Evaluation of Ventilation in Aircraft Maintenance and Restoration Hangars

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Contents

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The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation. Photo by NIOSH.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from managers regarding ventilation in four aircraft hangars used to maintain, repair, and restore active and historic aircraft. The managers wanted to know the airflow patterns in the hangars. The managers wanted to use this information to select worst case conditions when sampling for potential air contaminants.

What We Did

- We evaluated two maintenance hangars and two restoration hangars.
- We used a smoke machine to check airflow patterns in the hangars.
- We measured air speed and direction in the hangars.
- We measured pressure differences between the maintenance hangars and surrounding areas.

What We Found

- Some supply fans in the maintenance hangars were not operating, and one supply fan intake was closed.
- Many supply and exhaust fans were not operating according to design specifications.
- Many exhaust fans were blocked by equipment.
- Air flowed from maintenance hangars to the outdoors.
- Air flowed from the offices and into the maintenance hangar work areas.
- Areas around aircraft in the maintenance hangars had little or no air movement.
- Window-mounted wall exhaust fans in the restoration hangars were not operating.

We evaluated the ventilation systems and airflow in aircraft maintenance and restoration hangars. We found areas of little to no airflow above the wings and fuselage on the exhaust side of each maintenance hangar. Employees performing tasks that generate air contaminants at these locations should be monitored for exposure. The aircraft restoration hangars also had areas of low air flow, especially near the back of the hangar. Air monitoring should be done in these hangars after the ventilation system is repaired.

What the Employer Can Do

- Repair and adjust supply and exhaust fans in the maintenance hangars to meet their design specifications.
- Measure air speeds and flow patterns after fan adjustments or repairs have been made.
- Move equipment and supplies to a location that does not block exhaust fans.
- Design and install a supply and exhaust style ventilation system for the restoration hangars.

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Introduction

The Health Hazard Evaluation Program received a request from environmental health and safety managers at a military facility to characterize airflow inside four aircraft hangars. The hangars are used to maintain, repair, and restore active and historic aircraft. We visited the facility in March 2014 to tour the hangars and gather information on work activities and the ventilation systems. We returned to the facility in August 2014 to characterize airflow patterns inside each hangar while aircraft and employees were present. During our visit, no employees were sanding or painting aircraft, but some were inspecting aircraft engines, testing electrical systems, lubricating parts, and inspecting historical aircraft parts.

The employees working in the hangars use paints and paint removers on a variety of aircraft surfaces. Paints and paint removers are typically applied using low pressure spray guns or paint rollers. Employees remove old surface coatings using mechanical or pneumatically-driven sanding equipment (vented and unvented), grinders, or scrapers. Particulates generated during painting and coating removal may contain isocyanates, polyurethanes, solvents, or metals. Health and safety staff assigned to each hangar wanted to know if there were areas within each hangar that exhibited little or no airflow where exposure controls may be necessary. Also, the staff wanted to know where to conduct sampling for air contaminants (personal and area) so that exposures under worst case ventilation conditions (little or no ventilation) could be evaluated.

Hangar and Ventilation System Description

We evaluated two maintenance hangars (buildings 4015 and 4016) that were built in 2006–2007 and were identical in structure and ventilation design. Each hangar occupies more than 4.7 million cubic feet of air and includes an office (climate controlled by a separate ventilation system) and a large, open aircraft service bay with sectional, overlapping track doors driven by electric motors. Air supply and exhaust fans are located on opposite hangar walls to produce a cross-flow pattern of air movement (Figure 1). A shroud on each air supply fan directed air down at a 30-degree angle towards the floor (Figure 2). The exhaust fans were shrouded and had a straight through the wall design (Figure 3).

Figure 1. Photo showing location of air supply fans mounted on hangar wall. Photo by the National Institute for Occupational Safety and Health (NIOSH).

Figure 2. Photo of supply fan shroud oriented at a 30 degree down angle. Photo by NIOSH.

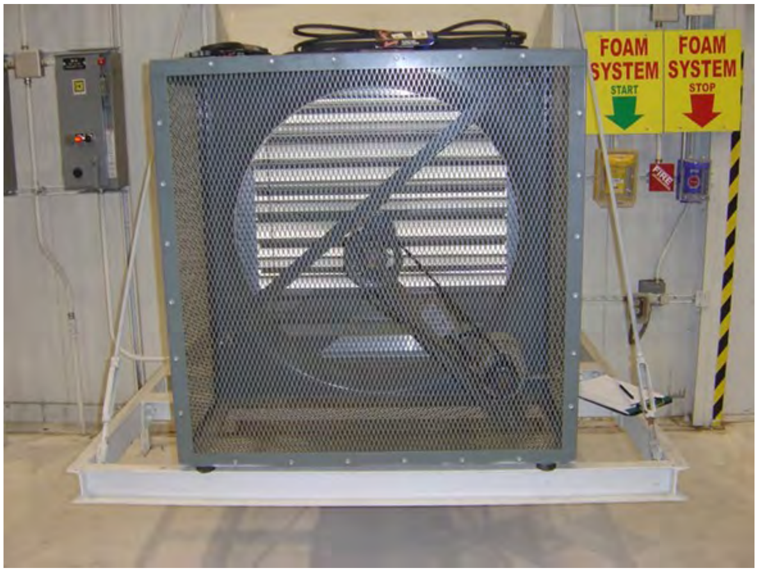

Figure 3. Photo of an exhaust fan extending straight through the exterior wall. Photo by NIOSH.

We also evaluated two historical aircraft restoration hangars, buildings 20004 C and 20004 D. These hangars were built in 1944 and did not have a supply and exhaust type of ventilation system. Instead, the ventilation system consisted of four window-mounted exhaust fans along the back wall (Figure 4), two portable, vertical floor fans located in different work areas (Figure 5), and forced air heaters along the side walls. No supply fan inlets or ducts were observed. All supply air entered the building through a single 13 foot long by 26 foot high open bay door (Figure 6). During cold weather, no air supply or exhaust is available because the bay doors are closed, and the exhaust fans remain off to retain heat. All employees conducting sanding operations used a ventilated, pneumatically-driven sander that is attached to a high efficiency particulate air filtered vacuum (Figure 7). The filter was reportedly changed by employees when they noticed a reduction in suction. When changing the filter, the employee reported wearing an elastomeric half-face respirator with P100 cartridges, a Tyvek® suit, and nitrile gloves. Any large-scale painting was done using rollers and latex paint. Spray painting of parts occurred inside a ventilated spray booth that was not evaluated as part of this survey.

Figure 4. Photo of window-mounted wall exhaust fans inside a restoration hangar. Photo by NIOSH.

Figure 5. Photo of movable vertical floor fan in a restoration hangar. Photo by NIOSH.

Figure 6. Photo of restoration hangar front bay doors that were opened to provide some supply air. Photo by NIOSH.

Figure 7. Photo of ventilated hand sander attached to a high efficiency particulate air filtered vacuum. The sander is used by employees in the restoration hangar. Photo by NIOSH.

Methods

Objectives:

1. Measure air velocities and flow rates within the work area to determine the magnitude and direction of airflow.
2. Visualize airflow patterns inside the hangars when aircraft are present.
3. Identify areas of little or no airflow.

During our second visit, we used quantitative and qualitative indicators to characterize the airflow in each hangar. We visually inspected and measured the dimensions of each supply and exhaust fan. We measured the average air velocity at six points across the face of each supply and exhaust fan using a Shortridge VelGrid® Model ADM 860 C micromanometer (Figure 8). The VelGrid averages air velocity readings from 16 sampling ports, resulting in an overall 96-point air velocity average (6 × 16 = 96). We used the same instrument to measure average air velocities at work locations above, below, and at the sides of the aircraft. We measured air velocities about 3 feet above either the hangar floor or the aircraft surface. To see airflow patterns we used a Rosco Laboratories Inc. model 1500 smoke machine to generate a smoke aerosol around the hangar aircraft (Figure 9). Finally, we determined whether the work area was under positive or negative pressure relative to adjacent areas using ventilation smoke tubes in the connecting doorways. All measurements were made with the hangar bay doors closed.

Figure 8. Photo of NIOSH investigator measuring air velocity at an exhaust fan outlet. Photo by NIOSH.

Figure 9. Photo of use of an aerosol-generating smoke machine to visualize airflow patterns near an aircraft. Photo by NIOSH.

Results and Discussion

Maintenance Hangars

The ventilation systems in the maintenance hangars (buildings 4015 and 4016) did not maintain the desired cross-flow ventilation because the air movement created by the supply fans on one wall did not reach the capture zone of the exhaust fans on the opposite wall. The resulting airflow pattern produced dilution-style ventilation that could provide climate control but was not an effective air contaminant control.

Eight air supply fans delivered unfiltered, unconditioned outdoor air to each hangar. With all supply and exhaust fans running, each maintenance hangar was under positive air pressure relative to the outdoors. This means that more air is supplied than exhausted from the hangars and that the airflow direction was from the hangar to the outdoors. The office area inside each maintenance hangar was under positive air pressure relative to the hangar, meaning that air flowed from the office to the hangar. This condition is desirable because it reduces the chance for air contaminants in the hangar to migrate into the office. The office was climate controlled by a separate air handling system located on the roof.

Our air measurements are shown in Appendix A, Tables A1 and A2. In building 4015, the measured airflow rate produced by the supply fans was 89% of the design specification while the exhaust fans were found to operate at 65% of the design specification. A similar finding was noted in building 4016 where supply fans operated at 83% of their design specification while the exhaust fans produced less airflow (64%). In both buildings, we noticed some supply air fans operated above their design specification while others did not. However, the opposite was true regarding the exhaust fans where each operated below their design specification. Air velocities around the C17 aircraft in building 4015 ranged from 0 to 78 feet per minute (Figure B1). Air velocities around a C17 aircraft in building 4016 ranged from 0 to 227 feet per minute (Figure B2). Clearly, there were areas of no air movement (confirmed by the smoke tests) and areas where the air from a supply fan reached the aircraft work zone. Most areas of little to no air movement were noticed in the area above the wings and fuselage and also on the exhaust fan side of the aircraft (Figures B1 and B2).

Upon closer investigation, we found in each maintenance hangar a supply air fan that was either not functioning or had a louver stuck in the closed position. Additionally, we noticed tables, equipment, and hangar supplies that were blocking some of the exhaust fans (Figures 10 and 11). When any fan is blocked, the air velocity is reduced, and the flow pattern becomes more turbulent. Such effects are shown in Tables A1 and A2 as well as Figures B1 and B2. Air velocities were always higher on the supply side of the aircraft than the exhaust side because the supply air fans were not blocked. These fans also operated closer to design specifications. The lowest air velocities were above the aircraft, which can be attributed to the supply air fans being oriented downward towards the floor. Ideally, the air from individual supply fans would spread and combine to create a consistent air mass that would "wash" the entire aircraft work zone and move air towards the exhaust fans.

Figure 10. Photo of table and equipment blocking exhaust fan outlet. Photo by NIOSH.

Figure 11. Photo of fenced area blocking three exhaust fans. Photo by NIOSH.

Restoration Hangars

Airflow patterns and velocities were highly variable within both restoration hangars (Figures B3 and B4) as a result of the absence of a conventional supply and exhaust ventilation system. Also, the use of portable fans of different sizes in different locations resulted in variable air velocities and increased turbulence. In general, air velocities decreased with distance away from each fan, with the lowest values measured near the back wall of each restoration hangar.

Conclusions

We were unable to find out what criteria were used for the overall design of the maintenance hangar ventilation systems in buildings 4015 and 4016 (e.g., airflow rate, desired air velocity, airflow direction, laminar airflow, reduced turbulence), therefore it is not possible to assess the adequacy of each system with regard to the design intentions. Furthermore, many of the fans (supply and exhaust) did not produce the designed airflow. The ventilation systems for these hangars were somewhat effective for climate control but ineffective for air contaminant control. The air velocities in the work zones surrounding the aircraft were too low for air contaminant removal. On the basis of the results obtained during this evaluation, personal and area air sampling efforts should focus on the work zones above the wings and fuselage and on the side of the aircraft closest to the exhaust fans, as these tend to have little or no air movement.

The restoration hangars have variable air movement created by portable cooling fans, which provide some comfort during warmer days. However, the inoperability of the window-mounted exhaust fans may lead to a buildup of air contaminants. Because the air movement magnitude and patterns are variable, personal and area air sampling to estimate a worst case scenario exposure could be conducted during air contaminant generating tasks that occur away from the portable cooling fans (e.g., tasks performed near the back wall or in the center of the hangar).

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage this aircraft maintenance and restoration facility to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at this facility.

Our recommendations are based on an approach known as the hierarchy of controls. This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and personal protective equipment may be needed.

Engineering Controls

Engineering controls reduce employees' exposures by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls protect employees effectively without placing primary responsibility of implementation on the employee.

1. Repair, adjust, and maintain all fans associated with the ventilation system in the maintenance hangars. Two supply fans, one in each maintenance hangar, were inoperable while another unit had louvers stuck in the closed position. The ventilation system should operate according to design specifications. Once the fans are repaired, test each fan to verify proper operation according to design specifications.
2. Repair the exhaust fans in the windows of the restoration hangars and perform area and personal air monitoring for possible air contaminants associated with each work task.

Administrative Controls

The term administrative controls refers to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Move equipment and supplies that block any fan so that airflow is not impeded.

Appendix A: Tables

Table A1. Building 4015 volumetric supply and exhaust airflow measurements

Fan ID	Design airflow (cubic feet per minute)	Actual airflow (cubic feet per minute)
SF–1*	11,650	13,870
SF–2	11,650	NS†
SF–3	11,650	8,100
SF–4	11,650	14,600
SF–5‡	11,650	9,300
SF–6	11,650	13,050
SF–7	11,650	11,700
SF–8	11,650	12,700
Total supply	93,200	83,320
EF–1§	11,650	6,700
EF–2	11,650	6,800
EF–3	11,650	8,000
EF–4	11,650	9,400
EF–5	11,650	7,000
EF–6	11,650	6,600¶
EF–7	11,650	9,100
EF–8	11,650	6,600¶
Total exhaust	93,200	60,200

*Supply fan

†Not sampled; fan inoperable

‡Louvers stuck closed

§Exhaust fan

¶Material or equipment stored in front of fan

Table A2. Building 4016 volumetric supply and exhaust airflow measurements

Fan ID	Design airflow (cubic feet per minute)	Actual airflow (cubic feet per minute)
SF–1*	10,550	10,600
SF–2	10,550	10,400
SF–3	10,550	9,700
SF–4	13,200	19,500
SF–5	13,200	5,000
SF–6	13,200	16,200
SF–7	13,200	NS†
SF–8	13,200	9,400
Total supply	97,700	80,800
EF–1‡	10,550	4,200
EF–2	10,550	5,300
EF–3	10,550	4,900§
EF–4	10,550	12,000
EF–5	10,550	6,600§
EF–6	10,550	7,100§
EF–7	10,550	7,500
EF–8	10,550	6,500§
Total exhaust	84,400	54,100

*Supply fan

†Not sampled; fan inoperable

‡Exhaust fan

§Material or equipment stored in front of fan

Appendix B: Figures

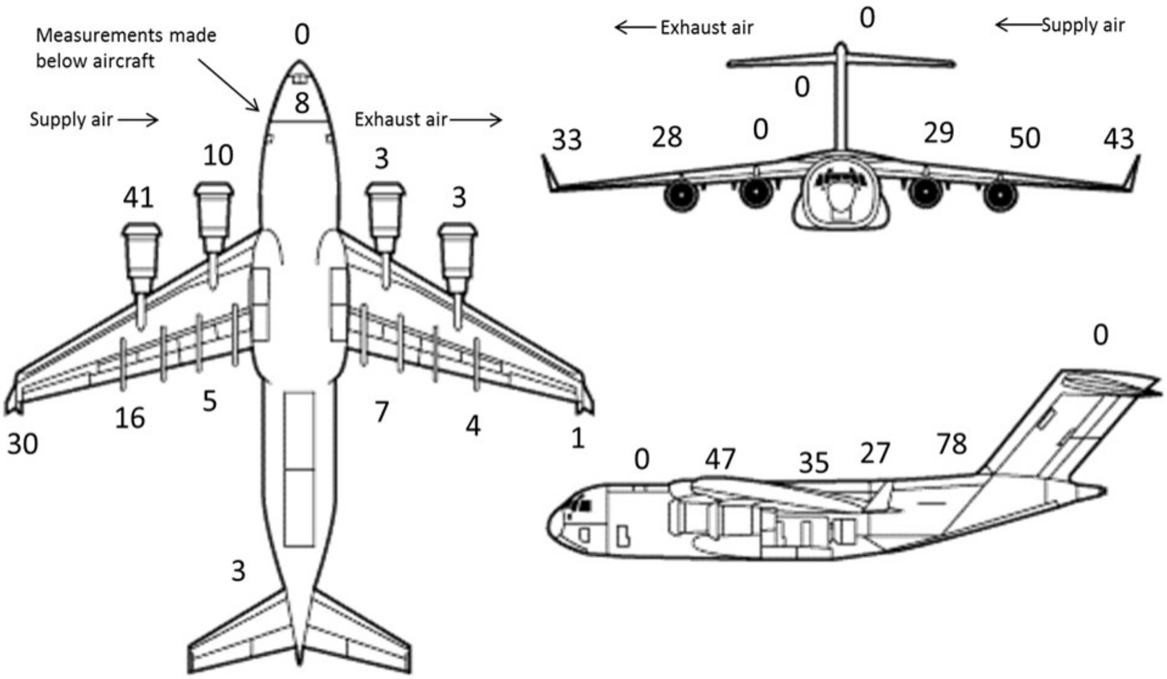

Figure B1. Building 4015: Air velocity in feet per minute around C17 aircraft.

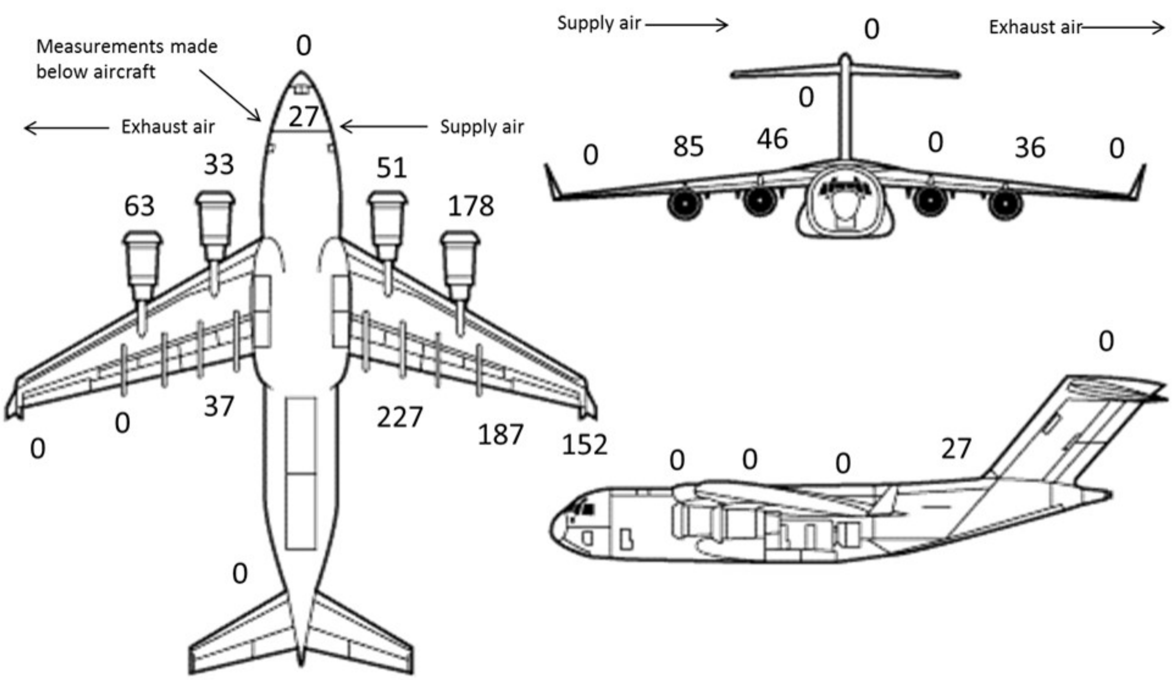

Figure B2. Building 4016: Air velocity in feet per minute around C17 aircraft.

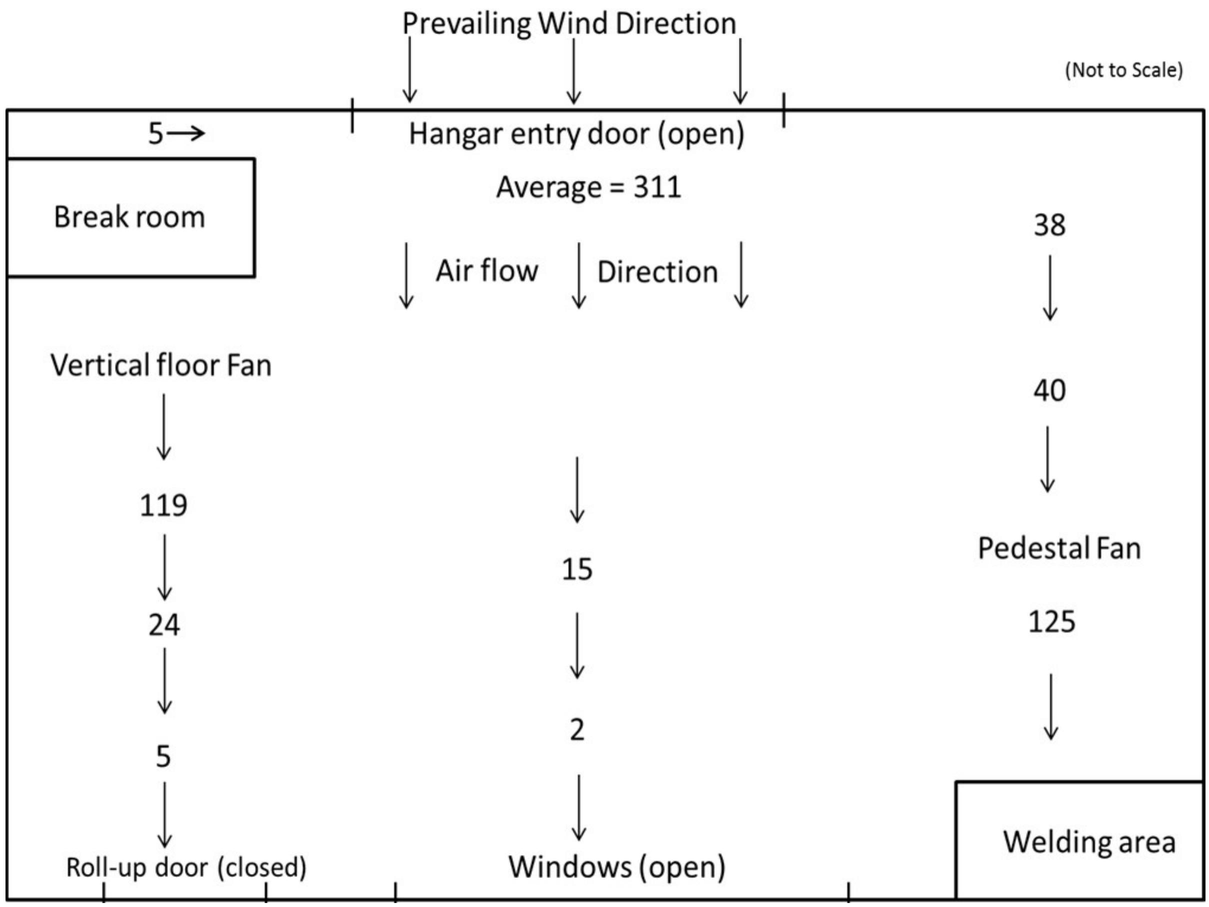

Figure B3. Building 20004 C: Air velocity in feet per minute in restoration hangar.

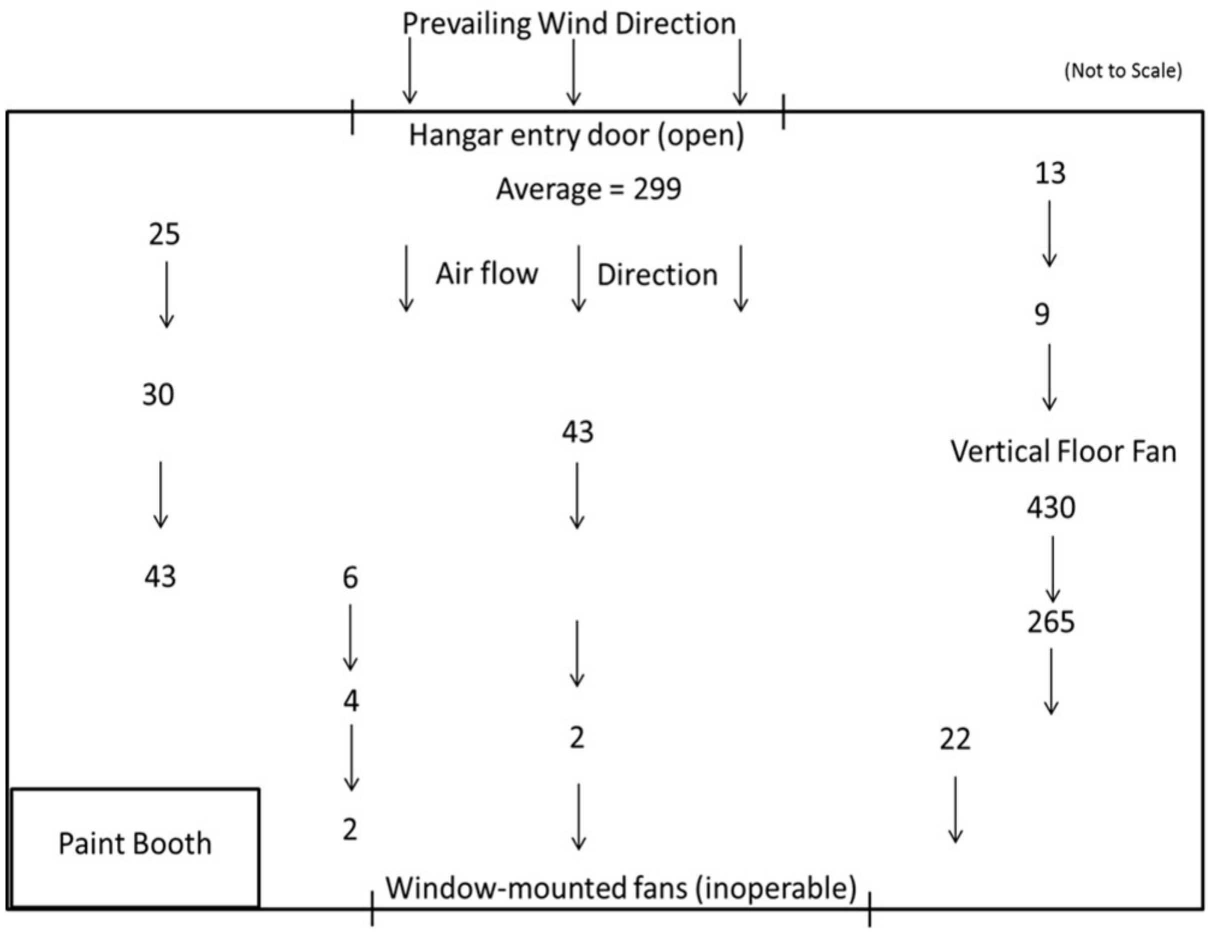

Figure B4. Building 20004 D: Air velocity in feet per minute in restoration hangar.

Keywords: North American Industry Classification System 928110 (National Security), Ohio, aircraft maintenance and restoration, ventilation, airflow measurements, airflow patterns

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