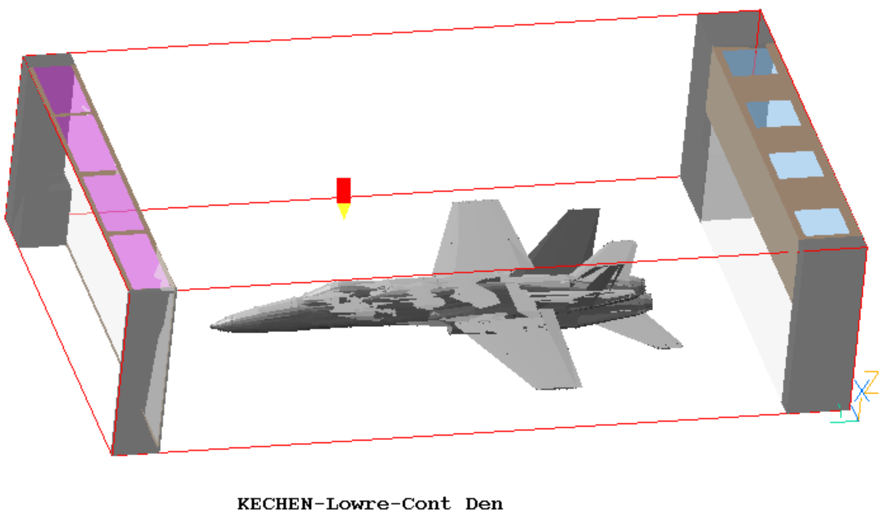
CFD Modeling & Verification in an Aircraft Paint Hangar



Airflow Rates and OSH&E Protection

E2S2 May 9-12, 2011

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **MAY 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**
4. TITLE AND SUBTITLE **CFD Modeling & Verification in an Aircraft Paint Hangar**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Facilities Engineering Command,Engineering Service Center,1100 23rd Street,Port Hueneme,CA,93043**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **Presented at the NDIA Environment, Energy Security & Sustainability (E2S2) Symposium & Exhibition held 9-12 May 2011 in New Orleans, LA.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**24**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Navy and NIOSH Collaboration

- Navy Bureau of Medicine and Surgery (BUMED), IH Division
  - Assists CNO with health and safety of Navy aircraft artisans
  - Quarterly monitoring for hexavalent chromium and hexamethylene diisocyanate
  - Sharing data and ideas, based on IH expertise and knowledge of day-to-day operations
- National Institute for Occupational Safety and Health (NIOSH)
  - Application of computational fluid dynamics to ventilation design
  - Tracer gas studies to evaluate ventilation effectiveness
  - Project final report (still in draft)

Short History of Efforts

- **1985 – Started writing Department of Navy (DON) design manual:**
  - **Concern: excessive energy use in hangars when supplied air respirator systems are *required* due to Cr(VI) and isocyanate exposure**
- **1997 – Interpretation Letter: DON to OSHA on Paint Hangar Flow**
  - *http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=22383*
  - Even after DON-OSHA correspondence, whether corrosion-control hangars are **spray areas** or **spray booths** still requires **clarification**
  - *But must comply with* 29 CFR 1910 Subpart Z (AKA the PELS)
- **2005 – Began a Navy environmental RDT&E project to model aircraft paint hangars**

Energy Issues

- **Once through vs. recirculation**
- **Airflow across the hangar vs. immediately around aircraft**

Safety and Health Issues

- **Safety: Flow must dilute to below 25% of the LFL for combustible & flammable materials**
  - Velocity of 20 fpm meets requirement
  - Today's material is less flammable than materials used when the OSHA standard was first promulgated
- **Health: Workers cannot go w/o respirators**
  - Cr(VI)
  - Isocyanates
  - Exposure problem ***INSIDE*** aircraft and some obstructed areas (e.g. wheel wells)

Environmental Issues

- **Typically focus on Delta P across filtration & hangar +/- Pressure**

Health Effects and Evaluation Criteria

- **Hexamethylene Diisocyanate**
  - **Respiratory sensitization and occupational asthma (can be fatal)**
  - **Once sensitized, a worker must never be exposed again, even to trace amounts (essentially ends their ability to work in that environment)**
  - **NIOSH Ceiling 0.140 mg/m^3 (10 min.); NIOSH REL 0.035 mg/m^3; ACGIH TLV TWA 0.035 mg/m^3**
- **Hexavalent Chromium**
  - **NIOSH potential occupational carcinogen (lung and upper airway)**
    - REL 1 μg Cr(VI)/m^3 ACGIH TLV 10 μg Cr(VI)/m^3
  - **OSHA PEL of 5 μg Cr(VI)/m^3 for 8-hr TWA**
    - Special provision for aerospace industry: when workers are painting aircraft or large aircraft parts the employer must use feasible engineering and work practice controls to reduce worker Cr(VI) exposures to levels ≤25 µg/m^3. The employer must supplement its engineering and work practice controls with respiratory protection to achieve the PEL. *Applicable to work done in corrosion-control hangars?*
- **Explosion Hazard (easily controlled)**
  - **Lowest LEL among coating mixture components is 0.9% or 9,000 ppm. Concentrations are < 1% of LEL. NFPA requires < 25% of LFL.**

Hexavalent Chromium Exposures

- Aircraft Priming 2008 – 2010
  - 18 % of hexavalent chromium samples > 5X PEL
  - Painters / Assistant Painters (hosemen)
  - Range 1.6 - 55.1 µg/m³
  - Mean 16.2
  - Median 11.7
- Highlighted dates indicate NIOSH study
- Exposures are for unbalanced, full flow
  - Supply = 136 fpm
  - Exhaust = 99 fpm

Date	Location	Job Task	Monitoring Duration (minutes)	Concentration for the Monitoring Period (µg/m³)	Work shift 8-hour TWA Results (µg/m³)	Over-exposure (Yes/No)
8 Jan 10	Bay 8	Priming E-2C	293	8.1 µg/m³	4.9 µg/m³	**Yes**
8 Jan 10	Bay 8	Priming E-2C	292	1.5 µg/m³	0. 18 µg/m³	No
13 Apr 10	Bay 6	Priming F/A-18	30	281.0 µg/m³	17.6 µg/m³	**Yes 3.5x PEL**
13 Apr 10	Bay 6	Priming F/A-18	27	183.0 µg/m³	10.3 µg/m³	**Yes 2x PEL**
13 Apr 10	Bay 6	Priming F/A-18	30	623.0 µg/m³	38.9 µg/m³	**Yes 8x PEL**
13 Apr 10	Bay 6	Priming F/A-18	33	654.0 µg/m³	44.3 µg/m³	**Yes 9x PEL**
17 Jun 10	Bay 7/8	Priming E-2C	69	106.0 µg/m³	15.2 µg/m³	**Yes 3x PEL**
17 Jun 10	Bay 7/8	Priming E-2C	72	65.9 µg/m³	9.9 µg/m³	**Yes 2x PEL**
17 Jun 10	Bay 7/8	Priming E-2C	69	34.2 µg/m³	4.9 µg/m³	**Yes**
17 Jun 10	Bay 7/8	Priming E-2C	69	97.3 µg/m³	14.0 µg/m³	**Yes 3x PEL**
23 Sep 10	Bay 7/8	Priming E-2C	147	71.5 µg/m³	21.9 µg/m³	**Yes 4x PEL**
23 Sep 10	Bay 7/8	Priming E-2C	479	25.2 µg/m³	25.1 µg/m³	**Yes 5x PEL**
27 Oct 10	Bay 6	Priming F/A-18	86	0.288 µg/m³	0.051 µg/m³	No
27 Oct 10	Bay 6	Priming F/A-18	85	8.37 µg/m³	1.48 µg/m³	No
23 Nov 10	Bay 6	Priming F/A-18	39	101.3 µg/m³	8.23	**Yes 2x PEL**
23 Nov 10	Bay 6	Priming F/A-18	38	< 0. 66 µg/m³	< 0.05	No
23 Nov 10	Bay 6	Priming F/A-18	39	215.3 µg/m³	17.49	**Yes 3x PEL**
23 Nov 10	Bay 6	Priming F/A-18	41	0.67 µg/m³	0.06	No
1 Dec 10	Bay 5	Priming F/A-18C	87	119.0	21.6	**Yes 4x PEL**
1 Dec 10	Bay 5	Priming F/A-18C	87	172.9	31.4	**Yes 6x PEL**
1 Dec 10	Bay 5	Priming F/A-18C	73	0.43	0.6	No

Hexavalent Chromium Exposures, cont.

During Aircraft Priming 2008 – 2010

- 18 days of sampling
- 50 personal air samples
- 72% of samples above OSHA PEL, 5 μg/m³
- 16% of samples above OSHA aircraft industry limit, 25 μg/m³

Date	Location	Job Task	Monitoring Duration (minutes)	Concentration for the Monitoring Period (μg/m³)	Work shift 8-hour TWA Results (μg/m³)	Over-exposure (Yes/No)
9 Apr 08	Bay 4	Priming F/A-18	57	91.2 μg/m³	10.86 μg/m³	**Yes 2x PEL**
9 Apr 08	Bay 4	Priming F/A-18	57	149.9 μg/m³	17.80 μg/m³	**Yes 3.5x PEL**
9 Apr 08	Bay 4	Priming F/A-18	65	76.1 μg/m³	10.3 μg/m³	**Yes 2x PEL**
8 Jul 08	Bay 3	Priming F/A-18	325	26.9 μg/m³	18.2 μg/m³	**Yes 3.5x PEL**
8 Jul 08	Bay 3	Priming F/A-18	325	9.0 μg/m³	6.1 μg/m³	**Yes**
8 Jul 08	Bay 3	Priming F/A-18	325	13.9 μg/m³	9.4 μg/m³	**Yes 2x PEL**
8 Oct 08	Bay 3	Priming E-2C	248	7.19 μg/m³	3.7 μg/m³	No
8 Oct 08	Bay 3	Priming E-2C	252	24.9 μg/m³	13.1 μg/m³	**Yes 2.6x PEL**
8 Oct 08	Bay 3	Priming E-2C	226	5.33 μg/m³	2.5 μg/m³	No
31 Mar 09	Bay 1	Priming Parts	164	37.3 μg/m³	12.7 μg/m³	**Yes 2.5x PEL**
31 Mar 09	Bay 1	Priming Parts	154	5.0 μg/m³	1.6 μg/m³	No
13 Jul 09	Bay 12	Priming UH-1	133	91.0 μg/m³	25.2 μg/m³	**Yes 5x PEL**
13 Jul 09	Bay 12	Priming UH-1	131	20.1 μg/m³	5.5 μg/m³	**Yes**
23 Jul 09	Bay 6	Priming F/A-18	39	36.7 μg/m³	2.98 μg/m³	No
23 Jul 09	Bay 6	Priming F/A-18	51	72.6 μg/m³	7.71 μg/m³	**Yes**
23 Jul 09	Bay 6	Priming F/A-18	49	540.0 μg/m³	55.12 μg/m³	**Yes 11x PEL**
23 Jul 09	Bay 6	Priming F/A-18	47	220.0 μg/m³	21.54 μg/m³	**Yes 4x PEL**
4 Aug 09	Bay 6	Priming F/A-18	27	166.0 μg/m³	9.3 μg/m³	**Yes 2x PEL**
4 Aug 09	Bay 6	Priming F/A-18	29	130.0 μg/m³	7.8 μg/m³	**Yes 1.5x PEL**
4 Aug 09	Bay 6	Priming F/A-18	29	578.0 μg/m³	34.9 μg/m³	**Yes 7x PEL**
4 Aug 09	Bay 6	Priming F/A-18	33	615.0 μg/m³	42.3 μg/m³	**Yes 8x PEL**
11 Aug 09	Bay 2	Priming parts	102	11.8 μg/m³	2.5 μg/m³	No
11 Aug 09	Bay 2	Priming parts	84	9.14 μg/m³	1.6 μg/m³	No

Problem Statement

- **DON currently designs large paint facilities without the benefit of clear airflow criteria for large paint facilities**
  - **Initial design meetings, EACH design team spends considerable time rehashing the required airflow for large paint hangars**
  - **Without scientific documentation to prove lower flow is equally protective, Navy OSH staff requires design flow rate – 100 fpm, based on the OSHA ventilation standard, 29 CFR 1910.94, Table G-10, *Minimum Maintained Velocities Into Spray Booths.***
  - **Current recommended guidelines (ACGIH IV Manual) and standards (NFPA 33 & ANSI Z9.4) permit flow to 50 fpm for large facilities and 25% of the lower flammable limit, respectively.**

- **Each hangar industrial ventilation system designed to meet OSHA Standard 1910.94**
  - **$250k for capital costs (fan air, ductwork, pollution control systems)**
  - **Another $250k annually in energy & operating costs for EACH facility.**

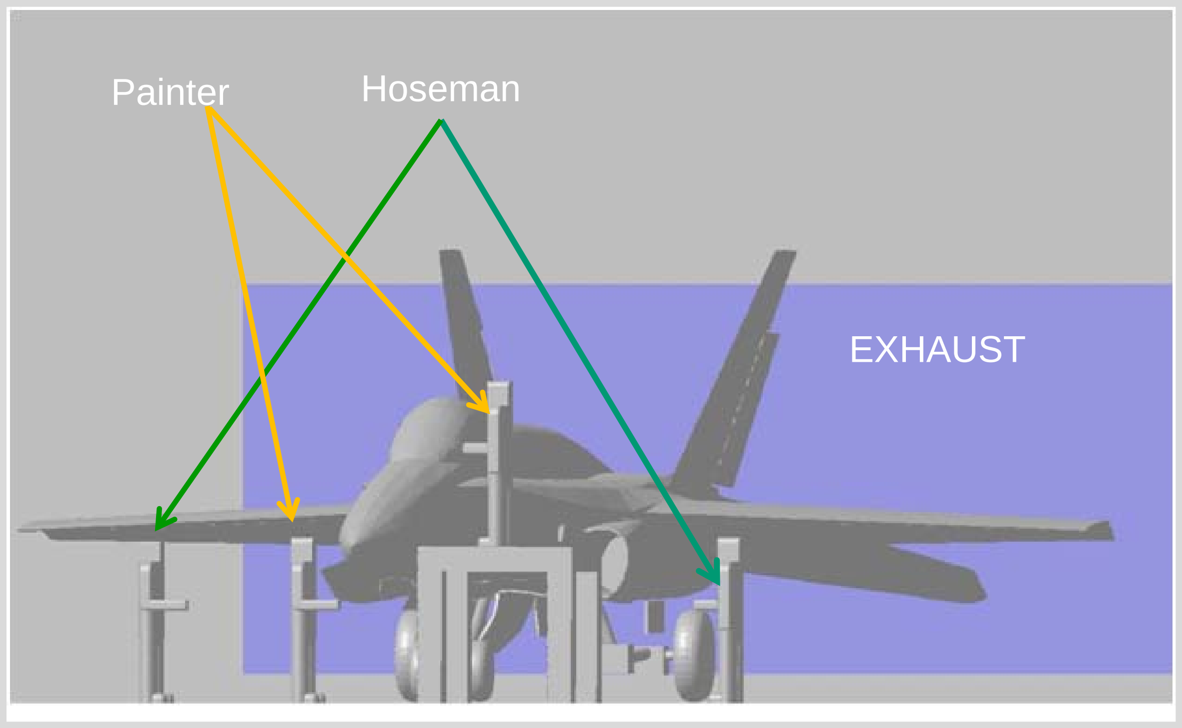
CFD Analysis Looks Easy… Yeah, Right!

- Finding the right modeling program
- Getting a “water tight” aircraft model.
- Finding the processing power
- Determining complexity levels
- Handling paint particulates and vapors

Verification Pitfalls

- Artisans change process in the weeks between baseline and verification
  - Added a fabric blanket in front of filter to save filter bank blocking exhaust airflow during sanding
- Learn how to go w/o sleep
  - Consider working after hours to stay out of production's way
  - Observe what artisans are supposed to do & ACTUAL practices
- Expect maintenance surprises
  - Try figuring out the system Delta P w/ hole in exhaust plenum wall
  - Tracer gas MIRANs take a while to set up – back to sleep issue

October 2010 Findings



Geometry of workers, exhaust wall filter, and F-18.

Hosemen farther from aircraft & further downwind than painters.

Contaminant source is located at the end of the painters' right arms.

Houston - We have a problem!

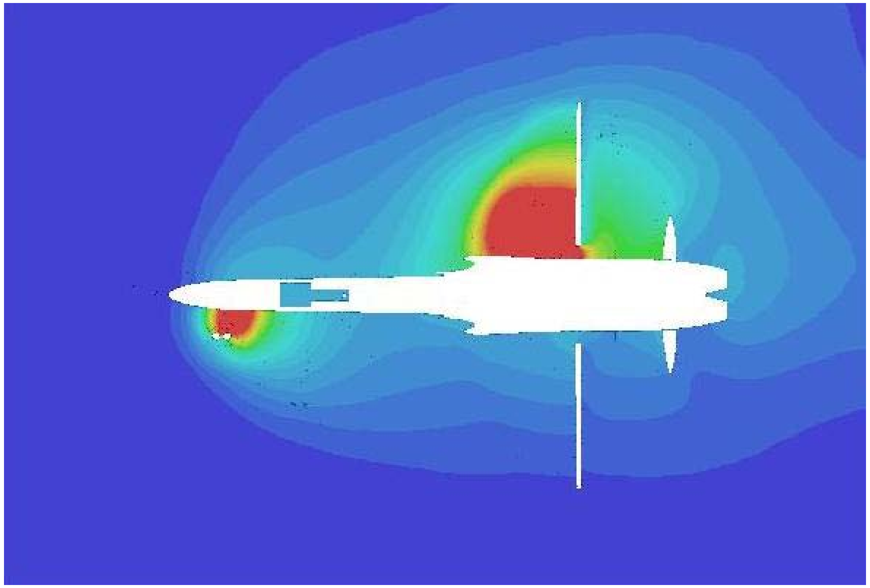
- **Supply 136 fpm**
- **Exhaust 99 fpm**

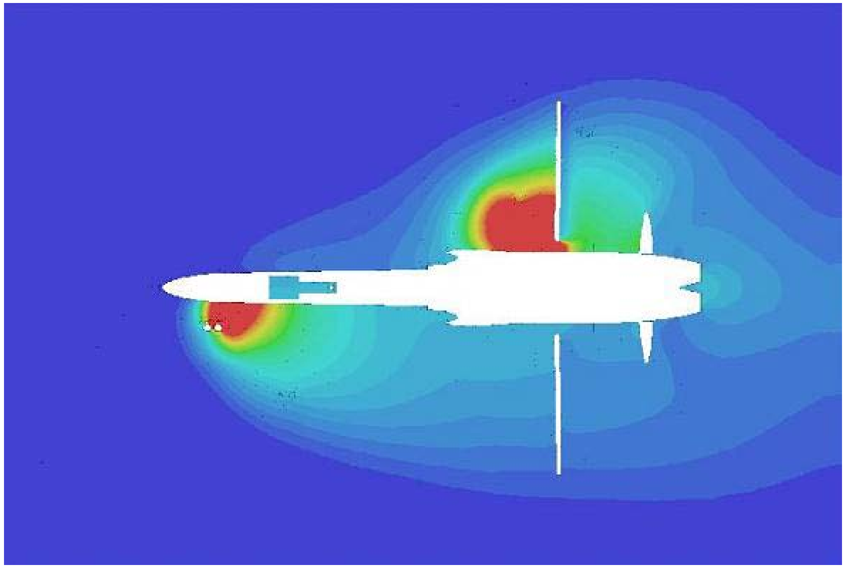
CFD Analysis

=> Indicated turbulent flow near sources/workers

=> Identified improved OELs w/ balanced airflow

CFD Contours of MIBK Conc at BZ Height





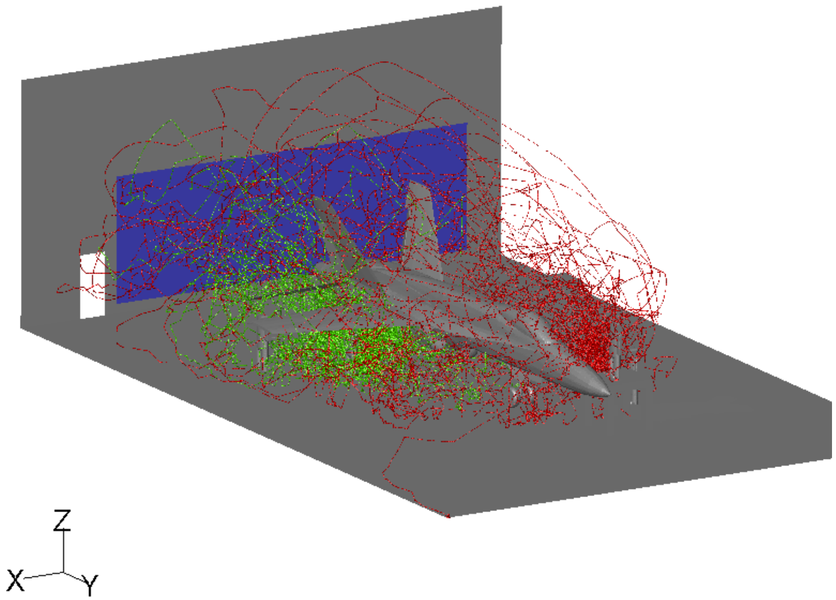
Unbalanced Case
125 fpm Supply & 75 fpm Exhaust

Balanced Case
75 fpm Supply & 75 fpm Exhaust

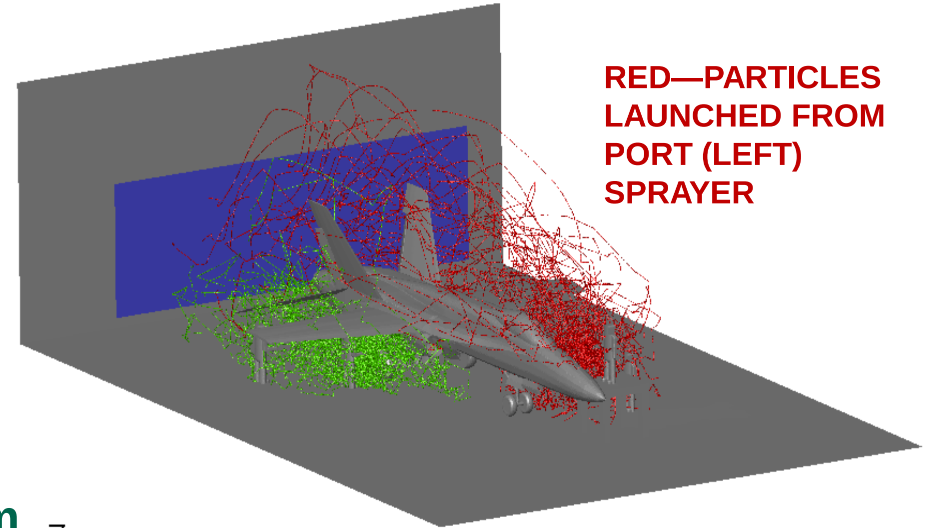
High concentration areas and contaminant cloud are larger for the unbalanced case

Particle Tracks for Unbalanced Vs. Balanced Case

The balanced case shows less particle dispersion.



Upper Left – 125 fpm supply & 75 fpm exhaust



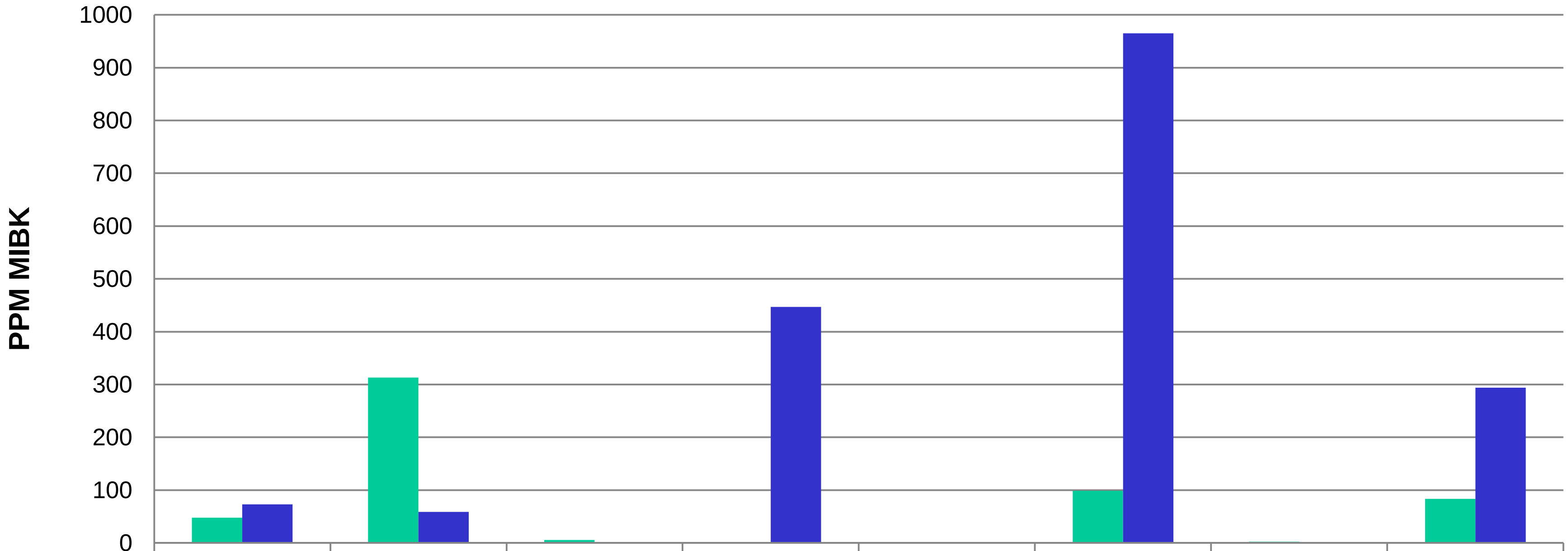
RED—PARTICLES LAUNCHED FROM PORT (LEFT) SPRAYER

Lower Right – Balanced 75 fpm

GREEN—PARTICLES LAUNCHED FROM STARBOARD (RIGHT) SPRAYER

April 2010 Verification

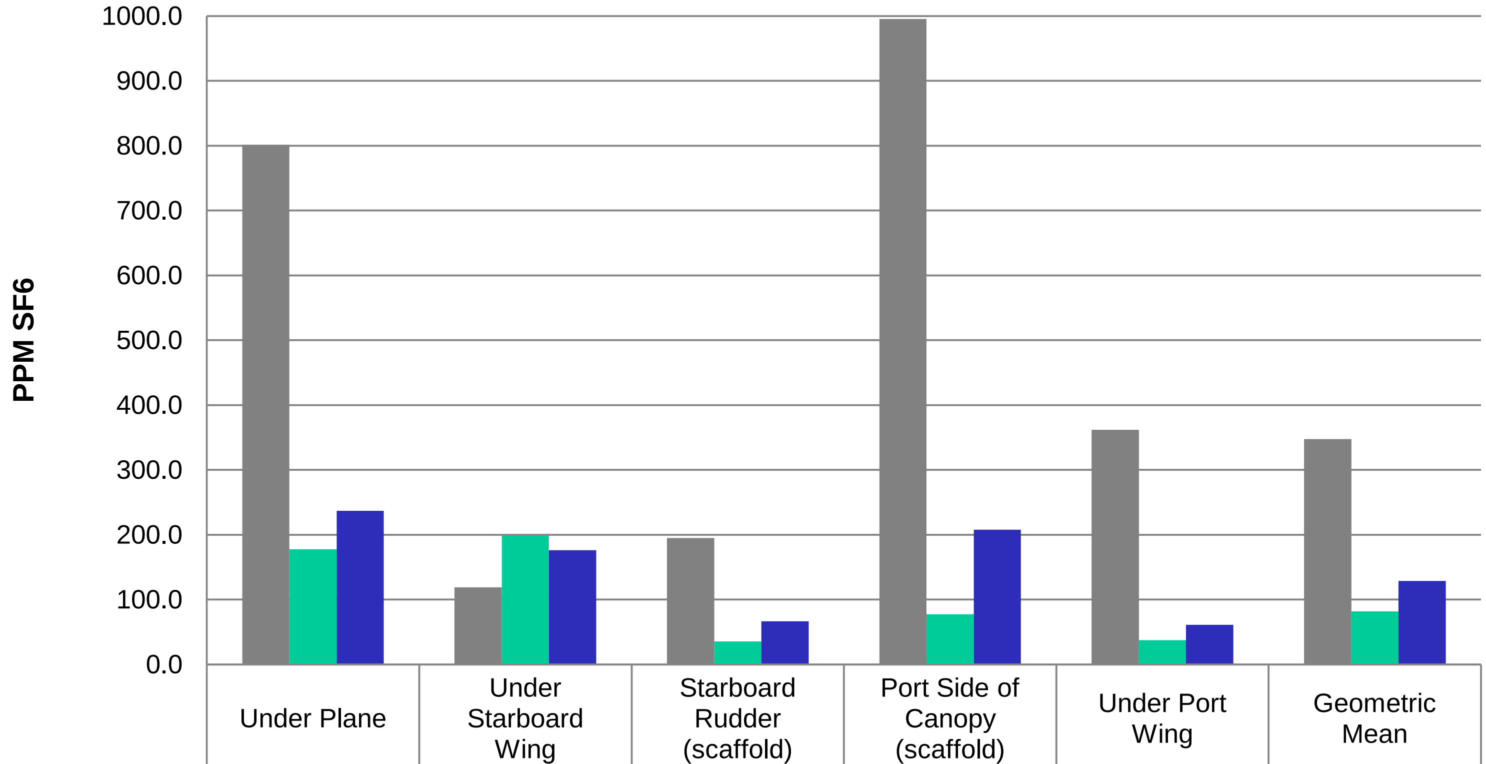
CFD Modeled Conc. vs. Air Velocity & Location (run II)



	BZ Height	Under Plane	Hoseman Port	Hoseman Starboard	Sprayer Port (scaffold)	Sprayer Starboard (wing)	Geometric Mean	Arithmetic Mean
75 FPM	47.9	313	5.85	0.59	0.00	98.6	2.07	83.61
100 FPM	73.2	58.7	0.00	447	0.00	965	0.00	294.14

CFD simulation results, at balanced flow velocities of 75 & 100 fpm, using an advanced turbulence model & stricter convergence criterion (10^{-4})

Real Tracer (SF_6) Conc. vs. Air Velocity & Location (instrument ID)



	Under Plane	Under Starboard Wing	Starboard Rudder (scaffold)	Port Side of Canopy (scaffold)	Under Port Wing	Geometric Mean
HALF-FLOW	801.6	118.7	195.1	995.5	361.9	347.4
3/4-FLOW	177.5	198.8	35.7	77.3	37.6	81.8
FULL-FLOW	236.9	176.3	66.6	207.7	61.2	128.7

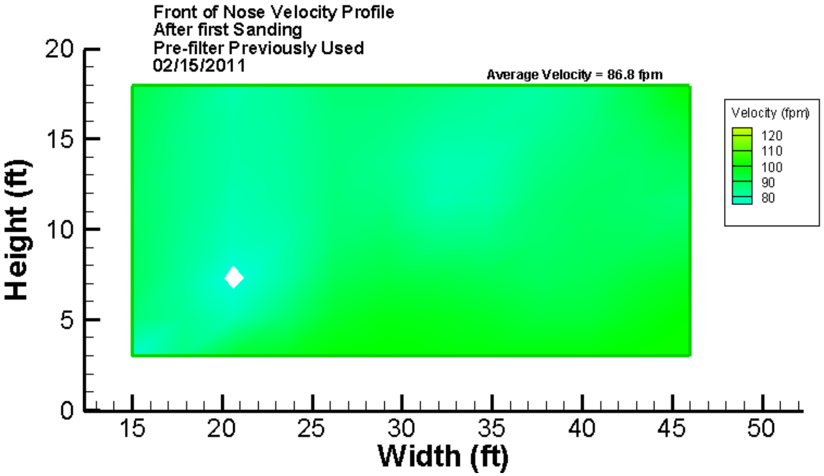
- ***Half, 3/4, and full flows correspond to unbalanced supply/exhaust velocity pairs of 73/49, 102/69, and 136/99 fpm, respectively***
- ***Tracer studies under balanced flows are underway***

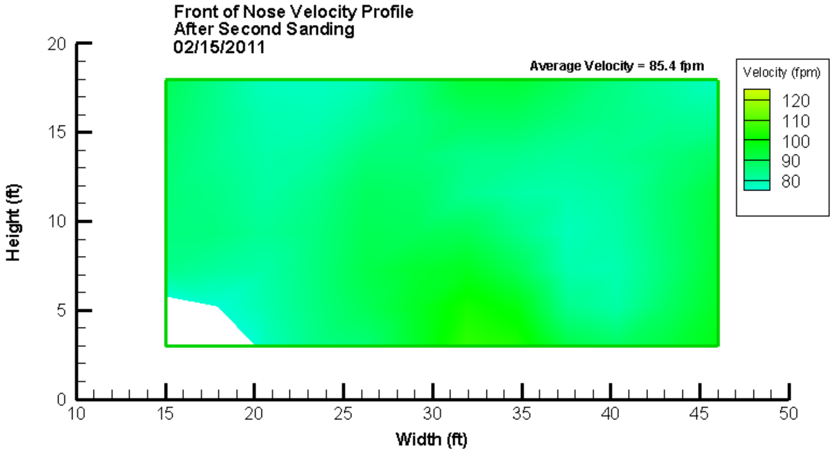
October 2010 Painting Operations

Hoseman is often downwind of sprayer (source)

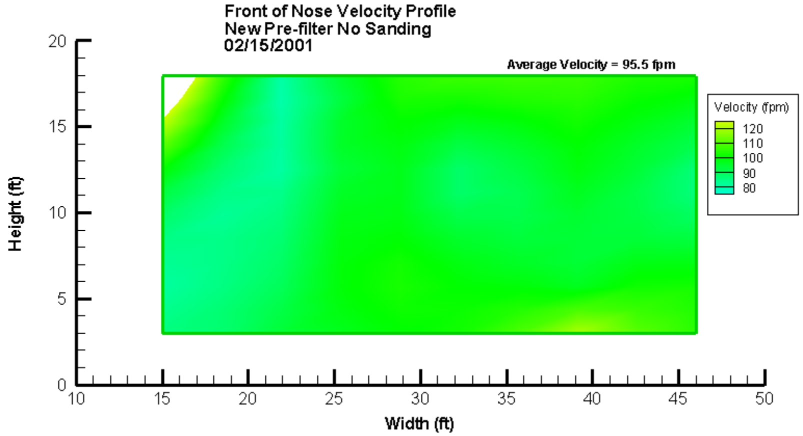
UPSTREAM OF AIRCRAFT NOSE

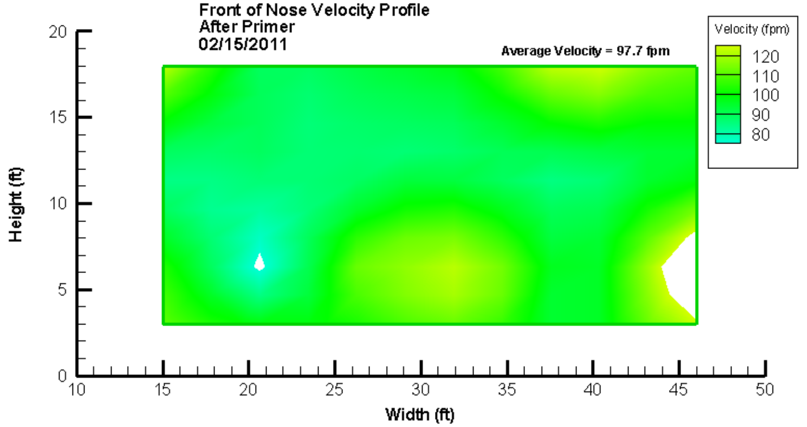
~ 8 to10 FT FROM SUPPLY WALL FILTER



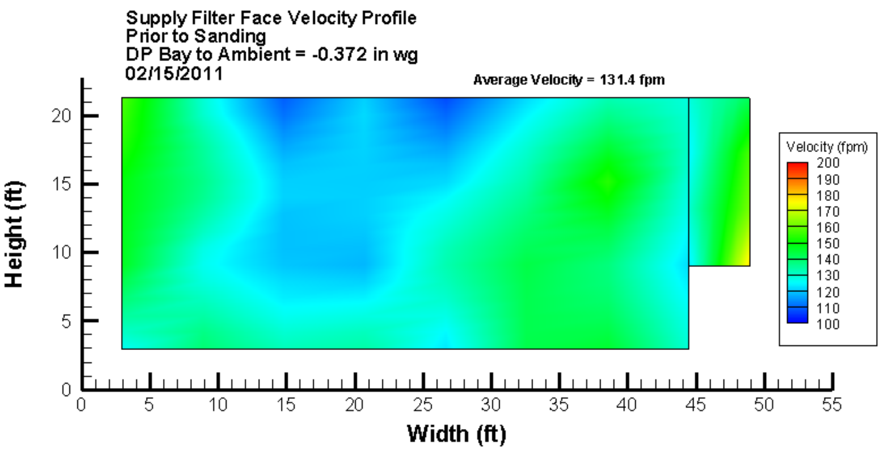


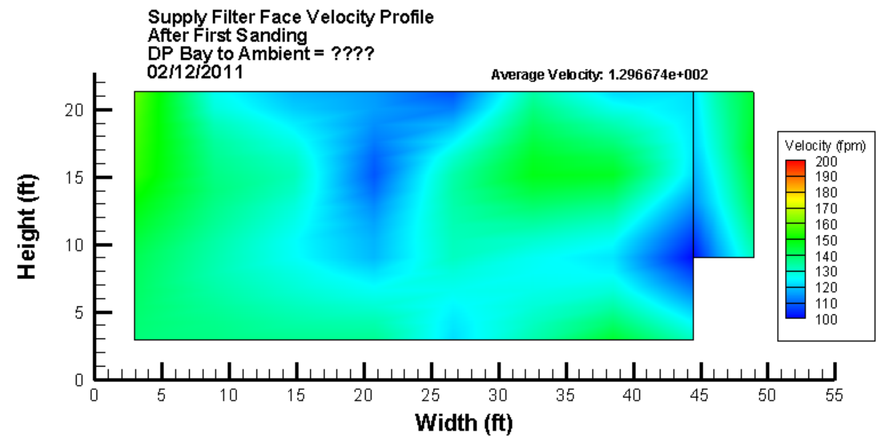
Showing only the OSHA Range of 75-125 fpm. White color is outside the range.

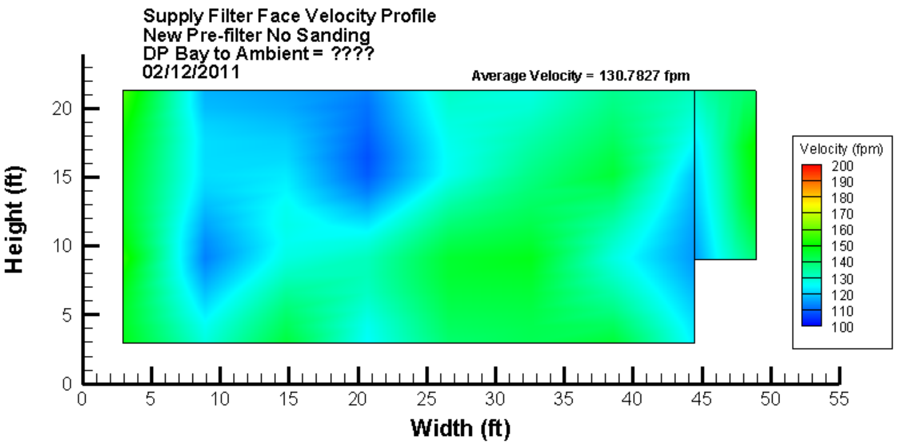


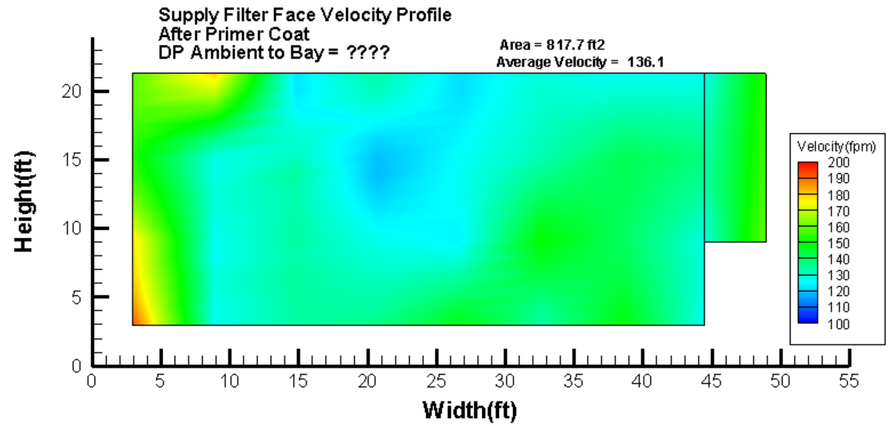


SUPPLY FILTER FACE VELOCITY PROFILE 02/15/2011

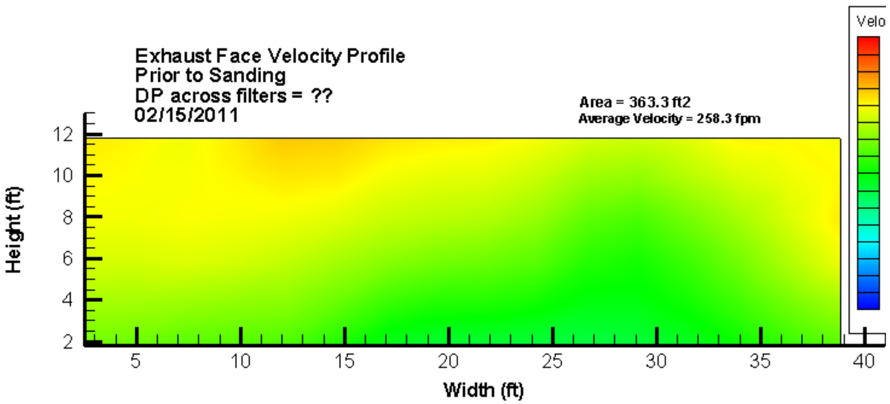


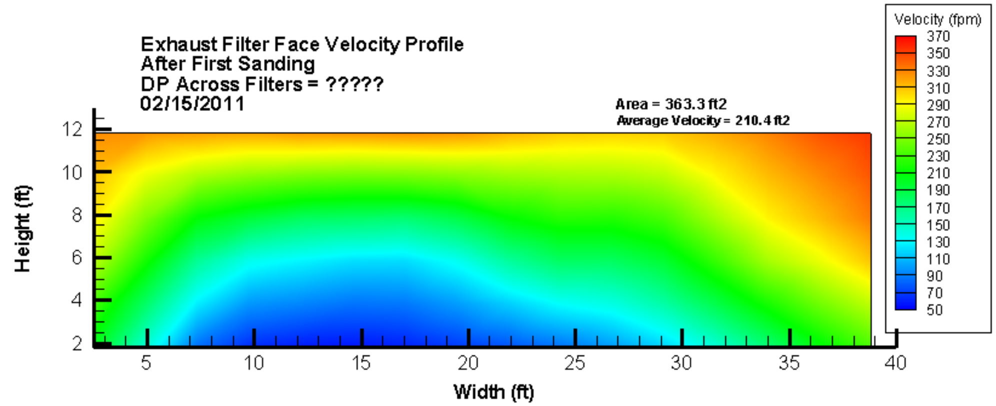






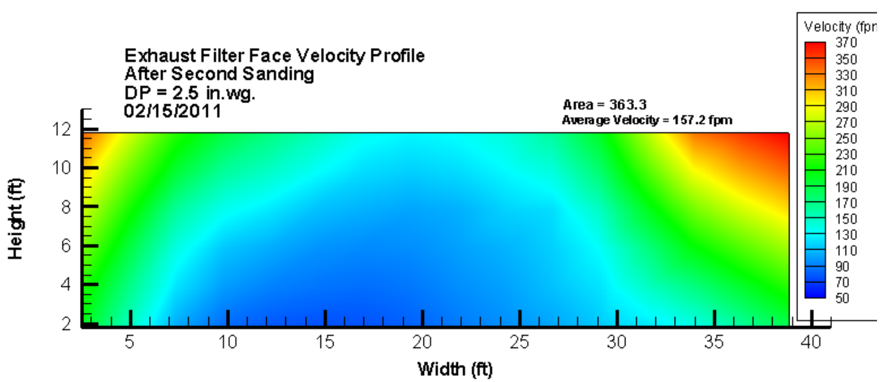
EXHAUST FILTER FACE VELOCITY PROFILE 02/15/2011

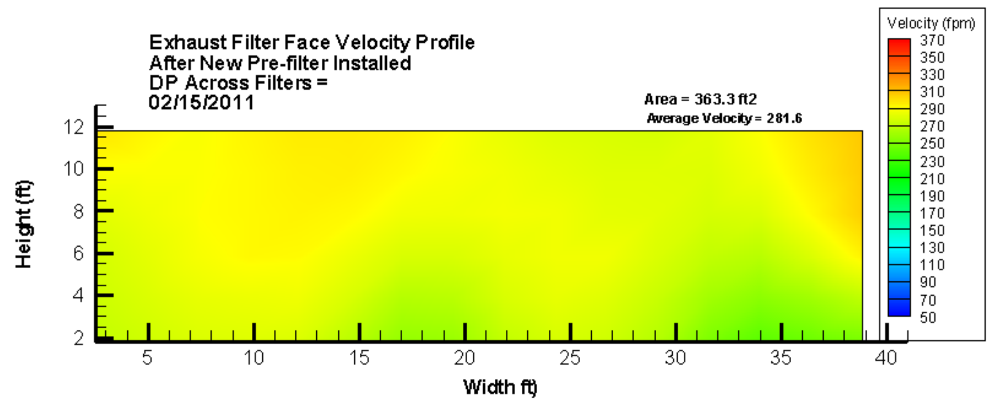




PARTICULATE AND OVERSPRAY LOADS FILTER

- *Downwind of higher contaminant areas*
- *Obstructs flow*
- *Creates dead zones upwind*





Discussion

- **CFD results**
  - 75 fpm is more protective near sources (less turbulent mixing of contaminants)
  - 100 fpm is more protective farther downwind from sources (after mixing) if the flow is obstructed
  - Near-source protection is more important in most situations because exposures are usually higher near sources
  - CFD is a model
  - Balanced flow
- **Tracer gas experiments**
  - Unbalanced flow
  - Supply/exhaust of 103/64 fpm is more protective than 136/99 fpm
  - 73/49 fpm is least protective
- **Overall interpretation**
  - A balanced flow at 75 fpm provides protection similar to a balanced flow at 100 fpm

Current & Future Efforts

- **Tech Transfer**
  - **NIOSH publish results in technical journals**
  - **NAVFAC ESC completes NESDI report**
  - **Incorporate into UFCs: (1) IV and (2) CC Hangars**

- **NAVFAC ESC seeking ESTCP funding continue modeling verification**
  - **1 larger fixed wing**
  - **2 rotary wing operations**
  - **Other paints**

We're a bargain, we already identified the pitfalls!

Conclusions

- Balanced systems are more protective than unbalanced systems
  - No rocket science there
  - Keeping system maintained is sometimes rocket science or at least it feels that way.

- Lesson Learned – Overdesigned or poorly designed supply system can destroy a decent exhaust system
  - No rocket science there either
  - My mantra – ***Look at quantity and distribution***!

- CFD and tracer gas analysis indicates that 75 fpm may have similar protection value as 100 fpm
  - Remember artisans MUST wear respirators for isocyanates, Cr(VI) and other VOCs exposures, as neither flow rate controls adequately
  - Still completing field verification and reporting

Project Test Team

- NAVFAC Engineering Service Center
  - Raymond Lucy
  - Kathleen Paulson, PE
- NIOSH
  - James Bennett, PhD
  - David Marlow
  - Duane Hammond, MS, PE
- Southwest Regional Maintenance Center (NASNI, Coronado)
  - James Breay, CIH
  - Carol Lavery, CIH
  - Lydia Ensor – SWRMC Paint Production Manager