WINDSHEAR OCCURRENCES IN EUROPE.
- SOME ANNOTATED CASES AND
INQUIRY INTO A WINDSHEAR DATABASE -

by

H. Haverdings, W.F.J.A. Rouwhorst
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Prepared under the auspices of the Responsables for Flight Mechanics, Systems and Integration of the Group for Aeronautical Research and Technology in EURope (GARTEUR).

GARTEUR aims at stimulating and coordinating cooperation between Research Establishments and Industry in the areas of Aerodynamics, Flight Mechanics, Helicopters, Structures & Materials and Propulsion Technology.

* DLR
** ONERA

Completed : 950715
Order number : 534.408
Typ. : MM
Summary

GARTEUR Flight Mechanics Action Group FMAG05 started activities in 1991 by addressing the problem of windshear and its effect on flight operations. One of the first tasks defined was to inquire if a database of windshear cases that have occurred in Europe could be set up. Such a database may be used for transfer of windshear training, for certification of new windshear airborne detection equipment, for realistic windshear modeling purposes, etc. A number of windshear cases was documented by the participating members. An annotated account of these occurrences is given in this report. FMAG05 held an inquiry amongst European airlines to inventory their experience with occurrences of windshear events and their attitude towards cooperating in contributing to such a European windshear database. Results from this inquiry are reported. Finally recommendations are given on how to proceed with this activity.
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List of abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACMS</td>
<td>Aircraft Condition Monitoring System</td>
</tr>
<tr>
<td>DLR</td>
<td>Deutsche Forschungsanstalt für Luft-und Raumfahrt</td>
</tr>
<tr>
<td>DRA</td>
<td>Defense Research Agency</td>
</tr>
<tr>
<td>FDAU</td>
<td>Flight Digital Acquisition Unit</td>
</tr>
<tr>
<td>FDR</td>
<td>Flight Data Recorder</td>
</tr>
<tr>
<td>GARTEUR</td>
<td>Group for Aeronautical Research and Technology in EURope</td>
</tr>
<tr>
<td>HAT</td>
<td>Height Above Terrain</td>
</tr>
<tr>
<td>KNMI</td>
<td>Royal Netherlands Meteorological Institute</td>
</tr>
<tr>
<td>NIVR</td>
<td>Netherlands Agency for Aerospace Programs</td>
</tr>
<tr>
<td>NLR</td>
<td>National Aerospace Laboratory NLR</td>
</tr>
<tr>
<td>ONERA</td>
<td>Office National d'Etude et de Recherches Aérospatiales</td>
</tr>
<tr>
<td>QAR</td>
<td>Quick Access Recorder</td>
</tr>
<tr>
<td>RLD</td>
<td>Netherlands Department of Civil Aviation</td>
</tr>
<tr>
<td>WINDSTREAM</td>
<td>WINDShear Technology REsearch Advances Masterplan</td>
</tr>
</tbody>
</table>
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1 Introduction

In 1991 the Group of Aerospace Research Technologies Europe (GARTEUR) Flight Mechanics Action Group FMAG05 was initiated, with as purpose to investigate various aspects of windshear. In a two-task program, the first task visualized was to inquire about setting up a database of windshear cases, because it was felt there was a lack of knowledge and/or data in this area, as to the frequency of occurrence of windshear, the severity associated with it, etc. The occurrence of severe downbursts, for example, is generally accepted in the United States, but within the European theatre there is not much information available about their occurrence, and consequently its danger is underestimated. However, there is evidence that such windshears, and especially the severe cases, do occur much more frequently in Europe than generally assumed. For example, in the Faro-DC10 accident, Portugal, December 1992 (Ref. 11) windshear was estimated to have played a role, and in the A320 runway overrun accident at Warsaw, Poland, in September 1993 (Refs. 12, 13), windshear was a contributing factor.

In the 1970's both DRA and NLR collected flight data, from British Airways (BA) and KLM respectively, for about a year's time, in order to build a database of wind profiles, through which statistical inferences could be drawn. Both inertial and aerodynamic data were recorded during about 10,000 BA and 10,000 KLM landing approaches with the B747 (or DC-10), enabling the calculation of wind profiles for each landing. Landings were made on a world-wide scale, within the operational network of either BA or KLM. Although the intent was to investigate the frequency of occurrence of windshear, this database was not destined to be a windshear database, since all the cases registered were not specific windshears, but rather "normal" wind profiles. To analyze these databases for the occurrence of windshear would be rather costly and time-consuming, and a more direct source of windshear is to be found.

Fortunately, with the advent of windshear knowledge within the aviation community in Europe, the airlines have become more keen on detecting these phenomena, and have started recording these events using their on-board data acquisition systems, such as the Aircraft Condition Monitoring System (ACMS) and Quick Access Recorders (QAR), apart from the legally required Flight Data Recorders (FDR).

In order to fill the gap in knowledge an inquiry was held among about 80 European airlines, from April to August 1993, to investigate the possibility of establishing a European windshear database, with their help. Having such a database of windshear occurrences will be very helpful in a number of areas, viz:

- Development and/or validation of windshear models, for use in flight simulators, for realistic and better training of aircrews.
- Transfer of training, or possibly changing the training methodology for aircrews when
operating in a windshear environment.

- Addressing safety issues, such as air-ground data links, ATC procedures, communication, etc.
- Determining the frequency of severity of windshear, and the conditions under which they are prone to occur.
- Drafting of requirements for new windshear avoidance/alert/detection systems, both airborne and ground-based.
- Certification of new or upgraded airborne or ground-based systems, destined to reduce the windshear hazard, such as windshear alert systems, detection and avoidance systems, etc.

The efforts undertaken by GARTEUR FMAG05 are done in a European scale. This specific effort is carried by three research institutes, viz. the National Aerospace Laboratory NLR of the Netherlands, ONERA of France and DLR of Germany. Participation of Great Britain by the Defence Research Agency DRA was long pending, but has ultimately been deferred.
2 General description of sources of windshear cases

Of the countries participating in the GARTEUR Action Group FMAG05, the sources of windshear events which are available are listed in Table 1, see next page. Both KLM, Air France and Lufthansa operate in a regular network. Transavia and Martinair are Dutch charter operators, operating into and out of the general holiday resorts in Europe or the Mediterranean, and are known to encounter orographic shears due to the mountainous environment of several local airports, with much convective heating during the summer periods. Aircraft operated by Transavia and Martinair generally have a windshear alert system installed (B737 and B767), and hence any windshear warning that occurred is recorded.

Table 1 European airlines as source of windshear cases

<table>
<thead>
<tr>
<th>Country</th>
<th>Airline(s)</th>
<th>aircraft type used for windshear cases</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Netherlands:</td>
<td>KLM</td>
<td>B737</td>
<td>ACMS-flight data. Only windshear alerts delivered and analyzed by NLR.</td>
</tr>
<tr>
<td></td>
<td>Martinair</td>
<td>DC-10</td>
<td>DC-10 ACMS data processed by KLM; B767 data processed by SAS.</td>
</tr>
<tr>
<td></td>
<td>Transavia</td>
<td>B737-300</td>
<td>FDAU/FR processing by external company FDAU/FR processing in-house</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B757</td>
<td></td>
</tr>
<tr>
<td>France:</td>
<td>Air France</td>
<td>B727, B747, Airbus</td>
<td>In-house analysis</td>
</tr>
<tr>
<td></td>
<td>Air Inter</td>
<td>Airbus</td>
<td>In-house analysis</td>
</tr>
<tr>
<td>Germany:</td>
<td>Lufthansa</td>
<td>Airbus</td>
<td></td>
</tr>
</tbody>
</table>

The more modern aircraft, such as the B737 and B767, have an on-board data recording system, like ACMS or QAR. Such a system records many parameters in digital form, with varying
sampling rates, but in most cases it is used only for analysis of operational and engineering aspects, for engine condition monitoring, etc. The ACMS system on board the B737 of KLM, for instance, records those parameters which allow for a complete windshear analysis. All the required aerodynamic and inertial data are recorded, with adequate accuracy. In some cases a higher sampling rate than provided would be desirable, but generally an adequate quality of windshear analysis can be achieved. However, many aircraft carry only the legally required FDRs, which record the lowest amount of parameters allowed, and with too low sampling rates to allow such a full windshear analysis to be performed.

In the Netherlands all the required windshear analysis is performed by NLR. This work is performed in a national cooperative program called WINDSTREAM (Refs. 1, 2), in which both KLM and NLR cooperate, together with the National Meteorological Institute (KNMI) and others, and supported by the Netherlands Agency for Aerospace Programs (NIVR) and the Civil Aviation Department (RLD). A Kalman filter and smoother program, developed by NLR, imbedded in a computer program called 'OUTFLOW' (Refs. 3, 4), determines the flight state trajectory, from which the required inertial velocities in three dimensions are determined. These are needed in order to determine the wind velocity vector in three dimensions. Once these wind profiles have been determined another program, called 'GNI' (Ref. 5), is applied to identify the underlying windshear model(s). This windshear identification package has also been developed by NLR.

If a windshear alert has occurred onboard a KLM aircraft, this case is delivered to NLR for further analysis, within the national cooperative program WINDSTREAM mentioned before. Mutual interests are protected by a bi-lateral non-disclosure agreement understanding between NLR and KLM. Data peculiar to aircraft registration and the like, are hidden from the analysis, so as to assure anonymity of the aircrew.

In France data analysis is performed directly by the airlines (Air France, Air Inter). Air France and Air Inter aircraft are equipped with on-board data recording systems; the number of parameters recorded depend upon the category of the aircraft. In their modern aircraft many parameters, in digital form, including aerodynamic and inertial data, are thus recorded. Post-flight analysis is performed in an automated way, but up to now no special data processing system was dedicated to automated windshear analysis. Recorded data can be provided to research organisations, such as ONERA, for further windshear analysis, if necessary.

In Germany no windshear analysis is presently being performed in a coordinated manner by the national airlines. Fundamental research has been performed in the past, however. Swolinsky (Refs. 7, 8) introduced several windshear models for use in flight simulation, based on quasistationary engineering models, and discussed some typical models for thunderstorms, the frontal
shear, and the flow over a flat hill. He developed the well-known low-level-jet model (Ref. 7). Data was gathered on board a Lufthansa A300 plane for about one year and analyzed by Schänzer (Ref. 6) in order to derive windshear statistics. At the end, in 1981, about 600 take-offs and landings mainly on European airports were recorded, of which more than 200 flights had been analyzed. The results of the analyses could be separated into three groups: windshear statistics, engineering models for typical windshear situations, and simulation results in different windshear conditions. The statistics showed a comprehensive data collection of recorded wind vector, temperature, and flight path profiles versus altitude and distance. Furthermore the maximum windshear gradients that occurred were calculated and a hazard characterisation was performed by the computation of the energy height error.

In 1983 Uckermann et al (Ref. 9) from DLR published the results of a windshear inquiry based on the analysis of a questionnaire distributed to about 2300 members of the German pilot association "Vereinigung Cockpit". In 339 out of 562 responses specific comments on windshear and windshear encounters were given. These pilot reports on their personal experience with windshear formed the basis for a statistical analysis. Two hundred and forty-three reports were evaluated. Approximately 70 percent of the reports were related to landing situations, and only 30 percent related to the take-off. The analysis yielded essential factors, from the subjective point of view of the pilots, as well as a starting point for a general assessment of danger in windshear situations. It was concluded that particular windshears during approach and landing were very critical. A follow-on simulator investigation pointed out that a windshear warning system would be a great help to the pilot.
3 Windshear occurrences in Europe

3.1 General

For the analysis of occurrences of windshear the limiting conditions are that no extensive literature search has yet been performed by FMAG05. The original raw ACMS data set available may, or may not contain genuine cases of windshear; this can only be established after analysis of the data. Furthermore airlines have to be willing to provide this data for those cases where windshear is suspected. Despite these limitations it may still be very illuminating to study a few cases of windshear that were especially recorded in the European environment, and that are known to the GARTEUR FMAG05 authors.

Only those cases are described where either enough information is available to guarantee validity of the event, or where a full analysis has already taken place.

The severity of the windshear encountered will be depicted using the general windshear hazard function $F$, which is generally defined as:

$$F = \frac{1}{g} \frac{dW_x}{dt} + \frac{W_z}{V} \tag{1}$$

where $W_x$ is the horizontal along-track wind component ($>0$: tailwind), $W_z$ is the vertical wind component ($>0$: downdraft), and $V$ is the airspeed of the aircraft. When the aircraft traverses an area where the wind decreases from headwind to tailwind, i.e. the gradient $dW_x/dt>0$ ($W_x$ changes from a negative value to a positive value), then $F>0$. In this case additional thrust is required to keep the airspeed constant.

From analyzing the flight mechanics it is clear that the F-factor is the equivalent measure of additional engine thrust-to-weight ratio required to "keep up the airspeed", in case the wind varies with time. In this mechanisation a system which can determine $F$ would then be suitable to provide a warning whenever a limiting thrust margin condition is being reached. From Eq.(1) it is clear that such a system should be capable of determining the vertical wind component $W_z$ as well as the horizontal wind component $W_x$ during flight.

Since most transport aircraft in landing configuration have an additional thrust-to-weight ratio margin of about 0.15g, this value was originally set as the limit for $F$, beyond which an alert would be given. Precise values, however, are still subject to detailed tuning per aircraft to either avoid nuisance alerts, or not to miss alerts that should have been given.
3.2 Description of windshear cases

Five cases which occurred within the last decade, and which are available to the members of the GARTEUR FMAG05, will be annotated. These are all landing approaches, one with a KLM B737 at Amsterdam International airport (Schiphol) on 12 February 1988, one at Paris/Charles de Gaulle airport with an Air France B727 on 2 October 1984, one at Amsterdam International airport (Schiphol), also with an Air France B727, on 27 April 1990, one at Warsaw airport in October 1993, and one at Faro, in December 1992.

3.2.1 Case 1: Amsterdam International airport (Schiphol) 12 February 1988

This case is a ILS landing approach on runway 27 at Amsterdam International airport (Schiphol), on 12 February 1988. Data were recorded on-board a KLM B737 aircraft, where the windshear alert was triggered just before, or during the flare. The pilot noted a "small Cb-cell just above the runway, which caused a strong wind from the right, triggering the windshear alert". From the meteorological point of view the weather was benign, in fact it was the most uninteresting day that could be imagined. There were no any clues that could indicate the presence of windshear. The atmosphere was unstable though, causing locally scattered Cb's to develop, with maximum tops reported up to 18,000 ft.

The following (windshear) models were used in the identification: a downburst or microburst ring-vortex model (of which two were employed), and a boundary layer model.

The following particulars apply:

a) vortex-ring #1: radius R1 = 1443 m; core diameter d1 = 200 m; height z = 860 m; vortex strength Γ1 = 48,800 m²/s. The center of the ring vortex was located about 724 m upwind from the runway threshold, and 571 m to the right of the runway centerline.

b) vortex-ring #2: radius R2 = 1888 m, core diameter d2 = 200 m, height z = 533 m, vortex strength Γ2 = 11,000 m²/s. The center of the ring vortex was located 259 m downwind from the runway threshold, and 214 m to the right of the centerline.

c) boundary layer: exponent n = 0.61, wind direction/speed at upper height: 297°/15 m/s; boundary layer thickness H = 400 m. The wind change through the layer Δχ=34 degrees.

A plot of the three wind components, as determined by applying the various programs, is given in figure 1, together with the wind profile as obtained from the identified wind shear models. A situational sketch of the location of the vortex-rings is given in figure 2. From the plot and situational layout, together with the prevailing wind, one could hypothesize that there is a downburst/microburst with two vortex-rings. The top one, at 860 m (radius 1443 m), is the
strongest one, the second one has descended to 533 m, and has traversed with the wind to the southeast, while at the same time it has also expanded to a larger size (radius 1888 m) and reduced in strength.

The severity of the windshear encountered was determined by calculating a slightly modified hazard index, which is the negative of the windshear hazard factor $F$ as given before in Eq.(1). The modified $F$ has the interpretation that a negative value also has a negative sense, i.e. danger or a performance loss. The F-factor thus defined was calculated, both using the raw wind data, with the 6-second filtered F-value according to TSO-C117 (Ref. 10), and the data generated by the windshear-model derived wind profile. One might consider the latter case as the "ideal", or noise-free windshear hazard. As indicated in Fig.3 the raw windshear hazard exceeds the alert levels ("MUST" at ±0.175, "MAY" at ±0.1) several times. The 6-second filtered hazard index (thin line) crossed the "MAY" alert level at the end of the flight.

The hazard index as determined from the windshear model-derived wind profile only just touched the "MAY" alert level at the end of the flight data. Notice the much smoother trend with time of this hazard index.

A correlation table was also computed for the various F-factors, in order to see which filtering, in terms of filter interval time $T_x$, correlates best with the windshear model profile. The correlations are given in table 2. Best correlation ($r=0.65$) between the windshear model-predicted hazard and the hazard derived from the filtered data is for a filter time interval $T_x$ of 3 seconds. Note that the hazard index correlation coefficient between the model and the raw data is even less than this.

<table>
<thead>
<tr>
<th>F-Factor type</th>
<th>Raw data</th>
<th>Filter interval time $T_x$ (s)</th>
<th>Model</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td>3s</td>
<td>6s</td>
</tr>
<tr>
<td>Raw data</td>
<td>1.0</td>
<td>.72</td>
<td>.54</td>
</tr>
<tr>
<td>$T_x=3s$</td>
<td>.77</td>
<td>1.0</td>
<td>.81</td>
</tr>
<tr>
<td>$T_x=6s$</td>
<td>.54</td>
<td>.81</td>
<td>1.0</td>
</tr>
<tr>
<td>$T_x=10s$</td>
<td>.40</td>
<td>.64</td>
<td>.88</td>
</tr>
<tr>
<td>Model</td>
<td>.56</td>
<td>.65</td>
<td>.60</td>
</tr>
</tbody>
</table>

3.2.2 Case 2: Paris/CDG on 3 October 1984
A take-off from runway 27 of Charles de Gaulle airport near Paris was performed by an Air France B727 on 3 October 1984 (Ref. 14), when the aircraft was hit by a windshear just after
rotation. The indicated airspeed (IAS) dropped rapidly and the pilot not-flying reported "negative vario". The aircraft reached a maximum height of 20 ft and then, with the landing gear down, hit the ground twice. The first time this occurred at about 700 m after the lift-off position, with a force of 1.6g, the second time was 200m further, i.e. about 2000 m from the runway threshold. The aircraft accelerated again, and got over the 50 ft fence height with a speed of 165 kts, at about 2700 m from the runway threshold. At the beginning of the take-off the control tower reported a windspeed of 5 kt from 160 degrees. There was heavy rain at the moment of rotation, and wind gusts south-west of the runway. The crew thought that these gusts were not too severe. For 14 seconds the aircraft did not gain altitude or accelerate. Moreover, the airspeed decreased more than 12 kts in 6 seconds. The estimate, made with the method defined in RIT of total height (with a thrust of 5500 daN, corresponding to an EPR of 1.85 and a slope without engines in take-off configuration of about 11 %) provided an increase of more than 13 %. Radio-altitude and airspeed data are shown in figure 4.

It is suspected that the aircraft encountered a "microburst", associated with the presence of heavy rain, in the vicinity of the airport.

3.2.3 Case 3: Amsterdam International airport (Schiphol), 27 April 1990

The third case constitutes a landing approach at Amsterdam International airport (Schiphol), on runway 27 with a B727 of Air France, flight AF1260, landing at 1606 UTC (Ref. 14). The wind was reported variable on the ground, 320°/17 kts at 1000 ft, 290°/10 kts at 2000 ft, visibility 10 km, 1 okta clouds at 4000 ft, temperature 9 degrees C, altimeter 1024 hPa. The aircraft was at a landing weight of 66,100 kg, Vref was 130 kts. The aircraft was established on the localizer of the ILS of runway 27 at 8 nm, 215 kts, 2800 ft when intercepting the glideslope. It passed the Outer Marker (OM) at 1230 ft, 210 kts, flaps 2°. The flaps were set at 30° at 650 ft, and the aircraft was stabilized at 450 ft at Vref+18 kts, EPR 1.2. The turbulence was moderate. The final approach was performed with variations in speed and EPR. There was no flare. The aircraft touched down at a sink rate in excess of 600 ft/min. Thelanding was very hard (2.1g). The aircraft bounced and touched down again with 1.27g landing load.

During the final phase of flight a horizontal windshear was encountered. With the B727 configuration a maximum thrust should have allowed a correct flare to be made, but the duration (4 s) was not enough to develop the desired thrust. The flight data were analyzed by Air France, and the resulting data, in terms of horizontal wind gradient and integrated wind, are given in figure 5.

3.2.4 Case 4: Warsaw 14th September 1993

The fourth example of a windshear encounter took place on the 14th of September 1993 when a Lufthansa Flight 2904 crashed at Warsaw, Poland (Refs. 12, 13). The Lufthansa A320 flew from Frankfort to Warsaw and executed an ILS approach. The pilot tried to land in a heavy rainstorm on runway 11. At 15:30 GMT, 13 minutes before the crash, the airport reported a heavy
thunderstorm near the field and a wind of 150 deg/12 kt. At that moment the temperature was 22 degrees Celsius. At 16:00 GMT, recordings showed that the wind had changed to 270 deg/20 kt and the temperature had dropped 7 degrees. The complete final approach was carried out in a tailwind situation. At a height of 140 ft the tailwind decreased (performance-increasing windshear) by about 15 kts. This resulted in a flight path of about 2 dots above the nominal glideslope. The aircraft performed a very light touchdown on the runway surface with the right landing gear. The lack of compression of the left landing gear strut was interpreted by the computer as insufficient ground contact, with a resultant delay in deployment of the ground spoilers. The aircraft overran the 9240 ft long runway, impacted and caught fire. Two people of the 70 on board died. Accident investigation has shown that the pilot encountered a tailwind of 20 kt (35 km/hr) on touchdown, while he had already added 20 kt to the approach speed to compensate for a possible windshear occurrence. Due to this high speed, the aircraft made a touchdown 700 m (2,300 ft) past the threshold and overran the runway. It should be noted however that windshear was only a contributing factor to the accident. The primary cause of the accident was found to be a design error in the main landing gear’s "touchdown safety switches". The high touchdown speed, in combination with the wet runway, caused aquaplaning which prevented the aircraft main gear wheels from spinning up. Subsequently the safety switches prevented deployment of the ground spoilers and thrust reversers for almost 9 seconds (until the wheels were spun up).

3.2.5 Case 5: Faro airport, 21th December 1992
The fifth example of a case where windshear was involved happened on 21 December 1992 at Faro airport, Portugal. A DC-10 was landing on runway 11 at 07:53 UTC, where it crashed on the runway, leaving 55 dead and more injured. Extensive analysis was performed by NLR to identify the windshears associated with microbursts, boundary layers, etc. Several new windshear models had to be developed; also the angle-of-attack vane signal needed correction because of sideslip effects, which occurred during flight.

The North and East wind components derived from the flight data are shown as function of time in figure 6a, and the vertical wind component is shown in figure 6b. In the vertical wind component one can clearly discern the pattern of a vortex in the first half of the time history. After several trials three windshear model types were used in the identification process. These were a time-varying model, three microbursts at different locations, and a frontal shear layer type model. Details of the parameters identified are given in reference 11. The most important microburst identified, with a preset core diameter of 700 m, had a radius of 2646 m, a vortex strength of 12,008 m²/s, and a vortex height of 381 m above terrain (HAT). The vortex core diameter had to be preset to a value known from experience because it could not be identified. In view of experience with identifying strengths of ring vortices associated with microbursts, a value of 12,000 m²/s should not be considered heavy or severe, but rather as moderate. The other two microbursts were of even less severity, viz. 1776 m²/s and 1382 m²/s.
A situational sketch of the location of the three microbursts is given in figure 7. The identified windshear model-generated wind components have been plotted together with the original wind data in figures 8a-c for the three wind components. It illustrates well the success of the identification process.

The windshear hazard can be judged from the windshear hazard factor \( F \) as obtained for the windshear model-identified wind profile, which is given in figure 9. This trace history actually is a "noise-free" trace of \( F \). The limit value of \( F \), beyond which a warning may, or should, be given, has been exceeded as indicated in the figure.
4 Inquiry into windshear occurrences

4.1 Windshear Database Questionnaire
In order to investigate the scope and number of occurrences of windshear, and the airline’s willingness to contribute to the research in the area of windshear, a questionnaire was set up and distributed among European airlines. It was mailed to about 80 airlines in Europe, in the period of April to August 1993. A list of the airlines is given in appendix A. The questionnaire has been given in appendix B.

4.2 Questionnaire statistics
Of the 80 airlines to which the questionnaire was issued, 21 responded (i.e. 26 %). Such a return is quite good, considering the fact that generally the return to a written questionnaire varies from 5 to 10 percent. Of the airlines which responded, 2 responded negatively to the question of whether they were willing to cooperate because of reasons of economy, manpower availability, etc, so the average positive response among the respondents is an overwhelming 90 percent. An overview is given in table 3.

Of the 21 airlines which responded, 8 (38 % of respondents) had experienced one or more windshear events in Europe, and one experienced a windshear event outside Europe (Bangkok).

From 1985 to 1993 about 93 windshear events in Europe have been recorded by them, of which ±87 were stored in some form of database. A relatively large number of events still need to be analyzed. Notable is the relatively large number of events recorded by KLM and Maersk Air. An overview is given in table 4.

<table>
<thead>
<tr>
<th>Table 3 Response to questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>airlines response</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>windshear events</td>
</tr>
<tr>
<td>No windshear events</td>
</tr>
<tr>
<td>Total:</td>
</tr>
<tr>
<td>(24%)</td>
</tr>
</tbody>
</table>

GARTEUR OPEN
Table 4  Windshear events recorded, stored or analyzed

<table>
<thead>
<tr>
<th>airline</th>
<th>number of windshear events:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>recorded</td>
<td>stored in database</td>
<td>analyzed</td>
</tr>
<tr>
<td>Air France</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Air Malta</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>British Midland</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>KLM</td>
<td>±52</td>
<td>±52</td>
<td>±5</td>
</tr>
<tr>
<td>Maersk Air</td>
<td>±30</td>
<td>±30</td>
<td>0</td>
</tr>
<tr>
<td>Martinair</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Tap Air Portugal</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>TAT European</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Airlines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sabena</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>±93</td>
<td>±87</td>
<td>±10</td>
</tr>
</tbody>
</table>

Of the respondents only 2 out of 21, i.e. 10 percent, were unwilling to participate in delivering data for the database. It is remarked here, however, that those airlines which are not interested in participating, will likely not have filled out the questionnaire in the first place, so this percentage is not representative of the total negative response population.

Nineteen airlines, i.e. 90 percent of the respondents, were willing to participate. In expressing their willingness to cooperate, 42 percent of the positive respondents (9 airlines) were willing to cooperate free-of-charge, while the remaining 19 positive respondents (58 percent) specified that additional costs would be incurred, see figure 10. A breakdown of these costs is given in figure 11. A total of about 70 percent of the costs specified have to do with data processing and handling.
5 Windshear data processing

In view of the amount of windshear events available but not yet analyzed, the question arises how and where to process them for further analysis and storage in a database, and how to solve associated funding problems. Several options are open to be pursued.

5.1 First option for data processing

The first option is that the aerospace laboratories in each of the nations participating in GARTEUR become the focal point for the national airlines to provide their windshear event data. By having these nations cooperate within the framework of GARTEUR ensures that a common database can be set up, and that experience can be shared. The setting up and maintenance of such a database should then become the primary task of following GARTEUR Action Groups, i.e. this activity may spread across more than one (next) Action Group. Therefore a well-defined end point has to ensure that this activity does not endure forever. This definition has to be made by the first Action Group embarking on this task. Another part of the task of this Action Group should be the definition and setting up of technical and jurisdical procedures related to the analysis of the events entered in the database, proprietary rights and claims, etc., the actual data processing responsibility and the reporting of results to the airlines.

Advantages

Funding for this activity should be set up within the structure of GARTEUR, i.e. all the funding is raised by the national partners collaborating within GARTEUR. Generally partners already participating in GARTEUR are willing to provide such funding. Furthermore the GARTEUR membership is expanding, and hence the support for such Action Groups may also be expanding. Furthermore the cost of harmonisation of data streams is distributed among the members participating in GARTEUR. Most, if not all, of the national research institutes which participate in GARTEUR already have a communication link with their national airlines. It is likely therefore that the airlines will be more willing, and find it easier to provide their windshear events to GARTEUR through their own national institute. Hence GARTEUR will likely have easier access to such events.

Disadvantages

Drawbacks with this option are the acquisition and processing of windshear events from airlines in those nations, which are not a member of GARTEUR. Bi-lateral agreements between those airlines and GARTEUR have to made. Also the contract negotiations with the other airlines in order to account for the costs specified by them (e.g. data handling and processing) may be complex because of the lines of authority. Another difficulty is the communication between the national databases within GARTEUR, and how to unify these into one database. This requires
harmonisation of both tools and models. Management of such a database becomes complicated, since responsibility resides under several GARTEUR-members, and furthermore continuation of Action Groups is required to maintain the database. The question of what to do in case a member drops out of an Action Group, and what consequences it has on further participation and access to the database, also remains to be solved.

5.2 Second option for data processing
The second option is that somebody will be appointed the focal point for this activity. Preferably this should be a research institute having experience in processing windshear events and having programs available to identify windshears from wind data. All airlines having windshear events to report are requested to forward these to the focal point directly.

The focal point will be tasked primarily with filling and maintaining the windshear database during the active period of those Action Groups which support this task. Whenever they are inactive, the focal point should perform this task under own funding, if necessary. As a secondary task the focal point should regularly exchange information within GARTEUR (Action Groups) about the events recorded, will perform analysis of incoming and interesting events, and will report to GARTEUR, the European airlines and the aviation authorities.

Advantages
Communication links are uncomplicated, and so is management of such a database. Making bilateral agreements with airlines, also those in nations which are not a member of GARTEUR, is simpler because of the authority invested in the focal point for performing negotiations, e.g. with regard to non-disclosure agreements with airlines, and requires less management and overhead. Because of the greater ease of working, shorter decision making processes and shorter lines of control will exist. Continuation of the task of filling, maintaining and operating on the database no longer requires the presence of an active Action Group of GARTEUR.

Disadvantages
Funding of this task can no longer be done under the umbrella of GARTEUR, and should therefore be done partly through the national contribution to GARTEUR, and partly by national sponsors. They will have a relatively greater contribution, and hence get more control over the activity. It is possible that airlines will be more reluctant to provide windshear events to a "foreign" focal point because of fear of unwanted manipulation of "their" data. This will also make negotiations harder to accomplish. Because of the national aspects involved (ie. it is a national focal point acting on the database) it is harder to highlight the international character of the activity. Because of the harmonisation of data streams required, a greater cost burden will come upon the focal point to perform this sub-task.
6 Conclusions and recommendations

Many problems related to the windshear hazard still need to be solved. An alert triggered by one airborne system does not automatically mean that the aircraft’s safety has been in jeopardy, and more research is needed to address the question of windshear hazard in relation to the severity of the phenomenon itself. Some of the parameters are aircraft type and flight speed (or energy management). If, through proper pilot training and increased knowledge alone the awareness has increased that windshear may be liable to exist under certain conditions, resulting in a safer operation, the aviation community has then made a step forward towards the goal of overcoming the windshear hazard. Having a database of windshear events in Europe may well be a valid contribution towards this goal, because these cases of windshear, of various types, are very useful, e.g. for accident reconstruction purposes, flight simulator training and for certification issues.

The case studies presented in this report show that it is important to recognise that windshear occurrences in Europe are not as rare as generally assumed, and especially that the downburst-type of windshear does occur in Europe, and not only in the USA.

In view of the number of windshear events recorded by the various airlines the setting up of a windshear database is feasible and highly recommended. Participation of the airlines in filling and supporting this database is indispensable.

It is recommended that a next GARTEUR Group (Working or Exploratory) will study on the technical and juridicial procedural aspects of implementing and operating a windshear database, and to solve problems related to funding, access rights, proprietary rights, etc., and to make a recommendation as to which option is the best.

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1In case option 2 is recommended or selected, the National Aerospace Laboratory NLR has expressed its willingness to act as focal point with regard to setting up a windshear data base.
7 References

Fig. 1  Wind components (data and model) at Schiphol airport, 12 Feb. 1988
EHAM, 12 Feb.88; Runway 27, 1455 GMT

**c) Vertical wind component**

*Fig. 1 Continued*

*Fig. 2 Situational sketch of microburst with 2 vortex-rings at Schiphol airport*
Fig. 3 Windshear hazard at Schiphol airport

Fig. 4 Radio-altitude and airspeed data during CDG airport take-off
Fig. 5 Altitude, wind gradient and integrated wind change at Schiphol airport, 27 April 1990
Fig. 6a  North and East wind components at Faro, 21 December 1992

Fig. 6b  Vertical wind component at Faro, 21 December 1992
Fig. 7 Situational sketch of microbursts location at Faro, 21 December 1992

Fig. 8a Windshear model fit to East wind component at Faro
**Fig. 8b** Windshear model fit to North wind component at Faro

**Fig. 8c** Windshear model fit to vertical wind component at Faro
Fig. 9 Windshear hazard factor from model for Faro case

Fig. 10 Airline respondents cooperating free-of-charge
Fig. 11  Distribution of cost components among respondents
Appendix A  List of airlines in inquiry

Aer Lingus, Dublin, Ireland
Aero-Lloyd, Oberursel, Germany
Aeroflot Soviet Airlines, Moscow, Russia
Air 2000, Crawley, England
Air Atlantis, Lisboa, Portugal
Air Belgium, Zaventem, Belgium
Air Berlin, Berlin, Germany
Air Charter, Rungis, France
Air France, Charles de Gaulle, France
Air Holland Charter, Amsterdam-Schiphol, The Netherlands
Air Inter, Paray, France
Air Liberté, Senia, France
Air Malta Co Ltd, Luqa, Malta
Air Sweden, Karlstad, Sweden
Air UK, Stansted, England
Air UK Leisure, Stansted, England
Air Ukraine International, Kiev, Ukraine
Airtours International, Helmbone, England
Alitalia, Rome, Italy
Austrian Airlines, Vienna, Austria
Balair, Basel, Switzerland
Balkan Bulgarian Airlines, Sofia, Bulgaria
Braathens SAFG, Stavanger, Norway
Britannia Airways, Luton, England
British Airways, Heathrow, England
British Midland, Derby, England
Brymon European AW, Birmingham, England
Caledonian Airways, Gatwick, England
Cargolux Airlines International, Luxembourg, Luxembourg
Conair A/S, Copenhagen, Denmark
Condor Flugdienst GmbH, Neu-Isenburg, Germany
Corsair, Orly, France
Cyprus Airways, Nicosia, Cyprus
Czechoslovakia Airlines CSA, Prague, Czechoslovakia
Danair AS, Kastrup, Denmark
Deutsche BA, Friedrichshafen, Germany
Deutsche Lufthansa AG, Frankfurt, Germany
DLT Deutsche Luftverkehrs-Gesellschaft mbH, Kriftel, Germany
Euralair International, Le Bourget, France
Eurobelgian Airlines, Melsbroek, Belgium
Eurocross, Paris, France
Eurocypria Airlines, Larnaca, Cyprus
Excalibur Airways, Verby, England
Finnair, Helsinki, Finland
Futura, Palma de Mallorca, Spain
German Cargo Service, Kelsterbach, Germany
Germania Fluggesellschaft, Köln, Germany
Hapag-Lloyd Flug GmbH, Hannover, Germany
Iberia, Madrid, Spain
Icelandair, Reykjavik, Iceland
Inter European Airways, Cardiff, England
Leisure International Airways, Stansted, England
Linjeflug AB, Stockholm, Sweden
LOT Polish Airlines, Warszawa, Poland
LTE International Airways, Palma, Spain
LTU Luft Transport-Unternehmen GmbH + Co.KG, Düsseldorf, Germany
LTU Sued International Airways, Munich, Germany
Luxair, Luxembourg, Luxembourg
Maersk Air, Dragør, Denmark
Malev Hungarian Airlines, Budapest, Hungary
Martinair Holland, Amsterdam-Schiphol, The Netherlands
Monarch Airlines, Luton, England
Oasis International Airlines, Madrid, Spain
Olympic Airways, Athens, Greece
Ryanair, Dublin, Ireland
Sabena, Roissy, France
Sabena Technics, Zaventem, Belgium
SAS, Stockholm, Sweden
Scanair-Sweden, Bromma, Sweden
Sobelair, Brussels, Belgium
Spanair, Palma, Spain
Sterling Airways, Dragør, Denmark
Swissair, Zürich, Switzerland
TAP Air Portugal, Lisbonne, Portugal
Tarom Transporturile Aeriene Romane, Bucharest, Romania
TAT European Airlines, Tours Cedex, France
Tea Basel, Basel, Switzerland
 Thy Turkish Airlines Inc., Istanbul, Turkey
Transavia, Amsterdam, The Netherlands ¹)
Virgin Atlantic Airways, Crawley, England
Viva Air, Palma, Spain

¹) added to list for distribution purposes
Appendix B  Airline questionnaire

You are kindly requested to answer the following questions:

A.1 Fleet composition

Specify the type(s) of aircraft your airline operates:

..............................................................

A.2 Fleet operation

Specify the area of operation the fleet is used in (more than one area may be encircled):
Europe / Asia / Africa / USA / Latin America / Other (specify):

..................

A.3 Data registration and analysis

A.3a) Specify which of the above aircraft type(s) have an on-board digital data recording system, other than the required (crash) flight data recorder:

..............................................................

A.3b) Specify the type of data recording (tick off as appropriate):

Quick-Access recorder
Digital AIMS Recorder
other (please specify):

..............................................................
The following questions all apply if 3a) has been answered affirmatively. Indicate, by encircling or tick marks, the correct answer (more than one may be chosen).

A.3c) Which type of parameters are recorded:
    air data / inertial data / miscellaneous

A.3d) Who does the analysis of the recorded data:
    none / own company / outside company / other (please specify: 
    ..................................................)

A.3e) Has any data post-processing been performed: yes / no

A.3f) What is the analysis used for (tick off as appropriate):
    engine health and performance monitoring
    in-house special engineering analysis
    tracking of special events
    trend detection
    autoland analysis
    other (please specify): ............................

A.3g) Do some, or all of the aircraft in your fleet have an on-board windshear detection and alerting system installed: yes / no

A.3h) If (3g) has been answered with yes, has the detection/alerting system been integrated with the GPWS system: yes / no

A.3i) Has your company recorded one or more events where windshear may have occurred or has been suspected: yes / no

Answer the following 4 questions when 3i) has been answered affirmatively:

A.3j) How many events were recorded:

A.3k) Have these events been saved and kept in some database: yes / no

A.3l) Have some or all of these events been analyzed? yes / no

A.3m) If analyzed, who did the analysis:
    own company / outside laboratory / other (please specify: .......... 
    ..................................................)

A.4 Company position with respect to cooperation

Although the form of cooperation has not yet been defined, recorded data from participating airlines will likely be sent to the GARTEUR FM/AG05, who may process and analyze the data. Results from analyses, etc. will be reported to, and shared with the airlines that participate in this action. Bearing this in mind, please answer the following questions:

A.4a) Is your company willing to cooperate by providing the required flight data, free-of-
charge, for the analysis of windshear:
   yes / no

A.4b) If costs are involved, these will primarily be for the following reasons (tick off as appropriate):
   additional data processing    
   outside company data analysis  
   mailing and data medium handling 
   other(specific): ....................

A.4c) For reasons of confidentiality, non-disclosure agreements may be required. If so, this would (likely) apply to:
   all data / partial set of data / not applicable

A.4d) Please specify any special non-disclosure clauses you may have:
       ............

A.5 Questions were answered by:

   Name(s):
   Address:
   Phone:

Thank you very much for your cooperation.
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THE NETHERLANDS  

All 81 airlines participating in the questionnaire (see Appendix A)