# Paint Spray Booth Modifications for Recirculation Ventilation

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*Editor's Note: In an effort to help small-size automotive refinish shops comply with state emissions regulations that may be enacted in response to EPA's National Ambient Air Quality Standards for ozone, EPA is procuring equipment to test emissions from paint formulations in spray booth applications.*

*This paper discusses related pollution prevention research to develop a lower emitting air recirculation spray booth. EPA will continue to share findings from its pollution prevention research with Modern Paint readers in upcoming issues. The agency welcomes discussions with paint formulators who share an interest in developing lower emitting coating materials. Those interested may contact Geddes Ramsey at 919-541-7963.*

Spray painting facilities have long been under pressure to acquire technologies to reduce the discharge of volatile organic compound (VOC) emissions to the atmosphere. Some have been able to convert to lower VOC containing paints and coatings such as powder or waterborne coatings or via electrocoating.

Due to the unique requirements for some painted surfaces, however, acceptable low polluting substitutes are not available. In these cases, conventional paints and painting equipment must continue to be used.

The control of emissions from spray paint booths has long been considered too expensive for some companies due to the high volume of exhaust that must be treated. However, studies conducted by EPA with various Department of Defense (DOD) services have demonstrated that the cost of typical spray booth control technologies can be significantly reduced through the use of spray booth recirculation.

Using recirculation, reductions of exhaust flow rates of up to 90 percent can be achieved in properly designed and operated booths. This can be achieved without presenting the industrial hygiene or fire safety concerns typically mentioned when discussing these systems.

This paper presents the results of the design and demonstration program for a full-scale recirculating spray paint booth installed and operated at the U. S. Marine Corps (USMC) facility at Barstow, CA. It also summarizes the legislative and research history of recirculation spray booths.

## Background

The use of spray booth air recirculation is not a new concept. As early as 1981, the John Deere Company patented a spray booth concept using recirculation.[1] The company's recirculating design allowed for the passage of exhaust air to hot water heaters to be as used as combustion air and simultaneously destroy the VOC content of the exhausted gases.

Recirculating spray paint booths are designed to operate by extracting a portion of the exhaust via a bleed-off

**Figure 1. Conventional Single Pass Spray Booth Ventilation**

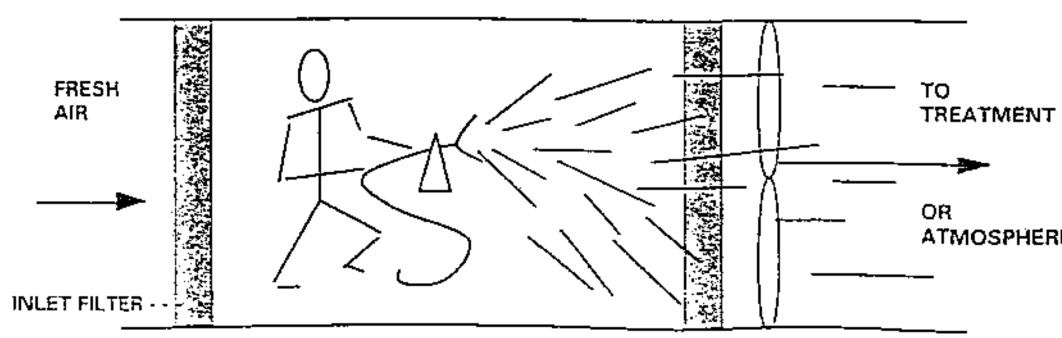


**Figure 2. Exhaust Recirculation Spray Booth Ventilation**

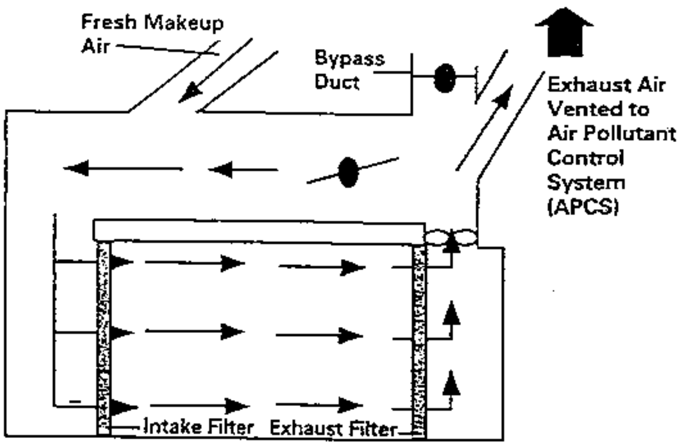
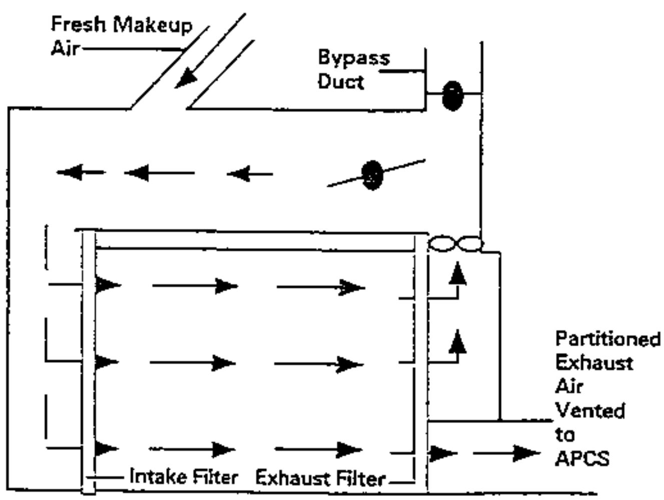



**Figure 3. Recirculation/Partitioned Spray Booth Ventilation**




stream and venting to a control system. The remaining air is returned to the booth after mixing with fresh air equal to the exhaust volume to ensure that the recirculated air does not exceed safe pollutant concentration levels. Figures 1 and 2 show schematics of a single pass ventilation and an exhaust recirculation ventilation system, respectively.

Unfortunately, even as late as 1989, recirculation was not widely used due to misinterpretation of OSHA regulations and the post-1985 National Fire Protection Association (NFPA) code on recirculating air in a paint spray booth.

In 1988 a series of studies were conducted by the U.S. Air Force (USAF) and EPA to characterize booth emissions. The studies were conducted at Hill Air Force Base (AFB) in Utah, Travis AFB and McClellan AFB, both in California, on booths of various designs and sizes. Using multiple sampling systems, the booth environments were evaluated along their lengths, heights and widths to define the average concentrations in various regions of the booth during operation.

The studies indicated that recirculation can be employed as a method to reduce exhaust flow rates from spray booths without exceeding the exposure limits as defined by OSHA.[2,3]

The studies also suggested a unique phenomenon in the exhaust flow patterns from the booths. A concentration gradient at the exhaust face was formed as the pollutant flowed from the booth with the concentration relatively high at the lower region of the booths and decreasing toward the ceiling. Thus, by taking advantage of this phenomenon, it was speculated that recirculation could be further enhanced by partitioning (dividing) the exhaust into two streams and allowing the removal of the maximum amount of pollutant in a smaller exhaust stream from the lower region of the booth.

Figure 3 presents a conceptual schematic of the recirculating/partitioned paint booth formulated from the results of those studies.

## Codes, Regulations Affecting Design

The design, ventilation and operation of paint spray booths are governed by codes and regulations established by consensus organizations and various state and federal agencies. These include OSHA, NFPA and the American Conference of Governmental Industrial Hygienists (ACGIH). The federal OSHA regulation is generally based on the prevailing consensus codes, in this case those established by NFPA and to a lesser degree ACGIH.

The pre-1985 NFPA code for spray painting using flammable or combustible materials prohibited the use of recirculation in paint spray booths. This NFPA prohibition was incorporated into the OSHA regulation and has been consistently misinterpreted to apply to industrial hygiene safety. However, the original intention of the code was to prevent the formation of the lowest explosive level (LEL) of VOCs and was included due primarily to the lack of reliable and accurate monitoring equipment to ensure that VOC concentrations in the booth and exhaust did not exceed the 25 percent LEL for the volatile constituents. In 1985, the NFPA code was revised to permit recirculation with strict provisions for monitoring the air streams.

The concentration needed to reach an explosive level is several orders of magnitude higher than the concentration found in typical spray booths even when operating in a recirculating mode. Thus, the deciding factor and the most important design criterion for a manned recirculating booth atmosphere is not whether the booth will reach 25 percent LEL. Instead, it is whether the booth atmosphere approach the established permissible exposure limits (PELs) as defined in OSHA 29 CFR Part 1910 subpart z Toxic and Hazardous Substances.[4] This regulation specifies maximum allowable worker exposure limits. Similar limits also are recommended by ACGIH guidelines.

In 1989 OSHA issued a policy directive accepting the use of recirculation in spray booths when operated under the established PEL.[5] In 1992 ACGIH concurred on the use of recirculation in spray booths when designed and used properly. The conditions under which recirculation is acceptable are presented in the ACGIH Manual of Recommended Practice.[6]

## Recirculating/Partitioned Booth Demo

In 1993 EPA and the USMC initiated a demonstration

**Table I: Demonstration spray booth dimensions**

| Booth No. | Depth, m (ft) | Width, m (ft) | Height, m (ft) | Partition Height, m (ft) |
|---|---|---|---|---|
| 1 | 18.2 (60) | 6.1 (20) | 5.5 (18) | 2.7 (8.9) |
| 2 | 6.1 (20) | 9.1 (30) | 3.0 (10) | 2.0 (6.7) |
| 3 | 3.0 (10) | 6.7 (22) | 3.0 (10) | 2.0 (6.7) |

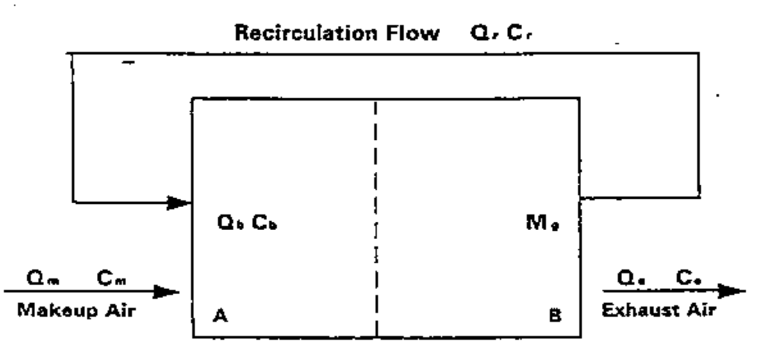



**Figure 4. Paint Booth Control Volume Configuration for Determining Partition Height**

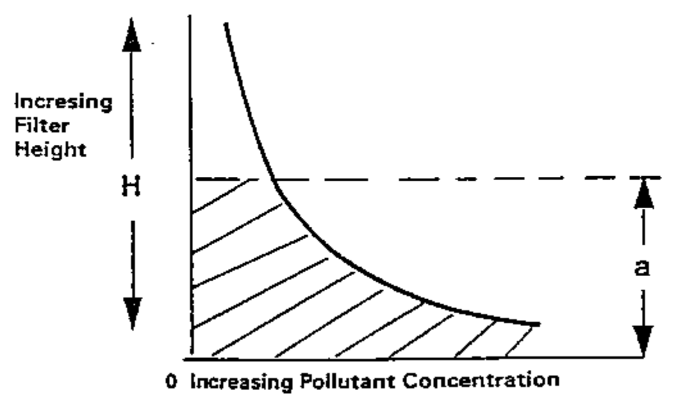



**Figure 5. Total VOC Concentation Profile at the Exhaust Face**

project sponsored by the Strategic Environmental Research and Development Program (SERDP) to design and demonstrate a recirculation/partitioned spray booth facility.

A general schematic of recirculating/partitioned booth design used for the demonstration program is shown in Figure 3. The demonstration included three modified booths and an end-of-pipe control system serving all three booths. Each booth used the partitioned design which permits the removal of the greatest volume of pollutant in the least volume of air exhausted. Table 1 presents each demonstration booth's dimensions.

## Booth Design

Operating safety is the prime consideration in the design of manual spray booths. The safety requirements that drive spray booth design are codified in OSHA 29 CFR 1910.1000 and OSHA 29 CFR 1910.107[7], which govern booth ventilation and worker exposure requirements, respectively. However, since the ACGIH threshold limit value (TLV) limits tend to be more conservative than the OSHA PELs, the ACGIH time weighted average (TWA) for each pollutant was used to develop booth design for the demonstration program. Also, a safety factor of 2 was also included in the design.

The mathematical expression for determining an efficient booth partition height is developed using a simple mass balance based on Figure 4.

By assuming steady state booth operation, the most conservative, worst case result is derived. In this case, the mass balance equation at the booth intake face (Location A) in Figure 4 is defined by:

$$(Q_r \times C_r) + (Q_m \times C_m) = (Q_b \times C_b) \quad (1)$$

where:

$Q_r$ = volume flow rate of recirculated air
$C_r$ = hazardous constituent concentration in recirculated air
$Q_m$ = volume flow rate of fresh makeup air
$C_m$ = hazardous constituent concentration in fresh makeup air
$Q_b$ = volume flow rate through paint booth
$C_b$ = hazardous constituent concentrations in air upstream of painter location

Since it can be assumed that the booth makeup air is free of hazardous constituents, Equation (1) at Location A becomes:

$$(Q_r \times C_r) = (Q_b \times C_b) \quad (2)$$

Under steady state conditions the mass balance equation at the booth exhaust face (Location B, Figure 4) is defined as:

$$(Q_b \times C_b) + M_g = (Q_r \times C_r) + (Q_e \times C_e) \quad (3)$$

where:

$M_g$ = hazardous constituent mass generation rate from paint application process
$Q_e$ = volume flow rate of exhaust air vented to the air pollutant control system (APCS)
$C_e$ = hazardous constituents concentrations in exhaust air vented to the APCS

The left side of Equation (3) represents the mass flow

$$C_r = (M_g \times X) / Q_r \times (a/H) \quad (6)$$

The partition height and corresponding recirculation rate that yield acceptable hazardous constituent concentrations in the booth intake stream may be derived iteratively from Equation (6).

**Table 2: Summary of volumetric flow rate reduction achieved at Marine Corps Logistics Base (MCLB) paint booths.**

| Booth No. | Initial Exhaust Flow Rates $m^3$/min (cfm) | Projected Flow Rates $m^3$/min (cfm) | Final Exhaust Flow Rates $m^3$/min (cfm) | Reduction Achieved % |
|---|---|---|---|---|
| 1 | 1,500 (53,000) | 566 (20,000) | 572 (20,210) | 62 |
| 2 | 1,783 (63,000) | 580 (20,500) | 604 (21,330) | 66 |
| 3 | 778 (27,500) | 393 (13,900) | 415 (14,660) | 47 |
| Total | 4,061 (143,500) | 1,539 (54,400) | 1,592 (56,200) | 61 |

rate at the booth intake face plus the mass of pollutant generated by the spray gun in the booth during painting. The right side of Equation (3) defines the mass flow rate exiting the booth into both the recirculation duct and the exhaust duct to the APCS.

Based on previous research, it is known that the exhaust concentration profile is not uniform across the exhaust face and forms a non-linear decreasing concentration gradient from the bottom to the top of the exhaust filter face.[8] Figure 5 is a general concentration profile at the exhaust face. The shaded area of Figure 5 represents the pollutant mass that enters the exhaust duct at the exhaust face below height a.

It is possible therefore to take advantage of this profile by strategically locating the exhaust duct to the APCS. The location of the flow partition is determined experimentally by testing and developing a concentration profile of the exhaust face of the booth.

Therefore, an additional element is added to Equation (3) that defines the impact of the partitioning of the booth flow to the recirculation and exhaust ducts. When incorporated into Equation (3), it locates the exhaust duct and relates the pollutant mass flow rate to the exhaust stream at the exhaust face. This relationship is defined by:

$$Q_e C_e = M_g(1 - X) + C_b Q_b(a \backslash H) \quad (4)$$

where:

X = percent of hazardous constituents generation in the booth exiting above height a.

a = partition height

H = exhaust face height

Substituting Equation (4) into Equation (3) yields:

$$(Q_r \times C_r) = (Q_b \times C_b)( 1- a/H ) + (M_g \times X) \quad (5)$$

The $(Q_b \times C_b)( 1- a/H )$ term in Equation (5) represents the hazardous constituent mass flow rate in the recirculation stream that is reintroduced at the intake face at Location A in Figure 4. The third term in Equation (4) represents the mass of pollutant that is introduced into the recirculation duct by the painting operation. The mathematical expression that defines the relationship between the constituent concentrations in the recirculation stream and the partition height therefore becomes:

## Results and Conclusions

The spray booth installations at the Barstow facility met all operating and safety design requirements projected at the beginning of the program. It was shown that concentrations in the booth were not significantly increased with the use of recirculation. To some degree the flow pattern in the booth improved the overall atmosphere of the booth. Each booth exhibited the concentration gradient found in previous booths tested and thus enhanced the recirculation potential of the designs.

Finally, after enclosing the booths, the atmosphere in the general work area was improved since out-leakage from the booths was reduced or eliminated. Table 2 presents a summary of the flow reductions achieved with the new or modified booths.

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