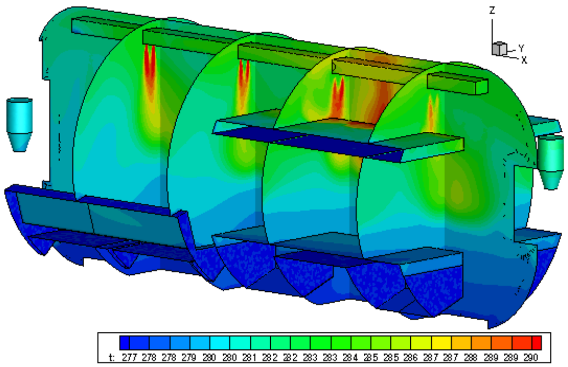
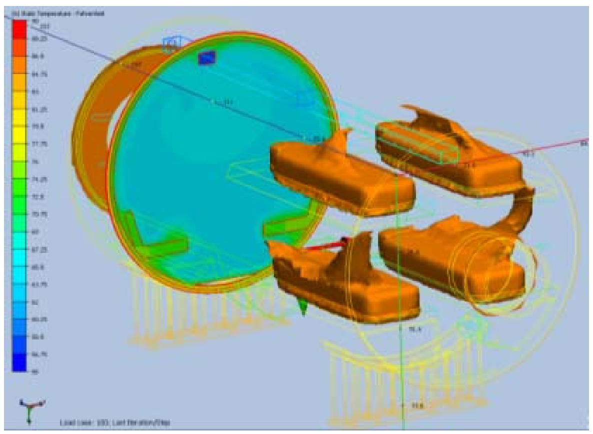
Hyperbaric Life Support Compartment Ventilation Modeling





Objectives

- Develop computational fluid dynamics (CFD) modeling techniques to support simulation of atmosphere quality (heat, CO_2, O_2, smoke, etc.) in SOF mobility and diving hyperbaric compartments.
- Validate techniques by modeling a compartment that has test data.

Approach

- Collaborated with SEA00C3 to use saturation diving compartment as test bed.
- Developed CFD models to investigate fundamental behaviors with representative ventilation and metabolic loading.
- Conducted tests and compared CFD model results with compartment ventilation data.
- Used CFD models to predict performance at operational extremes.

Principal Investigators

- Dr. John Camperman
- Mr. Robert Hughes
- Dr. Richard Smith

TEST CASE SATURATION FLY AWAY DIVE SYSTEM (SATFADS) DECK DECOMPRESSION SYSTEM LIVING COMPARTMENT

Representative Gas Mixtures

			AIR		He		O2		N2		
FSW	ATA	PSIA	pp (ata)	Vol %	pp (ata)	Vol %	pp (ata)	Vol %	pp (ata)	Vol %	Mix
0	1.00	14.67	1	100.0							1
36	2.09	30.67	2.09	100.0							2
34.5	2.05	30.00			1.64	80.0	0.41	20.0			3
300	10.09	148.00			8.00	79.3	0.44	4.4	1.65	16.4	4
1000	31.30	459.11			29.21	93.3	0.44	1.4	1.65	5.3	5
1000	31.30	459.11			30.83	98.5	0.47	1.5			6

Primary Questions

- Internal temperature distributions?
- Environmental control system adequacy for desired operational weather envelope?

Computational Fluid Dynamics

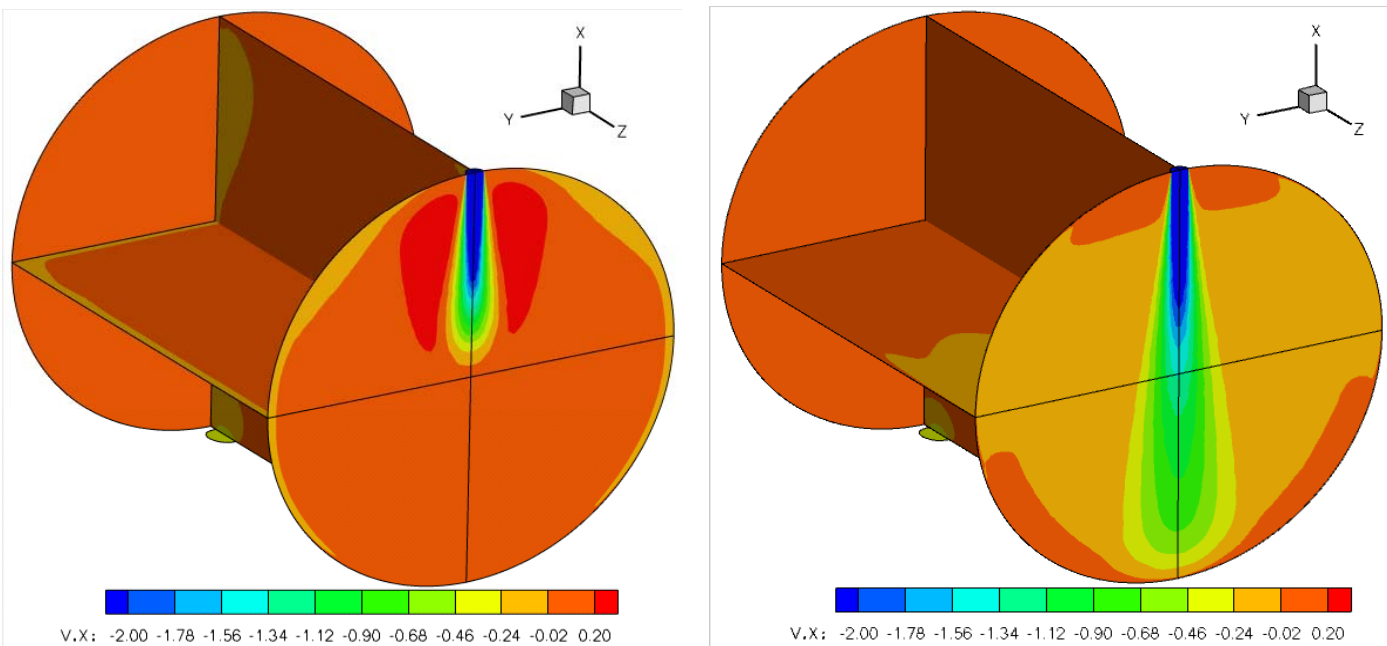
- Model and solve for internal circulation and temperature distribution
- Validate model with test data
- Use fluid-thermodynamics model as a basis for modeling other systems and atmosphere properties

FUNDAMENTAL VENTILATION BEHAVIORS

Generalized Hyperbaric Chamber Model

- SATFADS Living Compartment overall internal dimensions modified for symmetry
- Investigate jet momentum, buoyancy, and mixing

Pressure	Inlet temp.	Wall temp.	Inlet dia.	Outlet dia.	Inlet vel.
2.05 atm	339 K (150 F)	280 K (45 F)	8.64 cm	17.3 cm	3.2 m/s



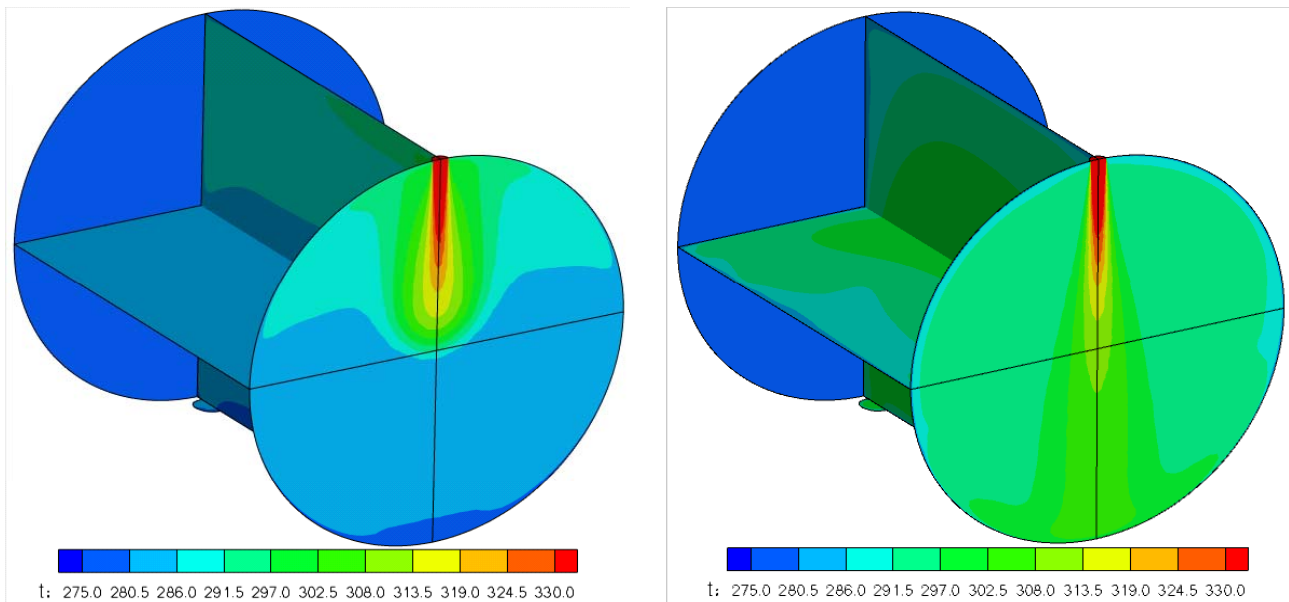
Comparison of jet axial velocity contours (m/s) with buoyancy effect active (left) and for buoyancy effect inactive (right) for generalized half-chamber model

- Buoyancy opposes jet momentum

FUNDAMENTAL VENTILATION BEHAVIORS

Generalized Hyperbaric Chamber Model

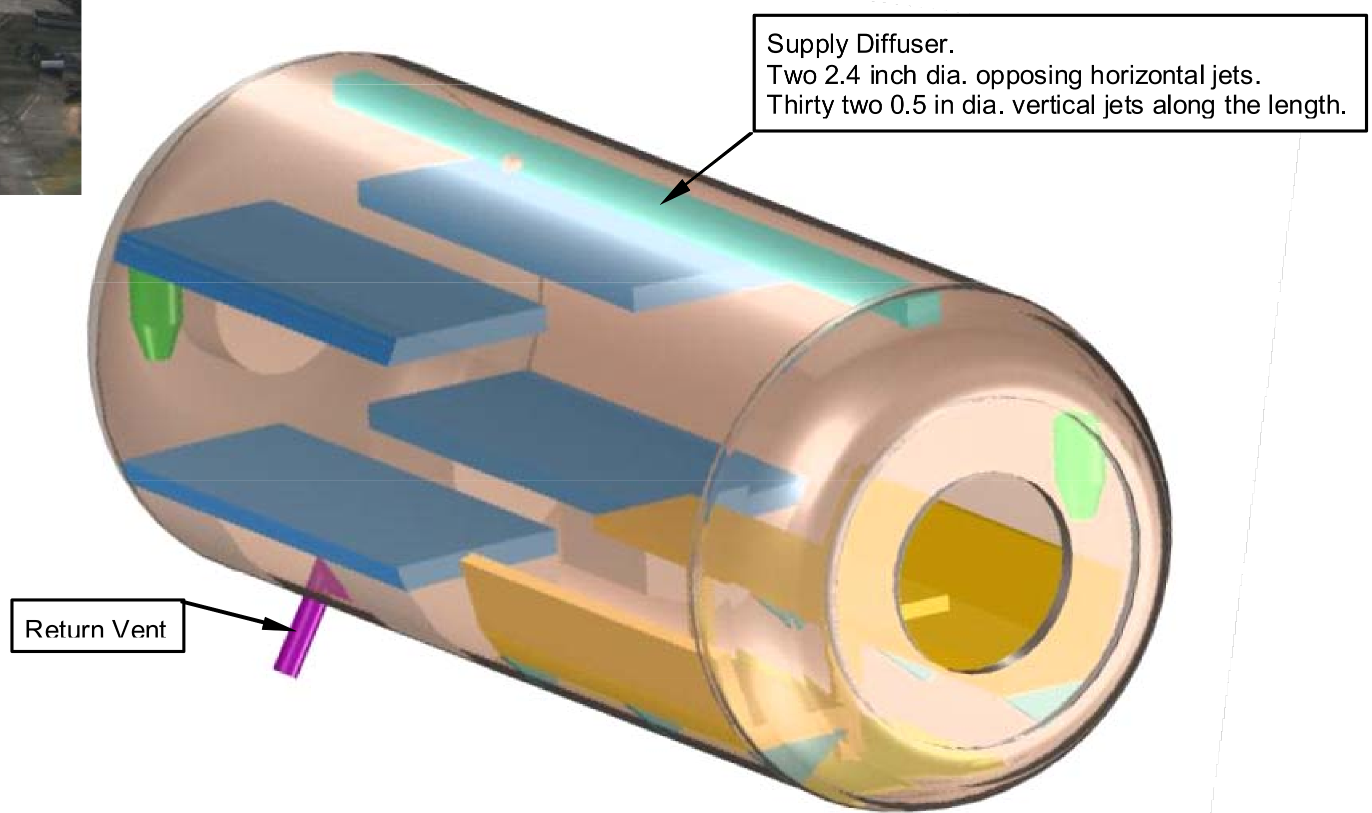
Pressure	Inlet temp.	Wall temp.	Inlet dia.	Outlet dia.	Inlet vel.
2.05 atm	339 K (150 F)	280 K (45 F)	8.64 cm	17.3 cm	3.2 m/s



Comparison of temperature contours (^{o}K) with buoyancy effect active (left) and for buoyancy effect inactive (right) for generalized half-chamber mode

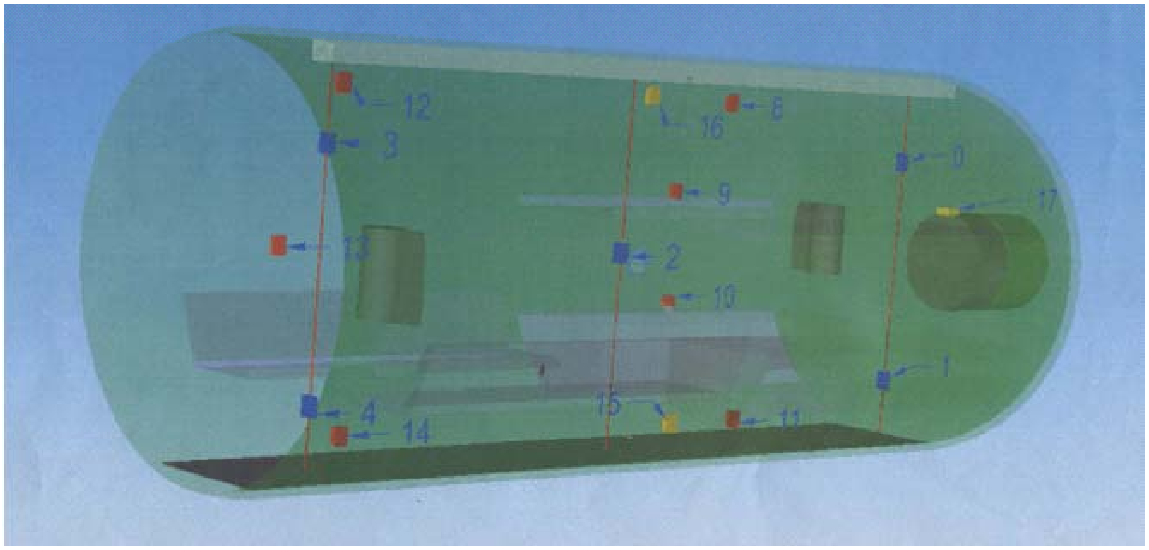
- Buoyancy opposes jet momentum causing thermal stratification

SATFADS LIVING COMPARTMENT SIMPLIFIED MODEL

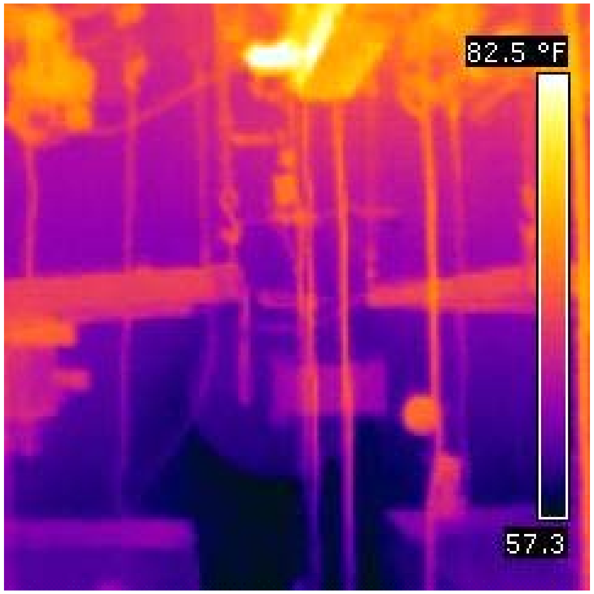


SATFADS Living Compartment simplified geometric boundary conditions. Supply diffuser, return vent, bunks, benches, table, and two CO_2 scrubbers included

SATFADS LIVING COMPARTMENT TESTS

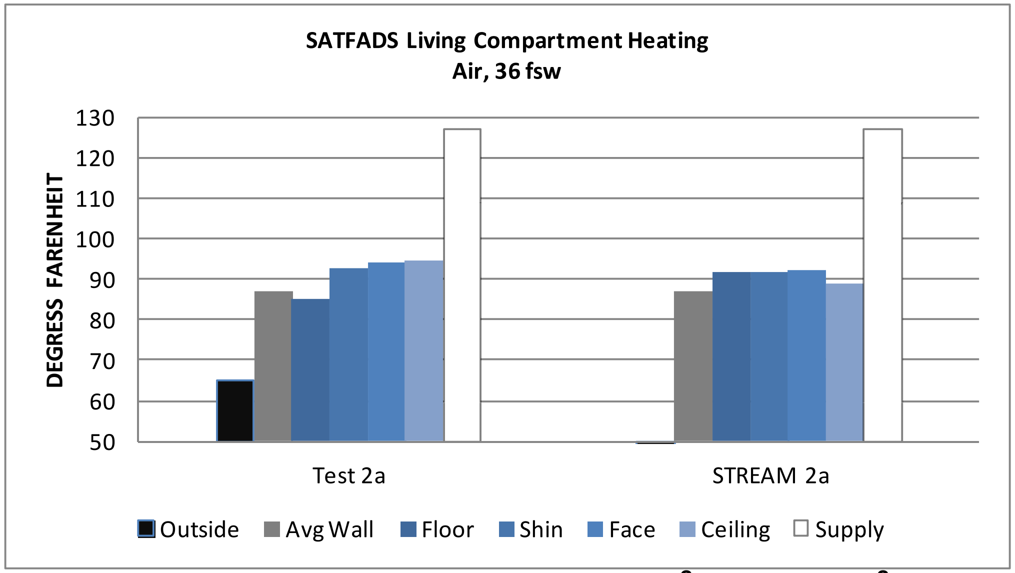


Test sensor locations. Blue: gas temperature; red: wall and adjacent gas temperatures; yellow: gas temperature and humidity

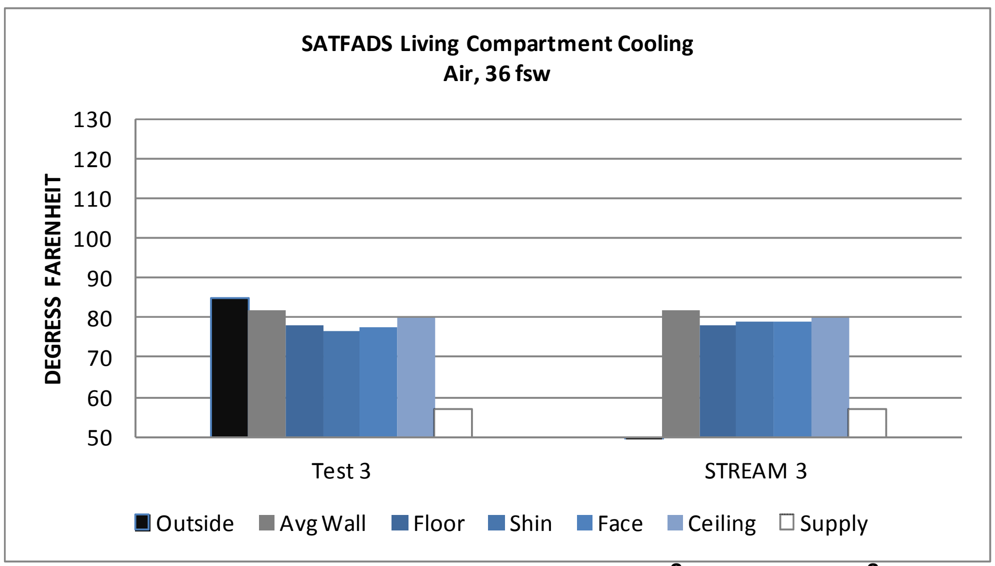


Left: Forward bulkhead in background with four bunks, several temperature sensors and gas temperature arrays (polypropylene rope) in foreground. Right: Infrared image of the same area shows thermal stratification on bulkhead and air

SATFADS LIVING COMPARTMENT TEST DATA AND CFD MODEL RESULTS

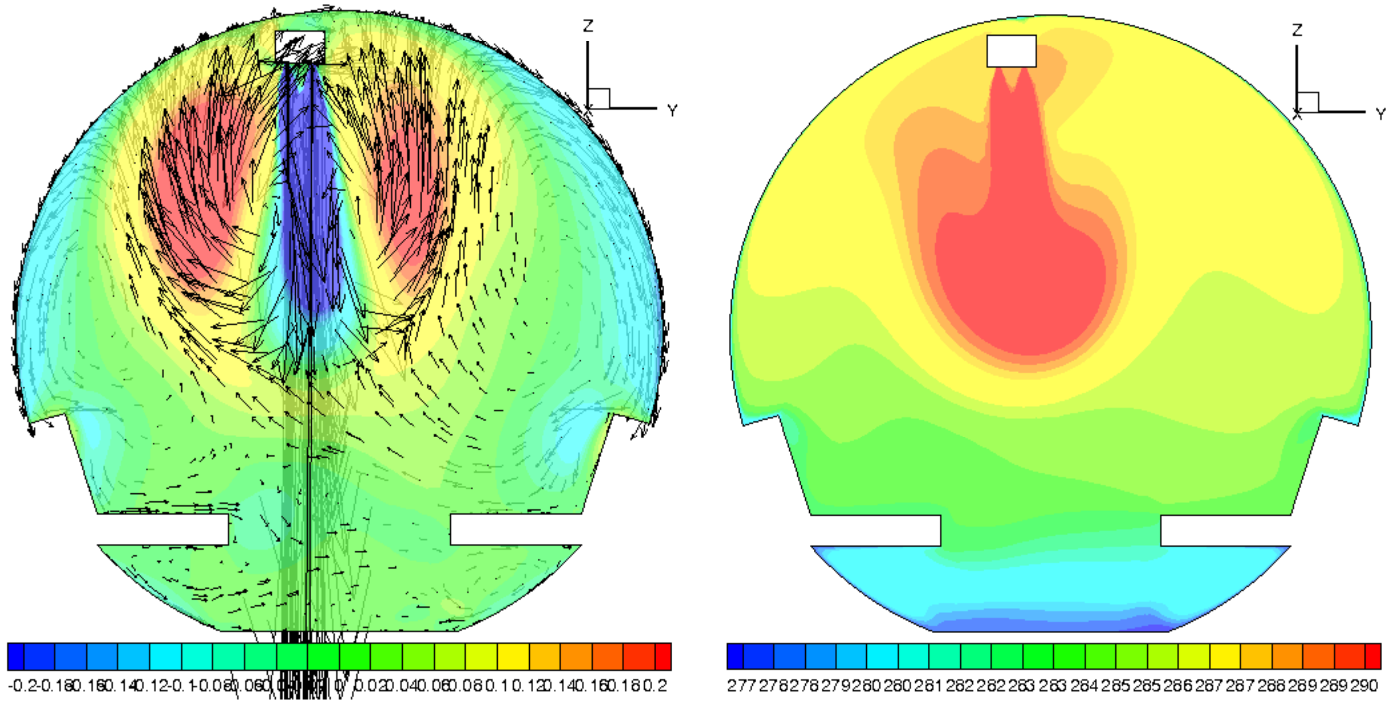


Comparison of high heating flow, 95 ft^3/min (161 m^3/hr) test data and model results



Comparison of high cooling flow, 90 ft^3/min (153 m^3/hr) test data and model results

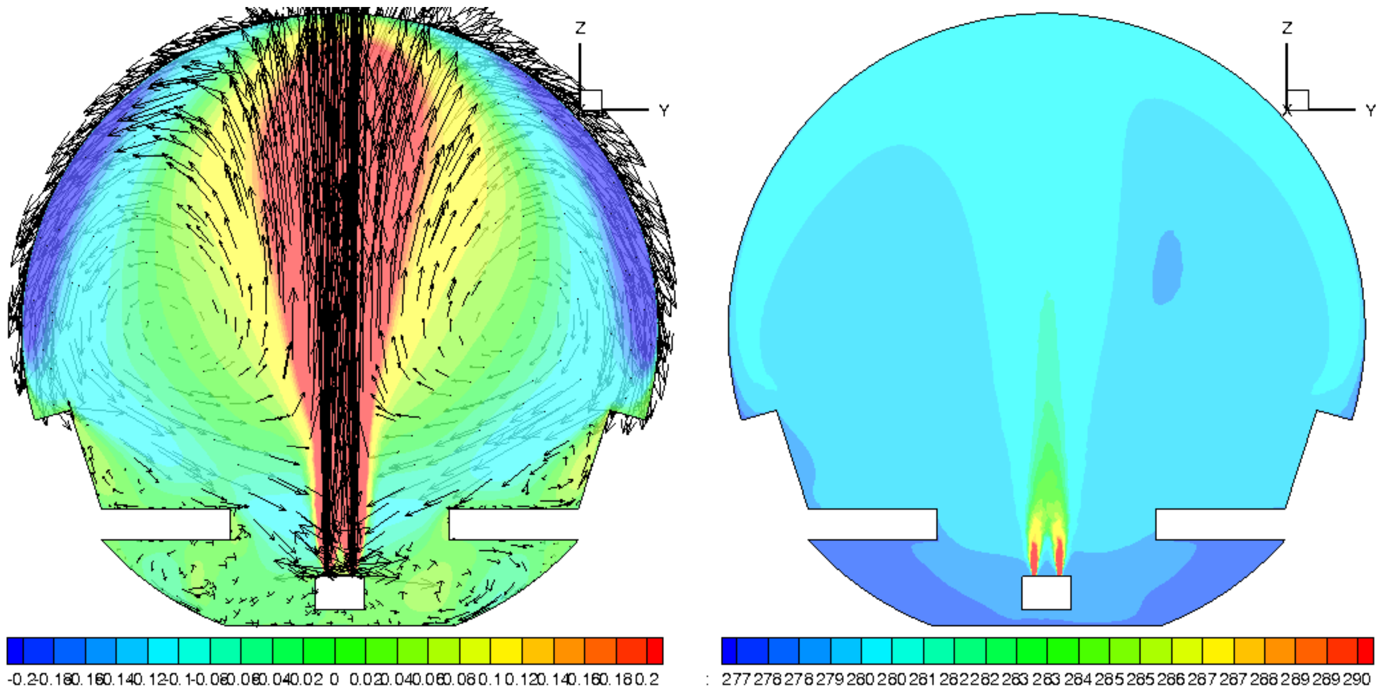
FUNDAMENTAL CIRCULATION AND TEMPERATURE CONTOURS WITH CEILING SUPPLY



SATFADS LC cross section; 1 atm (0 fsw) air;
120^{0}F (322^{0}K) 59 ft^3/min (100 m^3/hr) supply flow from ceiling;
40^{0}F (277^{0}K) interior walls.
Left: velocity vectors and contours (m/sec). Right: temperature contours (^{0}K)

- Buoyancy opposes jet momentum causing thermal stratification

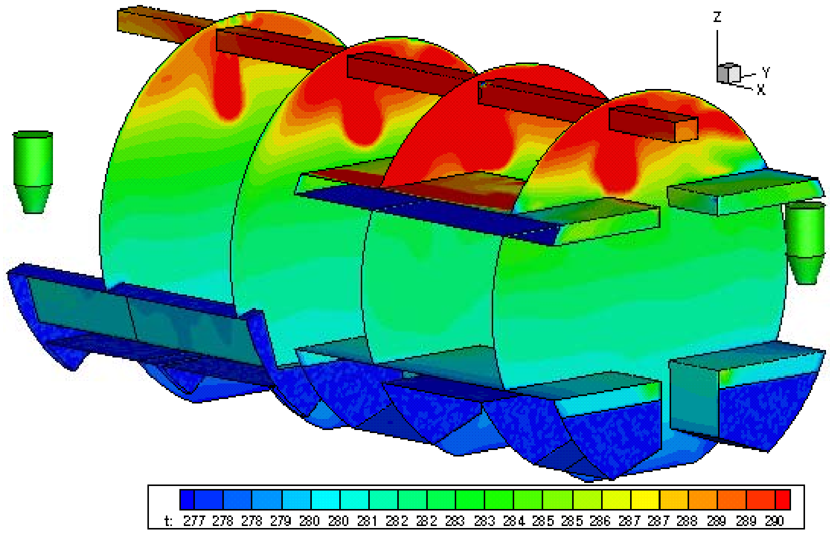
FUNDAMENTAL CIRCULATION AND TEMPERATURE CONTOURS WITH FLOOR SUPPLY



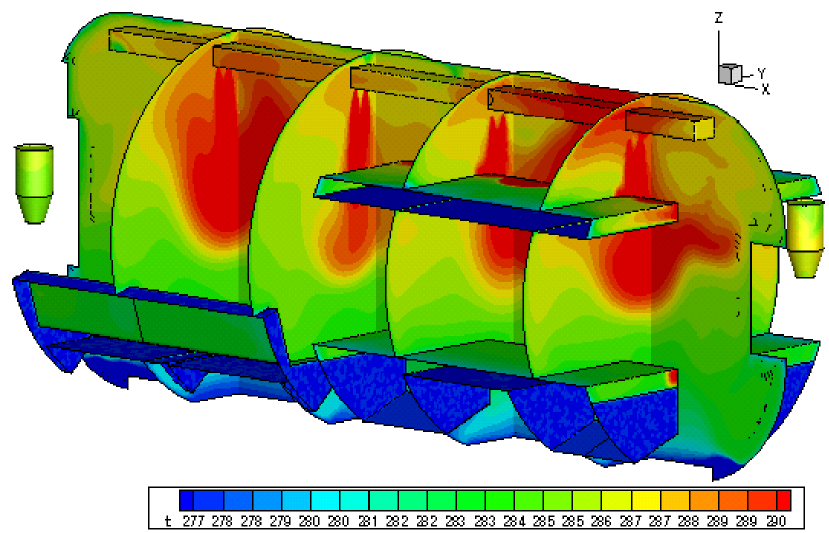
SATFADS LC cross section; 1 atm (0 fsw) air;
120^{0}F (322^{0}K) 59 ft^3/min (100 m^3/hr) supply flow from floor;
40^{0}F (277^{0}K) interior walls.
Left: velocity vectors and contours (m/sec). Right: temperature contours (^{0}K)

- Buoyancy enhances jet momentum causing mixing and increased cooling via wall boundary layers

TEMPERATURE DISTRIBUTION SENSITIVITY TO SUPPLY REGISTER CONFIGURATION



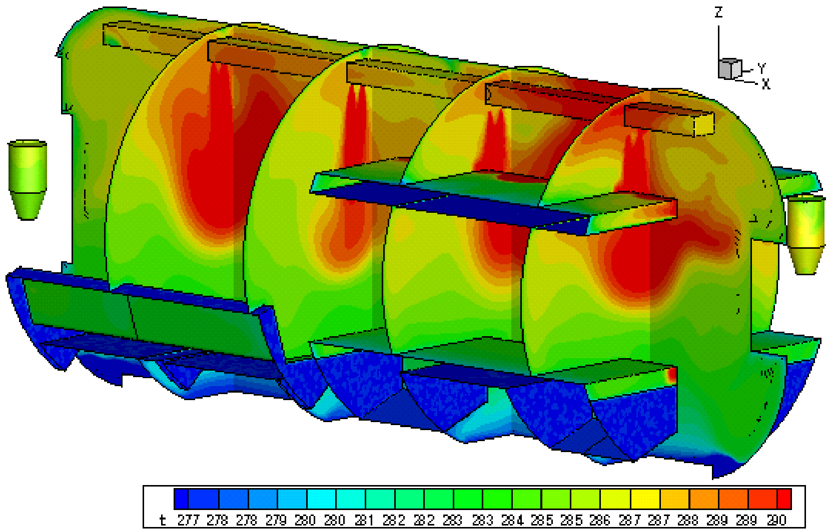
SATFADS LC temperature contours (^{0}K) for 1 atm (0 fsw) air;
120^{0}F (322^{0}K) 59 ft^3/min (100 m^3/hr) supply flow, 40^{0}F (277^{0}K) interior walls



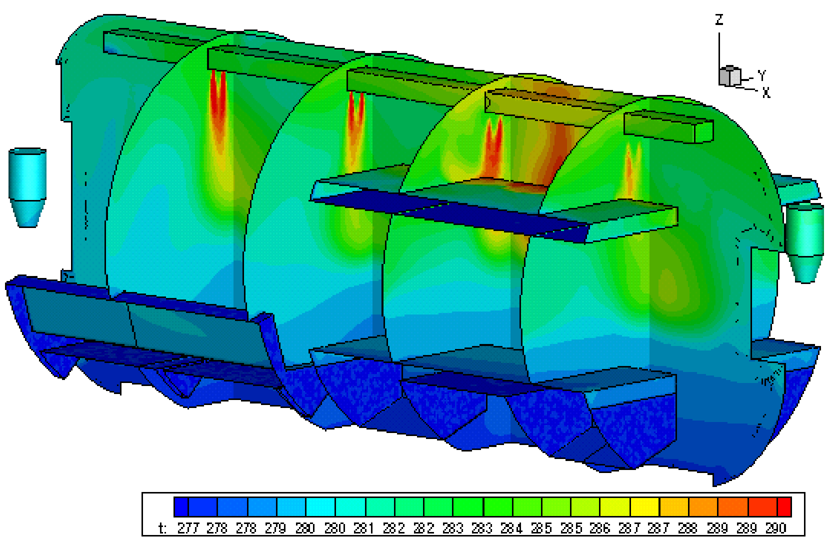
Same conditions as above but with large horizontal supply registers closed

- Operator 's local adjustments impact entire chamber

TEMPERATURE DISTRIBUTION SENSITIVITY TO PRESSURE AND GAS MIXTURE



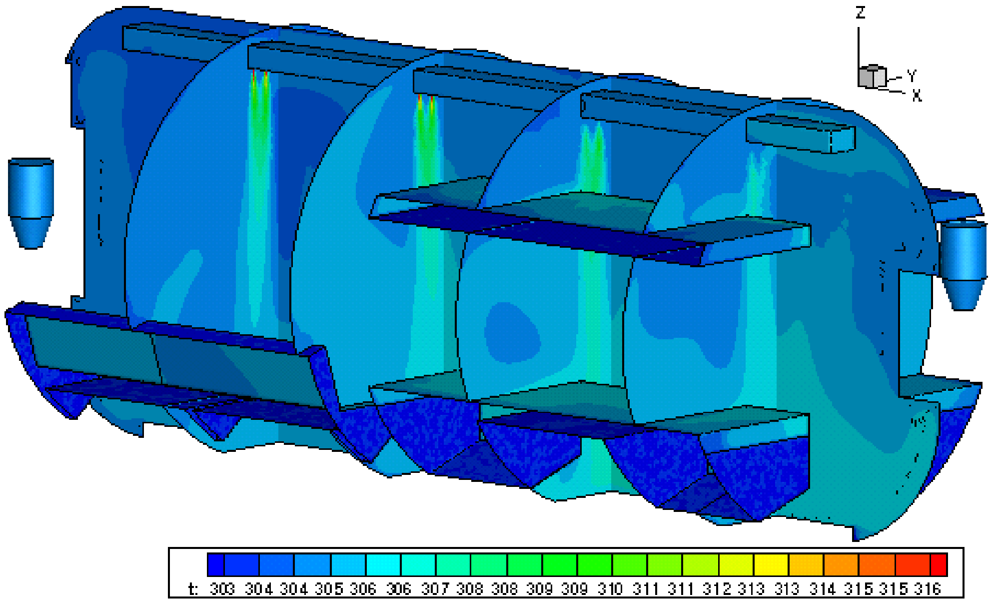
SATFADS LC temperature contours (^{0}K) for 1 atm (0 fsw) air;
120^{0}F (322^{0}K) 59 ft^3/min (100 m^3/hr) supply flow, 40^{0}F (277^{0}K) interior walls



Same conditions as above but with 31.3 atm (1000 fsw) heliox Mix 6

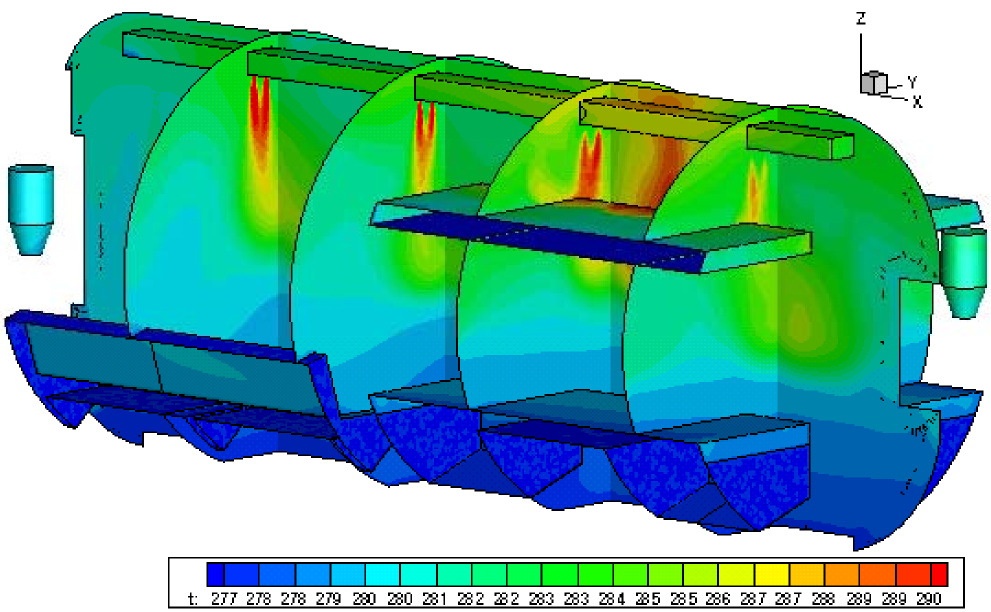
- Increased density, thermal conductivity, and specific heat
- Increased cooling and stratification

TEMPERATURE DISTRIBUTION SENSITIVITY TO RANGE OF BOUNDARY CONDITIONS, 1000 FSW



Temperature contours (^{0}K) for high heating flow, 31.3 atm (1000 fsw) heliox; 127^{0}F (326^0K) 95 ft^3/min (161 m^3/hr) supply flow and 87^{0}F (303^0K) interior wall

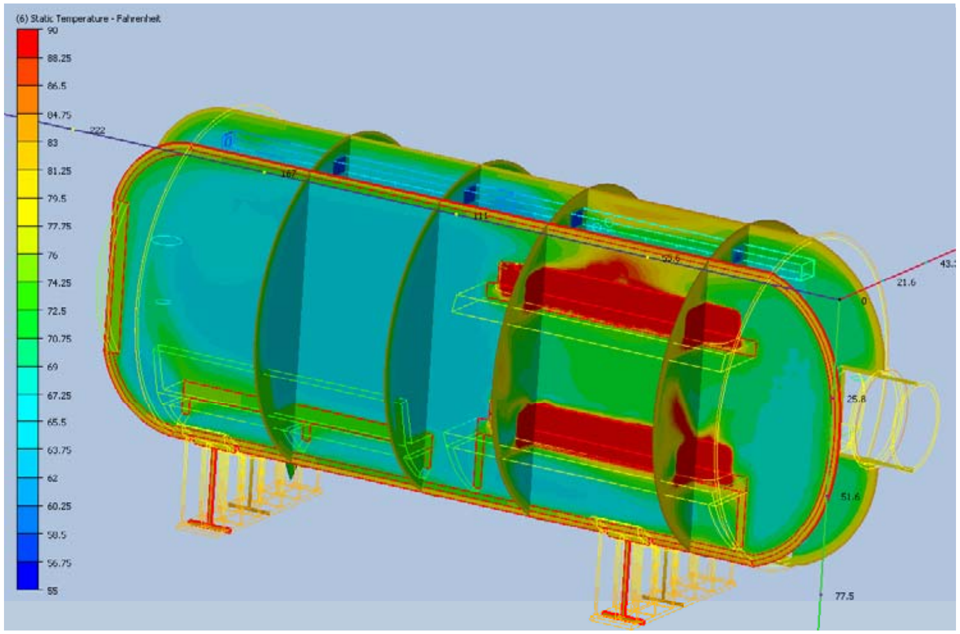
- High ventilation flow and small supply-wall ΔT
- Warmer, less stratified



Temperature contours (^{0}K) for moderate heating flow, 31.3 atm (1000 fsw) heliox; 120^{0}F (322^0K) 59 ft^3/min (100 m^3/hr) supply flow and 40^{0}F (277^0K) interior walls

- Moderate ventilation flow and large supply-wall ΔT
- Cold, more stratified

OCCUPANT HEAT LOAD MODELING



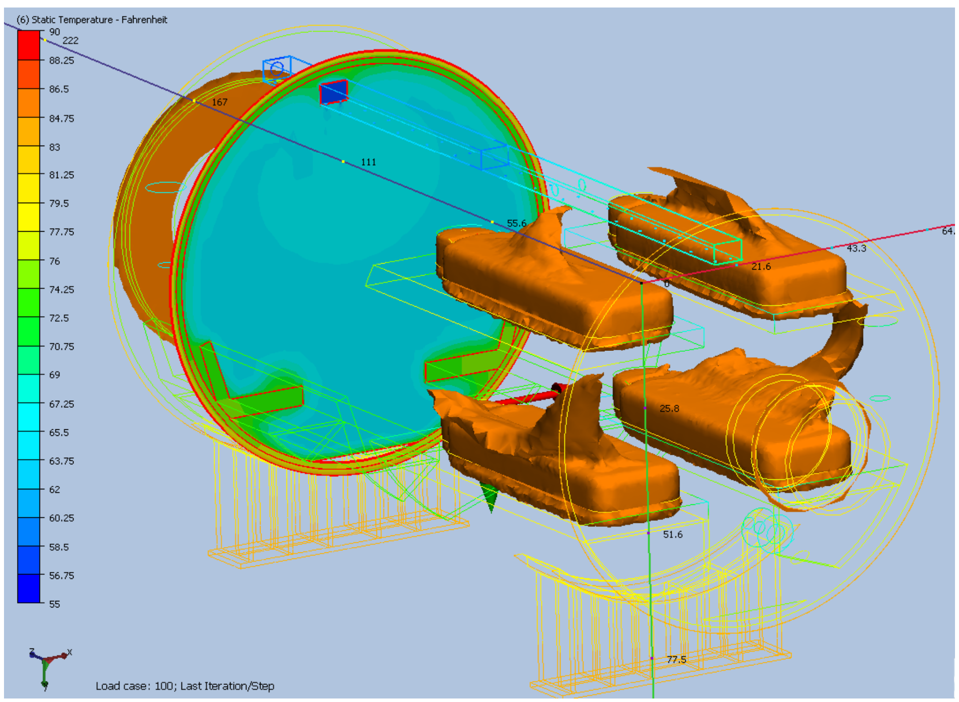
Model including shell heat transfer cooling, 2.1 atm (36 fsw) air, 57^0F (287^0K), 90 ft^3/min (153 m^3/hr) supply flow; 88^0F (304^0K) ambient exterior.

Extremely well insulated.

Simulation includes heat load from four sleeping occupants.

Vertical cross section through two resting occupants shows temperature contours.

Ghosted hull and support structure temperatures are also shown.



Same conditions as above.

The circular plane through the benches shows temperature contours.

The 85^0F isosurfaces show occupant thermal plumes and a ring of compartment gas on the aft (far) wall adjacent to the outer lock which acts as a heat source.

Ghosted hull and support structure temperatures are also shown.

LIFE SUPPORT COMPARTMENT VENTILATION MODELING OBSERVATIONS TO DATE

- Computational fluid dynamics models corroborate operator comments regarding thermal stratification
- CFD models of compartment atmosphere temperature distribution are in good agreement with test data when actual wall temperatures are a boundary condition
- CFD models are practicable for predicting hyperbaric life support atmosphere conditions
- CFD model boundary conditions must be chosen wisely to simplify computations without loss of fidelity

TRANSITIONS

- Refining SATFADS model with 1000 FSW test data for use in recommended operational envelope
- CFD models may be further developed to map gas constituents and smoke clearance