Trudi McCleery
Yes thank you.

Female Participant
Yeah deep sea fishing.

[Multiple Speakers]

Trudi McCleery
They do, thank you, yeah. We were extremely diverse I mean anything you can think of that is really is the workplace safety and healthy? We have somebody here that worries about it and works with outside agencies and people to do research in that area.

Male Questioner
You cover a very large area [Unclear].

Trudi McCleery
Any other question?

Male Questioner
Thank you. Alright, okay.

(2) "Exposure Control and Sustainability in Large Aircraft Painting Facilities"
James Bennett

NAVFAC

ESTCP

Exposure Control and Sustainability in Large Aircraft Painting Facilities

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CDC 1

Learning Objectives for this Session

- **Identify potentially hazardous compounds in aircraft coatings that motivate industrial ventilation**
- **Understand fan laws for power usage as a function of delivered airflow**
- **Recognize important design considerations for ventilating large aircraft painting operations**

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Introduction. Why ventilate aircraft painting?

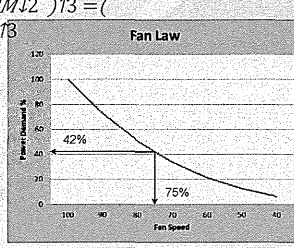
- Historical goal - explosion protection
- Currently
  - No longer using high VOC paints
  - Reduced overspray due to HVLP spray guns
  - Very restrictive occupational limits on chemical stressors
    - Hexavalent chromium (CrVI): Sanding, painting with primer
    - Organic solvents: Wipe-down
    - Isocyanates: Painting with topcoat
  - Workers MUST wear respirators
    - OSHA PEL for CrVI is 5 μg/m³ and HDI is an occupational asthma sensitizer

Ventilation Standards

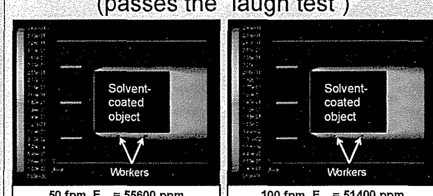
- OSHA 29 CFR 1910.94 requires that spray booths and spray rooms maintain air velocity of 100 fpm (100 cfm/ft²)
  - **No guidance for "spray areas"**
- NFPA
  - **Maintain concentrations of flammable gases and vapors below 25% of the LEL**
- ACGIH Vent Manual (26th ed.) recommends
  - **50 cfm/ft² for large (cx area > 150 ft²) vehicle spray booths/rooms**
  - **60 cfm/ft² for smaller (cx area < 150 ft²) vehicle spray booths/rooms with high (air-)volume low pressure (HVLP) spray gun**
  - **100 cfm/ft² for smaller (cx area < 150 ft²) vehicle spray booths/rooms in general**

Ventilation Rate and Energy Use

- $PWR_1 / PWR_2 = (RPM_1 / RPM_2)^3 = (Q_1 / Q_2)^3$
- RPM term
  - operation
- Flow term
  - specification
- Theoretical
- Real systems have losses



Test of Concept (passes the "laugh test")

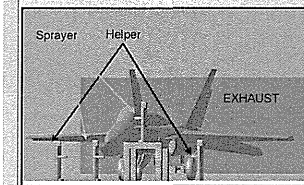


$$\frac{E_{50}}{E_{100}} = \frac{5.56}{5.14} = 1.08$$

Methods

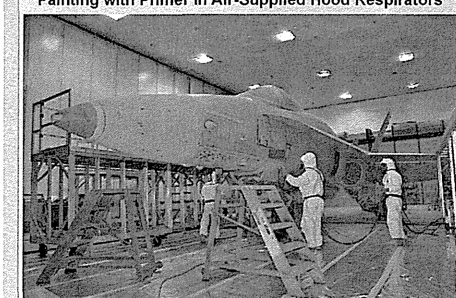
- CFD modeling in existing hangars allows us to:
  - Anticipate results at varying flow rates
    - Baseline
    - Reduced Flow Conditions
  - Eliminate the need to conduct "human testing"
- Validation
  - Tracer gas testing
  - Occupational exposure monitoring
- Addressing resistance in the industrial hygiene community
  - Counterintuitive (less flow is not less protection?)
  - Maintenance issues, safety factor

Strike Fighter Aircraft

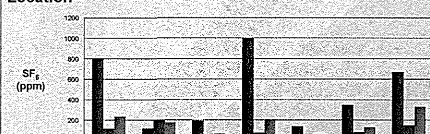


- Geometry of workers, exhaust wall filter, & airframe.
  - Helpers farther from aircraft & further downwind than sprayers.
  - Contaminant source is located at the end of the sprayer's right arm.
- Onsite ventilation measurements indicated unbalanced flow
  - Supply 136 fpm
  - Exhaust 99 fpm

Painting with Primer in Air-Supplied Hood Respirators



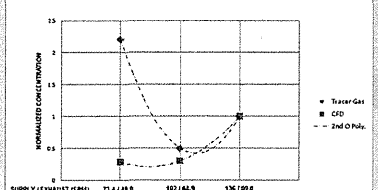
Tracer Gas (SF_6) Mean Concentration vs. Air Velocity and Location



	Under Plane	Under Starboard Wing	Starboard Rudder	Port Side Canopy	Under Port Wing	Overall Geometric Mean	Overall Arithmetic Mean
■ HALF FLOW	802	119	195	996	137	347	667
■ 3/4 FLOW	118	199	36	77	38	82	148
■ FULL FLOW	237	176	67	208	61	129	331

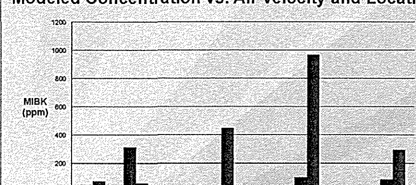
- Half flow: 73.4 fpm supply, 49 fpm exhaust
- 3/4 flow: 102 fpm supply, 68.9 fpm exhaust
- Full flow: 136 fpm supply, 99 fpm exhaust
- Half-flow clearly less protective
- 3/4 flow has lowest mean concentration
- Full and 3/4 flow about the same

Tracer Gas and CFD Location Means



- Five-location-mean concentrations for CFD simulations and tracer gas experiment means, as a function of flow rate.

Modeled Concentration vs. Air Velocity and Location



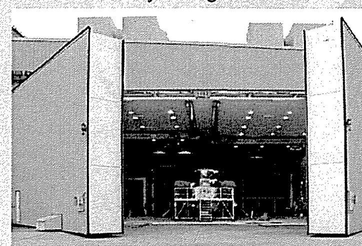
	BZ Height	Under Plane	Hoseman Port	Hoseman Starboard	Sprayer Port (scaffold)	Sprayer Starboard (wing)	Geometric Mean	Arithmetic Mean
■ 75 FPM	47.9	313	5.85	0.59	0.00	98.6	2.07	83.61
■ 100 FPM	73.2	58.7	0.00	447	0.00	965	0.00	294.14

CFD results at 75 fpm and 100 fpm using the RNG k-epsilon turbulence model and a convergence criterion of 10^{-4} for the normalized residuals.

Electric Cost

- Each painting bay costs between $4000 –$5000 in electricity per month to operate
- Annual electric cost for a four-bay hangar is about **$200,000**
  - Total FY 2009
    - Bldg 464 **$239,000**
    - Bldg 465 **$239,000**
  - Total FY 2010
    - Bldg 464 **$178,000**
    - Bldg 465 **$179,000**
- Over 90% of building electricity is used by supply and exhaust fans

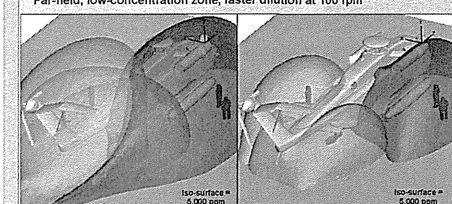
Rotary Wing Aircraft



- *Floor-to-ceiling plenum supply doors, fed by ceiling ducts.*
- Floor-to-ceiling, wall-to-wall exhaust in the rear
- Airflow nose-to-tail

CFD Iso-surfaces

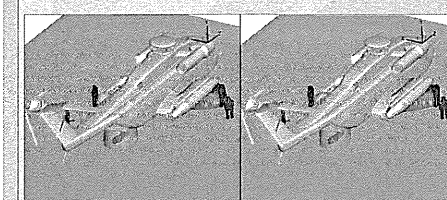
Far-field, low-concentration zone, faster dilution at 100 fpm



75 fpm 100 fpm

CFD Iso-surfaces

Near-field, high-concentration zone (where it matters most) similar for both velocities



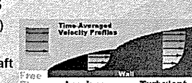
75 fpm 100 fpm

Discussion

- In all three investigations, 50 fpm was clearly less effective than 75 fpm or 100 fpm
- 75 fpm and 100 fpm seem to be equally effective
- Optimal velocity for worker protection and energy management depends on airframe geometry, ventilation configuration, and painting process

Boundary Layer Considerations

- External flow around airframe
  - Laminar, transitional, or turbulent? $Re = Ux/v$
- BL development on a flat plate
  - At 50 fpm, laminar region lasts 30 m (98 ft)
    - $x = vRe/U$, $Re \sim 5 \times 10^5$
  - At 75 fpm, it lasts 20 m (66 ft)
  - At 100 fpm, 15 m (49 ft)
  - Length of strike fighter aircraft
    - 17m (56 ft)
  - Not a flat plate, more turbulent
  - Turbulent BL thicker than laminar BL
    - $\delta = 5\sqrt{vx/U}$, $\delta = 0.37 x^{4/5} (v/U)^{1/5}$

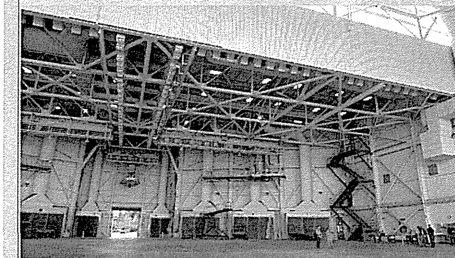


Ventilation Configurations

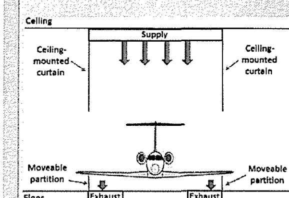
- End-to-end ventilation seems optimal
  - Study sites used this configuration
  - Integration of ventilation into the building structure
    - Hangar door built to act as supply plenum
    - Exhaust filter bank and plenum covers opposite wall
- It is common to see individual ceiling-mounted supply terminals and low wall-mounted exhaust
  - Difficult to maintain plug flow

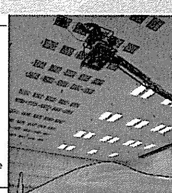
Ceiling Supply Diffusers

Can induce mixing rather than the desired plug flow



Possible Remedy





Conclusions/Recommendations

- **Aircraft painting is a hazardous operation that requires worker protection**
  - **Ventilation is necessary but not sufficient to control the hazard**
  - **Moderately reduced airflow does not necessarily result in reduced protection**
    - **Higher velocities lead to more turbulence and isotropic dispersion of contaminants**
- **A reduction in delivered airflow can result in a larger reduction in power usage**
- **Aircraft painting ventilation should be designed to maximize directional transport of contaminants for capture by the exhaust**
  - **End-to-end plug flow seems to be the best configuration**

Acknowledgments

Kathleen Paulson, Scott Hermon, Edwin Chiang, Raymond Lucy

U.S. Naval Facilities Engineering Command Expeditionary Warfare Center

Joe Wander

U.S. Air Force Civil Engineer Center

Questions?

Jamie Bennett

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James Bennett
Trudi gave us a nice overview of NIOSH and all many things that we knew and I really don't know what NIOSH does overall, so many things that this is Trudi's job to understand how it all fits together and this is – I'll be talking about a very specific project and I'll try not to get bogged down in the details too much so that we have time for everybody to talk about very interesting research.

The painting of aircraft involves two chemical stressors primarily hexavalent chromium and diisocyanate, so there is a lot of interest in how to best control these exposures and kind of a competing interest is how to do this in an energy efficient manner because if you're painting a large aircraft these things are really, really big, it's particularly military aircraft. You're using a lot of energy to move a lot of air through the space. So – I'm sorry this is from the ASHRAE conference last spring but just this does give us overview of the three main points to look at. First is the most hazardous compounds involved in the aircraft painting operation and developing understanding of how airflow and power are related, it's not a linear relationship, it's more complex than that and also how to best design the ventilation systems for these large facilities.

The reason we ventilate aircraft painting is to control the hazards. Now historically the motivation for ventilation of aircraft painting was to control the fire hazard because the coatings had high solvent content, highly flammable and thus less of a concern now because the formulations have changed so the fire hazard has reduced that we've reintroduced other health hazards in the substitution of materials. There's three parts of the process of aircraft coating and each process has different hazards associated with it so the exposure to hexavalent chromium comes in the removal of the old coating and the painting of new primer so the hexavalent chromium tends to be in the primer. After the sanding comes the wipe down [ph] and that's kind of a basic organic solvent exposure tends to be methyl ethyl ketone and methyl isobutyl ketone. Then the top coat contains hazard of isocyanates so the top coat is the paint that's applied after the primer has cured.

Male Questioner
Why you do like that?

James Bennett
To remove dust.

Male Questioner
Okay.

James Bennett
In a nice good coating.

Male Questioner
What HVLP - what is HVLP, what it stands for?

James Bennett
That is high velocity low pressure.

Male Participant
High volume low pressure.

James Bennett
High volume low pressure.

Male Questioner
I see, I see not substances.

James Bennett
Right. It's a way to get – the idea is to deliver as much material to the surface and minimize the overspray that's going elsewhere. Now this operation always involves using respirators because it's so difficult to control the exposures particularly to hexavalent chromium to below the OSHA PEL. So we talked about something a lot called the hierarchy of controls where you considered were respirators are pretty much the last thing we considered using after we've exhausted other possibilities that are less I'll say almost impressive to workers but this – we haven't been able to get out of respirators for premier aircraft paintings.

The ventilation standards is kind of an interesting situation so we think it's kind of the workforce standard as OSHA 1910.94

for spray booths requires 100 feet per minute. Now the problem or one kind of ambiguity with aircraft painting is that these spaces are not really considered spray boost they're too large and OSHA has interpreted the large military hangars where the aircrafts were painted as spray areas and there's no ventilation standard for spray area. We're free to look at, at other velocities if there's a reason to do this. Kind of the more traditional purpose of industrial ventilation is controlling flammable gasses and FBA [ph] standard as this says you need to maintain concentrations below 25% as a lower explosive level.

The American Conference of Governmental Industrial Hygienists ventilation manual has looked at this a little more closely and you see the idea here in this three different velocities specified 50, 60, and 100 that as the space gets larger we want a lower velocity moving through there and I'm not sure what the motivation was, it might have – some of these standards are kind of historical not really science based all the time but one idea that I've seen is that you want to reduce the turbulence as much as possible so if you have a larger space you have a larger [Unclear][ph] number so you can reduce that [Unclear] number by reducing the velocity.

Ventilation rate and energy use. So what's interesting here is that there is a cubic relationship between the velocity also the volumetric flow rate and the power that's used, I mean in an ideal sense. So if you – so what does this mean practically? Well if you reduce your velocity by 25% you actually reduce your power by 58% theoretically. If we're looking at – from an occupational point of view we might think that a more ideal velocity is slightly lower than hundred due to these turbulence considerations and that gets the attention of people who are concerned about carbon footprint and energy cost because of this cubic relationship. You're saving a lot more than 25% if you can reduce your velocity by 25% but this is a theoretical relationship and the real systems have additional losses so you'll never get all of that savings back.

The first test of the concept of looking at reducing velocity and still have that be acceptable from occupational health point of view, I did this in 2008 and I was approached by people of the Navy Facilities Command and when I first heard about the idea of wanting to reduce the velocity in his aircraft training operations from 100 to 50, I really thought, this is – I don't want to touch this, this is kind of administrative issue and I'm not sure how I can pull anything interesting technically out of this because obviously there's a linear relationship between exposure and velocity but I did the simulation anyway and what I found was very surprising and this kind of proved configuration where the aircraft is really just a rectangle and the workers are adjacent in the boundary layer. The exposure at 50 feet per minute compared to the exposure of 100 feet per minute was not much higher, in fact it was only 8% higher. So that provided a motivation to keep looking at this that there really might be something going on that made this interesting area.

We wanted to – we designed a more careful project involving a more detailed CFD modeling and validation which we have to eventually include occupational exposure monitoring but the idea was to do as much as we could from a modeling and a tracer gas testing point of view before we actually looked at changing anything in an operation. Of course because the intuitive concept in the industrial hygiene community is ventilation is a great thing that we often have to fight very hard to provide is if we dial that back are we giving up some worker protection? And that's exactly the technical question that has to be answered.

The operation that we looked at was painting F/A-18 and strike fighter aircraft and here's the scenario that we modeled using CFD and the workers are – the work geometry was build from measurements of actually one of our engineering interns from past years when he was wearing a [Unclear] suit and that's what the workers wear [Unclear].

Male Questioner
Excuse me may I [Unclear]?

James Bennett
Sure absolutely. You can also have a copy of the slides. Yes it is as a matter of fact.

Female Participant
There's a picture that I'm requiring.

Male Questioner
This is it.

Male Participant
[Unclear] has a nickname.

James Bennett
Another thing that we [Unclear] when we're on site was that ventilation system that they were using was on [Unclear] the normalized rate coming from the supply was 136 feet per minute and the exhaust was 99 and so the hangar was under 5 in pressure. The photograph, this is the – you can see they are applying the primer and you can tell they are wearing air supply hood respirators.

Male Questioner
Sorry, sorry, the slides before this it says supply 136 and exhaust 99 what the difference here where is it going? Yeah yeah.

James Bennett
They went out the doors.

Male Questioner
Doors?

James Bennett
Yeah so if you – the [Multiple Speakers].

Male Questioner
You have the contaminated area through the outside?

James Bennett
Yes. [Multiple Speakers] they were not containing the hazard.

Female Participant
It was not a good design.

James Bennett
No, it was…

Male Questioner
I see, I see, okay.

James Bennett
Right and maintenance of ventilation system is a huge problem [Unclear] every time you go [Unclear].

Male Questioner
That's velocity that flows so you measured across the phase of the hanger?

James Bennett
I should explain that. I called that the normalize velocity, it's the flow divided by the cross sectional area so it really does represent – it correlates to the floor area. The actual – I'll explain this when we see the other figures a little bit.

Okay some tracer gas results. We looked at, we're dealing with the existing system and I've labeled these half flows, 3/4 flow, and full flow because it's not a nice round number full flow is not 100 feet per minute and I've indicated at the bottom what these different operational settings resulted. Within this tracer gas experiment the interesting thing we found was that 3/4 flow tended to be more protective than the full flow. We apparently found a kind of speed spot if you will that was lower velocity but not so low that we were losing protection. I think this phenomenon is repeating processes. In general you want to reduce your average resonance [ph] time as much as possible. You want as much flow as you can have. On the other hand, the more velocity you have the more turbulence you have near sources and if a worker is near a source that's going to increase their exposure. It's a matter of finding a balance. The balance seems to be somewhere less than 100 feet per minute and more than – perhaps more than 70.

Male Questioner
Have you found that specific to aircraft [Unclear] is it universal [Unclear]?

James Bennett
That's what we're looking at and it's a really important question. One thing about this area that we looked was it basically end-to-end ventilation where you had the supply filter was most of one wall, the exhaust filter was most of the opposite wall and you had – and the hangar was essentially a very large rectangular duct and I think that's probably the ideal configuration, so that starts to sound kind of general like if you can – if it works there.

Male Questioner
[Unclear]?

James Bennett
Comparing the CFD to the tracer gas it's a little bit different, the CFD found very little different between the half flow and the 3/4 flow condition but the full flow was higher in concentration. The tracer gas found that tracer has – experiment found the half flow was a much higher exposure and we normalize these two curves so that the full flow condition was set identical so we're talking about a normalized concentration and I think that's okay because we're only interested in the relative performance of the different velocities. It's hard to create source and CFD that has exactly the same strength as what you're actually finding in the field. I rely on normalize concentration quite a bit.

This seems to once again suggest the 3/4 flows that it working better in some ways. Alright, so I mentioned that in the real hangar that we were working on we had unbalance flow and the supply was higher than 100 feet per minute suggested by or implied by OSHA so we setup a more idealized simulation where we're comparing a balanced flow of 100 feet per minute to 75 feet per minute and the results are revealing. One thing to point out is that in the difficult to ventilate area underneath the fuselage under the plane, a 100 feet per minute is better. You have 58.7 parts per million compared to 313 parts per million and if you think about it so there's a lot of flow resistance near the aircraft and if you start with higher velocity you kind of force some air to move through the – underneath the fuselage.

Now looking at the sprayer, the sprayer location you have on port side of the aircraft the exposure was basically zero just from where the fume was going, on the starboard side the sprayer exposure was a factor of 10 lower or 75 feet per minute compared to 100. If you look at the locations overall the geometric mean exposure was higher or 75, the earth mean exposure was lower. It seem – I guess I would come of the saying it really doesn't make a difference. It doesn't help you to do a 100 versus 75 and I'm not saying 75 are better in real life but I can't convince myself that it's worst.

The electric cost is the other side of this project something that NIOSH is not really that interested in although we have – we do have some global warning initiative now that looks effects on workers of climate change and I guess you could fit this into the context and if people are making changes based on climate concerns we need to understand the effects of this.

Aircraft ventilation is a very big, is most of the cost of – is most of the energy cost of these facilities and it's enough to get the attention of energy managers and accountants, yes.

We also look at rotary wing aircraft. Different geometry in this similar ventilation design and the doors that you see opening that's actually the supply plenum. Within here that's a plenum.

Male Questioner
Plenum?

James Bennett
Yeah and it closes in – so there's the supply filter on the other side and when these doors close in position the ducts from the air handling units come down to the top of the plenum. It's kind of clever design for dealing with ventilating these large phases. We have to wheel the aircraft in and out. These facilities have to handle very large planes like transport like the C5. This is a helicopter that we're looking at and we did

not get a change to do tracer gas experiments in this facility, but we did get geometry information and [Unclear] files so that we can do a CFD simulation and comparing 75 feet per minute to 100, looking at iso-surfaces so these bubbles or balloons the surface of them is at certain concentration so 5000 parts per million and what I see in this is that in the far field you have faster removal. You see how the balloons are starting to trail off toward the exhaust which is at the tail of the aircraft and that's important, far from [ph] concentrations of quarter for non-contaminating other operations but the far field tends to be lower concentration.

Now the higher concentration so we have iso-surfaces I believe this is 10,000 parts per million this is just – the number doesn't mean very much it's just the metric for the simulated concentration. You can see if the two velocities, the shape of those near source iso-surfaces is not distinguishable.

We're consistently seeing the 50-feet per minute is less effective than 75 or 100; 75 and 100 seem to be indistinguishable, and to this, we'd like to find an optimal velocity for worker protection, energy management, it's going to be a function to some extent of the airframe geometry and the ventilation configuration.

Take a minute to think about what might be going on here delving into the fluid dynamics of it. It seems that when dealing with something the size of an F/A-18 you're looking at possibly the transition point between laminar and turbulent boundary layer. This kind of exactly the rider [ph] the long size these aircraft are. At 75 feet per minute thinking of the ideal case of a flat plane. The laminar region of the boundary layer lasts for 20 meters. At 100 feet per minute it lasts for only 15 meters and an F/A-18 is about 17 meters. We're kind of right in that area where lower velocity is really leading to less turbulence and I think that's why we're seeing some advantage to the moderately decreased velocity.

In doing the study, we saw other ventilation configurations in other facilities. Some of them are truly, truly bad. Some designs that work well [Unclear]. The ideal design is where the hangar functions as a very large rectangular dock and with the main hallmark in that is you have directional flow. You have flow from the supply too the exhaust, you not have re-circulations. One thing that we saw a lot was individual ceiling-mounted supply terminals and if you have all these individual jets they're not going to coalesce into a nice uniform flow that's marching through the space. We see there are actually 318 supply terminals on the ceiling and that's – if you're trying to transform a hangar into an aircraft painting space this is the type of thing you'd end up doing because you have to add on the equipment after the construction and it's not ideal, it creates too much mixing.

At a commercial facility in somewhere in the western part of the United States we saw another low resistance of this ceiling mounted supply terminals and you see the large distance between the ceiling and the aircraft and that's actually that's me up on the scaffold of the ceiling measuring the velocity through there. What we were seeing was these circulation patterns so the supplier was not actually getting down to the work zone. He was just creating – driving these nice large circulations that are mixed to contaminant throughout the whole space. So we're recommending these ceiling mounted curtains that channel the supply flow down closer to the work zone. We're also suggesting movable partitions that force the floor exhaust to draw air from the plane surface area rather than across the floor. Looking forward to going back and seeing how that works.

Conclusion, we've learned that aircraft painting is hazardous operation that requires aggressive steps for worker protection. Ventilation is necessary but seems not be sufficient to control the hazard. That being said slightly reduced airflow does not hurt protection and slightly reduced airflow delivered very large savings in power usage which can make ventilation more attractive to people in charge of the operation and this idea of maintaining plug flow this is uniformed directional flow from supply to the exhaust through the work zone seems to be the most important consideration certainly more important than velocity within the specified range.

Male Questioner
What is platform?

Male Interpreter
[Unclear] I can replace [Unclear] it for him.

[Multiple Speakers]

Male Questioner
Replace [Unclear].

Male Interpreter
From one to the other end.

James Bennett
I see thank you.

Male Interpreter
In preparation...

Male Questioner
Sorry for that.

James Bennett
It's like the flow in the pipe. I worked with people of the Navy's Facilities Engineering Command and Air Force Civil Engineering Center. I don't know, do we have time for the second one or should we move on?

Moderator
We can step on it.

James Bennett
Okay.

Moderator
[Unclear] is going to be move to afternoon maybe.

James Bennett
Okay. Let's see...

Male Questioner
I thought cubic feet [Unclear] [Japanese] we don't use the...

Male Interpreter
Yeah that's right [Unclear] I forgot about that.

Male Questioner
I think Jim used the [Unclear] when you do that measurement do you English unit or just...?

Male Questioner
I used both I think but you have to report of both, if you [Unclear] straight but ventilation engineering tends to use [Unclear] I mean very important [Unclear] always have to come in try to not use English [Unclear].

James Bennett
Oh I see.

Male Questioner
If we use all [Unclear] sometimes you don't get the feel how fast [Unclear] health problem.

James Bennett
It's a little bit confused.

Male Questioner
Well [Unclear]

James Bennett
I had to get – I had to learn English units again in industrial hygiene graduate school. My other project we'll be talking about today is 'Heat Stress Management and maybe someone could help me with pronunciation of the...

Japanese Male
Yokoshita [ph].

Japanese Male
Yokosuka?

Japanese Male
Yokosuka in Japan. You have the US base?

James Bennett
Right. Right.

Male Participant

How do you pronounce it?

Japanese Male
Yokosuka.

James Bennett
Yokosuka, okay. Thank you.

Male Participant
Pretty close.

James Bennett
I was approached by once Naval Facilities Engineering Command because they have – they're having heat stress issues at a ship refit facility in Yokosuka and this is a – maybe logged up.

Male Participant
Still running, you see that?

James Bennett
Okay, it still loading.

Female Participant
That has been going the whole time.

James Bennett
This facility was actually a Japanese naval building pre-World War II and it's near the end of its lifespan so there's not a lot of interest in a complete retro fit to try to install nice air conditioning, climate control, so people always wanted to do computational fluid dynamics modeling on a very difficult problems where conventional wisdom doesn't seem to work. So I was trying to come up with little cost solutions about how they could best use their existing facility to reduce the heat stress on these workers and so we're exploring solutions of spot cooling, reducing the solar load through roof insulation and enhancing natural ventilation through selectively driving it with mechanical ventilation.

The first thing I did was look at the climate and prevailing wind during the hottest months thinking about natural ventilation once again and it looks like, [Unclear] the warmest months or during the summer but during those summer months the prevailing wind is from the south so I was designing – I was looking to building in terms of how it's oriented on the compass and we have the – so it's once again saying June, July, and August the dominant wind direction is from the south.

James Bennett
Now I was not able to visit the site and the only information I had was architectural drawings that were not really detailed or very accurate. This building was built a very long time ago and I didn't have a lot to go on but we were able to find some photographs on the internet not very, yeah kind of grainy not very detailed but we did what we could. One thing we realized is that even though it doesn't look like it the ceiling is actually very high in this facility it's just massive, the facility is massive and so you do have a high ceiling and there's lots of opportunity for heat build-up on the upper flows so we thought maybe upper level heat removal as part of the lateral – combined with lateral main flow would give us the lowest wet-bulb globe temperature and we're also looking at reducing the radiant heat from the roof. The roof is basically either corrugated enamel or fiberglass panels and so it offers – there's no insulation and it just heated to whatever temperature in the sun heats it to. Also we wanted to prevent short-circuiting. There had been some attempts to install the ventilation system but attended to not really do anything but flow out the windows. Some ideas installing additional louvers on the sides of the building, roof heat exhaust, the idea of a roof cooler also known as a swamp cooler that was rejected pretty quickly evaporating cooling devices do not work well in high humidity environment, you don't get enough cooling effect nothing is change, but also we wanted to make sure that there were some spaces cafeteria and break room where workers could be comfortable for a period of time so those should be air conditioned.

The first floor basically three different zones where we have zone A very large open space, zone B is a difficult to ventilate there were area, and zone C is where you have specialty shops and lots of [Unclear] so you can think about maybe there are solutions that are better for one zone versus another. The zone A is the main space we're looking at ventilating through assisting the National Ventilation. Other areas maybe best serve for spot cooling, office, or have some conditional window mounted air conditioners. This concept of relief area is very important in controlling heat stress.

Here's our fist rendering of the building using CFD. This is a gamut grid and you get a sense of even though the little cells seem quite small I believe these are, I think they're 1 foot, I don't quite remember we did this in the early part of the summer but it's still a little pretty mess in here and we used several processors to solve it. Then we through conversations with people who visited the site, photographs, the internet, we're able to refined the geometry which is important for getting more accurate internal volume for air flow and we're able to, despite this large size in the kind of complex geometry where we built the structured grid in this.

Okay so more input parameters we looked at kind of worst case – reasonable worst case temperature observations that we pulled from 2012 heat stress survey it was done by the Navy. So we looked at outdoor temperature of essentially 30 degrees Celsius, relative humidity 85%, the wall temperature creature by solar load 40 degrees Celsius, roof temperature quite high we looked at two different roof temperatures 66 Celsius, 49 Celsius, and the way we came up with two different roof temperatures was the 66 degrees Celsius was what was observed during the heat stress survey in 2012 and we attributed a savings in temperature of above, I guess that would be 17 degrees Celsius if roof tiles were installed to reduce the solar load.

We did some validation or promptly verification tests on the CFD simulations. We didn't have any experimental measurements to go on using our input parameters but we were able to compare two different grids. First order versus second order discretization and we found that – so let's just observe a listing of what we – different cases that we read. We decided to use the coarse grid first order solutions because we were not finding any advantage in doing otherwise. You can see that the – so the metrics we evaluated to see if our grid was sufficient was the average breathing zone apparent temperature will get the calculating that in a moment but you can see that that did not vary across the five different simulations and the near ceiling temperature did vary somewhat but we were not so interested with that because the workers are not occupying the area near the ceiling.

We considered the radiative heat transfer because of the metal walls structure of the building and we also looked at the high humidity. We looked at the effect of the high humidity of the air and effect of that on the depending on scattered coefficient. We're pretty careful on how we calculated the heat transfer. We used the apparent temperature. There are different ways to get at this idea of what sort of temperature function is most important for heat stress and we decided on apparent temperature part of it because of what we're able to calculate and pull out of the CFD simulation. The most traditional metric is the wet bulb globe temperature, but I don't know how to use fundamental flow parameters to calculate that quantity. Because the instrument that we used depends on evaporation and I didn't feel like I could model the cooling effect of evaporation very accurately. We looked at apparent temperature which uses the dry bulb temperature and the vapor pressure and the wind speed, all of these are qualities that are available on CFD.

The initial geometry – actually let's just go to the refined geometry. We can see that, hard to read this table but we looked at the breathing zone apparent temperature third column from the right as our most important metric for the performance of the ventilation system in reducing heat stress. We looked at three different [Unclear] flow rates, sorry, and these were constructed by installing fans just to the lower floor windows just to the upper floor windows with the idea this upper zone [Unclear] in both or also minimum or no ventilation at all and we also looked at how much air we're going to blow through the opening that we are using.

Here is a map of the dry bulb temperature standing breathing zone height and you could see most of it is green that's around 91 degrees Fahrenheit, sorry about the [Unclear] there. You could see the window openings that they were forcing air through and you can see how in spaces that are harder to reach the temperature is higher. The difference between – so this is the initial geometry, the refined geometry you can see that the temperature is a little bit lower because we reduced the building volume through more accurate ceiling height and so you have a shorter restless time.

By the initial geometry what we found is that using both the upper openings and lower openings and flow rate of about 1 million CFM you get the best result. The best result is still pretty high. I mean apparent temperature of 104 degrees Fahrenheit is still too warm, it's still a little problem. The refined results looks like best 1 million CFM there's not a lot of savings and the effect of the cool roof is to decrease the breathing zone temperature by about 1 degree Fahrenheit and the effective cool roof is more pronounced at lower flow rates.

Basically we've found that you'd be able to reduce the apparent temperature of these worst case scenarios to about 104 degrees Fahrenheit and 1 million CFM stands out as a more practical design flow rate. Temperatures are still too high which whether are we overestimated the worst case scenario. I mean we're looking maybe a handful of days and during the hottest months where you encountered these conditions. On the other hand they already have no problem with heat stress is that it had something to do with [Unclear].

Recommendations, the detailed recommendations of a heat stress report which involves spot cooling, air conditioning of break areas and have kind of respite areas is critical. They might need to have people wearing cool suits but if they're going to address the overall building ventilation system we found that the high-bay-only exhaust was the mixture of breathing zone-height inlets on the south wall and that's important because of National Ventilation direction and high-bay-only also provided the second most effective temperature reduction. So really it's worth installing these fans both the high-bay and the standing and the standing-bay to get the best possible cooling involving the existing facility.

Now we should probably look at wider range of environmental conditions and more closer integration of field survey, temperature measurements and of course to really evaluate whether this was effective we need to visit the site, but I'm not sure at this point what they've done with these recommendations.

Any questions? [Unclear] out of time.

Male Questioner
The basic question what's inside the building? They have some materials or some another structure?

James Bennett
Its repair shops so that...

Male Questioner
Repair shop?

James Bennett
Yeah the buildings are very open so you have – they have to be able to house a ship?

Male Questioner
Ship.

James Bennett
Yeah, it's a very large open space.

Male Questioner
It's not calibrated in your [Unclear] the ship was...

Female Participant
The presence of [Unclear].

James Bennett
Right, I simulated empty building. But it's usually empty. Usually – I mean the fraction of the space taken up by objects and the process is very small compared to overall facility.

Male Questioner
I see.

Male Questioner
It's [Unclear] more than 6 feet or something?

James Bennett
Right.

Male Questioner
Its machines are like [Unclear] and...

James Bennett
I haven't been there, [Unclear]. Yeah it's usually repair of...

Male Questioner
[Unclear]

James Bennett
...yeah smaller parts and...

Male Questioner
I have a question in your first presentation...

Male Questioner
In the previous presentation.

James Bennett
Should I look at this? Okay. Yeah okay.

Male Questioner
Painting of aircraft.

James Bennett
Okay which?

Male Questioner
Last described – yeah, yes [Unclear] you recommend – in this case you recommend [Unclear] how should we remove the [Unclear] downside area of the [Unclear]?

James Bennett
Right.

Male Questioner
Yes.

James Bennett
How do we remove them so it can work? I was – we were thinking of an office space on their partitions. I think we don't have some around here but these things are removable so you just push it out of the way, so...

[Japanese]

Yeah it's just it could be out on wheels [Unclear].

Male Questioner
Yeah I [Unclear].

Male Participant
Like a [Unclear] curtain maybe an example.

James Bennett
Okay.

Male Questioner
Maybe it's more like a [Unclear] preparation type of...?

James Bennett
Well this is in the floor; the floor grid so it's actually it's in the floor. It's built but we wanted to move – create a partition to force the air to come from here versus without that it will go.

Male Questioner
There are movable package on both sides.

James Bennett
Right yes it's movable because they have to remove it to be able to flush down the floor and bring in the aircraft and the curtains where you think they could collapse, like being ceiling mounted and then collapse toward one end of the [Unclear] and so I'd like to get back there and see if they actually did that but this is a survey that was, it's really a project from another part of NIOSH from our as an evaluations branch.

Male Questioner
Yeah, I understand, I'm sorry.

James Bennett
Okay.

Male Questioner
The floor [Unclear] corresponds directly with the [Unclear] throughout the wherever is [Unclear] corresponding for it?

James Bennett
Pretty much. It's a little bit further out to the side. So it's where you – typically you see grains, right so that...

Male Participant
It was grating on the floor.

James Bennett
This is grating on the floor and at first I thought it was grain but actually they have dots coming underneath the cement floor going pulling [Unclear] which is great idea but flanges. Essentially this is flange concept.

Male Questioner
Right, right [Unclear].

James Bennett
Anything else?

Male Questioner
Is it popular ventilation system for in this country for the aircraft?

James Bennett
Is it popular?

Male Questioner
Right, is it popular to this system the down flow.

James Bennett
Unfortunately the down flow supply seems to be the most common. It is not very good.

Male Questioner
It's not very good.

James Bennett
No, it creates large circulations instead of a nice flood flow, nice directional flow, and it's very common and not very effective.

Male Questioner
Have you want to – I mean [Unclear] theaters will do that [Unclear] ceilings how do they do not get the recirculation is it smaller space to put?

James Bennett
Yeah. You see the problem is these spaces are so big that no one wants to create a uniform grid of supply devices throughout the whole ceiling so they think, okay we'll just put [Unclear] which makes some sense I mean they can deliver fresh air to the workspace but then once that fresh air has contaminated by the process it just mixes.

Male Questioner
The flow rate is high [Unclear]?

James Bennett
Right and then I don't have a pretty high velocity too to...

Male Questioner
That's why I created [Unclear].

James Bennett
Yeah.

Male Questioner
Eventually the high ceiling, I was wondering how effective they get, I mean [Unclear] can be [Unclear] is it too high or way too high?

James Bennett
It is too high and the ceiling mounted curtains might help with that, might help [Unclear].

Moderator
Should we take a break? Do you feel like take a break [Unclear] do you want to go to restroom?

Male Participant
Yeah, restroom. Anybody wanted to use the restroom?

[Multiple Speakers]

Male Participant
Maybe continue [Unclear]?

Moderator
Yeah, yeah, we can come back maybe, yeah [Multiple Speakers]

Li-Ming Lo
They provided the seminar item forms [Unclear] from the 19200 bid for [Unclear] per minute and owner container will be delivered through the air return and – actually they told me for release it down [Unclear] they keep t 100C [Unclear] but they keep it down for operated number of under the negative pressure so that [Unclear] actually data on nanomaterial [Unclear] anything our instruments cannot detect any particle, any nano particles outer front deposits. We are very impressed how this kind gain control so they kept [Unclear] they also keep a low background concentration so the data should [Unclear] how effective than a number of room has been used in this situation.

Male Questioner
Super techno product [Unclear]?

Li-Ming Lo
Yes, so as we got...

Male Questioner
They keep materials from blowing away?

Li-Ming Lo
Actually not really. I mean that probably I would say a different material they produces this so called nanosheet.

Male Participant
Nanosheet, okay.

Li-Ming Lo
Not the copper [Unclear] tube so that is not the [Unclear] but inside. Yeah. So once we gather that result we talked to some a couple of our research partners and came out with the idea and some [Unclear] as I mentioned by the NORA project. This project was founded by NIOSH NORA. This 4-year project been just started and actually started progress is to design and build a mobile, our use to mobile downflow booth having flexibility and low cost to be used at different tasks so I'm not just talking about use of this downflow booth for the nano manufacturing I also – I will prefer to promote using this downflow booth to different workplace and also we try to measure more details about this mobile downflow booth later.

Design criteria actually before we came out of this idea we talked to some other companies why don't we – I mean I mentioned the downflow booth or downflow room to some companies they mentioned, oh they are very expensive so we try to contacted some builder and building expensive and actually the downflow room I mentioned before was built up by research center. The operation cost was shared by three different companies so that is a special case so the companies use downflow room and shared cost so in that case they can handle the [Unclear] for the other company like most of the nano [Unclear] small business, they don't have a budget to install a downflow room or regular downflow booth so that's why we talk a research partner, we want to build downflow booth with low cost or maybe maybe ideally we just try to build this downflow booth like a Lego [ph] you can – like [Unclear] make it bigger or smaller.

Male Questioner
You know what Lego is?

Li-Ming Lo
Lego.

Male Questioner
Lego, ah L-E-G-O.

Li-Ming Lo
Yeah so I will show you later how I mentioned – I want to build like a Lego so...

James Bennett
The term is modular.

Li-Ming Lo
Yeah. Yeah I would yes. Actually I try to modularize the...

Male Questioner
Modularize it.

Li-Ming Lo
The size that we had a discussion with our research partner so we came out some dimension so will be the 10 feet wide and probably depths were 9 feet and 8 feet high so that's just the size that we try to build for recent mobile downflow booth. Safe working zone actually we try to have, I would call the [Unclear] of the depth if you can use a curtain you can extend a little bit probably to 80% of the depths to make a bigger worker safety zone.

Again airflow [Unclear] usually the regular downflow booth will keep it 90 to 110 feet per minute average. We also use prefilter MERV 11 prefilter inside our downflow booth. Of course HEPA filters were installed in the air return and the air supplier. Noise level, lighting, electrical, as you can see it has a wall frame I will use aluminum because it's light and the raw material we just use a vinyl wall try to make it as light as possible.

Exhaust fan, so far the exhaust fan we are using can provide 1.5 horsepower so actually they can – I think I will show you later. As a result the downflow booth was built for this project just as the way will be up to 2000 [Unclear]. Ideally I would – there was a desire to be installed by two men in 4 hours. Once they finished to build this downflow booth and [Unclear] I spent afternoon by myself to install the downflow booth. I will show you this afternoon. I did by myself.

Male Participant
You're a handyman.

Li-Ming Lo
I needed just a ladder and some [Unclear] tools [Unclear] so it seems so pretty [Unclear]. This downflow booth as you see here the exhaust fan can produce 5500 cubic feet per minute and as you can see here the supply air 5000 so usually I have to have them make up air around 5000 so keep them negative pressure inside the downflow booth. I have a mega quick configuration because the all the exhaust fan and the supply fan can be adjust the specific adjustment so I can operate this downflow booth with the air changing from the 100 to 500 so as I mentioned most of the [Unclear] manufacturers they would like come down or come off the [Unclear] so I won't try to not use the higher airflow rate I use lower. I want to see how it works when they do some testing.

As I mentioned I want to build like Lego, actually as you can see the left part can be taken away I can just make it I called a short configuration and this would be the full configuration and once they will be assembled I can put the sidebar on the two sides it would be easy to see here on the sidebar here and put [Unclear] and we didn't move the downflow to the location you want so it works.

That make it more attracted to the nano manufactures because they wanted low-cost, they wanted more flexible because some use the downflow was due to different tasks. So you can see here that the vinyl wall here I can easily take away [ph] so they can probably just move to the furnace or the reactors and as [Unclear] and here I also used the curtain to extend as I mentioned before, I would like to use the curtain to extend the worker safety zone. Yes?

Female Questioner
What is the floor [Unclear] floor so the air can actually go through the floor?

Li-Ming Lo
Actually the air retained would be right here right – so the air [Unclear] supply for our ceiling so they would be [Unclear].

Female Questioner
It's coming in, in the ceiling and out to through the floor?

[Multiple Speakers]

Li-Ming Lo
Out to the air inside and outer side.

Male Questioner

Does the floor [Unclear]?

Li-Ming Lo
Yes.

Male Questioner
You [Unclear].

Li-Ming Lo
Ideally you probably would have to perform the task as the course of the air returned that's safety zone, there's a boundary you can measure the boundary with them, [Unclear].

Female Questioner
Yeah.

Male Questioner
This would be good concept for portable [Unclear] with two or...

Li-Ming Lo
Yeah solo [ph]. Solo.

Male Participant
That's why it's called total dust control not necessarily for nano.

Male Questioner
Right, right.

Li-Ming Lo
Because I'm still doing the data collection I don't have much data to show you. So far I'm doing the airflow measurement and visualize it. This kind of data will be use to the next step to do the numerical simulation. Also we would like to do some simulated process or task like dry powder, transfer, or use of tracer gas to see how this downflow booth performed. I do have – I'm planning to use the [Unclear] with two different sizes 5 micron and [Unclear] micron to do this so called dry powder test these are some reference data can be used ISPE, IEST; tracer gas there will be the ASHRAE measure 110. Numerical simulation will be due to later because we try to manipulate the airflow, try to use different airflow and to see how the safety worker zone change and so in the case numeral simulation will help us to identify this safety zone and we also want to use this numerical tool to see how other engine controls or how other – how the task any effect of [Unclear] of the downflow booth and also we already are talking to some, actually just one, one research partner they are very happy to use our downflow booth because it's very close by, just in the Dayton Ohio. They have tried to use our downflow booth in their facility maybe just put over there one or two months. They allow us to collect data so we can have few data will be publish later.

James Bennett
Close to mind for me is the importance of the vinyl curtains. You are enclosing and enclosing the flow.

Li-Ming Lo
Yeah that's true.

James Bennett
Going back to what I was talking about I wonder can you use, are you planning on using CFD to look at the performance under like real world comprised operating circumstances, like I can imagine workers going to think. I don't really want these curtains to be down; I think the powder inside let's brought in with some open to get more clean air in here.

Li-Ming Lo
Yes because they and these are things that you can see that they are just curtain. You can easily just open and go in and out of the downflow booth so they might have some effect to under this performance on the downflow booth but usually we will keep it out under curtain trying to extend the worker [Unclear] the safety zone as bigger as possible.

James Bennett
Yeah they might begin to understand exactly how, what the effect like if they have a high tight production schedule maybe they're going to let me going in and out a lot and I think this convenience – these are curtains are inconvenient for me.

Li-Ming Lo
Yes. We also considered to put additional engineering control inside the downflow

booth. I actually built a custom made downflow – not downflow booth enclosures inside the downflow booth so I'm trying to do the kind of test and also on numerical tool [Unclear] be capable of handling this additional and new controls so the CFD will be used to do another stimulation. In the meantime I also talk to the [Unclear] for my case, they also recommended a dynamic mesh method can be used to stimulate the operation of the worker inside the downflow booth so that will be more helpful to see because the space is not that big like James' case it's big space, for my case it's small space so the...

James Bennett
Two extremes.

Li-Ming Lo
Yeah the worker motions might have some impact, many of that impact on the downflow booth so we wanted to learn how they – [Unclear] each other.

James Bennett
Workers is a large – is appreciable fraction of the total volume of the...

[Multiple Speakers]

James Bennett
Right [Unclear].

Li-Ming Lo
Yes, yes. That's my presentation so far I still collected the data so I don't have much data to show you right now and I will finish this soon and maybe proper [Unclear]. Thank you.

Male Participant
In the afternoon we will have the lab tour.

Li-Ming Lo
Yeah.

[Multiple Speakers]

Li-Ming Lo
Yes. Any question or suggestion? Right.

Male Questioner
What kind of parameter do you measure to evaluate the [Unclear]?

Li-Ming Lo
I see, actually there are some reference [Unclear] mentioned that ISPE, IEST. To answer to questions the first step of data collected it will be the air velocity coming from the ceiling and the space because I tried to use the data to identify my CFD model later and I also needed to see how the safety worker zone change with the [Unclear] by operator the downflow booth under different air is changing rate, different support air, different air [Unclear] also use of the...

Male Questioner
Can you just take like [Unclear] measure like various heights and [Unclear] cross section?

Li-Ming Lo
Yeah exactly and also we can use the smoke test to have the flow profile, to see the flow profile. They will be helpful to visualize how the flow change and the powder test actually this downflow has been widely used in the pharmaceuticals company so they have – they have the standard to test this downflow booth so [Unclear] I also use just like them I use the dry powders to do the simulation like transfer the powder from one container to the other container the kind of task is quite common in their company, try to transfer and then we have another of their [Unclear] instruments so we can see the particle concentration different in different area even from the worker breathing zone.

Male Questioner
To come the particles...

Li-Ming Lo
That's a particle data.

Male Questioner
Number of concentration?

Li-Ming Lo
Yeah number of concentration, yes.

Male Questioner
I see, I see.