Crew and Thermal Systems Division CFD Activities

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April 30, 2013

Crew and Thermal System Division (EC)

EC1 MANAGEMENT INTEGRATION OFFICE

EC2 DESIGN & ANALYSIS BRANCH

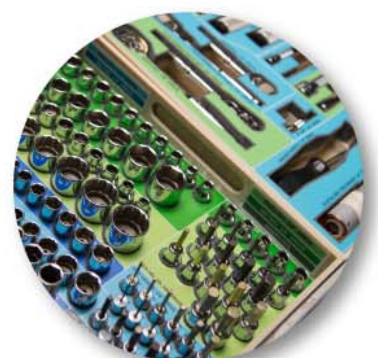
EC3 LIFE SUPPORT SYSTEMS BRANCH

EC4 SYSTEMS TEST BRANCH

EC5 SPACE SUIT & CREW SURVIVAL SYSTEMS BRANCH

EC6 THERMAL SYSTEMS BRANCH

EC7 TOOLS, EQUIPMENT & HABITATION SYSTEMS BRANCH



EC8 SPECIAL PROJECTS BRANCH

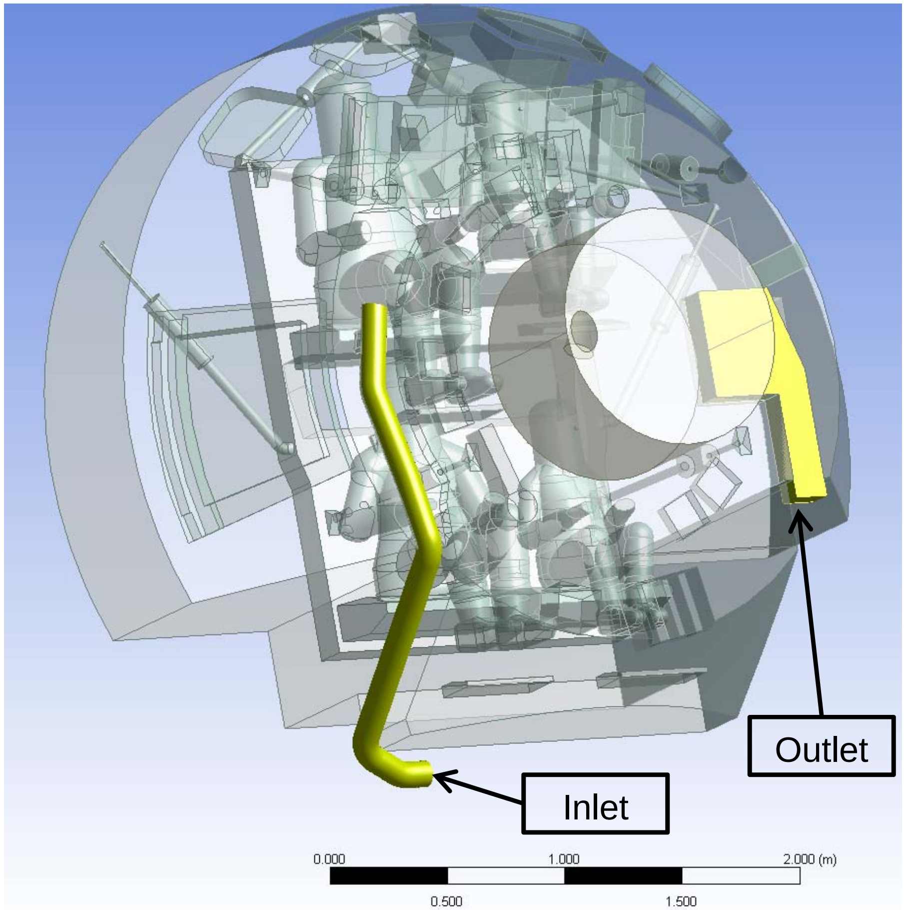
EC2 Numerical Analysis Group

- ***The Numerical Analysis Group at the NASA Johnson Space Center performs analyses of environmental control and life-support systems (ECLSS) and thermal control systems (TCS).***
- ***The group uses ANSYS® Fluent to analyze the transport of momentum, energy and gas species to understand the performance of spacecraft and spacesuit systems.***
- ***Our EC division is also supported by contractor analyst.***

Carbon Dioxide Washout

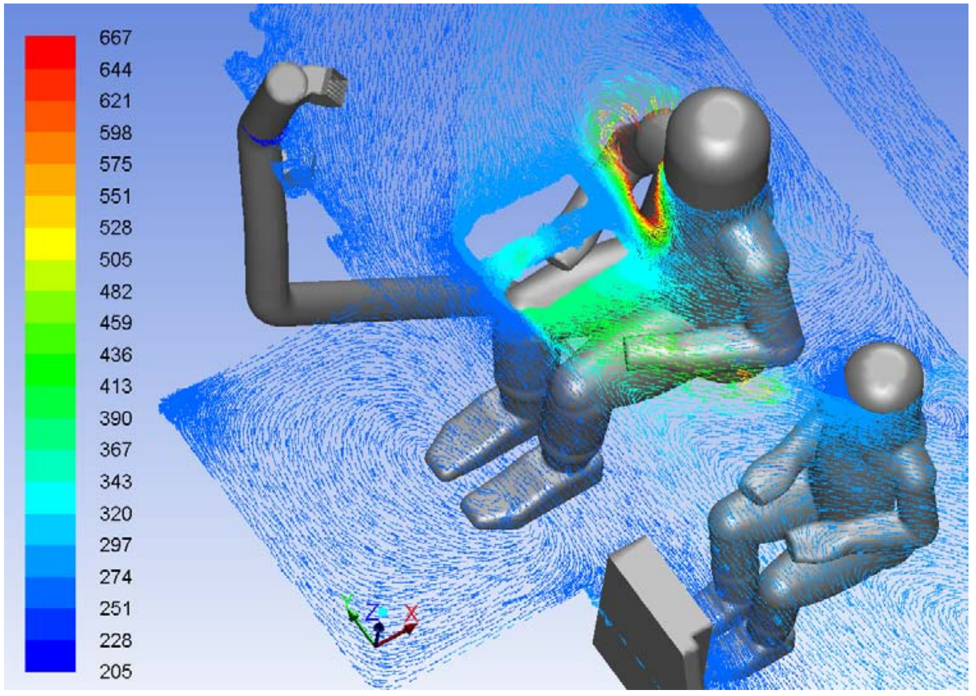
- ***Carbon dioxide (CO_2)washout is the capability of the ventilation flow to provide low concentrations of CO_2 to the crew member to meet breathing requirements.***
- ***Maximizing CO_2 washout performance is desired in the design of spacesuit and spacecraft applications.***
- ***The accumulation of CO_2 in a closed environment can cause crew member incapacitation, and in the worst case scenario, loss of life.***

Multi-Purpose Crew Vehicle (MPCV)

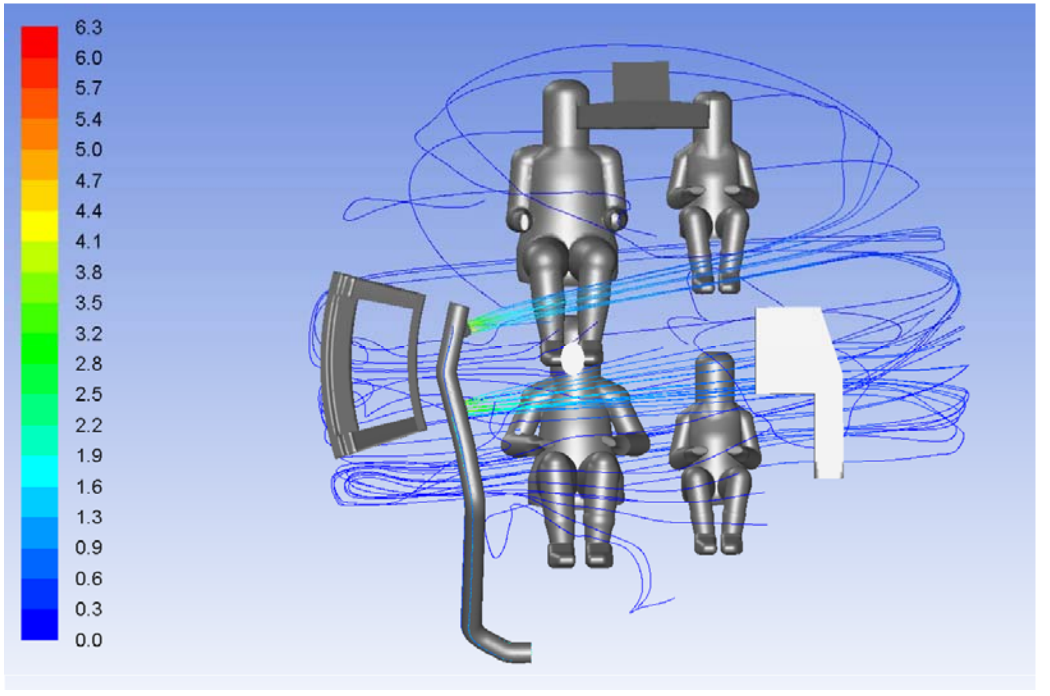


- **Computational fluid dynamics (CFD) is being used to understand how ventilation flow rate, vent location, and vent geometry affect the flow field within the MPCV capsule.**
- **Sizing flow rates are critical because they have an impact on resources (power, mass, volume) that we strive to minimize in human spaceflight.**

MPCV Post-Processed Results



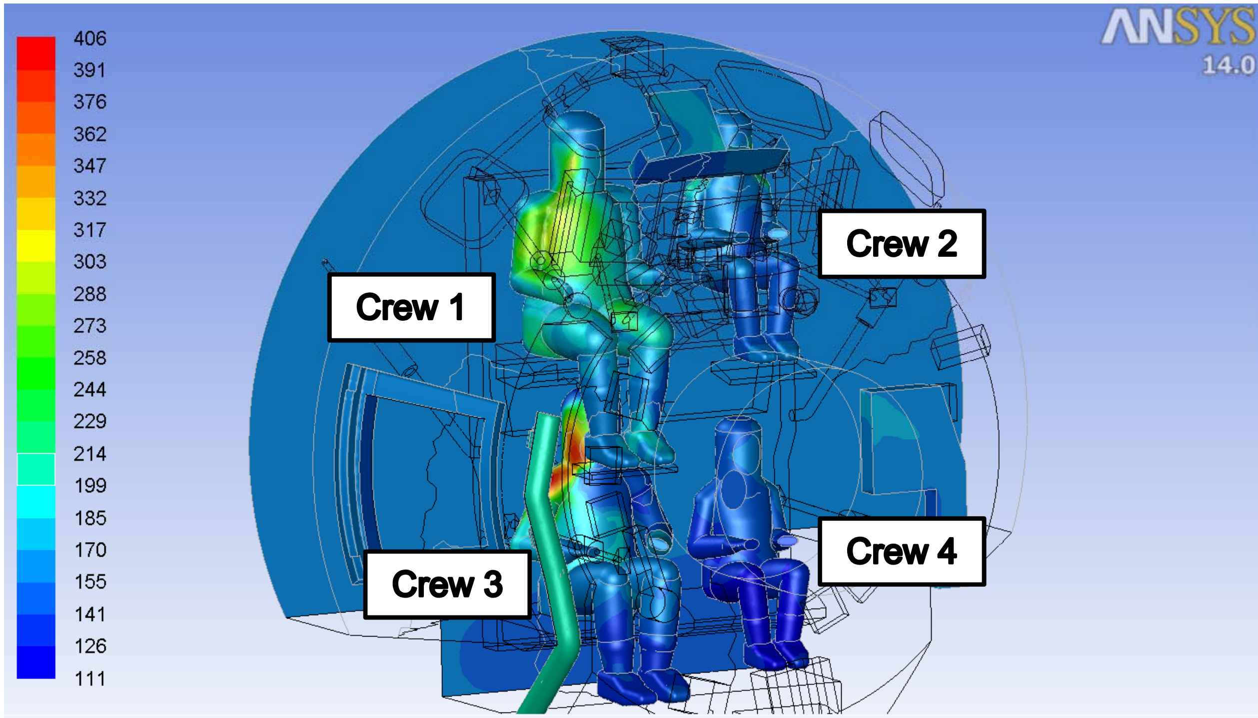
Velocity Vectors Colored by CO_2 Partial Pressure (Pa)



Pathlines Colored by Velocity Magnitude (m/s)

- **CFD results of interest consists of CO_2 levels around the oral/nasal area of the represented crew members, volume-weighted average velocity magnitude, and pressure drop.**
- **Visualization of the flow field gives additional insight into the "macro" predicted results.**
- **Visualizing the cabin flow-field also helps with the iteration design cycle.**

Carbon Dioxide Partial Pressure Contours



Pressure	
mmHg	Pa
1	133
2	267
3	400
4	534
5	667
6	800
7	934
8	1067
9	1201

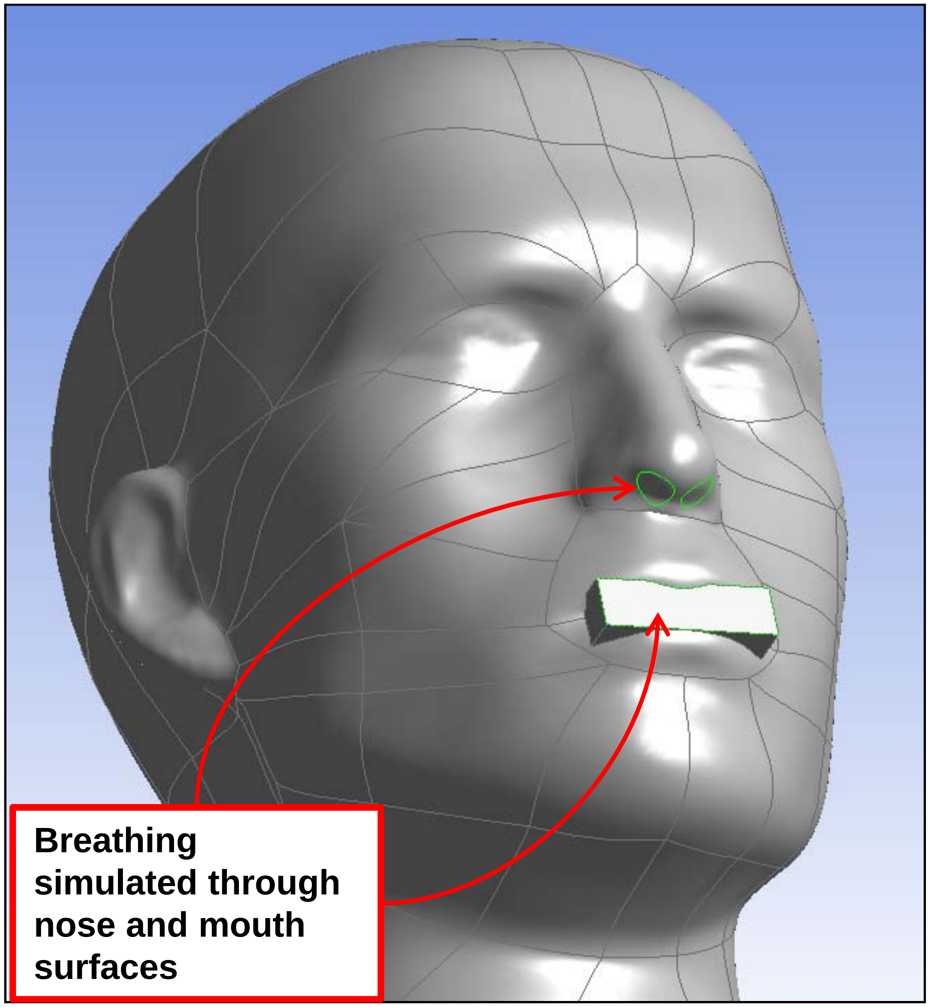
- **Ventilation flow and vent design will have an impact on CO_2 levels, which is an area of concern in human spaceflight.**

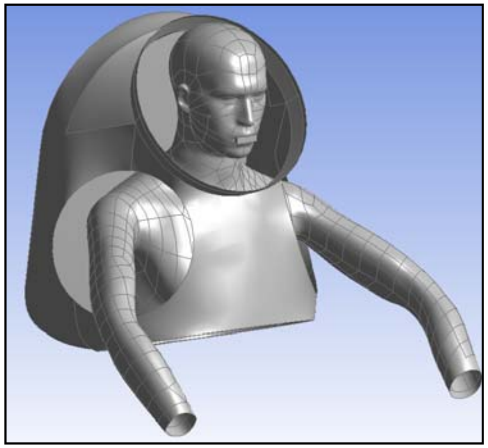
Space-Suit Ventilation CFD Modeling

Space-Suit Ventilation CFD Modeling

- ***CO_2 washout is the capability of the ventilation flow in the spacesuit helmet to provide low concentrations of CO_2 to the crew member to meet breathing requirements.***
- ***Numerous CFD analyses have been performed to determine CO_2 washout effectiveness in a spacesuit environment.***
- ***The amount of CO_2 inhaled depends on the concentration of CO_2 at the suit inlet, the amount of volumetric flow, flow inlet design, helmet design, metabolic rate, simulated breathing pattern, and head shape/orientation.***
- ***Analysis results have showed that certain inlet configuration can induce more mixing than others, which increases the amount of CO_2 inhaled.***

Portion of Z1 Suit with Manikin

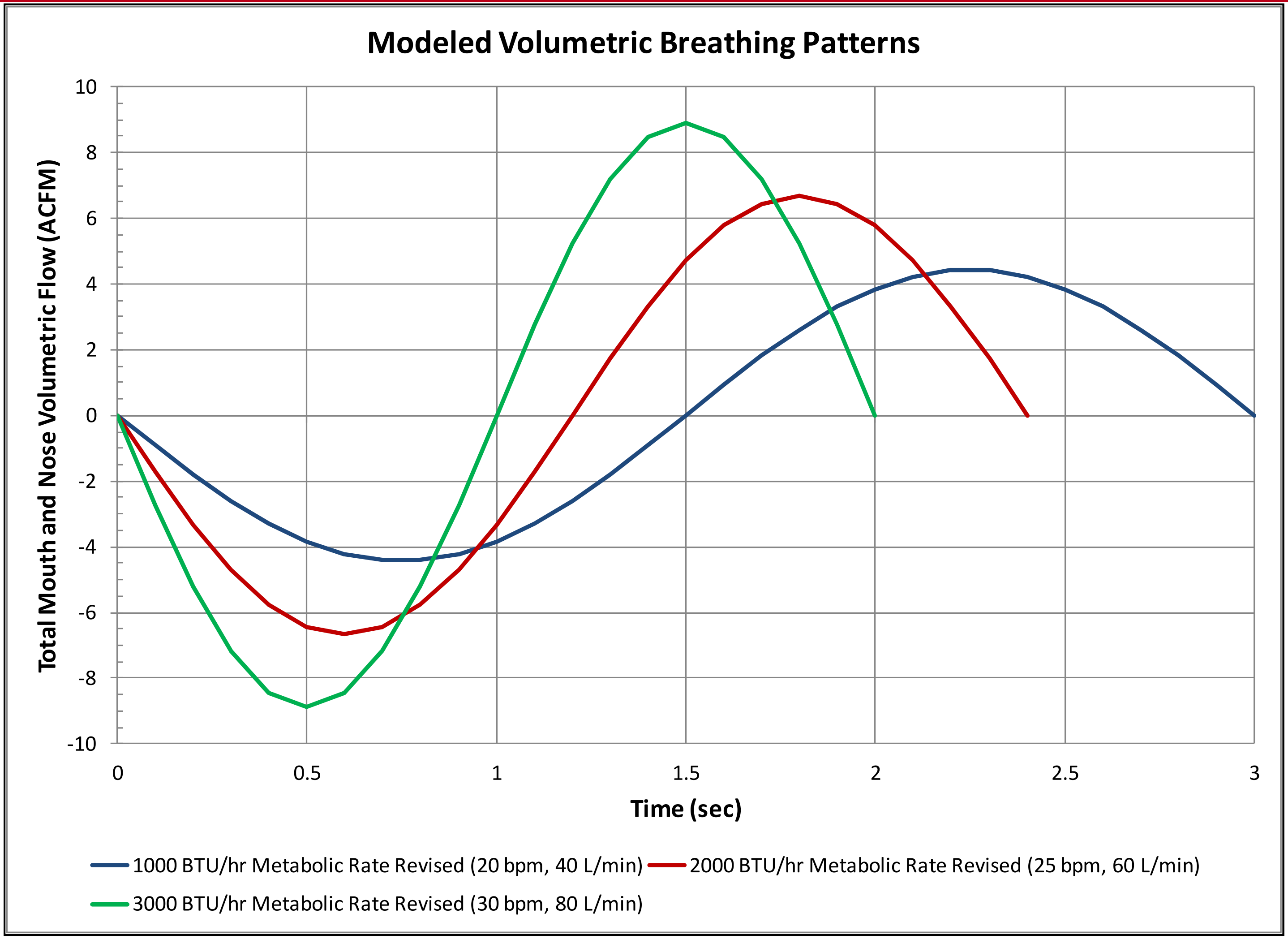




Portion of Z1 Suit with Manikin

Z1 Spacesuit

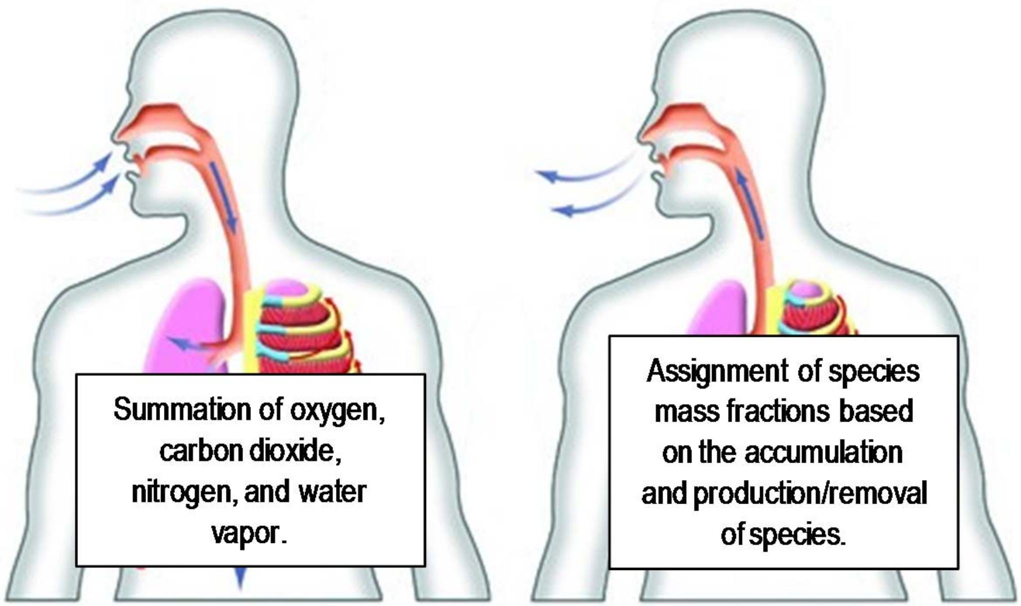
UDF: Breathing Approach and Assumptions



- ***The breathing of the simulated crew member is performed with a user-defined function (UDF) that interacts real-time with the CFD model simulation.***
- ***Sinusoidal volumetric flow rates for a given assumed metabolic rate are modeled as velocity inlet boundary conditions.***
- ***The relationship between breathing displacement and frequency was based on published empirical data [1].***

UDF: Breathing Approach and Assumptions

- ***The tracking of the different species across the mouth and nose domain surfaces is also performed with the same UDF, as is the simulated metabolic removal of oxygen and the production of carbon dioxide and water vapor.***
- ***The calculated oxygen consumption and carbon dioxide production rates are performed with heritage equations [2].***
- ***Mass fractions are assigned to the mouth and nose faces based on the species calculations.***



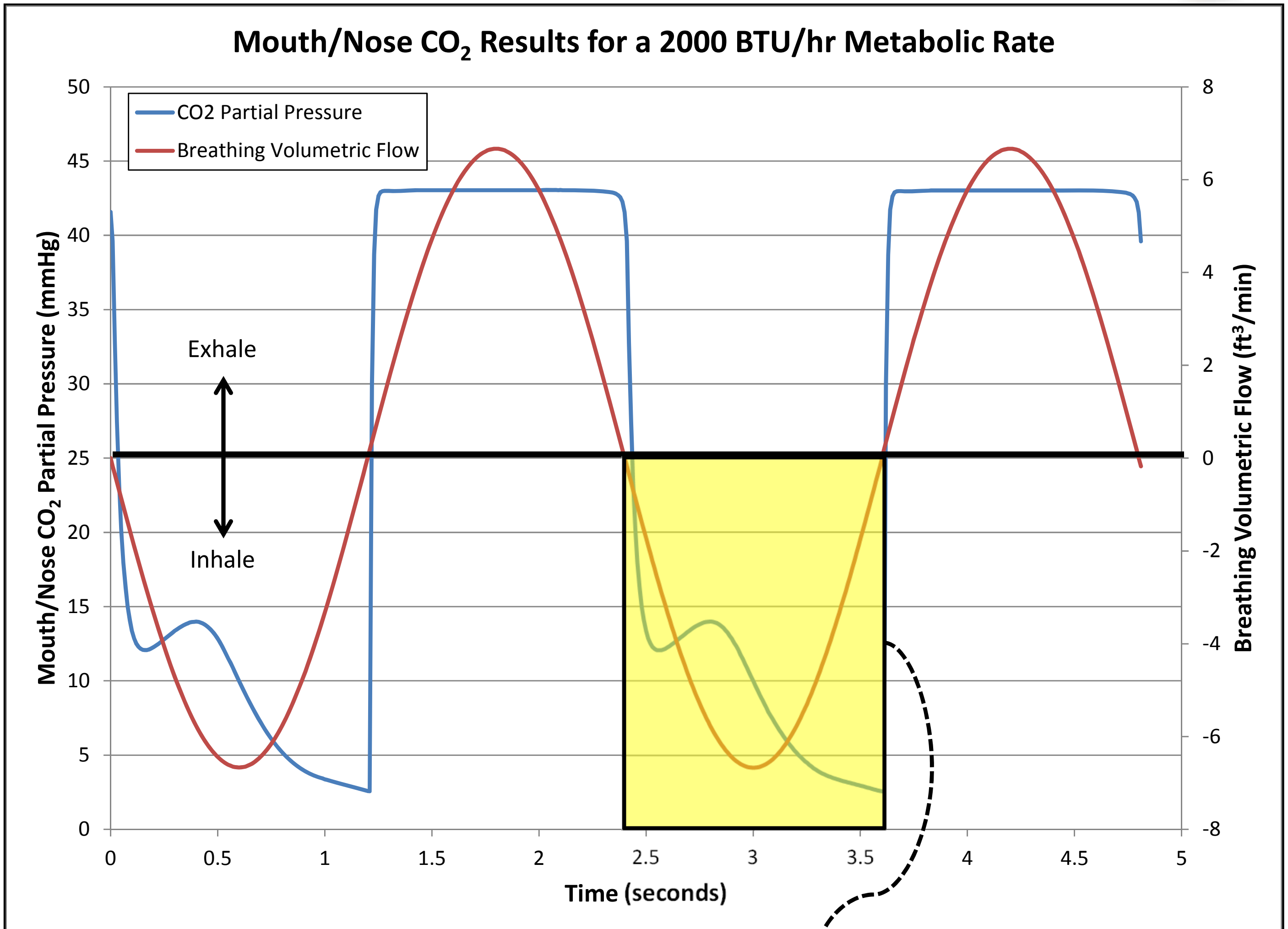
$$\dot{m}_{O2\ cons} = \dot{Q}_{metabolic}\left(2.0265e^{-4} - 4.5055e^{-5} R_{resp}\right)$$

$$\dot{m}_{CO2\ prod} = \dot{m}_{O2\ cons}\left(\frac{44.0}{32.0}\right) R_{resp}$$

- $m_{O2\ cons}$ = the rate of oxygen consumption (lbm/hr)
- $m_{CO2\ prod}$ = the rate of carbon dioxide production (lbm/hr)
- R_{resp} = the respiratory quotient
- $Q_{metabolic}$ = the assumed metabolic rate (BTU/hr).

UDF: Inhale CO_2 Averaging

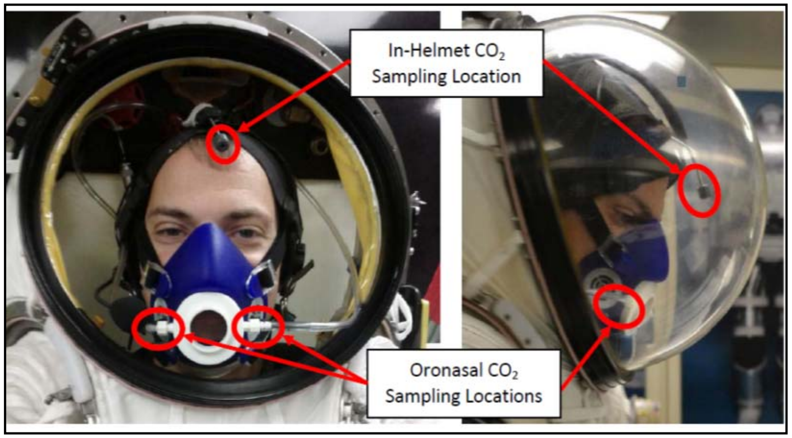
- *The plot on the right shows the area-weighted CO_2 partial pressure for the mouth and nose of the simulated crew member.*
- *The plot also shows the volumetric breathing flow-rate of the simulated crew member for an assumed 2000 BTU/hr metabolic rate (mouth/nose flow distribution was 80/20).*
- *Given that the inhale flow-rate is time dependent, the averaged CO_2 amount over a given inhaled interval should be flow-rate weighted averaged.*



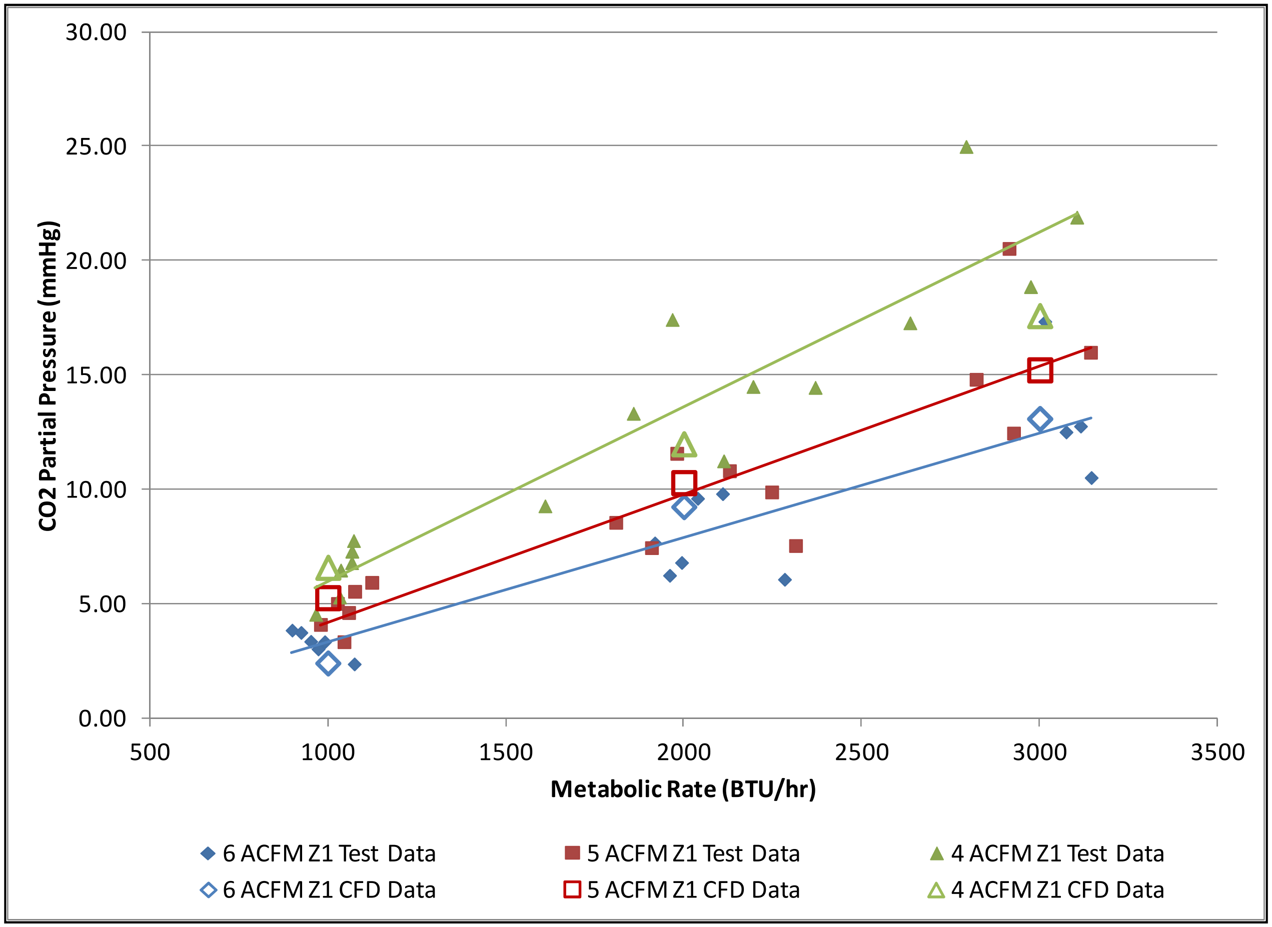
$$\overline{P_{CO_2}} = \frac{\sum_{i=1}^{n} Q_i P_{CO_2 i}}{\sum_{i=1}^{n} Q_i}$$, **CO_2 Flow-rate weighted average**

Numerical vs. Experimental Results

- ***Preliminary model results were compared to Z1 test results (see plot on right)***
- ***The CFD model consistently predicted CO_2 inhale values within the Z1 test data scattered values.***
- ***Effects of facial mask used during testing have not been evaluated with the model***

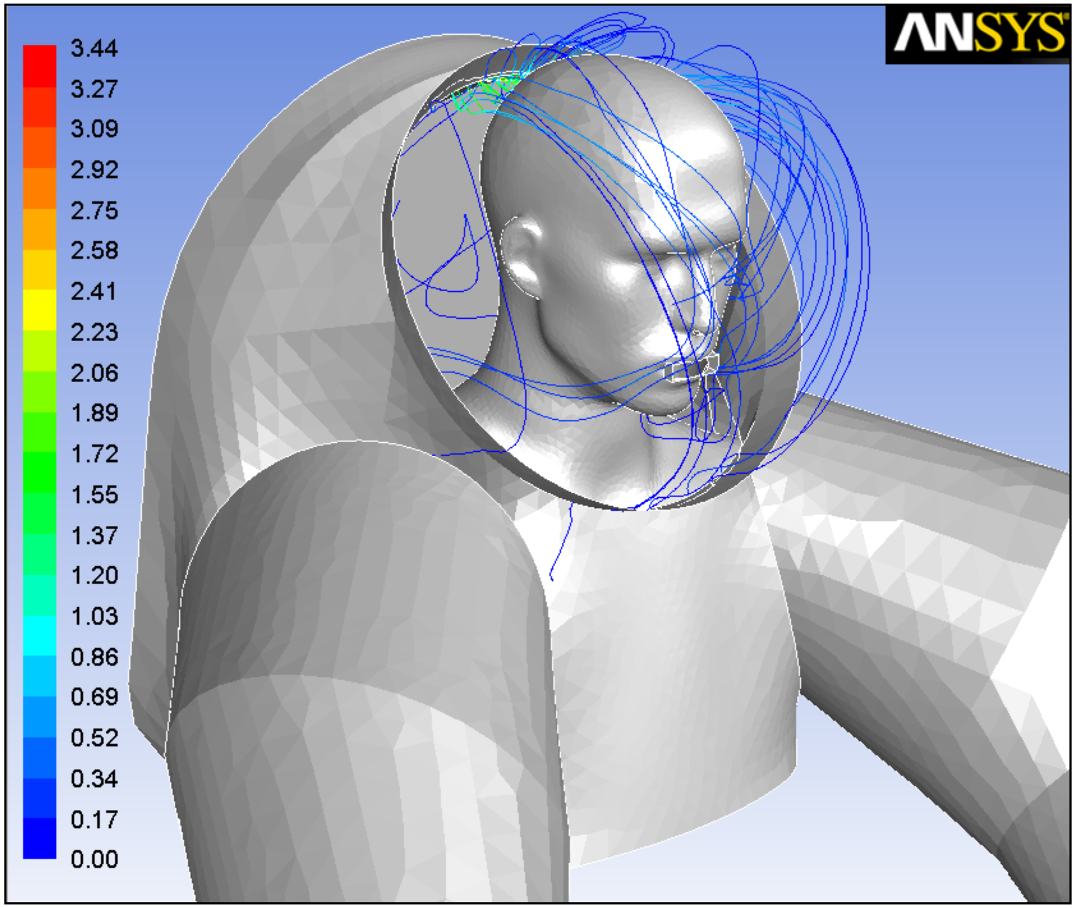


Average Inhale CO_2 Levels (mmHg)



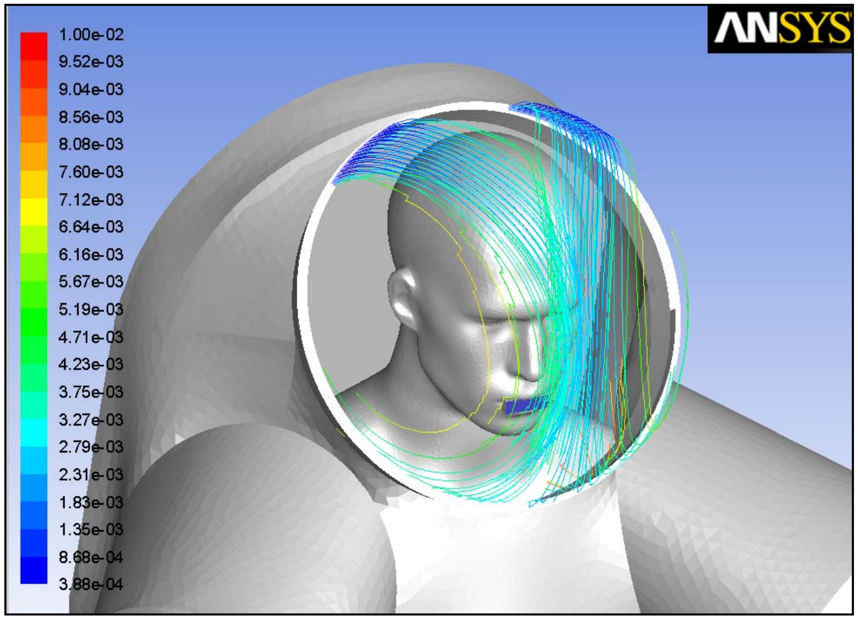
Z1 Suit Model

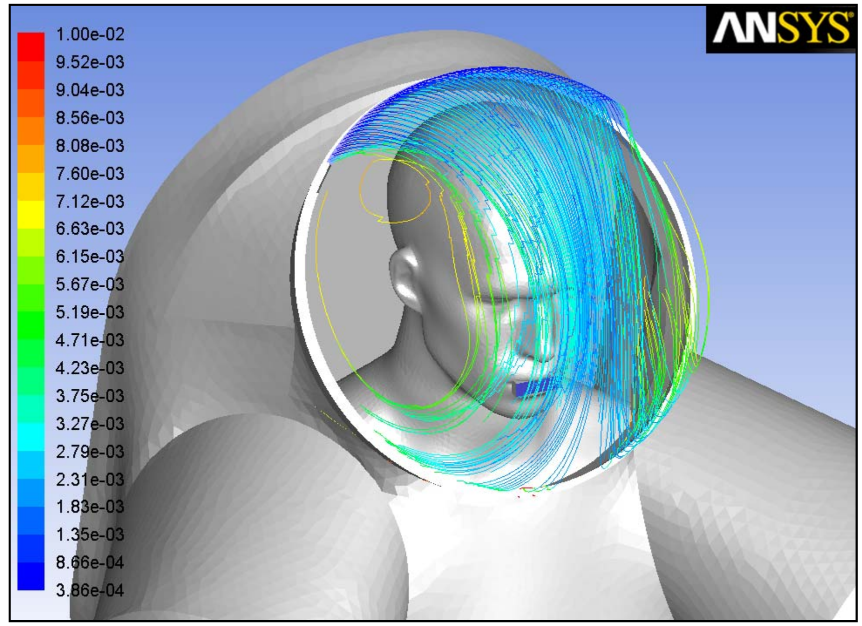
Z1 Spacesuit Helmet Close-up

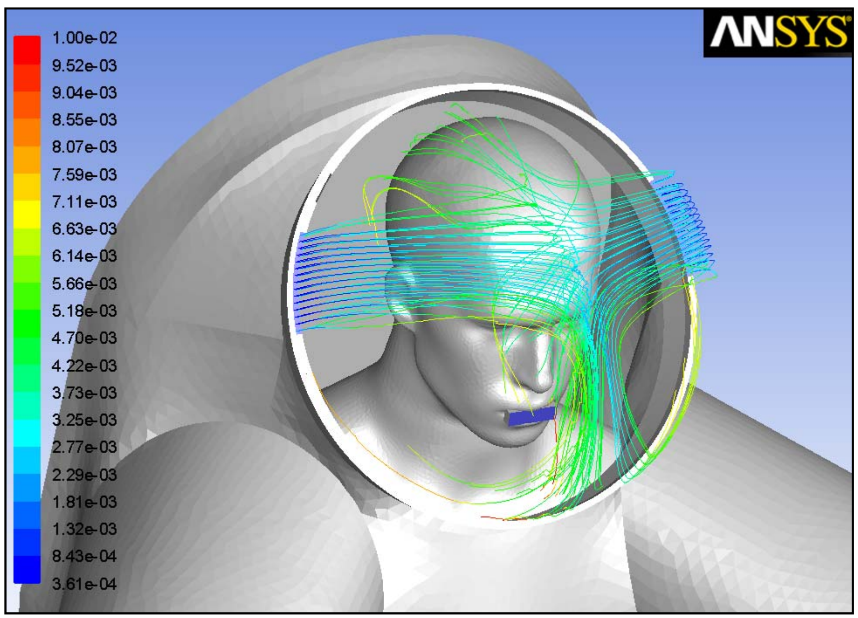


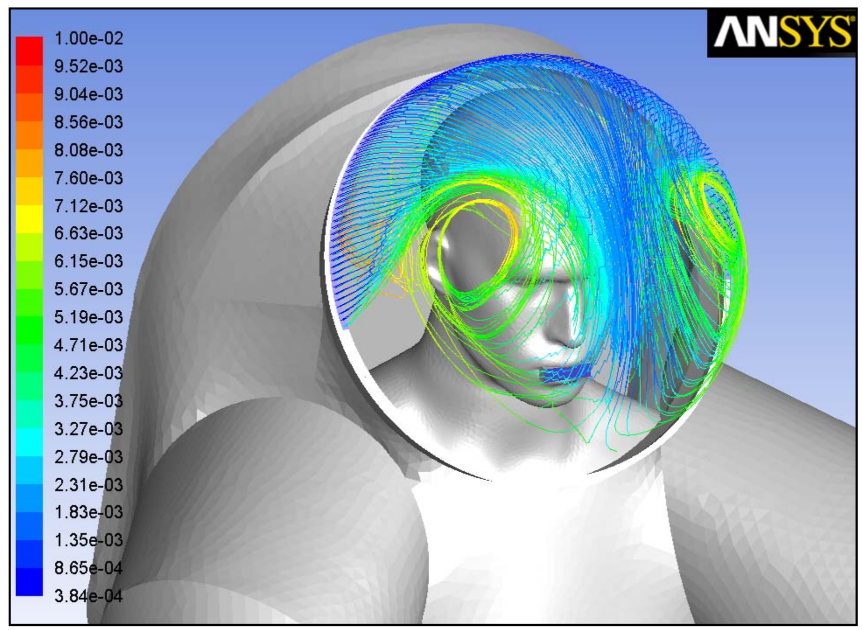
Pathlines Colored by Velocity Magnitude (m/s)

Air Vent Design Brainstorming









Conclusions

- ***Several ECLSS and thermal analyses are performed in the Crew and Thermal Systems Division at the NASA Johnson Space Center.***
- ***The Numerical Analysis Group in EC2 uses ANSYS® CFD software to analyze the CO_2 washout performance of spacecraft and spacesuit systems.***
- ***UDFs are used to perform dynamic updates of model boundary conditions based on human breathing/metabolic assumptions. UDFs are also used to perform real-time averaging calculations, versus performing the tedious calculations post-process.***

References

1. ***Blackie, S. P., McElvaney, N. G., Morrison, N. J., "Normal Values and Ranges for Ventilation and Breathing Pattern at Maximal Exercise," University of British Columbia, Pulmonary Research Laboratory, St. Paul's Hospital, Vancouver, British Columbia, Canada.***
2. ***Bue, G. C., "Computer Program Documentation 41-Node Transient Metabolic Man Program," LESC-27578, NASA Johnson Space Center, Houston, TX, Aug. 1978***