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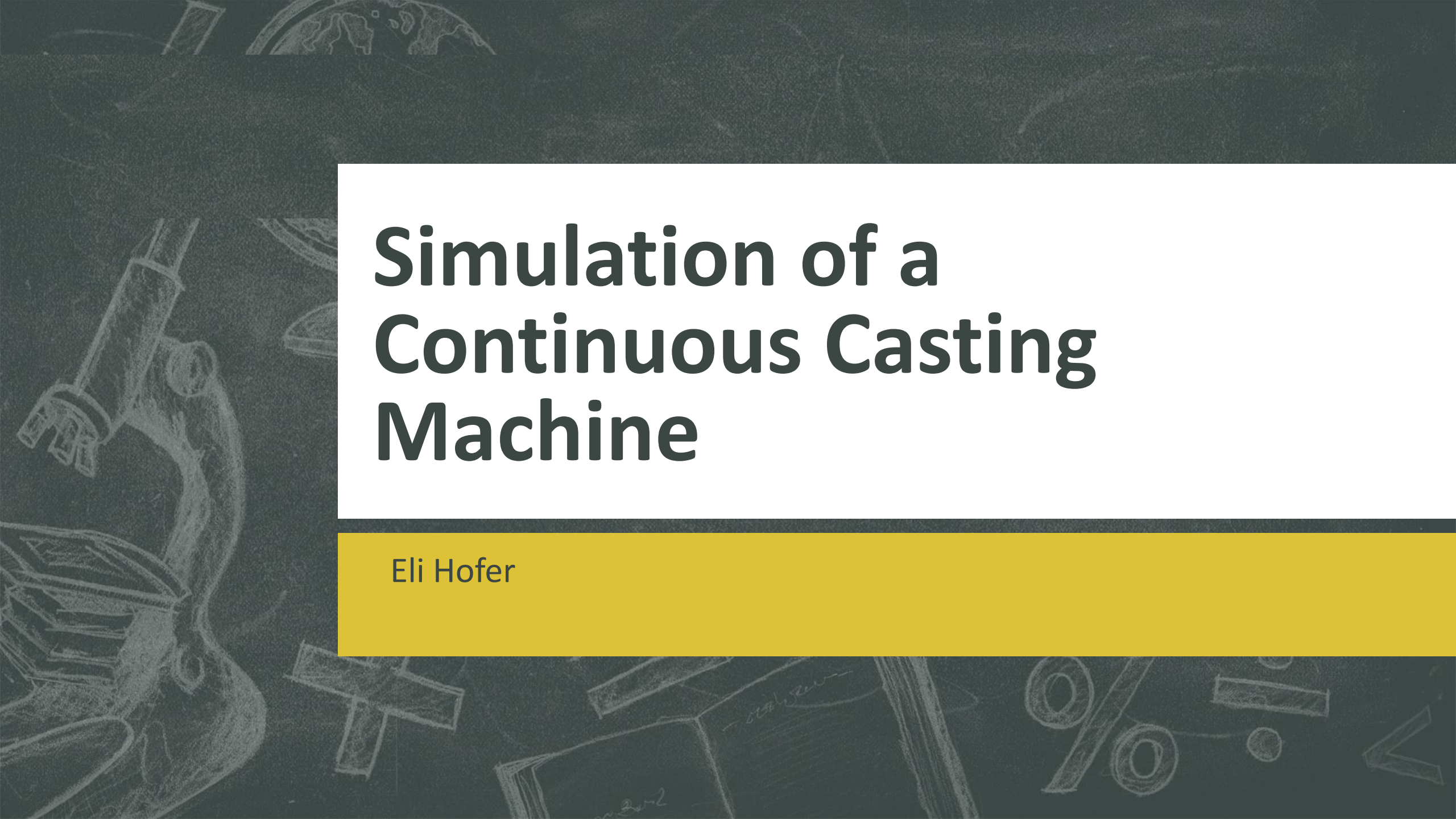
Simulation of a Continuous Casting Machine

Eli Hofer
eli.hofer@valpo.edu



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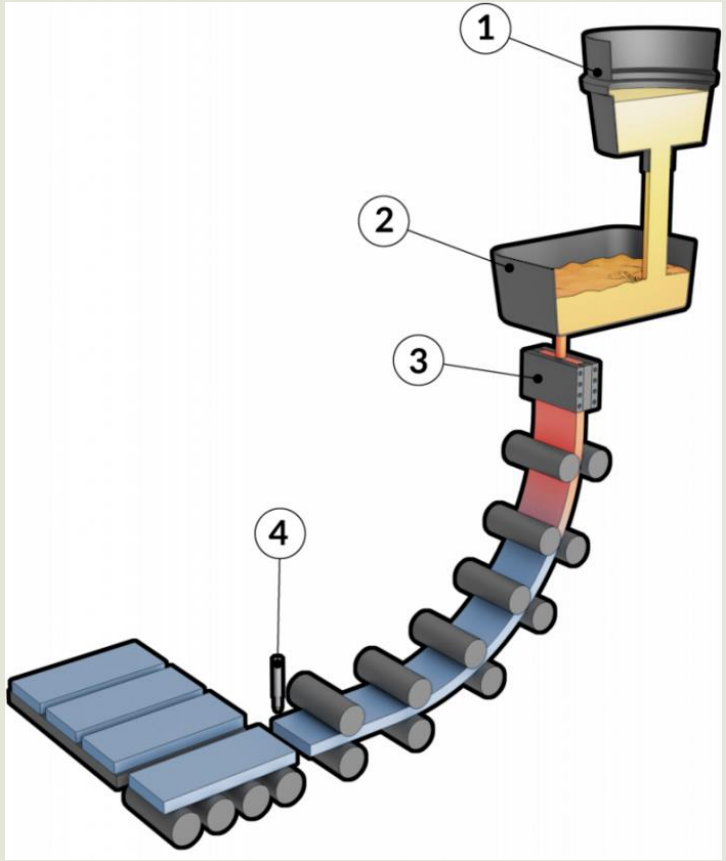
What is a continuous caster?

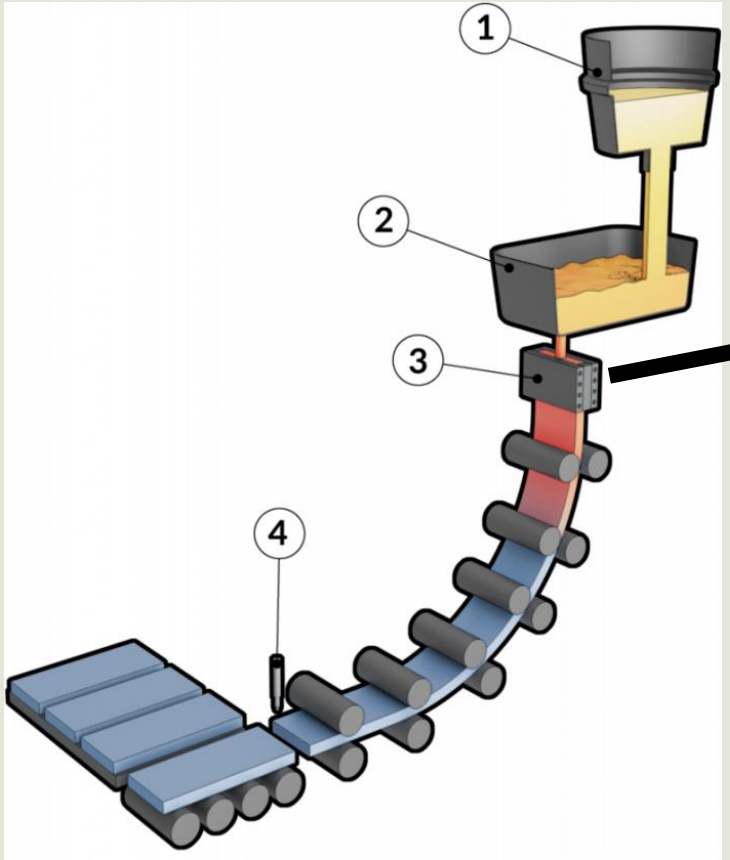
- Pinnacle of bulk metal casting technology
- Most popular way to make steel in 2018
  - > 90% of steel production is continuously cast
  - ~1.8 billion tons globally

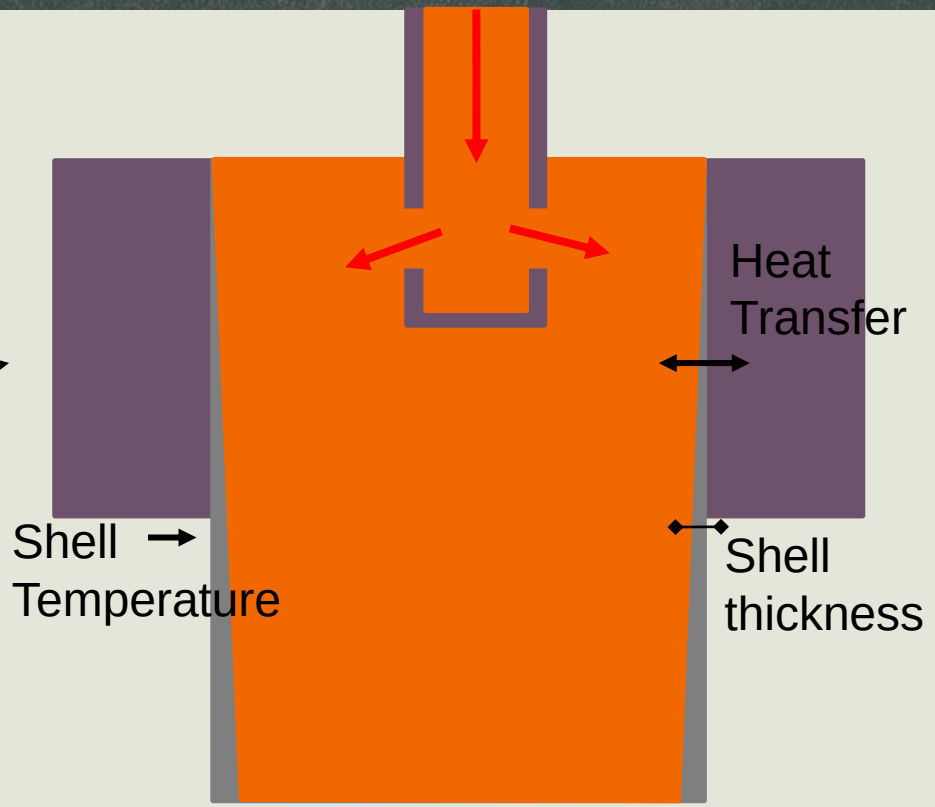


1. **Ladle** 1st reservoir
2. **Tundish** 2st reservoir
3. **Copper Mold** Begins solidification of molten metal into the strand
4. **Oxygen-Gas Torch** Cuts the fully solidified strand into slabs

Goal: Simulate Solidification in the Mold

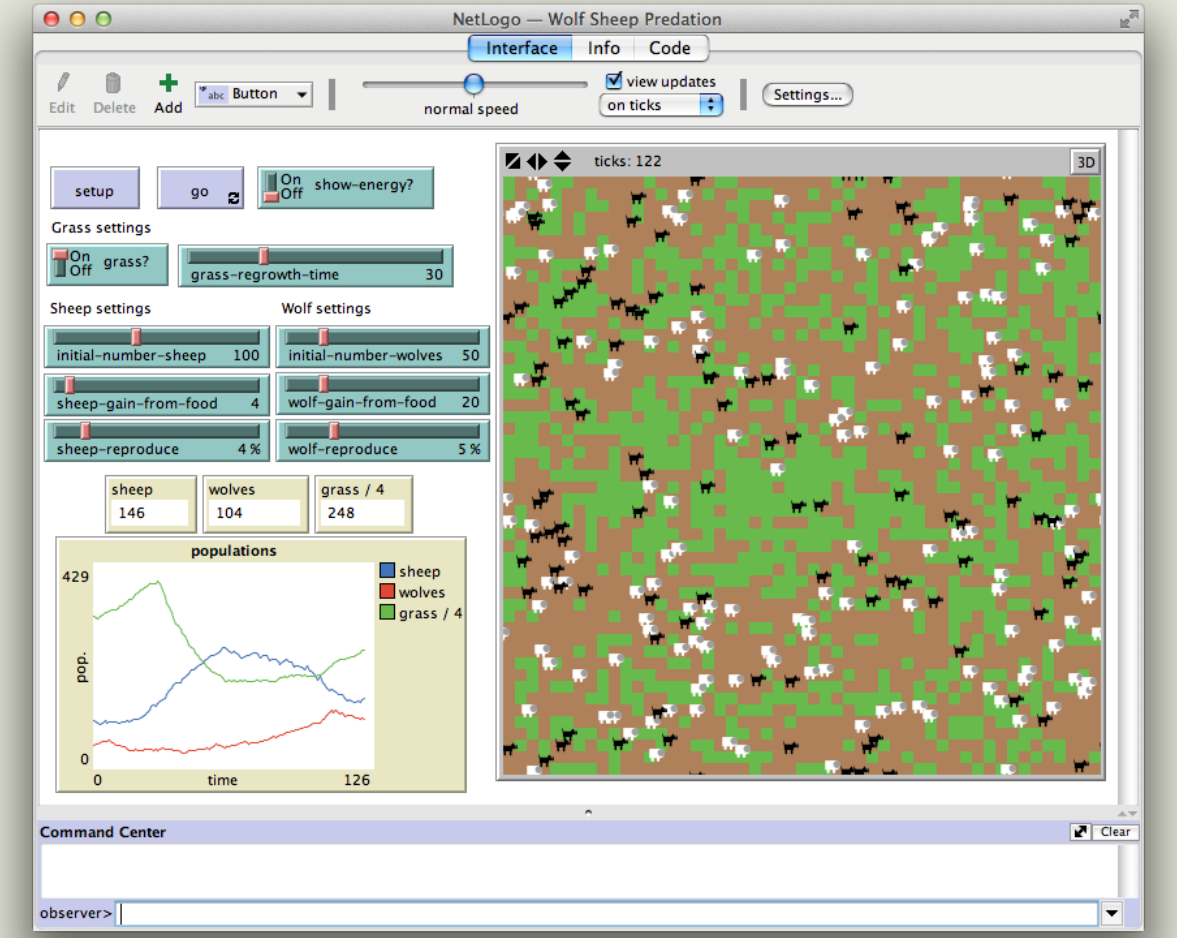
- Predict important parameters in the continuous casting process:
  - Thickness of the solidified shell in the mold
  - Temperature of the surface of the shell as it exists the mold
  - Amount of heat transfer occurring in the mold





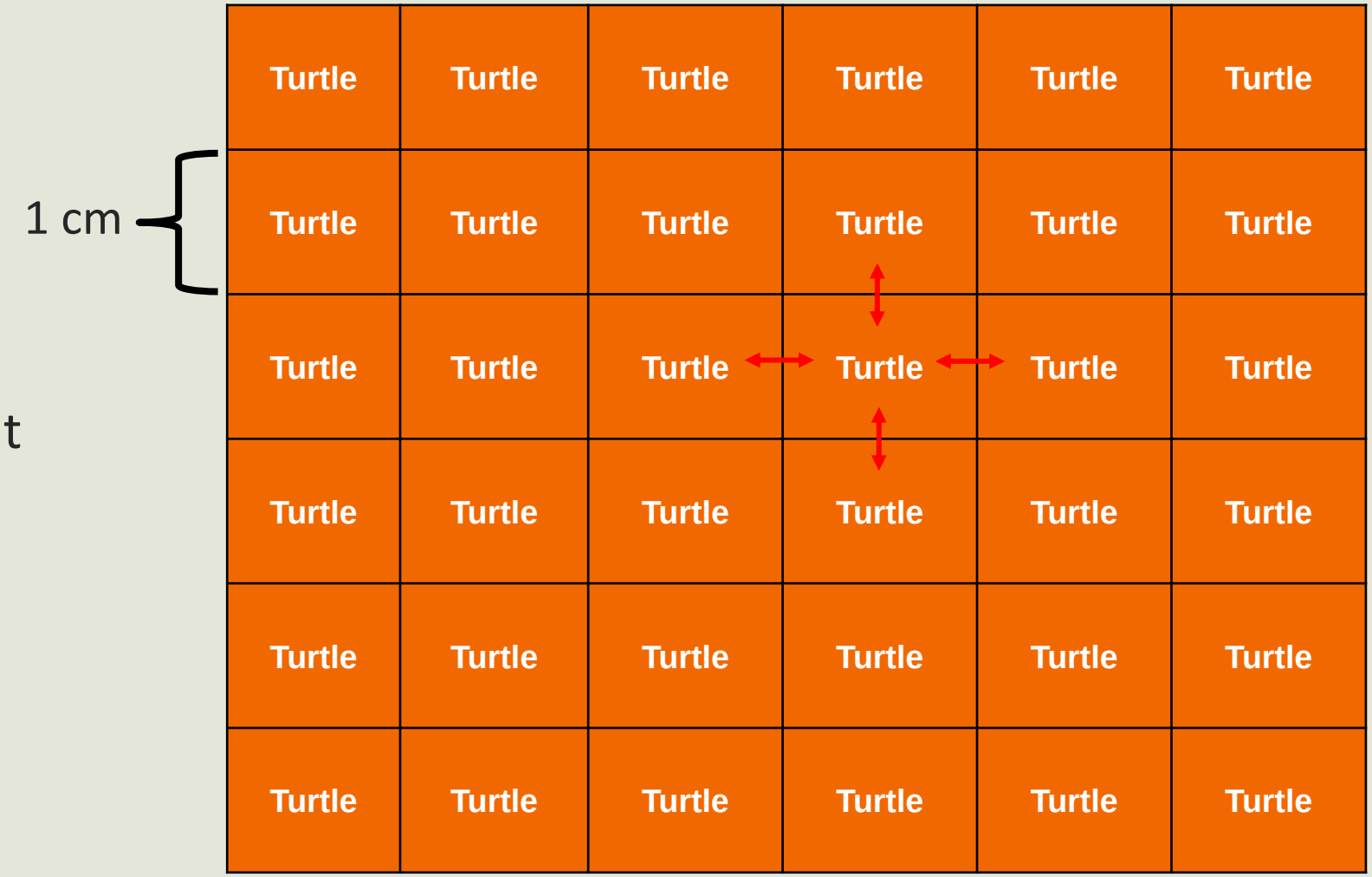
Simulation: Software

- **NetLogo 6.1.1**
  - **‘multi-agent programmable modeling environment’**
- **Used by students, teachers, and researchers for agent-based simulations and models**
- **Emergent Behavior**
- **Turtle = Agent**



Simulation: Assumptions

- Finite-Difference method will be used to simulate a slice of the mold.
- Each NetLogo turtle will represent 1 cm^3 of material. Simulation of Heat transfer can then take place between each turtle and its neighbor.



Simulation: Assumptions

- Mold width is functionally infinite and does not affect heat transfer through the mold thickness (2-Dimensional Simulation).
- Heat Transfer:
  - No heat/cooling by convection
  - Heat transfer is rated limited by the least conductive material
  - Heat of fusion required for solidification included
- No lubrication needed in between the solid steel shell and the mold wall
- No deformation of the solidified steel shell
- No ferrostatic pressure from gravitational forces on the liquid steel
    - For all intents and purposes, the only force acting in this simulation is the steel being pulled out of the mold

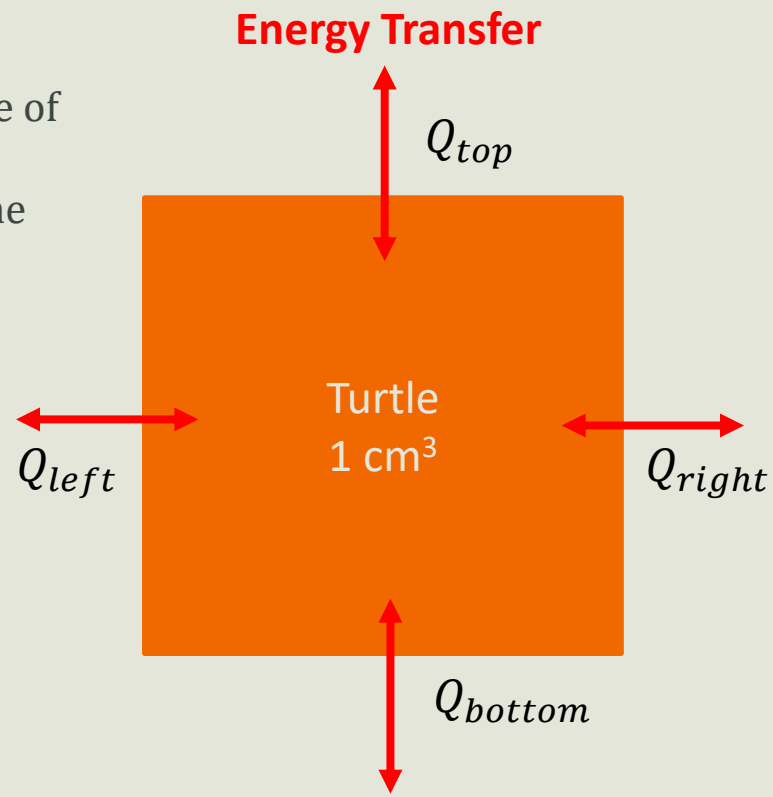
Simulation: Math Model

- The change in energy Q between each turtle and its neighbor can be calculated for a step in time.

$$Q_i = \frac{k * A * (T_{neighbor} - T_i)}{L} * \frac{1}{4}$$

- That total change in energy can then be used to calculate the change in temperature of each turtle

k = thermal conductivity
A = Flat side area
L = Length
$T_{nieghbor}$ = Temperature of the adjacent turtle
T_i = Temperature of the core turtle
Q = Energy



$$Q_{total} = Q_{top} + Q_{bottom} + Q_{left} + Q_{right}$$

Simulation: Math Model

- Once the total energy transfer is found, this equation is used to find the new temperature of the turtle:

$$\frac{Q_{total}}{C_p * w} = \Delta T$$

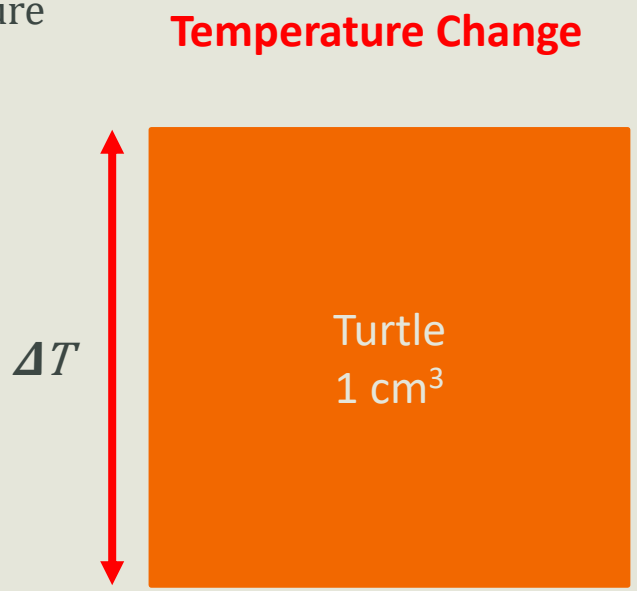
- Each step in the simulation is equivalent to one second of heat transfer
  - Makes all the equations and math really easy!

C_p = Heat Capacity

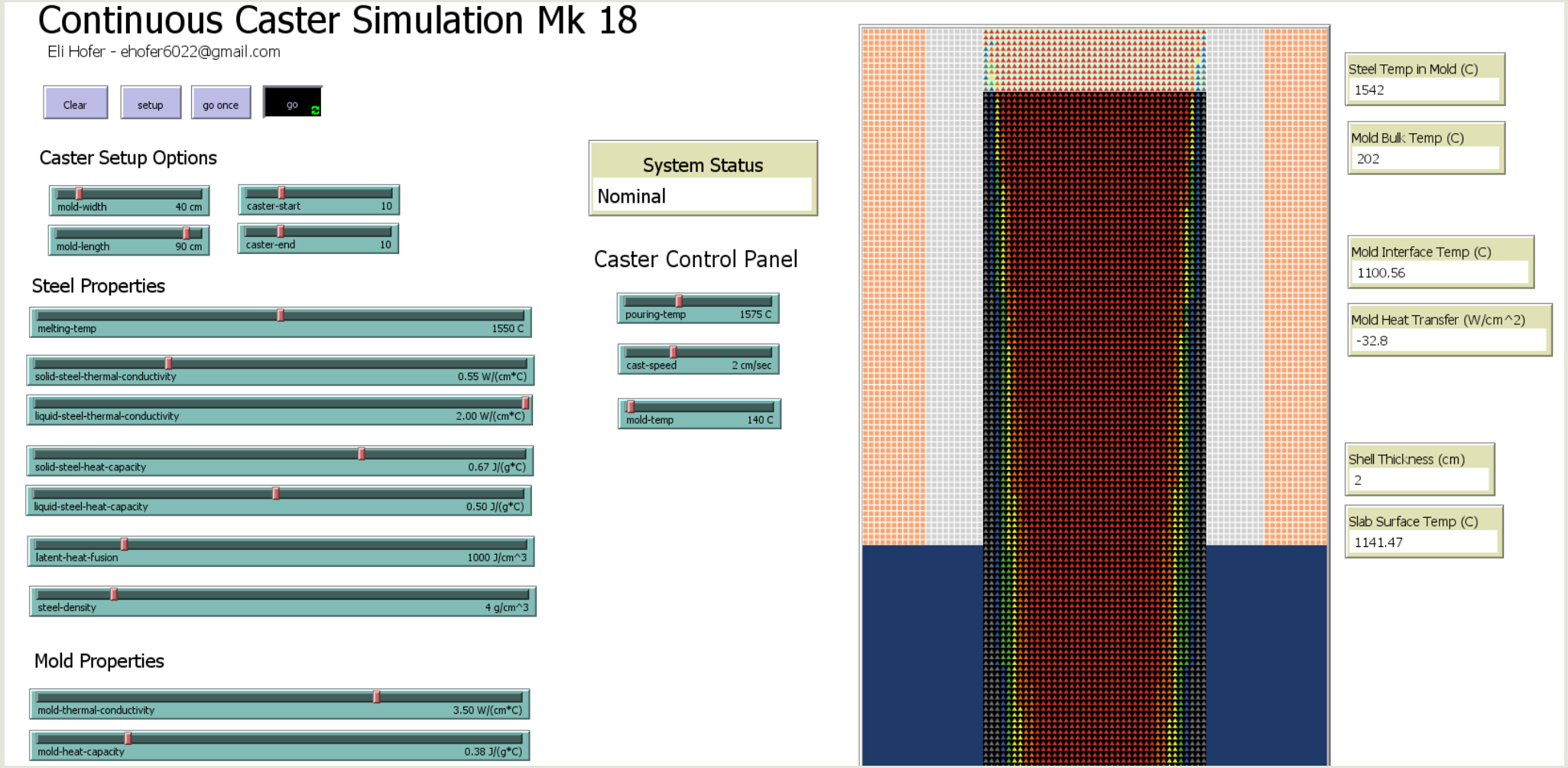
w = weight / mass

ΔT = Change in Temperature

Q = Energy



Simulation: Implementation



Simulation: Verification

- Used empirical results from *Transport Phenomena in Materials Processing*
  - A. W. D. Hills & M. R. Moore
- Input Variables:
  - Casting Speed
  - Mold Length
  - Thermal Conductivity
  - Heat Capacity
  - Melting Temp.
  - Mold Temp.
  - Steel Density
  - Heat Transfer Coefficient

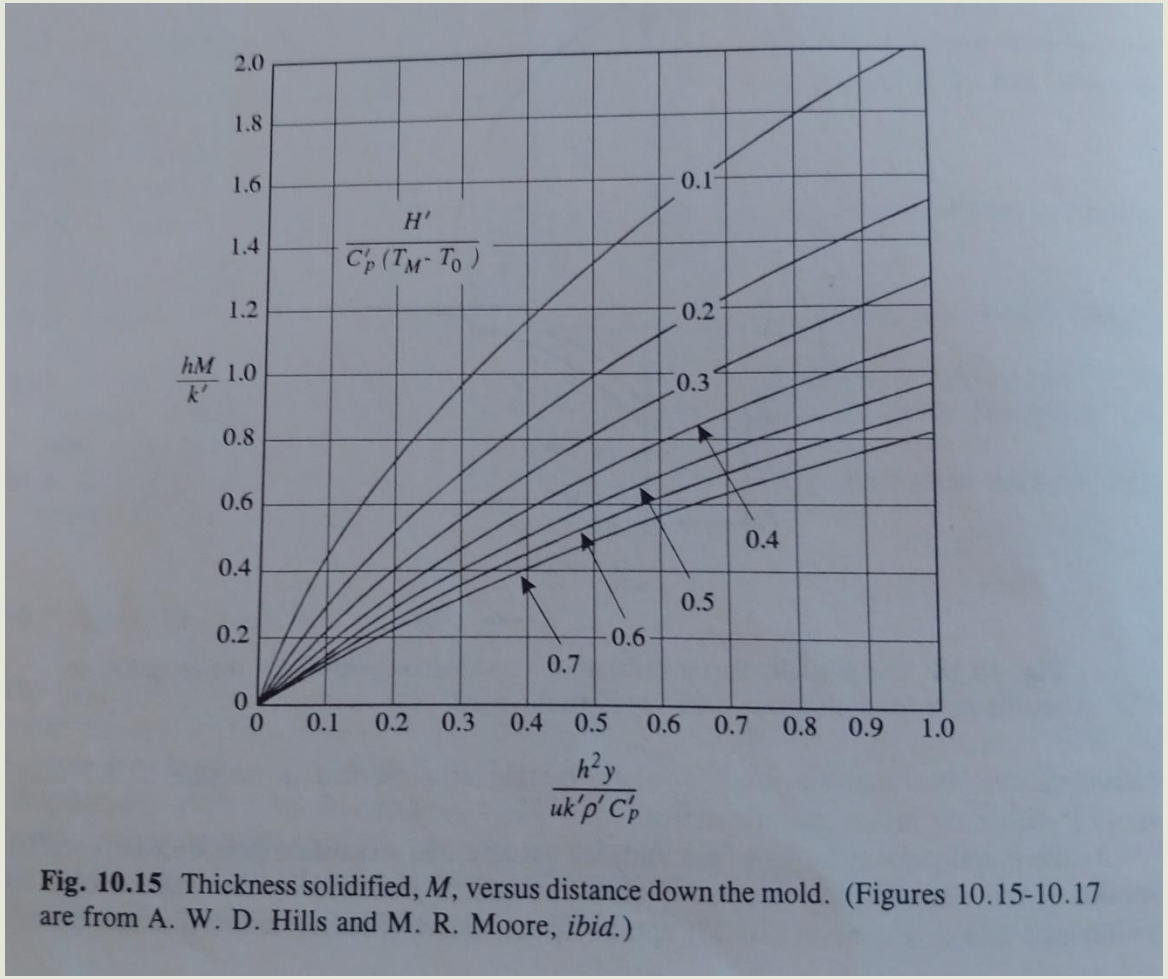


Fig. 10.15 Thickness solidified, M, versus distance down the mold. (Figures 10.15-10.17 are from A. W. D. Hills and M. R. Moore, *ibid.*)

Simulation: Sensitivity Analysis

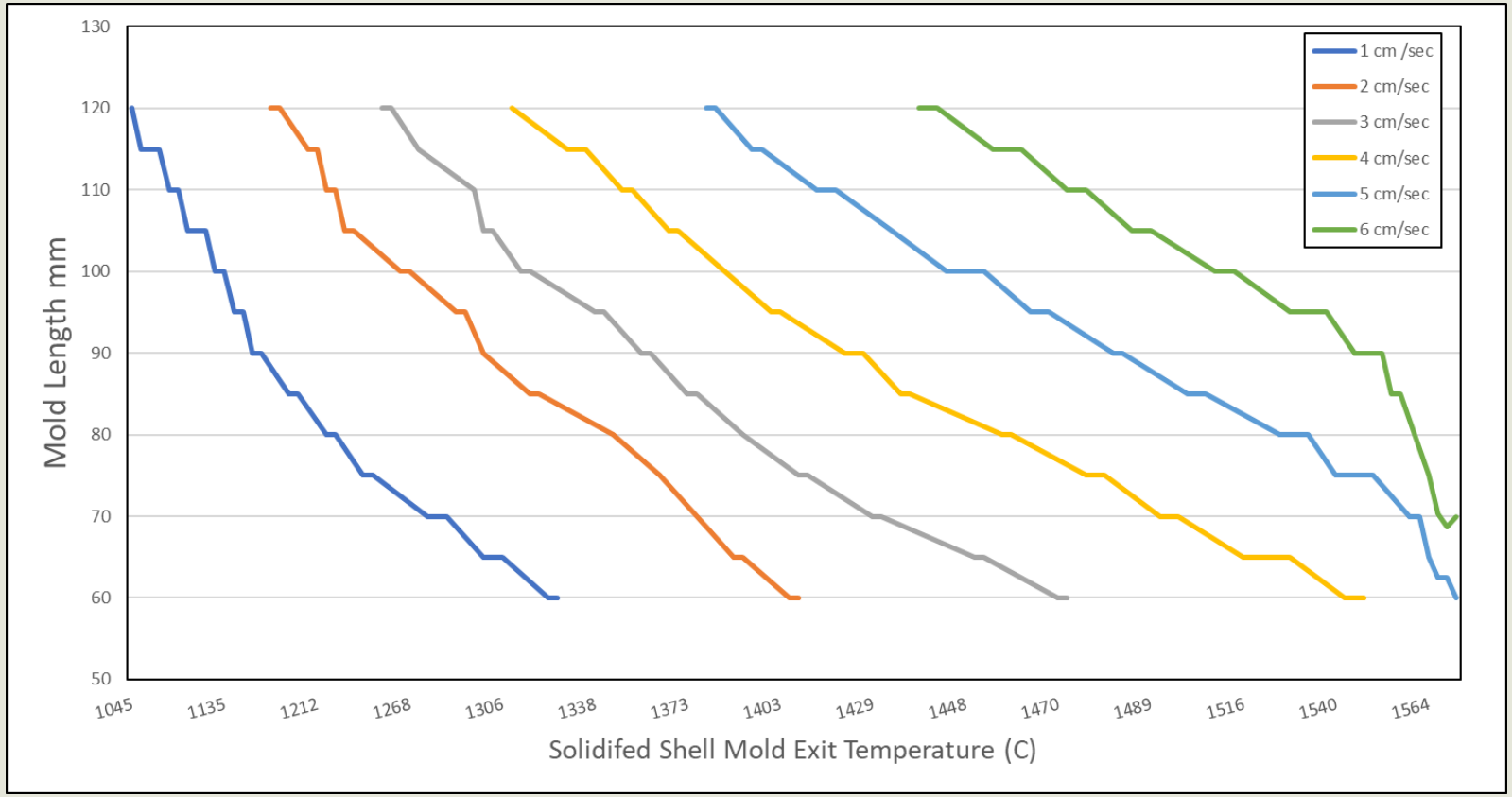
Used NetLogo behavior Space to Examine variables commonly controlled in industry:

Input Parameters:

- Casting Speed
- Mold length
- Pouring Temperature
- Mold Temperature

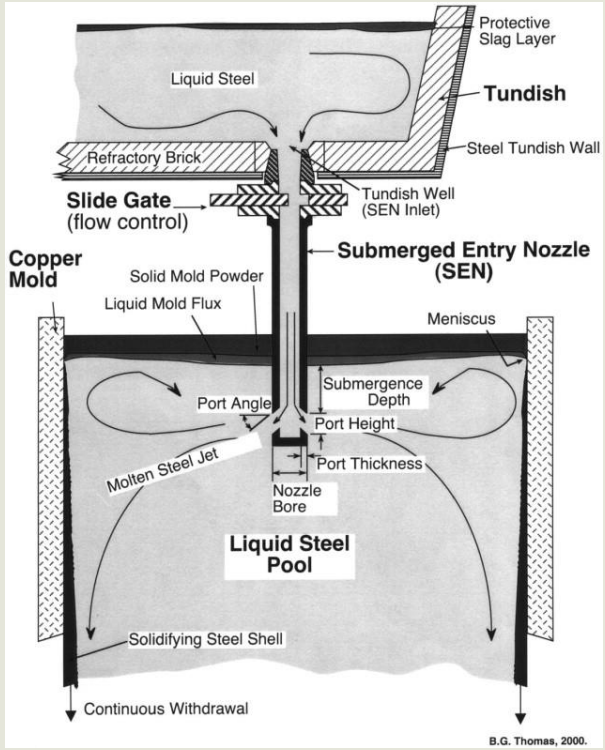
Measurements:

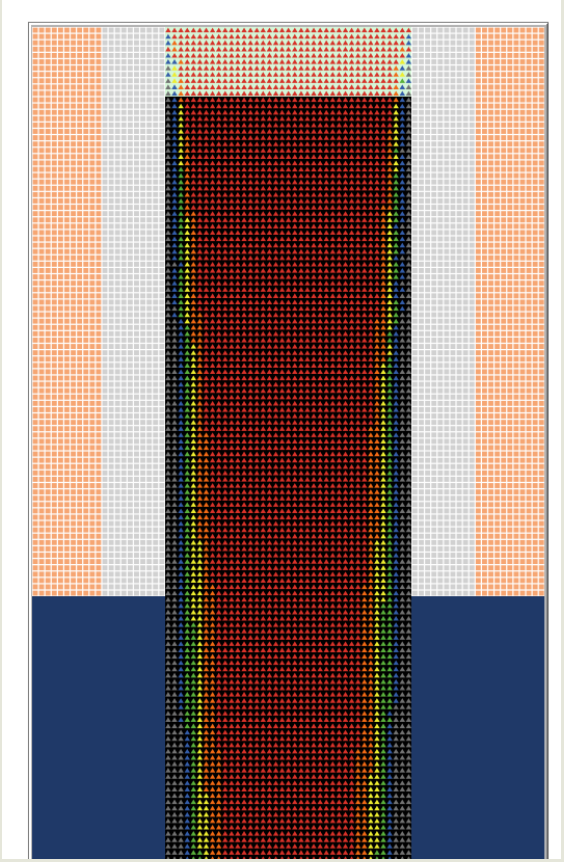
- Mold Exit Temperature
- Shell Thickness



Simulation: Verification

- **Results**: Simulated mold shell thickness reasonable compared to available empirical measurements.
- Needs WAY more verification to be considered accurate but is a good tool for training and teaching!
- Best way to learn a process is to try simulating it.





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Questions????

Thank You!