Digital Twin of an Industrial Condenser for Lunar In-Situ Resource Utilization

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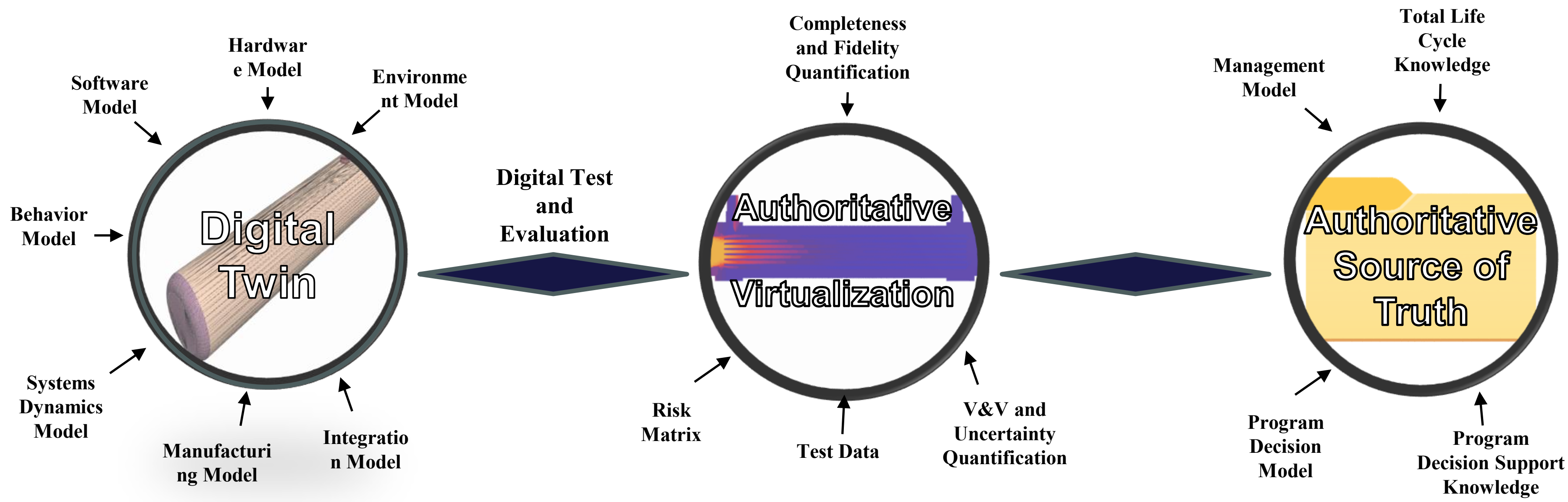
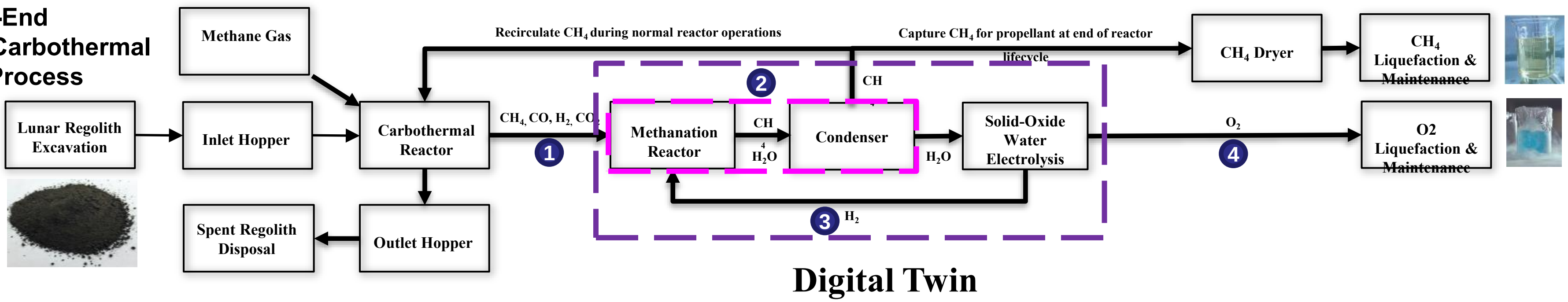
Digital Engineering | Transformation

Digital Engineering (DE): An integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support life cycle activities from concept through disposal.

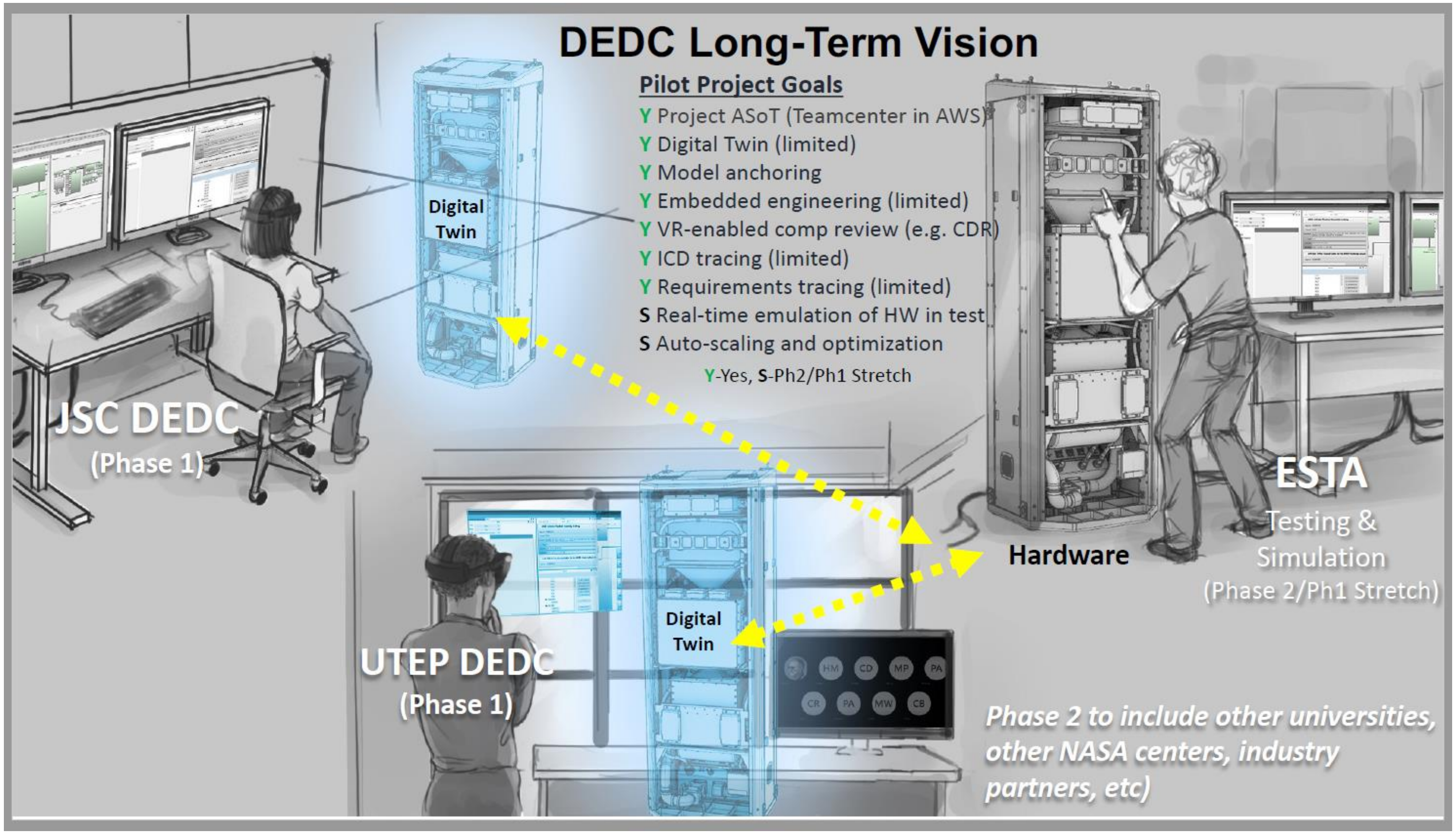


Lunar Carbothermal Reduction with Solid-Oxide Electrolysis

End-to-End Lunar Carbothermal O2FR Process



Digital Twin



Simulation Software

NX : CAD

- Import STEP files for relevant geometry
- Optimize geometry for simulation processing

STAR-CCM+ : CFD

- Mesh imported geometry from NX
- Conduct computational fluid dynamics simulations to validate part designs

Teamcenter : MBSE

- Thread subsystems
- Parameterize inputs/outputs to quickly update different environments

Overview: Condenser Modeling

Methanation Reactor → Condenser → Solid-Oxide H2O Electrolysis

Condenser Modeling Overview

Optimizing CAD Model in NX

Importing Parasolid to STAR-CCM

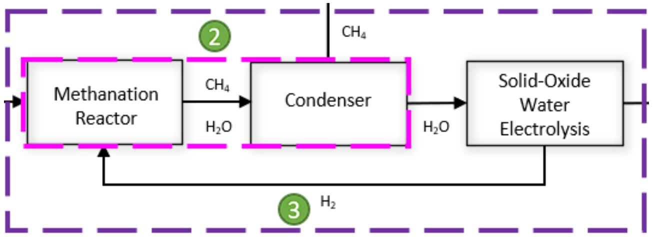
Physics Continuum

Setting Regions and Boundary Conditions

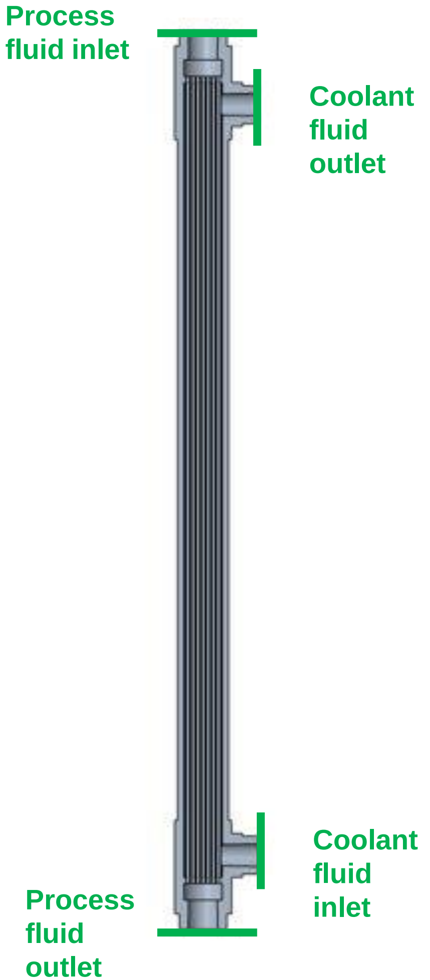
Robust Meshing

Solvers and Outputs

Overview



- Methane and water vapor enter the condenser
- Water vapor condensates and is led to electrolyzer
- The condenser consists of three main parts:
  - inner fluid (where liquid water is formed)
  - outer fluid (where coolant draws heat from process fluid)
  - solid shell (the structure containing and separating the inner and outer fluid)



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CAD of the Industrial Condenser

Optimizing CAD Model in NX

Importing Parasolid to STAR-CCM

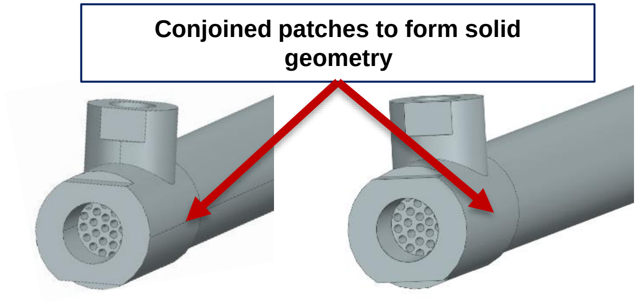
Physics Continuum

Setting Regions and Boundary Conditions

Robust Meshing

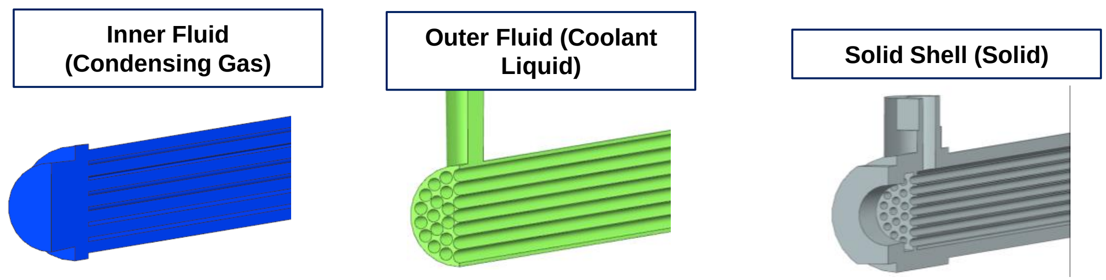
Solvers and Outputs

- Used the functions in NX to optimize CAD drawing for better meshing operations and Parasolid generation



- Original CAD models solid regions, fluid volume extracted as separate parts for different physics

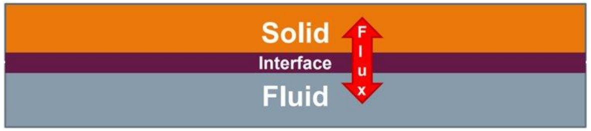
- Model is bisected along a symmetry plane to reduce computation



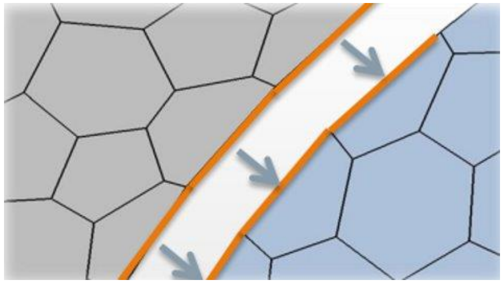
Import to CFD

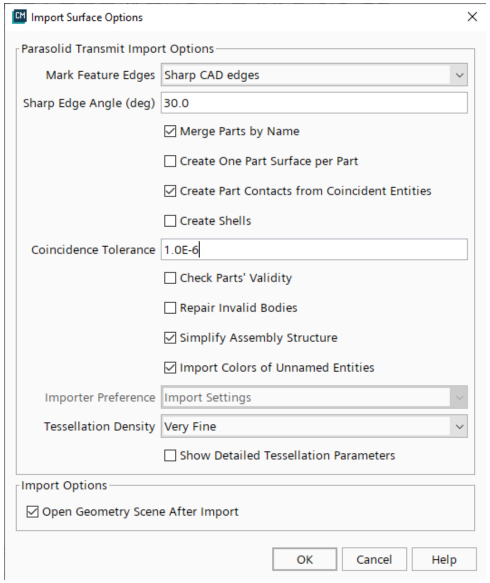
- Optimizing CAD Model in NX
- **Importing Parasolid to STAR-CCM**
- Physics Continuum
- Setting Regions and Boundary Conditions
- Robust Meshing
- Solvers and Outputs

- The CAD is exported as a Parasolid file and then imported to STAR-CCM+
- The tolerance and grain size can be adjusted for better resolution
- The conformal imprinting of coincident entities allows more accurate iterations



Interface of coinciding bodies


Conformal Meshing cell to cell



Settings for import

Physics Continuum

- Optimizing CAD Model in NX
- Importing Parasolid to STAR-CCM
- **Physics Continuum**
- Setting Regions and Boundary Conditions
- Robust Meshing
- Solvers and Outputs

- The initial heat transfer model was simple air flow at 22.25C in counter flow with cold water at 5C in steady state
- Models are chosen for accuracy to the situation while avoiding inefficiencies with unnecessary calculations
- Models below are used to simulate heat transfer

Enabled Models
- [x] Coupled Energy
- [x] Ideal Gas
- [x] Coupled Species
- [x] Gradients
- [x] Coupled Flow
- [x] Non-reacting
- [x] Multi-Component Gas
- [x] Solution Interpolation <Not required by other models>
- [x] Laminar
- [x] Steady
- [x] Three Dimensional

Physics models for Inner Fluid

Enabled Models
- [x] Coupled Energy <Not required by other models>
- [x] Gradients
- [x] Coupled Flow
- [x] Solution Interpolation <Not required by other models>
- [x] Laminar
- [x] Steady
- [x] Constant Density
- [x] Liquid
- [x] Three Dimensional

Physics models for Outer Fluid

Enabled Models
- [x] Gradients
- [x] Coupled Solid Energy <Not required by other models>
- [x] Solution Interpolation <Not required by other models>
- [x] Constant Density
- [x] Steady
- [x] Solid
- [x] Three Dimensional

Physics models for Solid Shell

Physics Continuum

- Optimizing CAD Model in NX
- Importing Parasolid to STAR-CCM
- **Physics Continuum**
- Setting Regions and Boundary Conditions
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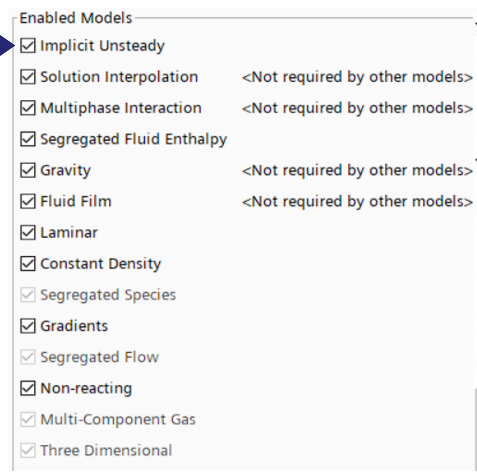
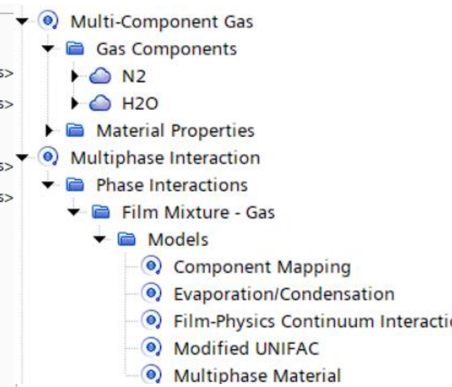
- A separate simulation that only includes the inner fluid part is used to model condensation. This is done to simplify and reduce computation requirements during model development until both simulations are combined.

- The condenser physics initializes in implicit unsteady state



Physics models for Inner Fluid (Condensation)



Selected gas components and enabled models for MP interaction

Enabled models for fluid film

* N2 was used in physical testing

Boundary Conditions

Optimizing CAD Model in NX

Importing Parasolid to STAR-CCM

Physics Continuum

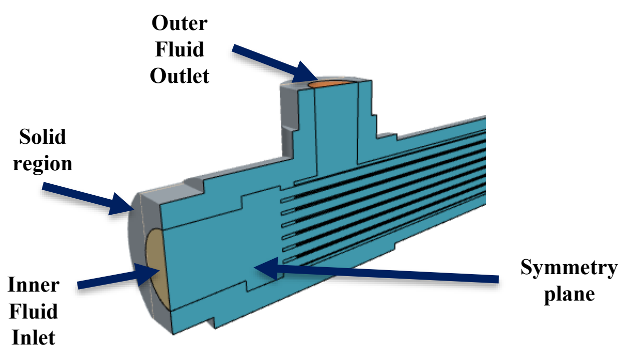
Setting Regions and Boundary Conditions

Robust Meshing

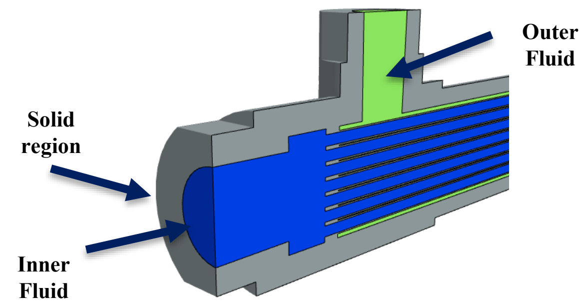
Solvers and Outputs

- Each fluid/solid part is assigned to its own region
- Each fluid region is split by patch to identify an inlet, outlet, wall, and symmetry plane
- Appropriate boundary conditions and interfaces are defined

Define Boundaries



Boundaries defined in model

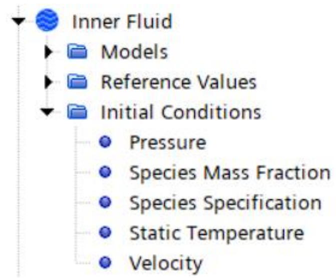


Regions defined in model

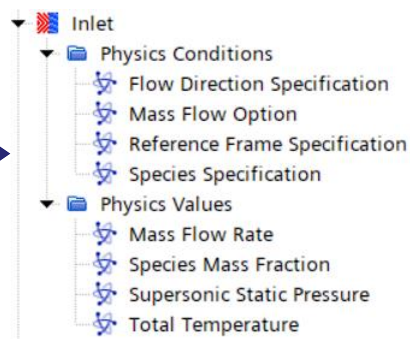
Boundary Conditions

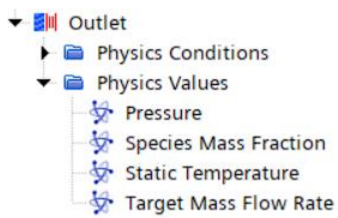
- Optimizing CAD Model in NX
- Importing Parasolid to STAR-CCM
- Physics Continuum
- **Setting Regions and Boundary Conditions**
- Robust Meshing
- Solvers and Outputs

Boundary conditions and initial conditions are set based on test cases



- Inner fluid initial conditions set to conditions measured at inlet
- Repeat for outer fluid and solid shell





- Inlet and outlet conditions set to match measurements
- Wall thermal specification set to convection, allowing heat transfer coefficient (calculated from measured heat exchange) to be set

Boundary Conditions

Optimizing CAD Model in NX

Importing Parasolid to STAR-CCM

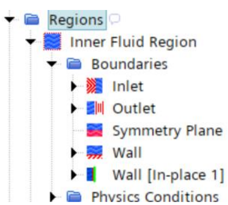
Physics Continuum

Setting Regions and Boundary Conditions

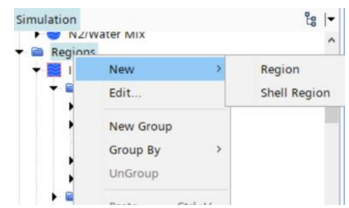
Robust Meshing

Solvers and Outputs

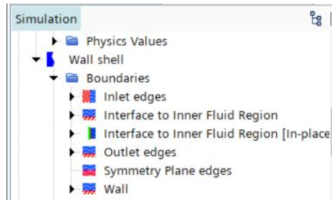
- Boundaries for condensation and heat transfer models are identical where applicable
- The fluid film model requires a shell region
- The film region boundary conditions should reflect the parent region



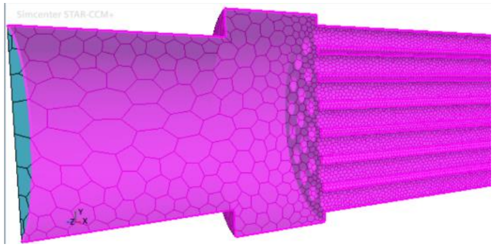
Fluid boundary conditions



Create shell region



Boundary conditions of film



Shell region in fluid film

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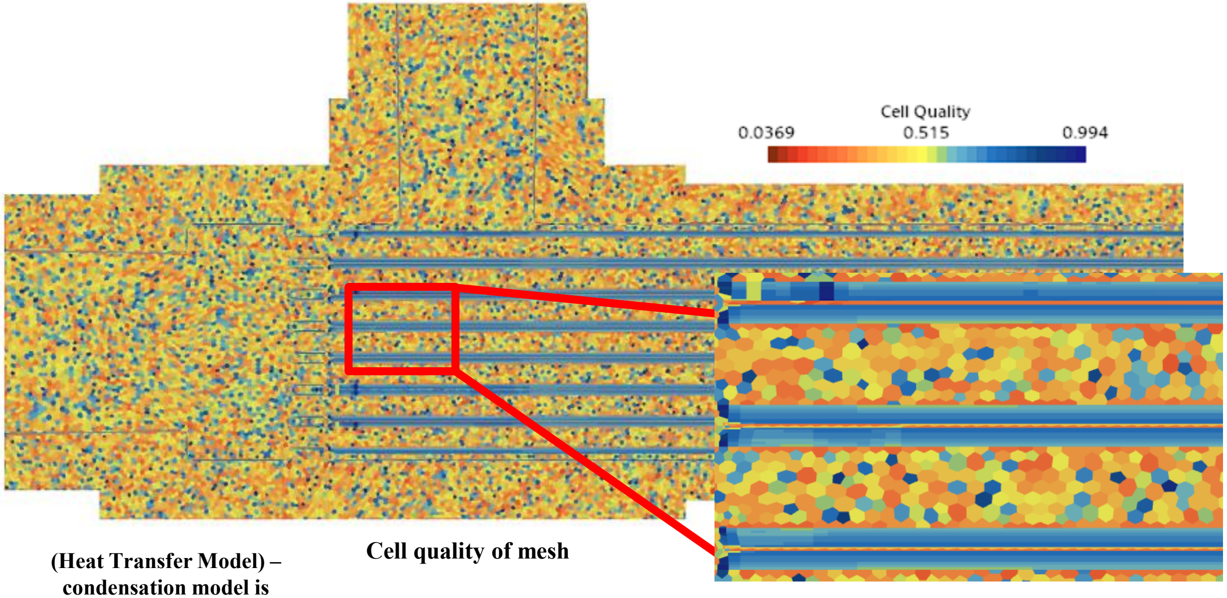
Meshing

- Optimizing CAD Model in NX
- Importing Parasolid to STAR-CCM
- Physics Continuum
- Setting Regions and Boundary Conditions
- **Robust Meshing**
- Solvers and Outputs

- The automated mesher is used to generate mesh of volume
- The mesher uses the prism layer, surface remesher, and polyhedral volume mesher
- Thin mesher is used in the solid tubes
- The set base cell size allows easy manipulation of relative target & minimum sizes
- Lower value cell quality indicates more reliable calculations in the cell



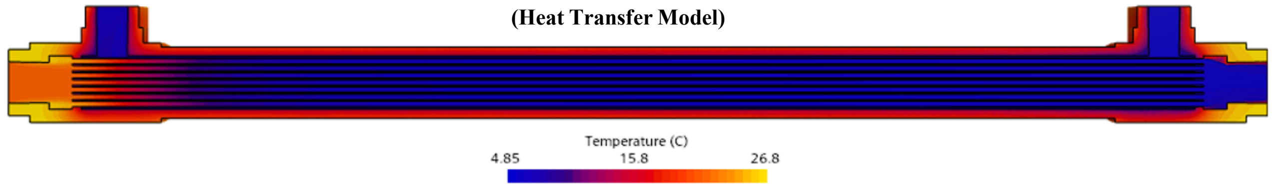
(Heat Transfer Model) – condensation model is equivalent minus other regions

Cell quality of mesh

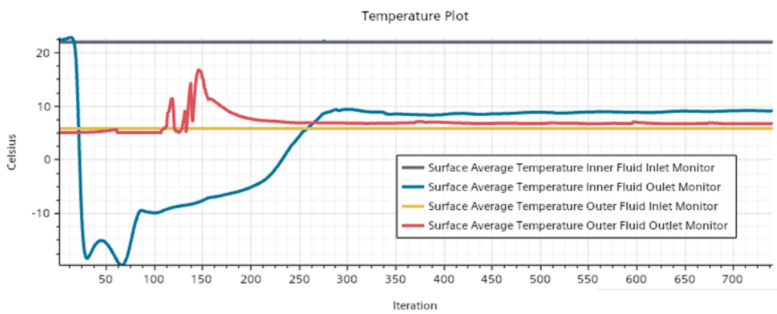
Condenser Modeling Results

- Optimizing CAD Model in NX
- Importing Parasolid to STAR-CCM
- Physics Continuum
- Setting Regions and Boundary Conditions
- Robust Meshing
- **Solvers and Outputs**

- Scenes can be created to visualize different values in space

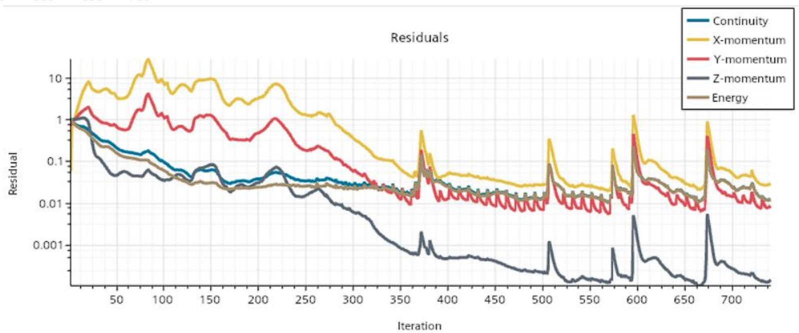


Initial flow field model with heat transfer temperature profile



- The solvers can be customized and allow for desired outputs for data validation (ex: location, data type, analysis method, etc.)

- Convergence of residuals towards zero shows increased certainty in results



Condenser Modeling Results

Optimizing CAD Model in NX

Importing Parasolid to STAR-CCM

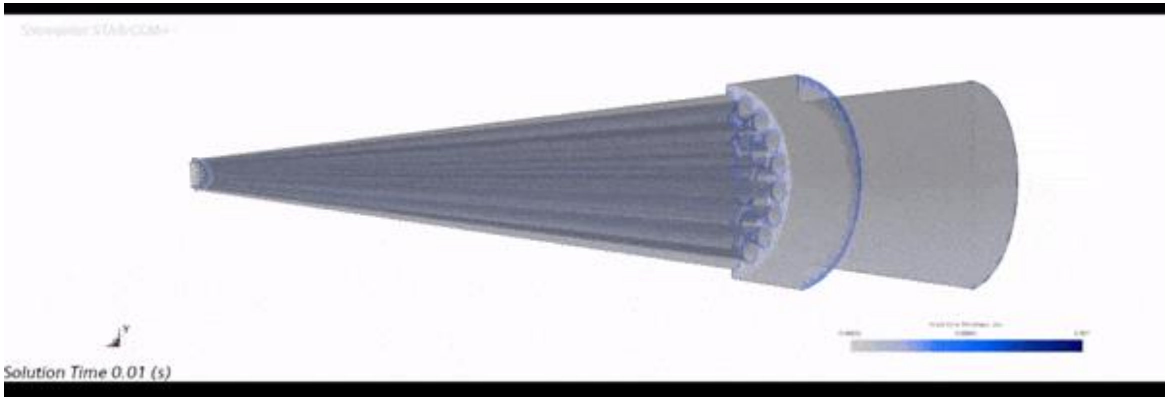
Physics Continuum

Setting Regions and Boundary Conditions

Robust Meshing

Solvers and Outputs

(Condensation model)

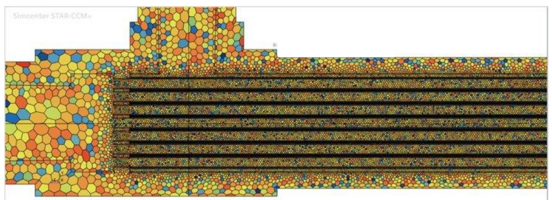


Inner fluid film thickness increasing as water condensates down the tube walls

Condenser Modeling Results

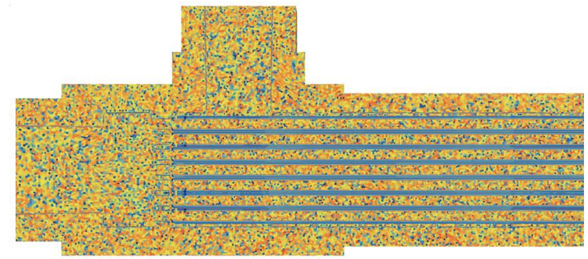
- Optimizing CAD Model in NX
- Importing Parasolid to STAR-CCM
- Physics Continuum
- Setting Regions and Boundary Conditions
- Robust Meshing
- **Solvers and Outputs**

- Continue to refine model and simulation into a digital twin to accurately represent data
- Digital twin is then utilized to drive and support engineering



Previous mesh model

Refinement



Modified mesh model

Previous mesh & thermal settings

Modified mesh & thermal settings