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Executive summary

Analysis of existing practices and issues regarding near-ground wind gust information for flight crews

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Correct wind information is essential to flight crews in assessing takeoff/landing performance and limitations such as allowable crosswind and tailwind for takeoff/landing. Following a serious incident EASA launched a study to analyse the possibilities and issues related to gusty wind measurement and reporting.

Description of work
Three major tasks are conducted: Analysis of existing practices and issues regarding near-ground wind gust information for flight crews; a survey of existing sensors and measurement techniques for near ground wind gusts detection; and formulation of recommendations for improved practices to support flight crew decision-making.

Results and conclusions
Several issues related to wind measuring, reporting and interpretation are identified and recommendations to solve these issues are given.

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Summary

Correct wind information is essential to flight crews in assessing takeoff/landing performance and limitations such as allowable crosswind and tailwind for takeoff/landing. Since 1990 there have been more than 280 approach & landing and 66 takeoff accidents/incidents investigated with FAR/JAR/CS 25 certified aircraft operated in commercial operations worldwide in which crosswind or tailwind was a causal factor. Occurrences related to gusty wind conditions are also very common in Europe. A crosswind related incident at Hamburg airport resulted in the following recommendation to EASA by the German Federal Bureau of Aircraft Accident Investigation (BFU): 'Determine what measuring systems are suitable to detect the presence of near-surface gusts on airports, and how the resulting gust data and wind direction information should be processed and communicated to pilots'. Following this recommendation EASA launched a study to analyse the possibilities and issues related to this recommendation.

In this report a survey and analysis is presented of the existing technological means and techniques for the detection of near-ground wind gusts while considering the issues of appropriate interpretation and use of wind gust data for flight crews decision-making. Three major tasks are described in the report: analysis of existing practices and issues regarding near-ground wind gust information for flight crews; a survey of existing sensors and measurement techniques for near ground wind gusts detection; and formulation of recommendations for improved practices to support flight crew decision-making.

Several issues related to wind measuring, reporting and interpretation are identified and recommendations to solve these issues are given.

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1 INTRODUCTION

1.1 Background

Currently at controlled aerodromes the provision of wind information to flight crews is ensured through communications with air traffic controllers and via information provided on the Automatic Terminal Information Service (ATIS). Correct and accurate wind information is essential to flight crews in assessing takeoff/landing performance and limitations such as allowable crosswind and tailwind for takeoff/landing. Since 1990 there have been more than 280 approach & landing and 66 takeoff accidents/incidents investigated with FAR/JAR/CS 25 certified aircraft operated in commercial operations worldwide in which crosswind or tailwind was a causal factor. These occurrences typically resulted in wingtip strikes, tail strikes, hard landings and/or runway excursions. The wind in these occurrences was often very gusty.

Occurrences related to gusty wind conditions are also very common in Europe. The crosswind related incident with an A320 on 1-3-2008 at Hamburg airport resulted in the following recommendation to EASA by the German Federal Bureau of Aircraft Accident Investigation (BFU)[1]: 'Determine what measuring systems are suitable to detect the presence of near-surface gusts on airports, and how the resulting gust data and wind direction information should be processed and communicated to pilots'. Following this recommendation EASA awarded a contract to NLR-ATSI to analyse the possibilities and issues related to this recommendation.

1.2 Project objectives and scope

The main objective of the present study is to conduct a survey and analysis of the existing technological means and techniques for the detection of near-ground wind gusts[2] in the context of large aircraft operations, during flight instrument approaches and while considering the issues of appropriate

[1] See BFU investigation report 5X003-0/08, March 2010.

[2] A gust can be defined as the difference between the extreme value and the average value of the wind speed in a given time interval. A gusty wind is characterized by rapid fluctuations in wind direction and speed. At airports, gustiness is specified by the extreme values of wind direction and speed between which the wind has varied during the last 10 minutes. (source: WMO-No. 731)

interpretation and use of wind gust data for flight crews decision-making. Three major tasks are conducted in this study:

- Analysis of existing practices and issues regarding near-ground wind gust information for flight crews;
- A survey of existing sensors and measurement techniques for near ground wind gusts detection; and
- Formulation of recommendations for improved practices to support flight crew decision-making.

The scope of the study includes the analysis of the existing information available to flight crews and operators (as provided by the aircraft manufacturers and used by the operator in standard operating procedures) regarding wind gust near-ground at different timeframes prior to the landing time. Also the potential ambiguities or confusions encountered while checking forecast and actual data against published aircraft operational limitations and recommendations on crosswind and tailwind will be considered in the analysis.

2 ANALYSIS OF EXISTING PRACTICES AND ISSUES

This section covers the analysis of the existing weather data available prior or during the flight for the assessment of near ground wind gust for the takeoff/landing. The potential issues of availability, completeness and interpretation of such weather data (under current practices) are analysed considering the different decision making processes applied in commercial air transport operations. For this task an analysis is conducted of the existing cockpit procedures on assessing wind information using available flight crew operating manuals (FCOM), aircraft flight manuals (AFM) and flight crew training manuals (FCTM) of JAR/FAR/CS 25 certified aircraft types. These manuals are part of the NLR-ATSI library which covers operating and training manuals of a wide range of commercial aircraft that are currently in use (ranging from turboprop aircraft, regional jets, to narrow, and wide bodies jets). Both the original, up-to-date aircraft manufacturer operating manuals as well as manuals customised by operators are considered for this study. From these manuals an overview of the common procedures and existing practices to assess wind data in relation to demonstrated values and/or limits is made. As the number of customised operator manuals available to NLR-ATSI is not extensive and therefore may not be fully representative for the variations in operational procedures in practice, a survey amongst airline operators is also conducted.

The results obtained from the analysis of operating & training manuals and the airline survey are used to identify safety issues related to the completeness and interpretation of wind data and how this could affect the decision-making process in current commercial air transport operations. These findings are compared with a limited set of accidents/incidents in which gusty wind was a factor. These accident/incident data will be obtained from the NLR-ATSI Air Safety Database and are used to validate the findings from the analysis of operating and training manuals, and the airline survey.

2.1 Crosswind values provided by manufacturers

Manufacturers of aircraft provide information regarding the crosswind capabilities of their aircraft. Such information can be found in the aircraft flight manual (AFM), flight crew operating manuals, and flight crew training manuals.

Aircraft with a maximum takeoff mass of 5,670 kg or higher are certified according to the US Federal Aviation Regulation FAR 25, the European EASA CS 25 or equivalent regulations. All these regulations state the following regarding crosswind (as of 1978):

> §25.237 Wind velocities.
> For landplanes and amphibians, a 90-degree cross component of wind velocity, demonstrated to be safe for takeoff and landing, must be established for dry runways and must be at least 20 knots or 0.2 V_{so}, whichever is greater, except that it need not exceed 25 knots.
>
> *Note that V_{so} means the stall speed or the minimum steady flight speed in the landing configuration. The wind velocity must be measured at a height of 10 meters above the surface, or corrected for the difference between the height at which the wind velocity is measured and the 10-meter height.*

Before 1978 both the CAA-UK (British Civil Airworthiness Requirements BCAR regulations) and the FAA (Federal aviation regulations FAR) had different versions of the current regulation regarding crosswind. A major difference from the current regulation is that the minimum crosswind of 20 knots was not specified by both the CAA-UK and the FAA. The BCAR (section D) which was used from 1962 until 1978, only stated a minimum crosswind value of 0.2 V_{so}.

In general if the demonstrated crosswind is not considered to be a limiting value for aircraft handling characteristics, the demonstrated value is placed as information in the AFM. Higher crosswinds are then in principle allowed. This means that the choice to operate above the maximum demonstrated crosswind value is then subject to the Commanders discretion (considering all other options). Many operators choose to consider the demonstrated crosswind value as a company limit (see also section 2.3). In a very few cases the aircraft manufacturer advised not to exceed the demonstrated (not limiting) crosswind. If the demonstrated crosswind is considered to be a maximum limiting value up to which it is safe to operate the aircraft, the demonstrated crosswind value will appear as a limiting value in the AFM. It is not allowed to operate the aircraft beyond this crosswind.

Figure 1 gives an overview of demonstrated crosswinds of civil transport aircraft since 1950. These values are obtained from Aircraft Flight Manuals, Operating Manuals, and/or Flight Crew Training Manuals of aircraft certified under EASA CS 25 or equivalent rules. The majority of the demonstrated crosswind values vary between 20 and 40 knots. The variation in demonstrated crosswind values is partly the result of the variability in wind conditions encountered wind during such flight tests. However, also the different ways of determining the crosswind by the manufacturers has an influence. Finally for some aircraft it is stated that the demonstrated crosswind values includes gusts. Note that the manufacturer is not required to publish information about the gust factor present during testing. The fact that it is not stated that the demonstrated crosswind includes gusts does not automatically mean that the demonstrated crosswind provided in the AFM is a mean wind value.

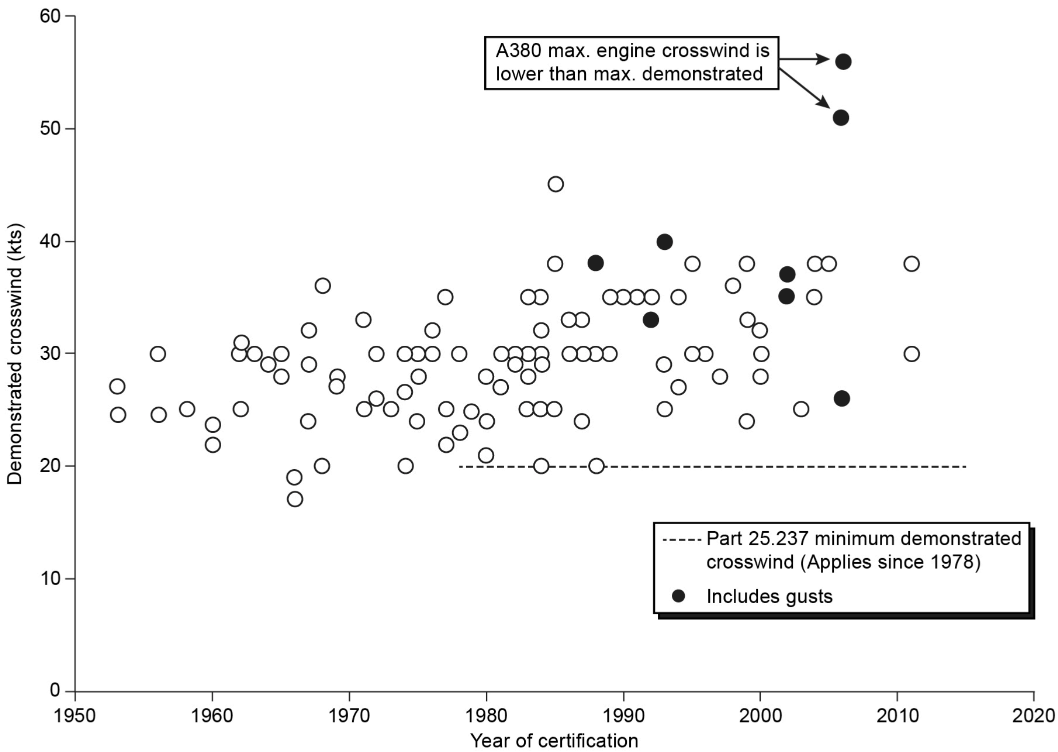

Figure 1: Demonstrated crosswinds for civil transport aircraft since 1950.

The demonstrated crosswinds for most of the aircraft certified by EASA, FAA and other regulators were not considered as limiting during normal operations by the test pilots during the last forty years. Typically hard crosswind limits are found when for instance the rudder and control wheel inputs approach full deflection or wingtip/engine pod clearance becomes marginal when controlling the aircraft in crosswind conditions. Also when it is judged by the test pilot that exceptional pilot skills are required to control the aircraft, taking into account variability in the application of crosswind techniques and covering for some overcompensation that may be found in daily operations, hard limits could be established. Rare examples of modern aircraft with a hard crosswind limit are the Fokker 70 and the SAAB 2000 (without aileron modification). Another example is the A380. Although the A380 was demonstrated for crosswinds of 39 knots gusting 51 during takeoff and 42 knots gusting 56 knots during landing without handling problems, engine inflow limited the crosswind to 35 knots and 40 knots (including gusts) for takeoff and landing respectively. Hard limits for crosswind do exist for many aircraft for cases such as (control) system malfunctions, for autoland operations, asymmetric wing fuel loading etc. For some aircraft models the demonstrated crosswind value was put under the limitations section of the AFM. This would imply a hard limit. However, it was discovered that often also a statement was added that this demonstrated crosswind was not considered to be limiting. The British Civil Airworthiness Requirements BCAR for instance demanded that limiting crosswind values were established. However, it also recognised that the establishment of such crosswinds is depending on suitable ambient conditions. This would explain that for some aircraft types demonstrated crosswinds that were not considered to be limiting were placed under the limitations section of the AFM.

For most commercial aircraft designed since 1950 no crosswind limits were established during certification flight testing.

For the vast majority of aircraft certified since 1950 the demonstrated crosswinds presented in the AFM do not mention if any gust are included in the crosswind value or not. An evaluation of an aircraft's crosswind takeoff and landing handling qualities in gusty wind conditions is not required by regulations, nor is the aircraft manufacturer required to publish information about the gust factor present during flight testing. The only exception is Airbus which has included gust values in the demonstrated crosswind starting with the A320. Typically a mean value and gust component of the demonstrated crosswind is provided by Airbus for the fly-by-wire range of aircraft certified since the introduction of the A320. Airbus also stated that for the previous Airbus models the demonstrated winds are to be considered as a maximum for an average wind[3]. In a private communication with Boeing, it was learned that the demonstrated crosswind for Boeing aircraft is the average crosswind as the aircraft passes through an altitude of 10 meters[4]. Although Boeing does not refer to gusts in their demonstrated crosswinds they have provided information regarding gust and crosswind in their Flight Crew Training Manuals[5]. For most other aircraft manufacturers it remains unclear whether or not gusts are included in the published demonstrated crosswind values.

For most commercial aircraft designed since 1950 gust is not mentioned with the demonstrated crosswind nor is the manufacturer required to publish information about the gust value.

For a few aircraft types the crosswind demonstration flight test reports were available. This gave some interesting information how the crosswind was determined during flight tests and how it was put into official certified aircraft flight manuals. For instance for a particular aircraft type it was determined during flight tests that the maximum demonstrated crosswind was 35 knots including gusts. However the official AFM for this aircraft does not mention gusts and only gives a demonstrated crosswind of 35 knots. In theory it could be that an operator uses this value as a steady wind. In practice this could result in crosswind limits as high as 53 knots (using a typical gust factor of 1.5) which is beyond the demonstrated capabilities of the aircraft and could be well beyond the capabilities of the crew. In another case the aircraft manufacturer had chosen to use the tower wind as the source. However when the instantaneous crosswind derived from flight aircraft parameters was compared to the average tower crosswind at a height of 10 meter differences of 5-15 kts between both results were found (above or below the tower crosswind). Demonstrated crosswind of different aircraft types cannot be compared with each other as different ways of wind determination during the flight tests are allowed (e.g. tower wind, reconstructed from on-board recorded data, a flight test wind measurement station etc.). Furthermore it is not always stated if gusts are included and what

[3] "Crosswind landing technique", Airbus, 7th Performance Operations Conference, 1992.
[4] "Demonstrated crosswind takeoff and landings", Response of C. Shure, Boeing Flight Operations, 1998 (Ref. M-7661-498-3431).
[5] Boeing states in their guidelines "Gust effects were evaluated and tend to increase pilot workload without significantly affecting the recommended guidelines". These "guidelines" refer to so-called advised crosswinds and not demonstrated crosswinds. See also "Crosswind guidelines", by J. Cashman, Boeing Flight Operations Conference, 2002.

the direction of this gusts component is (e.g. taken in the direction of mean wind or omnidirectional).

Demonstrated crosswind of different aircraft types cannot always be compared with each other as different ways of wind determination during the flight tests are allowed and applied.

For some aircraft different demonstrated crosswind values are given for takeoff and landing. This is often the result of the fact that during the flight tests different wind conditions existed during the takeoff and landing.

Typically manufacturers provide a wind component chart (see Figure 2). The wind component chart shows lines which represent the angular difference between the wind direction and the runway. Gusts are not mentioned in these guidelines.

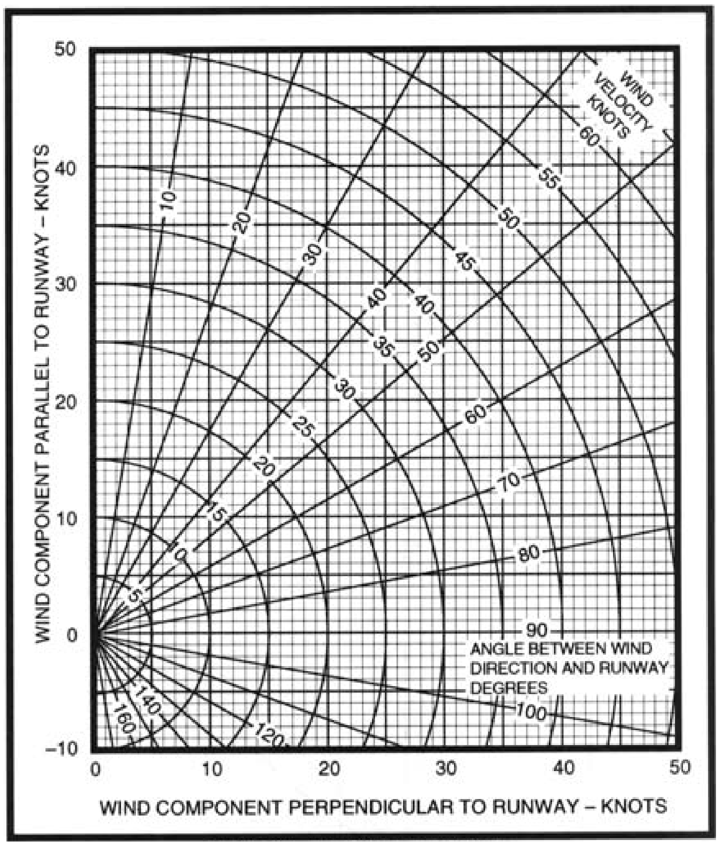

Figure 2: Example of a wind component chart.

2.2 Tailwind values provided by manufacturers

The impact of tailwind on aircraft operations is typically related to aircraft takeoff and landing field performance. Controllability issues are normally less of a concern. Tailwind provided by aircraft manufacturers are always hard limitations. Under FAR Part 25 or EASA CS 25 no specific flight-testing is required for approval of operations in tailwind components of up to 10 Knots. Aircraft certified according to FAR/CS Part 25 are therefore approved for operations in tailwind components of up to 10 Knots[6]. For some aircraft higher tailwind limits are provided by the manufacturer. These tailwinds are not provided as standard. Operators need to pay a fee for using these higher limits. Specific flight-testing is required for approval of operations in tailwind components greater than 10 kts. The requirements for these tests are provided in the Flight Test Guide. For the certification of tailwind operations greater than 10 Knots, it is required that testing is done with a tailwind greater than 150% of the value to be certified. During the flight testing of tailwinds above 10 knots both aircraft performance as well as handling qualities should be evaluated.

During tailwind certification flight tests the measured wind data can come from the Inertial Navigation System (INS), tower, or portable ground recording stations similar to crosswind certification flights (See Flight Test Guide for details).

During this study no aircraft could be identified for which gusts were mentioned in the tailwind limits in the AFM.

2.3 Operator survey

To understand how operators deal with wind information in their day-to-day operation (in particular crosswind) a survey was sent to 115 commercial operators. A response was received from 36 (31%) operators. Of these respondents 19 (54%) had their home base in Europe and the remainder were stationed elsewhere (mainly Asia and North-America). Fleet sizes of the respondents varied from 15 aircraft to almost 800 and covered aircraft from all major manufacturers including Airbus, Boeing, McDonald Douglas, Fokker, ATR, Embraer, and Bombardier. The responses to the questions asked in the survey are presented and discussed next.

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[6] The origin of this 10 Knots tailwind limit can be found in Federal Aviation Administration (FAA) Civil Air Regulations release 60-14, dated August 9, 1960.

1) What do you use as a basis for the crosswind guidelines/limit?

Basically all commercial operators do not use the AFM as an operational manual, but are authorised to use the Flight Crew Operating Manual (FCOM) as a substitute for the AFM instead. The information in the FCOM is based on and in agreement with limitations in the AFM[7]. However it can also include other sources like advisory information. Demonstrated crosswinds or crosswind limitations are provided in the AFM. Advisory data on crosswind values are typically provided in the manufacturer's FCOM[8]. The response to the question what the basis is for crosswind limits shows that the majority (75%) uses a combination of demonstrated and advised crosswinds (see Table 1). A number of operators defined their own crosswind values which are lower than the demonstrated/advised crosswinds. Three operators only used advised values. These advised values could be higher than the maximum demonstrated crosswinds. Boeing for example has demonstrated a crosswind of 33 kts for the B767-300. In their guidelines a value of 40 kts is given. Boeing states that these crosswind guidelines are excluding gusts and are derived through flight test data, engineering analysis and piloted simulation evaluations. Other manufacturers most likely follow a similar approach as Boeing however very little information could be found on this.

Table 1: Response to question what the basis is for the crosswind guidelines/limit.

Answer	Count	Percentage
Advised crosswind	3	8.3%
Crosswind based on own experience	6	16.7%
Demonstrated crosswind/advised crosswind	27	75.0%

2) Do you use hard crosswind limits?

For most aircraft no hard crosswind limits have been established during flight tests. The operators were asked if they used the crosswind wind as hard limits or not (see Table 2). The majority (82.9%) use the crosswind values as hard limits that should not be exceeded by the crew. Interesting is that there are still operators that have no hard crosswind limits defined in their procedures leaving

[7] Operators can use their own developed FCOM or they can use the FCOM as provided by the manufacturer. From a cost saving and liability point of view many operators choose to use the FCOM as provided by the manufacturer with or without company made supplements on top of these manuals.

[8] Tailwinds are always given as limitations (normally 10 knots however values up to 15 knots are possible).

the crew responsible of making critical safety decisions when taking off or landing in strong crosswind conditions. In this respect it is interesting to know that in 1960, the US FAA, proposed that any demonstrated crosswind and tailwind should be considered as a limiting factor[9]. The reason was to provide a safe and uniform standard. Hard crosswind limits were later not required by the FAA for large aircraft certification and operation whereas for tailwind all values shown in the AFM are always hard limits. The British Civil Airworthiness Requirements BCAR for instance demanded that limiting crosswind values were established. However, it also recognised that the establishment of such crosswinds is depending on suitable ambient conditions. Most manufacturers do not provide clear guidance on how to use a demonstrated crosswind that was not considered to be limiting. However one manufacturer does recommend that operators should not intentionally operate in crosswinds that exceed this demonstrated value.

Table 2: Response to the question if hard crosswind limits are used.

Answer	Count	Percentage
Yes	30	83.3%
No	6	16.7%

3) Do your crosswind limits include wind gusts?

Except for the fly-by-wire aircraft from Airbus, gusts are not mentioned in the demonstrated crosswinds or advised crosswind values. The fact that a manufacturer does not mention gusts does not mean that operators cannot include gusts themselves in their crosswind values. The survey showed that slightly more than half of the respondents include gusts in their crosswind values (see Table 3). These operators do not necessarily operate FBW Airbus aircraft. In fact only 19% of them operate exclusively Airbus FBW aircraft. Furthermore 24% do not have any Airbus FWB aircraft in their fleet. Of the respondents 33% indicate that they do not include gusts in their crosswind values. None of these operators have FBW Airbus aircraft. Three operators gave as reason for not including gusts that the manufacturer does not do this. A small number of the respondents left the decision to include gusts or not up to the Captain.

[9] Crosswind and tailwind takeoff and landing limitations, Notice of proposed rule making, Draft Release 60-14, 1960.

Table 3: Response to question whether or nor gusts are included.

Answer	Count	Percentage
Captain to judge to include or not	3	8.3%
No - no reason given	9	25.0%
No - manufacturer doesn't include them	3	8.3%
Yes	21	58.3%

4) Do you have clear procedures how pilots should calculate the crosswind? How are gusts treated?

A significant number of the respondents (67%) replied that they have procedures how their pilots should calculate the crosswind component (see Table 4). Of these operators 58% also indicated how the pilots should take gusts into account. Most of them take the gust in the direction of the mean wind. Only one operator stated that gusts are taken omnidirectional which means that the full gust component is taken into the crosswind. Of the operators that did not state how to deal with gusts 5 (55%) did not include gusts in their limits.

It is interesting to note that in 1954 the US government stated that the maximum gust and most unfavourable direction should be used in computing the crosswind component[10]. Out of the survey only one operator is actually doing this.

Table 4: Response to question if there are clear procedures for crosswind determination.

Answer	Count	Percentage
No	7	19.4%
No reply	5	13.9%
Yes	10	27.8%
Yes - gusts are included	2	5.6%
Yes - gusts are included (direction of mean wind)	11	30.6%
Yes - gusts are included (omnidirectional)	1	2.8%

[10] see: Civil aeronautics board, Part 40 – scheduled interstate air carrier certification and operation rules, 1954.

5) Please indicate which sources pilots should or can use for determination of the crosswind

There are several wind data sources available to pilots. Two primary sources can be identified: ground sensors and aircraft systems. Before discussing the responses to the survey question these sources are described in some detail.

Wind data from the ground systems are reported through several means: Meteorological Aerodrome Report METAR, Automatic Terminal Information Service (ATIS) and by the Air Traffic controller (Tower wind). PIREPS normally do not consider such wind information and typically only report on low-level wind shears. The wind data available through ATIS and the tower wind are averaged over the past two-minute period to provide the so-called average wind. For the METAR the period that is used to calculate an average is 10 minutes. ATIS and METAR are typically updated every 30 minutes, where the tower wind is available at any given moment. For ATIS and tower reports variations from the mean wind speed (gusts) during the past 10 minutes are reported when the maximum wind speed exceeds the mean speed by 5 kts or more when noise abatement procedures are applied in accordance with ICAO PANS-ATM (Doc 4444), or 10 kts or more without when noise abatement procedures. The 10 kts threshold is also used in METAR reports. The surface wind direction and speed are reported in steps of 10 degrees and 1 knot, respectively. The wind reported in the ATIS can be specified for the runways in use, or it can give one value for all runways in use. Currently there are discussions that the tower/ATIS wind could include the cross- and tailwind components. One of the issues identified with this type of reporting is if and how to include the wind gust in these reports[11].

On-board aircraft wind direction and speeds are available on the navigation display. This is sometimes called the FMS wind as it can be computed by the FMS. However the wind can also be computed by the inertial reference system (IRS). The wind derived by the FMS is normally more accurate than the IRS derived wind. The FMS wind is typically averaged over a 30 second period. The FMS has some major drawbacks as source for determining crosswind and tailwind limits. First of all crosswind and tailwind values refer to a wind measured at 10 meter above ground level whereas the FMS wind is based on the average aircraft height during the past say 30 seconds. Under sideslip conditions (e.g. during a crosswind landing) the FMS wind becomes inaccurate. A comparison between FMS wind, tower wind and actual encountered wind of an approaching aircraft from 400 ft to touchdown is shown in Figure 3. In this example large differences

[11] Report of the ad-hoc working group on the calculation of crosswind and tailwind components with particular regard to the inclusion of gusts, AERODROME METEOROLOGICAL OBSERVATION AND FORECAST STUDY GROUP (AMOFSG), NINTH MEETING, 2011.

exist between the actual wind and the FMS wind. Although there seems to be a good match between the tower and actual wind, it should be realised that the tower wind is measured at 10 meters above ground level and that the aircraft in this example was flying from 400 ft. until touching the runway.

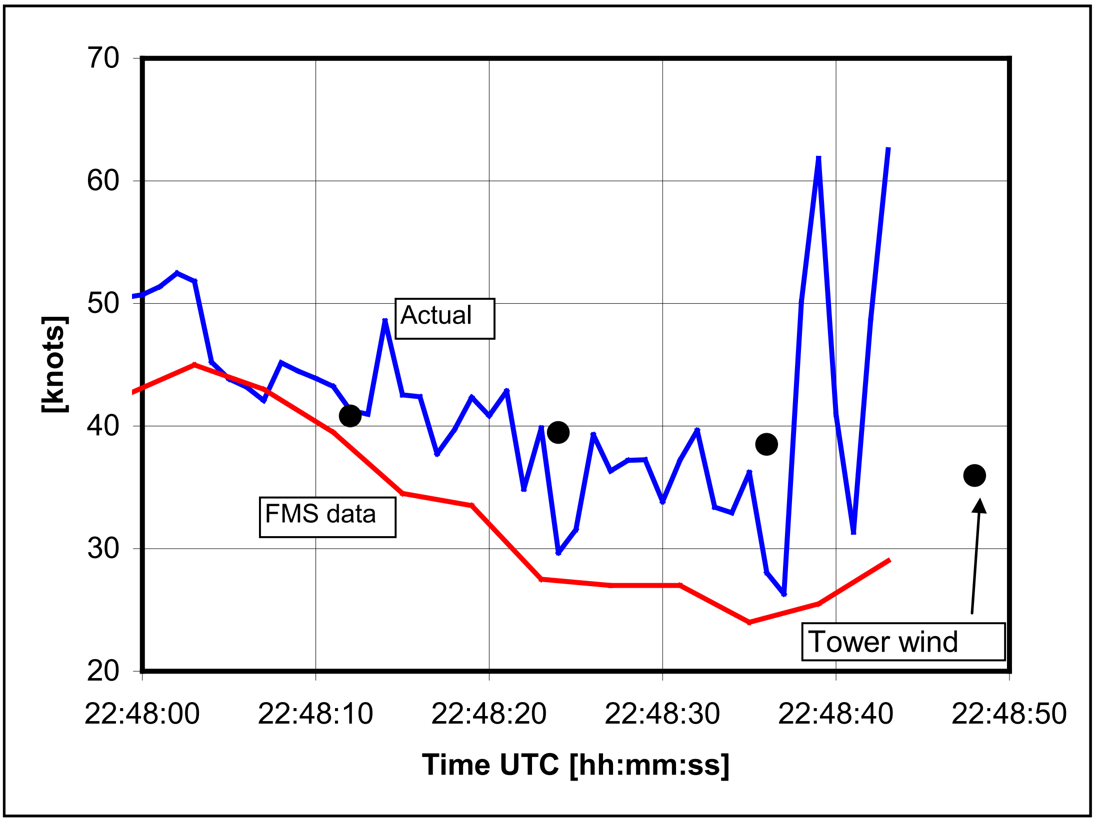

Figure 3: Comparison of on-board FMS wind, tower wind and actual wind encountered by an approaching aircraft.

The survey showed a wide variation in responses to which wind information sources pilots could use (see Table 5). All operators that replied to this question mentioned tower wind. Nine operators only mentioned tower wind. This does not seem very likely as pilots will normally prepare their takeoff and landing in advance using information from the ATIS. The final decision to continue a landing should then still be based on the reported tower wind during the approach or before starting the takeoff. This is a very common procedure (see overview Figure 4). At some airports instead of 2-minute average wind also an instantaneous reading can be provided if pilots want this. However the usefulness of such wind information is questionable as indicated by [Wieringa, (1980)] because over shorter periods the wind speed and direction have a lower persistence as the wind variability is high for small times scales[12].

Finally, although not very accurate and not included in the review, a windsock may provide an additional visual indication of the current wind at the take-off position of the runway.

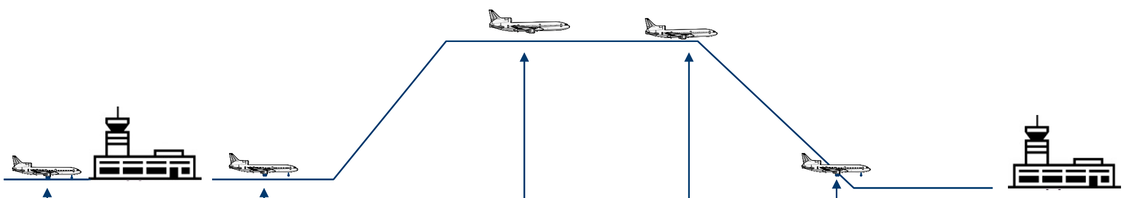

Figure 4: Schematic overview of wind sources used for takeoff and landing.

Table 5: Response to question which wind data pilots can use.

Answer	Count	Percentage
ATIS, METAR, Tower	3	8.3%
ATIS, Tower	5	13.9%
ATIS, Tower, FMS	1	2.8%
METAR, ATIS, Tower, FMS	1	2.8%
No reply	13	36.1%
Tower	9	25.0%
Tower, ATIS, METAR (FMS NOT ALLOWED)	1	2.8%
Tower, FMS	3	8.3%

[12] The crosswind related accidents with a British Aerospace Jetstream 41 (G-MAJD), is a good example in which instant wind reports gave the flight crew a wrong picture of the possible winds that they could encounter. (see: http://www.aaib.gov.uk/cms_resources.cfm?file=/British%20Aerospace%20Jetstream%2041,%20G-MAJD%2010-11.pdf)

6) Do you provide separate crosswind values for different runway condition?

The majority of operators in the survey responded that they had separate (lower) crosswind values for different runway conditions (see Table 6). Most based their values on the advisory information provided by the manufacturers. Others used values based on their own experiences that were lower that the values provided by the manufacturers.

During a crosswind landing, the tire cornering force is one of the primary ways of maintaining the aircraft on the runway. Experiments have shown that tire braking and cornering capabilities are affected by ground speed, wheel yaw attitude and the extent of surface slipperiness. Runway condition therefore affects crosswind capability. Many aircraft manufacturers give advisory data on the crosswind capability of their aircraft on non-dry runways. Typically a combination of piloted evaluations in simulators and engineering desktop simulations are used to derive these advisory numbers. Although the fidelity of simulation capability to replicate aircraft ground handling performance has improved significantly over the years, there are still concerns about the quality of the mathematical ground models used in a flight simulator or engineering simulation[13]. Another problem exists in simulating gusty wind conditions. The fidelity of the wind models used is not sufficient to simulate gusty crosswind takeoffs and landings[14]. Therefore the simulations are normally done for steady wind. There is currently no common industry standard on how to derive advisory crosswind values for different runway conditions or in general using simulation models.

[13] "Enhancement of Aircraft Ground Handling Simulation Capability", AGARDograph 333, 1998, states that "model of the forces generated between the wheels and the ground are over-simplified, and are invalid for extreme conditions, such as large tire slip angles", and "model validation is inadequate".
[14] See for instance: NTSB report AAR10-04, Boeing 737-500, NN186111, Denver, Colorado, December 20, 2008.

Table 6: Response to question if separate crosswind are used for different runway conditions.

Answer	Count	Percentage
Capt. judgement	1	2.8%
No reply	1	2.8%
Yes - source not specified	1	2.8%
Yes - based on own experiences	10	27.8%
Yes- based on advisory data of manufacturer	23	63.9%

2.4 Review of some occurrences related to gusty crosswind/tailwind

A short review of some occurrences related to gusty crosswind and tailwind is conducted as part of the present study. The NLR-ATSI Air Safety Database is queried for occurrences in which gusty crosswind and/or tailwind was a contributing or causal factor. The query is limited to FAR/JAR/CS 25 (or equivalent) certified commercial aircraft certified for the period 2000-2010. The query resulted in 45 occurrences[15]. The following typical causal factors are identified from these 45 occurrences[16]:

- Only wind from the ATIS was used by pilots which was lower than the wind during the landing. The tower wind was not used to check if the wind conditions were still within limits;
- The actual wind encountered was different from the Tower/ATIS wind which resulted in the aircraft exceeding limits (cross- or tailwind):
  - Due to local effects (e.g. buildings);
  - Unexpectedly strong and gusty winds;
- The runway friction condition was worse than expected (e.g. more slippery);

[15] The objective of this project was not to have a complete dataset of occurrences related to gusty crosswind and tailwind. A limited set was proposed at the beginning of this project to compare with the findings of the present study.
[16] Because the sample is considered to be small no numbers are given on the frequency of occurrence of these causal factors.

- The location of the wind sensors was not representative for winds at the active runway;
- An incorrect crosswind technique was applied by the pilot flying.

Note that there is often more than one single factor that resulted in the occurrence.

A comparison is made between encountered crosswinds and the demonstrated, manufacturer advised or operator applied crosswinds for a number of occurrences. The results are shown in Figure 5 and Figure 6. These results show that staying below a demonstrated crosswind or limit does not guarantee that a crosswind related occurrence like a wingtip strike will not occur. Other factors also play a role such as the use of an inadequate crosswind technique, unknown runway conditions, unrealistic crosswind limits, and none representative wind reports.

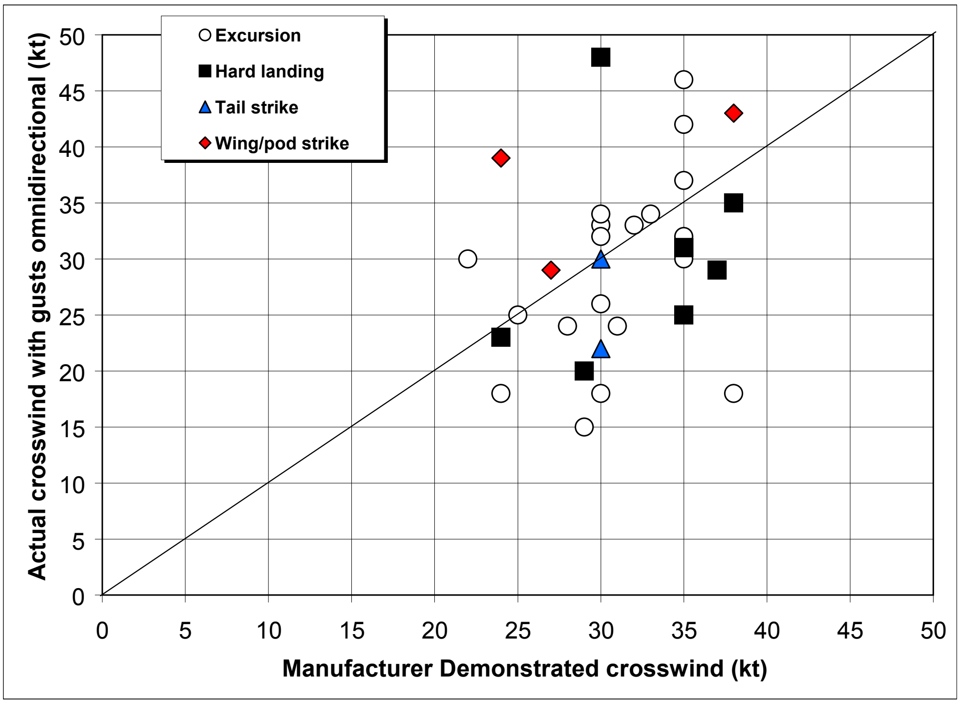

Figure 5: Comparison demonstrated crosswind and crosswind encountered during occurrence.

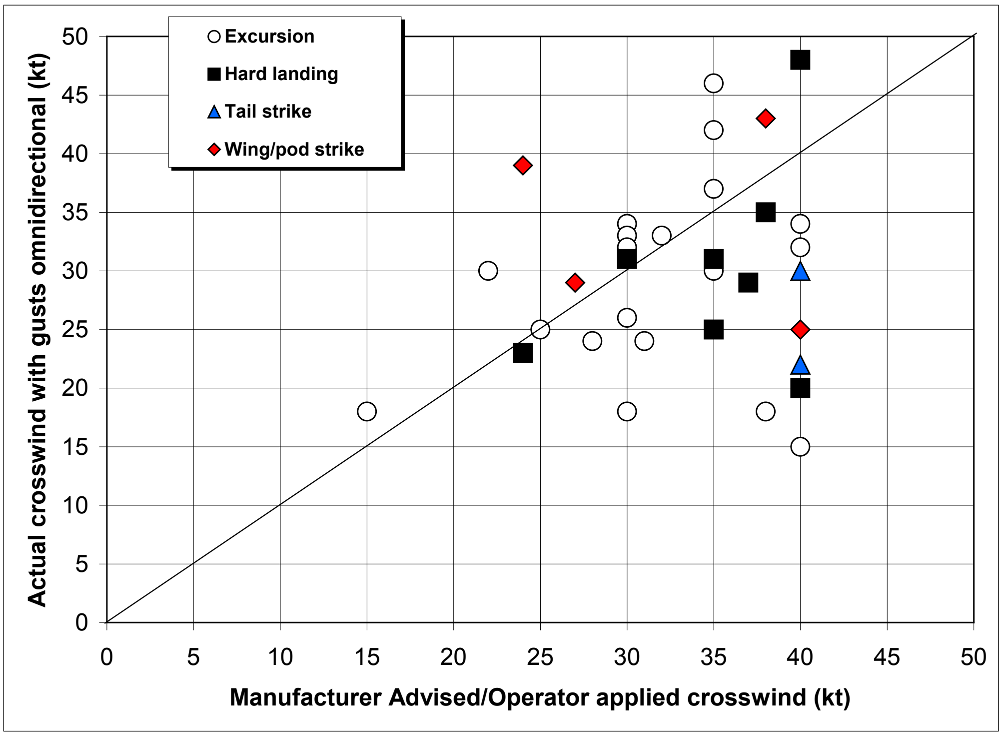

Figure 6: Comparison advised/operator applied crosswind and crosswind encountered during occurrence.

2.5 Overview of important findings

The previous sections identified a number of issues that can play a role in the safe operation in gusty winds near the ground. In this section these findings are summarised (in no particular order of importance):

- Demonstrated crosswind of different aircraft types cannot always be compared with each other as different ways of wind determination during the flight tests can be used;
- For most commercial aircraft designed since 1950 no crosswind limits were established during certification flight testing;
- For the vast majority of commercial aircraft designed since 1950 gust is not mentioned in the demonstrated crosswind;
- There is currently no common industry standard on how to derive advisory crosswind values for different non-dry runway conditions;

- Most, but not all operators use hard crosswind limits;
- There is no general accepted way in decomposing reported gusts into cross- and tailwind components;
- Staying below the demonstrated/advised crosswind winds does not guarantee that unsafe events related to crosswind will not occur;
- The surface wind reports that are most commonly used by pilots to determine their margins with respect to limiting values are: tower wind and ATIS wind. These wind reports may differ from the actual wind encountered during take-off or landing;
- Some operators allow the use of FMS wind despite known inaccuracies of this information during the final approach;
- The possible absence of hard crosswind limits and the availability of different wind reports from different sources leaves room for variation in the application of discretion by the Commander;
- Instantaneous wind reports during the approach are of limited value to pilots because over shorter periods the wind speed and direction have a lower persistence as the wind variability is high for small times scales;
- Wind reports given to the pilots should be representative for the complete runway at the time of take-off or landing. This is however not always the case and can result in large differences between the expected wind and the actual wind encountered.

One of the objectives of this study was to look at existing technological means and techniques for the detection of near-ground wind gusts in the context of operating large aircraft in gusty winds. Most of the above mentioned findings are not related to wind sensors. Only the finding related to the representativeness of wind reports seems to be relevant in this respect. In the next sections the focus is on surface wind sensors and how these sensors can contribute to a representative wind reporting system.

3 SURVEY AND ANALYSIS OF SURFACE WIND SENSORS

3.1 OVERVIEW OF COMMON WIND SENSORS

There are various physical principles that can be used to measure wind speed and direction. The most classical and commonly employed way of measuring surface wind today is by a wind vane[17] and a cup anemometer. Other types are propeller anemometers, pressure anemometers, hot-wire anemometers, ultrasonic anemometers, and tracer techniques. Some of these systems can also measure the wind direction. The following systems are currently used or under investigation for measuring surface wind speed and direction (based on [WMO, (2008)], vendor descriptions and other public sources):

- **Cup and propeller anemometer**: Both the cup and propeller anemometer are of the rotation type. They have been the standard for many years now. At airports the cup anemometer is more common than the propeller type. A cup anemometer consists of three or four cups arranged around a vertical axis that drives a signal generation device. The propeller type has a horizontal axis to which a propeller is connected. A wind vane is attached to the tail of the propeller anemometer. The characteristics of cup and propeller anemometers are well-known. Cup anemometers with a relatively fast response (low distance constant[18]) can measure gusts accurately. Propeller anemometers typically have a lower distance constant than the average cup anemometer [ESDU, (1990)] and could measure gusts somewhat more accurately than the average cup anemometer.

- **Pressure type anemometers**: The pressure type anemometers were in general use at a number of meteorological offices in the world. Compared to the rotation type of anemometer the calibration of the pressure type is affected by air density and the length of the connecting tube the manometer. The calibration of the rotation types is almost unaffected by

[17] This is a device that mechanically turns in the direction of the wind.
[18] Is the length of air column that passes a sensor for the sensor to record 63.2% of the change in speed of a step gust.

air density which is a major advantage over the pressure type. Pressure type anemometers are not very common at airports anymore.

- **Sonic sensors**: Sonic wind sensors[19] use ultrasound to determine horizontal wind speed and direction. These sensors measure the time a sound pulse takes to travel between two transducers. A 2D sonic wind sensor has two transducer pairs and measures the horizontal wind direction and speed. Gusts can be accurately measured with 2D sonic sensors. A 3D sonic anemometer monitors wind speed as vectors in three directions. In recent years 2D sonic wind sensors have been installed at a number of airports. Compared to rotation types, sonic anemometers have no moving parts reducing maintenance costs. A disadvantage seems to be the fact that some large deviations and even data outages can occur with sonic sensors. These problems are related to the influence of precipitation, icing and birds disturbing or blocking the sonic sensor measurement path [20]. These problems are serious and several solutions are proposed: the icing problem could be solved by sufficient heating; the influence of precipitation by adequate filtering; and the bird problem by special anti-bird measures such as described Kays and Schwartz [Kays and Schwartz, (2001)].

- **Hot-wire anemometer**: Hot-wire anemometers use a very thin wire that is heated to a temperature above ambient. The wind cools the wire and hence the electrical resistance from which the wind speed is calculated. Hot-wire anemometers are not used for long term wind measurements and are therefore of less interest as a sensor at airports.

- **Tracer sensors**: Tracer sensors use for instance radar or lasers to detect the movement of particles in the air. These systems are typically used in detecting wind shear and wake vortices at airports. They typically only measure a wind component rather than the total wind and direction. Tracer techniques could in theory be used for surface wind detection. The big advantage over the fixed positioned sensors is that they can measure the wind components spatially e.g. along the runway. However, drawbacks of tracer systems are the high costs, significant post processing, and limited wind measurements (basically only a wind

[19] Also known as ultrasonic sensors.
[20] W. Wauben, 2D sonics: experiences with birds and solid precipitation, Presentation, KNMI 2010.

component is measured). Measurement of 3 second peak gusts is also difficult or impossible.

Currently the cup anemometer combined with a wind vane is the most commonly used sensors for measuring surface wind speed and direction at airports (see also section 3.4). Ultrasonic sensors (2D) are also becoming popular mainly because of their lower maintenance costs compared to cup anemometers. Comparisons between cup anemometer - wind vane and sonic wind sensors showed that very similar values are obtained for average wind speed, wind direction and gusts [Groen, (2011)].

Tracer techniques like a LIDAR system are not planned to be used as sensors for measuring ground surface winds at airports. Some tests with scintillometers at an airport are currently on-going. The University of Wageningen is looking at the use of a scintillometer to measure crosswind along a runway at Schiphol Airport[21]. The scintillometer measures the turbulent fluctuations from which the turbulent fluxes are derived and spatially averaged over the path length. The scintillometer like other tracer systems cannot measure wind speed and direction. Instead it can only measure wind components perpendicular to the optical path established between a transmitter and a receiver. Scintillometers can measure this crosswind over spatial scales from 100 meters up to 10 kilometres. The spatial capability results in significant advantages over fixed point measurements. However there are also some serious drawbacks when using the scintillometer for surface wind measurements. For a measurement a period of typically 5 minutes is needed[22]. This is clearly too long to measure any gusts and also to calculate an average wind according ICAO Annex 3 and WMO (to be discussed in next section). Another drawback of the scintillometer is the fact that signal attenuation can occur in thick fog, heavy rain, or snow. The scintillometer will clearly not be able to fully replace the currently used surface wind sensors at airports.

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[21] This is the WindVisions project run under the Knowledge & Development Center organisation, http://www.kdc-mainport.nl. The project WindVisions examines which combination of sensors is available to monitor the 3D wind field just above Schiphol and performs tests with the selected sensors.

[22] Private communication Oscar K. Hartogensis, Meteorology and Air Quality Group, Wageningen University, 2012.

3.2 REPRESENTATIVENESS OF WIND REPORTS AT AIRPORTS

As indicated in section 2.5 representative wind reports are very important when operating in strong, gusty wind conditions at an airport. If for any reason wind reports do not provide representative values for the runway in use, flight safety could be compromised.

When considering the need for representative wind reports the first thing to consider is the accuracy of the wind sensor itself. Table 7 gives an overview of the accuracy of some commonly used surface wind sensors at airports. From this overview it follows that the accuracy of all sensors considered is very high. Also there is no major difference in accuracy between the classical cup/propeller and the more modern 2D sonic sensors.

Table 7: Overview of the accuracy of common surface wind sensors used at airports.

Type	Speed accuracy*	Direction accuracy*
Cup anemometer with wind vane	±0.2-0.5 m/s ±2-3%	±3 degr.
Ultrasonic Wind Sensor (2D)	±0.1-0.3 m/s ±1-3%	±2-3 degr.

* *Based on vendor statements.*

At first the values for the accuracy of these listed wind sensors seem to comply with ICAO Annex 3 [ICAO, (2010)] that gives the following operationally desirable accuracy of measurement of the mean surface wind[23]: wind direction: ± 10 degr. and wind speed: ± 0.5 m/s up to 5 m/s and ± 10% above 5 m/s. However there are other errors that influence the representativeness of the wind reported to the pilots. These errors can be divided into three basic groups [Wieringa, (1980)]: observation error, anticipation error, and translation error. Each of these errors is discussed in more detail.

- The **observation error** is the uncertainty in the actual measurement. It consists of an instrument error (see e.g. Table 7) and a random error. The random error for cup anemometer is in the order of 1% [KNMI, (1997)].

[23] According to ICAO Annex 3: 'The operationally desirable accuracy is not intended as an operational requirement; it is to be understood as a goal that has been expressed by the operators.'

- The **anticipation error** is caused by the time lag between the reporting of the wind information and the period in which the aircraft is at the runway. The wind provided by the ATIS or tower controller is an average wind taken over a certain period (see section 3.3). These reported (average) wind values can be seen as forecasts. It is assumed that there is a continuation of the previous situation in the coming period. The anticipation error depends on the time used for averaging the measured wind. Winds measured over shorter periods possess greater variance and are therefore less useful to pilots in deciding that a safe takeoff or landing is possible. A study conducted by Dutton [Dutton, (1976)] analysed the influence of the time interval used for averaging on the error in the wind 30 seconds later. This study showed that the mean error could be minimised by using an averaging period of 5-10 minutes. However such high average periods also resulted in a higher frequency of absolute errors in excess of 10 knots or higher. A lower averaging period reduced these errors. However below 2 minutes these errors tend to increase again [Dutton, (1976)]. Averaging the speed over a period less than 2 minutes is therefore not recommended [Wieringa, (1980)]. A 2-minute average wind is currently assumed as an adequate compromise between mean errors and absolute errors. No public information could be found whether there are airports that use different averaging periods. It could be that local conditions influence the optimum time used for averaging the wind.
  The anticipation error can be as large as 15-20% [Dutton, (1976)] depending on the averaging times used and the lag between reporting and using the information. This error is typically considered to be the largest error in wind reports. It cannot necessarily be eliminated by using more sophisticated means of measuring or by adding additional wind sensors [Wieringa, (1980)].

- The **translation error** is the result of the fact that a wind sensor is located some distance from the runway in-use (this applies to the cup and the sonic anemometers). An optimum wind observation location is one where the observed wind is representative for the wind which an aircraft will encounter during takeoff and landing. However a wind sensor cannot be located very close to the runway for a number of reasons (e.g. influence aircraft wakes on the wind field around the sensor). Instead it is placed at some distance from the runway (typically near the runway threshold). This will result in errors due to the horizontal decorrelation associated with the lifespan of turbulent eddies [Wieringa, (1980)]. There

is also the fact that wind speed increases with height. For this reason, a standard height above open terrain is specified for the exposure of wind sensors. The WMO and ICAO now recommend a measuring height of 10 m[24]. This corresponds to the height which is used for the demonstrated crosswind and tailwind limits of aircraft. Measurements taken at a different height which are not corrected will show lower or higher winds and are therefore not useful to the flight crew. A third contribution to the translation error originates from differences in exposure between the measurement location and the runway. Buildings in the vicinity of the runway for instance can have a disturbing effect on the wind field along the runway. This will result in differences between the measured wind at location and the wind encountered by the aircraft. Insight into these effects can be obtained through e.g. wind tunnel experiments or by using numerical aerodynamic modelling. Combined with wind measurements this can provide insight in the mechanisms of wind flows and disturbances on the runway. An example of such an approach for Schiphol Amsterdam Airport is given in [Krüsa et.al., (2003)].
The total translation error can be as high as 7% [Wieringa, (1980)]. However, due to local disturbances much higher errors are possible.

The total operational error (the sum of the above described errors) for an airport is typically in the order of 10-15% [KNMI, (1997)]. However higher errors are possible when considering the extremes of all three error types. Although the accuracy of the common wind sensors is very high it still proves difficult with the other errors to achieve an operational error that meets the ICAO ANNEX 3 target of 10%. The accuracy of a wind sensor such as the cup anemometer - wind vane or a sonic sensor is clearly not the restrictive factor in obtaining representative wind estimates.

Accuracy of wind sensors is not the restrictive factor in obtaining representative wind estimates at airports.

Also the use of more sophisticated means of measuring wind or by adding additional wind sensors does not necessarily result in more representative wind reports.

[24] This used to be 6-10 m. according to ICAO Annex 3.

Using more sophisticated means of measuring wind or by adding additional wind sensors does not necessarily result in more representative wind reports.

The anticipation and translation errors should be minimised as much as possible to get representative wind reports.

3.3 Processing of wind data

There are several ways for processing the measured data of a wind sensor. The World Meteorological Organization WMO [WMO, (2008)] and ICAO Annex 3 [ICAO, (2010)] provide recommended procedures on this processing of data. Only a brief summary is provided in this study. More detailed information can be found in documentation provided by WMO and ICAO Annex 3.

The wind data available through ATIS or the control tower are averaged over the past 2-minute period to provide the so-called average wind. The 2-minute period was originally proposed by ICAO in 1967. It provides an adequate level of the error between reported wind and the wind encountered some time after the report [Dutton, (1976)]. The process of averaging the wind observations (speed and direction) involves overlapping averages as new measurements become available. Wind speed and direction sensors are interrogated typically every 1-5 seconds. The 2-minute average wind speed and direction are calculated every 10-60 seconds. Extreme speed and directions are based on 3-second actual values that have been recorded. A vector-averaging technique is recommended by WMO as wind itself is also a vector. Scalar averaging is only applied when the data are available in analogue form. Scalar averaging can introduce in an overestimation of the mean wind speed and in an incorrect mean wind direction[25].

For ATIS and tower reports variations from the mean wind speed (gusts) during the past 10 minutes are reported when the maximum wind speed exceeds the mean speed by 5 kt or more when noise abatement procedures are applied in accordance with ICAO PANS-ATM (Doc 4444), or 10 kt or more when there are no such procedures in place. Gustiness is specified by the extreme values of wind direction and speed between which the wind has varied during the last 10 minutes. WMO recommends that the wind measuring systems should be such that peak gusts should represent a three-second average[26].

[25] See WMO Guide on Meteorological Observation and Information Distribution Systems at Aerodromes (WMO-No. 731).

[26] See WMO Manual on Codes (WMO-No. 306), Volume I.1, Part A.

3.4 Wind sensors used at European airports

As part of the present study a survey was conducted to determine which wind sensors are commonly used at European airports, how the measured data are processed, and what the typical locations and heights are for the wind sensors. For this survey meteorological offices of different European countries were contacted. Also information provided in the AIP was used in this survey. Data on surface wind sensors were obtained for 76 civil airports from 13 European countries.

The vast majority (84%) of the airports in the survey used the classical cup anemometer plus wind vane. The other airports in the survey used the 2D sonic wind sensors. No other types were found amongst the 76 surveyed airports[27]. It was indicated by some of the contacted aviation meteorologists that there is an interest in replacing the cup anemometer-wind vane sensors at airports by 2D sonic wind sensors. The main argument for this replacement is the lower maintenance costs associated with the use of 2D sonic sensors.

All of the 76 airports reviewed reported wind data according to the ICAO standards: 2-minute average speed and direction; highest gust speeds over 3-seconds in a period of 10 minutes; 10-minute wind direction variation. Also instantaneous wind speed and direction are available at a number of airports. Many airports also report gusts during the past 10 minutes when the maximum wind speed exceeds the mean speed by 5 kt or more if they use noise abatement procedures are applied in accordance with ICAO PANS-ATM (Doc 4444).

ICAO Annex 3 states that sensors for surface wind observations should be sited to give the best practicable indication of conditions along the runway and touchdown zones. At airports where topography or prevalent weather conditions cause significant differences in surface wind at various sections of the runway, additional sensors should be provided. The survey showed that anemometers are generally installed close to the runway thresholds. Sometimes only one anemometer is installed near the runway. It could be that due local conditions only one sensor is sufficient to get representative measurements along the complete runway. Airports that used of multiple wind sensors along the runway were not identified in the survey.

ICAO ANNEX 3 states that surface wind should be observed at a height of 10±1 m above the ground. Most of the airports surveyed in this study follow this

[27] Experimental setups were not considered.

recommendation. However a few deviated by measuring the surface wind at for instance 6 m above the ground. It must be noted that previous releases of ICAO ANNEX 3 and WMO recommendations allowed a height for surface wind measurements between 6-10 m or even 6 -15 m above the ground. When measuring at a different height it is possible to correct the wind measurements to 10 m using a theoretical wind profile model that takes into account the local roughness length [Wieringa, (1980)]. However, it was not clear if this was actually done by the airports in this survey. There was no mentioning of this in the consulted AIP.

4 IMPROVED PRACTICES TO SUPPORT FLIGHT CREW DECISION-MAKING

The previous two sections revealed a number of issues related to operations in gusty wind conditions. Based on these identified issues recommendations are derived in this section for improved practices to support flight crew decision-making when operating in gusty wind conditions at airports. These recommendations are presented next.

4.1 FLIGHT OPERATIONS

- Pilot judgement should not be applied whether or not to exceed the crosswinds provided in the FCOM. Crosswinds given in the FCOM should always be used as hard limits.

- When decomposing reported wind into cross- and tailwind components gust should be included. In the most conservative way the gust could be taken omnidirectional which means that the full gust component is taken into the crosswind and tailwind. This could be over conservative for tailwind operations as the takeoff and landing performance is not significantly influenced by gusts. Use of a mean tailwind component by pilots could be sufficient from a safety point of view.

- The 2-minute average wind and gusts reported to pilots are a forecast of the wind an aircraft can encounter at and along the runway. Deviations from these reported winds are always possible and pilots should be prepared for this during the landing or takeoff.

- Pilots should always use the most recent wind report for final landing or takeoff decision. ATIS wind should never be used as the final wind report as significant changes in the wind are possible in the period from the ATIS wind report and the actual landing/takeoff. FMS wind should not be used during the final approach or just before takeoff.

- Instantaneous wind reports during the approach are of limited value to pilots because over shorter periods the wind speed and direction have a lower persistence as the wind variability is high for small times scales. Instantaneous wind reports should therefore not be used by pilots during the final approach.

- To some extend wind reports can be seen as a simplification of the actual wind field that is present along the runway. Obstacles at and around airports can have a significant influence on encountered wind. Pilots should be aware when large obstacles are present near the runway that the encountered wind field can be significantly different from what was reported. Even if the AIP does not explicitly mention this influence, pilots should be aware that it can occur.

- Staying below the advised maximum or demonstrated crosswind does not guarantee a safe operation. The use of an incorrect handling technique during a landing below the advised maximum or demonstrated crosswind could cause serious problems. Pilots should always follow the handling technique as recommended by the aircraft manufacturer. The best technique to use depends on aircraft geometry, aileron and rudder authority. This can vary between different aircraft types.

- Pilots should request a more favourable runway, if prevailing wind conditions are considered inadequate for a safe landing. If this is not possible pilots should not be reluctant to divert to another airport.

- Pilots should have crosswind limits for non-dry runways for their aircraft.

4.2 Miscellaneous items

- The airport metrological office should make sure that the anticipation and translation errors in wind reports are minimised as much as possible. If there is any suspicion that obstacles near the runway could influence the wind field on the runway, this influence should be investigated;

- Crosswind demonstration flight testing should be harmonisation as much as possible. Especially the way the wind is determined should be better addressed. The use of 2-minute averaged tower wind during such certification flight tests should be avoided as these are forecasts which are also subjected to different errors which could result in less representative winds. The turbulence intensity during the test flights should be determined[28]. Gust values should be stated in the AFM for the demonstrated crosswinds;

- A common industry standard on how to derive advisory crosswind values for different runway conditions should be developed.

[28] Gusts are related to the turbulence intensity which itself is related to the local surface roughness. The local surface roughness could vary for different airports and hence could influence the test results.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The main objective of the present study was to conduct a survey and analysis of the existing technological means and techniques for the detection of near-ground wind gusts in the context of large aircraft operations, and consider the issues of appropriate interpretation and use of wind gust data for flight crews decision-making.

The analysis of existing practices and issues regarding near-ground wind gust information for flight crews revealed several issues:

- Demonstrated crosswind of different aircraft types cannot be compared with each other as different ways of wind determination during the flight tests could be used;
- For most commercial aircraft designed since 1950 no hard crosswind limits were established during certification flight testing;
- For the vast majority of commercial aircraft designed since 1950 gust is not mentioned in the demonstrated crosswind;
- There is currently no common industry standard on how to derive advisory crosswind values for non-dry runway conditions;
- Most, but not all operators surveyed for this study used hard crosswind limits;
- Not all operators consider gusts when evaluating crosswind limits;
- There is no general accepted way in decomposing reported wind gusts into cross- and tailwind components;
- Staying below the demonstrated/advised crosswind winds does not guarantee that unsafe events related to crosswind will not occur;

- The surface wind reports that are most commonly used by pilots to determine their margins with respect to limiting values are: tower wind and ATIS wind. These wind reports may differ from the actual wind encountered during take-off or landing;

- The possible absence of hard crosswind limits and the availability of different wind reports from different sources leaves room for variation in the application of discretion by the Commander;

- Instantaneous wind reports during the approach are of limited value to pilots because over shorter periods the wind speed and direction have a lower persistence as the wind variability is high for small times scales;

- Wind reports given to the pilots should be representative for the complete runway. This is however not always the case and can result in large differences between the expected wind and the actual wind encountered.

The survey of existing sensors and measurement techniques for near ground wind gusts detection revealed a number of interesting facts:

- Accuracy of wind sensors is not the restrictive factor in obtaining representative wind estimates at airports;

- Using more sophisticated means of measuring wind or by adding additional wind sensors does not necessarily result in more representative wind reports;

- Buildings in the vicinity of the runway for instance can have a disturbing effect on the wind field along the runway. This will result in differences between the measured wind at location and the wind encountered by the aircraft;

- As part of the present study a survey was conducted to determine which wind sensors are commonly used at European airports. This survey revealed that the vast majority (84%) of the airports in the survey used the classical cup anemometer plus wind vane. The other airports in the survey used the 2D sonic wind sensors. The last sensors are becoming more popular because of their lower maintenance costs. All of the airports surveyed reported wind data according to the ICAO standards.

5.2 Recommendations

Based on the study results a number of recommendations are made:

- The results of this study should be distributed to all interested parties, e.g. aircraft operators, pilot associations, airport metrological offices, aircraft manufacturers, air traffic control organisations and civil aviation regulators.

- EASA should support the development of a common industry standard on how to derive advisory crosswind values for different runway conditions.

- EASA should harmonise the crosswind demonstration flight testing as much as possible together with other regulators (such as FAA, Transport Canada etc.) and the aircraft manufacturers. In particular the way the crosswind is determined during these flight tests should be harmonised.

- A recommended practice for using and interpreting reported wind information including gusts in relation to cross- and tailwind limits should be developed for pilots and operators.

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