



University Turbine Systems Research Program

# UTSR Fellowship

## Secondary Flow Modeling for Low Emissions Combustors

Kyle Gompertz

# Presentation Outline

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- Combustor Can #1
  - FABL Model Predictions
  
- Combustor Can #2
  - Modular FABL Model for concept design

# Combustor Can#1

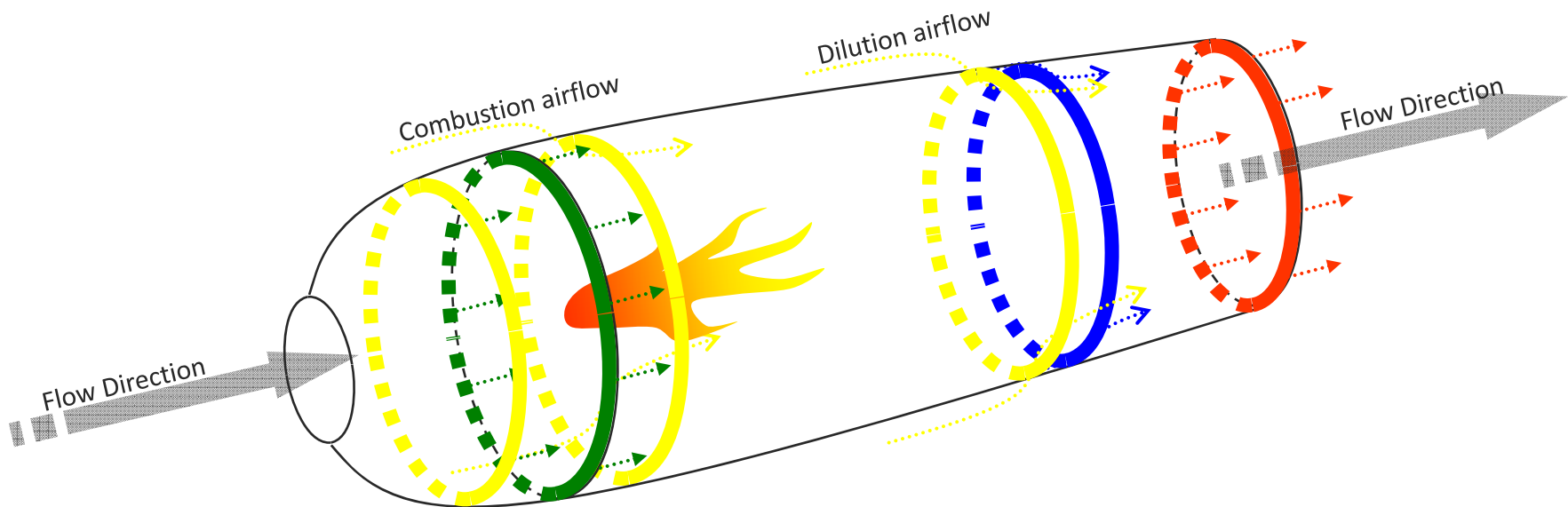
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## *Reduced cooling combustor liner designed and tested at P&W*

- A secondary flow model for a new reduced cooling low emissions combustor was developed
- This combustor achieved significant reduction in CO (relative to baseline design) without NO<sub>x</sub> penalty
- Engine validation underway
- The secondary flow model was used to interpret engine test results as well as guide design enhancements

# FABL Model: Model description

- Coolant Inlet Orifices
- Combustion and Dilution Grommets
- Surface heat transfer augmentation
- Cooling Exit Holes
- Z-Brackets and Liner TE Exit



# FABL Model Predictions

## Flow Network Chambers and Restrictions:

Chambers:



Both temperature and pressure are specified (“fixed”)



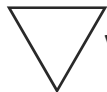
Only pressure is specified (temperature is variable)



Only temperature is specified (pressure is variable)



Neither temperature nor pressure is specified



Valve Chamber; the same specs. apply; can provide additional cond<sup>n</sup>s

Restrictions:



Pressure Ratio vs. Flow Parameter

1



Sharp and Rounded Orifices

2



Isentropic Nozzles

3



Compressible Flow Restrictions

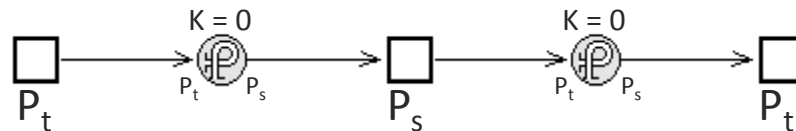
4

# FABL Model Predictions:

## Compressible Flow Restriction

- Can be composed of one or a series of individual K and/or friction factor ( $L/D_h$ ) pressure losses.
- When the inlet and exit flow areas for an individual K loss are different, the pressure loss calculation will be based on velocity head in the smaller area.
- flow areas of the individual losses should "fit" together
- Modeling problems avoided by specifying a  $P_t$  into the Restriction and  $P_s$  out, or a  $P_t$  in and a  $P_t$  out

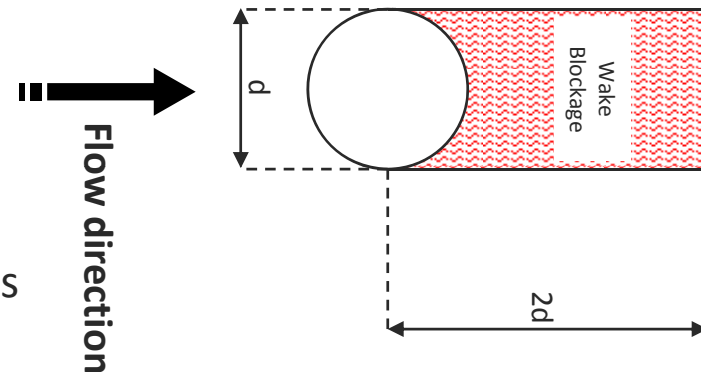
$$\Delta P_T = K(P_T - P_S)$$



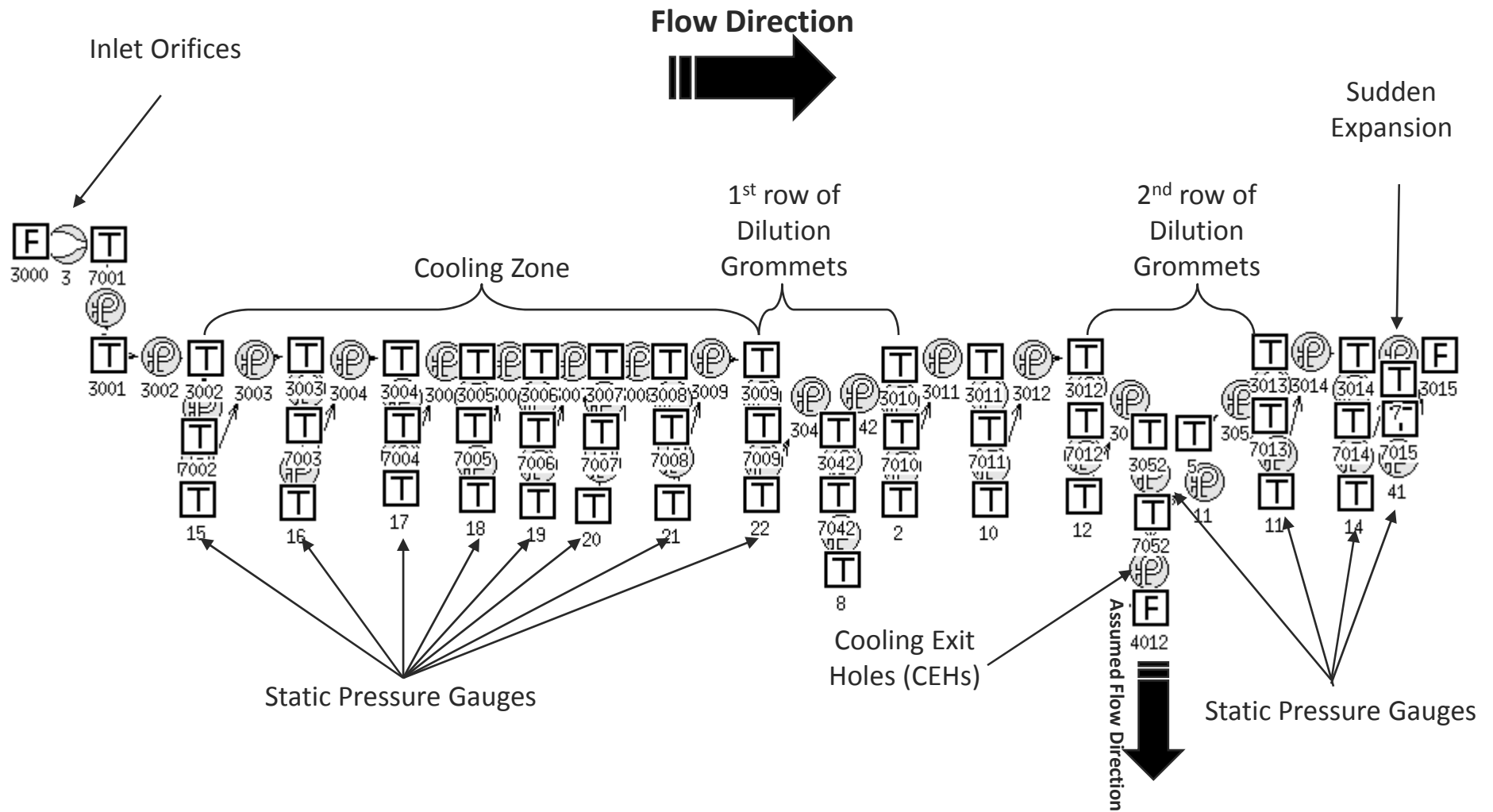
- Many elements in FABL do not distinguish between  $P_s$  and  $P_t$  and do not ask that they be identified from input
- FABL uses whatever chamber pressures are associated with upstream and downstream chambers.

# FABL Model: Grommet losses

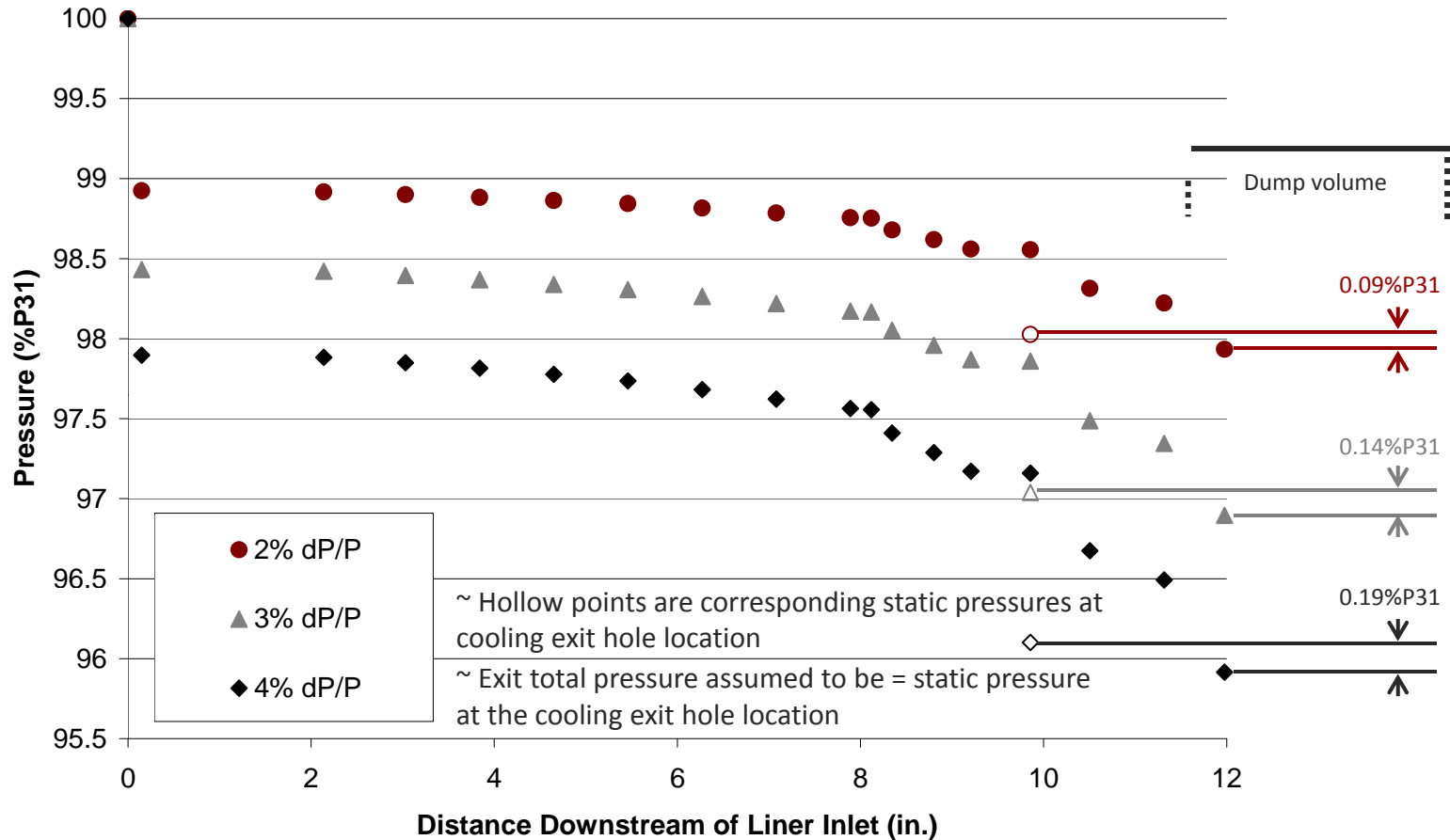
- 2<sup>nd</sup> row combustion grommets:
  - Neglected wake losses since there are impingement jets just down stream
- 1<sup>st</sup> and 2<sup>nd</sup> row dilution grommets:
  - Different sizes
  - Modeled with compressible flow loss restriction with essentially 3 steps
    1. Contraction from upstream area to throat; no  $P_t$  loss
    2. Imposed K-loss = 0.15
    3. Wake extend from the throat 2 grommet diameters downstream to account for wake blockage



# FABL Model: Flow Network Diagram



# FABL Model: Cold Flow Data Matching

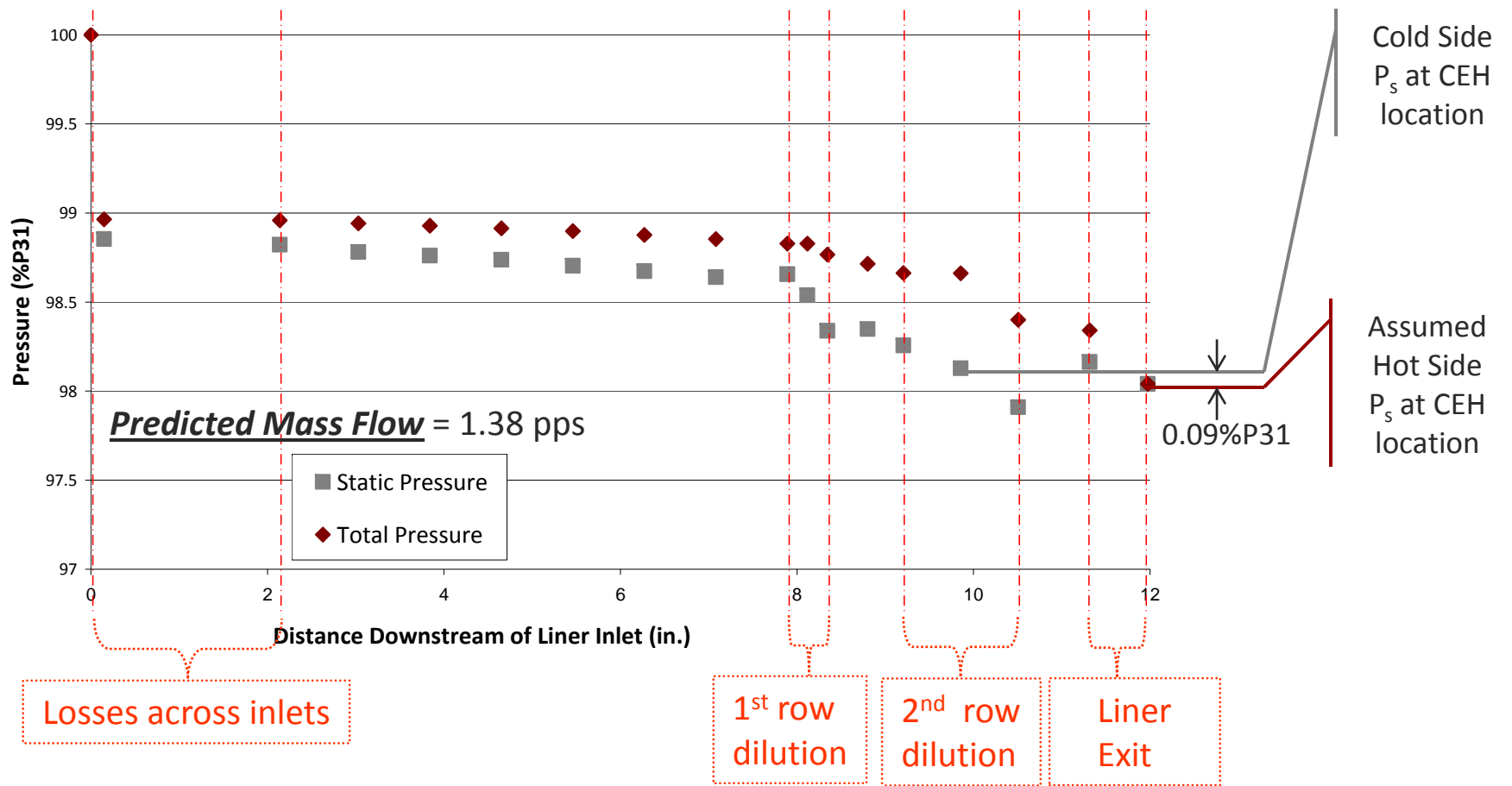


| Lumped Inlet Cd | FABL Computed Mass Flow (pps) | Cold Flow: Measured Nozzle Mass Flow (pps) | dP/P  | P <sub>Us</sub> (psia) | P <sub>Ds</sub> (psia) | T <sub>amb</sub> (°F) |
|-----------------|-------------------------------|--|-------|------------------------|------------------------|-----------------------|
| 0.3587          | 0.1314                        | 0.13135                                    | 2.07% | 14.4255548             | 14.1274807             | 71.8486988            |
| 0.3685          | 0.163                         | 0.16297                                    | 3.10% | 14.4255548             | 13.9778498             | 71.8486988            |
| 0.3615          | 0.1841                        | 0.18413                                    | 4.08% | 14.4255548             | 13.8363254             | 71.8486988            |
| <b>0.3629</b>   | <b>Average</b>                |  |       |                        |                        |                       |

Cold flow measured values arrived at by averaging differences between flowing the entire can, and flowing everything except the liner.

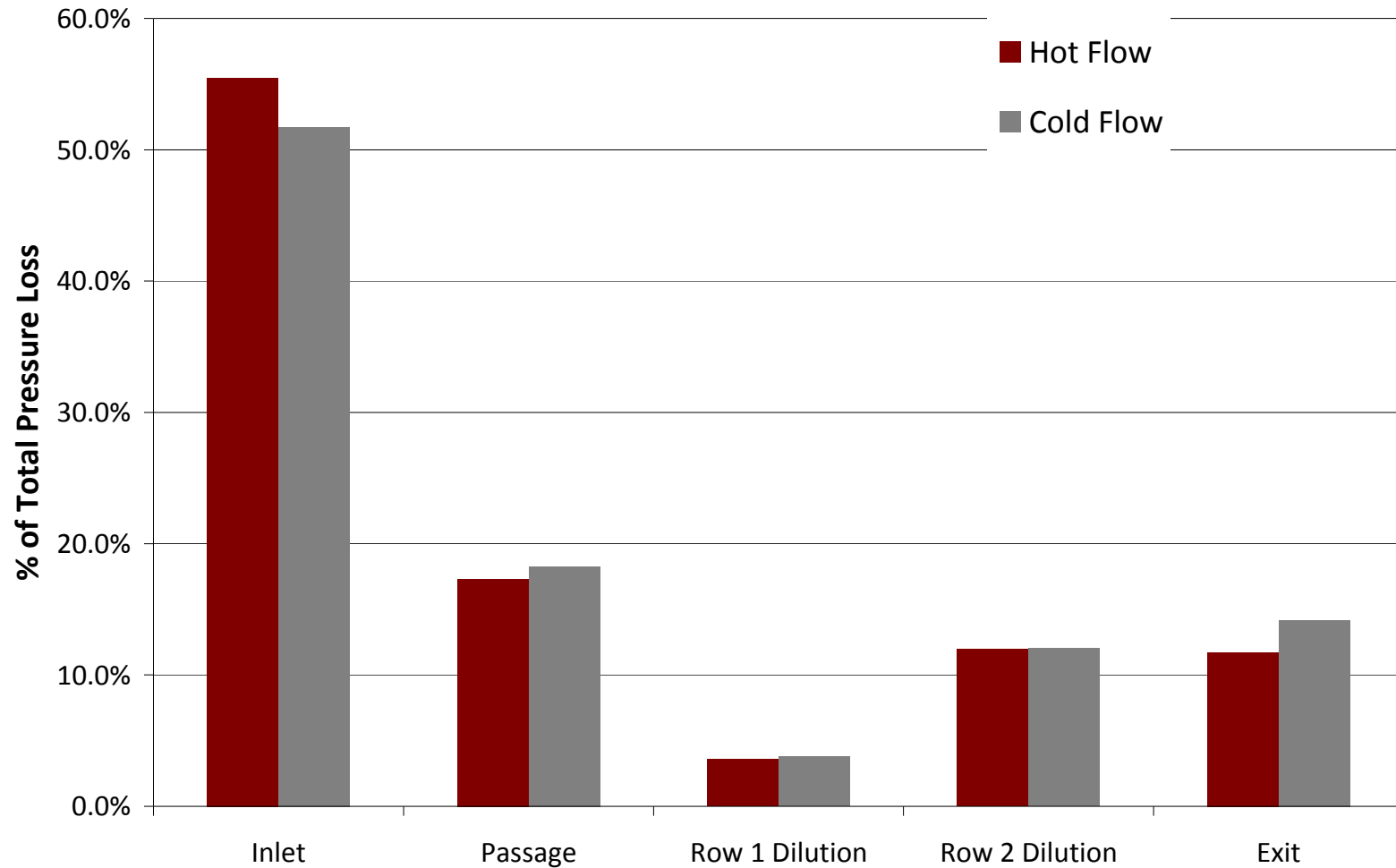
# FABL Model Predictions: Phase I design

Liner Pressure Profile: hot flow,  $dP/P \approx 2\%$



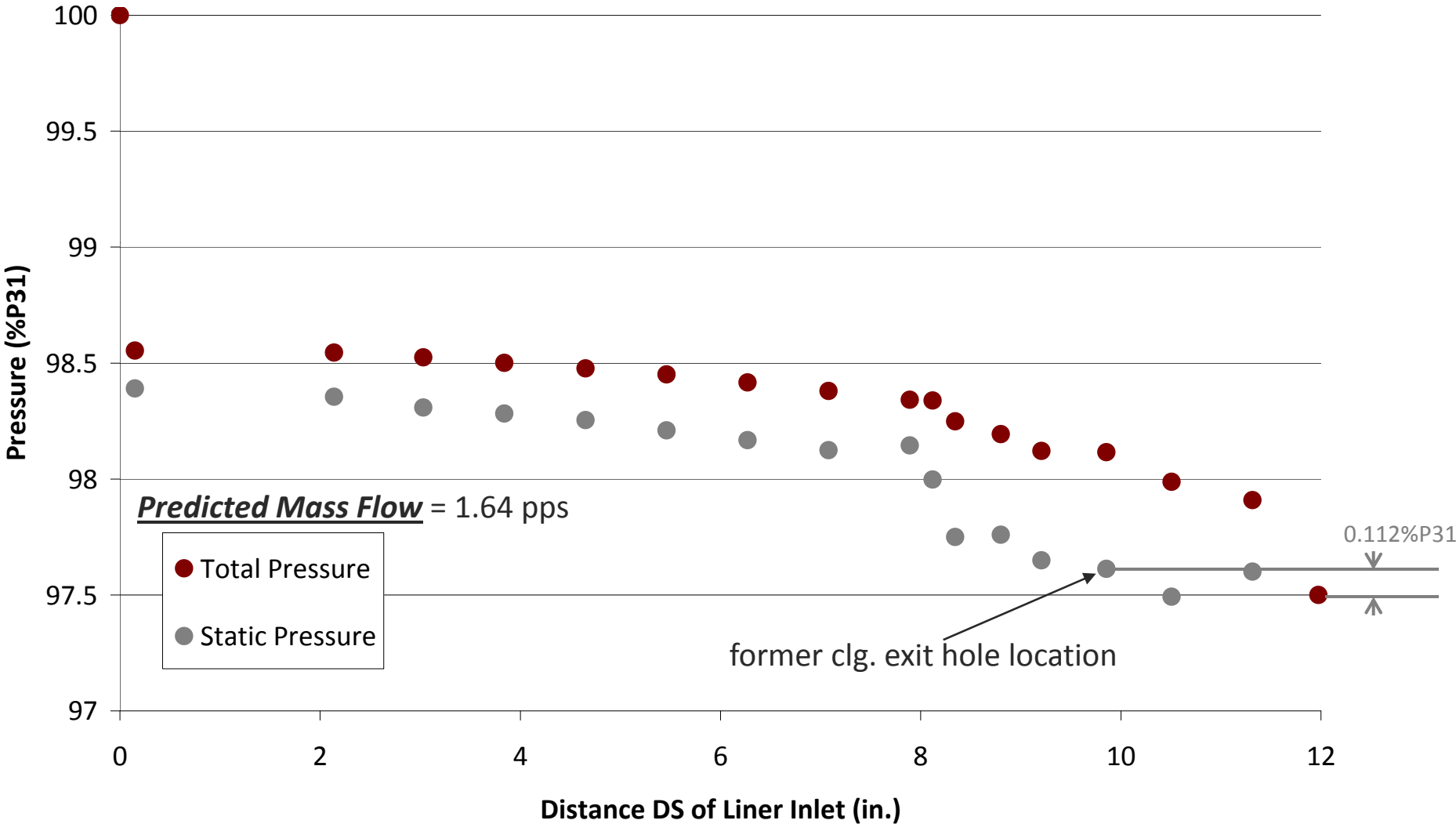
# FABL Model: Pressure Loss Breakdown

*Phase I design*  
*Greater than 50% pressure loss across cooling inlet*



# FABL Model Predictions: Phase II design

Liner Pressure Profile: hot flow, dP/P = 2.5%



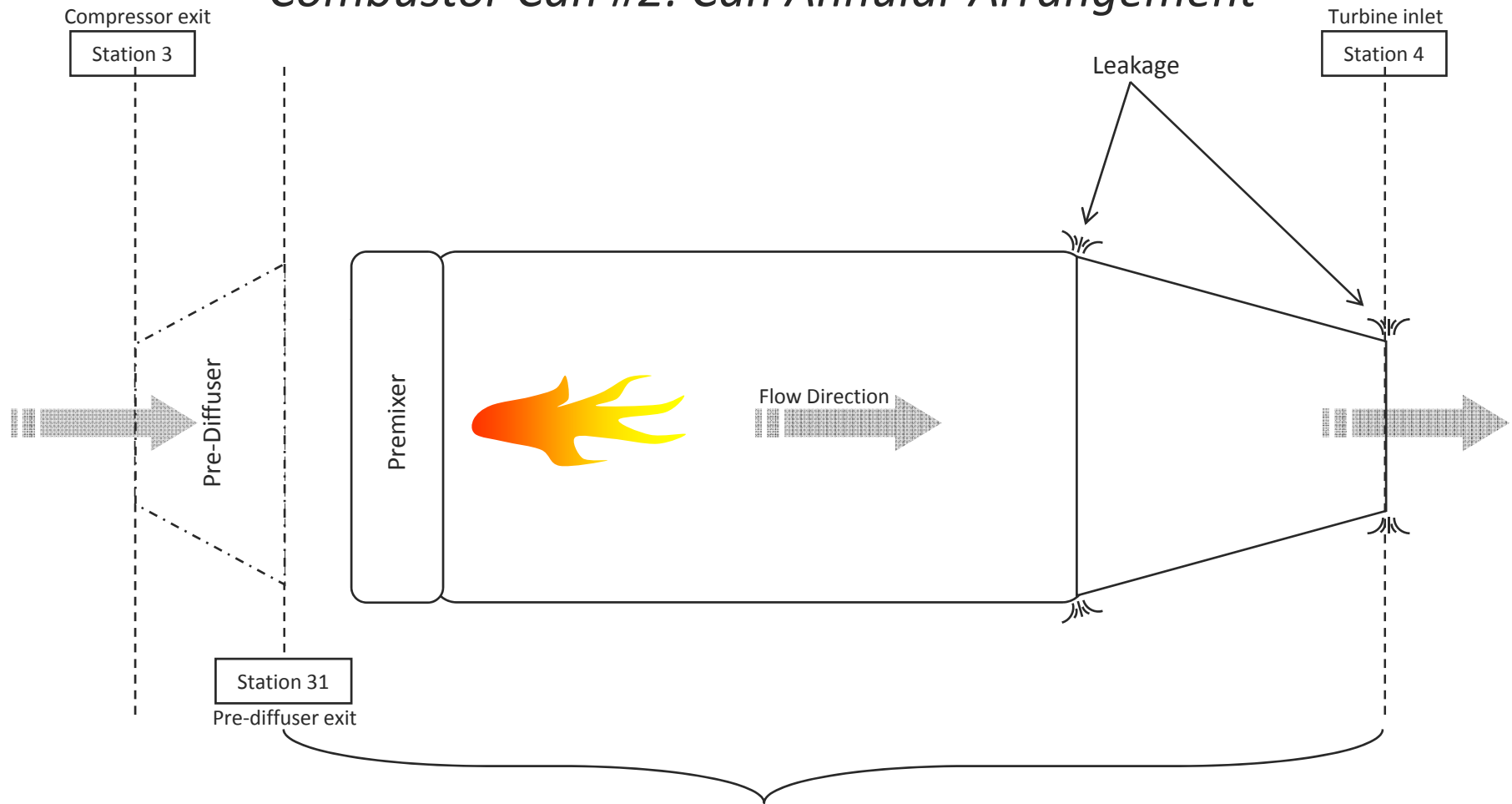
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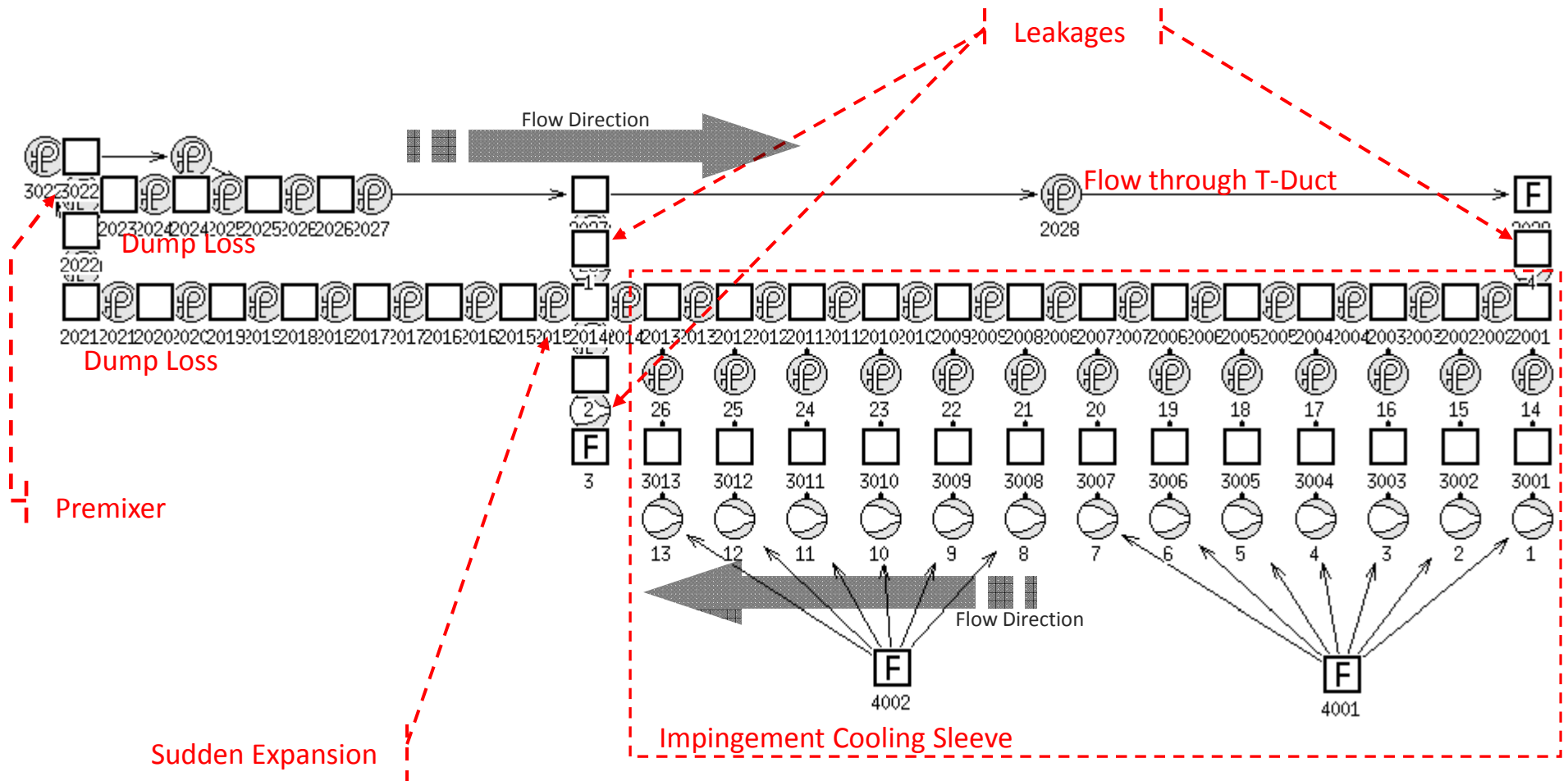
# Combustor Can#2

## Combustor Can #2: Can Annular Arrangement



Modeled flow through combustor inlet orifices, premixer, combustor can, transition duct, and interface leakages

# Combustor #2 FABL Model: Flow Network



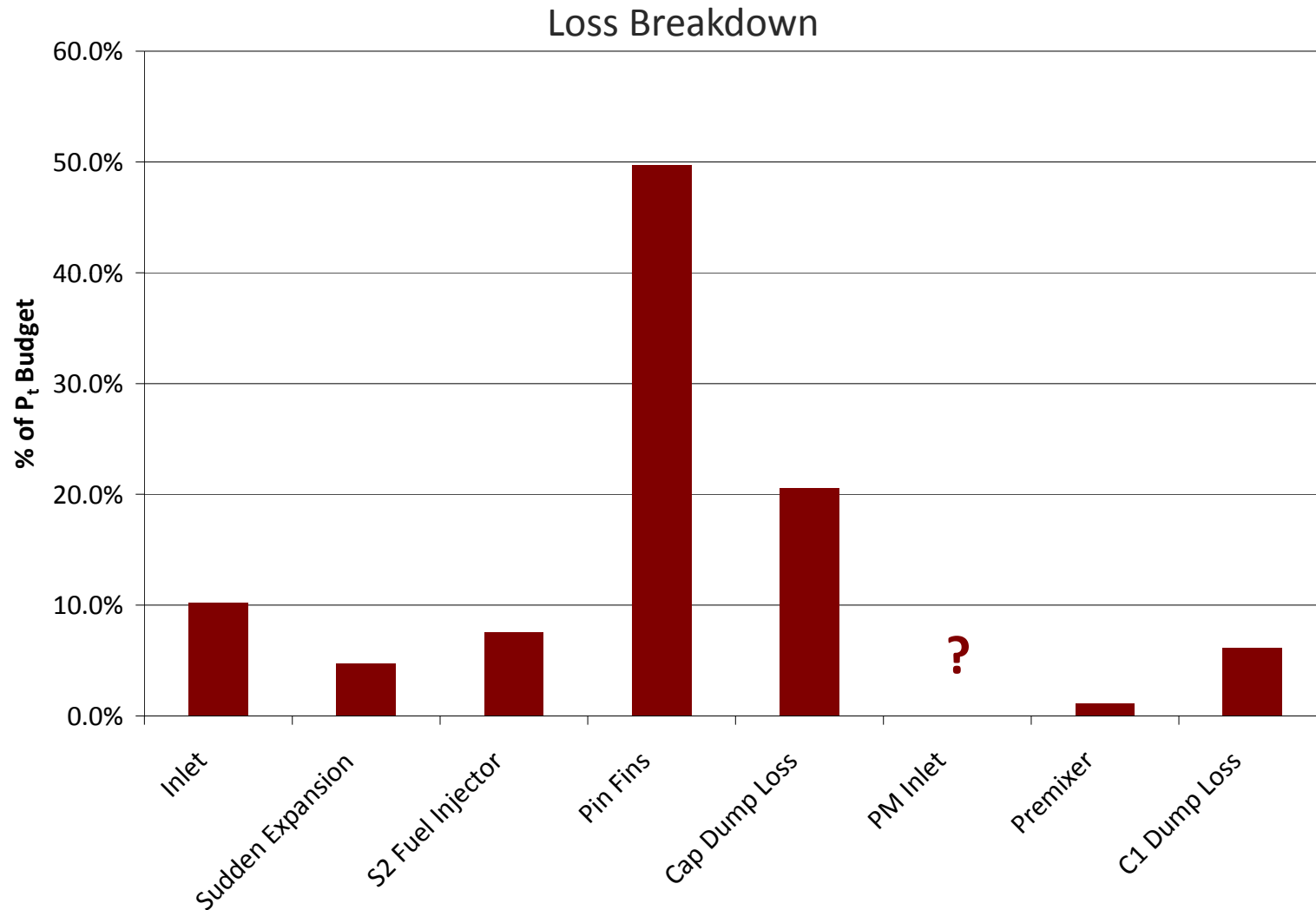
# Preliminary FABL Model Assumptions

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- Scaled transition piece area function
- Impingement sheet
  - Uniform surrounding source pressure,  $P_{31}$
  - 13 rings of impingement cooling inlets, each with 24 holes
  - 4 different sized holes: varied to maintain edge-to-edge spacing
  - $C_d = 0.7$
- Grommets
  - K-loss  $\approx 0.1$
  - Blockage extending downstream  $2d$  ( $d = \text{minor diameter}$ )
- Premixer inlet  $P_t$  loss
- K-loss through premixer = 0.15

# FABL Model Predictions: Sample Results

8-can baseline model,  $dP/P \approx 5\%$   
Model predictions:  $W_{31} \approx 18$  pps, primary stage airflow =  $31\%W_{31}$



# Special Thanks

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- Urmila Reddy
- Al Veninger
- Dick Tuthill
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- Jeff Melman
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