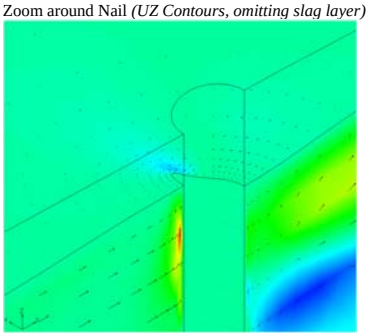


Velocity Results (steel with slag)

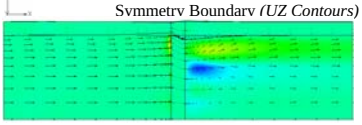
Vertical Far-field Boundary *(UX*

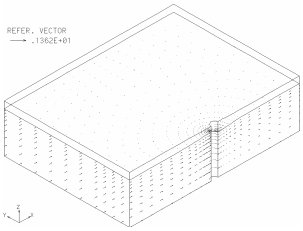


Zoom around Nail *(UZ Contours, omitting slag layer)*

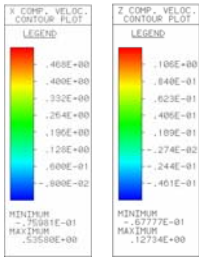


Symmetry Boundary *(UZ Contours)*

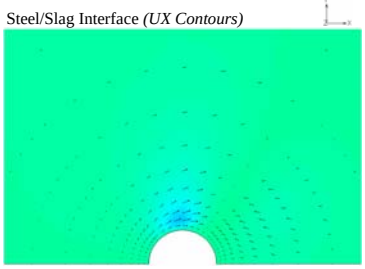




REFER. VECTOR
.5449E+00

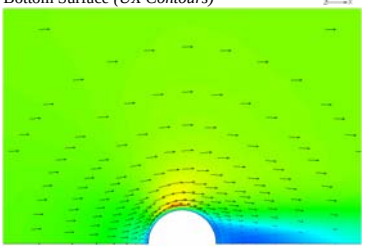


Steel/Slag Interface *(UX Contours)*

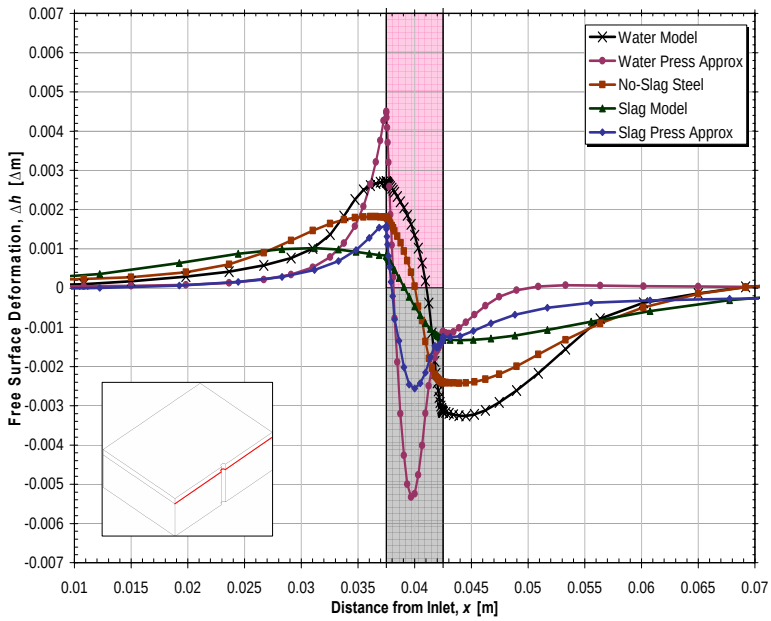


Outlet Boundary *(UZ Contours)*

Bottom Surface *(UX Contours)*



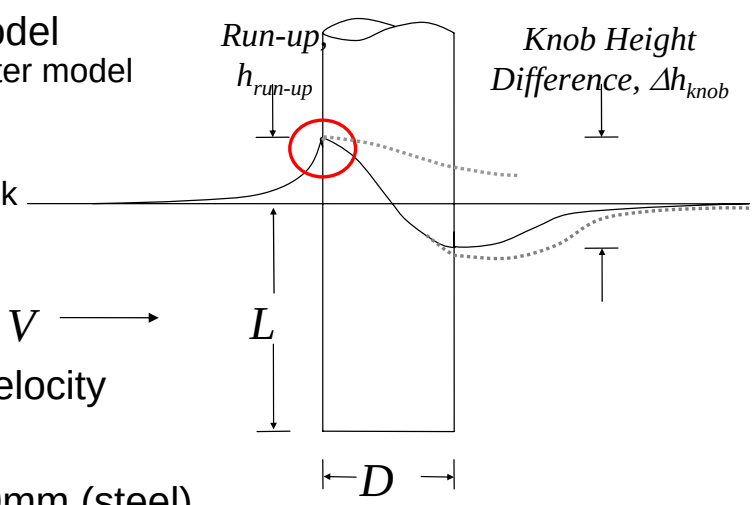
Flow profile predictions



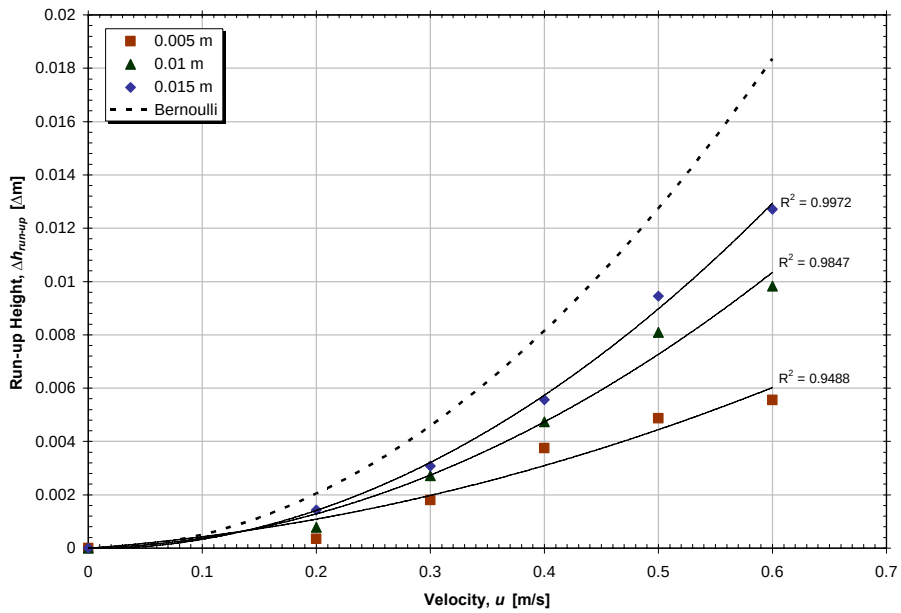
5-mm nail
0.3 m/s

Simulation Cases

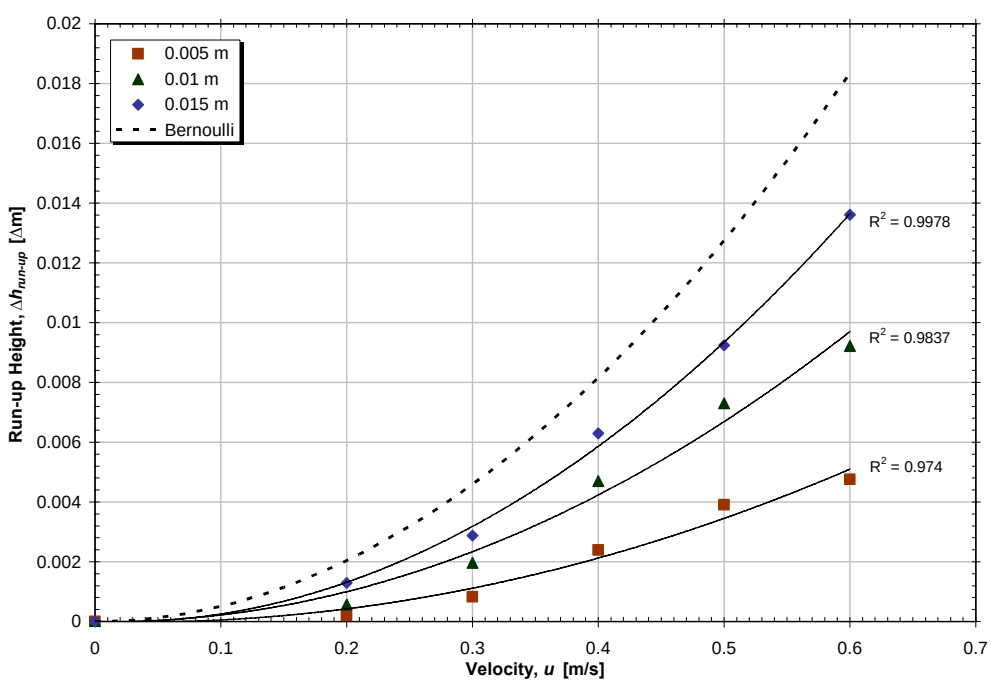
- 1. No-Slag layer model
  - Comparison with water model
- 2. Slag layer model
  - Realistic, 10mm thick
- Vary nail diameter:
  - 5, 10, 15mm
- Vary steel surface velocity
  - 0.1-0.6 m/s
- Domain depth: L=50mm (steel)
- Domain width: 25 D
- Domain length: 18.5 D



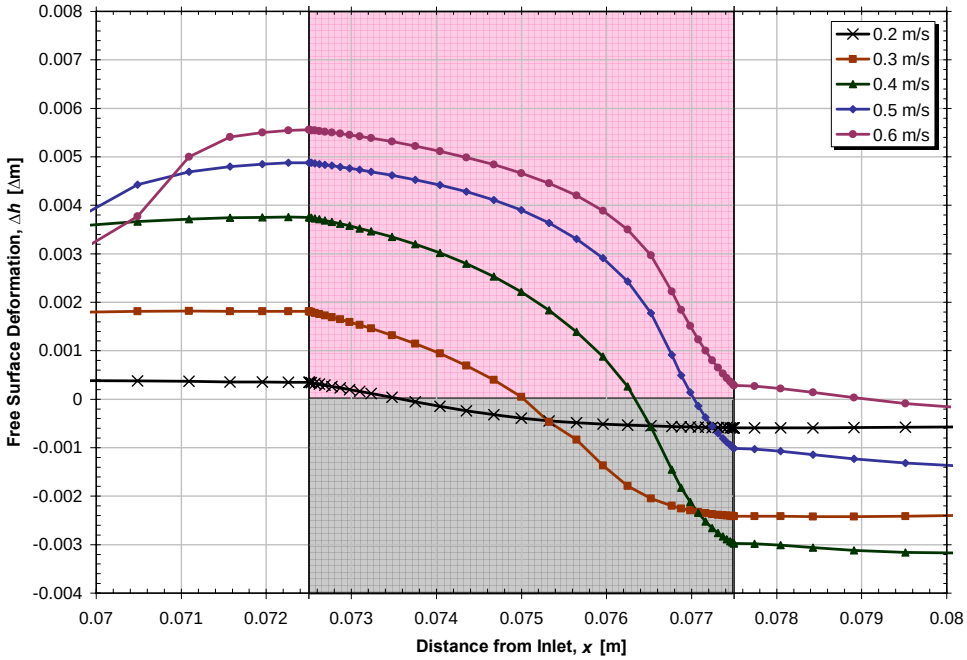
Leading-edge Runup (no slag)



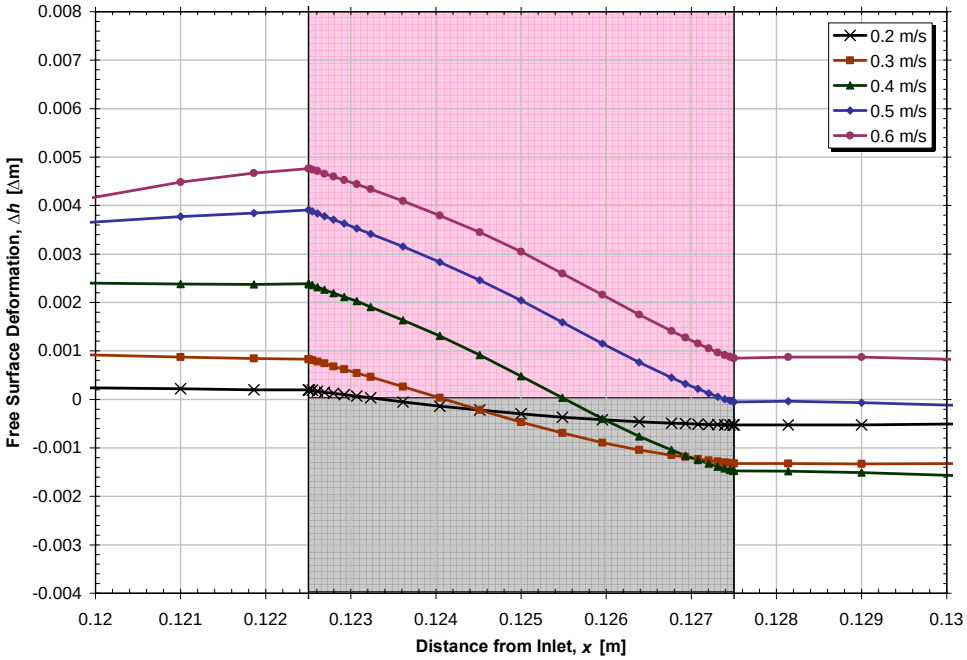
Leading-edge Runup (with slag)



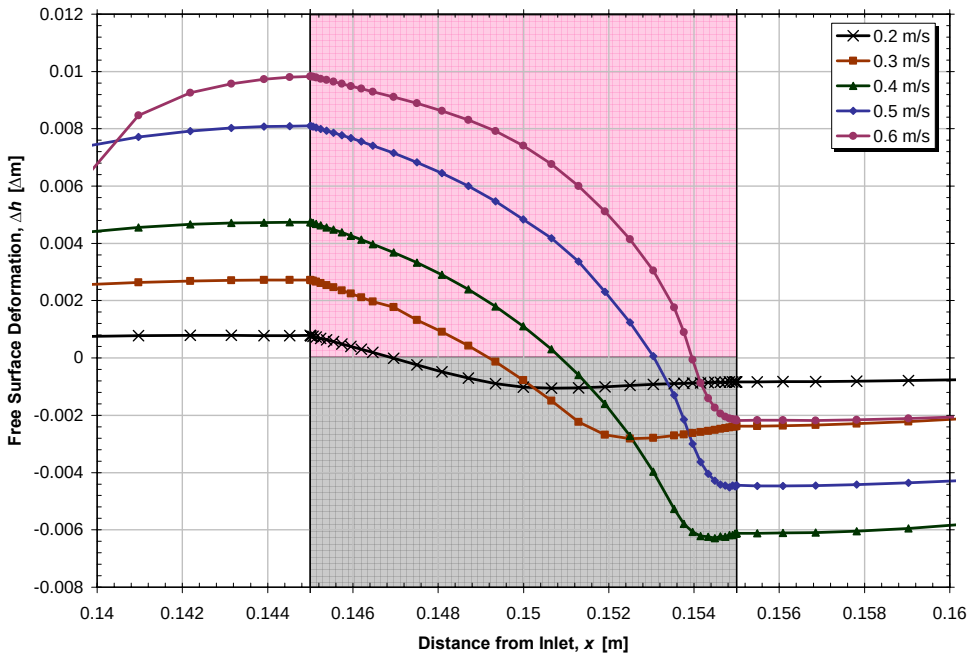
5mm-Lump profiles (no slag)



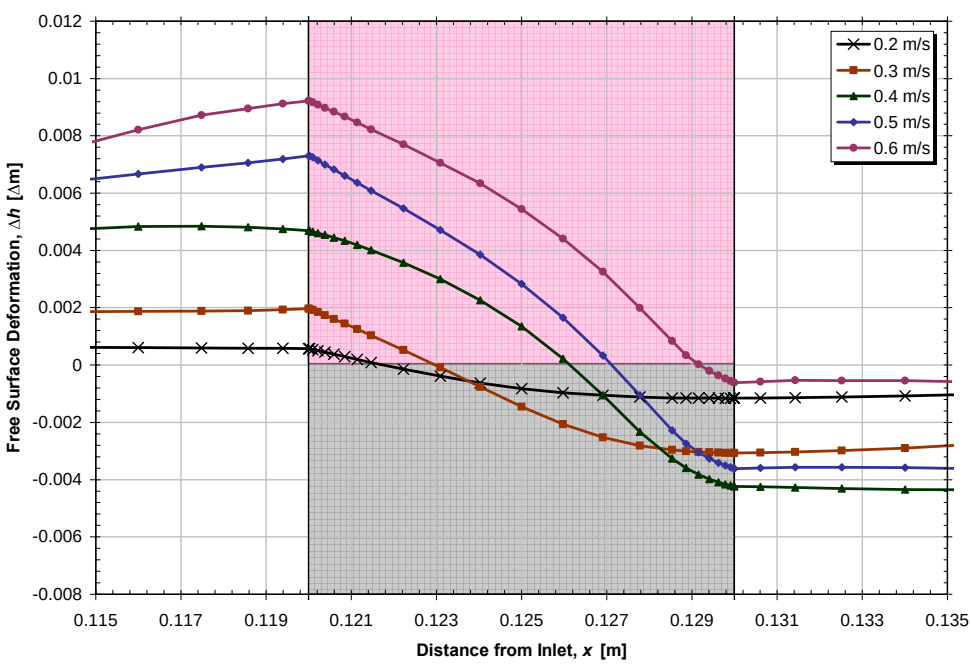
5mm-Lump profiles (with slag)



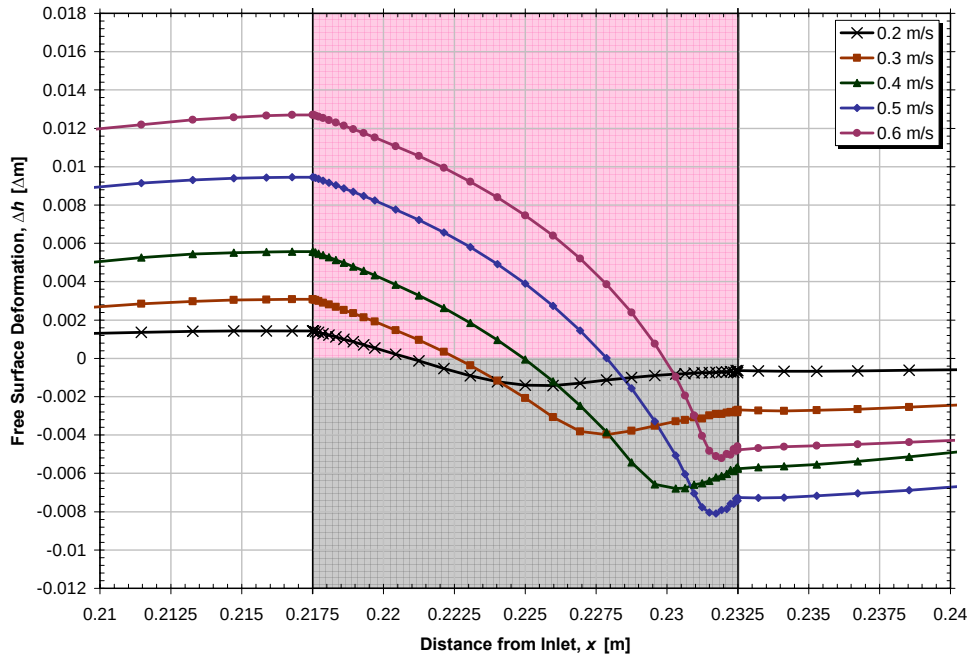
10mm-Lump profiles (no slag)



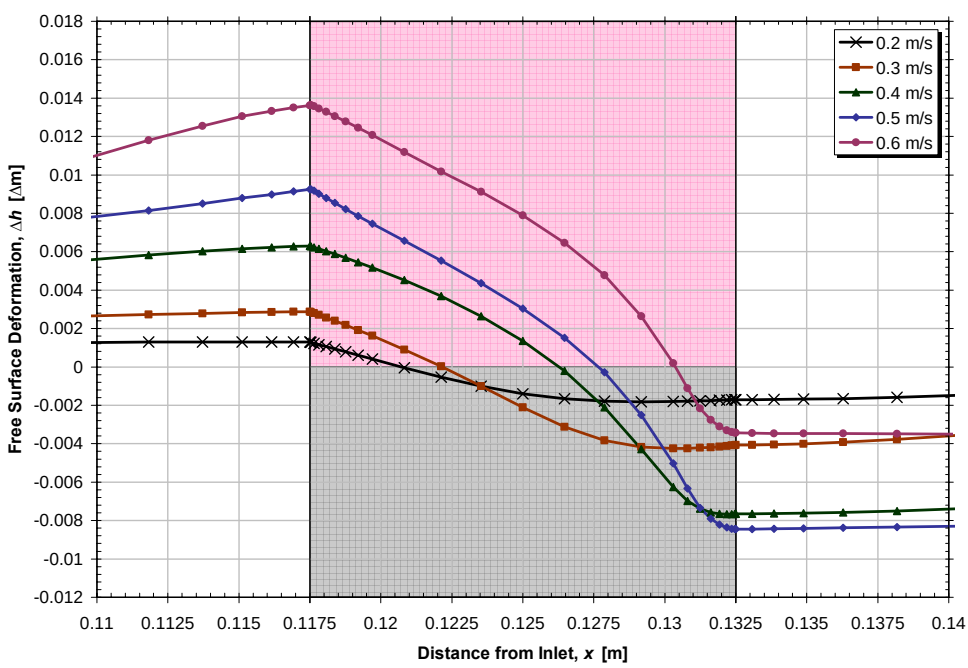
10mm-Lump profiles (with slag)



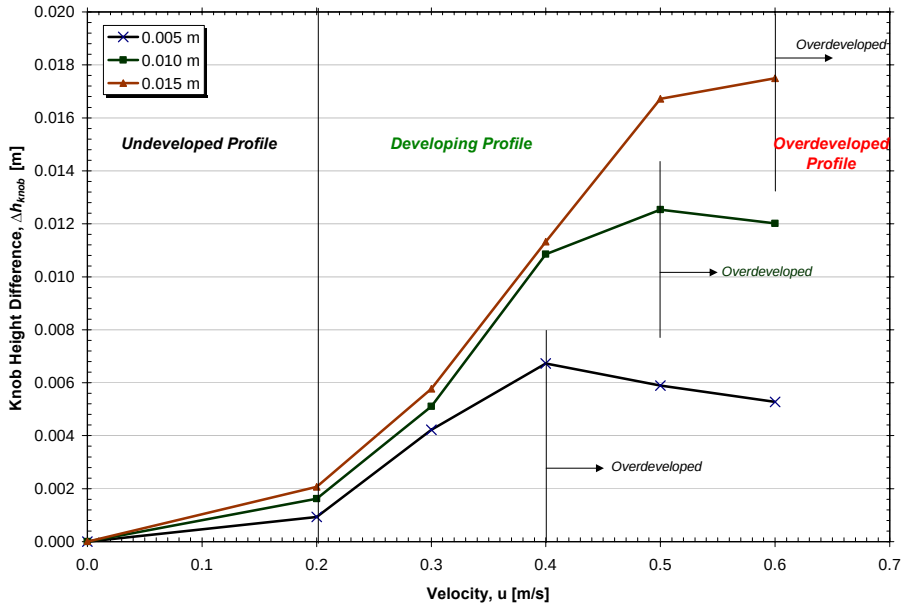
15mm-Lump profiles (no slag)



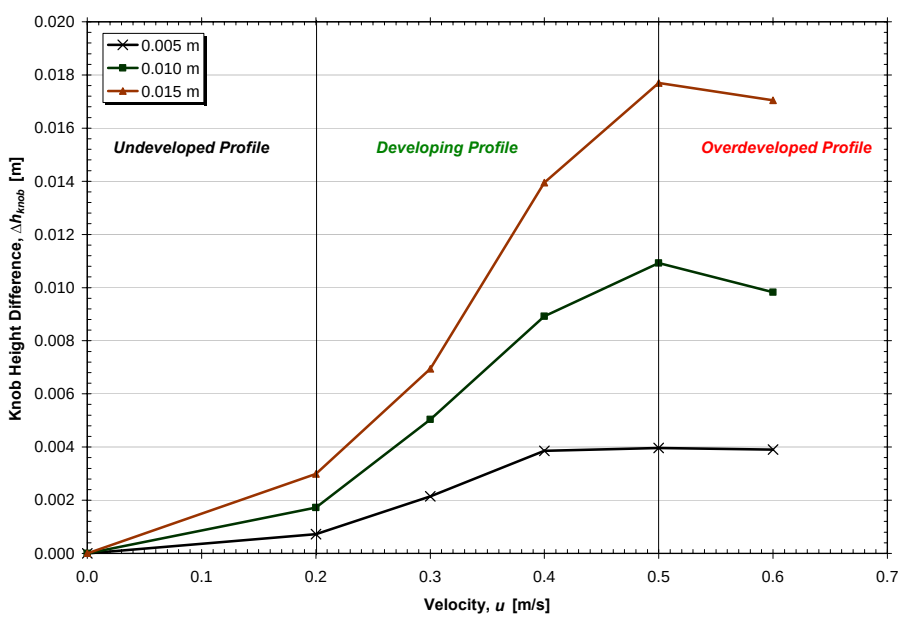
15mm-Lump profiles (with slag)



Lump height differences (no slag)



Lump height differences (with slag)



Conclusions

- Nail-board method to measure fluid velocity is feasible & is now quantified
- Leading edge run-up is best indication of velocity (if it could be measured)
- Runup increases with square of velocity.
- Runup increases with diameter,approaching upper energy-balance limit of Bernoulli
- Water models give much larger runup than steel caster (high surface tension of steel overcomes density amplification of slag layer)
- Pressure/height approximations are inaccurate (owing to sharp curvature near nail)
- Optimum nail submersion time varies with nail diameter (smaller nail: shorter submersion time).

Conclusions

With no slag layer:

- lump has distinct knob shape and curvature, that varies with velocity & diameter, making it useful in estimating fluid velocity.
- Best accuracy for high velocity (> 0.3 m/s), and large diameter (> 0.010 m) cases.

With a slag layer,

- steel/slag interface is almost linear, with similar lump shape
- height difference gives best indication of velocity,
- Best accuracy within 0.2 to 0.5 m/s range, where height increases linearly with velocity

Acknowledgements

- Continuous Casting Consortium Members (Nucor, Postech, LWB Refractories, Algoma, Corus, Delavan, Labein, Mittal, Baosteel, Steel Dynamics)
- National Center for Supercomputing Applications (NCSA) at UIUC
- Fluent, Inc., for FIDAP
- Nucor Steel and Ron O'Malley for help with the nailboard tests