Compact Models, Advanced Resistances

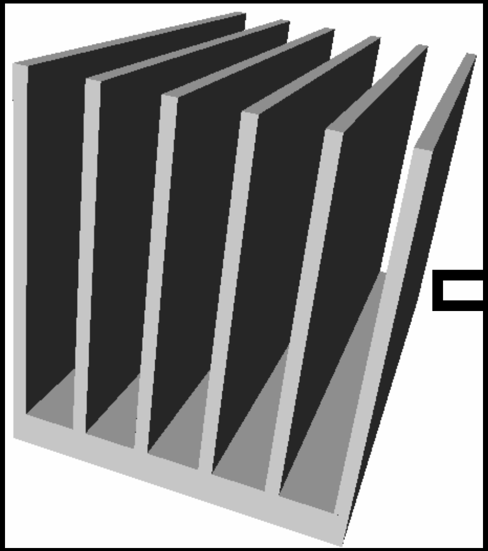
www.resheji.com

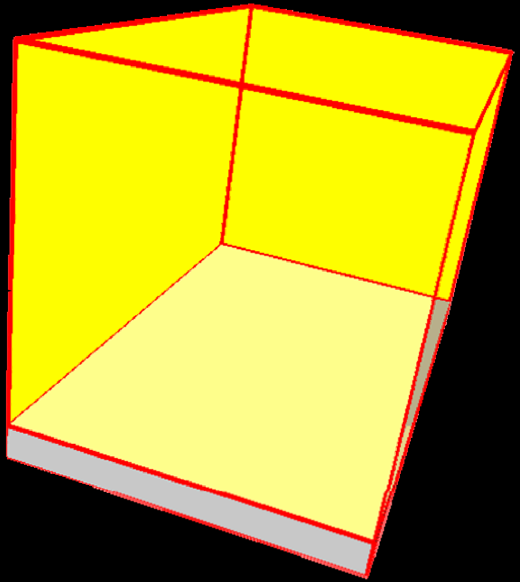
Compact Representation of Heat Sinks

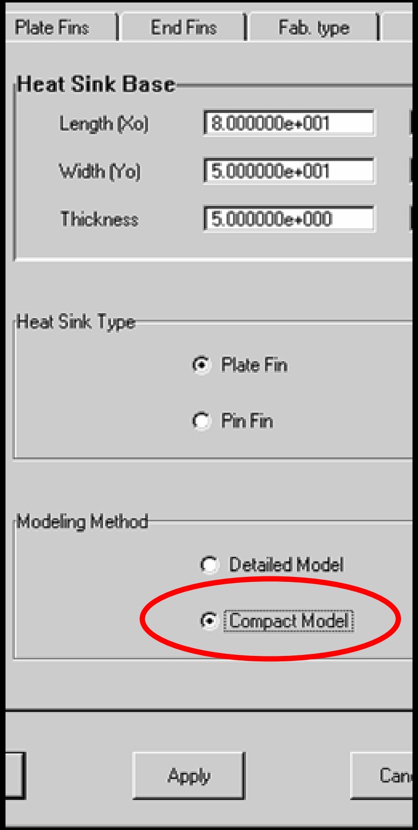
- Why Compact Representation in System Level Model?
  - Faster Solution
    - Less Grid
    - Fewer Iterations - Simplified Conjugate Heat Transfer Problem
  - Much Easier to Work With and Debug

Compact Representation of Heat Sinks

- Option 1: Heat Sink SmartPart Compact Model (It’s Automatic!)







Heat Sink Base

Length (Xo) 8.000000e+001

Width (Yo) 5.000000e+001

Thickness 5.000000e+000

Heat Sink Type

● Plate Fin

○ Pin Fin

Modeling Method

○ Detailed Model

● Compact Model

Index

Compact Representation of Heat Sinks

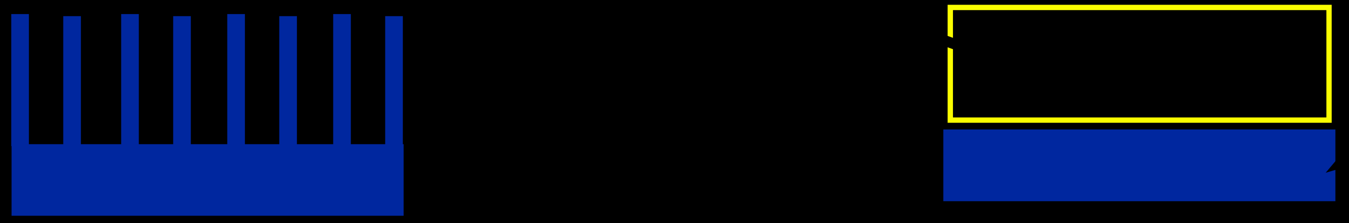
- Attributes of a Good Heat Sink Compact Model:
  - Preserve the Flow Characteristics Through and Around the Heat Sink
    - Correct Pressure Drop (Contraction, Expansion, Friction)
    - Correct Bypass to Sides and Top
  - Preserve the Conduction Characteristics in the Heat Sink Base and Fins (Heat Sink Efficiency)
  - Preserve the Convection Effects of the Base and Fins. (Forced or Natural Convection)
- The Heat Sink SP Compact Model Provides a Good representation of these attributes and saves modeling and solve time for System Level Modeling.

Compact Representation of Heat Sinks

- The Pressure Drop Terms Include:
  - Sudden Contraction Entrance Collapsed Resistance.
  - Sudden Expansion Collapsed Resistance for Exit and Top.
  - Volume Resistance for the Laminar or Turbulent Frictional Flow in the Heat Sink Channels
- Heat Transfer is Treated Using a Volumetric Based Heat Transfer Coefficient. This Coefficient is a Function of Flow Rate for Turbulent Flow and Constant for Laminar.
- The Heat Transfer Model Does Not Account For Fin Efficiency. Under Predicts Base Temperature for Highly Convective Cases Where Fins Are Thin.

Compact Representation of Heat Sinks

- Option 2: Approximation Based on Computational or Physical Wind Tunnel Characterization
  - Represent Heat Sink Base As a Conducting Cuboid
  - Perform(Separate) Computational/Physical Wind Tunnel Analysis to Determine Flow Impedance Characteristics of Fins
  - Account for Impedance of Heat Sink Fins With Volume Resistance in System Level Model
  - Account for Heat Dissipation of Fins with Volume Heat Transfer Coefficient in System Level Model



Index

Compact Representation of Heat Sinks

- Option 2: Approximation Based on Computational Wind Tunnel Characterization (Cont.)
  - Duct Detailed Fins (Only) of Heat Sink With Computational Domain: Use Symmetry Faces on 4 Long Sides and Open Faces on Ends
  - Extend the Computational Domain as Shown
  - Use Fixed Flow Device and Collapsed Resistance (or Nothing) for Ends

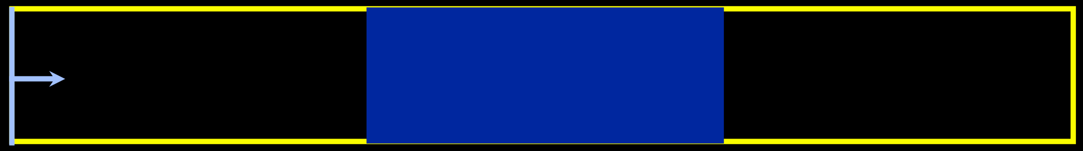
Index

Compact Representation of Heat Sinks

- Option 2: Approximation Based on Computational Wind Tunnel Characterization (Cont.)
  - Select Automatic Turbulence Model
  - Solve for Flow Only
    - Use Typical Velocities for Fixed Flow Device: e.g., 0.5, 1, 1.5, 2 m/s
  - Measure ΔP Across Wind Tunnel for each Velocity Used
    - P_{outlet}=0 (gage), So ΔP is Simply Average P at Fixed Flow Device End
    - Use Profiles Window to Show the Stream wise Pressure Drop and Monitor Point Far Upstream for the ΔP

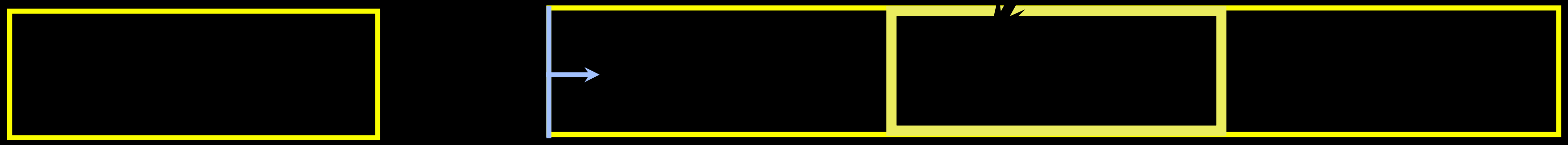
Compact Representation of Heat Sinks

- Option 2: Approximation Based on Computational Wind Tunnel Characterization (Cont.)
  - Use ΔP vs. V Data to Define Equivalent Non-Collapsed Resistance
    - Can Use Advanced Resistance Attribute (When ΔP Is Not α V^2 – Refer to Resistance Calculation Slides Later in this Lecture)
    - Typically Use Standard Resistance Attribute (Iteratively If ΔP Is Not α V^2)



Compact Representation of Heat Sinks

- Option 2: Improved Approximation Based on Computational Wind Tunnel Characterization (Cont.)
  - Replace Detailed Fins (Cuboids) With Non-Collapsed Resistance
  - Re-Run One Case to Ensure that Computed ΔP’s for Detailed and Compact Models Agree



Index

Compact Representation of Heat Sinks

- Option 2: Use a Specified h on Top of the Heat Sink Base Determined Also From a Computational Wind Tunnel Analysis
  - Obtain Loss Coefficients from Previous Computational Wind Tunnel Analysis
  - Perform New Analyses Including Heat Sink Base to Determine h
    - Place a Collapsed Region on Heat Sink Base Top
    - Solve for Flow and Heat Transfer
      - Again Use Typical Velocities for Fixed Flow Device: e.g., 0.5, 1, 1.5, 2 m/s

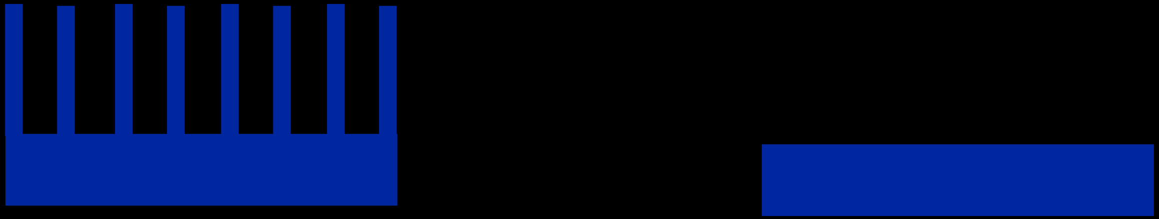
Compact Representation of Heat Sinks

- Option 2: Use a Specified h (Cont.)
  - Obtain Average T and Heat Flux Over Top of Heat Sink Base
    - Probe With Mouse for Desired T Over a Vis. Plane
    - Determine $q_{H.S.BaseTop}$ From Collapsed Region
    - Or
    - Or Read “h_fins” from the real fins in the Tables Window

Index

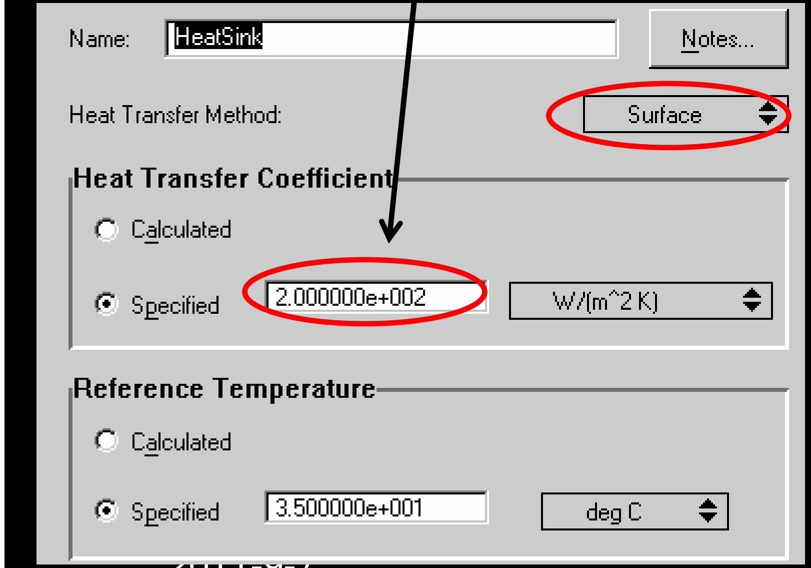
Compact Representation of Heat Sinks

- Option 3: Use a Specified h (Cont.)
  - Replace Detailed Model With Compact Model as Shown in System Level Model



Compact Representation of Heat Sinks

- Option 3: Use a Specified h (Cont.)
  - Surface vs. Volumetric Heat Transfer Coefficient



Name: HeatSink

Heat Transfer Method: Surface

Heat Transfer Coefficient

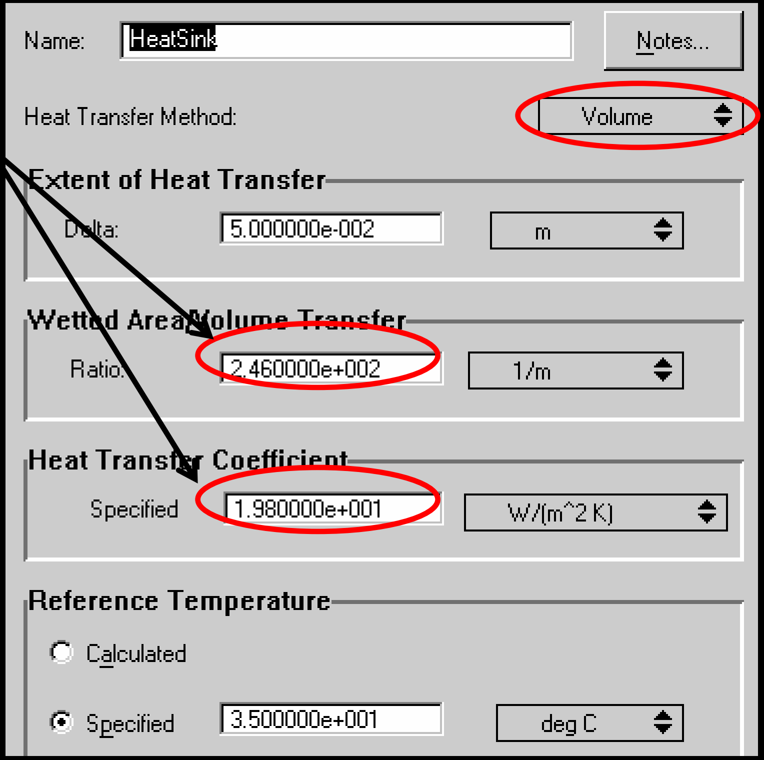
○ Calculated

● Specified 2.000000e+002 W/(m^2 K)

Reference Temperature

○ Calculated

● Specified 3.500000e+001 deg C



Name: HeatSink

Heat Transfer Method: Volume

Extent of Heat Transfer

Delta: 5.000000e-002 m

Wetted Area/Volume Transfer

Ratio: 2.460000e+002 1/m

Heat Transfer Coefficient

Specified 1.980000e+001 W/(m^2 K)

Reference Temperature

○ Calculated

● Specified 3.500000e+001 deg C

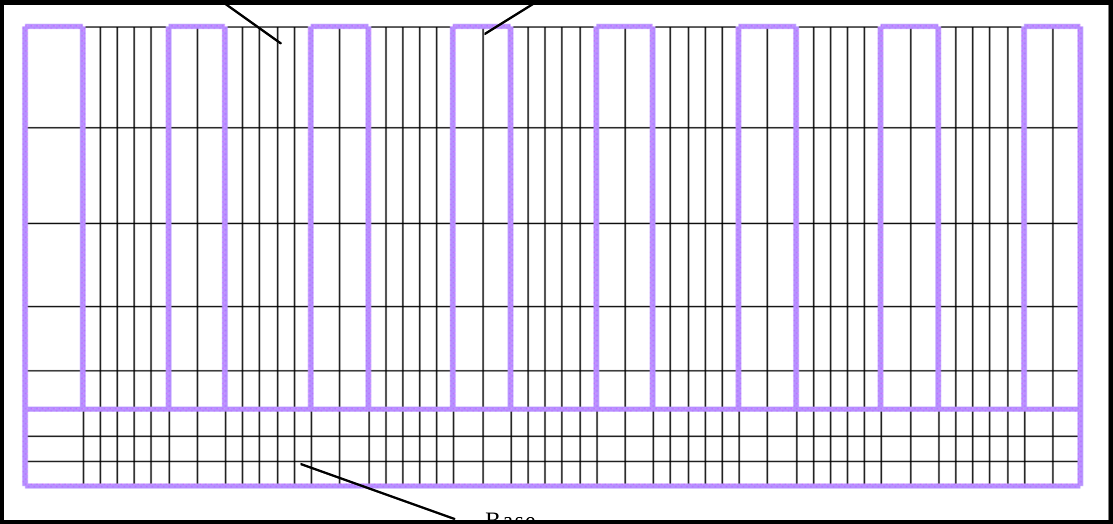
Compact Representation of Heat Sinks

- Option 3: Use a Specified h (Cont.)
  - Re-Run One Case to Ensure that Computed Results for Detailed and Compact Models Agree for Given Power Dissipation in Heat Sink Base

Index

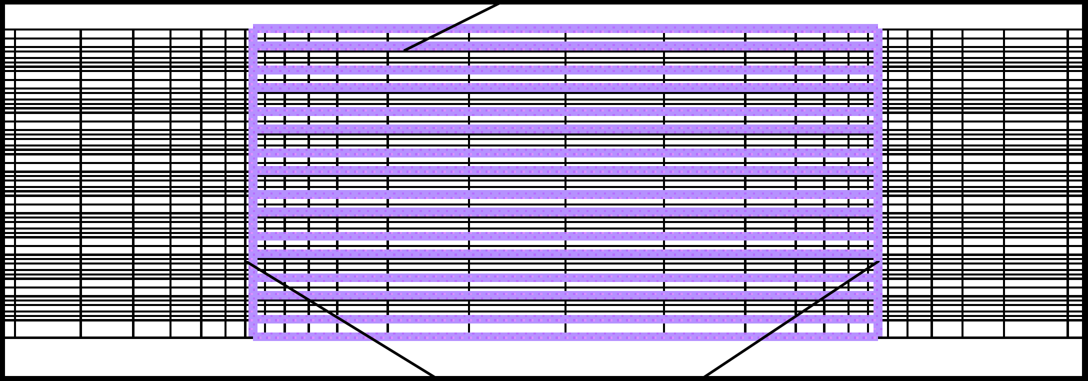
Compact Representation of Heat Sinks

- Grid Between Fins for Detailed Heat Sink in Computational Wind tunnel
  - 3 Cells Will Capture Thermal Effects Accurately
  - 4 Or 5 Cells Needed for Accurate Pressure Drop



Compact Representation of Heat Sinks

- Grid in Streamwise Direction
  - Cluster Grid at Entrance and Exit to Capture Contraction and Expansion Losses



Modeling Grilles, Filters and Other Flow Resistances

- Use a (Collapsed or Non-Collapsed) Resistance With Appropriate Loss Coefficient
- Recall, Definition of Loss Coefficient

$\Delta p = f\ (\rho v^2/2)$ (Collapsed)

$\Delta p/\Delta x = f_x\ (\rho v^2/2)$ (Non-Collapsed)

$\Delta p/\Delta y = f_y\ (\rho v^2/2)$ (Non-Collapsed)

$\Delta p/\Delta z = f_z\ (\rho v^2/2)$ (Non-Collapsed)

where:

v = velocity (device or approach)
f = loss coefficient

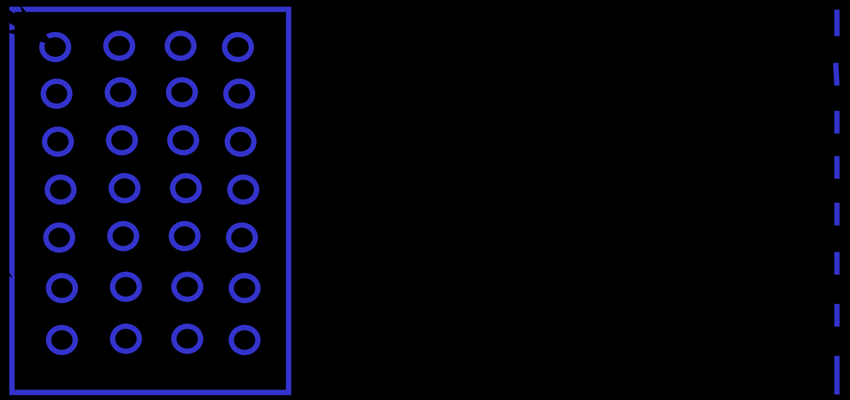
Modeling Flow Resistances

- Loss Coefficients Based on Device and Approach are Related by Geometry Alone

$$f_d/f_a=(f.a.r.)^2$$

where:

f.a.r. = free area ratio



Modeling Flow Resistances

- Available Loss Coefficient Options
  - Standard
    - Assumes $\Delta p \alpha v^2$
    - Constant Loss Coefficient f
  - Advanced
    - Allows complicated Δp dependence on v
    - Loss Coefficient f not Constant

$$f = a/Re + b/Re^{\alpha}$$

in which,

f = loss factor (as before)
$Re = \rho UL/\mu$ = Reynolds No. based on
a user specified length scale

a,b,α = constants specified by the user

Modeling Flow Resistances

- Where Do I Get Loss Coefficients?
  - Reference Texts, e.g., Fried and Idelchick
  - Manufacturer Data
  - Perform Computational Wind Tunnel Analysis on Device
- Advice on Loss Coefficients
  - Use Standard Model If You Have $\Delta P \sim V^2$
    - Most Turbulent, High Re Flows
  - Use Advanced Model If You Have $\Delta P \sim V$, $\Delta P \sim V^{1.7}$, etc.
    - Laminar and Transitional, Lower Re Flows
  - Can Always Use Standard Model If You’re Willing to Iterate

Example: Given $\Delta P=kV$

- This Case is Typical for Laminar Flow
- If Resistance Can Be Modeled As “Thin”:
  - Resistance Type: Planar
  - Loss Coefficients Based On: Approach Velocity
  - Resistance Formula: Advanced
  - Length Scale (L): 1 m
  - A Coefficient: $(2\ L\ k)/\mu$
  - B Coefficient: 0
  - Index: 0

Example: Given $\Delta P=kV^x$

- This Case is Typical For Flow Transitioning to Turbulent
- If Resistance Can Be Modeled As “Thin”:
  - Resistance Type: Planar
  - Loss Coefficients Based On: Approach Velocity
  - Resistance Formula: Advanced
  - Length Scale: 1 m
  - A Coefficient: 0
  - B Coefficient: $2\ k\ (L/\mu)^{(2-x)}\rho^{(1-x)}$
  - Index: 2-x
- This is General Case; Includes:
  - $\Delta P=kV$
  - $\Delta P=kV^2$
  - $\Delta P=kV^{1.4}$
  - etc.

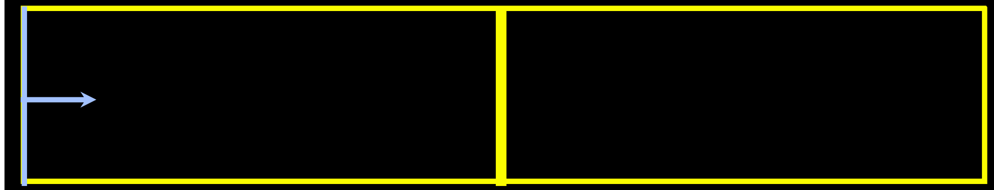
Example: Given $\Delta P=k_1V^2+k_2V$

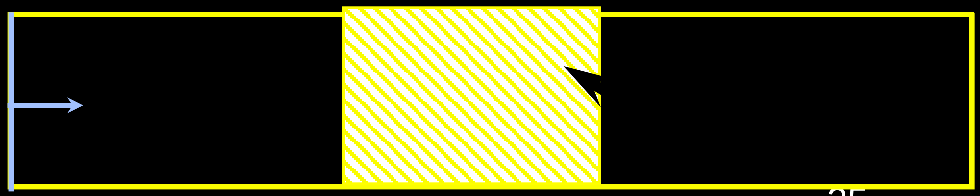
- This Case is Typical For Flow Transitioning to Turbulent (It Simply Contains a Laminar and Turbulent Term)
- If Resistance Can Be Modeled As “Thin”:
  - Resistance Type: Planar
  - Loss Coefficients Based On: Approach Velocity
  - Resistance Formula: Advanced
  - Length Scale: 1 m
  - A Coefficient: $(2\ L\ k_2)/\mu$
  - B Coefficient: $(2\ k_1)/\ \rho$
  - Index: 0
- This is General Case; Includes:
  - $\Delta P=kV$
  - $\Delta P=kV^2$
  - $\Delta P=k_1V^2+k_2V$

Index

Modeling Flow Resistances

- Validate Resistance in Computational Wind Tunnel Before Placing in System
  - Ensure That You Can Reproduce the ΔP vs. V Data Used to Build Resistance

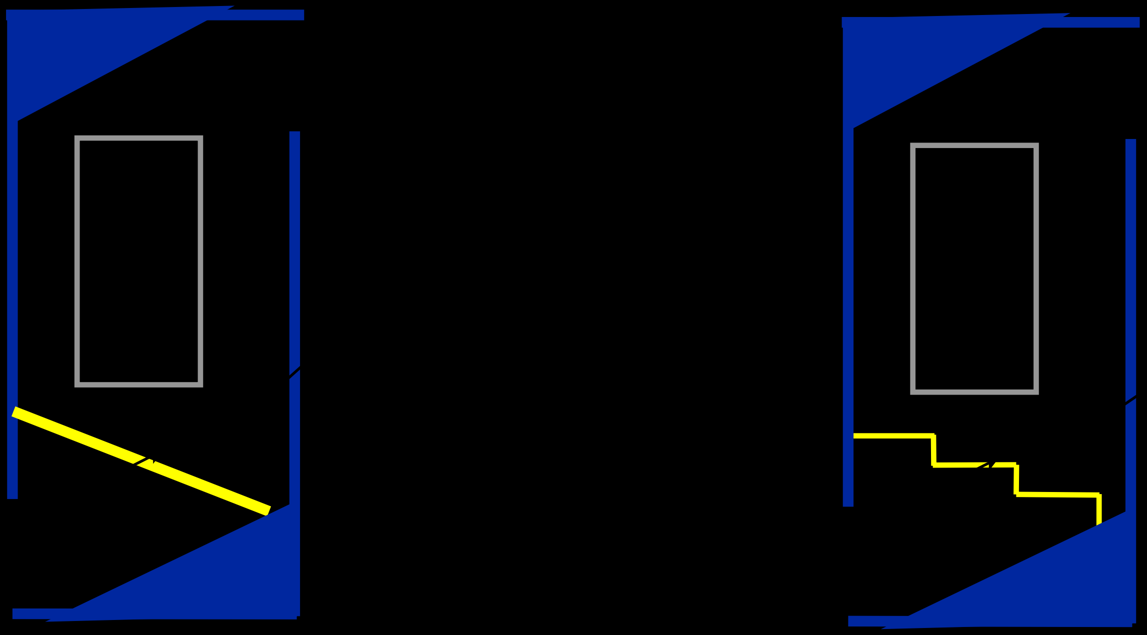




Other Compact Models

- The Flow Losses and Heat Addition of All Components/Modules in the Analysis Need to be Accounted For.
- In Cases Where the Details of those Components Are Not Important, the Above is Still True.
- Create Compact Models for These:
  - Guess the Losses and Heat (Typically Early in Concept Design and Optimization)
  - Use a Combination of Collapsed or Volumetric Resistances With Associated Sources.
  - Create Detailed Windtunnel Models of Modules, Characterize for Losses and Create Good Compact Models. (Later when more information is available).
  - This Process is Similar to the Manual Heat Sink Compact Model

Angled Resistances

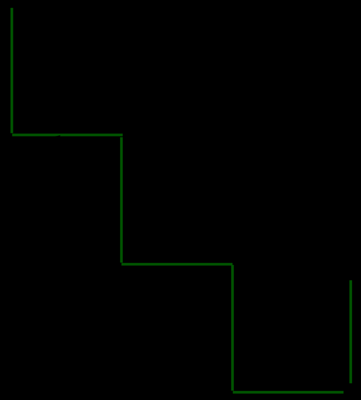


Angled Resistances

- There are 2 Ways to Create this Angled Resistance In Flotherm.
  - Use and go to the User Support Center. Choose [Support], Then [Web Parts].
  - Do it Yourself Using the Instructions on the Following Page.

Angled Resistances

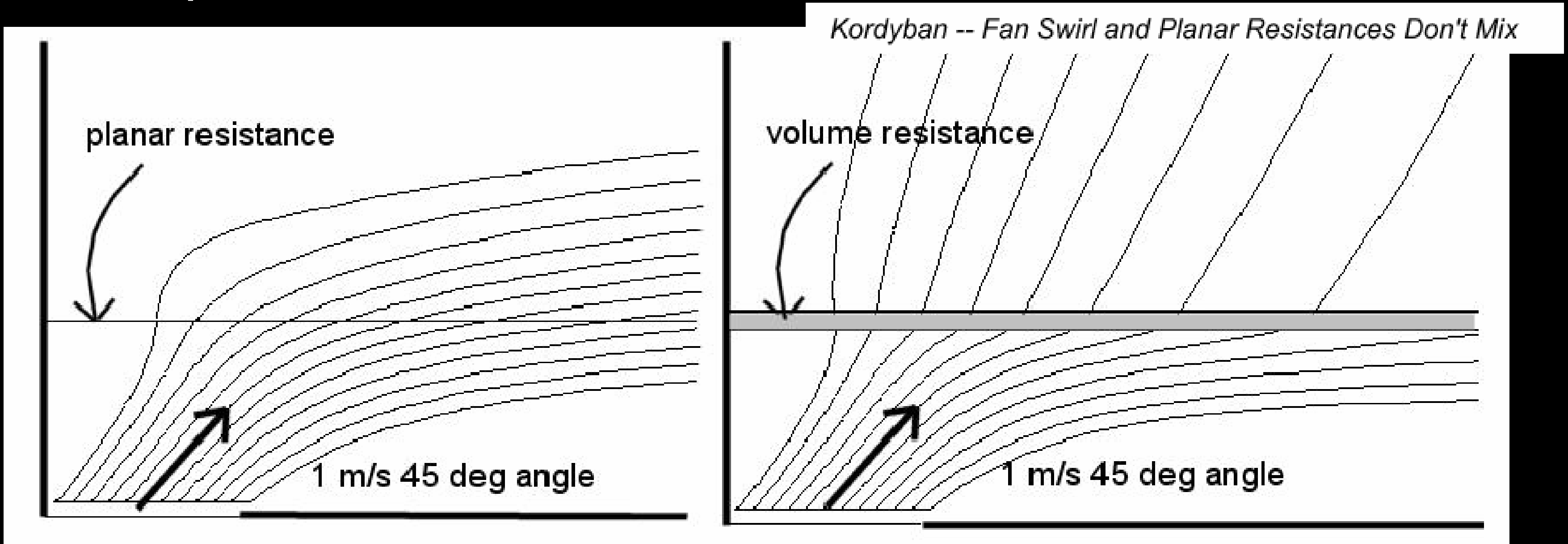
- Consider Collapsed Resistances Only
- Keep Stair-Step Fit Close to Local Grid Size
- Given Data $\Delta P = k\, V^x$, adjust k's as follows:
  - $k_x = k/\sin^x\theta$
  - $k_y = k/\cos^x\theta$
  - Then Model With Appropriate Standard or Advanced Attribute As for Non Angled Case



Index

Difference Between Thin and Thick Resistances

- Filters Tend to Straighten the Flow Due to Thickness (Need to Model With Non-Collapsed Resistances)
- Perforated Plates can be Modeled Correctly with Collapsed Resistances



Kordyban -- Fan Swirl and Planar Resistances Don't Mix

Figure 6. Stream plots from two FLOTHERM solutions of angled flow approaching an air filter. Which method gives the proper downstream velocity distribution?