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OPERATIONAL CONCEPT AND VALIDATION OF A NEW AIRPORT LOW-LEVEL WIND INFORMATION SYSTEM

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Abstract

Pilots are sometimes not provided with sufficient information to avoid go-arounds or other operational disruptions that result from low-level wind disturbances. We identified issues with existing windshear alerting systems, and developed three types of airport low-level wind information systems to enhance pilot situation awareness of wind conditions by providing landing aircraft with quantitative and visualized wind information, ultimately to mitigate air service disruptions due to low-level wind disturbances. The three systems, ALWIN (Airport Low-level Wind Information) and LOTAS (Low-level Turbulence Advisory System) that use Doppler radar/lidar, and SOLWIN (Sodar-based Low-level Wind INformation) that uses Doppler SODAR (SOnic Detection And Ranging), have different costs and capabilities which allow the most cost-effective system to be selected for an airport according to its scale and local weather characteristics. This paper presents the operational concepts of our newly-developed airport low-level wind information systems and describes their validation.

1 Introduction

Low-level wind disturbances, such as windshear and turbulence, near airports can present hazards to take-offs and landings since they disturb aircraft flight paths and attitudes. Following several tragic accidents due to strong windshear [(1)], the International Civil Aviation Organization (ICAO) recommended that airport meteorological services provide windshear warnings for aircraft flying below 1,600ft above the runway elevation [(2)]. In Japan, the Japan Meteorological Agency (JMA) provides windshear alerts at major airports when a headwind change of more than 20kt is observed by an airport-based Doppler radar / lidar sensor[(3)].

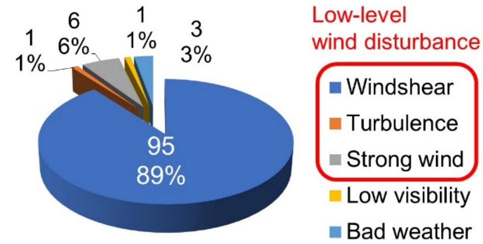

Figure 1. Causes of go-arounds at Narita International Airport (2008).

Although present low-level windshear alert systems contribute to the goal of preventing accidents, they do not always provide sufficient information on wind disturbances to prevent operational disturbances such as go-arounds. At Narita International Airport (Japan's largest international airport), for example, more than 90% of go-arounds occur due to wind disturbances such as windshear, turbulence, and strong headwinds or crosswinds, as shown in Figure 1.

On investigating this situation, we found that existing windshear alerting systems provide windshear alerts only when the windshear is severe enough to pose a high accident risk. In other words, even if the alerting systems detect less severe windshear which could nevertheless still cause a go-around or other air service disruption, this information is not provided to pilots. We have therefore developed a new airport low-level wind information system to provide landing aircraft with quantitative (numerical) and visualized (graphical) wind information to enhance pilot situation awareness of wind conditions and ultimately mitigate air service disruption due to low-level wind disturbances. Newly developed graphical and textual information provide tactical and strategic information on low-level turbulence and windshear to flight crews, airline dispatchers and other ground-based operations staff is intended to increase operational efficiency (by reducing the number of go-arounds) as well as to prevent accidents. Flight crews can obtain the information by ACARS (Aircraft Communications Addressing and Reporting System) datalink text message. This is the first system in the world that provides quantitative wind information to the cockpit.

Based on this concept, we have developed three types of airport low-level wind information system with different capabilities and costs: ALWIN (Airport Low-level Wind INformation) [(4)] and LOTAS (Low-level Turbulence Advisory System) [(5)] that use Doppler radar/lidar sensors, and SOLWIN (Sodar-based Low-level Wind INformation) that uses Doppler SODAR (SOnic Detection And Ranging). This allows the system with the best cost benefit for an airport to be selected according to the airport's scale and local weather characteristics. In this paper, airport scale refers to traffic volume (the number of daily scheduled flights) and the number of runways. The ALWIN system has been implemented and operated officially by the JMA at Tokyo's two international airports, Narita and Haneda, since 2017.

To verify the effectiveness of our concept, an operational evaluation was carried out by a questionnaire usability survey of flight crews and ground-based flight operations support staff.

This paper presents the operational concept of our newly-developed airport low-level wind information systems and describes their validation.

2 Operational Concepts

The newly-developed system architectures of the ALWIN, LOTAS and SOLWIN systems are shown in Figure 2. ALWIN and LOTAS automatically detect wind disturbances on approach flight paths, including disturbances with small-scale spatial structures, using Doppler radar/lidar, while SOLWIN automatically detects disturbances directly above Doppler SODAR sensors to monitor discrete locations such as runway thresholds. Sensor wind data are processed into graphical / textual representations useful for aircraft operations, and may be transmitted to flight crews in the cockpit via ACARS data link text message (e.g., Figure 3) or to ground users (airline dispatcher/operations officers) via the Internet to provide a graphical and textual web display, as we have described previously [(5), (6), (4)].

Although there are differences in the wind sensors used by the three systems, their architecture, that is windshear / turbulence detection and information provision methods, are very similar. Table 1 shows the operational concept of each system. Although the three systems all aim to provide tactical and strategic information on low-level turbulence and windshear, the type and cost of the wind sensor and the information content of the web display and ACARS message text differ according to the airport's scale and the characteristics of its local weather environment.

The main method for obtaining wind information also differs among the three systems. ALWIN is used mainly in a "pull" (request-response) mode of operation, while LOTAS and SOLWIN are used mainly in a "push" mode.

With a "pull" operation [(4)], flight crews can obtain low-level wind information from the cockpit at any time on request using ACARS. To implement this type of operation, airlines have to modify their ACARS ground systems to respond automatically to flight crew requests by retrieving the latest ALWIN / LOTAS / SOLWIN text information from the server and uplinking it. This automated response to flight crew requests can improve flight crews' wind situation awareness and enable them to more effectively conduct approach briefings and plan flight control strategy such as determining the target approach speed, as shown in Figure 4. Flight crews typically obtain wind information via ACARS datalink during cruise as part of their preparations for arrival, and use it to plan the approach and landing. In cases where the low-level wind information indicates turbulent conditions, flight crews can also obtain the most up-to-date information during the approach to allow them to monitor changes in the wind situation.

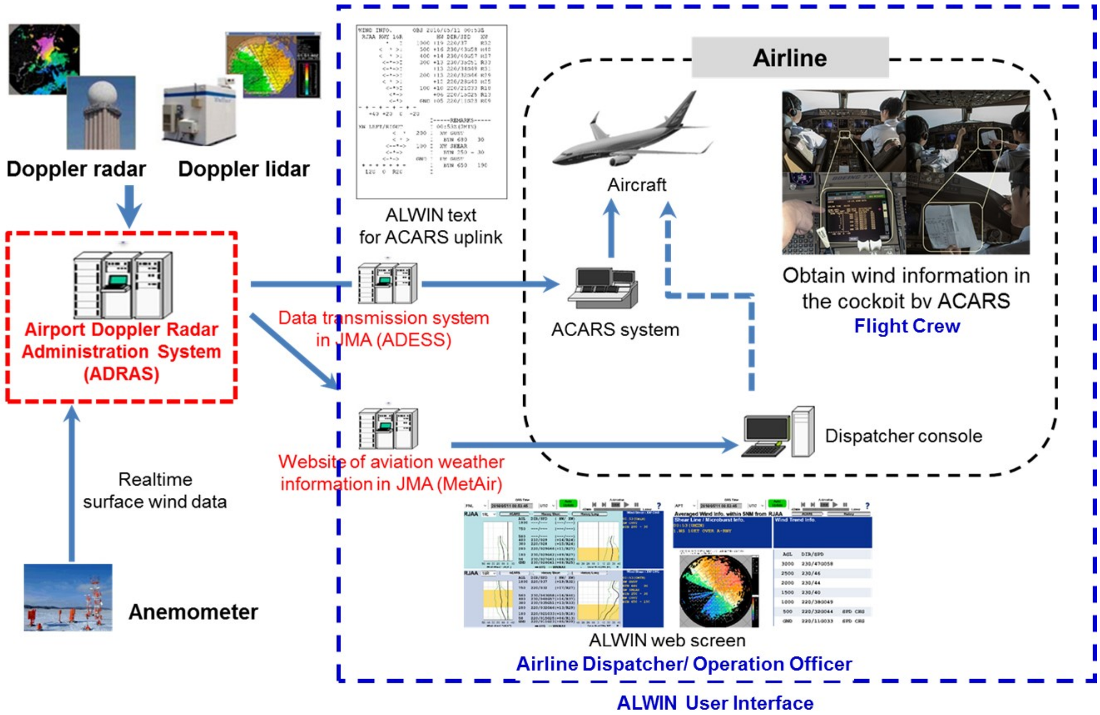

Figure 2-a. System architecture of implemented ALWIN (Airport Low-level Wind INformation).

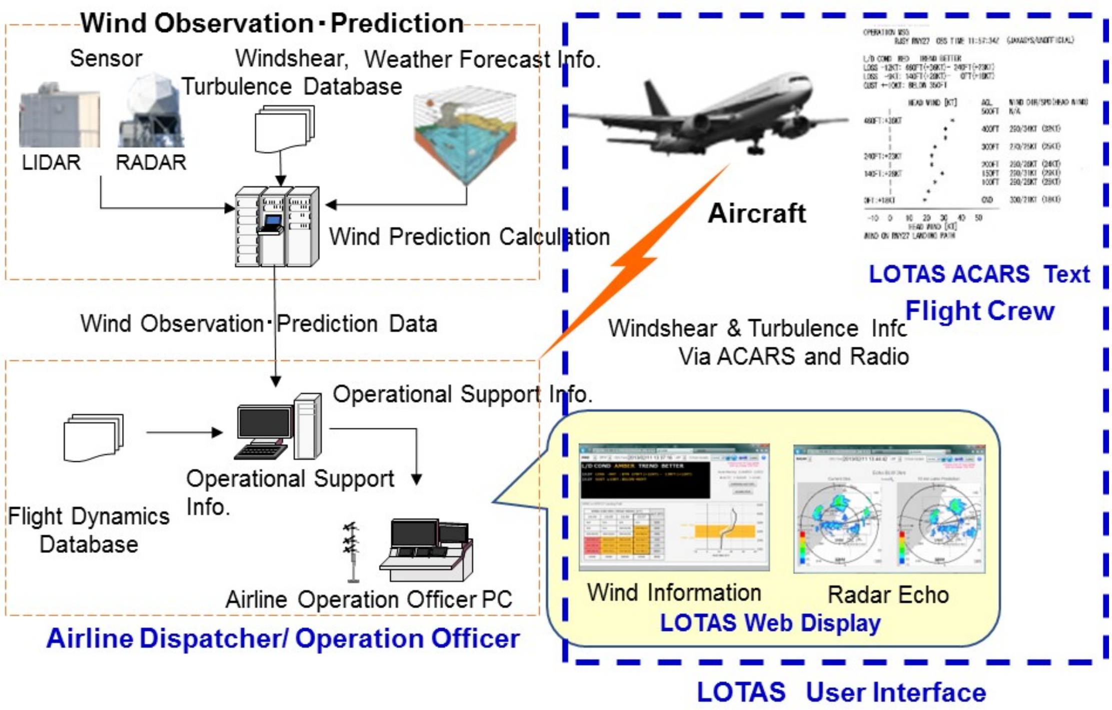

Figure 2-b. System architecture of LOTAS (Low-level Turbulence Advisory System).

On the other hand, with a "push" operation (4), ground-based dispatchers or operations staff monitor the wind situation using a web display screen, and transmit the information to aircraft in flight when notable wind disturbances are observed. Operations staff can either uplink the ALWIN / LOTAS / SOLWIN text information to the aircraft over ACARS, or verbally communicate the wind information indicated in information area of the display over the company radio frequency. To facilitate push mode operations, we designed a function to generate an

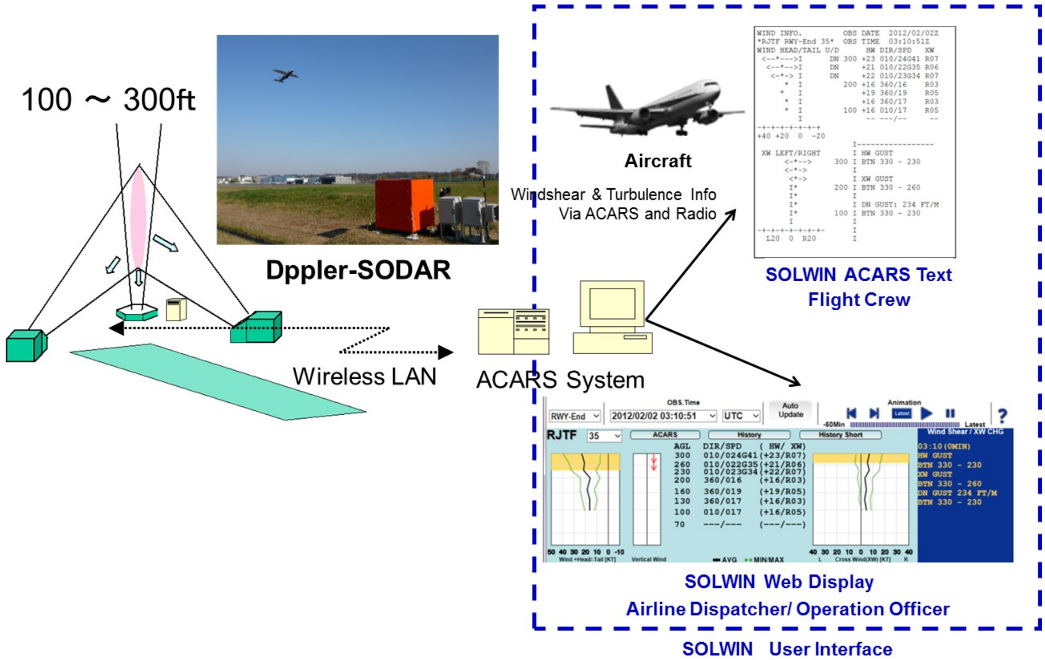

Figure 2-c. System architecture of SOLWIN (SOdar-based Wind INformation).

```
WIND INFO.       OBS 2016/05/11 00:53Z
 RJAA RWY 16R             HW DIR/SPD    XW
        *    I      1000 +19 220/37     R32
     <--*->I         500 +16 230/43G58 R40
     <--*->I         400 +14 230/40G57 R37
      <-*->I         300 +13 230/35G51 R33
      <-*->I             +13 220/34G49 R31
      <-*->I         200 +13 220/32G46 R29
      <-*->I             +12 220/28G40 R25
       <-*>I         100 +10 220/21G33 R18
        <*->             +06 220/15G25 R13
       <-*>          GND +05 220/11G23 R09
+-+-+-+-+-+-+-+-+-+
   +40 +20   0  -20
                        I-----REMARKS-----
XW LEFT/RIGHT           I 00:53Z(0MIN)
        <--*-    200 I  XW GUST
        <-*->        I   BTN 680 - 30
      <--*->     100 I  XW SHEAR
      <-*->          I   BTN 250 - 30
     <-*->       GND I  HW GUST
-+-+-+-+-+-+-+-+-       I   BTN 650 - 190
  L20   0   R20         I
```

Numeric information of Wind speed/direction

Graphs of headwind/ crosswind profile along flight path

Information area: showing latest windshear/turbulence information observed in last 10 minutes.

(1) FNL (Final) text <- ->: wind speed variance

```
WIND INFO.       OBS 2016/05/11 00:53Z
 RJAA AIRPORT
 AVERAGE WIND WITHIN 5NM FROM RJAA

AGL  DIR/SPD
3000 230/47G058
2500 230/46
2000 230/44
1500 230/40
1000 220/38G049
 500 220/32G044 SPD CHG
 GND 220/11G033 SPD CHG


---REMARKS---
00:53Z(0MIN)
WS 10KT OVER A-RWY
```

Numeric information of Wind speed/direction

Information area: showing latest windshear line/ microburst and wind temporal trend information observed in last 10 minutes.

(2) APT (Airport) text

Figure 3. Example of ALWIN text display .

ACARS text message when the user clicks the "ACARS text conversion" button in web display[e.g. (5)]. This type of operation does not require any modifications to existing airline systems.

At present, pull operation is used by Japan Airlines (JAL) with the ALWIN system at Japan's largest international airports, Narita and Haneda, and on a trial basis with the SOLWIN system at Oita, a regional airport with about fourteen daily scheduled flights. At the start of development, push operation was used with the LOTAS system at Shonai airport, but pull operation with LOTAS is also possible with modifications to the ACARS ground system.

Table 1. Operational Concepts of ALWIN, LOTAS and SOLWIN.

	ALWIN	LOTAS	SOLWIN
Airport Scale	Large airport e.g. International airport	- Regional - Large airport as required	- Regional - Large airport as required
Special Weather Characteristics	Windshear / Turbulence	- Rapidly changing weather under strong precipitation and low visibility - Low-level Windshear / Turbulence	Low-level - Windshear / Turbulence - Up and Down draft
Sensor	Airport-based - Doppler Radar - Doppler Lidar	Small but high update rate - Doppler Radar - Doppler Lidar	Small but high update rate Doppler Sodar
Operation	- Mainly "Pull" - "Push" as required	- Mainly "Push" - "Pull" as required	- "Pull" - "Push"
Main Information	i . Horizontal wind on approach path below 1000ft HW, XW ii . Horizontal wind over airport below 3000ft Wind Direction / Wind Speed	i . Horizontal Wind on approach path below 500ft HW, XW as required ii . Flight Control Difficulty Level ii . Radar Echo for landing timing decision support	i . Horizontal Wind over Sodar below 300ft HW, XW and VW
Cost	High (e.g.3~2 billion)	Middle (e.g.1.5 billion)	Low (e.g.0.5 billion)
Advantage	i . Wide observation area ii . Sufficient wind information form high to low altitude	i . Equivalent level of function as ALWIN if it below 500ft ii . Providing information for - Flight control difficulty - Landing timing decision support	i . Providing information for low-level updraft & downdraft ii . Low cost
Disadvantage	High Cost if new sensor is installed		Narrow observation area

We now describe the main operating characteristics of each system in the following.

2.1 ALWIN

ALWIN is intended for airports with multiple runways and a high daily airline traffic volume, such as international airports. Since high traffic means that low-level turbulence or windshear could affect many flights, and the impact of an accident or go- around will be high in such an operational environment, detailed wind information with a high update rate is needed. This requires a wind sensor that can

Figure 4. Use of ALWIN text display in the cockpit.

cover a wide area, as shown in Table 1, which inevitably has a high cost. The leads to ALWIN potentially having the greatest installation and maintenance costs of our three systems.

However, the ALWIN systems that have been operated by the JMA at Tokyo's Narita and Haneda airports since 2017 use the existing Doppler-radar and lidar sensors used for conventional windshear alerting, so only the ALWIN software development cost and the recurring sensor maintenance costs are incurred.

2.2 LOTAS

Although the LOTAS wind sensor is assumed to be smaller and cheaper than that used by the ALWIN system [(4), (6)], LOTAS can be considered as having the greatest functional capability of our three proposed systems since it provides novel information on flight control difficulty and landing timing decision support, listed as one of its advantages in Table 1.

LOTAS is intended to be best suited to airports with only a few scheduled daily flights but where the weather environment is prone to changing rapidly, with strong precipitation and low visibility, as shown in Table 1. Although strong windshear in low visibility is a difficult environment for aircraft operations, system installation and maintenance costs must be reduced due to the lower cost benefit of the system at regional airports with only light scheduled traffic.

Considering these factors, in order to satisfy the conflicting demands of low cost and the need for strategic information under rapidly changing weather conditions, LOTAS provides not only information on low-level wind conditions during the approach and landing phases, but also directly provides a measure of flight control difficulty, in addition to radar echo information to support landing timing decisions in dynamic weather situations [(5)].

2.3 SOLWIN

SOLWIN is targeted at regional airports with small budgets, and therefore uses a lower cost, less capable wind sensor than the other two systems, Doppler SODAR, as shown in Figure 2-c. Doppler SODAR measures upper-air winds by acoustic signals, has limited observation range and its valid wind information is limited to below approximately 300ft.

3 Operational Evaluations

Evaluations of the operational usability of the ALWIN, LOTAS and SOLWIN systems were carried out with a number of airlines during system development as shown in Table 2. Although the development of each system started

Table 2. Operational evaluations of ALWIN / LOTAS / SOLWIN.

	ALWIN	LOTAS	SOLWIN
Development Period	2014~2016	2012~2013	2017~2018 to be continue
Last Evaluation Period	March – May, 2016 (2 months)	January – February, 2013 (1 month)	January – March, 2018 (2 months)
Site (Japan)	Narita International airport Tokyo International airport	Shonai airport	Oita airport
Participated airline	Airline A	Airline B	Airline A, B, C, D
Operational environment	App. 30~50 / day flights Multiple Runways	4 / day flights Single Runway*1	14 / day flights Single Runway*
Operation Method	Pull	Push	Pull+Push
Participant's job title	Flight Crew	Flight Crew, Operation Officer	Flight Crew
Number of collected questionnaire data (final phase validation only)	1136	Flight Crew: 70 Operation Officer: 5	Airline A: 110, Airline B: 52 Airline C: 39, Airline C: 18

previous to the operational evaluation described in this paper, we focus here on the final operational evaluation period of the system design in Table 2. Since the evaluation of the general utility of the LOTAS system and requests for improvement have been presented previously [(5), (6)], these discussions are omitted from this paper.

Participants in the evaluation (pilots and ground-based operations staff from several Japanese airlines) were asked to rate the effectiveness and usability o f each system in questionnaires, and to provide comments. Information was gathered on which aspects of the system participants found to be useful or appraised positively, and which they did not find useful or appraised negatively.

4 Results and Discussion

Figure 5 shows overall pilot evaluation results of each system at each airport where it was deployed. It should be noted that rating scales used in the questionnaires differed among each system due to modifications to improve the usability questionnaire after each evaluation. The rating scale of ALWIN had four points, "Not useful", "Slightly not useful", "Slightly useful, "Useful", while those of LOTAS and SOLWIN had only two points, "Not useful" and "Useful".

More than 80% of the flight crews at Narita and more than 70% of the flight crews at Haneda who responded considered ALWIN to be "slightly useful" or "useful" shown in Figure 5-a. Figure 5-b shows that 94% of flight crews who responded considered the LOTAS ACARS message information to be useful. Figure 5-c shows that more than 70% of flight crew who responded considered SOLWIN to be useful.

In summary, more than 70~80% of flight crew who responded to the questionnaires rated our proposed new airport low-level wind information systems as useful, and we therefore consider that they are effective for supporting normal aircraft operations.

Flight crew comments on which aspects of the ACARS messages were found to be useful are summarized in Table 3. A "○" in a table cell indicates that obtain comments were made supporting the usefulness of an aspect, while "N/A" indicates that no such comments were obtained.

As shown in Table 3, the information provided by each system was considered to be applicable to improving situation awareness of low-level wind disturbances and enabling their prediction, and for flight control planning.

It is therefore possible that the provided information might contribute not only to greater safety but might also reduce the number of go-around events that disrupt smooth operations, particularly because crews will be able to predict the reduction of airspeed due to windshear, plan

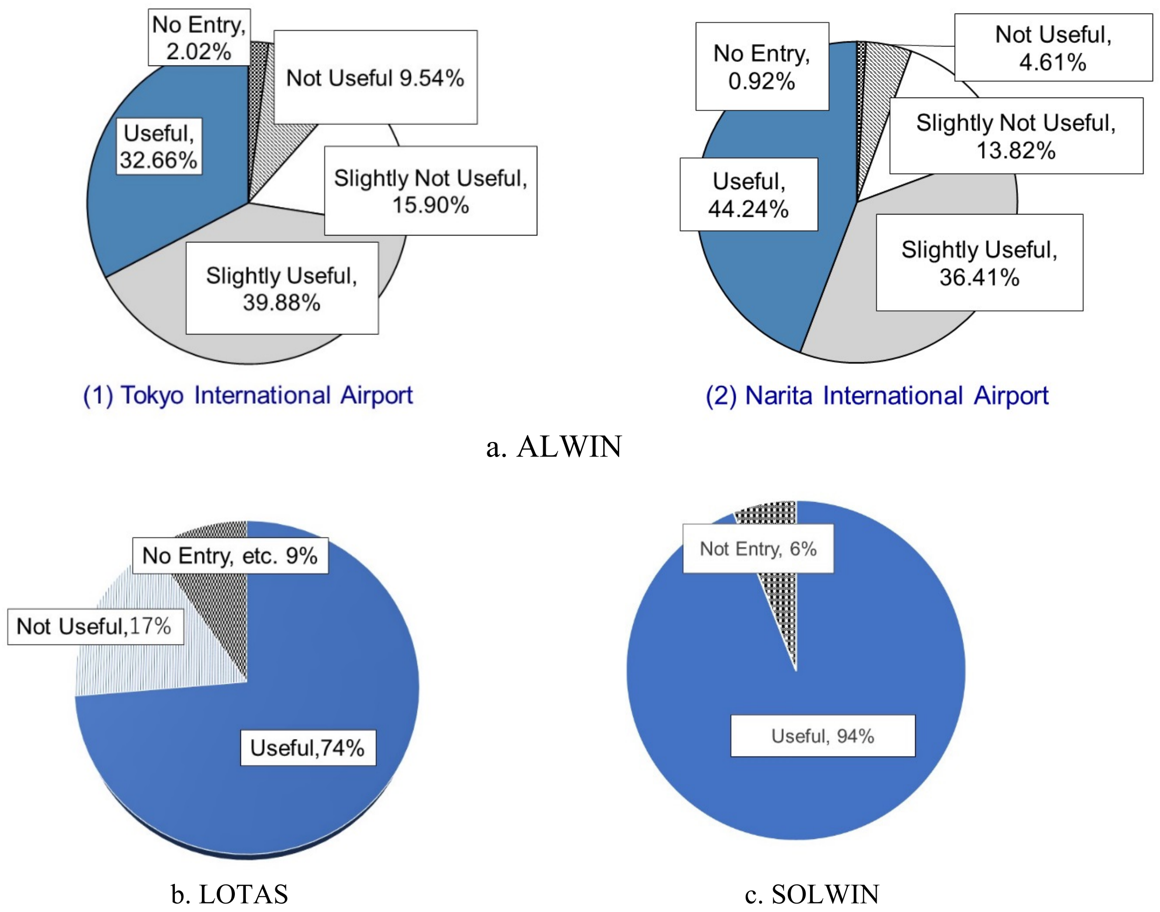

Figure 5. Overall flight crew usability ratings

flight control strategy and make runway selections accordingly.

As shown in Figures 6, the aspects that were found not be useful or were negatively appraised with the ALWIN system also received the same appraisal in the SOLWIN evaluation; that is, “difference between flight path (actual wind situation) and SOLWIN” and “not getting info. (information) just before landing”. Since SOLWIN cannot measure wind data on the approach flight path, unlike ALWIN, a difference between the actual encountered wind situation and SOLWIN wind information is considered unavoidable.

Nevertheless, there were almost unanimous flight crew requests for SOLWIN implementation, and we obtained positive comments shown in Table 3. These results indicate that SOLWIN will be useful for regional airports, although some issues remain to be addressed in the future.

From the result of “difficult to understand info. (information)” in SOLWIN, it is considered that the presentation of up and down draft information is novel and crews had no experience as to how it could be applied, and that ACARS the message text itself may also be hard for flight crews to understand. A method for presenting the new severity metric message and how to apply it are future issues.

We obtained many flight crew comments in the category “others” relating to SOLWIN’s limited observation range. Typical comments show that providing wind information only below 300ft is insufficient, and flight crews requested wind information above 300ft as an improvement.

Table 3. Useful aspects of system ACARS messages.

Aspect		ALWIN	LOTAS	SOLWIN
Runway Selection		○	N/A	○
		- Compare wind between runway16L and 16R, then request 16L due to better wind situation in16L	None	- Decision making of landing runway and departure runway - Decision making of landing or not under tail wind
Situation Awareness/ Prediction		○	○	○
		It was possible for flight crew to: - recognize headwind change / trend - predict course deviation - predict air speed reduction just before touch down - predict turbulence by wind direction and speed per altitude	Same as ALWIN	Same as ALWIN
Flight Control Planning	Briefing	○	○	N/A
		ACARS was used for approach briefing Ex. Common situation awareness of turbulence altitude by wind direction and speed changing point	Same as ALWIN	None
	Airspeed	○	○	○
		Airspeed control planning - under windshear/ turbulence condition - of reducing throttle timing before touch down or flare	Same as ALWIN	Same as ALWIN
	Path	○	○	○
		Path control planning by wind changing	Same as ALWIN	Same as ALWIN
	Roll	○	N/A	○
		Roll / lateral control planning - by cross wind information - by making image of decrab / cross control / wing low	None	Same as ALWIN

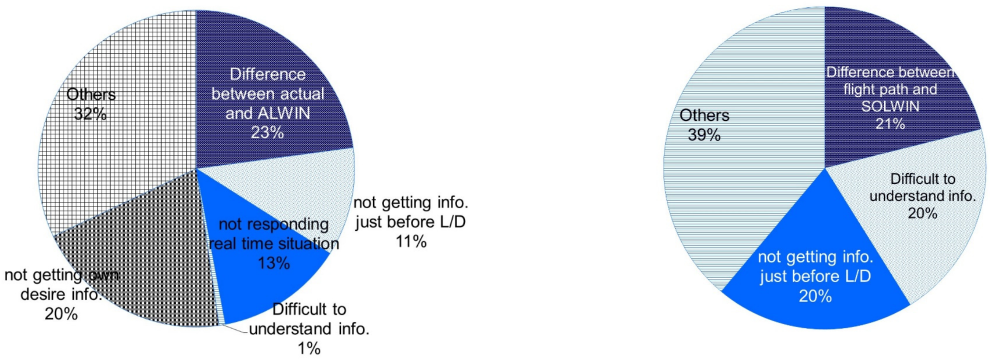

Figure 6. Non-useful or negatively appraised aspects of ALWIN (left) and SOLWIN (right).

Although SOLWIN's Doppler SODAR wind observation sensor was installed at the runway threshold in this evaluation, it is necessary to install the sensors at locations that are highly correlated with turbulence or wind shear on the landing path, for example due to local topography. It is therefore recommended that unless the Doppler SODAR observation range can be improved, the SOLWIN sensor locations should be determined at each airport by investigating the correlation between SOLWIN wind measurement data and flight data on the landing path.

5 Conclusions

This paper describes the design concepts and validations of three types of new airport low-level wind information system that provide landing aircraft with quantitative and visualized wind information to enhance pilot situation awareness of wind conditions and ultimately to mitigate air service disruption due to low-level wind disturbances. The results of evaluation of these systems during actual airline flight operations and issues for future consideration that arose are identified.

Given that 70~80% of flight crew ratings evaluated the systems as useful, our proposed new airport low-level wind information systems are considered to be effective for supporting aircraft operations. The information provided by the systems is considered to improve situation awareness of low-level wind disturbance, to enable its prediction and to allow flight control planning. Thus, the information by these systems might contribute not only to greater safety but might also reduce the number of go-around events that disrupt smooth operations, particularly because crews will be able to predict the loss of airspeed due to windshear, plan flight control strategy and make appropriate runway selection.

The method for presenting the new severity metric message in the SOLWIN system (as up and down draft indications), and how to apply it, how to determine the SOLWIN sensor locations are future issues.

We continue to discuss cost benefit analysis of all three systems in the future.

References

[1] Anon, Aircraft Accident Report: NTSB/AAR-82/02, NTSB, 1983.

[2] Anon, Meteorological Service for International Air Navigation. *ICAO Annex 3 to the Convention on International Civil Aviation, 16th edition, 2007.*

[3] anon, "Aviation/Marine Weather Services," JMA Web site, http://www.jma.go.jp/jma/en/Activities/aws.html (as of May 2016)

[4] Matayoshi, N., Iijima, T, Yamamoto, K. and Fujita, E., Development of Airport Low-level Wind Information (ALWIN), American Institute of Aeronautical and Astronautics Aviation 2016, AIAA-2016-3865, June, 2016.

[5] Iijima, T., Matayoshi, N. and Yoshikawa, E., Development and Evaluation of Low-level Turbulence Advisory Display for Aircraft Operation, 29th Congress of the International Council of the Aeronautical Sciences, St. Petersburg, Russia, Sep. 7-12, 2014.

[6] Matayoshi, N., Iijima, T., Yoshikawa, E. and Ushio, T., "Development of Low-level Turbulence Advisory System for Aircraft Operation," 29th Congress of the International Council of the Aeronautical Sciences, St. Petersburg, Russia, September 2014.

[7] ICAO, "Eleventh Meeting of the Communications/Navigation/Surveillance and Meteorology Sub-Group of Apanpirg Uplink and Downlink of Weather Information – *Recent Development in Hong Kong, China, CNS/MET SG/11-IP/12 Agenda Item 12 (4)*, Bangkok, Thailand, 16-20 July 2007.

[8] Iijima, T., Matayoshi, N., Fujita, E. and Yamamoto, K., "Development and Evaluation of Airport Low-level Wind Information, 53th Aircraft Symposium, 2015, Japan (in Japanese).

[9] https://www.metair.go.jp/metair/view/login/index.html

[10] Observation by Airport Weather Doppler Radar, http://www.jma.go.jp/jma/kishou/know/kouku/2_kannsoku/23_draw/23_draw.html

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