Industrial Applications of CFD

Paul Harris

November 2, 2023

pharris@airflowsciences.com
airflowsciences.com
azorecfd.com

Overview

- My Background

- What is Airflow Sciences?

- Example 1: Fermi 2

- Example 2: Global Supertanker

Background

- Worked with Prof Fasel at U of A 1992 - 1998

- Dissertation: "Numerical Investigation of Transitional Compressible Plane Wakes"

- DNS/LES CFD solver: nscc

- Data visualizer: x3dp
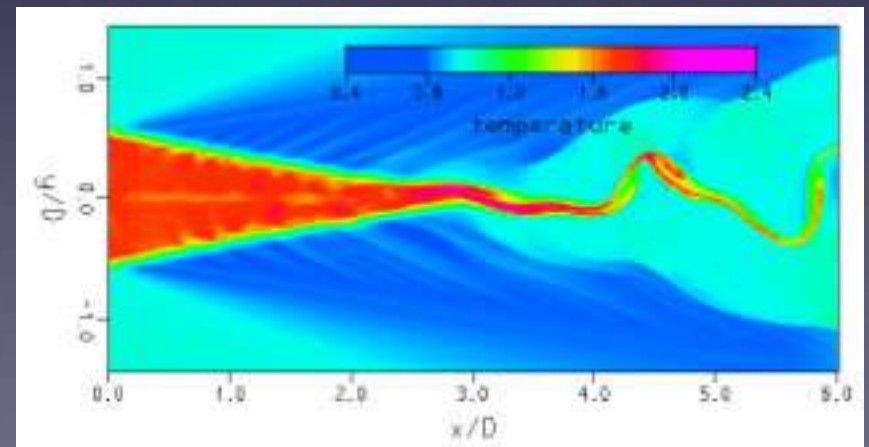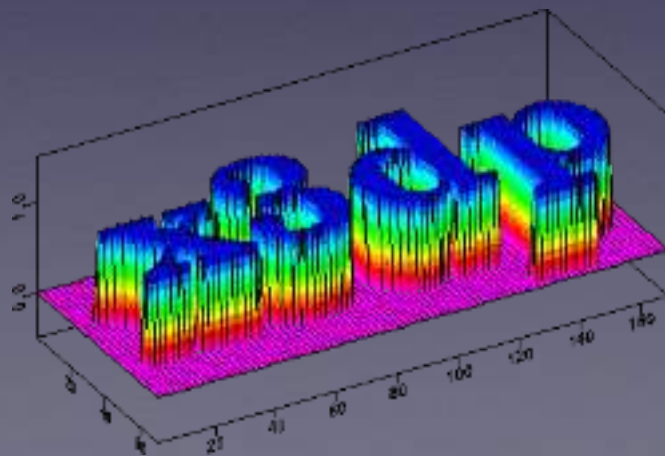
Background

- Employed at Airflow Sciences Corp. since 1999

- CFD Engineer

  - Use CFD to answer engineering questions

- Software developer

  - Azore CFD

  - Lots of other things

- So what is Airflow Sciences?

Company Overview

❖ Expertise is with fluid dynamic engineering, heat transfer, thermodynamics, combustion

❖ In business since 1975

❖ Consulting Engineering Services
  - CFD simulation
  - Laboratory prototype fabrication/testing
  - Wind tunnel testing
  - Field testing

❖ Software Development
  - CFD solvers - Azore®
  - Automated meshing

❖ Flow Test Equipment

❖ Flow Calibration Lab
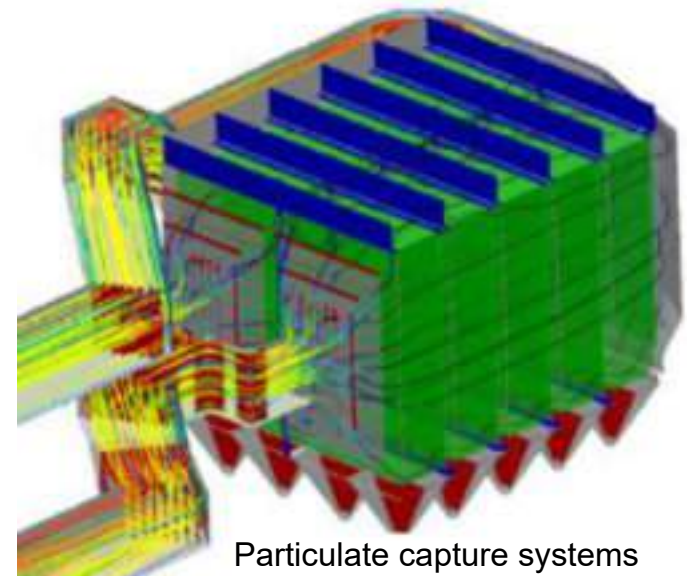
Particulate capture systems
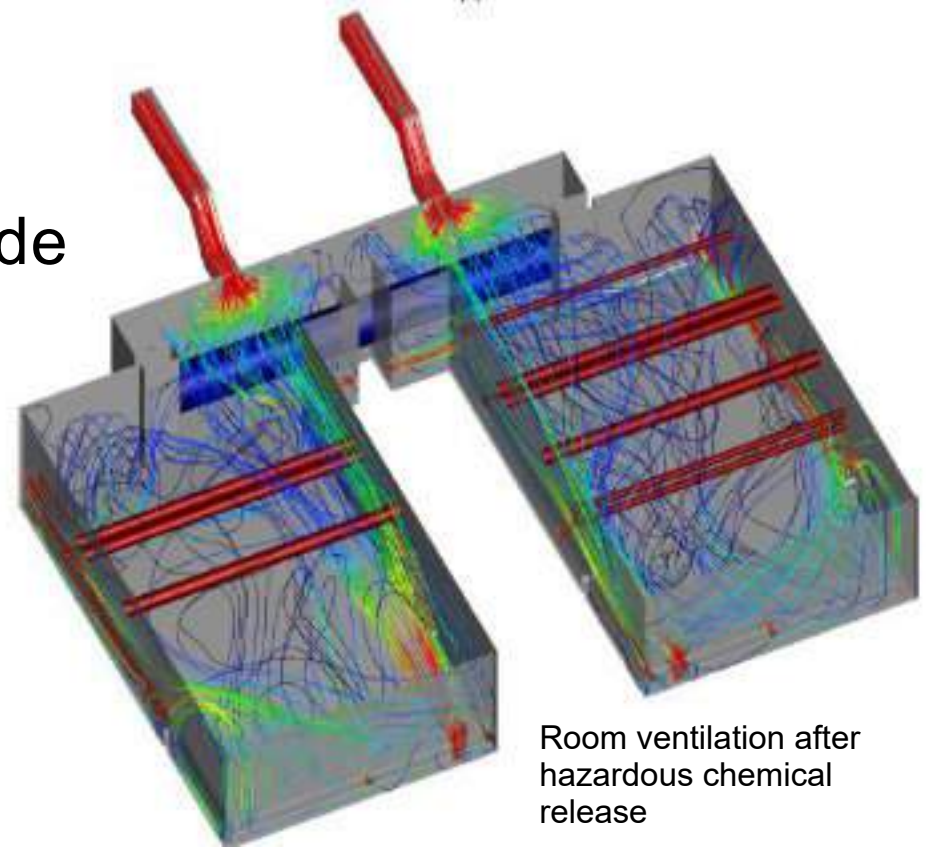

Onsite wind tunnel
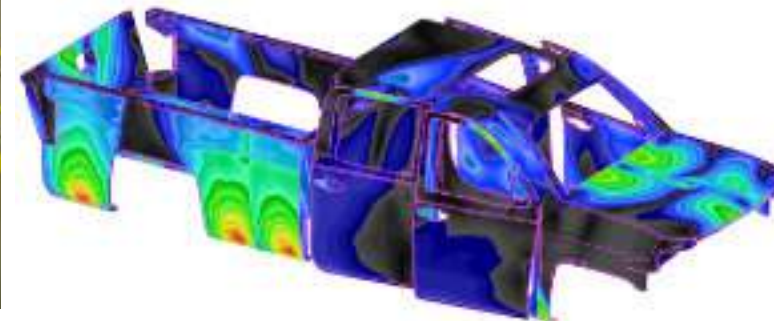
Automobile manufacturing

Company Overview

❖ Range of customers worldwide

- Architectural / HVAC
- Power & steam generation
- Specialty aerodynamics
- Food processing
- Automotive
- Aerospace
- Manufacturing
- Appliance
- And more

Room ventilation after hazardous chemical release

Euro Tunnel HVAC design

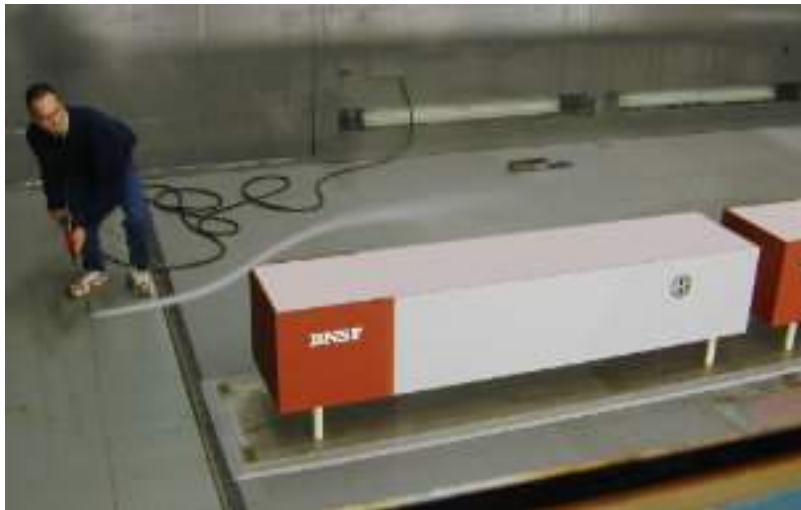
Pollution control equipment design

Indy car helmet aerodynamics

Airflow Sciences Corporation   Azore® Software   Airflow Sciences Equipment, LLC

Laboratory Testing

❖ Flow optimization and testing

❖ Fabrication shop for onsite model construction
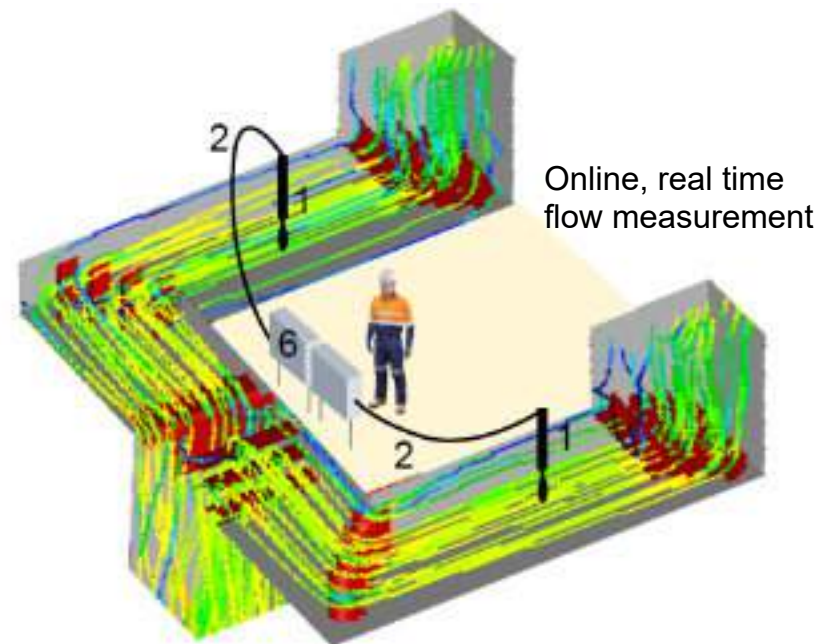

Velocity and pressure testing

Wind tunnel testing

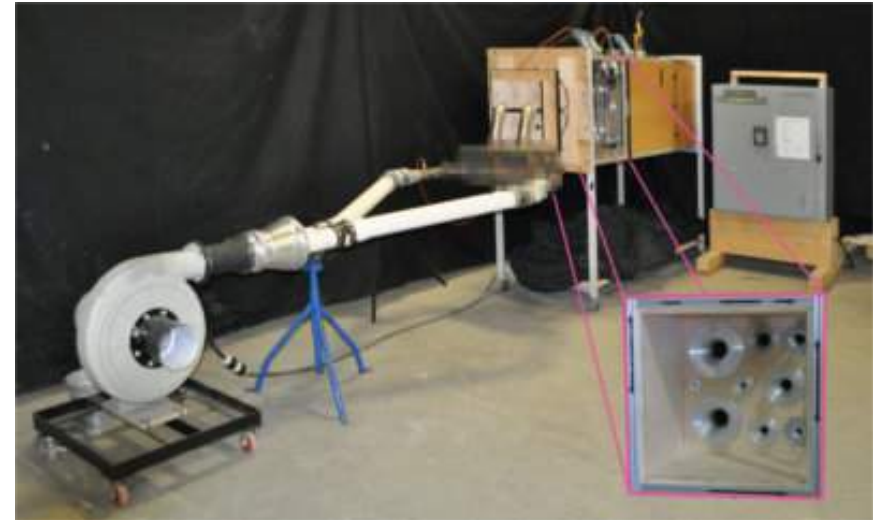Heat transfer measurement

Custom probes and instrumentation

Airflow Sciences Corporation

Azore® Software

Airflow Sciences Equipment, LLC

Flow Test Equipment

- ❖ Velocity

- ❖ Pressure

- ❖ Temperature

- ❖ Portable or Permanent

Online, real time flow measurement

Portable velocity measurement

Custom data acquisition systems

Airflow Sciences Corporation — Azore® Software — Airflow Sciences Equipment, LLC

Instrument Calibration

❖ Velocity

❖ Pressure

❖ Temperature

❖ Certified Wind Tunnel

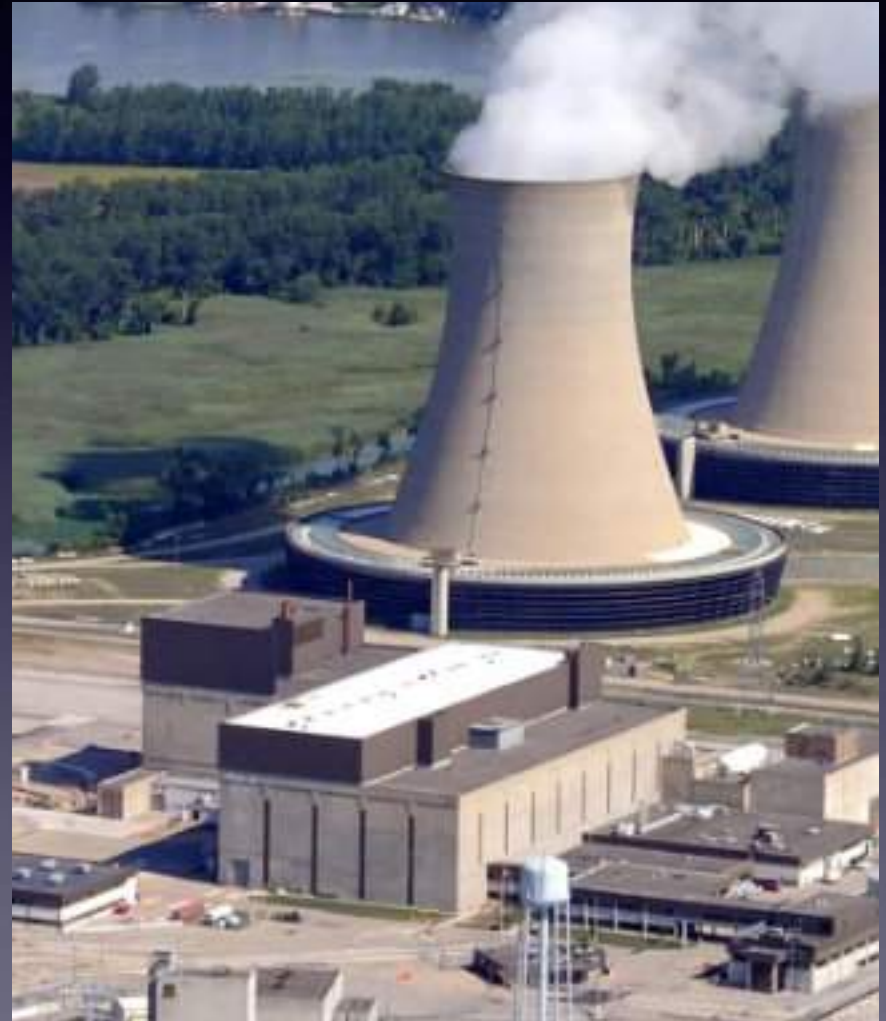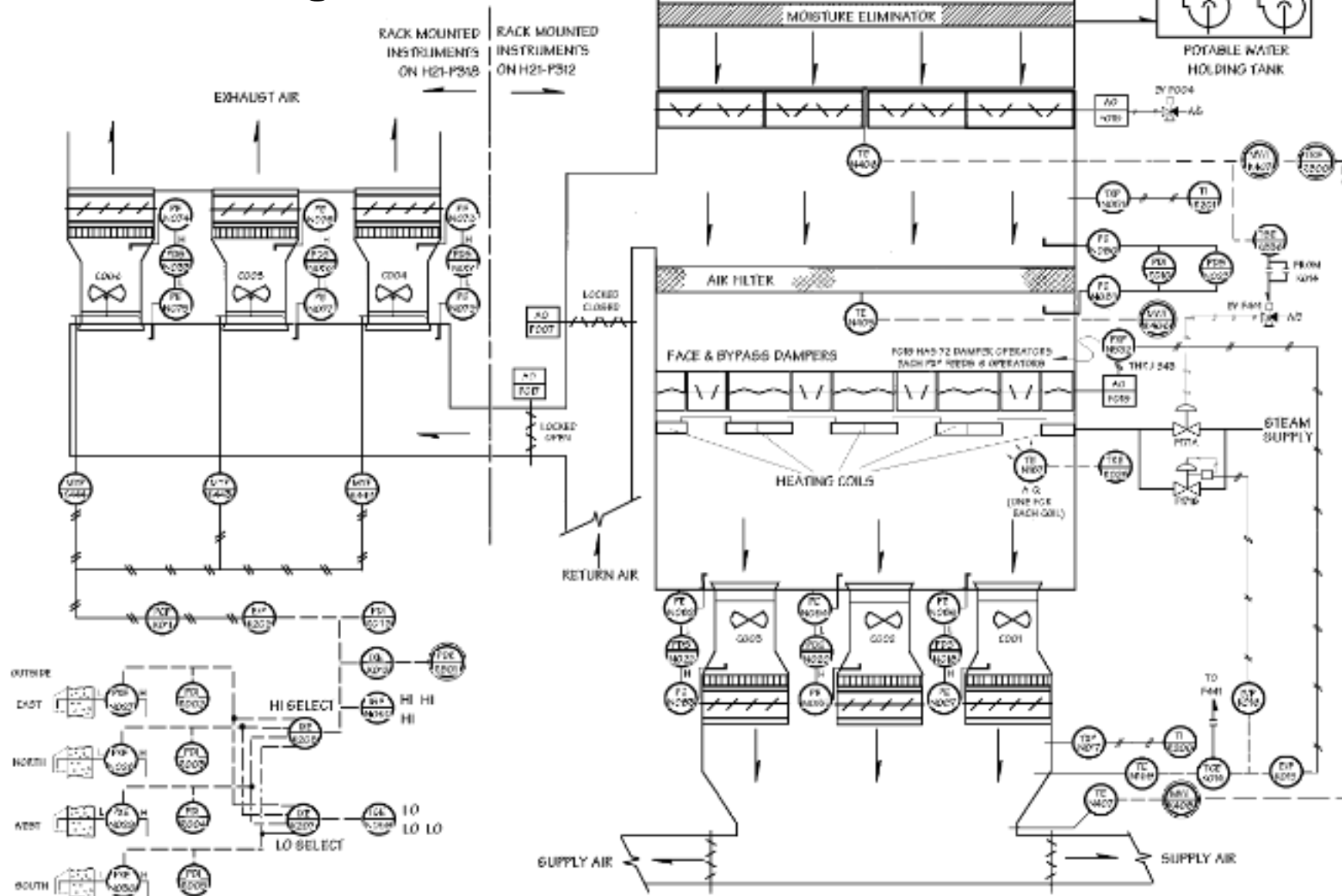Accurate, traceable flow measurement

In house wind tunnel

Automated data acquisition

Example 1: Fermi 2

- Nuclear generating station in SE Michigan

- Had issues with ventilation system in the turbine building

- Nuclear plants talk openly about *everything*

- Study presented at the Nuclear HVAC Utility Group meeting in 2015

TBHVAC Design

Exhaust Fans
Vaneaxial (3), 50% capacity, 215000 cfm @
4.5 in. w.c. 250 HP

Supply Fans
Vaneaxial (3), 50% capacity, 205000 cfm @
5.54 in. w.c. 250 HP

Issue Description

Since initial plant startup, the Turbine Building HVAC Exhaust fans experienced multiple catastrophic blade failures.

- The Center TBHVAC Exhaust fan experienced six (6) failures.
- The North TBHVAC Exhaust fan experienced six (6) failures.
- The South TBHVAC Exhaust fan experienced zero (0) failures.
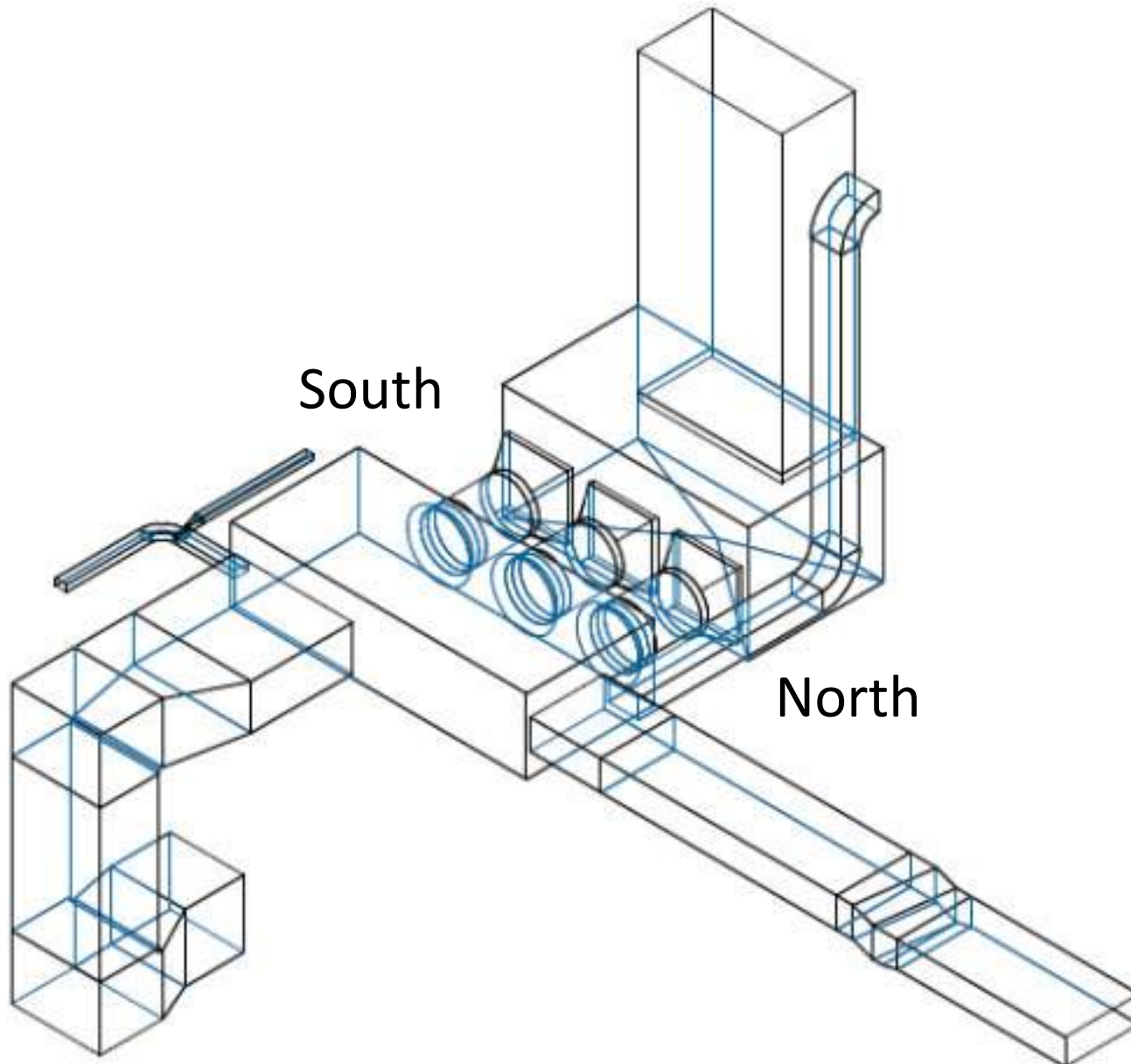- The Supply fans only experienced one catastrophic failure due to material intrusion.
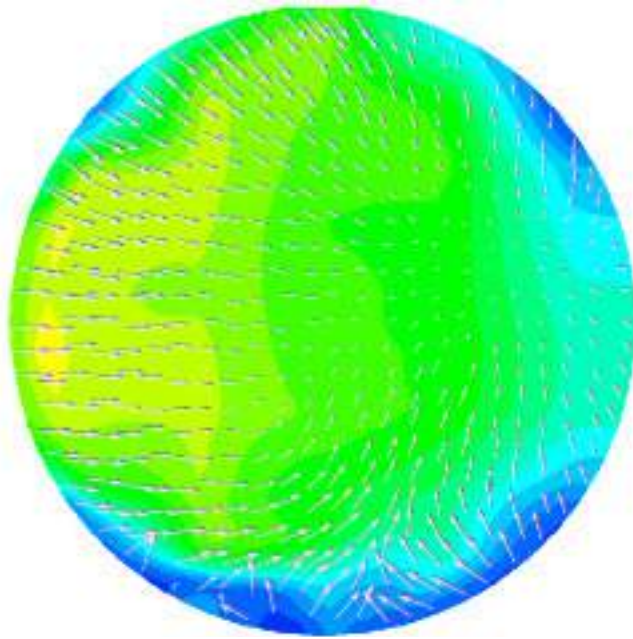
Catastrophic Fan Failures

Fermi 2 — CFD

- Model air flow from ducts to exhaust fans

- Steady, incompressible

- Mesh: 6,800,000 cells

- Results overnight

- Run in Azore
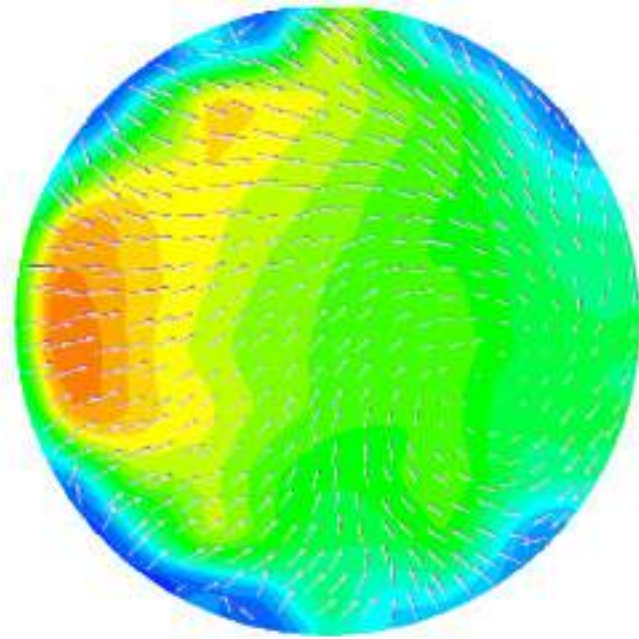
- Many (> 20) design iterations

Previous Exhaust Inlet / Outlet Plenums

South

North

Previous Exhaust Inlet Plenum,
# North and South Inlet Velocity Profile, 2010 Testing

South
RMS = 21.7%

North
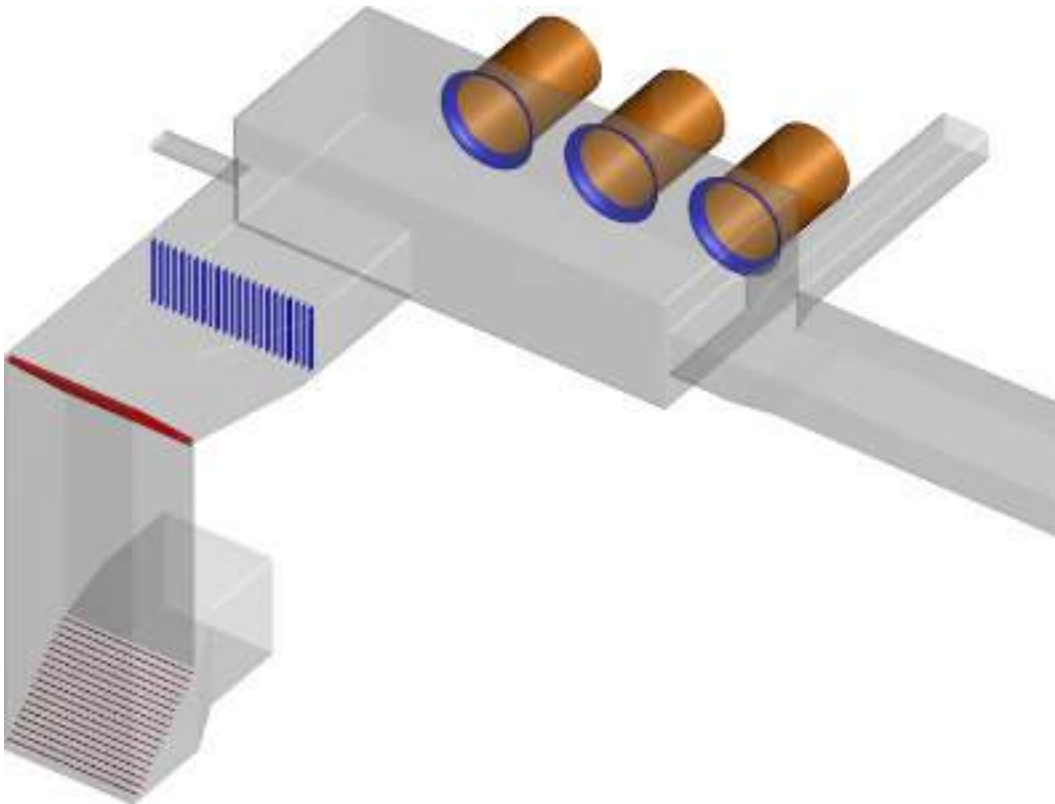RMS = 31.9%

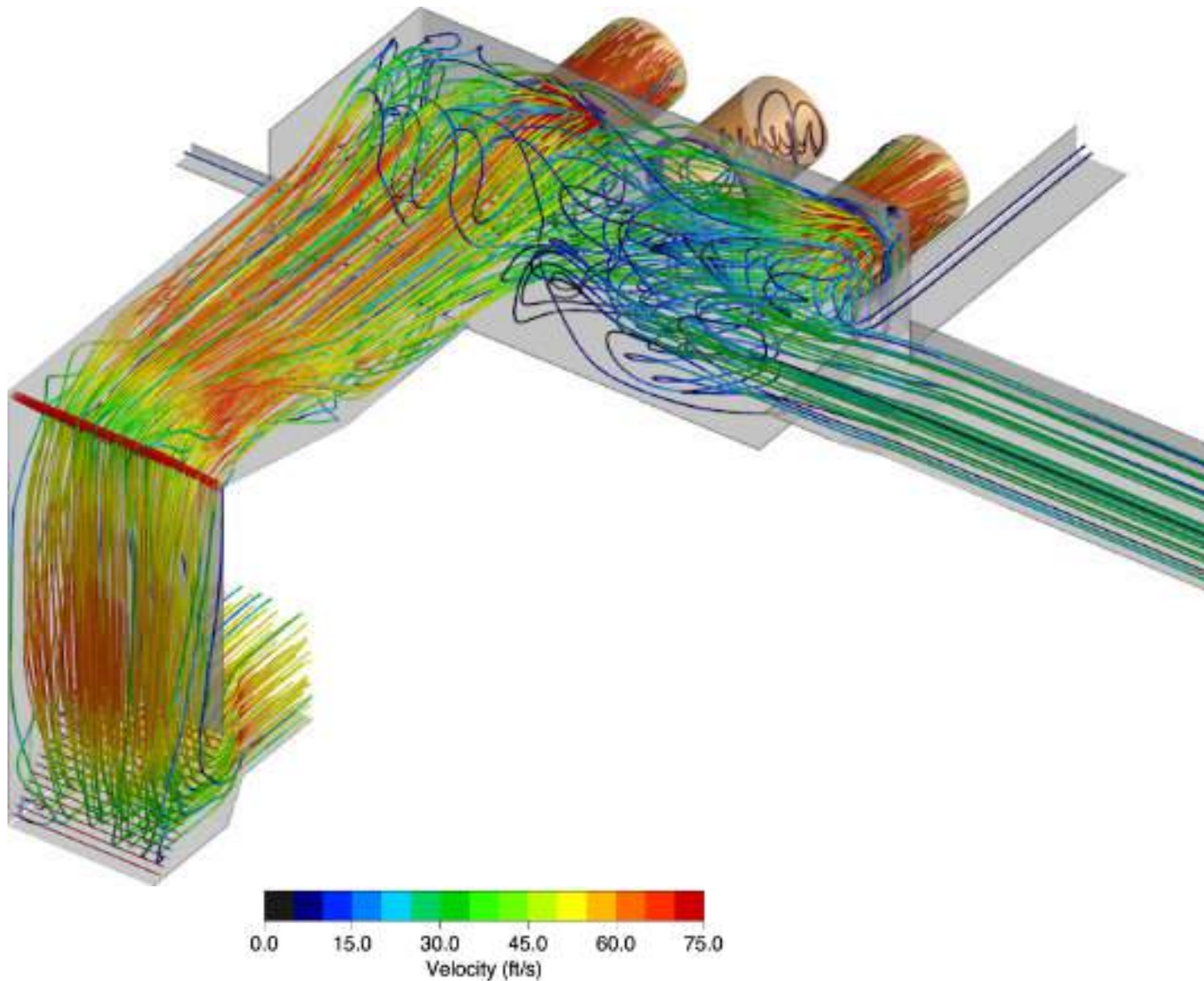0.0   25.0   50.0   75.0   100.0   125.0
Velocity (ft/s)

- Velocity RMS is the measure of the velocity uniformity at the plane of interest
    - Lower values are better
- AMCA 803 recommends velocity RMS of < 10% at the fan inlets

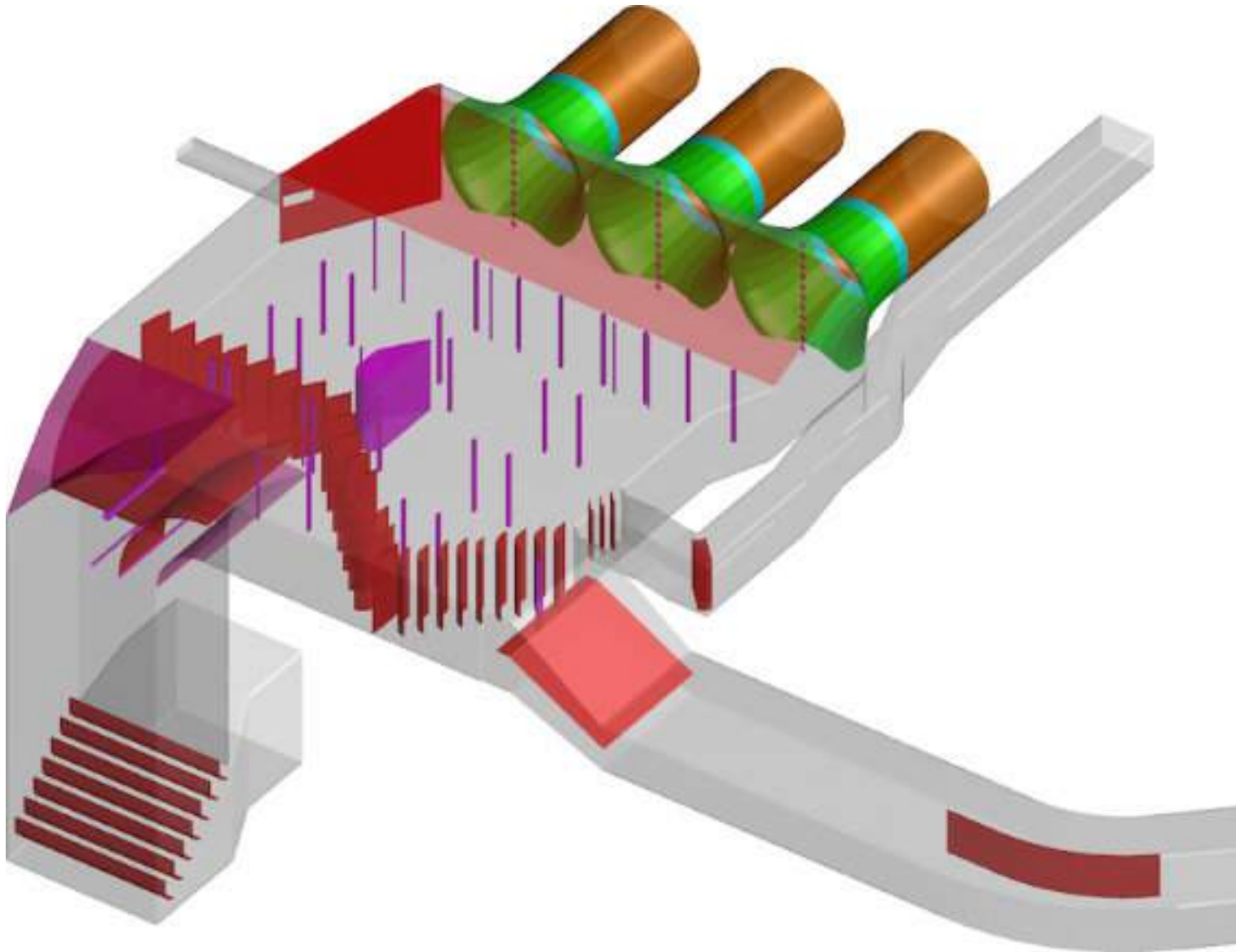# Previous Exhaust Inlet Plenum, North and South Fans in Service

Previous Exhaust Inlet Plenum, North and South Fans in Service

0.0   15.0   30.0   45.0   60.0   75.0
Velocity (ft/s)
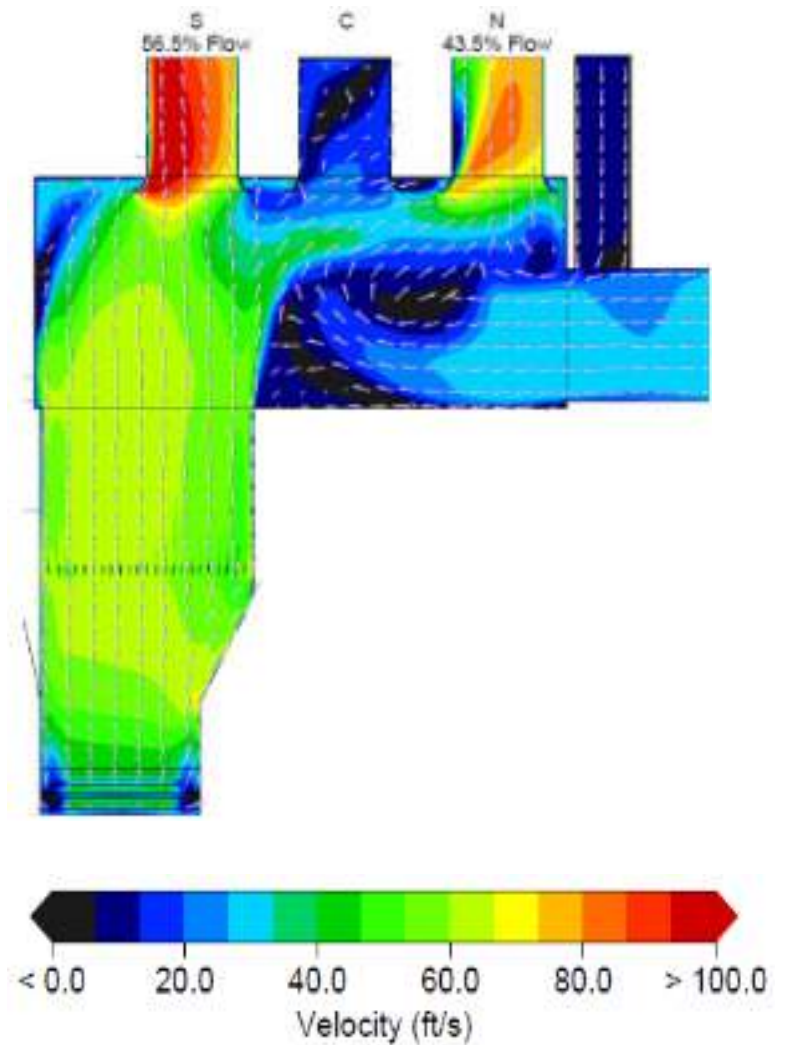
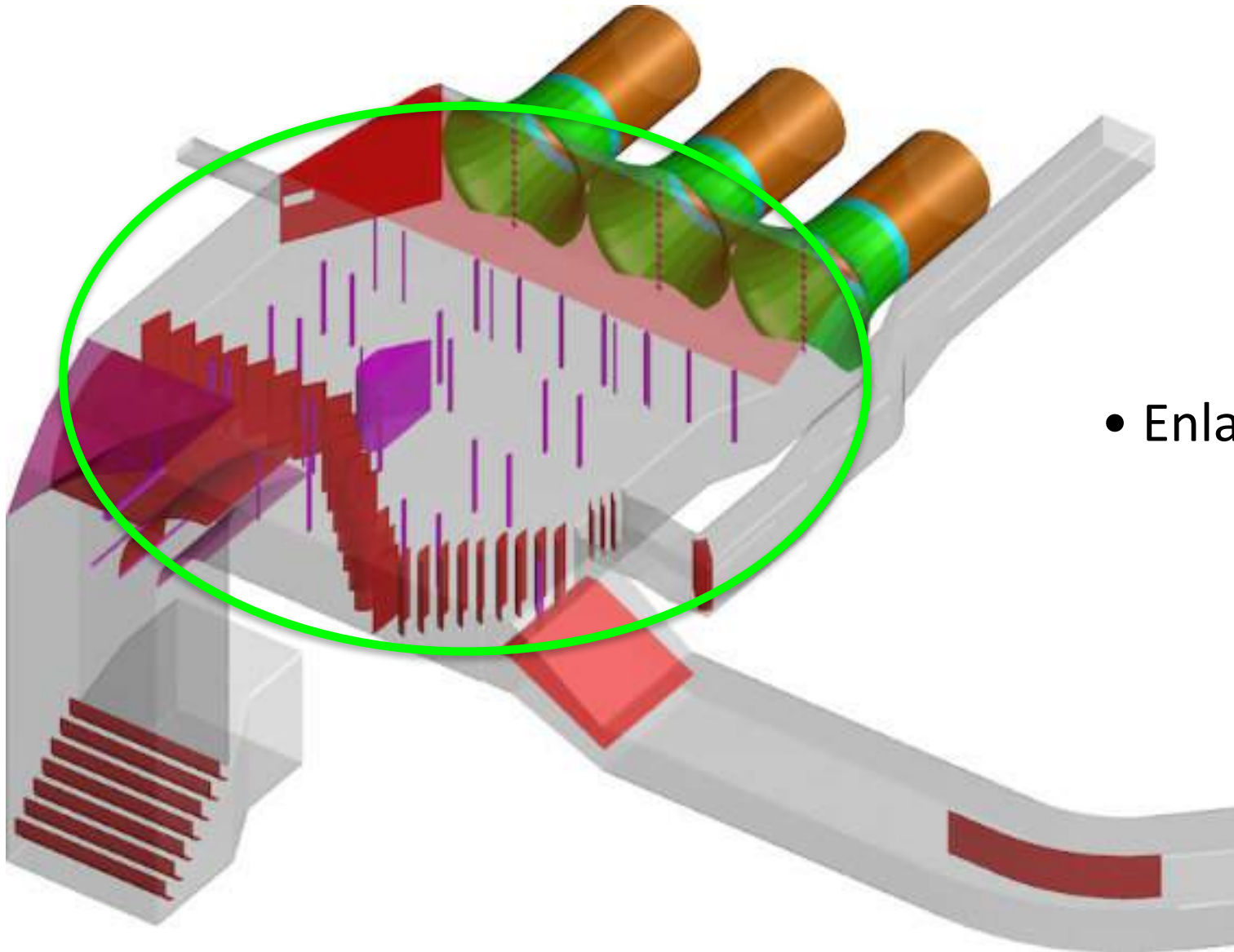# Plenum Design Objectives

- Reduce RMS at Fan Inlets (< 10% per AMCA)
  - Gas Flow Straight into Fans
  - Less Recirculation in Plenum
- Allow for Any Combination of Fans
- Reduce Pressure Losses
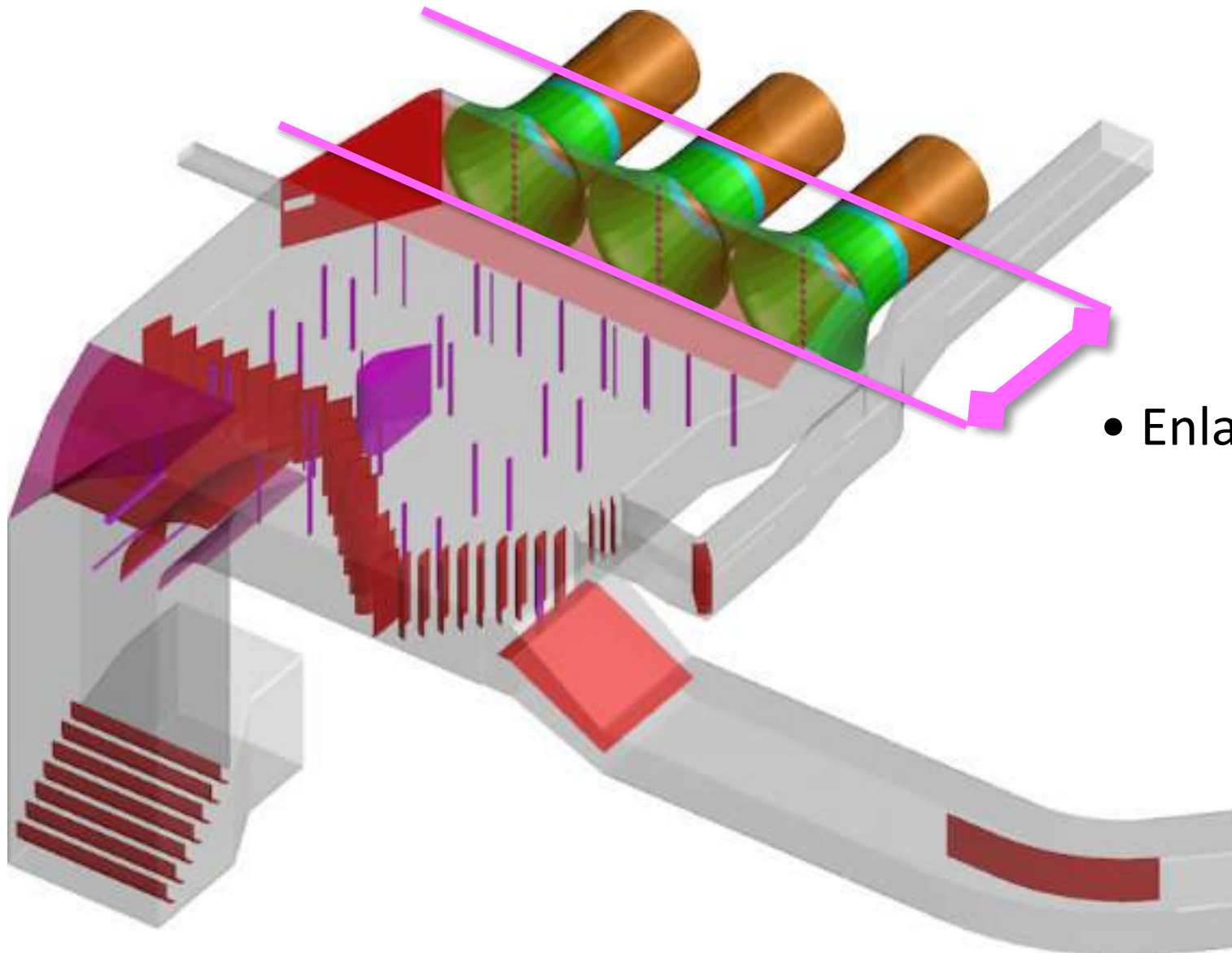- Constructability

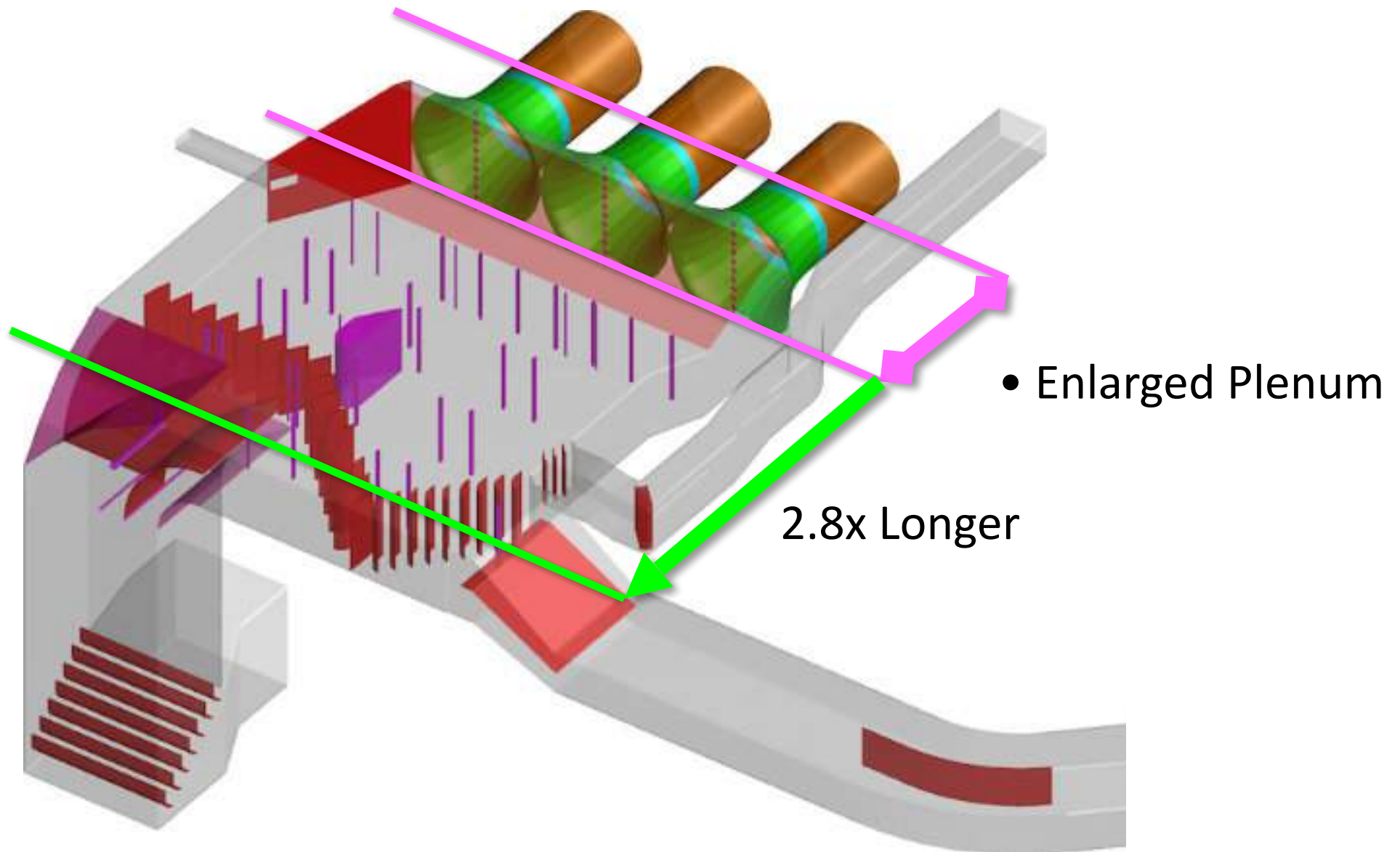# Final Exhaust Inlet Plenum Design

Final Exhaust Inlet Plenum Design

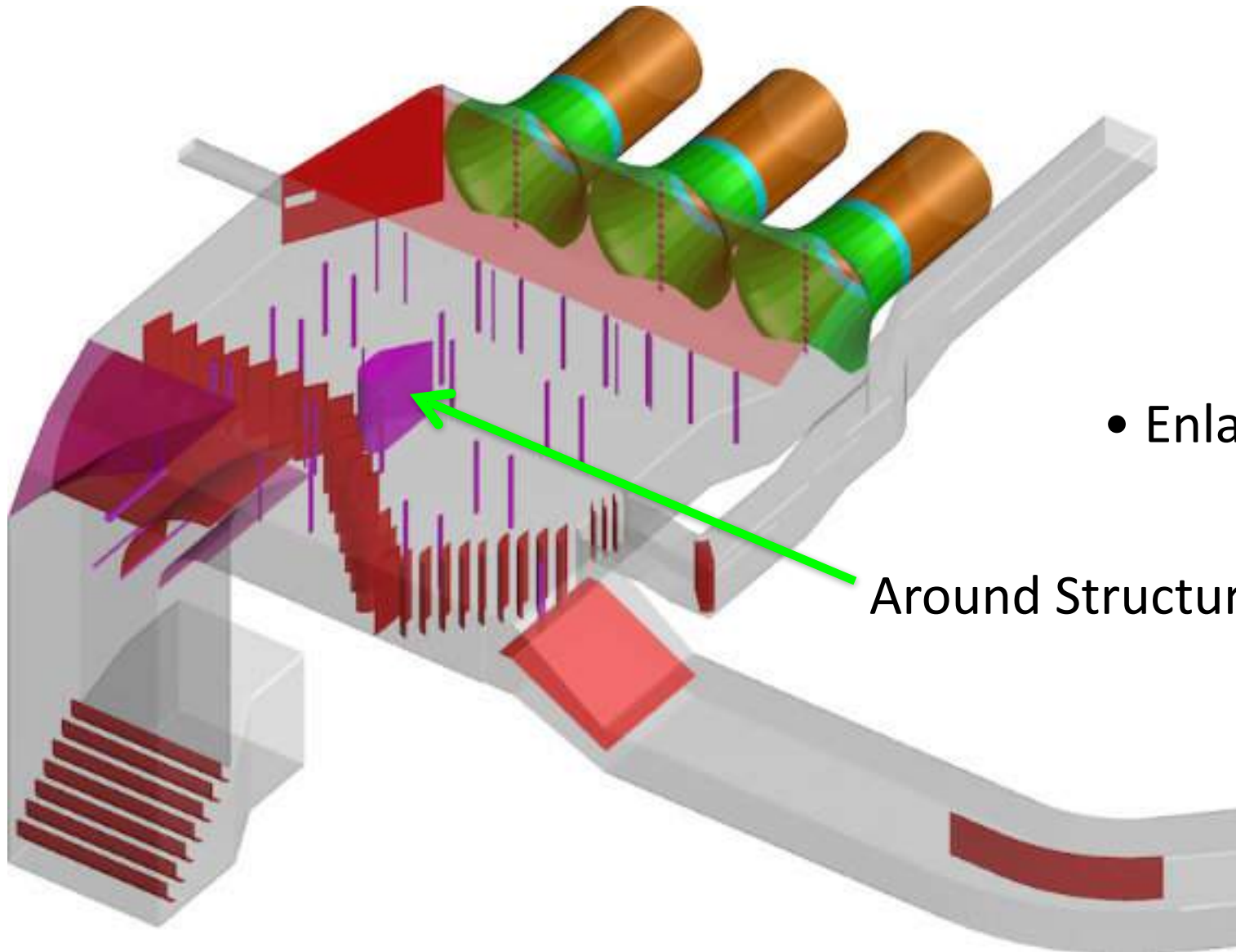- Enlarged Plenum

Final Exhaust Inlet Plenum Design
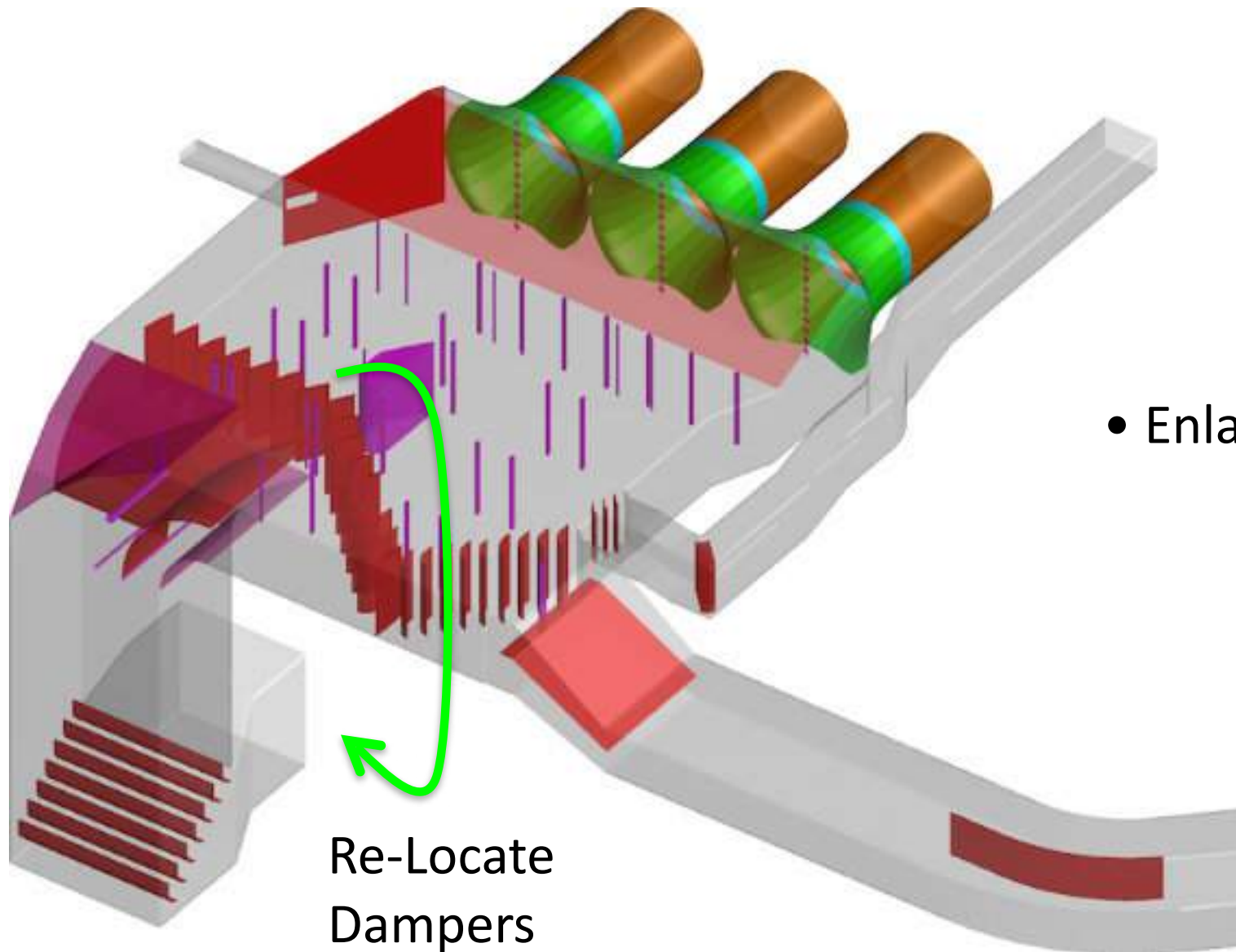

- Enlarged Plenum

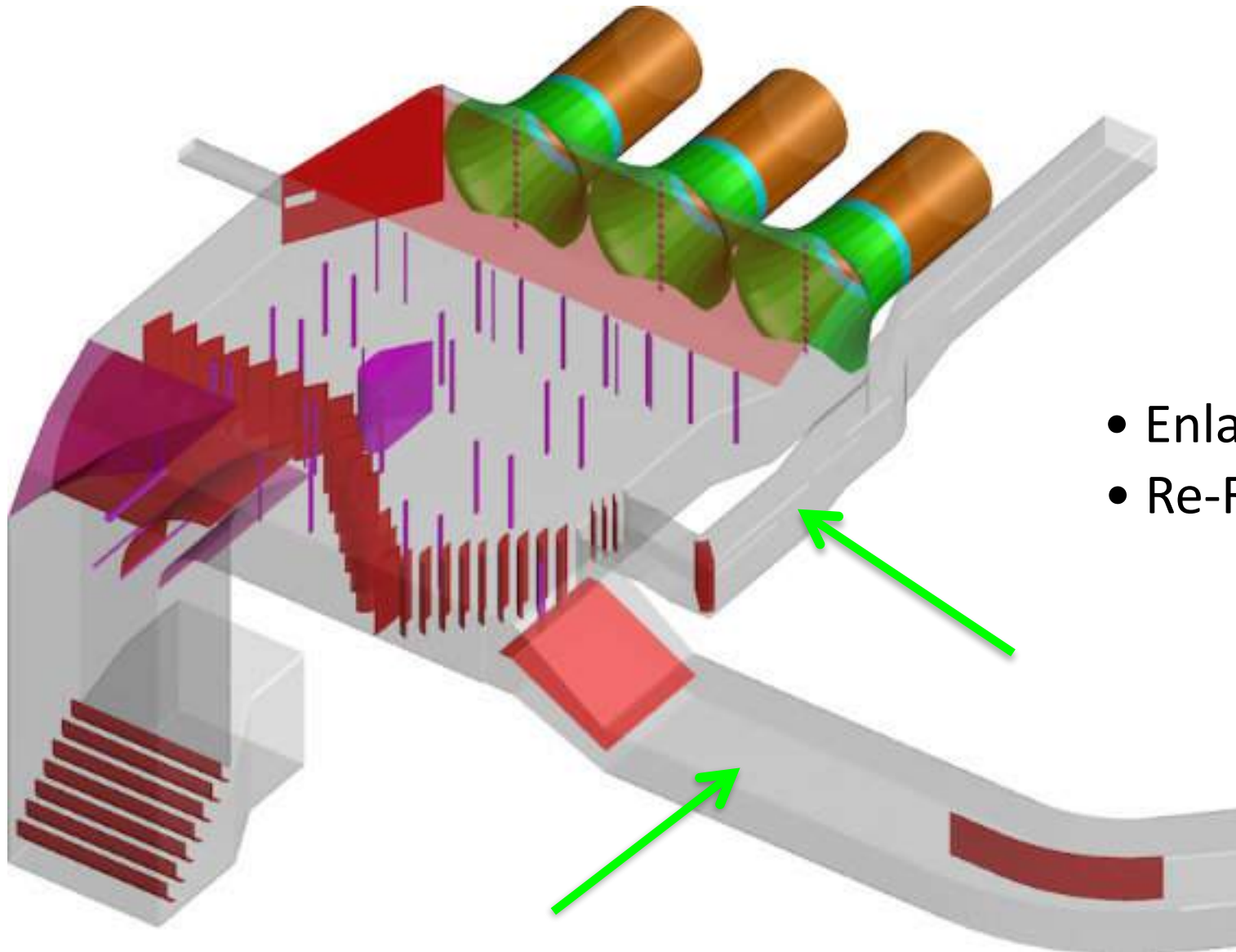# Final Exhaust Inlet Plenum Design

- Enlarged Plenum

2.8x Longer

Final Exhaust Inlet Plenum Design

- Enlarged Plenum

Around Structural Column

Final Exhaust Inlet Plenum Design

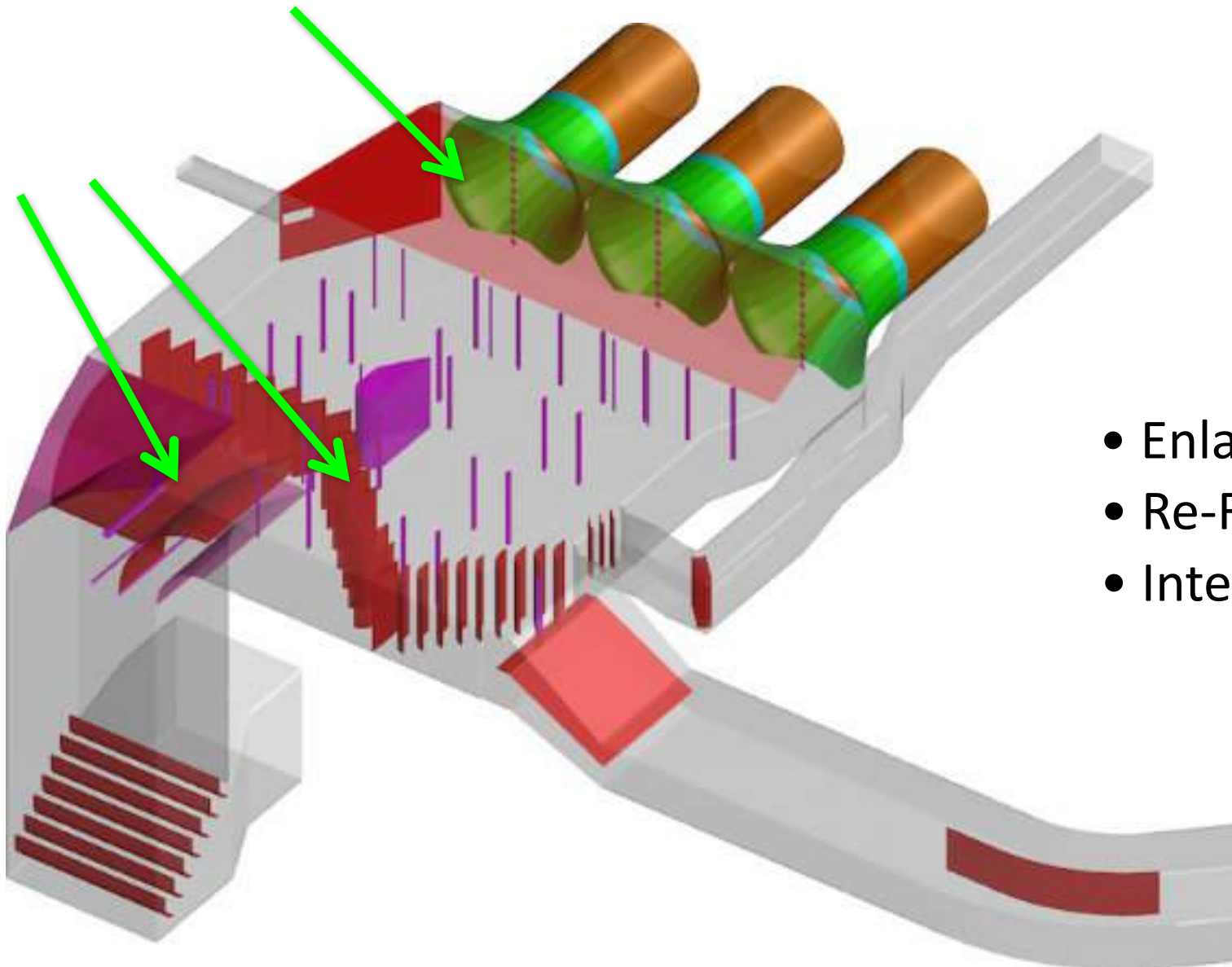
• Enlarged Plenum

Re-Locate Dampers

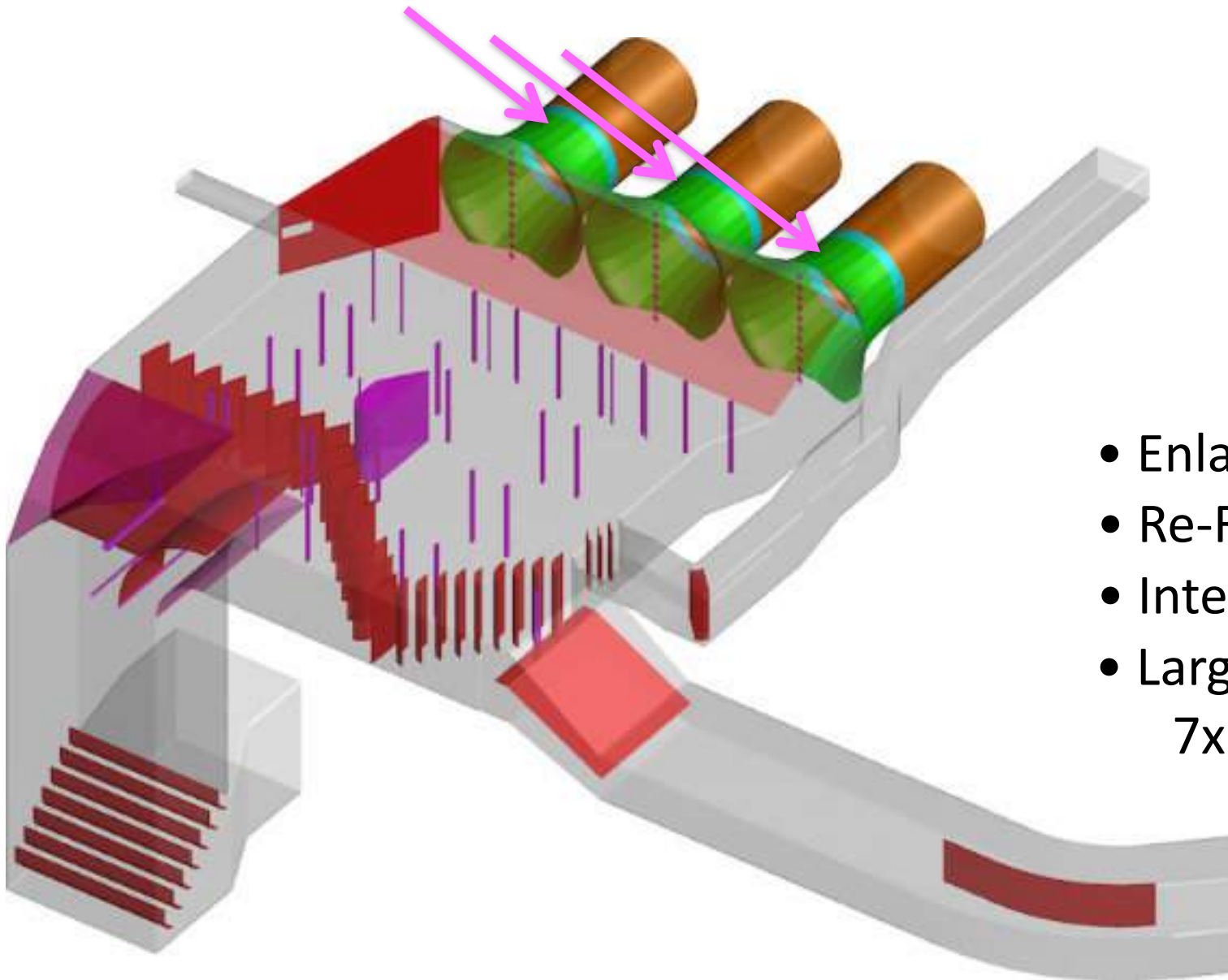# Final Exhaust Inlet Plenum Design

- Enlarged Plenum
- Re-Route Ducts
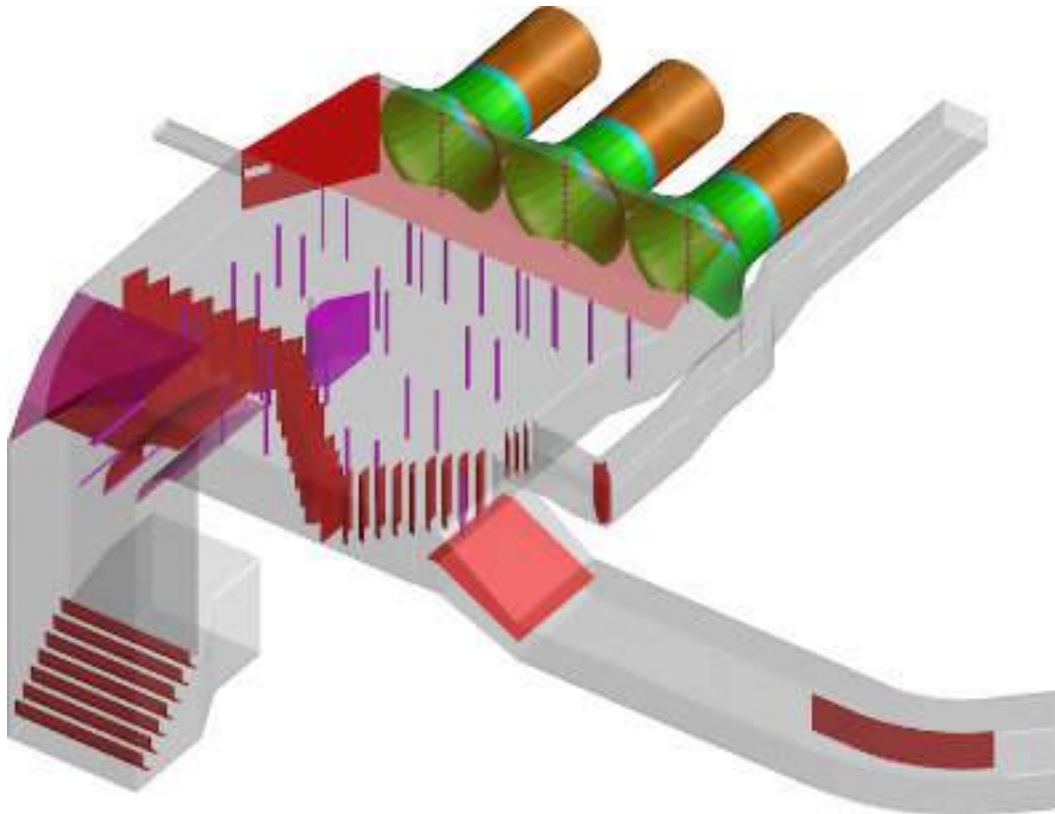
Final Exhaust Inlet Plenum Design

- Enlarged Plenum
- Re-Route Ducts
- Internal Vanes

20
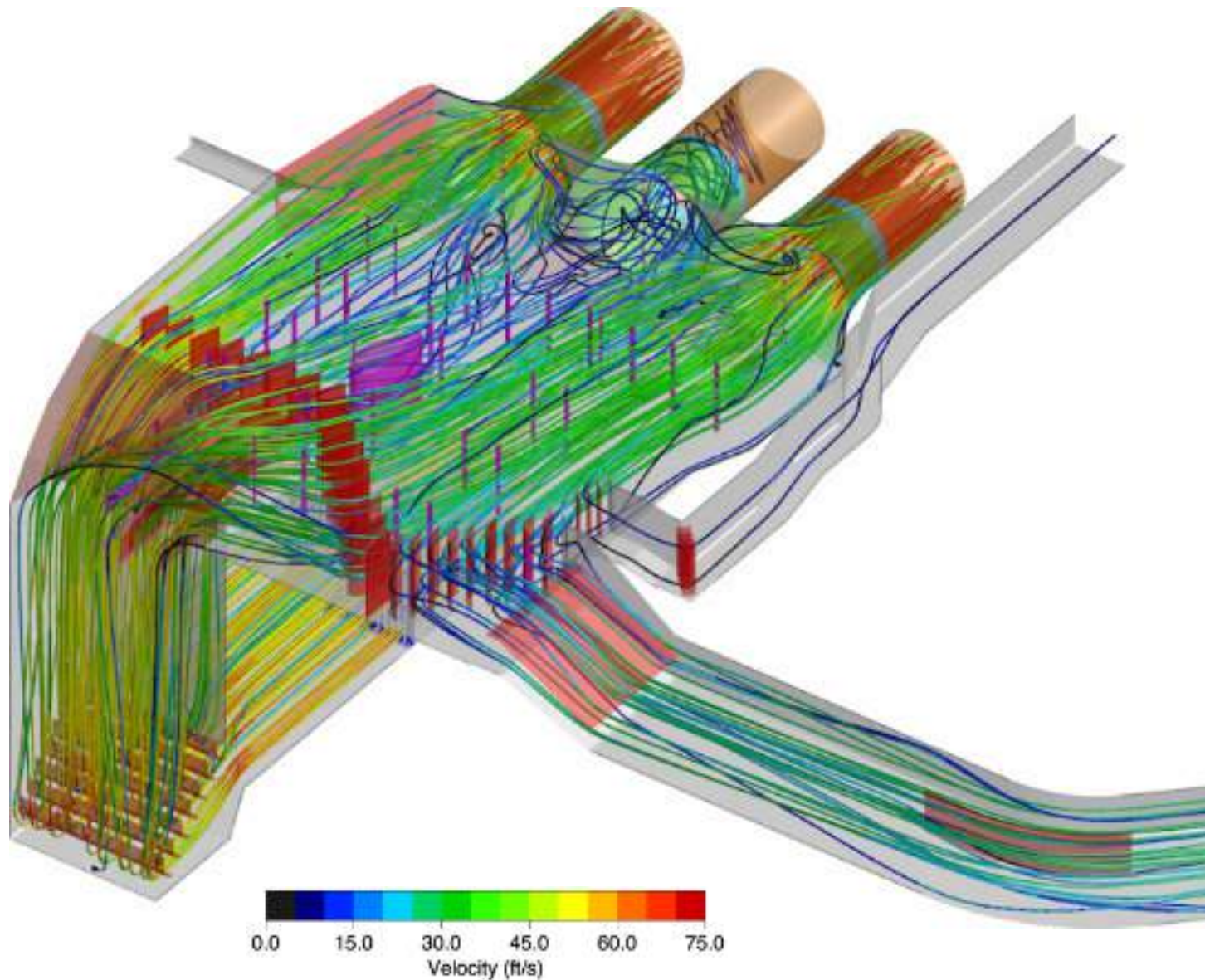
Final Exhaust Inlet Plenum Design

- Enlarged Plenum
- Re-Route Ducts
- Internal Vanes
- Larger Bellmouths
  7x Longer

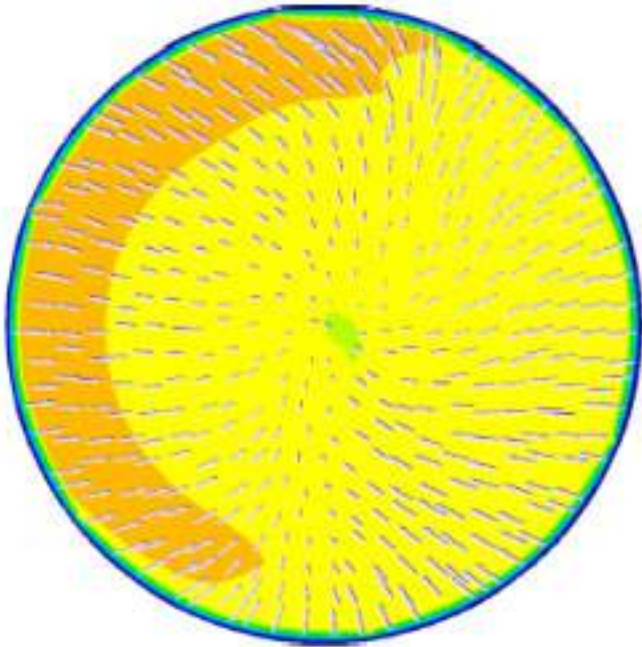# Final Exhaust Inlet Plenum Design, With Internal Geometry, North and South Fans in Service

Final Exhaust Inlet Plenum Design, With Internal Geometry, North and South Fans in Service

Velocity (ft/s)

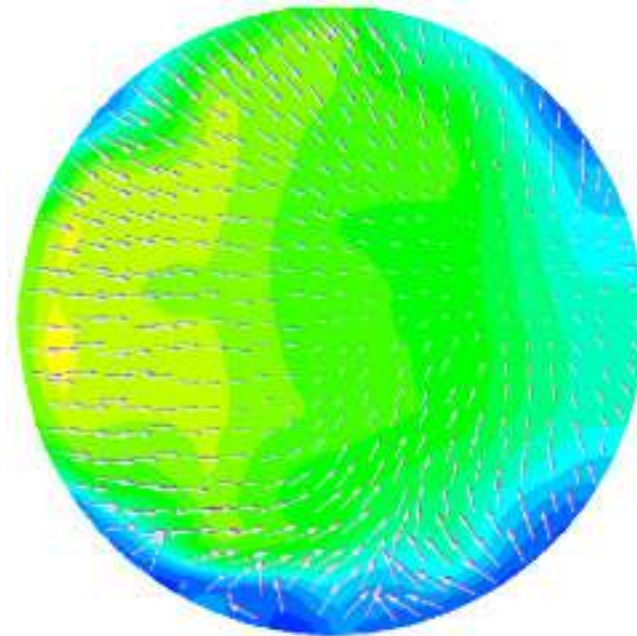0.0   15.0   30.0   45.0   60.0   75.0
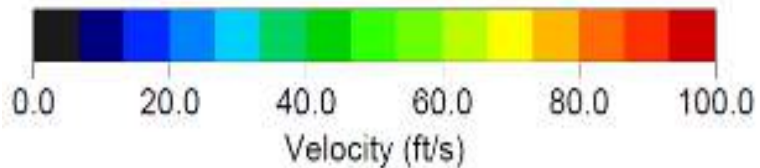
New Exhaust Inlet Plenum

Previous South Fan Inlet Velocity Profile Compared to Modified (Operating with The North Exhaust Fan)
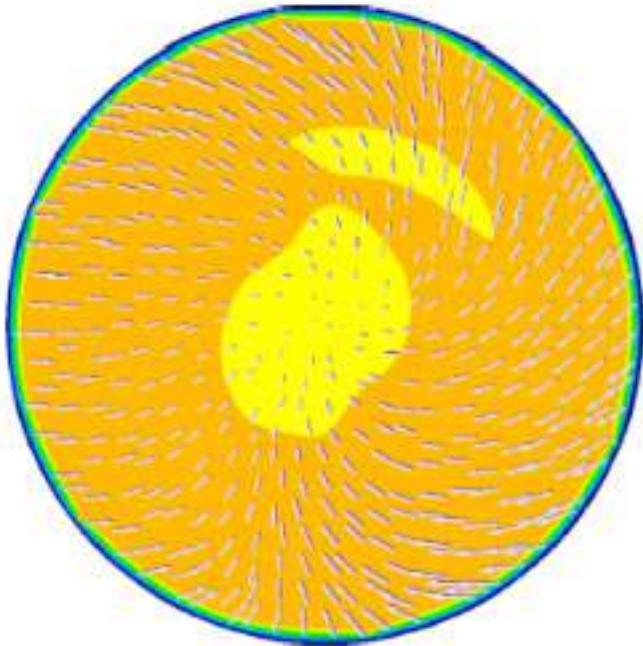

Modified Plenum, South Fan
RMS = 4.3%

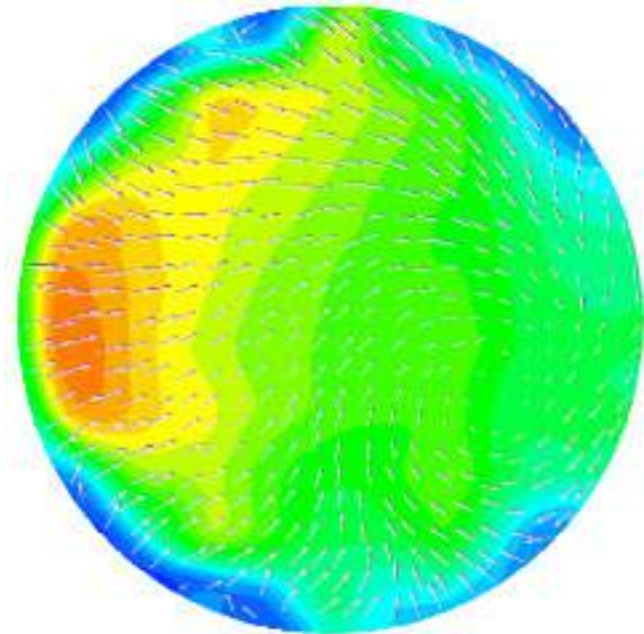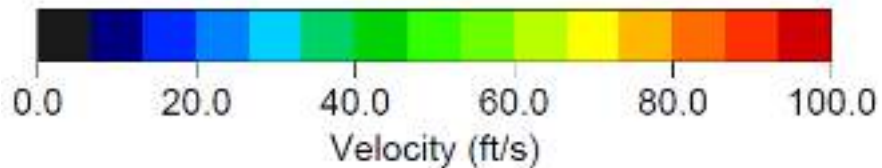Previous Plenum, South Fan
RMS = 21.7%

New Exhaust Inlet Plenum

Previous North Fan Inlet Velocity Profile Compared to Modified
(Operating with The South Exhaust Fan)

Modified Plenum, North Fan
RMS = 2.5%

Previous Plenum, North Fan
RMS = 31.9%

Summary of Final Inlet Plenum Design Results
- **Significantly Better (Lower RMS) for All Fan Combinations**

RMS Summary and Comparison

	2010 As-Found Baseline		2014 Post Modification	
Two Fan N + S	South	North	South	North
Axial Velocity RMS %	21.7%	31.9%	4.3%	2.5%
Two Fan N + C	Center	North	Center	North
Axial Velocity RMS %	29.0%	14.5%	6.6%	2.9%
Two Fan S + C	South	Center	South	Center
Axial Velocity RMS %	24.1%	20.2%	4.6%	3.5%
Single Fan North	North		North	
Axial Velocity RMS %	18.5%		3.7%	
Single Fan Center	Center		Center	
Axial Velocity RMS %	19.2%		3.7%	
Single Fan South	South		South	
Axial Velocity RMS %	20.0%		3.5%	

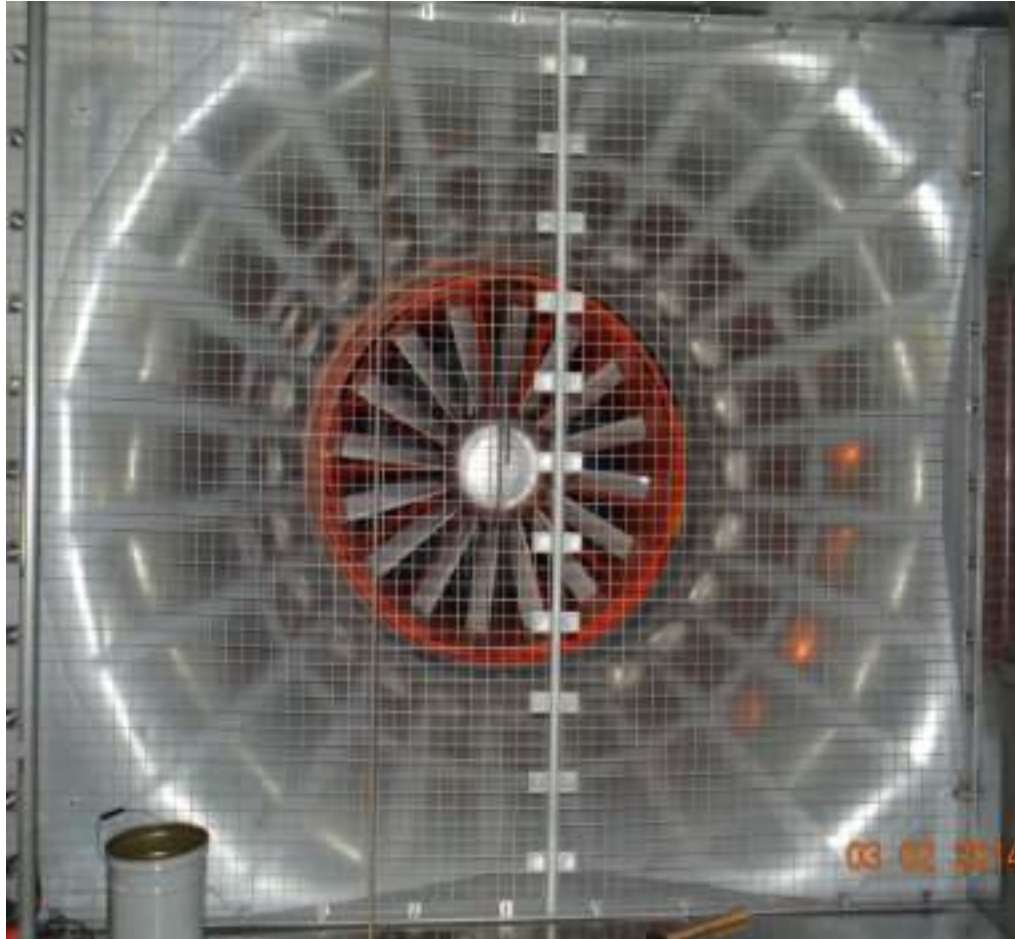# Isometric of Modules

HVAC MODULE FLOOR PLAN
SCALE: 1/4" = 1'-0"
NORTH
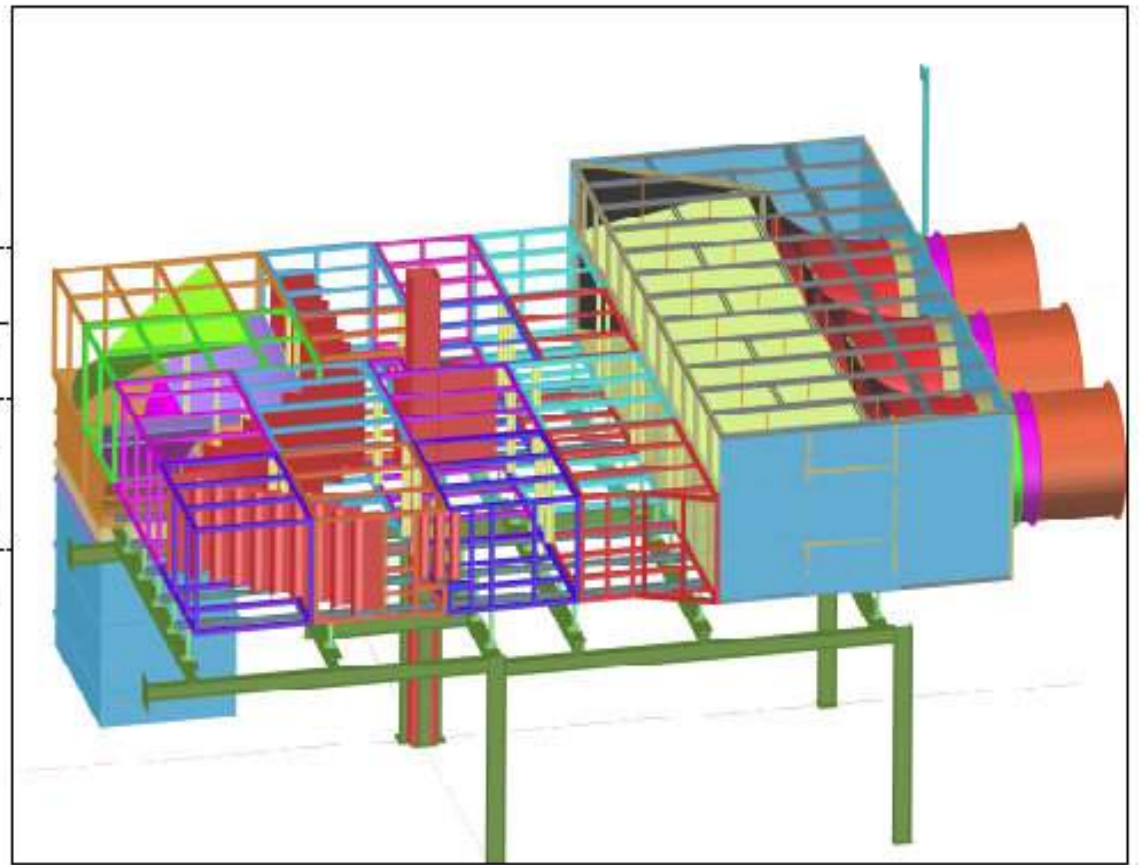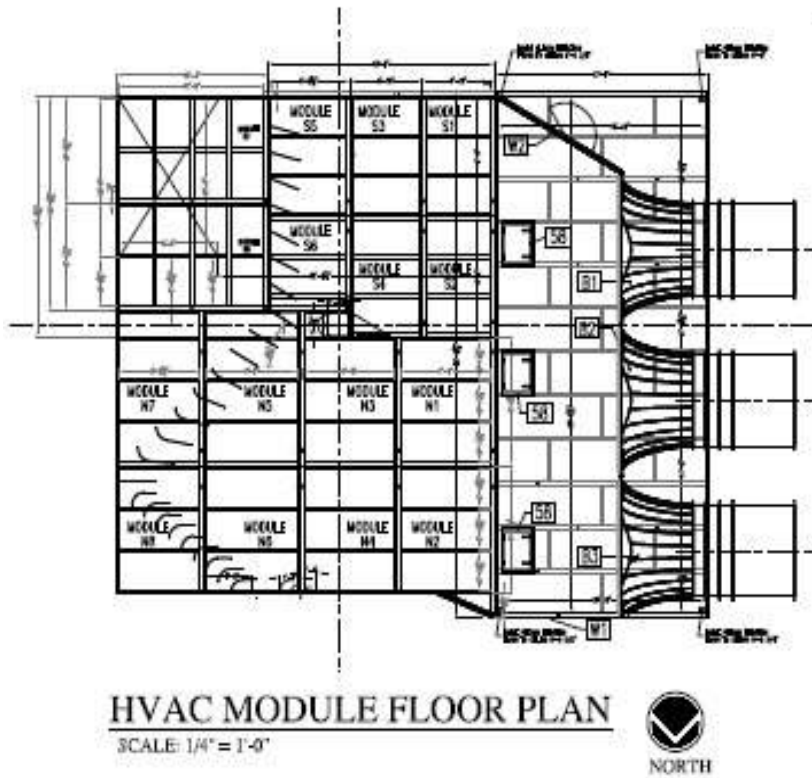
HVAC MODULES ISOMETRIC VIEW
NOT TO SCALE
NORTH

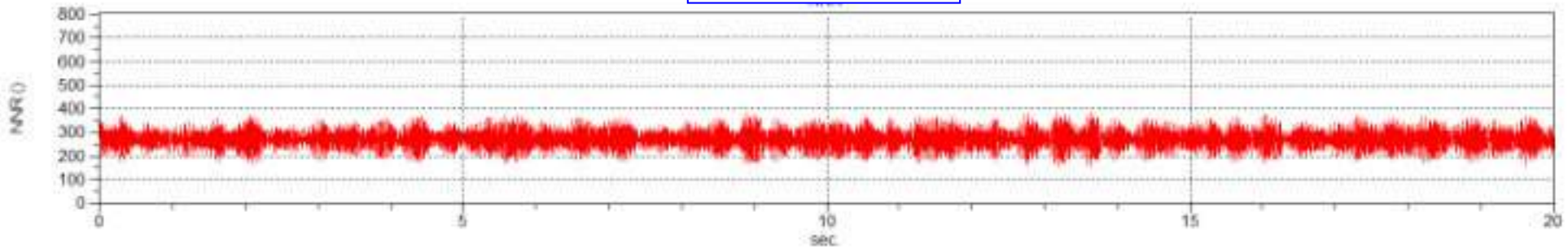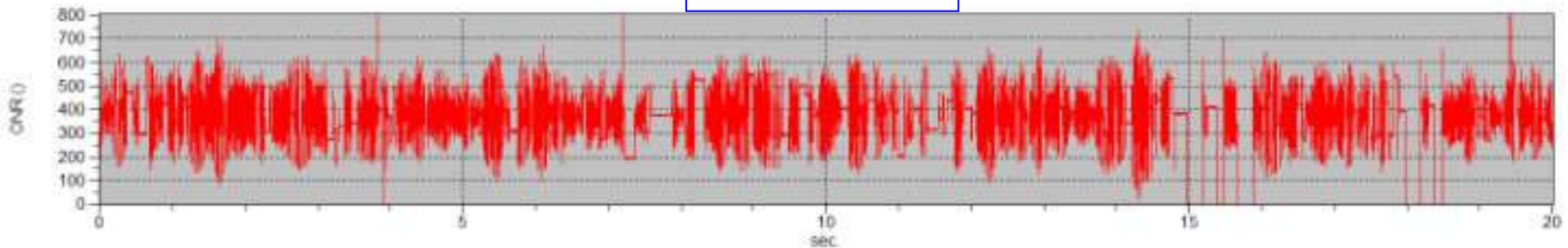# New Extended Fan Inlet Bell-mouth

Internal Inlet Bell-mouth

External Inlet Bell-mouth

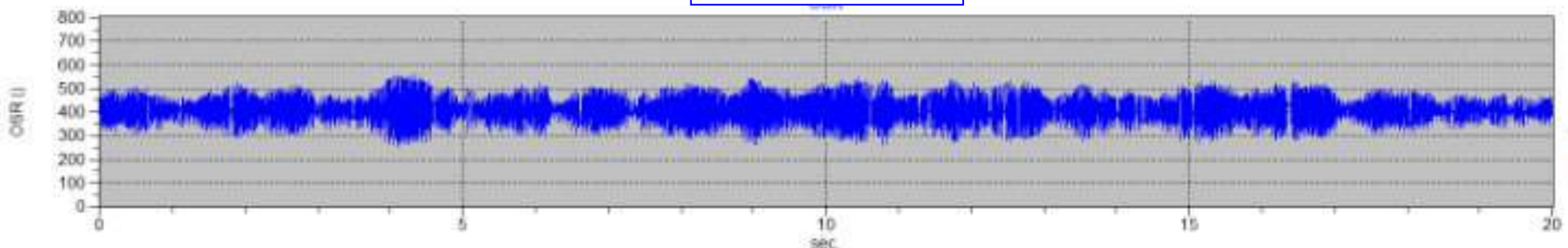# Strain Gauge Comparison to Old Data – Rear Position – Both Fans Before and After Exhaust Plenum Modification

NEW NORTH REAR

OLD NORTH REAR

OLD SOUTH REAR

Animation Comparing Air Flow in Previous and Modified Exhaust Inlet Plenums

https://www.youtube.com/watch?v=bsUfP8ZDySk
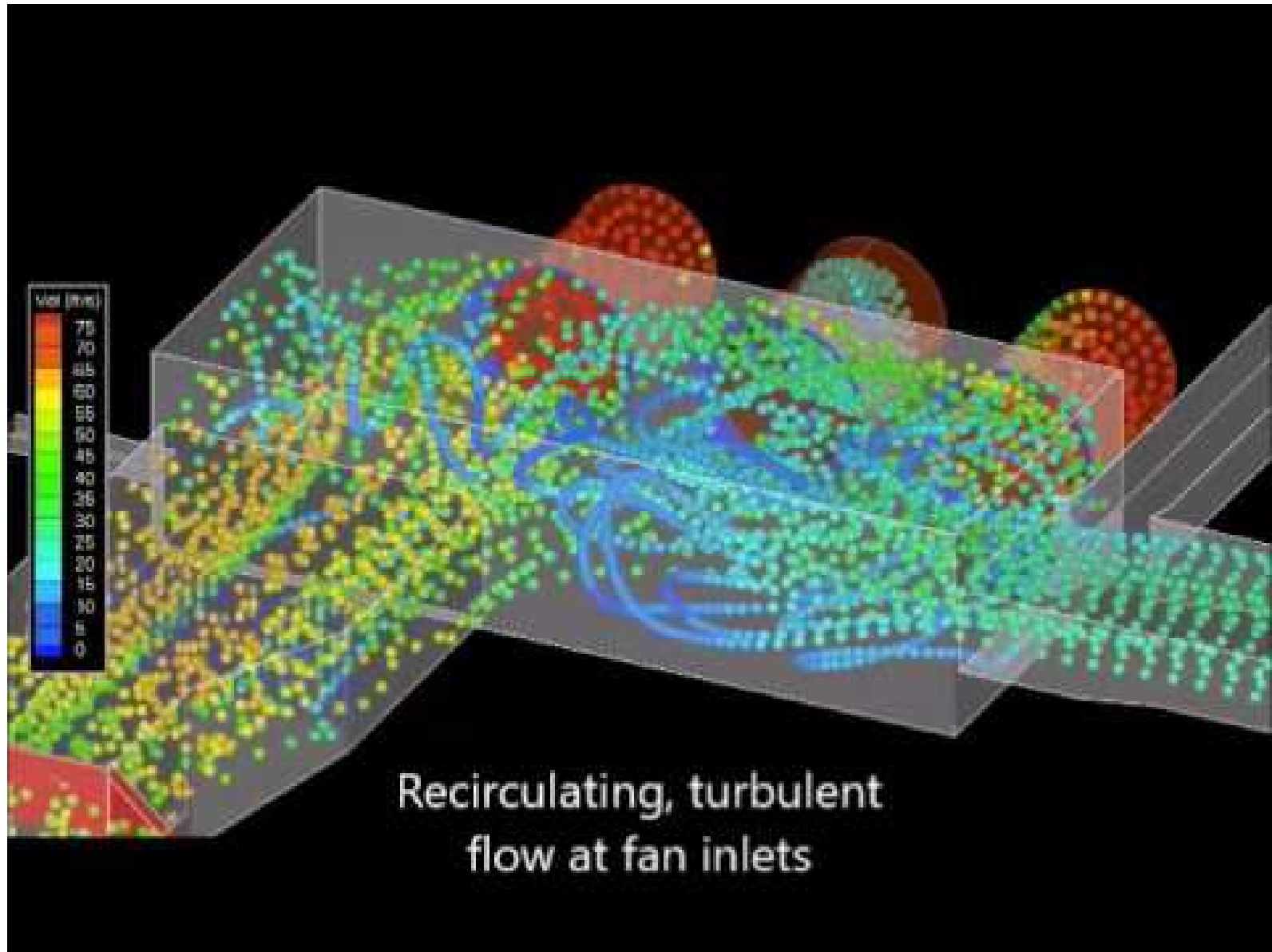
Example 2: Global Supertanker

747-400 • "World's Largest Firefighting Airtanker"
• Up to 19,000+ gallons in one drop

- Drop system powered by compressed air
- Two independent trains of 5 tanks
- Discharge through pipes behind main gear

Global Supertanker Test Drop
Marana, AZ • 2019

Global SuperTanker — Problems

- Highly regarded in action
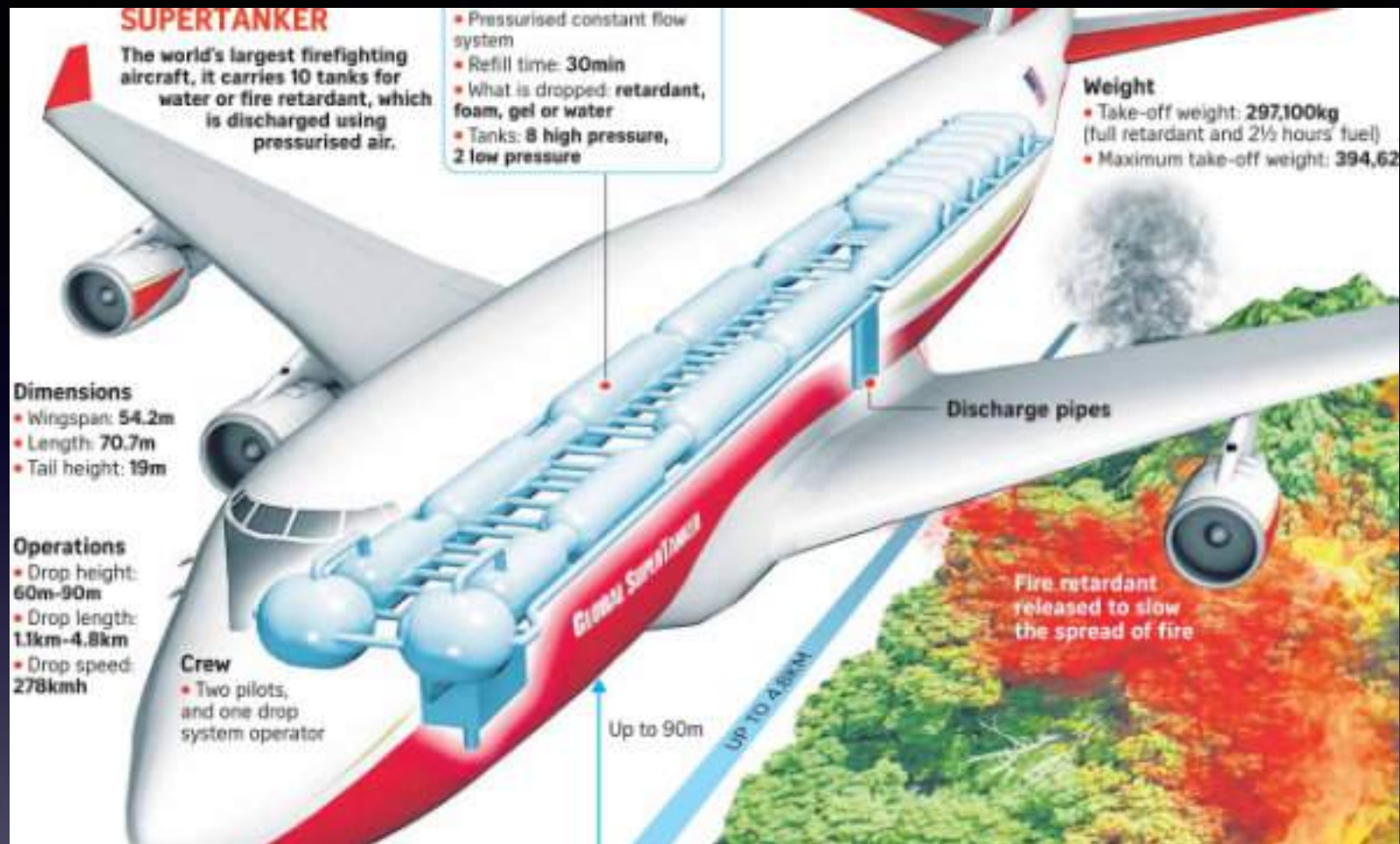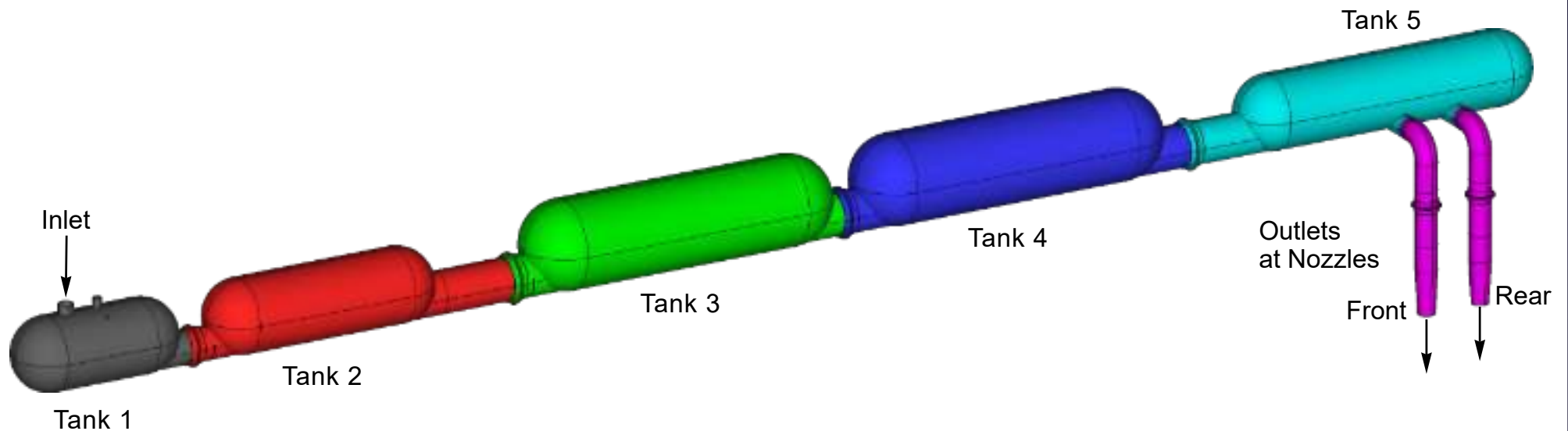- Trouble with certification (U.S. Forest Service)
- Could not pass the "grid" (expensive!)
- Poor understanding of flow within the tanks
- Poor control system

Global SuperTanker — CFD

- Model internal liquid & air flow

- Domain:

Global SuperTanker — CFD

- Model internal liquid & air flow

- VOF (Volume Of Fluid) model

- Unsteady, compressible, LES

- Variable inlet pressure boundary condition

- Results in about 2 weeks

- Coarse mesh: 720,000 cells, ~2"

- Run in Ansys-Fluent

Tanks 1 & 2 @ Time = 0.00 s
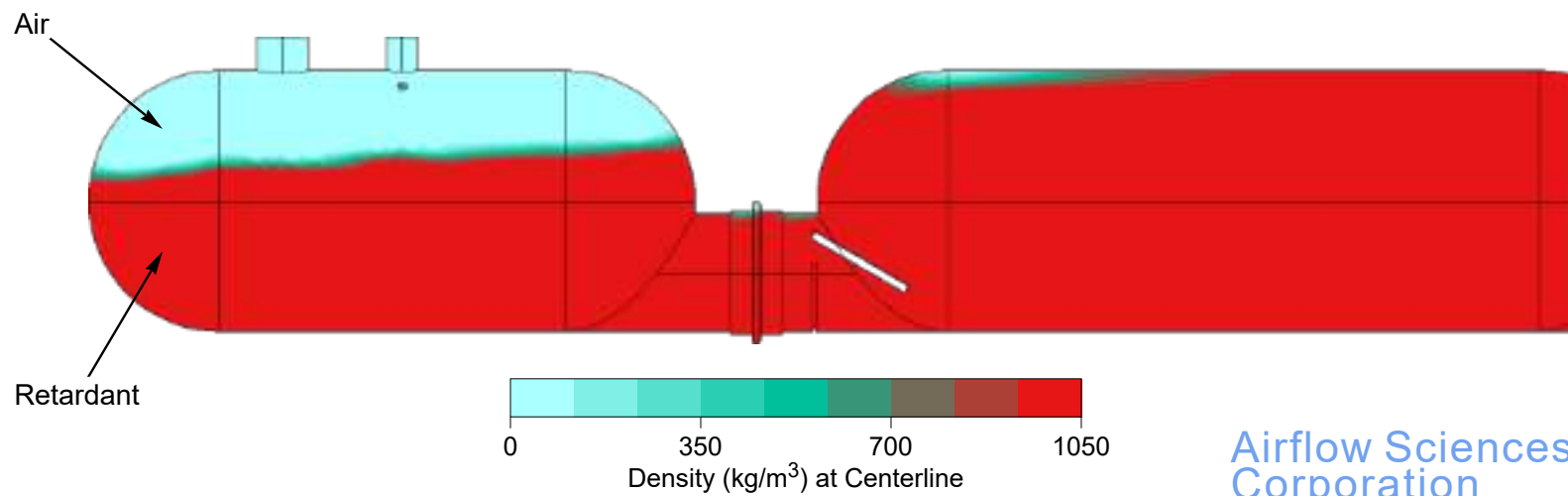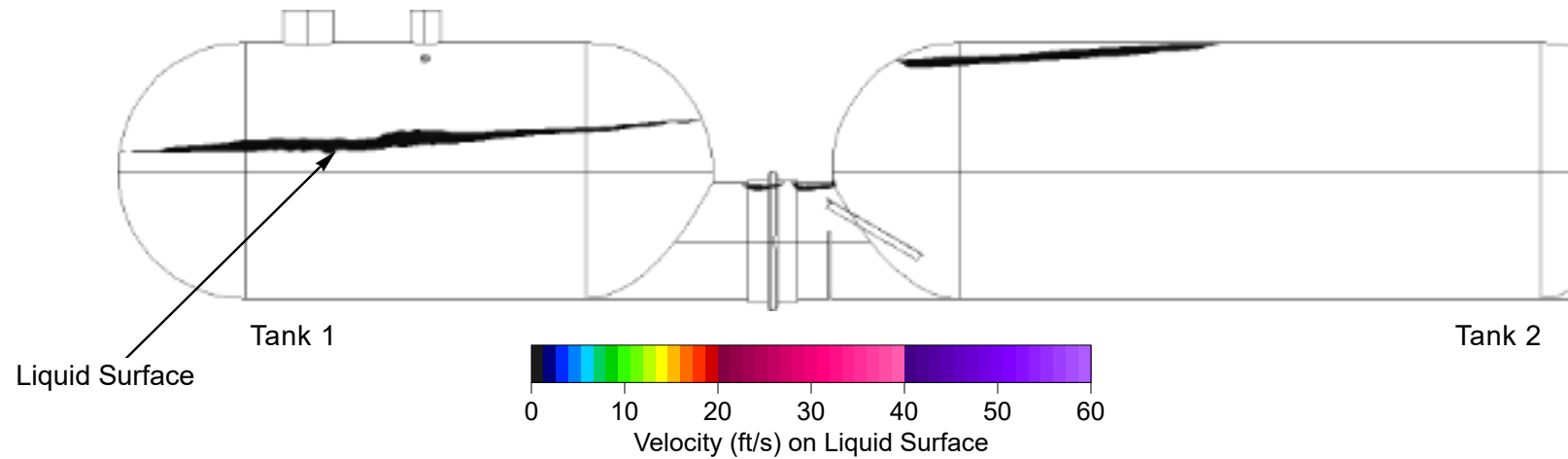
Run 1: MVP-FX / Full Drop / 3° AOA

CFD Simulation Results

Tanks 1 & 2 @ Time = 0.50 s

Run 1: MVP-FX / Full Drop / 3˚ AOA

Tank 1   Tank 2

0   10   20   30   40   50   60
Velocity (ft/s) on Liquid Surface

**Incoming Air Pushes Down
on Liquid Surface**

**Air Flowing through Connector Pipe
Balances Pressure in Tanks 1 & 2**

0   350   700   1050
Density (kg/m³) at Centerline

Airflow Sciences
Corporation

Figure 11

L-18-GST-03
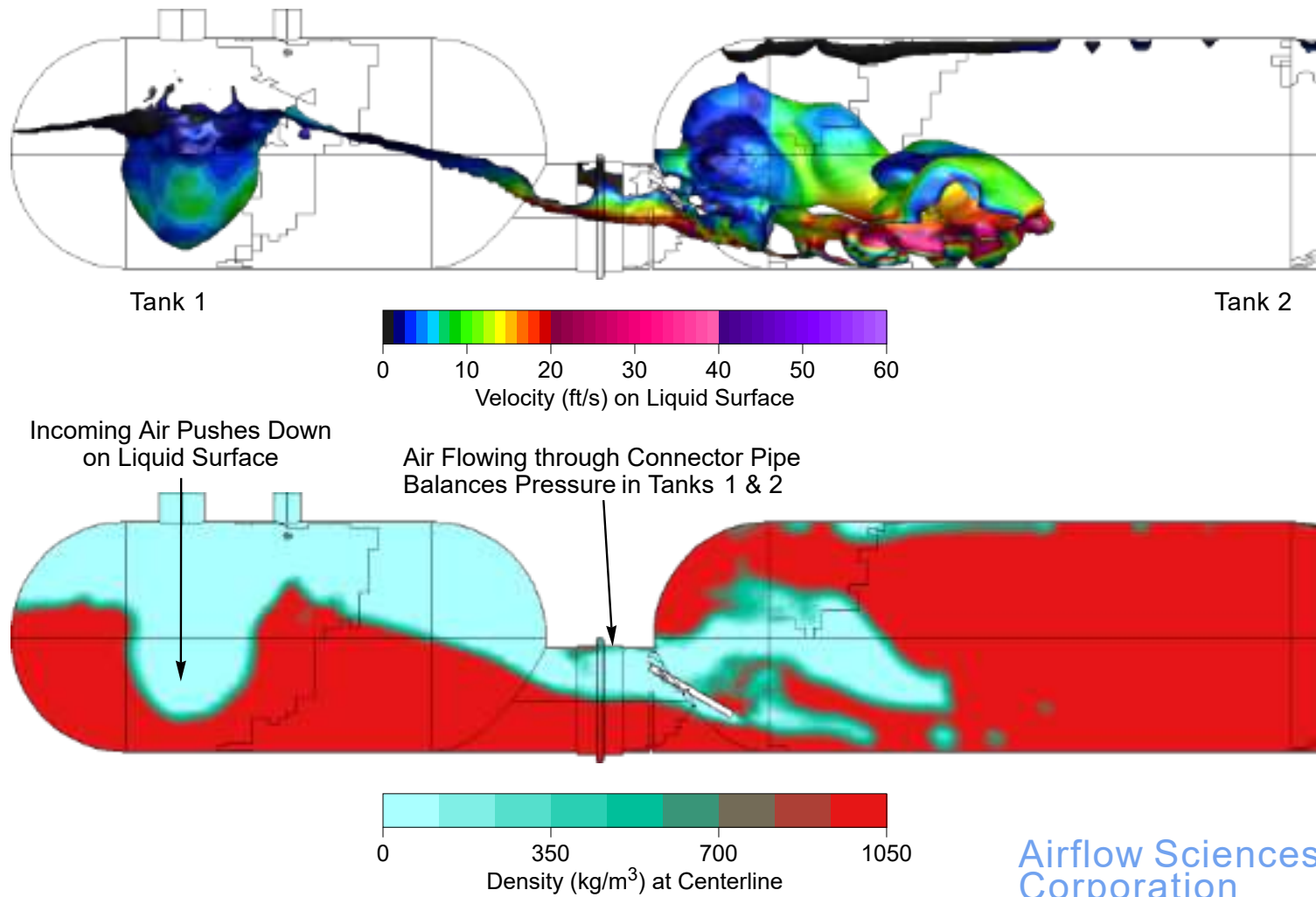
CFD Simulation Results

Tanks 4 & 5 @ Time = 7.80 s

Run 1: MVP-FX / Full Drop / 3° AOA

Tank 4

Velocity (ft/s) on Liquid Surface

Tank 5

Unrestricted Air Flow into Tank 5

Density (kg/m³) at Centerline
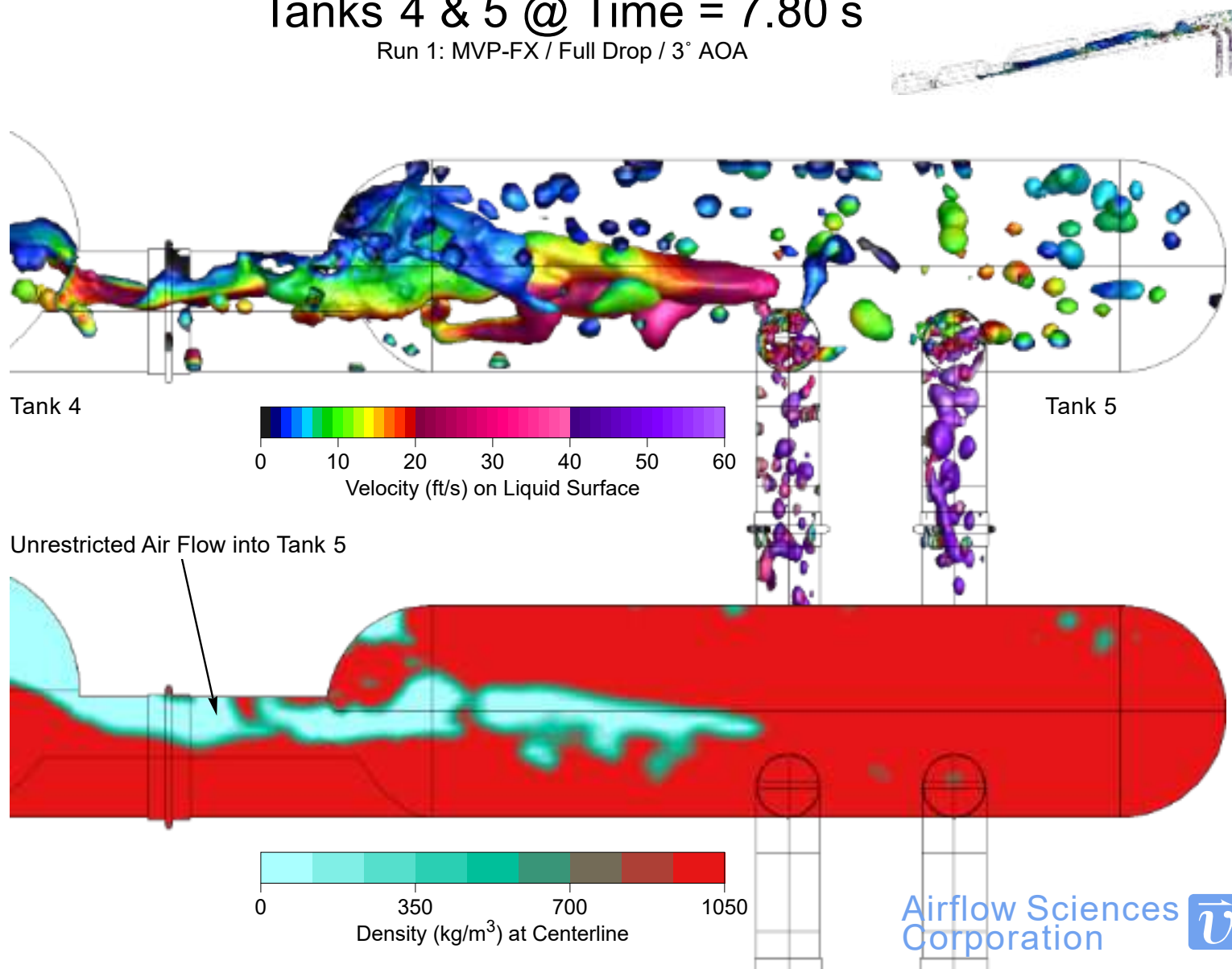
Figure 21

CFD Simulation Results

Tanks 4 & 5 @ Time = 9.00 s

Run 1: MVP-FX / Full Drop / 3˚ AOA

Tank 4

Tank 5

Velocity (ft/s) on Liquid Surface

0   10   20   30   40   50   60

Continuous Air Flow
into Front Nozzle Pipe

Density (kg/m³) at Centerline

0   350   700   1050
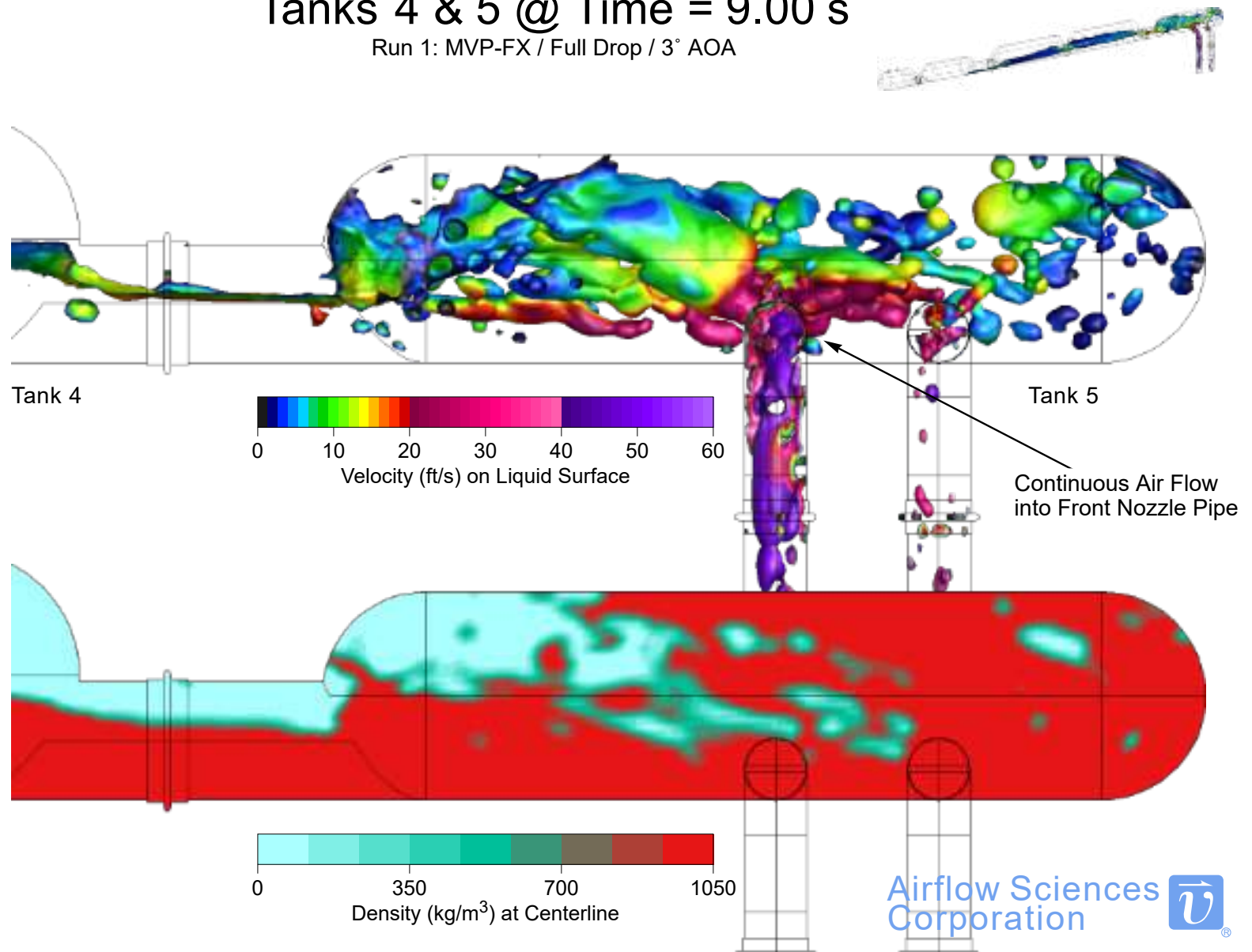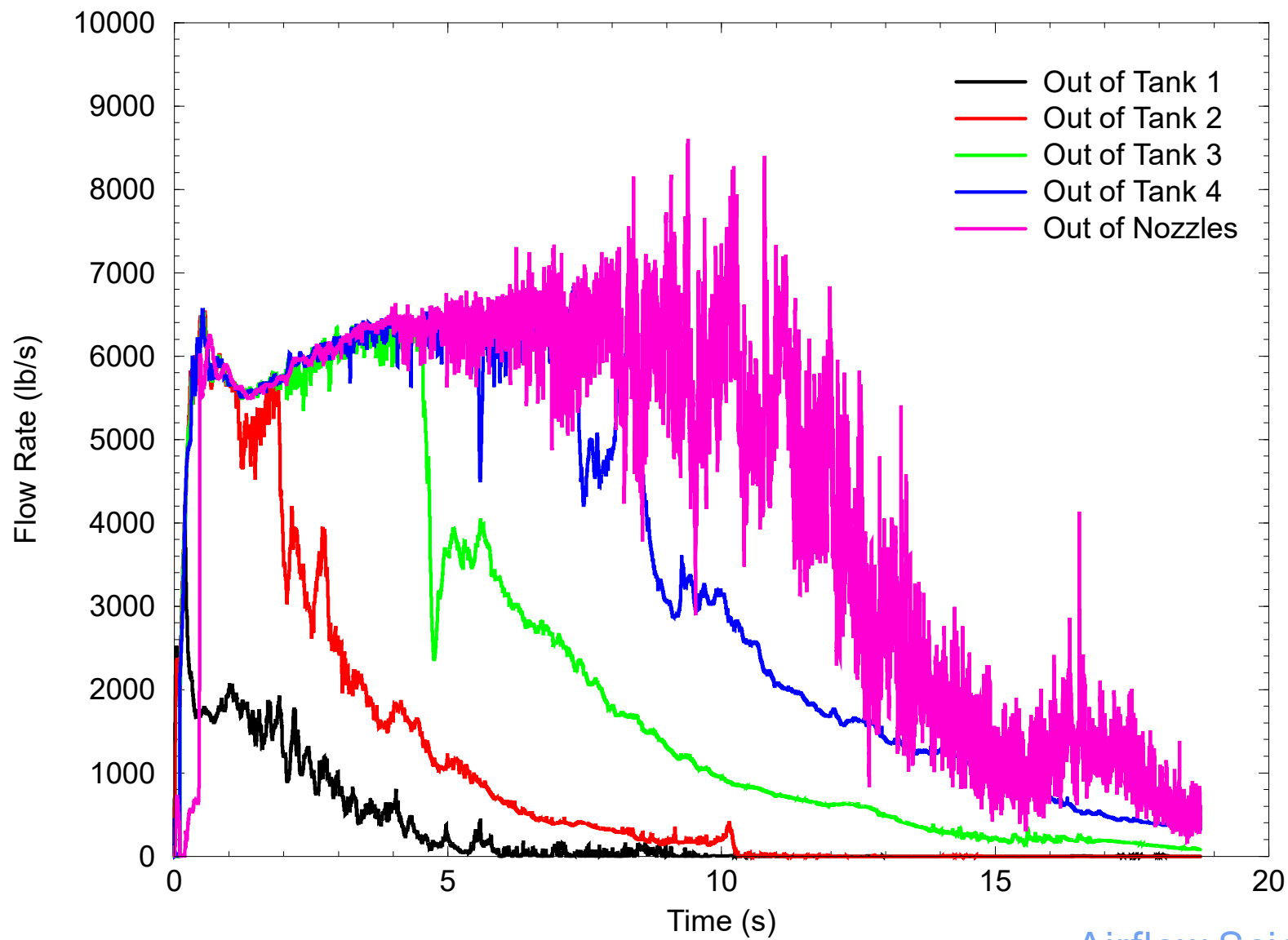
Airflow Sciences
Corporation

Figure 22

L-18-GST-03

CFD Simulation Results

Retardant Flow Rates

Global SuperTanker — Next Steps

- Developed test fixture to accurately measure liquid flow rate out of aircraft

- Built 1/4-scale model in lab for repeated tests

- Developed new control system

  - Drop time, flow rate, air speed, AOA

- Installed new control system in aircraft, conducted ground tests
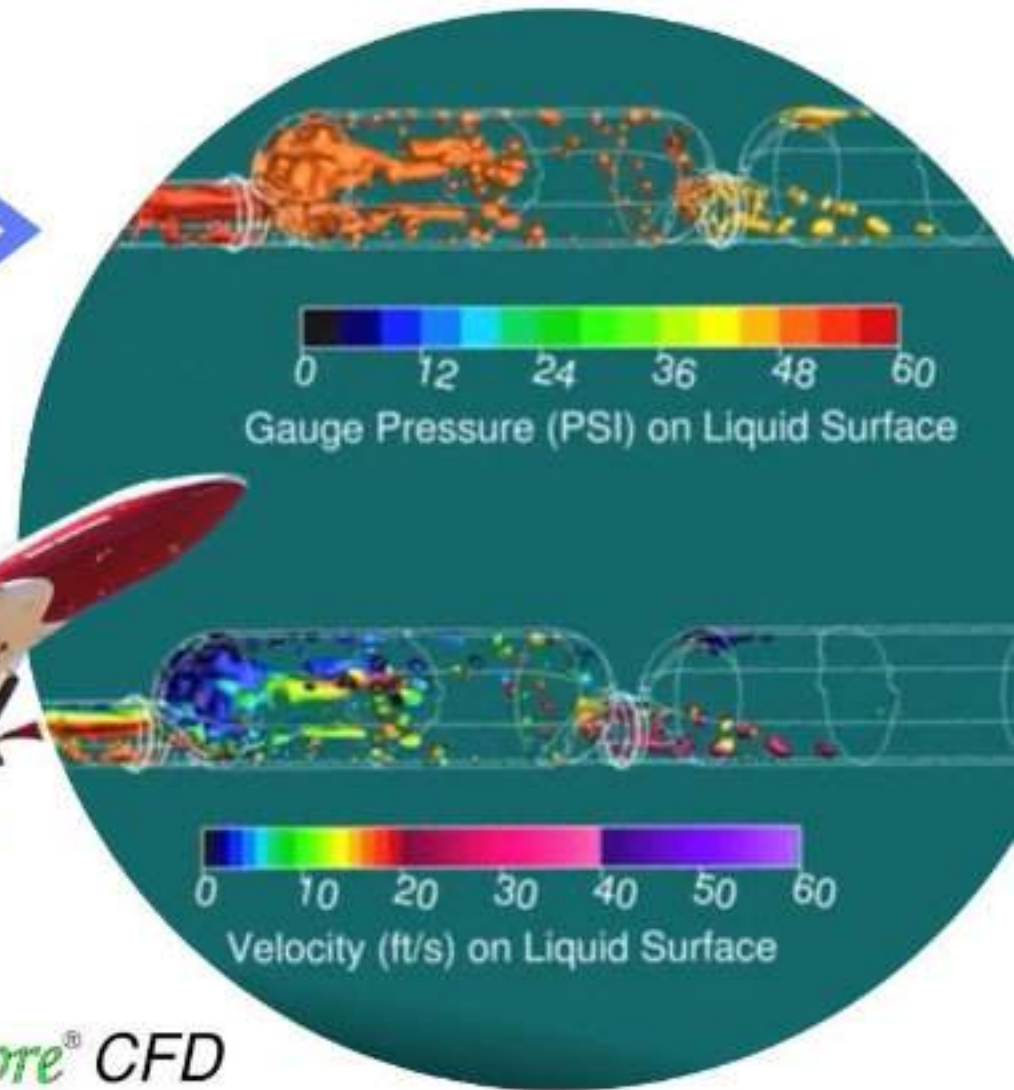
- Company closed, airplane & parts sold

https://www.youtube.com/watch?v=99muC0kfhIQ

Industrial Applications of CFD

Questions?

Paul Harris

pharris@airflowsciences.com
airflowsciences.com
azorecfd.com