Appendix C

Evaluation of Heat Transfer Parameters from CFD for Use in TMM in Case of Gas Convection in Vented Cavities

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Abstract

The analysis of the convection in Ariane 5 launcher's vented cavities on ground and during ascent is important for the thermal control of the equipments and of the propellants during flight phase. For the according analysis of the upper stage, a lumped parameter Thermal Mathematical Model (TMM) has been established within ESATAN.

As an input, heat transfer parameters (HTPs) have been derived from two related Computational Fluid Dynamic (CFD) analysis cases, the so called hot and cold case. The methodology for evaluation of these HTPs from the CFD analysis is described for one and more gas nodes based on steady state results. For a representative launcher cavity with laminar/turbulent buoyancy influenced flow, a comparison is provided between the TMM results and the CFD results obtained with the commercial tool ANSYS Fluent. Exact agreement is achieved between TMM and CFD for the hot and the cold case. Deviations for the analyzed intermediate cases turned out to be less than 5K in case of a one gas node TMM and less than 3K in case of a seven gas node TMM.

Evaluation of Heat Transfer Parameters from CFD for Use in TMM in Case of Gas Convection in Vented Cavities

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- **Introduction**
- **Background**
- **Description of Methodology**
- **Test Case**
- **Conclusion & Outlook**

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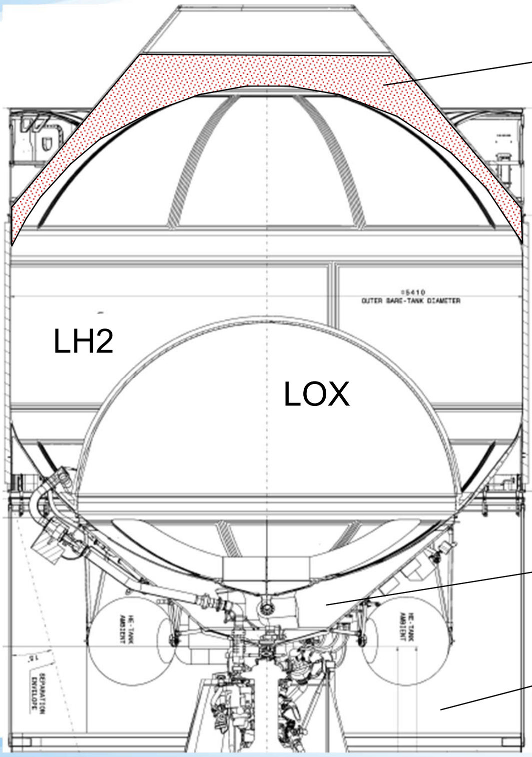
Introduction: Example A5ME Ground Phase



EBS Cavity with N2 venting (or He venting)

ETF Cavity with N2 venting

Interstage Cavity with N2 venting

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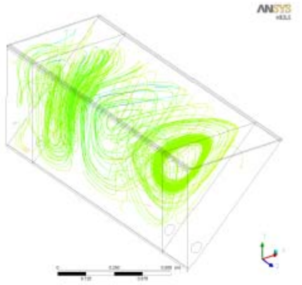
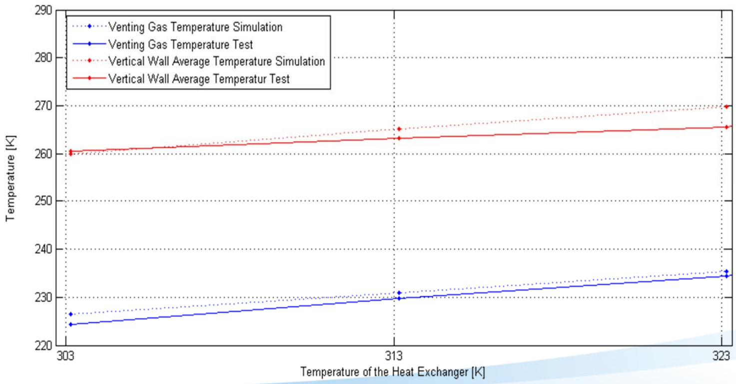
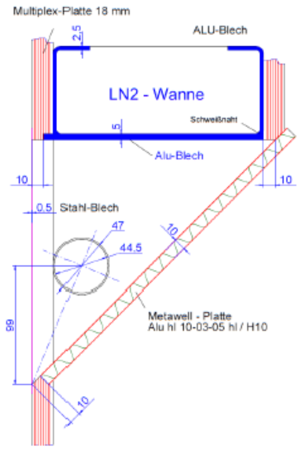
Background: Check of CFD with Cryo-Tests







- N2 vented cavity with a simplified typical geometry
- Variable temperature of heat exchanger to realize several test cases
- Good agreement between CFD and test

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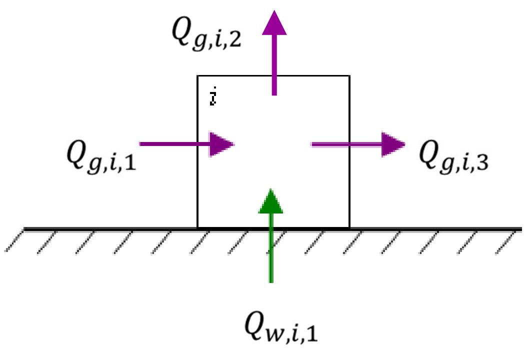
Method: Approach for HTPs from CFD

- Two CFD results: Hot and cold case (more intervals possible)
- Steady state:
  - Sum of all heat fluxes entering the gas is zero
  - For more than one gas node $0 = \sum_k Q_{w,i,k} + \sum_k Q_{g,i,k}$



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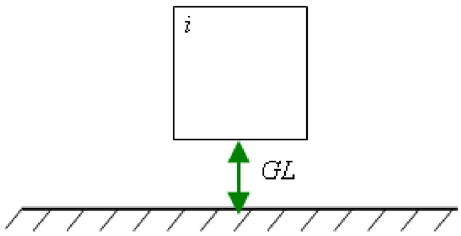
Method: Gas/Wall Heat Transfer ⇒ GLs from CFD

$$GL_{w,i}^{cold} = \frac{Q_{w,i}^{cold}}{T_i^{cold} - T_{w,i}^{cold}} \qquad GL_{w,i}^{hot} = \frac{Q_{w,i}^{hot}}{T_i^{hot} - T_{w,i}^{hot}}$$

$$\Rightarrow \quad GL_{w,i} = GL_{w,i}^{cold} + \frac{GL_{w,i}^{hot} - GL_{w,i}^{cold}}{\dot{m}_{in}^{hot} - \dot{m}_{in}^{cold}} \cdot (\dot{m}_{in} - \dot{m}_{in}^{cold})$$



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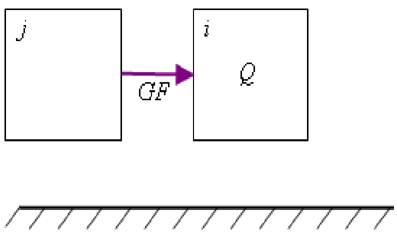
Method: Gas/Gas Heat Transfer ⇒ GFs and Qs from CFD

$$Q_{g,i}(T_i, T_j) = Q_{g,i}^{cold} + \frac{Q_{g,i}^{hot} - Q_{g,i}^{cold}}{(T_j^{hot} - T_i^{hot}) - (T_j^{cold} - T_i^{cold})} \left[(T_j - T_i) - (T_j^{cold} - T_i^{cold}) \right]$$

$$\Rightarrow \quad GF_i = \frac{Q_{g,i}^{hot} - Q_{g,i}^{cold}}{(T_j^{hot} - T_i^{hot}) - (T_j^{cold} - T_i^{cold})}$$

$$\Rightarrow \quad Q_i = Q_{g,i}^{cold} - \frac{Q_{g,i}^{hot} - Q_{g,i}^{cold}}{(T_j^{hot} - T_i^{hot}) - (T_j^{cold} - T_i^{cold})} \cdot (T_j^{cold} - T_i^{cold})$$



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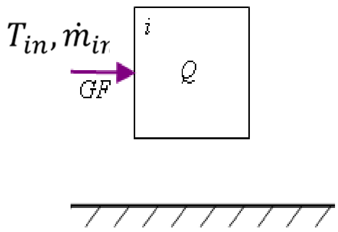
Method: Venting Inlet/Gas Heat Transfer ⇒ GFs and Qs from CFD

$$Q_{g,i}(\dot{m}_{in},T_{in},T_i)=Q_{g,i}^{cold}+\frac{Q_{g,i}^{hot}-Q_{g,i}^{cold}}{\dot{m}_{in}^{hot}(T_{in}^{hot}-T_i^{hot})-\dot{m}_{in}^{cold}(T_{in}^{cold}-T_i^{cold})}\left[\dot{m}_{in}(T_{in}-T_i)-\dot{m}_{in}^{cold}(T_{in}^{cold}-T_i^{cold})\right]$$

$$\Rightarrow \quad GF_i=\dot{m}_{in}\frac{Q_{g,i}^{hot}-Q_{g,i}^{cold}}{\dot{m}_{in}^{hot}(T_{in}^{hot}-T_i^{hot})-\dot{m}_{in}^{cold}(T_{in}^{cold}-T_i^{cold})}$$

$$\Rightarrow \quad Q_i=Q_{g,i}^{cold}-\frac{Q_{g,i}^{hot}-Q_{g,i}^{cold}}{\dot{m}_{in}^{hot}(T_{in}^{hot}-T_i^{hot})-\dot{m}_{in}^{cold}(T_{in}^{cold}-T_i^{cold})}\cdot\dot{m}_{in}^{cold}\cdot(T_{in}^{cold}-T_i^{cold})$$



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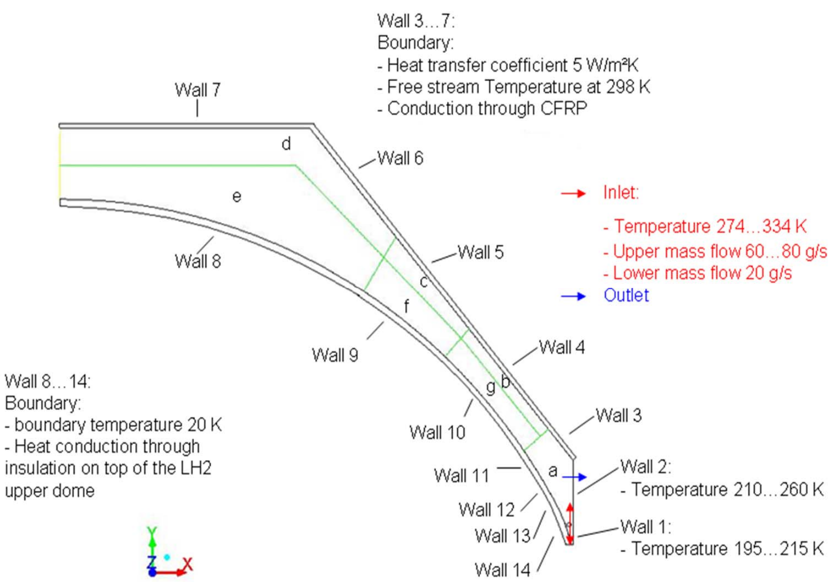
Test Case: EBS Cavity



Description	Temperature Wall 1 [K]	Temperature Wall 2 [K]	Mass Flow Temperature [K]	Mass Flowrate up [g/s]
cold	200	220	294	60
hot	210	250	314	80

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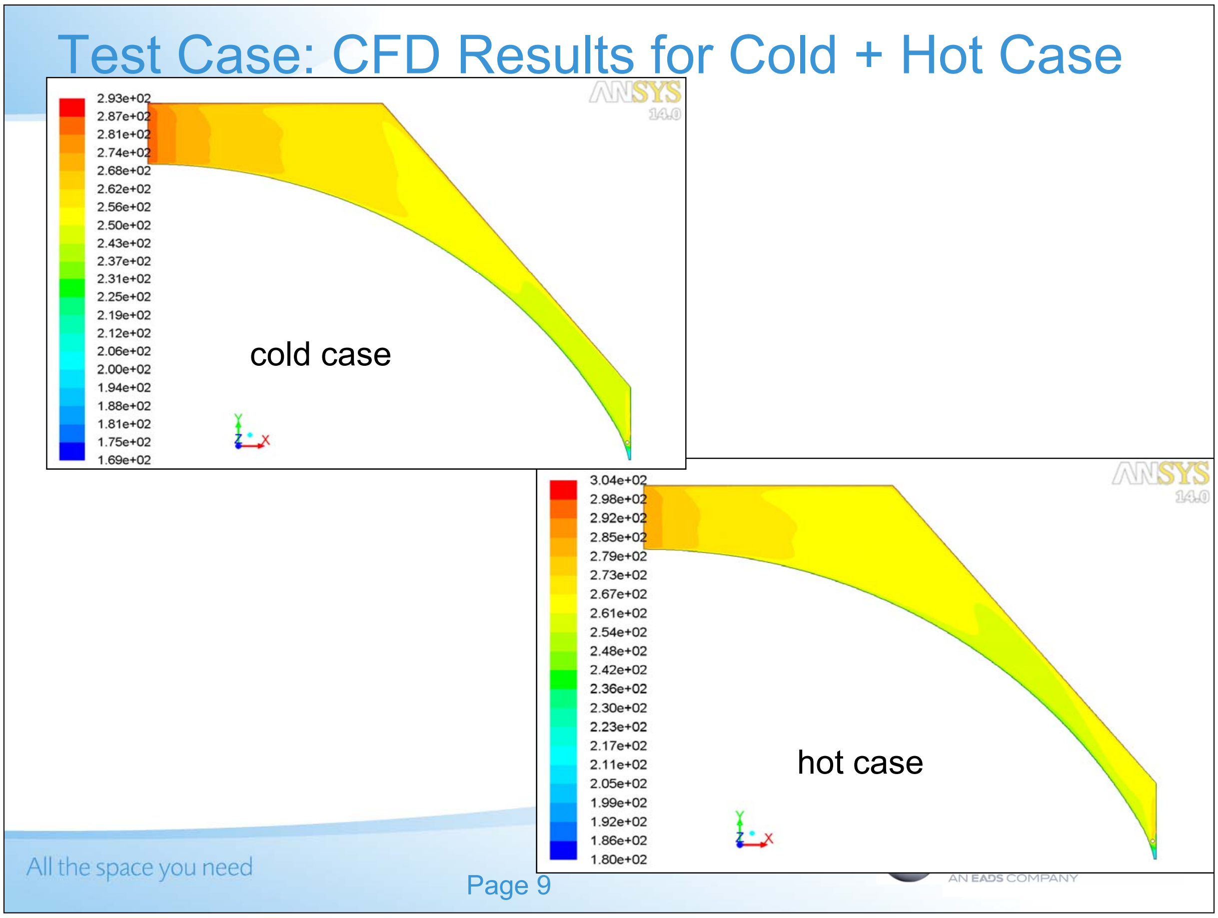
Test Case: CFD Results for Cold + Hot Case
ANSYS 14.0
2.93e+02
2.87e+02
2.81e+02
2.74e+02
2.68e+02
2.62e+02
2.56e+02
2.50e+02
2.43e+02
2.37e+02
2.31e+02
2.25e+02
2.19e+02
2.12e+02
2.06e+02
2.00e+02
1.94e+02
1.88e+02
1.81e+02
1.75e+02
1.69e+02
cold case
3.04e+02
2.98e+02
2.92e+02
2.85e+02
2.79e+02
2.73e+02
2.67e+02
2.61e+02
2.54e+02
2.48e+02
2.42e+02
2.36e+02
2.30e+02
2.23e+02
2.17e+02
2.11e+02
2.05e+02
1.99e+02
1.92e+02
1.86e+02
1.80e+02
hot case
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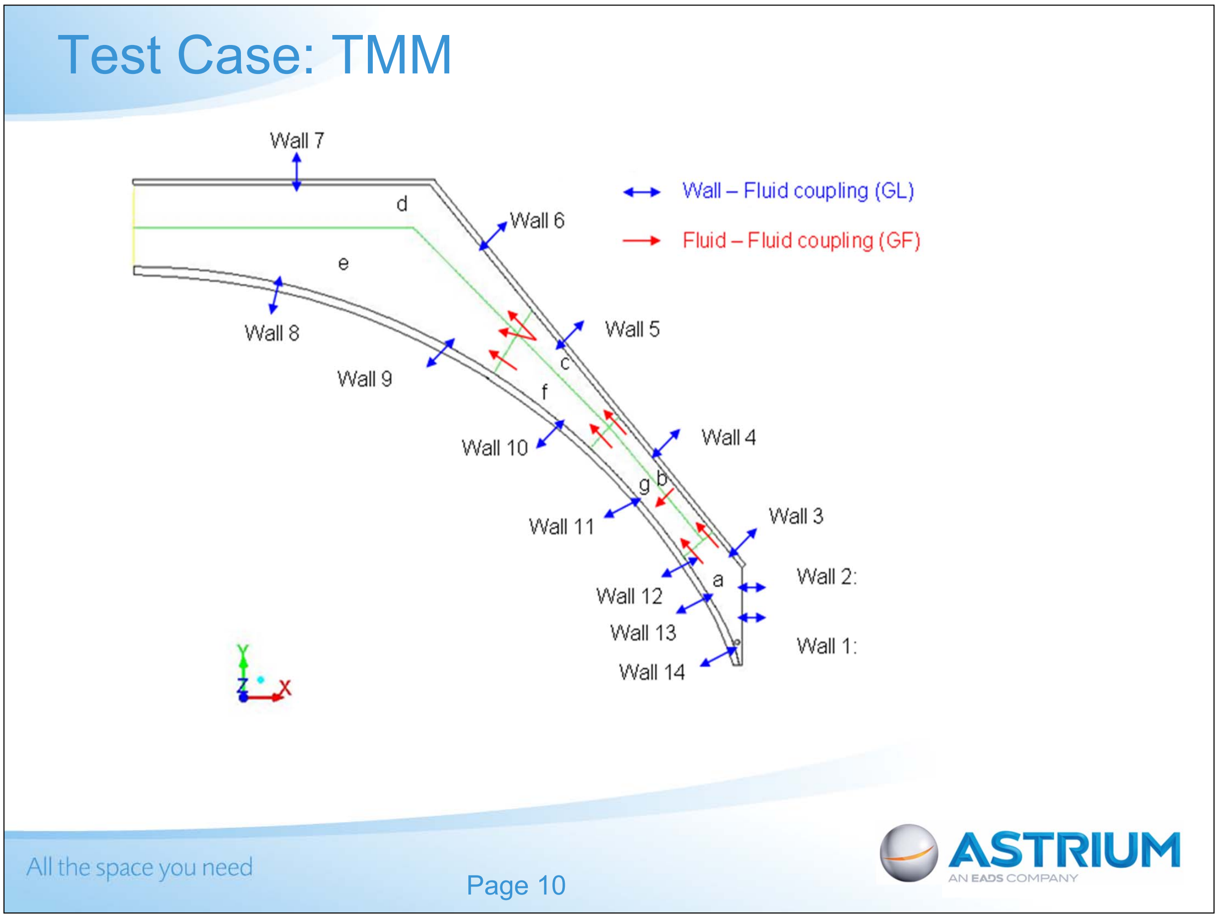
Test Case: TMM
Wall 7
Wall 6
Wall 5
Wall 4
Wall 3
Wall 2:
Wall 1:
Wall 8
Wall 9
Wall 10
Wall 11
Wall 12
Wall 13
Wall 14
a
b
c
d
e
f
g
Wall – Fluid coupling (GL)
Fluid – Fluid coupling (GF)
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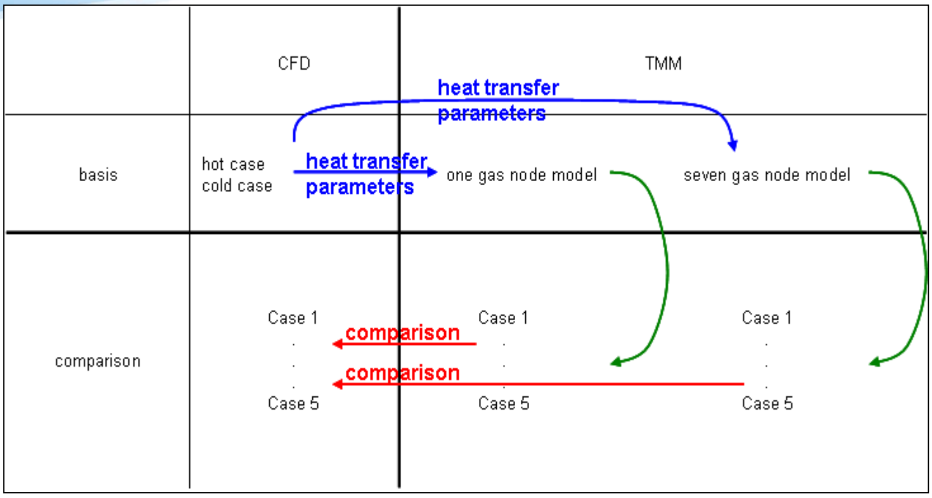
Test Case:Comparison between TMM and CFD



Case Nr.	Temperature Wall 1 [K]	Temperature Wall 2 [K]	InletTemperature [K]	Mass Flowrate up [g/s]
1	205	235	304	70
2	205	235	314	60
3	205	235	294	80
4	195	210	274	60
5	215	260	334	80

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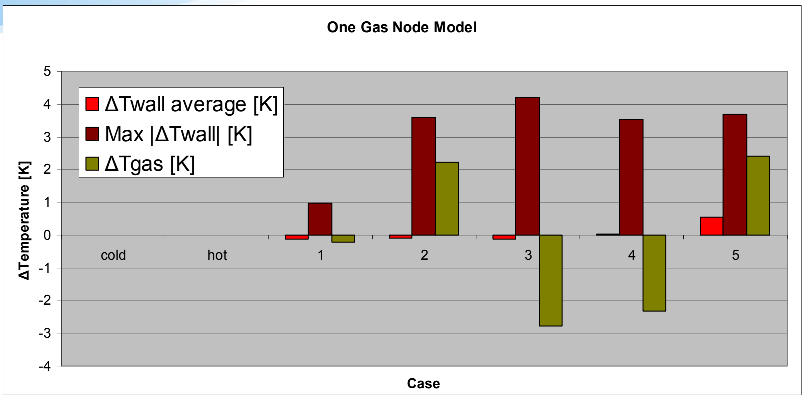
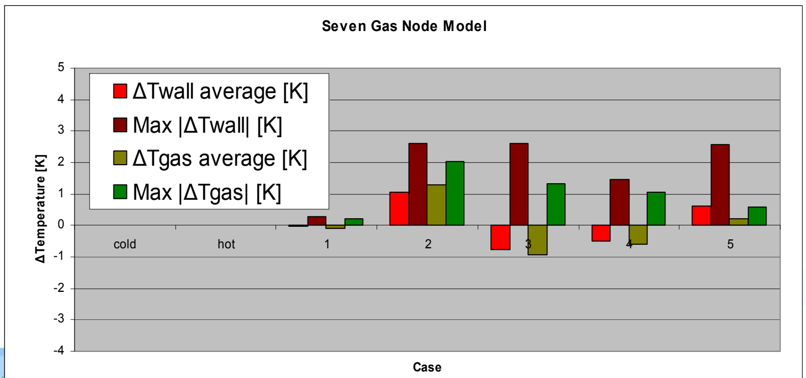
Test Case:Comparison between TMM and CFD





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Conclusion & Outlook

- Methodology for transfer from CFD to TMM explained for vented cavities
- Comparison beween TMM and CFD showed good overall agreement for EBS Cavity for the One Node and Seven Nodes Model as well: Seven Gas Node Model about ~40% better than One Gase Node Model

	One Node Model	Seven Node Model
maximum temperature deviation	~4K	~2.5K
maximum LH2 heat flux deviation	~1%	~0.5%

- Method is currently enhanced to include time dependency, as needed e.g. for propellant stratification phenomena

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