Notice of Proposed Amendment 2016-18

Prediction of wind shear for aeroplanes performing commercial air transport operations

RMT.0369 & RMT.0370 (OPS.077 (a) & (b)) — 15.12.2016

EXECUTIVE SUMMARY

This Notice of Proposed Amendment (NPA) addresses a safety issue related to the effects of wind shear on commercial air transport (CAT) aeroplanes. Wind shear is defined as a sudden change of wind velocity and/or direction. BEA, the French Bureau of Investigation and Analysis for Civil Aviation Safety, issued Safety Recommendation (SR) FRAN-2009-012[1] for a regulation to be introduced on the installation of predictive wind shear systems (PWSs) in accordance with ICAO recommendations contained in its Annex 6 Part I 'Operation of Aircraft — International Commercial Air Transport — Aeroplanes'.

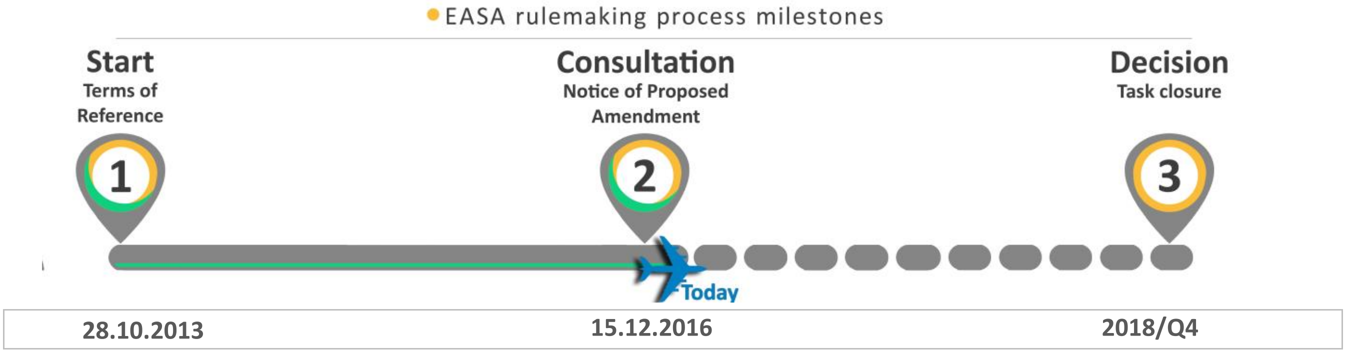
The objective of this NPA is to mitigate the risks linked to the effect of wind shear during a take-off from, approach to and landing at an airport.

Although large aeroplanes having a maximum certified take-off mass (MCTOM) of more than 60 tonnes manufactured today are generally equipped with PWSs, there are many aeroplanes in service which either only have reactive wind shear systems (RWSs) or no wind shear warning systems at all. RWSs only trigger a warning once wind shear has been encountered, thus preventing the flight crew from anticipating such an event. PWSs, however, provide alerts to the flight crew prior to encountering wind shear events, thus enabling better management of the safety risk related to it.

This NPA does not contain a regulatory proposal. Based on the assessment performed by EASA, the conclusion is that no regulatory action is needed to require RWSs and/or PWSs for European-registered aircraft. The NPA provides an answer to SR FRAN-2009-012 addressed to EASA as regards equipping aeroplanes with PWSs and RWSs.

The proposed way forward is expected to maintain the current level of safety.

Action area:	Runway safety		
Affected rules:	Regulation (EU) No 965/2012; ED Decision No 2012/018/R (AMC & GM to Part-CAT)		
Affected stakeholders:	CAT aeroplane operators		
Driver:	Safety; SR FRAN-2009-012	**Reference:**	SR FRAN-2009-012; ICAO Annex 6, Part I, 6.21.1 & 6.21.2
Rulemaking group:	No	**Impact assessment:** Full	**Procedure:** Standard



[1] See *Section 4.1.1* for the response to the Safety Recommendation.

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1. Procedural information

1.1. The rule development procedure

The European Aviation Safety Agency (EASA) developed this NPA in line with Regulation (EC) No 216/2008[2] (hereinafter referred to as the 'Basic Regulation') and the Rulemaking Procedure[3].

This rulemaking activity is included in EASA's 2016–2020 Rulemaking Programme under RMT.0369 & RMT.0370 (former task number OPS.077 (a) & (b)).

The text of this NPA has been developed by EASA. It is hereby submitted to all interested parties for consultation[4].

The major milestones of this rulemaking activity are presented on the title page.

1.2. The structure of this NPA and related documents

Chapter 1 of this NPA contains the procedural information related to this task. Chapter 2 explains the core technical content. Chapter 3 contains the proposed text for the new requirements. Chapter 4 contains the regulatory impact assessment (RIA) showing which options were considered and what impacts were identified, thereby providing the detailed justification for this NPA.

1.3. How to comment on this NPA

Please submit your comments using the automated **Comment-Response Tool (CRT)** available at **http://hub.easa.europa.eu/crt**[5].

The deadline for the submission of comments is **15 February 2017**.

1.4. The next steps in the procedure

Following the closing of the public commenting period, EASA will review all comments.

Based on the comments received, EASA will develop an ED Decision closing RMT.0369 & RMT.0370 (OPS.077 (a) & (b)).

The comments received will be reflected in a comment-response document (CRD). The CRD will be annexed to the ED Decision.

2 Regulation (EC) No 216/2008 of the European Parliament and of the Council of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC (OJ L 79, 19.3.2008, p. 1).

3 EASA is bound to follow a structured rulemaking process as required by Article 52(1) of the Basic Regulation. Such a process has been adopted by EASA's Management Board and is referred to as the 'Rulemaking Procedure'. See Management Board (MB) Decision No 01-2012 of 13 March 2012 concerning the procedure to be applied by EASA for the issuing of Opinions, Certification Specifications and Guidance Material (Rulemaking Procedure).

4 In accordance with Article 52 of the Basic Regulation, and Articles 5(3) and 6 of the Rulemaking Procedure.

5 In case of technical problems, please contact the CRT webmaster (crt@easa.europa.eu).

2. Explanatory Note

This NPA addresses the need to reduce the risk of accidents caused by a sudden change of wind velocity and/or direction close to the ground. This phenomenon is referred to as wind shear. The introduction of PWSs enables flight crew to be aware of wind shear ahead of the aircraft. This allows flight crew to take preventive action, such as aborting the approach, thus ensuring the safety of passengers and aeroplanes. In addition, RWSs will also provide wind shear recognition in those events where the PWS is unable to detect wind shear due to dry air masses.

2.1. Overview of the issues to be addressed

Wind shear represents a serious hazard for the operation of aeroplanes. Accidents and serious incidents have occurred due to the presence of wind shear during the take-off, approach and landing phases of flight.

SR FRAN-2009-012 was published by BEA after a serious incident, and was addressed to EASA in order to establish the regulatory conditions for installing predictive wind shear systems in accordance with the recommendations of paragraph 6.21 of ICAO Annex 6 Part I, which states the following: 'All turbo-jet aeroplanes of a maximum certificated take-off mass in excess of 5 700 kg or authorized to carry more than nine passengers should be equipped with a forward-looking wind shear warning system.'.

Following this SR, EASA assessed the possibility to introduce a requirement to install equipment capable of detecting wind shear. The initial wind shear detection systems relied only on actual air-data measurements to detect the presence of wind shear. Those wind shear detection systems were referred to as RWSs.

Wind shear incidents are regularly reported by European operators.

It is recognised that many of the large aeroplanes in service today are already equipped with PWSs. Some older aeroplane types, however, may only be equipped with RWSs. A number of aeroplane types may not be equipped with any form of wind shear detection system. One of the issues to be addressed in this NPA concerns aeroplane types that, because of their characteristics, may not currently be able to support PWSs due to the physical size of the radome.

2.2. Objectives

The overall objectives of the EASA system are defined in Article 2 of the Basic Regulation. This proposal will contribute to the achievement of the overall objectives by addressing the issues outlined in Chapter 2 of this NPA.

The specific objective of this proposal is to assess whether the number of accidents and serious incidents caused by wind shear in CAT operations can be reduced in a cost-effective manner.

2.3. Summary of the regulatory impact assessment (RIA)

This proposal considers three options.

Option 0: Do nothing. With this Option, there is no change to the rules; risk remains as outlined in Section 4.1.1.

Option 1: Implement PWSs and RWSs for all new[6] turbojet-powered aeroplanes with a CofA issued after 1 December 2023. This would provide a measure of protection for new aeroplanes after 2023 (> 5 700 kg and > 9 pax).

[6] For the purpose of this NPA, 'new' aeroplanes refers to aeroplanes whose first CofA will be issued after 1 December 2023.

Option 2: Implement PWSs and RWSs for all turbojet-powered aeroplanes as of 2023. This would reduce the risk.

The preferred option (**Option 0**) would be to 'do nothing'. There is no economic impact expected from this option. Although it is expected that the frequency of wind shear encounters will increase over the next 10 years due to the increase in aircraft movements, this Option is not considered to result in a decrease in safety.

Option 1, mandating the installation of PWS and RWS equipment on all new turbojet-powered aeroplanes with an MCTOM above 5 700 kg or certified to carry more than nine passengers, would provide a measure of protection for all new aeroplanes after 1 December 2023. However, the cost (EUR 27 million per accident prevented) cannot be justified by the safety benefit.

Option 2: the RIA demonstrates that the cost implications (EUR 51 million per accident prevented), related to retrofitting all turbojet-powered aeroplanes, versus safety benefits are not justified.

Discarded option: In performing the risk assessment, consideration was given as to whether or not all turbine-engined aeroplanes should be included in the scope of the rule. Turboprop-powered aeroplanes are able to provide increased thrust faster than turbojet-powered aeroplanes and, therefore, are better capable of reducing the effects of a wind shear event. Additionally, turboprop-powered aeroplanes are on average smaller compared to turbojet. Therefore, in economic terms, turboprop-powered aeroplanes would be more impacted by the cost of the system. The accident data does include an accident involving a turboprop-powered aeroplane; however, for the reasons mentioned above, turboprop-powered aeroplanes are not included in the proposed mandate.

Safety promotion: EASA will complement the measure proposed by the preferred option with a safety promotion initiative providing recommendations on wind-shear-related training in the context of evidence-based training (EBT)[7] and the oversight thereof. In this framework, recommendations and guidance to voluntarily install PWSs on other categories of aeroplanes not affected by the regulatory proposal of this NPA will be further considered.

2.4. Overview of the proposed amendments

There are no proposed amendments.

[7] For more information, please refer to EASA's ED Decision 2015/027/R 'Implementation of evidence-based training (EBT) within the European regulatory framework', available at https://www.easa.europa.eu/document-library/agency-decisions/ed-decision-2015027r.

3. Proposed amendments

Not applicable.

4. Regulatory impact assessment (RIA)

4.1. Issues to be addressed

Wind shear represents a serious hazard for the operation of aeroplanes. Accidents and serious incidents have occurred during take-off, approach and landing. Earlier wind shear detection systems relied on actual air-data measurements to detect the presence of wind shear. Those earlier wind shear detection systems were referred to as *reactive* wind shear systems (RWSs). PWSs, however, are able to provide an early indication of the presence of any wind shear ahead of the aircraft, thus providing flight crew with an advance warning. NASA studies[8] have shown that as little as a 10-second warning prior to encountering a wind shear event can significantly improve the recovery of the aircraft.

Despite the fact that some aircraft are equipped with RWSs, studies[9] have shown that wind shear detection and recovery has greatly improved with the introduction of PWSs. It is expected that many aircraft types are either equipped with RWSs or are able to activate RWS through existing terrain awareness and warning system (TAWS).

The effectiveness of PWSs in dry conditions is reduced; therefore, it is preferable to have both PWSs and RWSs installed.

Wind shear incidents are regularly reported by European operators, mostly regarding turbine-engined aeroplanes with an MCTOM in excess of 5 700 kg or authorised to carry more than nine passengers. In the last few years, around 1 200 occurrences were reported annually[10]. It is estimated that 40 % of those events occurred outside Europe[11].

It is estimated that 2 700 turbofan-powered aeroplanes in service in January 2015 are already equipped with PWS, out of a total of around 5 000. Some aeroplane types have RWS but no PWS. Many commuter-type aeroplanes are not equipped with any form of wind shear detection system. Therefore, one of the issues to be addressed by this proposal is the ability of smaller aeroplanes, due to the physical size of their radomes, to structurally support currently available PWSs.

4.1.1. Safety risk assessment

An assessment of the number of wind shear occurrences was completed by EASA.

In the 5-year period (2010–2014), EASA Member State (MS) operators had a total of 10 accidents/serious incidents involving CAT operations where wind shear is mentioned as one of the potential contributors. In one of them, there was no indication of whether the aeroplane involved had PWS installed. This is the accident that appears in **Table 1**. Another accident occurred in 2010 involving a turboprop-powered aeroplane that did not have the system installed but, for the reasons explained in Section 2.3, this is not considered in the risk assessment.

Accident reports do not usually state whether the aeroplanes involved in the accidents assessed had a PWS installed. Information obtained by EASA from aeroplane manufacturers (Boeing and Airbus) indicates that PWSs are installed as a standard on aeroplanes of an MCTOM over 60 t. However, PWSs were installed as standard equipment in some aeroplane models several years after they had been manufactured.

8 http://www.nasa.gov/centers/langley/news/factsheets/Windshear.html

9 Wind shear events were studied by the Flight Safety Foundation (see: http://flightsafety.org/files/alar_bn5-4-windshear.pdf for further information). One of its conclusions, also mentioned in the Airbus Flight Operations Briefing Notes (http://www.airbus.com/fileadmin/media_gallery/files/safety_library_items/AirbusSafetyLib_-FLT_OPS-ADV_WX-SEQ02.pdf), is that timely recognition of wind shear is vital for the successful implementation of a wind shear recovery procedure.

10 Source: European Central Repository (ECR).

11 IATA Annual Report 2010 (https://www.iata.org/pressroom/Documents/IATAAnnualReport2010.pdf).

EASA, after doing additional research, found that most of the aeroplanes involved in the above-mentioned accidents or serious incidents already had PWS and RWS installed. This is the main reason why these events were not considered as relevant, as a requirement to install PWS and RWS would have not affected the result.

Wind shear events are mostly encountered during the take-off, approach and landing phases when pilots may have less time to handle emergency situations.

The analysis included the following criteria:

— aircraft mass > 5 700 kg,

— time period: 2010–2015,

— propulsion type: turbofan,

— operation type: commercial air transport,

— events: weather — wind shear encounter.

Table 1: Wind shear accidents of EASA operators (CAT, 2010–2014)

Manufacturer	Type	Registration	Date	Casualties			Ascend and EASA estimates			
				Fatalities	Serious injuries	Minor injuries	Build year	Current value	Loss (percentage)	Loss (million)
Airbus	A321	OE-LBF	23-Dec-11	0	0	0	2001	:	:	:

The Internal Occurrence Reporting System (IORS) is EASA's occurrence repository[12]. Its database shows one wind shear accident by European operators in the last 5 years that is relevant to this task, for the reasons explained above, which equates to 0.59 wind-shear-related accidents per 10 million flights.

Although no catastrophic consequences followed the above-mentioned accident in Europe, wind-shear-related accidents of non-European operators, however, did result in a number of fatalities (see **Table 2** below). The location of these two accidents was outside the EASA Member States' territories and the MCTOM of the aeroplanes involved was below 60 t.

Table 2: Recent wind shear accidents of third-country operators (CAT, 2010–2014)

Manufacturer	Type	Registration	Date	Casualties			Ascend and EASA estimates			
				Fatalities	Serious injuries	Minor injuries	Build year	Current value	Loss	Loss (million)
Bombardier (Canadair)	CRJ Regional Jet	4L-GAE	04-Apr-11	32	1	0	1995	€ 1.0	100%	€ 1.0
Fokker	F28	VH-NQE	19-Oct-12	0	0	0	1993	€ 0.2	50%	€ 0.1
Average per accident				16.0	0.5	0.0		€ 0.6	75%	€ 0.5

The full safety analysis was completed by looking at the European Central Repository (ECR)[13] that contains all occurrences reported to the EASA MSs through the mandatory reporting systems of each MS. An overview of the occurrences where wind shear was a factor shows that in the recent years (2013–2015) around 1 200 of these occurrences are recorded annually in the European Central Repository (ECR). This number includes CAT aeroplanes above 5 700 kg equipped with turbofan engines. Approximately 80 % of these occurrences happened during the approach or landing phase, while 10 % occurred during take-off. None of these events resulted in injuries to persons on board. In more than half of the cases it led to the execution of a go-around or a missed approach. In 2% of the cases the encounter of wind shear led to an abnormal landing, in 1 % to upset of the aircraft and to the

[12] As per Commission Regulation (EU) No 966/2010, Commission Regulation (EU) No 376/2014, and Regulation (EC) No 216/2008.

[13] As established by Regulation (EU) No 376/2014.

triggering of stall or envelop protection warnings in 1 % as well. Other warnings (i.e. overspeed, sink rate) were triggered in 25 % of the cases.

The existing mitigating measures include:

1. weather information from air traffic control (ATC) or preceding aircraft to warn of pending wind shear event;
2. detection of wind shear event using on-board sensors (i.e. RWS); and
3. pilot training including detection and recovery from a wind shear event.

A wind shear event is dynamic, that is, it can appear very quickly and without necessarily being detected by the preceding aircraft.

Some aeroplanes are equipped with the RWS functionality. Although this should provide an alert to the flight crew, it may come too late as the aeroplane is already experiencing the effects of the wind shear.

Detection of wind shear by the pilot is usually slower than that of an aeroplane equipped with the PWS functionality; therefore, this mitigation may not provide sufficient awareness in time to prevent the full effect of the wind shear event. To complement this requirement, training should be provided in a simulated environment to enable familiarisation with wind shear aural and visual alerts together with the appropriate escape manoeuvres.

Through its Safety Recommendation, the BEA recommended that the DGAC, in liaison with the other European authorities, establish the regulatory conditions for installing predictive wind shear systems in accordance with the recommendations of paragraph 6.21 of Annex 6 (ICAO).

Paragraph 6.21 of ICAO Annex 6 reads:

'6.21.1 Recommendation.— All turbo-jet aeroplanes of a maximum certificated take-off mass in excess of 5 700 kg or authorized to carry more than nine passengers should be equipped with a forward-looking wind shear warning system.'.

ICAO recommendations have a voluntary character and, thus, operators may decide to not follow the recommendation given in this paragraph to equip their aeroplanes with a forward-looking wind shear warning system.

However, EASA considers that a cost–effectiveness analysis (CEA) should support the decision of whether or not to mandate the installation of PWSs and, if positive, define the conditions and the applicability of such regulatory proposal.

Finally, other initiatives on wind shear have started or are being planned as follows:

— As regards information on wind shear provided by the aerodrome meteorological office[14], EASA has included this requirement in its Opinion No 03/2016 'Maintaining the aerodromes rules — ICAO new approach classification'[15].

— EASA is also planning to examine, at a later stage, the possibility to require the installation of automated wind shear detection systems at aerodromes where wind shears are observed frequently.

[14] Commission Implementing Regulation (EU) 2016/1377, and more specifically point *MET.OR.235 Aerodrome warnings and wind shear warnings and alerts* contains requirements for the aerodrome meteorological offices to provide wind shear warnings for aerodromes where wind shear is considered a factor, in accordance with local arrangements with the appropriate ATS units and operators concerned, as well as to generate wind shear alerts if it is detected by automated, ground-based wind shear remote-sensing or detection equipment. The technical details are included in *MET.TR.235 Aerodrome warnings and wind shear warnings and alerts*.

[15] https://www.easa.europa.eu/document-library/opinions/opinion-032016

4.1.2. Who is affected?

Aeroplane manufacturers and European CAT operators of turbojet-powered aeroplanes with an MCTOM in excess of 5 700 kg or authorised to carry more than nine passengers.

4.1.3. How could the issue/problem evolve?

The expected growth of air traffic will increase the exposure to wind shear encounters, potentially leading to more wind-shear-induced accidents and incidents to European operators (see **Table 10** which estimates around six non-fatal accidents by 2053 in Europe).

4.2. Objectives

The overall objectives of the EASA system are defined in Article 2 of the Basic Regulation. The general objective of this proposal is to reduce the rate of wind shear accidents and serious incidents of European operators.

The specific objective of this NPA is to reduce the rate of wind shear accidents and serious incidents by mandating the use of on-board predictive wind shear technology in a safe and cost-effective way.

4.3. Policy options

This RIA assesses three possible options for the implementation of PWSs and RWSs on CAT aeroplanes.

The options are listed in **Table 3** below.

Table 3: Selected policy options

Option No	Short title	Description
0	Do nothing	Baseline option (no change to the rules; risks remain as outlined in the issue analysis).
1	Implement PWSs and RWSs for all new aeroplanes from 2023	Provides a gradual introduction of PWS and RWS protection for all new turbojet-powered aeroplanes. Many aeroplanes will already benefit from having RWSs installed.
2	Implement PWSs and RWSs for all aeroplanes from 2023	Provides a comprehensive introduction of PWS and RWS protection for all 'affected' turbojet-powered aeroplanes (new and in service). Some aeroplanes will already benefit from having RWSs installed.

4.4. Methodology and data

4.4.1. Applied methodology

The benefits and costs of the various options are compared in a cost–effectiveness analysis (CEA) for PWSs. The net cost of each option is calculated by subtracting the costs from the monetised benefits of each option. Costs might include the price of installing equipment on aeroplanes, while benefits might include the monetised value of aircraft damage and airport disruption avoided by each option.

The CEA ranks the regulatory options based on their net cost per unit of effectiveness. The unit of effectiveness can be the number of fatalities prevented or, as in this case, the number of accidents prevented.

For reasons of comparability, all monetary values are expressed in euros (EUR). Any exchange rates are based on the European Central Bank's annual average reference rates for 2014. For future costs and benefits expressed in euros, a standard discount rate of 4 % has been applied[16].

4.4.2. Data collection

The unit costs estimated in this RIA are based on information provided by manufacturers of aircraft and PWSs.

The evolution for the different options is generated based on:

— ASCEND/AIRCLAIMS database;

— forecasts from manufacturers;

— long-term traffic forecast by EUROCONTROL;

— an online survey of operators and manufacturers; and

— large-aeroplane retirement estimates generated from ASCEND data.

4.5. Analysis of impacts

It is assumed that the rate at which a PWS is introduced determines the safety impact of a particular option.

The three identified options result in different rates at which PWSs and RWSs are introduced. In order to assess these different options, the evolution was analysed. According to industry forecasts, a 2.7 % annual increase is expected in the number of in-service aeroplanes in Europe until 2053. In absolute numbers, the relevant number of aeroplanes would increase from around 5 000 in 2015 to 12 400 by 2050.

Option 0 is the reference option where there is no regulatory action taken. The share of new aeroplane deliveries with PWSs is estimated to be around 64 % in 2015.

[16] There is a general agreement among economists that discounting is necessary when comparing a stream of benefits and costs accruing over a number of years. EASA estimates contain both nominal and present values. EASA uses a discount rate of 4 % as recommended by the European Commission's (2009) Impact Assessment Guidelines. This discount rate is expressed in real terms, taking account of inflation.

The fleet can be divided into two distinct groups in terms of PWS equipment:

— Below 60 t of MCTOM: where only 11 % of the in-service aeroplanes are equipped with PWSs, and only around 15 % of the new deliveries are equipped with PWSs.

— Above 60 t MCTOM: where, on the contrary, the information received from two of the manufacturers consulted by EASA indicates that all new aeroplanes delivered are standardly equipped with PWSs. Additionally, data indicates that the share of existing aeroplane fleet equipped with PWSs is close to 76 %.

Table 4: Share of aeroplanes equipped with PWSs

Fleet	Below 60t	Above 60t	Total
In service	11%	76%	54%
New deliveries	15%	100%	64%

The share of new deliveries with PWSs in the 'below-60-t MCTOM' group saw a relatively modest growth in the last two decades (1998–2014), increasing on average 0.22 percentage points annually. If this growth rate will not increase, it is expected that only 22.8 % of new deliveries will be equipped with PWSs by 2050.

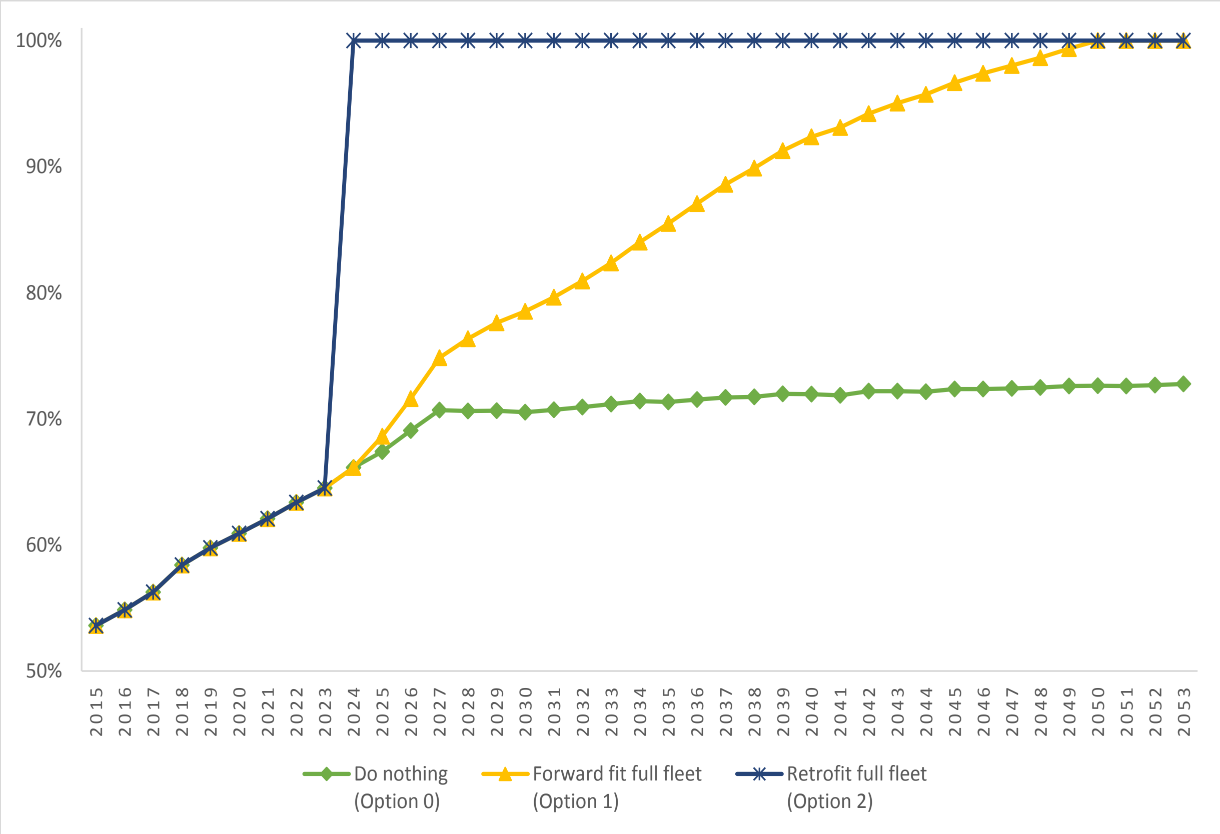
The share of in-service aeroplanes with PWSs in the whole fleet will increase from the current 54 % to 75 % by 2050 (see Figure 1 below).

Option 1 would eventually guarantee that, by 2050, all the fleet is equipped with PWSs after the retirement of the aeroplanes that have no PWSs installed.

Option 2 mandates that all new deliveries and all in-service turbojet-powered aeroplanes within the scope of this rulemaking task be fitted with PWSs and RWSs. By 2023 at the latest the whole of the EASA MS operators' fleet would be equipped with PWSs. It is assumed that most aeroplanes will already have RWSs.

Figure 1 assumes that the equipment would be installed in the implementation year. In reality, it is likely that the introduction will be carried out gradually as of the applicability date of the new rule. Thus, the associated costs and benefits are likely to occur somewhat earlier in time.

Figure 1: Share of aeroplanes equipped with PWSs



As the purpose of this rulemaking task is to assess whether installing PWSs would reduce the number of accidents, the analysis of the safety impacts didn't take into account accidents and serious incidents which occurred with aeroplanes equipped with PWSs. It was, therefore, assumed that there would be no accidents with aeroplanes equipped with PWSs in cases where wind shear was the main contributing factor. Like most safety systems, PWS has a lower-than-100-% effectiveness.

The current PWS technology relies on measuring the Doppler effect of moisture particles in the air ahead of the aircraft. It is possible, however, to encounter a 'dry air' wind shear event. In this case, the current PWS technology is unable to detect the event. Instead, the flight crew would have to rely on external references, such as change of airspeed or perceived aircraft performance. Alternatively, an RWS may detect the onset of wind shear events.

Typically, a wind shear alert is triggered when variations in indicated airspeed, in excess of 15 kt, are detected or when a vertical speed excursion of 500 ft/m is encountered. A PWS, however, calculates the energy level of the aircraft and generates an alert when the energy level of the aircraft falls below a predetermined threshold.

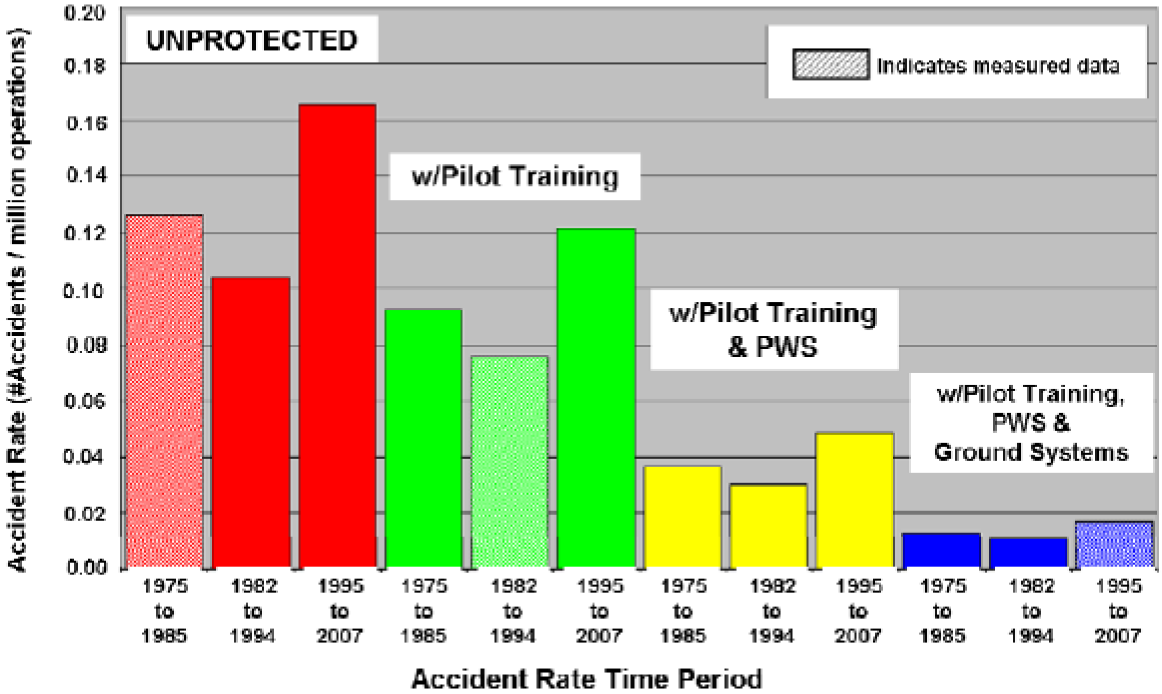
Generally, during take-off, wind shear alerts are inhibited above 100 kt until reaching 50 ft when they are active. For the approach, PWS alerts are active only within a certain range[17].

[17] The PWS should operate as follows, in accordance with RTCA DO 220A: Aural and visual textural alerts from ground level to a minimum of 1 200 feet during take-off. For landing, there is a requirement to have an accurate source of altitude above the ground available. Therefore, only a radio altimeter (rad alt) will supply this type of information. Most rad alts operate from approximately 2 500 to 0 feet. However, manufacturers can arm the PWS at, e.g. 2 300 feet, but only triggering below 1 500 feet above the ground.

Although the effectiveness of PWS radars has often exceeded 95 % in simulated environments[18], as discussed above, it is significantly reduced in dry-air environments. However, a different assumption would have not changed the result of the RIA.

RWSs can help recover from a wind shear encounter without coming in contact with the ground in around 40 % of the cases[19] (low and high estimates are around 30 and 60 % respectively). Accident modelling shows that pilot training alone can reduce wind-shear-related accident rates by around 25 %, while PWSs are estimated to further decrease the accident rate by almost 60 % (see **Figure 2**).

Figure 2: Comparison of measured and mitigation-adjusted accident rates for unprotected (1975-85), transitional (1982-94), and protected (1995–2007) time periods[20]. Measured data for Part 121/9.



Although the study has been conducted for a geographical area different than Europe, and regardless of the fact that weather conditions may vary from one location to another, it is considered that the impact for European operators would be similar regardless of the location because they fly to multiple destinations.

18 MIT (2009): Wind-Shear System Cost Benefit Analysis Update. Project Report ATC-341. Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts. Prepared for the Federal Aviation Administration, Washington, D.C. 20591. 13 May 2009, p. 36. Available at https://www.ll.mit.edu/mission/aviation/publications/publication-files/atc-reports/Hallowell_2009_ATC-341_WW-17238.pdf.

19 M. Martin (1994): Wind shear systems cost-benefit and deployment study: System engineering and integration contract for implementation of the National Airspace System plan. ATC-92-1201, p. 91.

20 Available at https://www.ll.mit.edu/mission/aviation/publications/publication-files/atc-reports/Hallowell_2009_ATC-341_WW-17238.pdf. Each grouping of accident rates show the accident rate based on corrections for either adding or subtracting the impact of various safety measures. For example, the red-hatched bar for 1975–85 represents the measured accident rate for that time period. When this accident rate is corrected, using a pilot training model, the solid green bar under the heading w/Pilot Training is obtained. Adding predictive wind shear systems results in the yellow bar and with the current ground-based constellation of TDWR, WSP, and LLWAS, the blue bar is obtained. Conversely, the measured 'protected' accident rate from 1995–2007 can be corrected backwards to remove each mitigation technique.

4.5.1. Safety impact

The installation of PWSs would provide an early indication of a wind shear event and, therefore, would reduce the likelihood of an accident or incident. The safety impact of the different options depends on the rate at which PWSs are introduced. The benefit is, therefore, assumed to be directly proportionate to the share of aeroplanes equipped with PWSs — see **Figure 1**.

As outlined in the safety risk assessment above, there is an estimated 0.59 wind-shear-related accidents with aeroplanes not equipped with PWSs per 10 million flights. In order to estimate the number of future accidents, two trends need to be considered: on the one hand, the number of both aeroplanes and flights is expected to increase around 2.7 % annually, which — assuming a constant accident rate — causes an increase in the number of accidents; on the other hand, as the share of new aeroplanes equipped with PWSs will increase, so will the number of flights with PWSs do, which causes a decrease in the number of flights without PWSs and, consequently, also in the number of accidents. A third factor contributing to the increased share of flights with PWSs is the fact that most aeroplanes that retire are not equipped with PWSs.

Table 11 shows the number of accidents prevented by each option in the 2024–2053 period. **Table 5** below summarises the estimated number of wind-shear-related accidents taking into account the growth and the various share of aeroplanes equipped with PWSs in the various options.

Estimating EUR 1.1 million average value of aeroplane damage per accident, the safety benefit in aeroplane damage resulting from avoiding 3.8 and 5.8 accidents with Options 1 and 2 is EUR 4.7 and EUR 8.6 million respectively (in present values).

Table 5: Cost of accidents prevented with the two options (EASA MSs operators, 2024–2050)

Costs	Option 1	Option 2
	Forward fit full fleet	Retrofit full fleet
Accidents prevented	3.8	5.8
Aircraft damage avoided	€ 1 380 208	€ 2 512 797
Airport disruption avoided	€ 3 352 203	€ 6 102 994

The benefit of preventing airport disruptions is estimated to be EUR 2.6 million per accident (see **Table 6** below).

Table 6: Estimation of airport disruption costs prevented per accident

Time after accident (hour)	Average delay (hours)	Arrivals				Departures				Total
		Diversions (aircraft)	Cancellations (aircraft)	Delays (aircraft)	Value	Diversions (aircraft)	Cancellations (aircraft)	Delays (aircraft)	Value	
0–1	9.5	5			€ 133 000		5		€ 165 500	€ 298 500
1–2	8.5	5			€ 133 000		5		€ 165 500	€ 298 500
2–3	7.5	5			€ 133 000		5		€ 165 500	€ 298 500
3–4	6.5		5		€ 165 500		5		€ 165 500	€ 331 000
4–5	5.5		5		€ 165 500		5		€ 165 500	€ 331 000
5–6	4.5		5		€ 165 500		5		€ 165 500	€ 331 000
6–7	3.5		5		€ 165 500		5		€ 165 500	€ 331 000
7–8	2.5			5	€ 98 750			5	€ 98 750	€ 197 500
8–9	1.5			5	€ 59 250			5	€ 59 250	€ 118 500
9–10	0.5			5	€ 19 750			5	€ 19 750	€ 39 500
0–10		15	20	15	€ 1 238 750	0	35	15	€ 1 336 250	€ 2 575 000

4.5.2. Environmental impact

None.

4.5.3. Social impact

None.

4.5.4. Economic impact

Two manufacturers of wind shear warning systems were contacted to provide comments on the expected costs of installing PWSs in large aeroplanes. Typically, the cost would be in the order of EUR 100 000 for new aeroplanes and EUR 150 000 in case of a retrofit.

In calculating the cost of the equipment, it was assumed that it would decrease with time for several reasons. It was estimated that if the system was mandated, there would be a higher demand, which would result in a cost reduction. Additionally, technical development allows for an improvement in the cost–efficiency ratio, which can be translated into a further reduction of the cost over time. All this, together with the fact that wind shear warning systems are likely to be integrated as part of other systems in the future, resulted in a potential decrease in the cost of the equipment over time. To facilitate the assessment, the average was estimated for the whole period. The rate of the price decrease is assumed to be 2 % per year.

The monetary values of the benefits of aeroplane damages and airport disruptions avoided are assessed in the safety impacts above and are illustrated in **Table 5**.

The implementation costs of RWSs are considered low when compared to the implementation costs of PWSs.

Option 0 would not have any economic impact for the reasons mentioned in Section 4.5 of the NPA.

Data shows that mandating all newly delivered aeroplanes to be equipped with PWSs and RWSs would increase the estimated number of new aeroplanes delivered with the systems in the period 2024–2053 from 11 039 to 15 134. The cost of equipping 4 095 aeroplanes with a unit cost of around EUR 85 100 in 2024, and decreasing by 2 % every year to around EUR 47 400 by 2053, amounts to EUR 111 million in present values[21]. However, for the CEA this cost is reduced by the cost of aircraft damages and airport disruptions avoided by preventing accidents (see Section 4.5.1 above). It is assumed that the cost of implementing RWSs is small when compared to implementing PWSs.

Table 7: Cost of forward-fit as percentage of new aircraft (aeroplane) price

Weight category (tonne)	New aircraft price (estimate)	Cost of forward fit		
		Year 2023	Year 2033	Year 2043
5.7<MTOW<15	€ 6 000 000	1.4%	1.2%	1.0%
15≤MTOW<40	€ 21 000 000	0.4%	0.3%	0.3%
40≤MTOW	€ 45 000 000	0.2%	0.2%	0.1%

The typical equipment changes required for the retrofit of a large aeroplanes to provide PWS functionality include new radar antenna, radar processor, control panel and dedicated wind shear caution/warning aural and visual annunciations. In some cases the control panel, aural and visual alerts may be included in the existing system architecture (e.g. electronic flight instrument system (EFIS) and central warning systems).

[21] See third paragraph of Section 4.4.1 ‘Applied methodology’.

Manufacturers did, however, explain that some aircraft types may not be able to support (physically) the larger antennas currently available to support PWS. This issue is currently being addressed by both manufacturers (Rockwell Collins and Honeywell), and a solution for these aircraft types will be available soon.

In addition, the radome needs to be of sufficient quality to support the operation of PWS. For this reason, it is expected that the retrofit costs for the smaller commuter-type aeroplanes would be similar (approx. EUR 150 000). The current PWSs also require inputs from an inertial reference system (IRS), air data system (ADC) and radio altimeter. Aeroplanes that do not have the required inputs may incur additional costs.

Given the information above, the installation of PWSs would require aeroplanes to be modified during a prolonged maintenance check or to be completed in small steps culminating in the activation of the system. These costs are assumed to be included in the expected retrofit costs.

By 2024 the number of aeroplanes is estimated to grow to 6 321, of which 4 181 aeroplanes will already be equipped with PWSs and 2 140 yet to be equipped. The cost of retrofitting 2 140 aeroplanes in 2024 and the cost of forward-fitting new aeroplanes from 2024 onwards amounts to EUR 522 million (EUR 306 million in 2015 values). This amount can be reduced by the costs of aircraft damages and airport disruptions avoided, resulting in EUR 297 million net cost expressed in 2015 values.

Conclusion

The cost of installing PWSs on various subgroups of the full aeroplane fleet is proportionate with the size of each group. Therefore, Option 0 implies no additional costs. Forward-fitting the full fleet would imply a cost exceeding EUR 100 million and retrofitting the full fleet would cost almost EUR 300 million even after subtracting the costs of aircraft damages and airport disruptions avoided (see **Table 8** below).

Table 8: Cost of fitting PWSs (EASA MS operators, 2024–2050, in euros)

Cost of fitting PWS	Option 1	Option 2
	Forward fit full fleet	Retrofit full fleet
Gross cost	€ 111 304 311	€ 306 003 808
Net cost	€ 106 571 900	€ 297 388 017

Table 9 compares the costs of the various options per accident prevented in order to establish the most cost-effective option.

4.5.5. General aviation and proportionality issues

General aviation is not affected by this proposal.

Commuter aircraft

Retrofit implementation of PWSs on in-service commuter aircraft may result in technical difficulties regarding the existing radome quality, the minimum size of radar antenna and required inputs. The cost to implement PWSs on these aeroplanes could be approximately EUR 150 000. Therefore, retrofitting smaller commuter aircraft is considered disproportional.

4.5.6. Impact on 'better regulation' and harmonisation

Option 0 does not result in any impact on 'better regulation' and harmonisation.

Options 1 and 2 are the only options that would partially or fully standardise the International Civil Aviation Organization's (ICAO) recommendation to equip 'all turbo-jet aeroplanes of a maximum certificated take-off mass in excess of 5 700 kg or authorised to carry more than nine passengers with 'a forward-looking wind shear warning system' (PWS) as set out in […]'.

Additionally, option 2 would achieve harmonisation with the FAA requirements.

4.6. Comparison and conclusion

4.6.1. Comparison of options

This proposal considers three options.

Option 0: Do nothing. With this Option, there is no change to the rules; risk remains as outlined in Section 4.1.1.

Option 1: To implement PWSs and RWSs for all new aeroplanes, which eventually guarantees that, by 2050, all the fleet would have the systems installed, thus further reducing the risk. However, the cost of this Option (EUR 26.6 million) may not be proportionate for smaller aeroplanes, and this is why it is discarded.

Option 2: To implement PWSs and RWSs for all aeroplanes is the Option that reduces significantly the risk. It is additionally expected that some operators/airframe manufacturers may take the opportunity to implement PWSs and RWSs before 2023, thus further reducing the risk. However, this represents the higher cost that cannot be justified by the safety benefit, and this is why this Option is discarded.

Table 9 gives a summary of the most important impacts expected. The results of the assessment suggest that Option 1 is the most cost-effective compared to the ones that have an economic impact, and that Option 0 represents no additional cost for industry. The cost of preventing an accident with Option 1, on the other hand, is still significantly high.

Option 2 could prevent more accidents, but the average cost (EUR 50.9 million) per accident prevented is substantial. The costs associated with the implementation of PWSs on smaller aeroplanes could be significantly higher if a new radome is required and flight deck modifications are taken into consideration. The costs of implementing RWSs are considered low when compared to the implementation of PWSs.

Although the RIA indicates that 54 % of the aeroplanes falling within the scope of the rulemaking task were already equipped with PWSs in 2015, the cost implications of PWS installation for the other 46 % versus hull damage, caused by the effects of a wind shear event, indicate that wind shear warning system installation costs for the operator are significant when compared to the potential damage to an aeroplane caused by a wind shear event.

Table 9: Summary of options (period 2024–2053)

Cost per accident prevented	Option 1	Option 2
	Forward fit full fleet	Retrofit full fleet
Gross cost	27 870 778	52 428 474
Net cost	26 576 466	50 915 033

Following the assessment of all the impacts, Option 0 is the preferred one. It is assumed that most of the larger aeroplanes are already equipped with PWSs and RWSs.

The year 2023 was chosen for Options 1 and 2 based on the expected time required by airlines/operators/manufactures to update their aeroplanes in accordance with the new rule.

Furthermore, the mitigation of the risk related to wind shear, which may be achieved with the use of PWS, should be corroborated by a safety promotion initiative recommending enhancing wind-shear-related training for flight crew and the oversight thereof. It is in fact recognised that, irrespective of the option finally chosen by the RIA, training is an essential part of the overall reduction of risk.

Therefore, EASA will complement this NPA with a safety promotion initiative that will provide recommendations both to authorities and operators in terms of strengthening wind-shear-related training in the context of evidence-based training (EBT)[22] and the oversight thereof. In this framework, recommendations and guidance to voluntarily install PWSs on other categories of aeroplanes not affected by the regulatory proposal of this NPA will be further considered.

4.6.2. Sensitivity analysis

The variation of accident rates would potentially change the preferred option. Although the safety analysis has only taken into account events occurring between 2010 and 2014, as these were considered to better represent the current scenario, the period from 2000 to 2009 was also reviewed and did not reveal any fatal accidents.

If it is assumed that around 40 % of the accidents would occur even if aeroplanes were equipped with PWSs, then the estimated net cost per accident prevented would increase proportionally for each option by 150 %. A lower-than-100-% effectiveness of the wind shear detection systems would not change the CEA result: Option 0 would remain cost-free and, therefore, the preferred one.

Wind-shear-related accidents have other direct and indirect costs that were not included in the calculation of economic benefits. These include accident rescue costs and accident investigation costs. The inclusion of these costs could somewhat decrease the net cost per accident prevented and make all options more cost-effective, although Option 0 would still be the preferred one.

4.6.3. Monitoring and ex post evaluation

Monitoring of wind shear events will continue to determine whether the rate of accidents, where a wind shear event was a causal factor, decreases.

[22] For more information, please refer to the EASA ED Decision 2015/027/R 'Implementation of evidence-based training (EBT) within the European regulatory framework', available at https://www.easa.europa.eu/document-library/agency-decisions/ed-decision-2015027r.

5. References

5.1. Related regulations

— Commission Regulation (EU) No 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council (OJ L 296, 25.10.2012, p. 1)

5.2. Related CSs, AMC and GM

— Decision N° 2012/018/Directorate R of the Executive Director of the Agency of 24th October 2012 on Acceptable Means of Compliance and Guidance Material to Commission Regulation (EU) No 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council (Acceptable Means of Compliance and Guidance Material to Part-CAT)

5.3. Bibliography

FAA: AC 25-12 — Airworthiness Criteria for the Approval of Airborne Windshear Warning Systems in Transport Category

AC 00-54 — Pilots Windshear Guide

AC 120-41 — Criteria for Operational Approval of Airborne Wind Shear Alerting and Flight Guidance

FAR Part 121.358 — Low-altitude windshear system equipment requirements

FAA Paper —- Airborne Short and Long Range Windshear Predictive Systems, Revision 10.2 (dated January 1995)

FAA TSO C63e – Airborne Radar Equipment

RTCA: DO-220 Minimum Operational Performance Standards (MOPS) for Airborne Weather Radar with Forward-Looking Windshear Capability

DO 220A Minimum Operational Performance Standards (MOPS) for Airborne Weather Radar with Forward-Looking Windshear Capability (available now)

ICAO: Annex 6, Part 1 — Recommendation of forward looking wind shear system (predictive)

BEA: FRAN-2009-012 Safety recommendation to establish regulation for installation of PWS in accordance with ICAO recommendations

Lincoln Laboratory: Wind-Shear System Cost Benefit Analysis Update, by R.G. Hallowell, J. Y. N. Cho, S. Huang, M. E. Weber, G. Paull, T. Murphy, dated 13 May 2009.

6. Appendices

Table 10: Option 0 ('Do nothing')

Year	Total number of flights	Flights without PWS	Number of accidents
2015	5 974 925	2 771 451	0.16
2016	6 136 248	2 771 270	0.16
2017	6 301 927	2 750 330	0.16
2018	6 472 079	2 674 133	0.16
2019	6 646 825	2 626 235	0.16
2020	6 826 289	2 606 477	0.15
2021	7 010 599	2 591 254	0.15
2022	7 199 885	2 561 895	0.15
2023	7 394 282	2 542 063	0.15
2024	7 593 928	2 480 423	0.15
2025	7 798 964	2 443 402	0.14
2026	8 009 536	2 369 177	0.14
2027	8 225 793	2 291 401	0.14
2028	8 447 889	2 353 585	0.14
2029	8 675 982	2 409 660	0.14
2030	8 910 234	2 482 841	0.15
2031	9 150 810	2 520 376	0.15
2032	9 397 882	2 561 161	0.15
2033	9 651 625	2 600 696	0.15
2034	9 912 219	2 638 035	0.16
2035	10 179 849	2 706 262	0.16
2036	10 454 705	2 752 287	0.16
2037	10 736 982	2 785 209	0.16
2038	11 026 880	2 835 007	0.17
2039	11 324 606	2 861 522	0.17
2040	11 630 370	2 930 765	0.17
2041	11 944 390	3 014 919	0.18
2042	12 266 889	3 054 918	0.18
2043	12 598 095	3 145 909	0.19
2044	12 938 243	3 242 190	0.19
2045	13 287 576	3 318 664	0.20
2046	13 646 341	3 396 192	0.20
2047	14 014 792	3 476 055	0.21
2048	14 393 191	3 559 416	0.21
2049	14 781 807	3 637 613	0.21
2050	15 180 916	3 734 101	0.22
2051	15 590 801	3 837 479	0.23
2052	16 011 753	3 929 310	0.23
2053	16 444 070	4 021 761	0.24
Total	404 190 176	113 285 446	6.69

Table 11: Number of accidents prevented (2024–2053)

Year	Option 0 Do nothing	Option 1 Forward fit full fleet	Option 2 Retrofit full fleet
2015	0.00	0.00	0.00
2016	0.00	0.00	0.00
2017	0.00	0.00	0.00
2018	0.00	0.00	0.00
2019	0.00	0.00	0.00
2020	0.00	0.00	0.00
2021	0.00	0.00	0.00
2022	0.00	0.00	0.00
2023	0.00	0.00	0.00
2024	0.00	0.00	0.15
2025	0.00	0.01	0.15
2026	0.00	0.01	0.15
2027	0.00	0.02	0.14
2028	0.00	0.03	0.15
2029	0.00	0.04	0.15
2030	0.00	0.04	0.16
2031	0.00	0.05	0.16
2032	0.00	0.06	0.16
2033	0.00	0.06	0.16
2034	0.00	0.07	0.17
2035	0.00	0.09	0.17
2036	0.00	0.10	0.18
2037	0.00	0.11	0.18
2038	0.00	0.12	0.18
2039	0.00	0.13	0.19
2040	0.00	0.14	0.19
2041	0.00	0.15	0.20
2042	0.00	0.16	0.20
2043	0.00	0.17	0.21
2044	0.00	0.18	0.21
2045	0.00	0.19	0.22
2046	0.00	0.20	0.22
2047	0.00	0.21	0.23
2048	0.00	0.22	0.23
2049	0.00	0.23	0.24
2050	0.00	0.25	0.25
2051	0.00	0.25	0.25
2052	0.00	0.26	0.26
2053	0.00	0.26	0.26
Total	0.00	3.80	5.76

Table 12: Estimated price evolution of PWSs

Year	Price of equipment	Forward fit	Retrofit
2015	100%	€ 100 000	€ 150 000
2016	98%	€ 98 000	€ 147 000
2017	96%	€ 96 040	€ 144 060
2018	94%	€ 94 119	€ 141 179
2019	92%	€ 92 237	€ 138 355
2020	90%	€ 90 392	€ 135 588
2021	89%	€ 88 584	€ 132 876
2022	87%	€ 86 813	€ 130 219
2023	85%	€ 85 076	€ 127 614
2024	83%	€ 83 375	
2025	82%	€ 81 707	
2026	80%	€ 80 073	
2027	78%	€ 78 472	
2028	77%	€ 76 902	
2029	75%	€ 75 364	
2030	74%	€ 73 857	
2031	72%	€ 72 380	
2032	71%	€ 70 932	
2033	70%	€ 69 514	
2034	68%	€ 68 123	
2035	67%	€ 66 761	
2036	65%	€ 65 426	
2037	64%	€ 64 117	
2038	63%	€ 62 835	
2039	62%	€ 61 578	
2040	60%	€ 60 346	
2041	59%	€ 59 140	
2042	58%	€ 57 957	
2043	57%	€ 56 798	
2044	56%	€ 55 662	
2045	55%	€ 54 548	
2046	53%	€ 53 457	
2047	52%	€ 52 388	
2048	51%	€ 51 341	
2049	50%	€ 50 314	
2050	49%	€ 49 307	

6.1. Survey of operators

6.1.1. General information

EASA developed and launched an online survey of EASA MSs operators in the first quarter of 2016 to gain a better understanding of the current situation of wind shear events in CAT operations in Europe.

6.1.2. General information

There were 35 valid responses from 15 EASA Member States. Around two thirds of the aeroplanes of the respondents' fleet were equipped with both predictive (PWS) and reactive (RWS) wind shear detection systems, one quarter were equipped with reactive (RWS) only, and 10 % had no on-board wind shear detection system at all.

Table 13: Wind shear detection system in the sample fleet

Propulsion	None	Reactive	Both	Predictive	Total
Turboprop	49				49
Turbofan	4	129	367	6	506
Total	53	129	367	6	555

While none of the turboprop-powered aeroplanes had wind shear detection systems on board, a quarter of turbofan-powered aeroplanes had reactive, and three quarters had both RWS and PWS.

Table 14: Share of wind shear systems per propulsion type

Propulsion	None	Reactive	Both	Predictive	Total
Turboprop	100%				100%
Turbofan	1%	25%	73%	1%	100%

6.1.3. Wind shear occurrences

The self-reported survey of EASA MSs operators is a non-random, self-selected sample with a large amount of variation in the occurrence rate.

Out of 32 operators who provided responses to the wind shear occurrence rate, 15 reported no wind shear occurrences at all, and 6 reported an unusually high occurrence rate (above 1 000 occurrences per million movements).

The average occurrence rate per million movements was 567 in the sample, which would amount to more than 3 000 occurrences per year for all EASA MS operators.

If we exclude zeros and outliers, the average number of occurrences per million movements decreases to 143. As it can be seen in **Table 15** below, the occurrence-reporting rate per million movements seems to vary substantially based on the presence or lack of wind shear detection system and the type of the system as well.

Having a PWS enables flight crew to be aware of the existence of a wind shear event. This allows them to better identify and react to these issues. Having a PWS may, therefore, result in more occurrence reports.

Table 15: Occurrences per system types

Wind shear detection system	Occurrences per movement	Per million movements
No	0.000021	21.4
Reactive	0.000236	236.1
Predictive	0.000431	431.3

Around half of the operators identified no location where wind shear occurs more frequently.

6.1.4. Risk mitigation measures

Two thirds of the operators considered wind shear as a risk in their current operations.

The most common risk mitigation measures are FSTD training and risk awareness campaigns to flight crew (**Table 16**). Most operators use a combination of these mitigation measures (**Table 17**). All but one operator include wind shear training in their training programme.

Table 16: Mitigation measures against wind shear

Mitigation measure	Number of replies	Share of operators
FSTD (Flight Simulator Training Device) training	30	91%
Risk awareness campaign to flight crew (safety bulletin, note to pilots, note to instructors, etc.)	23	70%
CRM (Crew Resource Management) training	17	52%
Change of procedure	5	15%
EBT (Evidence Based Training)	4	12%
Other	4	12%
Change of equipment	1	3%

Table 17: Most frequent combinations of mitigation measures against wind shear

Combination of mitigation measures	Number of replies	Share of operators
FSTD, CRM training, Risk awareness campaign	9	27%
FSTD, Risk awareness campaign	7	21%
FSTD, EBT, Risk awareness campaign	3	9%
FSTD, CRM	3	9%

6.2. Survey of manufacturers

6.2.1. General information

A survey of 8 manufacturers was carried out in the second and third quarter of 2016. 4 manufacturers responded to the survey supporting EASA to better understand the historical development of the installation of reactive and predictive wind shear detection systems, future intentions of their use and the costs of the systems.