IMPACT OF TRAUMA HELICOPTERS ON AIR QUALITY INSIDE HOSPITALS

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ABSTRACT

Many modern hospitals use trauma helicopters (air ambulances) to fly trauma teams to patients in need of urgent medical care. The helicopter deck is often situated on the roof of the hospital, where many of the hospitals air-conditioning vents are also located. As a result, the activities of a trauma helicopter can become a serious threat to the air quality inside the hospital. On many occasions wide spread complaints about unpleasant odours and related health problems manifest themselves throughout the hospital, even from staff in the operating theatres.

In order to determine the complex dispersion of air pollution, a scale-model of the hospital was built. The dispersion of exhaust fumes was thoroughly researched using tracer gas measurements executed in the Peutz atmospheric boundary layer windtunnel, in combination with air velocity and concentration measurements on site.

Various helicopter activities (take-off and landing, engine idling) and different windconditions (direction and speeds) were simulated and analyzed with windtunnelmeasurements. Local windspeeds, rotor blades induced airspeeds and air pollutant concentrations measured on site were used to verify results obtained by the scale-model in the windtunnel. For the maximum deployment of the helicopter, pollution levels both outside and inside the hospital were determined. For the latter the ventilation-rate of different rooms plays an important role. Based on the windtunnelstudy a plan was made to improve the indoor air quality by means of for example deflection, use of air filtration or repositioning the air-conditioning vents to clean surroundings.

INTRODUCTION

Peutz bv has researched the dispersion of the exhaust fumes from a trauma helicopter which is stationed on the roof of a specific hospital, see figure 1.

Figure 1: Top view of the hospital

The research consisted of 2 phases:

Phase 1: Measurements of the concentrations of hydrocarbons (volatile organic compounds) on the roof of the hospital near the air-conditioning vents of the hospital due to the helicopter activities, and measurements of the helicopter-induced air velocities on the roof;

Phase 2: Research into the dispersion of the fumes, using the Peutz atmospheric boundary layer windtunnel in order to make a plan to improve the air quality inside the hospital by means of deflection, the use of air filtration or repositioning of the air-conditioning vents.

This paper describes both phases of the research, the measuring methods, dispersion results and proposed solutions.

DESCRIPTION OF THE HOSPITAL AND HELICOPTER SPECIFICATIONS

The hospital has a staff of approximately 7000 and consists of 5 building layers, 1350 beds, 9 wings (wards) and 27 operating theatres. The hospital uses a trauma helicopter which is stationed on the roof of the hospital. In figure 2 a top view of the hospital is given, including the location of the helicopter deck and 8 air-conditioning vents on the roof of the hospital, near the helicopter deck. Many of the relevant air-conditioning vents are located within a radius of 50 metres from the helicopter deck.

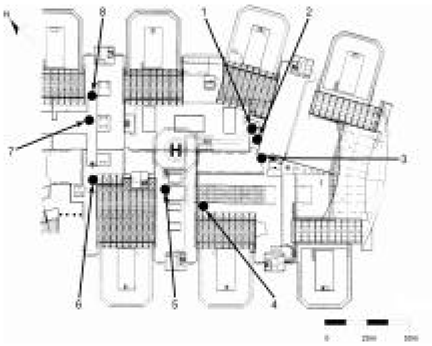

Figure 2: Location of the helicopter deck and air-conditioning vents

The rooms inside the hospital are connected to the air-conditioning vents on the roof. For the operating theatres the ventilation-rate is approximately 24 times per hour. For other rooms (wards etc.) the ventilation-rate is 4 to 6 times per hour.

The helicopter used is a Boeing MD Explorer 902, see figure 3. This helicopter has two Pratt & Whitney Canada PW206E turboshaft engines, and a rotor-diameter of 10.3 m.

Figure 3: Boeing MD Explorer 902

The emissions of hydrocarbons from the helicopter depend on the engine-load. During idling the emission of hydrocarbons per engine is approximately 1.06 g/s, during the take-off and landing this emission is 0.042 g/s (maximum-power), based on information given by Boeing [1]. The emissions of hydrocarbons during idling are (much) higher due to the engine operating outside it's optimal range.

The odour emissions from the helicopter are based on research by TNO in 1993 [2]. In a testcel several odour emission measurements were performed, combined with simultaneous measurements of hydrocarbon concentrations. Based on these measurements odour emission values for helicopter emissions were determined to be approximately 0.085 ou_E/µg (idling) and 1.5 ou_E/µg (take-off/landing). Using these results the total odour emissions from the 2 engines of the trauma helicopter can be estimated to be approximately 650 Mou_E/h during idling and 450 Mou_E/h during take-off and landing.

After starting the engine, the helicopter stays idling for 2 minutes. After that the helicopter needs approximately another 25 seconds to fully clear the building. During a normal working day the helicopter has 4 take-offs and landings on the helicopter deck. Landing takes also approximately 25 seconds and 2 minutes of idling.

PHASE 1: HYDROCARBONS AND AIR VELOCITIES

Hydrocarbons

During a series of 4 take-offs and landings of the helicopter, within a period of approximately half an hour, air samples were taken near several air-conditioning vents on the roof of the hospital. Measurements were also performed in two rooms of the hospital: in an operating theatre and in a waiting room. During the measurements the winddirection was north, the windspeed was approximately 4 m/s (at 10 m height, freefield). The measurements were performed using active carbon absorption-tubes. The active carbon absorption-tubes were then tested in a laboratory for over 120 organic compounds, such as n-butane and n-pentane (the most relevant compounds found in exhaust fumes), benzene and toluene (the most relevant aromatic hydrocarbons).

Analysis of the absorption-tubes showed that the measured concentrations of hydrocarbons near the air-conditioning vents on the roof of the hospital were all below the detection limit of the chosen measuring method. From this, the time average concentration of hydrocarbons during the measurements was calculated to be lower than 109 µg/m^3. This result will be verified by windtunnelmeasurements (see Phase 2).

Air velocities

During the helicopter activities air velocities were monitored in various positions near the helicopter deck, using heated-wire anemo-meters. Every 10 seconds both the maximum velocity and the average velocity over all the measuring positions were determined. In figure 4 the measured (maximum/average) air velocities during the measurements are shown. These measurements were used in Phase 2 to verify the windtunnelmeasurements.

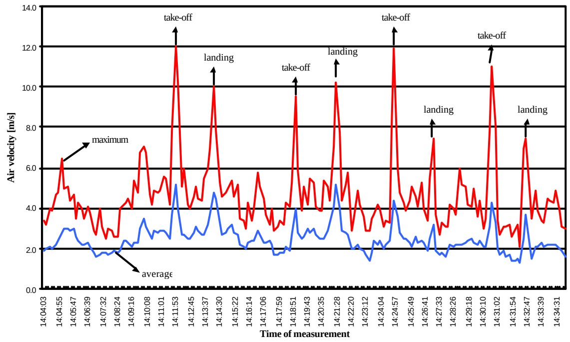

Figure 4: Air velocities around the helicopter deck during measurements

In figure 4 the effects of take-offs and landings can clearly be seen. The average air velocity around the helicopter deck was up to approximately 5 m/s, the maximum air velocity was approximately 12 m/s. Figure 4 also shows that during idling the maximum measured air velocities around the helicopter deck were comparable to the average air velocities over all the measuring positions. This means that during idling the influence of the helicopter on the air-flows on the roof of the hospital is relatively small. During take-off and landing, the helicopter has much more influence on the air-flows.

PHASE 2: WINDTUNNELSTUDY AND MEASURES

At this stage of the research a windtunnelstudy was made in order to get a clear understanding of the air-flows on the roof of the hospital. First a scale-model of the hospital and it's surrounding buildings was made (scale 1 : 200), see figure 5.

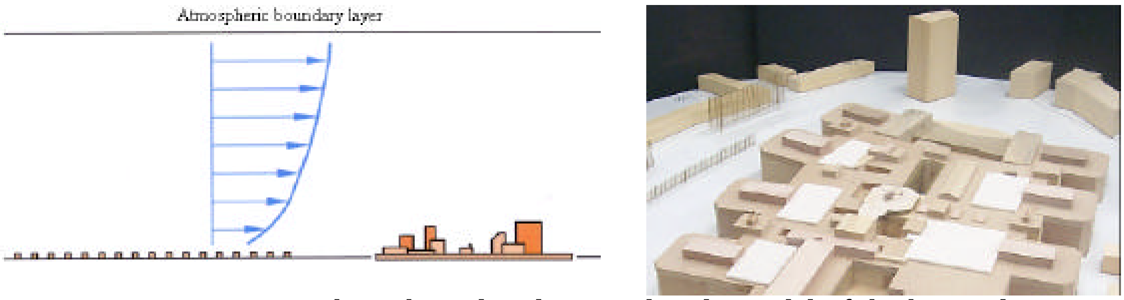

Figure 5: Atmospheric boundary layer and scale-model of the hospital

The helicopter-induced air-flows on the roof of the hospital were simulated in the Peutz atmospheric boundary layer windtunnel (see figure 6) using a tube above the helicopter deck. This tube was used to simulate a down-wind air-flow above the helicopter deck.

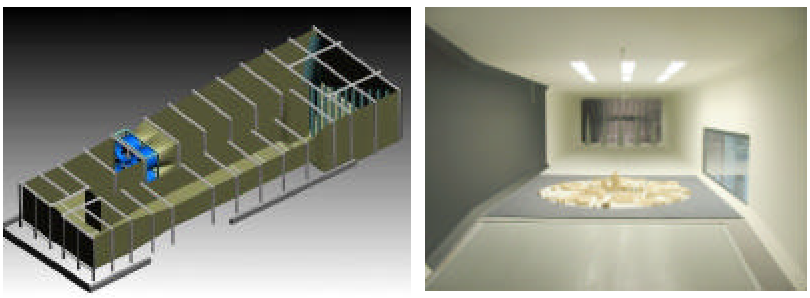

Figure 6: Peutz atmospheric boundary layer windtunnel

To verify the windtunnel scale-model, the results of the air velocity measurements on the roof of the hospital (see figure 4) were used. The situations *without* and *with* the influence of the helicopter were researched. In the windtunnel, the average windspeed was determined for every velocity-measuring position, related to the windspeed in the free field at a height of 10 m. For both situations, the results of the velocity measurements in the windtunnel were comparable to the velocity measurements on the roof of the hospital. The average deviation (RMS) over all the measuring positions was found to be around 6% for the situation *without* the influence of the helicopter. For the situation *with* the influence of the helicopter this deviation was found to be around 13%.

The optimal simulation of the actual velocity measurements on the roof of the hospital with the influence of the helicopter was found with U_s / $U_{10,m}$ = 3.0 and h = 0.05
where: U_s = vertical windspeed from tube-opening in windtunnel [m/s];
$U_{10,m}$ = windspeed in the windtunnel, freefield, at 10 m height [m/s];
h = distance between tube-opening and helicopter deck [m].

CONCENTRATION MEASUREMENTS

Using the windtunnelmodel, the dispersion of the exhaust fumes from the helicopter was researched. Measurements were performed by means of a tracer-gas (isobutylene). From the concentration measurements in the windtunnel a concentration coefficient K per winddirection could be calculated, see equation (1).

$$K = \frac{C \, . U_{10,m} \, . S^2}{Q} \tag{1}$$

where:
K = concentration coefficient [1/m^2];
C = tracergas-concentration at the measuring position [g/m^3];
S = scalefactor of the windtunnelmodel [-];
Q = tracergasflow [g/s].

Because the concentration coefficient K depends on the relation $U_s/U_{10,m}$, measurements were carried out for $U_s/U_{10,m}$ = 0 to 9.8. The actual immission concentration on the roof of the hospital could be achieved using equation (2).

$$C_i = \frac{K \, . Q}{U_{10,w}} \tag{2}$$

where:
C_i = actual immission concentration [g/m^3];
Q = emissionflow from helicopter [g/s];
$U_{10,w}$ = actual windspeed at 10 m height, free field [m/s].

CONCENTRATION OF HYDROCARBONS

Based on the windtunnelmeasurements, using the hydrocarbon emission values for helicopter emissions during idling and during take-off and landing (as presented before), the maximum immission concentration of hydrocarbons during the Phase 1 measurements on the roof of the hospital could be calculated. From the time the helicopter was active above the hospital during the measurements (approximately 20 minutes) the time average concentration of hydrocarbons was determined. In table 1 some results are shown.

Measuring point / vent (see figure 2)	Calculated immission concentration of hydrocarbons (µg/m^3)		
	idling	take-off / landing	time average
1	<1	20	3
2	<1	22	3
3	6	30	9
4	76	20	69
5	<1	37	5
6	<1	6	1
7	<1	<1	<1
8	<1	<1	<1

Table 1: Calculated immission concentrations during measurements on the roof of the hospital

The values in table 1 show that the time average immission concentrations during the actual measurements on the roof of the hospital were never higher than 70 µg/m^3, which is in agreement with the analysis results in Phase 1 (all concentrations below 109 µg/m^3).

From table 1 it can be seen that during idling the influence of the helicopter on the air-flows on the roof of the hospital is relatively small, because higher immission concentrations were found in only 1 or 2 positions (situated downwind during the measurements). During take-offs and landings higher immission concentrations were found in almost all positions, which means that the helicopter has a great influence on the air-flows on the roof of the hospital. These results are in agreement with the air velocity measurements in Phase 1.

From the results in table 1, and the time the helicopter was active above the hospital during the series of 4 take-offs and landings, it can be calculated that the contribution to the 8-hours average concentration levels was less than 3 µg/m^3. The contribution to the yearly average concentration was less than 1 µg/m^3. In table 2 maximum allowable concentration (MAC-) levels are shown for a few components, based on Dutch legislation [3] (in British legislation known as Occupational Exposure Limits).

Component	Limit (mg/m^3)	Average time
n-butane	1430	8 hour
n-pentane	1800	8 hour
benzene	3.25 / 0.01	8 hour /1 year
toluene	150	8 hour
naphthalene	50	8 hour

Table 2: Maximum allowable concentration levels (Dutch legislation)

It can be concluded firstly that the actual hydrocarbon levels due to the helicopter activities are relatively small and secondly that the measured concentrations were much lower than the maximum allowable concentration levels shown in table 2.

ODOUR CONCENTRATIONS

Using the windtunnelmeasurements and the odour emission values for the helicopter (as presented before), the odour immission concentrations near the air-conditioning vents were calculated to be 200 to 450 ou_E/m^3 during idling and 40 to 80 ou_E/m^3 during take-off and landing.

The odour immission concentrations inside the hospital can be obtained considering three situations:
Emission period 1 : idling (approximately 2 minutes);
Emission period 2 : take-off/landing (approximately 25 seconds);
Emission period 3 : no helicopter activities.

The concentration inside the hospital can be calculated using equation (3).

$$C_r = C_{in} + (C_o - C_{in}) . e^{-q.t} \qquad (3)$$

where:
C_r = odour concentration inside the room [ou_E/m^3];
C_{in} = odour concentration at the vent on the roof of the hospital [ou_E/m^3];
C_o = odour concentration inside the room at the beginning of an emission period [ou_E/m^3];
q = ventilation-rate of the room connected to the vent [1/s];
t = time [s].

With this equation, the odour concentration inside a waiting room and an operating theatre could be determined for 1 take-off or landing. In figure 7 the odour immission concentrations near the vent and inside the hospital during this take-off or landing are shown for a situation where the odour concentration at the vent was approximately 300 ou_E/m^3 during idling and approximately 55 ou_E/m^3 during take-off.

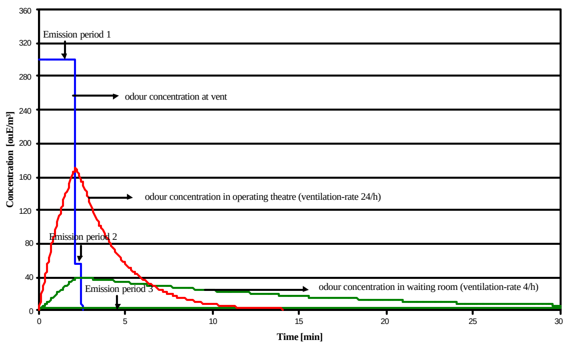

Figure 7: Odour immission concentrations near the vent and inside the hospital

The time that the odour can be present in the rooms inside the hospital was calculated to be from approximately 10 minutes (operating theatre) to over an hour (waiting room), see figure 7. These results confirm the complaints from the staff, that the odour nuisance can be present for a very long time, even long after the helicopter has left.

With the windtunnelmeasurements, the odour emission values and equation (3) it was possible to determine for every room inside the hospital the maximum odour concentration (taking place during the worst meteorological circumstances: low windspeed, 1 m/s, and wind blowing from the helicopter to the connected vent, during idling). In table 3 these results are shown for 3 different types of rooms (ventilation-rate 4/h and 6/h for waiting rooms and wards, and ventilation-rate 24/h for operating theatres).

Room connected to vent nr. (see figure 2)	Ventilation rate of the room		
	4/h	6/h	24/h
	Maximum odour concentration inside the hospital [ou_E/m^3]		
1	40	57	172
2	40	57	177
3	52	77	232
4	40	57	172
5	65	92	285
6	47	70	212
7	25	35	107
8	32	47	145

Table 3: Maximum odour concentration inside the hospital

From these calculations rooms connected to vent number 5 appeared to have the highest maximum odour concentrations. In consultation with the hospital, repositioning of vent number 5 and 8 was researched with windtunnelmeasurements.

For rooms with a ventilation-rate of 4/h the maximum odour concentration in the room was calculated to be approximately 65 ou_E/m^3, see table 3. With the odour emission factor of the helicopter for idling, the maximum concentration of hydrocarbons in these rooms turned out to be approximately 0.8 mg/m^3. For rooms with a ventilation-rate of 6/h and 24/h the maximum concentration of hydrocarbons in the rooms turned out to be approximately 1.1 and 3.4 mg/m^3. Based on calculations and windtunnelmeasurements (for different windspeeds and winddirections), the 8-hour and yearly average immission concentrations can be calculated (using meteorological data). It appeared that the relevant limits shown in table 2 will not be exceeded.

REPOSITIONING VENTS

For the air-conditioning vents with number 5 and 8 the effects of repositioning the vents to a location further from the helicopter deck was researched. In figure 8 the new situation is shown.

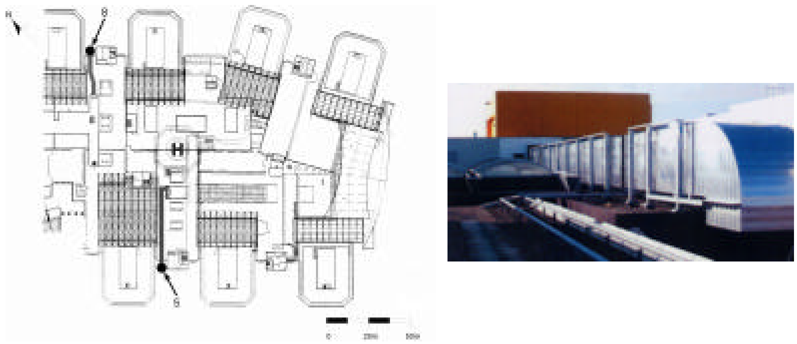

Figure 8: Location of vents 5 (photo) and 8 after repositioning

In table 4 the results of the new windtunnelmeasurements and calculations are shown.

Room connected to vent nr. (see figure 2&8)	Ventilation rate of the room					
	4/h		6/h		24/h	
	Maximum odour concentration inside the hospital [ou_E/m^3]					
	before	after	before	after	before	after
5	65	12	92	17	285	50
8	32	7	47	10	145	32

Table 4: Maximum odour concentration before and after repositioning the vents

The results show a significant reduction (up to 82%) in odour concentrations inside the hospital due to repositioning of the vents.

<u>ODOUR NUISANCE THRESHOLD VALUES IN THIS SITUATION</u>

Based on huge complaint-lists from the hospital staff (combined with the measurement results) "odour nuisance threshold values" for complaints regarding odour immissions from the helicopter for this situation could be obtained. These "odour nuisance threshold values" give an indication about the odour levels inside the hospital, at which people start to complain.

For rooms with a ventilation-rate of 4/h the "odour nuisance threshold value" was determined to be approximately 7 ou_E/m^3. For rooms with a ventilation-rate of 6/h and 24/h this value was determined to be respectively approximately 27 and 122 ou_E/m^3. These values are specifically for this situation and cannot simply be used in other situations.

Combining these deduced "odour nuisance threshold values" and meteorological information (windspeeds and winddirection), the probability of concentrations occurring inside the hospital that are higher than the threshold values were determined for rooms connected to vent number 5 or 8, see table 5.

Room connected to vent nr. (see figure 2&8)	Ventilation rate of the room					
	4/h		6/h		24/h	
	Probability of exceeding the "odour nuisance threshold value" inside the hospital before and after repositioning the vents [%]					
	before	after	before	after	before	after
5	24%	<1%	15%	<1%	7%	<1%
8	15%	<1%	1%	<1%	<1%	<1%

Table 5: Probability of exceeding the threshold value before and after repositioning

Table 5 shows that for less than 1% of all helicopter activities the "odour nuisance threshold values" will be exceeded after realising the measures (i.c. repositioning the vents).

<u>OTHER MEASURES</u>

The effect of deflection of the air-flow is not that great. Deflection of air-flows often calls for very elaborate constructions which often spoil the aesthetics of the building. The concentrations can be reduced by approximately 40 to 50%, however, the height of the deflecting objects must be significant (6 to 8 m) and over a considerable length (more than 75 m).

Active carbon air filters can be used to reduce up to 80% of the odour immissions in standard industrial situations. In this case the odour concentrations of the air entering the vents (several hundreds of ou_E/m^3) is relatively low compared to usual industrial situations (where odour concentrations are between 5,000 and 100,000 ou_E/m^3). Furthermore, the air-flow rate through the ventilation system of the hospital is relatively high (typical 40,000 - 60,000 m^3/h per vent). Due to this and the low odour concentrations, carbon filters will have problems to absorb the organic compounds effectively. High humidity is also a limiting factor (obstruction, saturating the filter with water). Furthermore dust-filters will be needed, causing a pressure loss and thus a loss of ventilation flow.

EPILOGUE

Considering the possibilities, the hospital has chosen to reposition vent number 5 and 8. At present time this repositioning is finished, and the first results are promising: many positive reactions on the air quality inside the hospital are reported from the staff.

REFERENCES

1. Emission Data Sheets PW206E, Pratt & Whitney Canada Inc., from Boeing.
2. Report R93/267 "Luchtverontreiniging en geur (Thematische bijlage bij het Integrale Milieueffect Rapport Schiphol), November 1993 from TNO-MW, The Netherlands.
3. Report "Nationale MAC-lijst 2004", from the Ministry of Social Affairs and Employment, The Netherlands.