MEASUREMENT OF PEAK TEMPERATURE RISE ABOVE HELICOPTER PLATFORMS DUE TO HOT GAS PLUMES

–INTERPRETATION AND EVALUATION OF REGULATIONS ON TURBULENCE AND HOT GAS PLUMES-

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Abstract

Turbulence and temperature rise criteria for helicopter platforms are defined in CAP 437. To the authors opinion there is no discussion on the relevance of these criteria. Guidance on the assessment techniques should be improved however as the current guidance seems to advise some techniques that cannot evaluate the physical properties defined in the criteria. Also guidance on the practical use of the results of the temperature rise assessment would be very useful. At the current state of the art the assessment of the turbulence and temperature rise criteria can only be made in a properly scaled buoyant plume wind tunnel experiment. Suggestions for improvement of the guidance on interpretation and evaluation are given.

1. INTRODUCTION

Design guidelines with respect to turbulence and hot gas plumes for offshore helicopter platforms are given in CAP 437 [1]. These regulations have originated form an extensive research programme, documented in CAA papers 99004 [2], 2004/03 [3], 2008/03 [4]. The research programme has shown that turbulence and air temperature are the most important environmental conditions, having a significant impact on the safe operations of helicopters. The advised methods for turbulence and hot gas plume assessment however are to the authors opinion not fully in agreement with the nature of the physical properties to be evaluated. Therefore there is the need for a harmonised approach to assess these parameters, especially concerning the assessment of temperature rise due to hot gas plumes.

2. TURBULENCE AND PEAK TEMPERATURE RISE CRITERIA

2.1. Turbulence criterion

CAP 437 [1] chapter 3, paragraph 2.3.2 states: *"All new build offshore helidecks, modifications to existing topside arrangements which could potentially have an effect on the environmental conditions around an existing helideck, or helidecks where operational experience has highlighted potential airflow problems should be subject to appropriate wind tunnel testing or computational fluid dynamics (CFD) studies to establish the wind environment in which helicopters will be expected to operate. As a general rule, a limit on the standard deviation of the vertical airflow velocity of 1.75 m/s should not be exceeded. The helicopter operator should be informed at the earliest opportunity of any wind conditions for which this criterion is not met. Operational restrictions may be necessary."*

2.2. Peak temperature rise criterion

CAP 437 [1], chapter 3, paragraph 2.3.3 states: *"Unless there are no significant heat sources on the installation or vessel, offshore duty holders should commission a survey of ambient temperature rise based on a Gaussian dispersion model and supported by wind tunnel tests or CFD studies for new build helidecks, significant modifications to existing topside arrangements, or for helidecks where operational experience has highlighted potential thermal problems. When the results of such modelling and/or testing indicate that there may be a rise of air temperature of more than 2°C (averaged over a three second time interval), the helicopter operator should be consulted at the earliest opportunity so that appropriate operational restrictions may be applied."*

2.3. Evaluation of good practise guidelines

Acknowledging the physical importance of these parameters the CAA guidelines advise to assess the properties of the airflow around the platform in the design stage. Also some guidance on the methods of assessment is given. For both criteria CFD and wind tunnel research are advised [4]. Strengths and weaknesses of both techniques are discussed. The conclusions of this discussion of strengths and weaknesses are to the authors opinion not fully in agreement with the nature of the physical properties to be evaluated:

1. CFD simulations cannot provide a direct measure for the turbulence criterion (standard deviation of the vertical airflow), because only mean flow properties (velocity and turbulent kinetic energy) are calculated. In wind tunnel research this quantity can be measured directly.
2. Although the use of turbulence models and their limitations in CFD calculations is discussed [4], this method is advised as best practise for hot exhaust gas dispersion calculations. This is not correct. Industrial CFD codes, usually Reynolds Averaged Navier Stokes (RANS) codes using a turbulence model, provide temporally and spatially averaged properties of the flow, like mean flow velocity. A plume dispersion calculation with such a model will result in an average stationary plume trajectory based on average flow properties, whereas the physical nature of a plume is a highly fluctuating one. Therefore it is impossible to obtain 3-second peak temperature data from a CFD calculation of average temperature rise.
3. Gaussian plume models are generally not well suited for evaluation of dispersion close to a source, especially when the flow is disturbed by nearby obstacles (which is mostly the case for offshore helidecks). Gaussian models can be used for a first estimate of dispersion conditions, especially at larger distances from the source.

When CFD codes are used the results need to be validated. Widely used is a comparison with the average flow field and TKE of a reference wind tunnel experiment. However, especially in dispersion modelling (dispersion of temperature or contaminants is similar) a validation of CFD code with average flow velocities and TKE as validation parameters is not sufficient to provide a validation on dispersion as these processes also depend on the size and distribution of eddies. A direct validation of temperature and concentration data is needed.

More advanced CFD methods such as LES, DES, DNS might provide better results than standard RANS models (at an enormous increase of time and cost) but there is often still a lack of sufficient validation.

A properly scaled wind tunnel experiment with sufficiently high measurement time resolution can provide actual data on the 3-second peak temperature from the highly fluctuating signal at any position in the flow field. Requirements on buoyant plume wind tunnel experiments are summarized in [4]. Proper modelling, validation and documentation of the approach flow velocity and turbulence profiles is also required.

2.4. Wind tunnel survey of a helideck

To illustrate the assessment procedure and interpretation of the criteria some examples of measured data from the assessment of a helideck located above the bow of a deep water construction vessel are shown. The vessel is equipped with a dynamic positioning (DP) system for stationkeeping during pipe-laying operations. The layout of the helideck is shown in figure 1, the proximity to the vessel's exhaust stacks is obvious.

Figure 1: Exhaust flow visualisation over helideck

The turbulence criterion is stated unambiguously, therefore the assessment of turbulence properties is rather straightforward. In figure 2 an example of a resulting limitations graph is given.

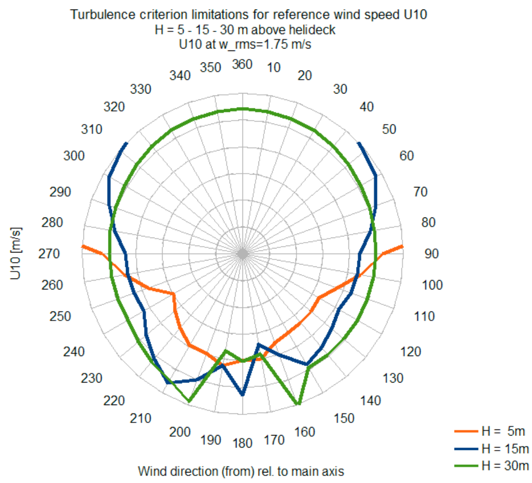

Figure 2: Turbulence limitations graph

This paper mainly focuses on the temperature rise criterion. The exhaust temperature is in the range of 300-400 ºC at an exhaust velocity of 30-40 m/s. The temperature of the gas plume was simulated using a buoyant gas plume. The dispersion of the tracer gas (density) is therefore a direct measure for the temperature. The wind tunnel experiment was conducted at a geometrical model scale of 1:200 and the flow parameters were scaled according to:

- Similarity of the Froude number between wind tunnel model and full-scale
- Similarity of stack exhaust velocity to free flow wind velocity ratio between wind tunnel model and full-scale
- Similarity of plume density to ambient air density ratio between wind tunnel model and full-scale

The approach flow profile was validated against reference profiles for mean wind velocity and turbulence specified by the American Petroleum Institute (API) [5].

A scaling to the above parameters puts a very high demand on the wind tunnel and measurement equipment. The wind tunnel needs to run stable at low wind velocities while maintaining the correct approach flow. The time scaling of the experiment results from the other scaling parameters. As a result of which a high demand is put on the time resolution of the measurement equipment to perform concentration measurements at a full scale equivalent of 3 seconds.

Apart from a high demand on the wind tunnel operating velocity range and time resolution of measurement equipment, also measurement time demand is very high to capture enough statistics of the fluctuating signal.

2.4.1. Statistics of the temperature signal

The highly fluctuating nature of the temperature in a plume close to the emission point is shown in figure 3, measured at 15 m above the centre of the helideck. The question should be raised how long a measurement series needs to be to measure the 3-second peak temperature rise.

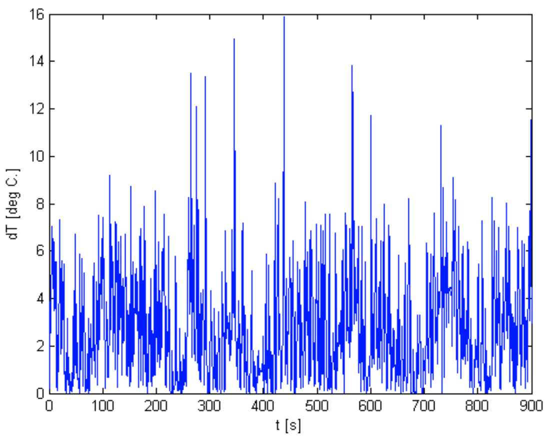

Figure 3: Example of 3-second temperature measurement time series

This is illustrated by the fact that the true maximum 3-second peak temperature rise at a specified wind condition is very unlikely to occur, for example only once in 45 minutes or even longer (full scale). Thus measurement time resolution needs to be sufficiently high to actually measure 3-second averaged temperatures (full scale) and measurement time needs to be long enough for the maximum value to occur at this condition. To the authors opinion therefore guidance needs to be provided on the required quality of the measurements in terms of a quality criterion on measurement time.

Considering that in real life wind conditions (wind velocity and wind direction) are rarely stable for time periods this long, it is very unlikely that a full scale reference experiment can obtain the true absolute maximum values. In a wind tunnel experiment however the flow can be conditioned for a sufficiently long measurement time. Therefore it is possible that even at a platform that shows good average flow properties or has a good service record, unfavourable conditions simply never occurred at the time of helicopter operations and therefore have not been identified. The added value of wind tunnel research is the fact that it can reveal unfavourable conditions, even if they are very unlikely to occur.

3. QUALITY CRITERION FOR MEASUREMENTS OF PEAK TEMPERATURE RISE

Guidance on the evaluation of the maximum temperature rise from a time series is needed. The temperature rise criterion suggests that it should be interpreted as the measured maximum 3-second temperature rise obtained from an infinite time series.

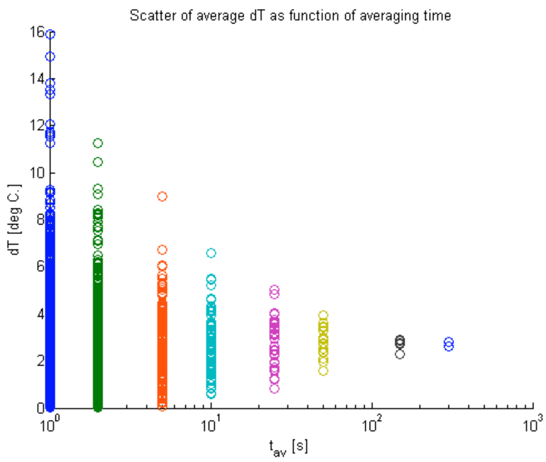

Figure 4: Scatter plot of temperature time series measurement

In an extremely long (infinite) measurement series, the measured maximum is the absolute maximum. For shorter measurement series (which are used in real life experiments) the guidelines should provide information on a quality criterion for the measurement duration (which influences the measured peak temperature) and the probability of the maximum value to be evaluated.

A proposal for a quality criterion on the measurement duration can be set as a maximum value of the standard deviation of several sets of average long term temperature rise data. From evaluation of the average temperature rise of multiple sets with increasing averaging time a convergence curve of the standard deviation of the average temperature rise with increasing measurement duration can be drawn, see figures 4 and 5.

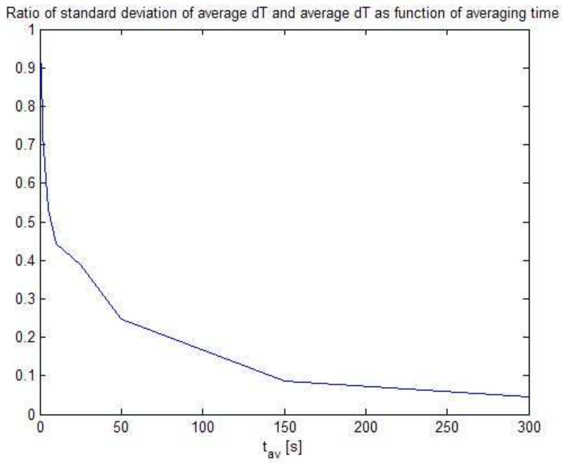

Figure 5: Convergence of standard deviation of time series

In dispersion modelling for example a standard deviation in the range of 1-5% is quite commonly used to evaluate measurement time. The convergence of the standard deviation with increasing measurement time also shows that the quality criterion needs to be chosen carefully as a small reduction of the standard deviation (for example from 5% to 2%) requires a large increase in measurement time, see figure 5.

In the example experiment the measurement duration was chosen as 300 s, which gives a standard deviation of long term averages of approximately 4.5%, see figures 4 and 5. The absolute measured maximum 3-second peak temperature was evaluated from this signal and reported. The probability of occurrence of the maximum is however very low approximately 0.1%.

Obviously this results in high temperatures specified as pilots information, see figure 6. If for example only average temperatures were specified (this could be compared to the result of a properly validated CFD experiment) a much lower temperature (a factor 5-10 lower) would be specified (with a high likelihood to be exceed).

If true maximum temperatures from engine exhaust stacks or similar equipment is evaluated this means very strict limitations will result as peak temperatures, depending on wind direction, up to 10-80 ºC can occur, figure 6. If however only the average values from a long term wind tunnel measurement or a CFD calculation are evaluated with the 2 ºC criterion, restrictions are less likely to be imposed as there can easily be a factor of 5-10 difference between true maximum 3-second temperature values and average values. Therefore guidance on the required assessment techniques and evaluation of the criterion should be developed.

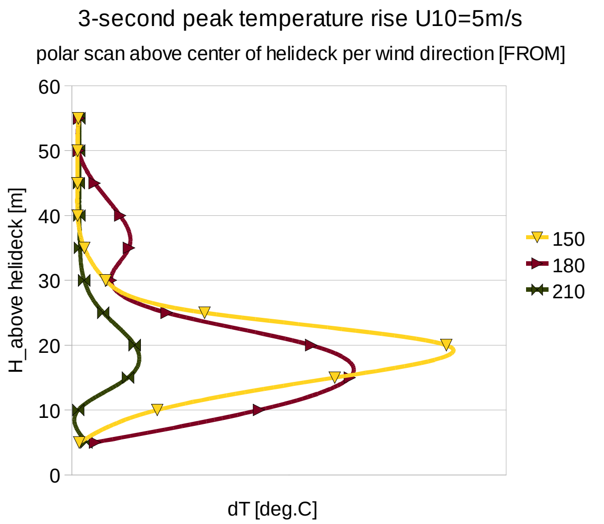

Figure 6: Vertical profile of 3-second peak temperatur rise

4. INTERPRETATION OF THE TEMPERATURE RISE CRITERION

To the authors opinion the CAA research clearly shows that any peak temperature rise larger than 2 ºC above ambient can be relevant to helicopter operations. However the assessment of the criterion and the practical use of the results of the assesment raise several questions. Safety could be improved by specifying guidance on the application of assessment techniques (based on the physical capabilities of the method) and guidance on the evaluation of the criterion and the operational use of the results.

A question to be raised is whether a platform should be designed or limitations imposed such that a 3-second temperature rise will never be larger than 2 ºC? Or is the criterion intended to provide pilots information only? In that case it is up to the pilot to decide whether a specified maximum temperature is acceptable or not.

If the criterion is used to specify pilots information of a 3-second peak temperature (evaluated as an absolute maximum temperature), than the question is to be raised how a pilot should actually use this information.

First of all the maximum value will most probably never be encountered, so comparison to field experience is of limited use. Second the pilot has no information on what 3-second temperature rise is still acceptable The performance tables specifying allowable payload as a function of the steady ambient temperature can give some guidance but they are to the authors understanding not intended to provide information on helicopter behaviour in short term exposure to increased temperatures.

5. DISCUSSION

Instead of specifying the absolute maximum temperature rise (as is requested by the current temperature rise criterion) it is not uncommon in other fields of research to set a limit value and to evaluate the probability of exceedance. Instead of evaluating the (absolute) maximum 3-second peak temperature rise it would not be uncommon to evaluate the a 3-second peak temperature rise with a specified probability of exceedance. Such an approach opens the way to an extreme value analysis of a time series of a fluctuating signal which might be a more robust approach than the search for one unique maximum value. In building physics for example a similar approach is used for the analysis of extreme values of the fluctuating wind pressures on buildings.

For evaluaton of a maximum value in a fluctuating signal (such as the temperature rise criterion), an additional quality criterion for the measurement duration should be specified.

6. CONCLUSION

Turbulence and temperature rise criteria for helicopter platforms are defined in CAP 437. These criteria are the result of an extensive research programme of the CAA. To the authors opinion there is no discussion on the relevance of these criteria. Guidance on the assessment techniques should be improved however as the current guidance (CAA paper 2008/03) seems to advise some techniques that cannot evaluate the physical properties defined in the criteria.

CFD can be a very useful tool in the design process to make initial comparisons between configurations concerning flow properties, hot gas plumes or pollution dispersion. The model should however be properly validated against scale model experiments for flow properties (mean velocity and turbulent kinetic energy) as well as concentrations or temperatures. It needs to be recognised however that only properly scaled wind tunnel experiments can provide accurate data on turbulence properties, hot gas plumes and pollution dispersion.

Additional to the current formulation of the temperature rise criterion a quality criterion for the measurement duration should be specified.

Also guidance on the operational use of the results of the temperature rise assessment would be very useful.

7. REFERENCES

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