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MODELING OF HELICOPTER EXHAUST AT EMERGENCY HEALTH CARE FACILITIES

By Simona Besnea, P. Eng. and Glenn Schuyler, P. Eng.

This Technote presents a helicopter exhaust design criterion based on odor panel testing, describes a method for dispersion modeling of the helicopter exhaust using a wind tunnel, and interprets the modeling results with a view to odor impact mitigation. The results of the wind tunnel tests indicate that, generally, the helicopter exhaust concentration did not exceed health limits, but strong odor occurred at many of the locations tested for certain wind and operating conditions.

Helicopter (Bell 412U shown) exhaust can enter the building via air intakes / operable windows

INTRODUCTION

Helicopters are frequently used for emergency medical evacuation purposes. Due to the time-sensitive nature of the service, helicopter landing pads (helipads) are located next to emergency facilities for maximum efficiency. Helicopter exhaust can infiltrate nearby buildings through outside air intakes, operable windows and entrances, resulting in poor indoor air quality within the facilities.

This can lead to odor complaints from the building occupants, and reduced quality of the workplace environment.

Prevention of indoor environmental pollution begins with building design.

RWDI assessed the potential impacts of a Bell 412U twin-engine helicopter exhaust using physical (wind tunnel) modeling and data on engine exhaust odor strength. The objective of the study was to determine impacts of the helicopter exhaust at outside air intakes and other receptors located near the helipad area, and to provide some general guidance on mitigation.

Sensitive receptor locations

DILUTION CRITERIA FOR HELICOPTER EXHAUST

Dilution criteria are important for interpreting the results of dispersion modeling. Determining the level of dilution required to control helicopter exhaust impacts at sensitive locations is an important step in optimizing helipad and intake design. The criteria can be either health- or odor-related. A dilution criterion is determined by dividing the concentration of a given pollutant in the exhaust stream by a target concentration. The resulting ratio is the amount by which the exhaust stream must be diluted to bring the concentration of the pollutant down to the target concentration.

RWDI's recommended practice is to set the dilution criterion for a particular source to account for the most stringent of all applicable air quality criteria, standards and/or odor thresholds. Standards that may be consulted include National Ambient Air Quality Standards (NAAQS), guidelines set by the National Institute for Occupational Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH). If the level of dispersion achieved by the exhaust is equal or greater than the target dilution, then the standard is met, and the exhaust is therefore in compliance with all other applicable air quality and odor requirements consulted.

The concern with helicopter exhaust is two-fold. There are health concerns caused by combustion by-products, such as particulate matter (PM), carbon monoxide (CO), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), and concerns due to the high odor level of the exhaust.

From a health perspective, the type of pollutant for which the greatest dilution is required to meet the standard varies with operating conditions. For the Bell 412U twin-engine helicopter assessed during idling mode the limiting pollutant was CO, while for take-off conditions was SO_2. The exhaust required a dilution of about 50:1 for the idling scenario, and 40:1 for the take-off scenario.

Helicopter exhaust is also associated with strong, objectionable odor. RWDI carried out an independent helicopter odor-sampling program for a twin-engine BK-117 helicopter. This type of helicopter is considered typical of the models used as air ambulances. Based on manufacturer's specifications, an exhaust flow rate of approximately 26,000 cfm was calculated for each engine at full load. Two samples were taken from each engine: one with the engine idling, and one with the engine at full RPM. The latter case represents the RPM at take-off conditions; however, it represents only about 60% of full power, since the rotor blades were feathered during the sampling to give zero lift.

Our suggested dilution criterion for the helicopter exhaust odor is based on the 50% detection threshold, which is used as an industry standard for quantifying odor impacts.

Odor panel testing used to establish design criterion

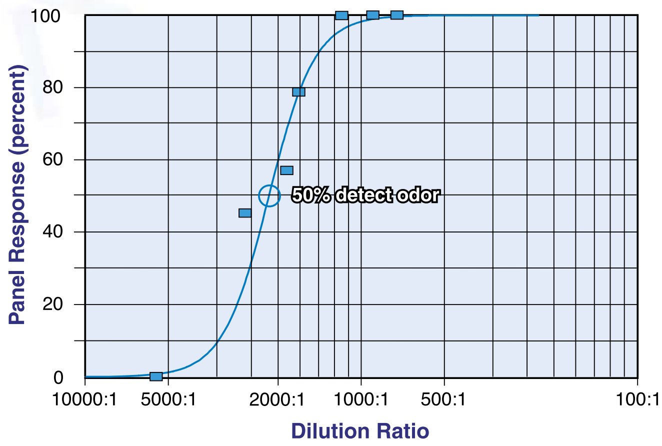

Figure 1: Human response data for idling helicopter engine

The odor threshold values differ based on the operating conditions assessed. When the engine is idling, the exhaust needs to be diluted by a factor of about 2,200:1 to reach a 50% detection response (i.e., 50% of a typical group of people can detect the odor). For full-power conditions, the same level of response was generated when the helicopter exhaust was diluted by a factor of about 1,500:1. Figure 1 illustrates the human response data for the idling engine. Note that 50% of the respondents detected the odor when it was diluted by 2,200:1.

WIND TUNNEL MODELING

For detailed assessments, where quantitative answers are needed to support costly design decisions, physical scale modeling in a boundary layer wind tunnel is the most accurate means of simulation. The boundary layer wind tunnel replicates the mean and turbulent characteristics of the approaching wind. It can simulate the behavior of wind flow around buildings and allows testing of many wind directions, wind speeds and a variety of design solution alternatives. The wind tunnel tests are conducted by emitting a tracer gas at a known concentration from the source. The measured concentration at each receptor is then compared to the tracer gas concentration at the source to determine the exhaust dilution.

The Bell 412U twin engine helicopter was assessed in the wind tunnel during two operating modes: full power and idle.

To gain a better understanding of the principles applied to simulating the helicopter rotor, one needs to review the effects the helicopter has on the airflow around the helipad area. Typical take-off conditions include the engines running at 100% power for about five minutes. During full-power mode, the helicopter rotor creates lift by pushing air down. At take-off or landing, the flow of air around the helicopter is pushed downward and spreads out, moving away from the center of the rotor. Once the helicopter lands, the thrust is reduced to zero and the downwash disappears. The velocity of the rotor wake of a helicopter is a function of the disc loading, which is defined as the gross weight of the helicopter divided by the rotor disc area (area of the circle scribed by the tip of the rotor blade). A heavier craft requires higher lift that can be accommodated by an increase in the disc area, disc loading, or a combination of both.

The modeling of the helicopter downwash is based on equating the lift force to the velocity pressure generated over the rotor disc. Lift is obtained from the rotation of the main rotor blades, and represents the upward force resulting from the combination of decreased pressure on the upper surface and increased pressure on the lower surface of the blades.

Based on simple momentum considerations, for a rotor in hovering condition out of ground effect, the mean induced velocity in the plane of the rotor is a function of the rotor disk loading. Published literature on experimental studies of the flow beneath a hovering rotor in the proximity of the ground shows that wake velocities similar to the values predicted by simple momentum theory are likely to be encountered along the surface of the ground.

To simulate rotor lift, the following main assumptions were made:

- Coefficient of lift for the model is equal to the coefficient of lift for the prototype (i.e., full scale helicopter).
- The ratio of downwash velocity to ambient wind velocity at ground level is the same in both model and prototype.
- All model dimensions were scaled equally including the diameter of the rotor.

The ratio of wind speeds at ground level and the ratio of disk areas were simulated based on wind tunnel scaling procedures.

The downwash generated during take-off conditions was simulated using a model propeller. The propeller was attached to a flexible shaft mounted on a strain-gauge flexure, calibrated to measure the uplift force of the propeller.

During idling conditions, when the rotor does not produce thrust, no downwash is created and therefore, the helicopter exhaust was modeled as a point source pointing towards the tail of the helicopter. The model helicopter and rotor can be seen in Figure 2. Note the exhaust source pointing rearward from the engine compartment.

DISCUSSION OF RESULTS

For the configuration tested, the helipad was located on the roof of the hospital and receptors representing sensitive areas, such as outside air intakes, pedestrian locations, operable windows, etc. were installed on the model (figure 3). The receptors were placed approximately 50 feet below the helipad, on the face of the building, and on the roof, at about the same distance. Local wind conditions and helicopter flight approach path generally dictate the directionality of the helicopter tail pipe. We selected a worst-case scenario, where the tail pipe was located directly above the face of the building where the receptors were located. Alternate receptor locations were selected over 100 feet away from the helipad, on the opposite side of the building.

Figure 2: Wind tunnel testing of helicopter model

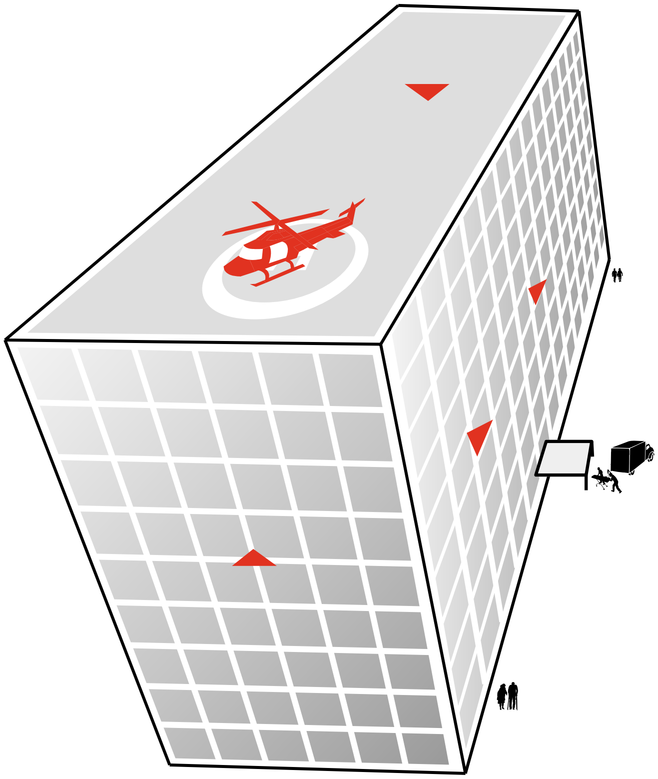

Figure 3: Receptor locations at health care facility

The results of the wind tunnel study showed that the health-related dilution criterion could be met at receptor locations at least 30 feet away from the helipad, in any direction.

The level of impact at the rooftop receptors varied with operating mode, location and wind conditions. For idling conditions, worst-case dilutions of about 500:1 were measured at the rooftop locations. For the take-off scenario, the helicopter exhaust, although influenced by the movement of the propeller, was caught in the recirculation zone of the building and experienced limited dispersion (dilutions of about 800:1). Receptor locations on the opposite side of the building offered better protection from the helicopter exhaust impacts and resulted in improved dilutions, greater than 1,300:1 during take-off conditions.

Generally, the actual take-off lasts less than one minute; however, the short preparation time when the helicopter's power and exhaust flow rate are increasing creates brief but strong odor impacts. The level of odor experienced within the building may be reduced much of the time. Internal dilution takes place within the air handling system when odor events are short, relative to the time it takes to replace the air in the building. The number of air changes provided through the ventilation system will affect the rate of build-up of odor within the building. As an example, for a ventilation rate of 10 air changes per hour and an odor event lasting one minute, the magnitude of odor infiltrated in the building will be about one tenth the level of odor reaching the air intake.

A probability analysis of the wind tunnel data was performed by combining the dilution data with site-specific hourly meteorological data, statistically analyzed to provide probabilities of occurrence for various combinations of wind speed and direction. The analysis is helpful in gaining perspective on the likelihood of an odor event occurring at a given location, based on dilution considerations and local meteorological conditions. As an example, there may be receptors where the dilutions measured are below the recommended target; however, the probability of odors may be sufficiently low that they may not represent a concern. Detailed results of the frequency analysis are not presented in this note.

CONCLUSIONS

Odors from helicopter exhausts are a concern at many healthcare facilities. Addressing this concern can become a challenge if helipads must be located close to sensitive intakes. Numerical modeling of the exhaust is likely to provide conservative predictions of impacts, as it does not account for the downwash effect. The level of conservatism will vary with the location of the receptor and operating mode.

Physical modeling of the helicopter exhaust provides valuable information regarding the magnitude of impacts during two main operating modes of the helicopter. Wind tunnel modeling of the helicopter exhaust not only provides a scale replica of the study site, it also simulates specific operating mode effects resulting in more accurate predictions of impacts.

The results of the wind tunnel testing of the helicopter exhaust show that strong odors are likely at many nearby sensitive areas for certain wind and operating conditions. Odors are strongest for the take-off condition, with worst-case dilutions being about 300:1, which is a factor of five below recommended values. During take-off, odors at locations below the helipad area are almost twice as strong as for the idling scenario. For idling conditions, rooftop areas will experience the strongest odors (dilutions of about 500:1), depending on the location and wind conditions.

Design guidance and mitigative measures are available based on the sensitivity of the receptors and characteristics of the site. Where feasible, consideration may be given to shutting down the outside air intakes during landing and take-off of the helicopter to eliminate potential odor infiltration. If helicopter exhaust odor is identified as a concern during the design stage, we recommend that the helipad-to-intake separation distance be increased to the greatest extent possible and hidden from direct line-of-sight by building elements.

REFERENCES

Evan A. Fradenburgh "Flow Field Measurements for a Hovering Rotor Near the Ground". Paper presented before the American Helicopter Society Fifth Annual Western Forum, Los Angeles, CA.