Inventory of current developments and new initiatives

T. Bechenecc, M. Mayolle, V. Krajenski, B. Larrouturou, F. Barbaresco

Short abstract: Future Sky Safety is a Joint Research Programme (JRP) on Safety, initiated by EREA, the association of European Research Establishments in Aeronautics. The Programme contains two streams of activities: 1) coordination of the safety research programmes of the EREA institutesand 2) collaborative research projects on European safety priorities.

This deliverable is produced by the Project P3 Solutions for Runway Excursions. The main objective is an inventory of current developments and new initiatives, including overview of past & current developments and new initiatives, descriptions, solutions and regulatory aspects that affect the application of new technology.

Programme Manager	Michel Piers, NLR
Operations Manager	Lennaert Speijker, NLR
Project Manager (P3)	Gerard van Es, NLR
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Contributing partners

Company	Name
Thales Avionics	BECHENNEC Thomas
Airbus Operations SAS	MAYOLLE Matthieu
Zodiac Aerosafety Systems	LARROUTUROU Benoit
DLR	KRAJENSKI Volker
Thales Air Systems	BARBARESCO Frédéric

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Prepared by: *(name)*	**Company**	**Role**	**Date**
Thomas Bechennec	Thales Avionics	Main author	12-10-2015
Checked by: *(name)*	**Company**	**Role**	**Date**
Frédéric Barbaresco	Thales Air Systems	WP3.4 leader	12-10-2015
Approved by: *(name)*	**Company**	**Role**	**Date**
Gerard van Es	NLR	Project Manager (P3)	13-10-2015
Lennaert Speijker	NLR	Operations Manager	27-10-2015

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Acronyms

Acronym	Definition
ACARS	Aircraft Communication Addressing & Reporting System
ASDA	Accelerate Stop Distance Available
ATN	Aeronautical Communication Network
BTV	Brake To Vacate
CFME	Continuous Friction Measurement Equipment
GPWS	Ground Proximity Warning System
ILS	Instrument Landing System
RAAS	Runway Awareness & Advisory System
RESA	Runway End Safety Area
ROPS	Runway Overrun Protection System
ROW	Runway Overrun Warning

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EXECUTIVE SUMMARY

Problem Area

The European Action Plan for the Prevention of Runway Excursions (EAPPRE) provides practical recommendations with guidance material to reduce the number of runway excursions. EAPPRE also identified areas were research is needed to further reduce risks. Four areas of research have been identified for which additional research is needed:

- Flight mechanics of runway ground operations on slippery runways under crosswind;
- Impact of fluid contaminants of varying depth on aircraft stopping performance;
- Advanced methods for analysis flight data for runway excursion risk factors;
- New technologies to prevent excursions or the consequences of excursions.

This study explores existing and new concepts for prevention or mitigation of runway excursions. Some technologies to reduce the risk of excursions, such as Take-Off Performance Monitoring systems and arresting systems, have been under investigation previously and have yet made it into today's cockpits and airports. Other preventive technologies such as on-board 3D active imaging systems for enhanced crew situation awareness on ground are still in the exploratory phases of development. Technologies to reduce the consequences of excursions, such as special pavements in the overrun area or new landing gear designs have seem limited operational use or are still in early development. Research is required to bring these technologies closer to application, either by removing technological or regulatory obstacles or by reducing risk and improving affordability. New technologies to prevent excursions or the consequences of excursions are to be explored. Alternatives to the relatively expensive Engineered Material Arresting System (EMAS) could be studied, as well new ways to guide pilots in making safe takeoff and landings without a high risk of running off the runway. Also new airframe technologies, such as new landing gear designs could be considered. Feasibility studies will be conducted for the most promising technologies, along with a definition of the R&TD required to overcome obstacles to implementation. Regarding new concepts and/or technologies, the following tasks are anticipated:

- Inventory of current developments and new initiatives;
- Feasibility study and definition of R&TD needed for implementation of new concepts;
- Assess impact of the new concepts on reducing excursions (no cost-benefit).

Description of Work

This study provides an inventory of current developments and new initiatives to reduce runway excursions, including:

- Overview of past and current developments and new initiatives intended to avoid or mitigate the risks associated with runway excursions;

- Developments and initiatives descriptions (not limited to partners developments but also from other entities);
- A list of solutions which prevent or mitigate the consequences of runway excursions (analysis based on patents, market);
- Regulatory aspects that affect the application of new technology.

Results & Conclusions

This inventory of current developments and new initiatives to reduce runway excursions describes:

- On board means to stop the aircraft (Avionics System: avionics means for alerting & awareness, automation systems for pilot, procedure)
- Airport infrastructure: runways surface control/analysis, environmental conditions/analysis.
- Airport/aircraft interaction: communication/measurements means for critical data, consolidation of onboard data with airport data.

A literature and patent survey on crosswind assistance systems is conducted. The survey shows that in early decades of aviation the crosswind landing capabilities of tail dragger aircraft was improved by using castering wheels. The renunciation from the tail dragger design and the introduction of the present front wheel steering improved the situation under crosswind operations and lessened the risk of a ground loop in case of an inappropriate landing under crosswind. Nevertheless, even today crosswind contributes to runway excursions during landing and take-off to a significant amount. Any crosswind assistance would inevitably improve flight safety. Furthermore, the introduction of steerable main landing gears could be a necessary technology for possible, nonconventional future aircraft designs, in order to enable crosswind operations. An automatic system that assists the pilot during crosswind landings by automatically adjusting the steering angle of each wheel does not exist today.

Existing ROPS (Runway Overrun Prevention System) and BTV (Brake-To-Vacate) systems, with their main capabilities, have been described.

Available sources for weather characteristics, such as Cross/Head/Tail Winds and EDR (Eddy Dissipation Rate), have been described. These available sources have been investigated in the EC FP7 Project UFO..

Applicability

This survey will be used as input for the feasibility study and definition of Research & Technology Development (R&TD) needs for implementation of new concepts to reduce runway excursions.

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1 INTRODUCTION

1.1. The Programme

The EC Flight Path 2050 vision aims to achieve the highest levels of safety to ensure that passengers and freight as well as the air transport system and its infrastructure are protected. However, trends in safety performance over the last decade indicate that the ACARE Vision 2020 safety goal of an 80% reduction of the accident rate is not being achieved. A stronger focus on safety is required. There is a need to start a Joint Research Programme (JRP) on Aviation Safety, aiming for Coordinated Safety Research as well as Safety Research Coordination. The proposed JRP Safety, established under coordination of EREA, is built on European safety priorities, around four main themes with each theme consisting of a small set of projects. Theme 1 (New solutions for today's accidents) aims for breakthrough research with the purpose of enabling a direct, specific, significant risk reduction in the medium term. Theme 2(Strengthening the capability to manage risk) conducts research on processes and technologies to enable the aviation system actors to achieve near-total control over the safety risk in the air transport system. Theme 3 (Building ultra resilient systems and operators) conducts research on the improvement of Systems and the Human Operator with the specific aim to improve safety performance under unanticipated circumstances. Theme 4 (Building ultra-resilient vehicles), aims at reducing the effect of external hazards on the aerial vehicle integrity, as well as improving the safety of the cabin environment. To really connect and drive complementary Safety R&D (by EREA) to safety priorities as put forward in the EASA European Aviation Safety plan (EASp) and the EC ACARE Strategic Research and Innovation (RIA) Agenda, Safety Research Coordination activities are proposed. Focus on key priorities that impact the safety level most will significantly increase the leverage effect of the complementary safety Research and Innovation actions planned and performed by EREA.

1.2. Project context

The European Action Plan for the Prevention of Runway Excursions (EAPPRE) provides practical recommendations with guidance material to reduce the number of runway excursions. EAPPRE also identified areas were research is needed to further reduce risks. Four areas of research have been identified for which additional research is needed:

- Flight mechanics of runway ground operations on slippery runways under crosswind;
- Impact of fluid contaminants of varying depth on aircraft stopping performance;
- Advanced methods for analysis flight data for runway excursion risk factors;
- New technologies to prevent excursions or the consequences of excursions.

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The main objectives of the Project P3 "Solutions for runway excursions" are:

- To identify shortcomings and improve methods and models for analysing aircraft ground control under crosswind and on slippery runways
- To gain insight into the impact of water/slush covered runways on braking performance for modern tyres and antiskid systems.
- To study and develop algorithms to identify veer-off risk using operational flight data.
- To explore new concepts for prevention or mitigation of runway excursions

This study addresses the fourth objective, i.e. explores existing and new concepts for prevention or mitigation of runway excursions. Some technologies to reduce the risk of excursions, such as Take-Off Performance Monitoring systems and arresting systems, have been under investigation previously and have yet made it into today's cockpits and airports. Other preventive technologies such as on-board 3D active imaging systems for enhanced crew situation awareness on ground are still in the exploratory phases of development. Technologies to reduce the consequences of excursions, such as special pavements in the overrun area or new landing gear designs have seem limited operational use or are still in early development. Research is required to bring these technologies closer to application, either by removing technological or regulatory obstacles or by reducing risk and improving affordability. New technologies to prevent excursions or the consequences of excursions are to be explored. Alternatives to the relatively expensive Engineered Material Arresting System (EMAS) could be studied, as well new ways to guide pilots in making safe takeoff and landings without a high risk of running off the runway. Also new airframe technologies, such as new landing gear designs could be considered.

1.3. Research objectives

The objective of this study is to provide an inventory (survey) of current developments and new initiatives to reduce runway excursions.

1.4. Approach

This report is an inventory of current developments and new initiatives, including:

- Overview of past & current developments and new initiatives intended to avoid or mitigate the risks associated with runway excursions;
- Developments and initiatives descriptions (not limited to partners developments but also from other entities);
- A list of solutions which prevent or mitigate the consequences of runway excursions (analysis based on patents, market);
- Regulatory aspects that affect the application of new technology.

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1.5. Structure of the document

This report on the inventory of current developments and new initiatives is structured in 3 chapters:

- Chapter 2: On board means to stop the aircraft. Avionics System: avionics means for alerting & awareness, automation systems for pilot, procedure
- Chapter 3: airport infrastructure: runways surface control/analysis, environmental conditions/analysis.
- Chapter 4: airport/aircraft interaction : communication/measurements means for critical data, consolidation of onboard data with airport data

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2 ON BOARD SYSTEMS

2.1. Avionics System

2.1.1. Alerting & awareness systems in approach and landing phases

In order to prevent runway excursion, it is possible to anticipate and to provide means for pilot to abort approach if approach is considered at risk. Runway excursion is likely to occur when pilot performs non-standard approach, and it has been shown that if approach is not correctly stabilized according to procedures, the risk of runway excursion significantly increases.

Up to now, avionics systems provide pilots with awareness and alerts during approach. Moreover, some of these systems aim at anticipating conditions leading to a runway excursion at landing. Unstabilized approaches are indeed likely to lead to runway excursion due to non-nominal conditions for landing and aircraft roll-out.

2.1.1.1. TAWS

TAWS (Terrain Awareness and Warning System is a standard alerting system on Air Transport aircraft. THALES is one of the main TAWS providers and this section explains how the TAWS provides flight crew with means to abort approach if situation is shown to be further at risk for landing.

2.1.1.1.1. TAWS general description

The TAWS function provides the flight crew with sufficient information and appropriate alerts to reduce the risk of inadvertent controlled flight into terrain (CFIT). The TAWS provides terrain situational awareness through surrounding terrain representation on display and associated aural and visual alerts in the cockpit. TAWS information does not intend to be used as a primary navigation means.

During normal flight operations, the system remains essentially silent. TAWS protection is given by GPWS mode, based on current aircraft sensor information and predictive mode, combining aircraft sensor information with digital terrain elevation model. The former mode allows greater anticipation by comparing aircraft projected flight path with terrain database for conflict detection and provide a permanent terrain depiction around the aircraft.

The TAWS design allows for special situations where aircraft are operating according to approved procedures at altitudes significantly below the surrounding local terrain height (for example, approaches in steep valleys).

TAWS provides caution and warning visual annunciations and aural alerts. In addition, it has all the basic Ground Proximity Warning System (GPWS) alerts. The basic GPWS function relies on the downward-looking radio altimeter.

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From an operational point of view, flight crew have to react to TAWS aural alerts, display pop-ups and visual annunciations as required by operational procedures. For example, an amber CAUTION requires immediate attention if the condition continues, whereas a red WARNING annunciation is a TAWS warning and requires immediate action by the pilot.

In relation to unstabilized approaches, TAWS provides two reactive modes (according to DO-161a) that alert flight crew in case of unusual situation during final approach. These two corresponding modes are called:

- Mode 4: Unsafe Terrain Clearance not in landing mode
- Mode 5: Excessive descent below glideslope

Moreover, TAWS also provide Altitude call-outs during descent phase, which allow pilot to be aware of current aircraft altitude above the ground. Such aural annunciations help the pilot to check correct operation of aircraft in relation to radio-altitude during approach and consequently participate to reduce the risk of unstabilized approach at low altitude.

Historically, the TAWS LRU can also host a Reactive Windshear function that will alert pilot in case of windshear ahead of aircraft, based on aircraft dynamics. This is also a means to provide pilot with adequate information that on-going approach is no more safe.

Figure 1: Mode 4

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Figure 2: Mode 5

2.1.1.1.2. Mode 4: Unsafe Terrain Clearance not in Landing mode

This mode monitors the radio altitude, landing gear configuration, landing flaps configuration, and airspeed and generates a caution alert if there is insufficient terrain clearance when the aircraft is not in the proper landing configuration. Specific aural annunciators are generated to inform the pilot of specific unwanted landing configurations. Mode 4 can generate the following alerts:

- Too Low Terrain Caution: A Too Low Terrain Caution is generated when radio altitude and airspeed are within the Too Low Terrain envelope described in the figure here below. When a Mode 4 Too Low Terrain Caution is generated, TOO LOW TERRAIN (for example) is announced over the speaker system. This caution is annunciated as long as the condition exists.
- Too Low Gear Caution: A Too Low Gear Caution is generated when radio altitude and airspeed are within the Too Low Gear envelope described in the figure here below and the landing gear is not in a correct landing configuration. When a Mode 4 Too Low Gear Caution is generated, TOO LOW GEAR (for example) is announced over the speaker system. This caution is annunciated as long as the condition exists.
- Too Low Flaps Caution: A Too Low Flaps Caution is generated when radio altitude and airspeed are within the Too Low Flaps envelope described in the figure here below and the flaps are not in a correct landing configuration. When a Mode 4 Too Low Flaps Caution is generated, TOO LOW FLAPS (for example) is announced over the speaker system. This caution is annunciated as long as the condition exists.

Thus, this mode 4 performs steady verification level that flight crew pilot is correctly managing the approach phase according to standard procedure. In this respect, this mode provides anticipation for

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pilot in order to decide, if necessary, to abort approach and perform go-around if recovery of stabilized approach is no more possible.

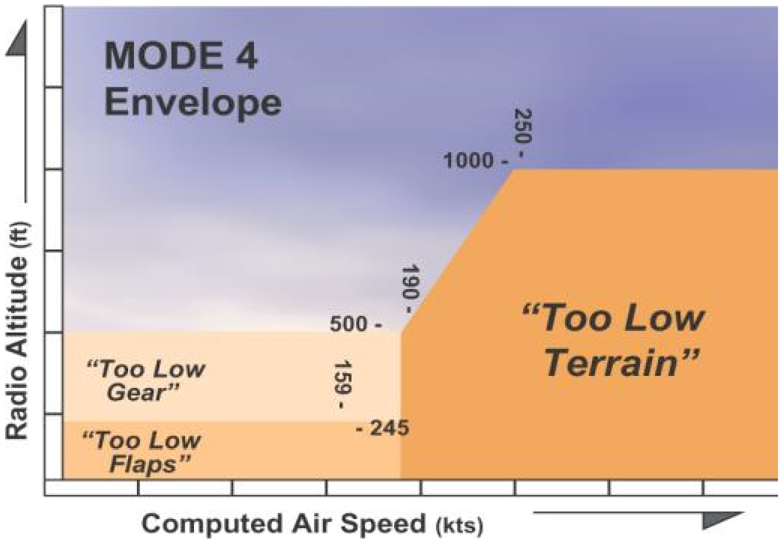

Figure 3: Example of Mode 4 envelope

2.1.1.1.3. Mode 5: Excessive descent below Glideslope

This mode monitors the radio altitude and glideslope deviation. It generates a caution alert if there is excessive descent below the instrument glidepath when making a front course approach. The Glideslope Caution is generated when the radio altitude and the glideslope deviation are within one of the two envelopes described here below. When a Glideslope Caution is generated, the caution annunciator lights and GLIDESLOPE (for example) is announced over the speaker system. Intensity of the aural message may depend on the level of current glideslope deviation.

The Glideslope Caution is generated as long as the radio altitude and the glideslope are within one of the two Mode 5 envelopes.

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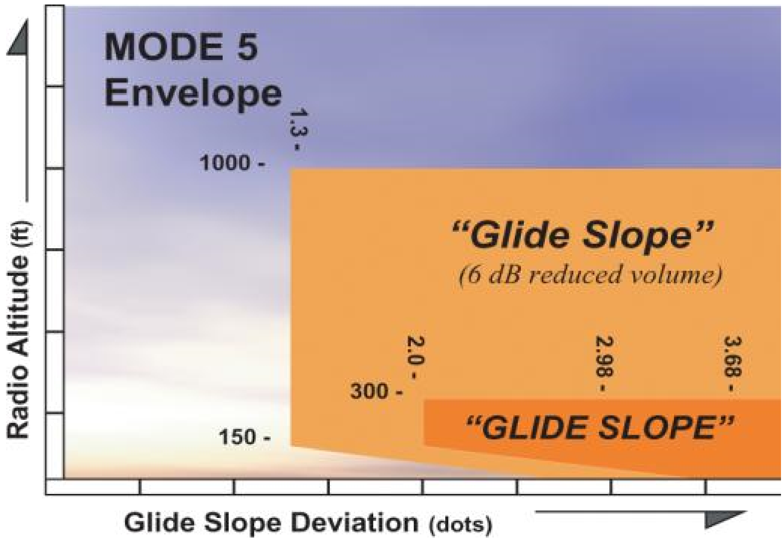

Figure 4: Example of Mode 5 envelope

This mode provides alerts for the pilot exclusively in the case ILS (Instrument Landing System) approach. Consequently, it has to be noticed that this mode covers a restricted number of cases of unstabilized approach. However, in case of ILS/MLS or LPV approach, this mode provides additional warning to pilot by monitoring aircraft position in regard to standard approach trajectory.

2.1.1.1.4. Mode 6: Altitude call-outs

The system monitors radio altitude and generates altitude callouts for descent below a set defined altitudes. Each selected altitude callout is delivered once during an approach.

Example of the possible altitude call-outs are the following:

- 2,500 ft TWO THOUSAND FIVE HUNDRED or TWENTY FIVE HUNDRED or RADIO ALTIMETER VALID
- 1,000 ft ONE THOUSAND
- 500 ft FIVE HUNDRED
- 400 ft FOUR HUNDRED
- 300 ft THREE HUNDRED
- 200 ft TWO HUNDRED
- 100 ft ONE HUNDRED
- 80 ft EIGHTY
- 60 ft SIXTY
- 50 ft FIFTY
- 40 ft FORTY
- 35 ft THIRTY FIVE

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Moreover, some call-outs can indicate the aircraft is approaching the minimum altitudes for decision to continue or abort approach: decision height (for precision approaches) and minimum descent altitude (for non-precision approaches).

For example, the possible corresponding call-outs can be the following:

- APPROACHING DECISION HEIGHT
- DH DECISION HEIGHT
- APPROACHING MINIMUM
- MDA MINIMUM or MINIMUM, MINIMUM

These call-outs allow increasing pilot awareness of aircraft position in relation to the ground. Consequently, this mode provides additional help for flight crew to complete in due time operational procedure during final approach, decreasing the risk of unstabilized approach.

2.1.1.1.5. Reactive Windshear System

The TAWS function may also incorporate a reactive windshear feature. The reactive windshear system monitors aircraft performance on both takeoff and approach to identify the presence of severe low-level, downburst/microburst--type windshear.

The reactive windshear system does not provide climb guidance. The reactive windshear system monitors factors that affect aircraft performance on both takeoff and approach to identify the presence of severe low-level, downburst/microburst--type windshear. If these wind factors cause the aircraft performance to decrease to a predetermined level, audio and visual warnings are sounded, indicating to the crew that the aircraft's net performance capability is deteriorating and rapidly approaching a critical state.

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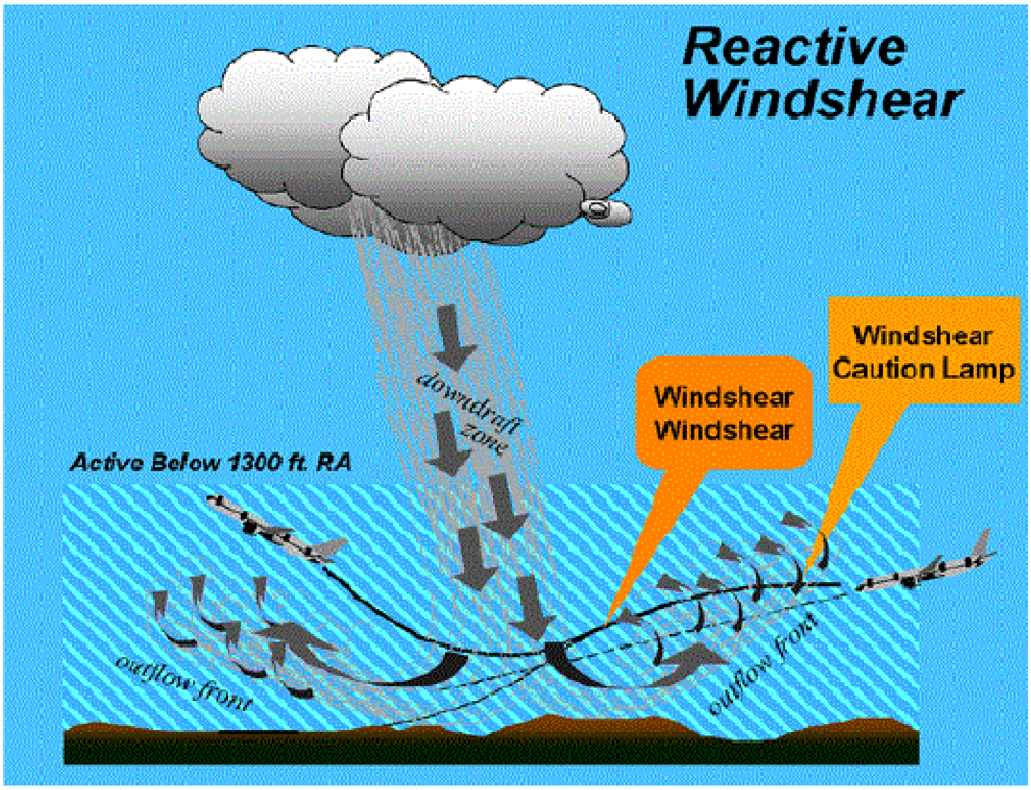

Figure 5: Windshear situation

In this respect, such windshear alert allow pilot to anticipate foreseen phenomenon that will unstabilize approach. If pilot would continue approach with a windshear ahead of aircraft, risk of runway excursion at landing would be significantly increased. In such case, the procedure recommends to abort approach and perform an escape (go-around).

2.1.1.2. SmartRunway® and SmartLanding® (Honeywell)

Honeywell proposes to airlines additional functions and features SmartRunway® and SmartLanding®. These are flight safety functions included in the Enhanced Ground Proximity Warning System (EGPWS), all of which are non-TSO functions.

The SmartRunway® function includes the following:

- The Runway Awareness & Advisory System (RAAS), including Taxiway Landing and optional caution level alerts for Taxiway Takeoff and Short Runway on takeoff and landing. These provide alerts and advisories to increase crew situational awareness during operations on and around airports. It also includes the Incorrect Takeoff Flap Configuration Monitor.

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The SmartLanding® function includes the following:

- The airborne and landing rollout calls of the Runway Awareness & Advisory System (RAAS), the Stabilized Approach Monitor, the Long Landing Monitor, and the Altimeter Monitor.

2.1.1.2.1. RAAS: General description

The Runway Awareness and Advisory System (RAAS) offers situational awareness for the flight crew in order to help lower the probability of runway incursion incidents and accidents by providing timely aural messages to the flight crew during ground taxi, takeoff (including rejected takeoffs), final approach, and landing/roll-out operations.

Advisories/cautions are generated based upon the current aircraft position when compared to the location of the airport runways, which are stored within the Runway Database.

The aurals can be grouped into two categories:

- Routine Advisories (annunciations the flight crew will hear during routine operations) and
- Non-Routine Advisories/Cautions (annunciations the flight crew will seldom or perhaps never hear).

RAAS provides the flight crew with five „routine" advisories. Three of these annunciations will be heard by the crew in normal operations, providing increased position awareness relative to the runway during taxi and flight operations. They are intended to reduce the risk of a runway incursion. The two remaining „routine" advisories provide information about the aircraft location along the runway, and are intended to reduce the risk of overruns. These advisories are:

- Approaching Runway - In Air advisory provides the crew with awareness of which runway the aircraft is lined-up with on approach.
- Approaching Runway - On-Ground advisory provides the flight crew with awareness of a proximate runway edge being approached by the aircraft during taxi operations.
- On Runway advisory provides the crew with awareness of which runway the aircraft is lined-up with.
- Distance Remaining advisories enhance crew awareness of aircraft along-track position relative to the runway end.
- Runway End advisory is intended to improve flight crew awareness of the position of the aircraft relative to the runway end during low visibility conditions.

In addition, RAAS provides the flight crew with several „non-routine" advisories/cautions. These annunciations are designed to enhance safety and situational awareness in specific situations not

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routinely encountered during normal aircraft operations. Some of the RAAS advisories include distance information. The unit of measure used for distance can be configured to be either meters or feet.

- Approaching Short Runway - In-Air advisory provides the crew with awareness of which runway the aircraft is lined-up with, and that the runway length available may be marginal for normal landing operations. If desired, an additional caution annunciation can be enabled which provides the crew with awareness that the issue has not been resolved when the aircraft is on final approach.
- Insufficient Runway Length - On-Ground Advisory provides the crew with awareness of which runway the aircraft is lined-up with, and that the runway length available for takeoff is less than the defined minimum takeoff runway length. If desired, an additional caution annunciation can be enabled which provides the crew with awareness that the issue has not been resolved when the aircraft is on the final stage of takeoff.
- Extended Holding on Runway advisory provides crew awareness of an extended holding period on the runway.
- Taxiway Take-Off advisory enhances crew awareness of excessive taxi speeds or an inadvertent take-off on a taxiway. If desired, this function can provide a caution annunciation in lieu of an advisory annunciation.
- Distance Remaining advisories provides the flight crew with position awareness during a Rejected Take-Off (RTO).
- Taxiway Landing alert provides the crew with awareness that the aircraft is not lined up with a runway at low altitudes

In addition to the aural annunciations provided, visual annunciations can be activated in the form of caution indications if the annunciations are considered cautions.

2.1.1.2.2. Stabilized approach monitor

The Stabilized Approach Monitor offers a safety advancement to supplement flight crew awareness of unstabilized approaches as described below.

The Stabilized Approach Monitor uses the inputs described below and the Runway Database to provide visual and aural annunciations that supplement flight crew awareness of unstabilized approaches as described below.

An unstabilized approach can lead to a runway overrun accident as a result of long touchdown and/or insufficient runway length left to stop. Many airlines view an unstabilized approach as one of the biggest remaining safety issues. They have created “approach gates” in their Standard Operating Procedures (SOP) to help pilots decide whether a go-around action needs to be taken. The gates are

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typically at 1,000 feet and 500 feet above field elevation (AFE). A typical SOP states that the aircraft should be stabilized by 1,000ft AFE, and must be stabilized by 450ft AFE. A go-around must be initiated if the stabilized approach criteria are not satisfied. The stabilized approach criteria can vary from operator to operator, and also on the type of approach (precision approach vs. non-precision approach, for example). The criteria for a stabilized approach for air transport category aircraft is typically:

- Landing Gear down
- Landing Flaps set
- Aircraft Speed within the final approach speed +10 knots / -5 knots
- Vertical Speed less than -1,000 fpm
- Aircraft on approach profile (Glideslope and Localizer captured)

The Stabilized Approach Monitor function can monitor these parameters during the approach and automatically issues advisories if the stabilized approach criteria for Flaps, Speed, and approach profile are not met.

The aircraft is stabilized during the final approach if the aircraft is fully configured to land and the aircraft"s energy is properly managed. If the aircraft is not configured properly at certain gates or is flown with excessive energy, the Stabilized Approach Monitor function issues an annunciation indicating which parameter needs attention giving the pilot a chance to correct the problem. When the aircraft reaches the final "gate", which is typically 450ft AFE and the problem(s) still exists, an "Unstable Unstable" alert is issued suggesting a go-around.

The Stabilized Approach Monitor specifically has the following monitoring functions:

- Landing Flap Monitor – Issues an annunciation if the landing flaps are not set.
- Excessive Speed Monitor – Issues an annunciation if the aircraft speed becomes excessive compared to the final approach speed (Vref or Vapp).
- Excessive Approach Angle Monitor – Issues an annunciation if the aircraft approach angle to the runway threshold becomes too steep.
- Unstabilized Approach Monitor – Issues an annunciation if the aircraft has not been stabilized at the 450 feet Gate.

2.1.1.2.3. Long landing monitor

The Long Landing Monitor function offers the pilot runway awareness and complements the RAAS Distance Remaining callouts. The function advises the crew of their position during a landing when the aircraft has not touched down in a nominal amount of time and/or distance.

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The Long Landing function adds two new distance remaining annunciations to enhance crew awareness of aircraft along-track position relative to the runway end. If the aircraft has not touched down before a configurable threshold, the EGPWS will activate an aural message. In addition, airborne only aural annunciations of current distance from aircraft to the runway end can be enabled.

2.1.1.3. Runway Overrun Prevention System (ROPS)

2.1.1.3.1. Definition

Runway Overrun Prevention System (ROPS) is made up of two sub-functions, Runway Overrun Warning (ROW) and Runway Overrun Protection (ROP). The ROW function generates alerts which incite the flight crew to perform a Go-Around whereas the ROP function generates alerts which incite the flight crew to apply available deceleration means.

2.1.1.3.2. Description

ROPS is an Airbus system designed to continuously calculate whether the aircraft can safely stop in the runway length remaining ahead of the aircraft. If at any point the system detects there is a risk of a runway overrun, flight deck alerts are generated to help the crew in their decision making.

ROPS is hosted in the aircraft avionics. The system has access to the parameters which affect an aircraft's stop distance, such as:

- Aircraft position
- Aircraft & engine type
- Aircraft weight
- Ground speed
- Outside air temperature
- Slat/Flap configuration
- True and calibrated airspeed
- Wind
- CG

ROPS is also connected to a runway database. The source of the runway database may be the Terrain Awareness Warning System (TAWS) or the Onboard Airport Navigation System (OANS). ROPS automatically detects the current landing runway using the runway database.

2.1.1.3.3. Runway Overrun Warning (ROW)

ROW becomes active at 500ft and remains active throughout short-final, the flare and touchdown until transition to ROP. ROW stopping distances are based on the same principles as the Airbus In-Flight Landing Distances.

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On Airbus A380, A330 and A320 family, ROW continuously calculates two stopping distances, the stopping distance on a DRY runway and the stopping distance on a WET runway. If the stopping distance on a WET runway becomes longer than the available runway length, the system triggers an amber message on the PFD "**IF WET: RWY TOO SHORT**". If the stopping distance on a DRY runway becomes longer than the available runway length, the system triggers a red message on the PFD "**RWY TOO SHORT**" and a below 200ft an aural message "**RUNWAY TOO SHORT**".

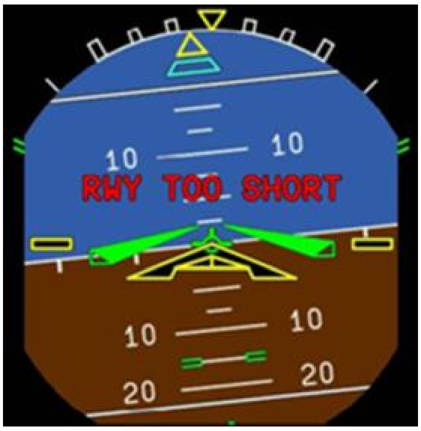

Figure 6: RWY TOO SHORT message on the PFD

On the Airbus A350, the flight crew has a runway state selector knob on the instrument panel. Consequently, ROW predicted stop distance is based on the runway state selected by the crew and thus ROW alerts are directly "**RWY TOO SHORT**" corresponding to the flight crew selection. At entry-into-service of the A350, the runway states DRY and WET are available for pilot selection. Extension to contaminated runway states is planned.

Figure 7: RWY TOO SHORT message on the PFD

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2.1.1.3.4. Runway Overrun Protection (ROP)

ROP becomes active on-ground after transition from ROW and remains active until taxiing speed. ROP uses the aircraft's current deceleration and aircraft characteristics to determine where the aircraft can safely stop on the runway. If ROP detects a risk of runway overrun, aural and visual alerts are triggered.

On the PFD the red visual alert "**MAX BRAKING, MAX REVERSE**" is displayed. Aural alerts are prioritized: "**BRAKE, MAX BRAKING, MAX BRAKING**" aural alert is triggered until pilot application of pedal braking, then aural alert "**SET MAX REVERSE**" if maximum reverse thrust has not been selected. If overrun condition still exists at 70kt, the aural alert "**KEEP MAX REVERSE**" will trigger to remind the flight crew to keep maximum reverse thrust.

ROP is reversible and alerts are cancelled when overrun risk is no longer present.

On the Airbus A380 and A350, if an Autobrake mode is engaged, ROP will automatically apply maximum braking in case of runway overrun risk.

2.1.1.3.5. ROPS and Navigation Display

On the Airbus A380 and A350, ROPS is integrated with the aircraft flight management and navigation systems and provides pilots with a real-time, constantly updated picture on the navigation display of where the aircraft will stop on the runway in WET or DRY conditions (or pilot selected runway condition for A350).

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Figure 8: Flight display showing magenta lines on runway where the aircraft will stop in WET and DRY conditions

2.1.1.3.6. ROPS and Brake-to-Vacate

On the Airbus A350 and A380, the ROPS system is directly integrated with Airbus' Brake-to-Vacate (BTV) which is an autobrake mode that optimizes the deceleration to achieve the runway exit selected by the pilot.

2.1.1.3.7. ROPS on Airbus Aircraft

ROPS was certified for:

- Airbus A380 in 2009
- Airbus A320 Family in 2013
- Airbus A350 in 2014
- Airbus A330 in 2015

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2.1.1.4. Onboard and aircraft based computation of Braking Action

Runway safety remains one of the three major safety priorities at Air Transport System (ATS) level. Between 2010 and 2014, taxiway and runway excursions were accounting for 22% of accidents. Survivability of these accidents is high with less than 6% of fatalities over the 5 last years.

Although the occurrence rate of aircraft landing on contaminated runways remains low, the number of runway excursions on wet or contaminated runways remains high. Considering all the non-fatal aircraft accidents over the 5 past years, roughly 4%[1] of them involved poor braking action related to a contaminated runway.

That is the reason why Airbus has committed to developing an onboard function aiming at delivering an objective, timely, non-intrusive and consistent with aircraft performance means of evaluating the runway slipperiness through a real time Braking Action computation. The project is called CORSAIR (Contaminated Runway State Automatic Identification and Reporting).

This project addresses the problem of inadequate assessment and reporting of contamination and runway condition at airports. Indeed, inaccurate knowledge of the actual runway status at landing contributed to several accidents that occurred in the past few years[2]. In particular, runway friction coefficient lower than expected and/or contaminated runways (e.g., snow, ice) are listed among the potential contributing factors of runway overruns incidents. CORSAIR strives to address these shortfalls by providing reliable, objective, and timely (i.e., real-time) runway status information and disseminating it to all stakeholders that need that additional information. This includes pilots of arriving aircraft that may utilize this information to compute landing distances (through ATC), airport operators for planning runway maintenance operations, and other stakeholders.

[1] Source : IATA Safety Report, 2014

[2] Southwest at Chicago Midway in 2005, Air Méditerranée at Paris Charles De Gaulle in 2009 are two examples.

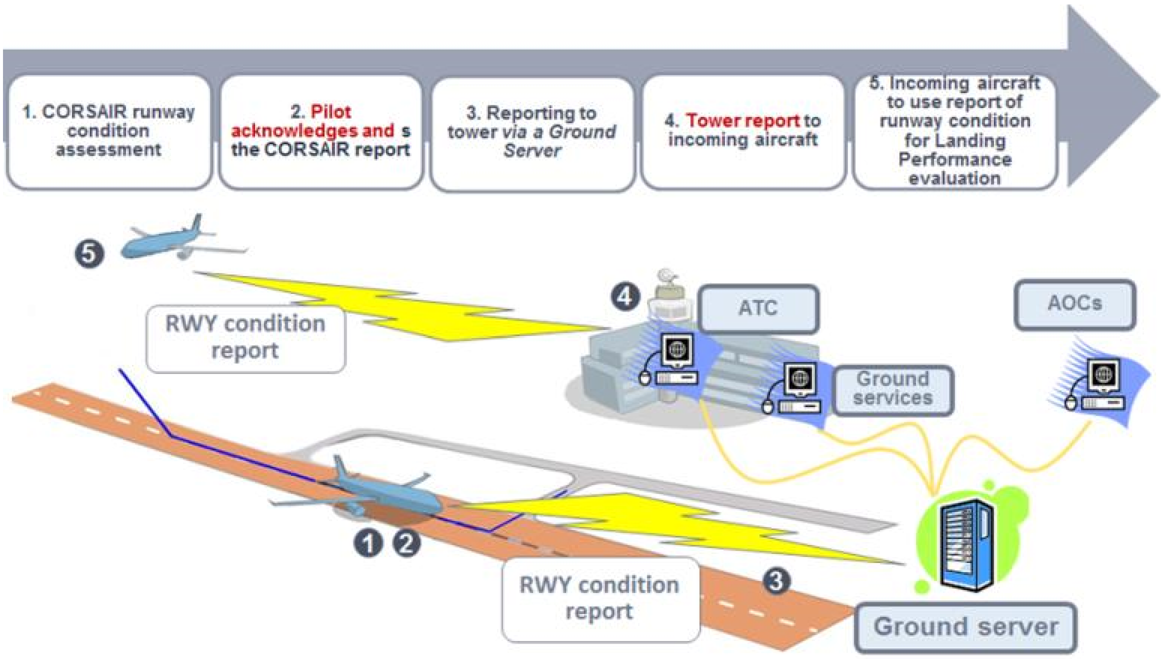

Figure 9: CORSAIR function principle

2.1.2. Alerting & awareness systems at take-off

2.1.2.1. Take-Off Securing

Airbus' strategy is to improve safety at take-off by adding several functions to protect the aircraft. The concept is to trigger an alert only in case of a detected abnormal situation so as not to interfere with the standard take-off operational procedure.

All these functions are designed to alert the pilot as soon as possible. It means that alerts shall be triggered far before V1 to minimize operational consequences and to secure potential rejected take-offs.

Take-Off Securing pack 1 (TOS1)

First, Airbus developed the Take-Off Securing 1 (TOS1) function to check that the speeds inserted by the pilot in the FMS are consistent (V1/VR/V2). The checks done are:

- Are speeds inserted the FMS?

  If take-off speeds are not inserted by crew in the Flight Management System (FMS) then an ECAM alert is triggered during Take-Off configuration test procedure and when Take-Off power is set:

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T.O SPEEDS NOT INSERTED

- Are speeds inserted in the right order ($V1 \leq VR \leq V2$)?

  If not, a FMS message is triggered at parameter insertion:

  T.O V1/VR/V2 DISAGREE

  If necessary the alert is triggered again with an ECAM alert at Take-Off configuration test procedure and when Take-Off power is set:

  T.O V1/VR/V2 DISAGREE

- Are speeds consistent with speed envelope (V_{Mu}, V_{MCA} , V_{MCG}, V_{SR})?

  If not, a FMS message is triggered at parameter insertion :

  T.O SPEEDS TOO LOW

  If necessary the alert is triggered later with an ECAM alert at Take-Off configuration test procedure and when Take-Off power is set:

  T.O SPEEDS TOO LOW

TOS1 package is mainly designed to prevent from tail-strikes at take-off by avoiding operational issues during take-off preparation.

FMS messages are already available on whole Airbus fleet.

ECAM alerts are already available on A350.

TOS1 is hosted in aircraft avionics (Flight Management system)

Take-Of Securing pack 2 (TOS2)

As a complement to TOS1, TOS2 is developed so as to check aircraft position at take-off initiation.
Main objective is to decrease risk of runway overrun at take-off.
Different checks are developed:

- Is the aircraft on a runway when take-off power is applied?

  If not, an ECAM alert is triggered at take-off power:

  NAV ON TAXIWAY

- Is the aircraft on the planned runway when take-off power is applied?

  The planned runway is the runway inserted in the FMS.
  If not, an ECAM alert is triggered at take-off power:

  NAV NOT ON FMS RUNWAY

- Is the aircraft capable to lift-off on the runway used?

  It means that the aircraft lift-off distance computed for the current conditions is lower than the current runway length. This check is done in preflight to check that the take-off

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preparation is correct and at take-off power to check that for the current aircraft configuration, the predicted take off distance is still compatible with the remaining runway length (correct insertion on the runway).

If an inconsistency is detected during preflight phase an ECAM alert is triggered:

T.O RWY TOO SHORT

This alert becomes a red one when take-off power is set:

T.O RWY TOO SHORT

TOS2 is already available on A350.

TOS2 is hosted in aircraft avionics (Flight Management system and OANS system)

Take-Off Monitoring

After TOS checks, any remaining issue during take-off may then principally come from a lack of performance during take-off roll or an erroneous take-off weight evaluation.

Airbus is currently studying a function whose objective is to check the aircraft performance during take-off roll in order to identify those remaining issues.

2.2. Crosswind Landing Assistance Technology

The work of DLR Institute of Flight Systems in the framework of Future Sky Safety's project P3 "Prevention of Runway Excursions" focusses on assistance systems for take-off and landing under crosswind conditions, with special emphasis on crosswind landing. Crosswind conditions are a main driver for runway excursions, which are mostly runway veer-offs under such circumstances. Statistics show that about one third of all wind-related accidents are due to crosswind [1].

As will be described in the following section, landing under crosswind conditions, especially under strong crosswind, requires complex manoeuvring shortly prior touchdown, hence at very low altitude. In case of unforeseeable gusts or other additional disturbances safe landing can be a demanding task for pilots under such circumstances. Although crosswind landings should not be regarded as hazardous in general, flight safety could be further increased if the complex manoeuvre close to ground could be prevented. This would be possible if all landing gears could be steered, passively or actively, in flight direction so that the aircraft could touch-down in crabbed motion and not (or not fully) aligned with the runway.

Besides a pure increase in flight safety, the implementation of a main gear steering functionality for crosswind landing could be necessary for future non-conventional aircraft concepts, such as aircraft with very high aspect ratio wings or blended wing bodies. These aircraft could possibly be hard to land under crosswind conditions due to geometrical limitations or limitations in their manoeuvrability.

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Same as for the only aircraft that currently possesses a steerable main gear for crosswind landing assistance, the B-52, it could be necessary for future aircraft as well to have such a system, in order to anyhow allow landing under crosswind because of the aircraft's unconventional layout.

Another additional advantage could arise for future aircraft with high aspect ratio wings equipped with a steerable main landing gear, namely that it could be parked slightly sideways at the gate without violating the maximum width of the parking position even with a large wing span. However, this should not be in the scope of the state-of-the-art survey presented here.

2.2.1. Crosswind Landing Techniques

Keeping the aircraft on the desired flight path during approach under crosswind conditions requires action to prevent the aircraft to drift away from the extended runway centreline by the wind. There are mainly two different flying techniques to do so, namely the crabbed approach and the sideslip approach. It is also possible to combine both techniques.

Figure 9 shows these different techniques. During the crabbed approach (left side in Fig. 9) the aircraft flies with wings level and a windward correction of the heading in order to prevent wind drift. In this case the aircraft flies without a sideslip angle and with all control surfaces in neutral position. However, as the aircraft's heading is not aligned with the runway centreline during the approach a so-called de-crab manoeuvre is necessary to be performed prior touch down in order to prevent too high forces on tyres and gear struts and allow a proper aircraft control on ground. The other crosswind landing technique is the so-called sideslip approach (right side of Fig. 9). In this case the aircraft's heading is aligned with the runway centreline and the wind drift is prevented by applying bank angle. This flight state (steady-heading-sideslip) requires a permanent deflection of both rudder and ailerons to keep the aircraft at a constant heading. Shortly prior touch-down the pilot only needs to level the wings. However, under strong crosswinds the necessary bank angles to keep the aircraft on the approach line can be large and beyond what is acceptable concerning passenger comfort. Also, the bank angle is strongly limited close to ground due to geometrical reasons to prevent wing strikes. For this reason Airbus recommends the crabbed approach for transport aircraft.

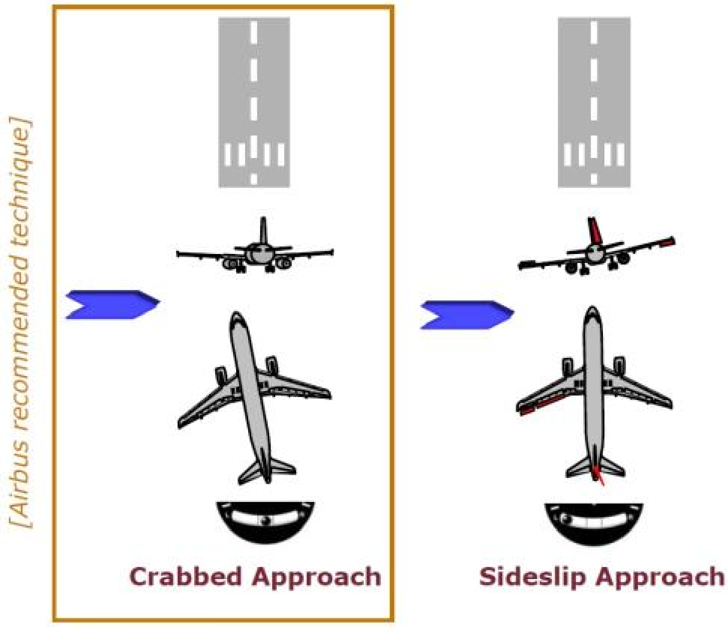

Figure 10: Crosswind Landing Techniques [2]

As mentioned before, the crabbed approach requires the so-called decrab manoeuvre shortly prior touch-down. During this manoeuvre, when the aircraft is being aligned with the runway, wind drift can be prevented by carefully applying a windward bank angle. In this case the aircraft touches down first with the windward wheel. For the pilot this is a complex manoeuvre requiring simultaneous application of rudder and aileron in different directions, while the flare needs to be performed as well with the elevator. Usually pilots are well trained to perform this manoeuvre, but if during this manoeuvre unforeseeable gusts or anything else unplanned occurs the task can be challenging or at least highly demanding for the pilot. Any system allowing the pilot to land the aircraft in crabbed motion would inevitably lower the demands on the pilot and hence improve flight safety.

2.2.2. Passive Systems

Landing under crosswind is especially crucial for tail dragger aircraft because of the risk of a ground loop. As the centre of gravity of tail dragger aircraft lies behind the main gear the aircraft tends to rapidly turn in case that the aircraft touches down with a crab angle. For this reason it is important with a tail dragger aircraft to properly perform a de-crab manoeuvre and align the aircraft with the runway.

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A passive solution for this problem was found early in aviation by simply using castering wheels. These wheels caster in runway direction in case that the aircraft touches down with a crab angle. Examples are the Blériot VIII and XI (s. Fig. 10), built in 1908 and 1909,or theEtrich Taube, built in 1910.

Figure 11: Early passive crosswind castering gear technology of Blériot XI [Source: Internet]

Castering wheels were also used in 1947 by Goodyear for a crosswind landing gear [3], which was installed e.g. at the Cessna 190 and 195 or the Stinson 108 (s. Fig. 11).

Figure 12: Passive crosswind castering gear system of a Stinson 108-2 [Source: Internet]

Castering wheels indeed improve the safety of crosswind landings, as they prevent tail dragger aircraft from ground looping; however they also degrade ground handling.

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Today, castering wheels are not used for transport aircraft. Indeed, the B737 is often supposed to have such a system but it does not. Only the shimmy dampers of the B737 unintentionally allow the wheels to caster a few degrees [4]. However, this was not a design issue for crosswind landings.

2.2.3. Active Systems

The main focus of this work is on active systems. Today, most active (means: actuated) main gear steering systems are designed for improving ground control or prevent tyre scrubbing during narrow turns. These systems can only be applied on ground and the actuation system is locked during take-off and landing. Nevertheless, these systems show that it is possible in principle to steer the main landing gears, even as the weight on the main gear struts is much higher than on the nose wheel.

One example for steering of a complete bogie is the B747. The inner, aft two main gear struts of the B747, the so-called body gears, are steerable on ground so that all bogies have the same turn centre. For this reason, the steering angle of the steered main gears is coupled with nose wheel steering angle (s. Fig. 12). The main gear steering of the B747 is solely designed to improve ground handling and cannot be applied at higher speeds or in flight. Body gear steering operates when the nose wheel steering angle exceeds 20°. Body gear steering is activated when ground speed decreases through 15kts. As speed increases through 20 kts, the body gear is hydraulically centred and body gear steering is deactivated [5].

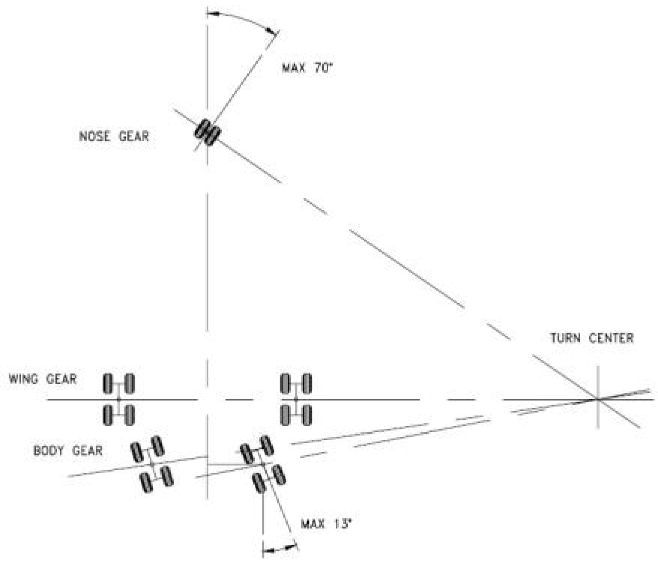

Figure 13: Hydraulically actuated main gear steering system of B747 for improved ground handling [6]

Similar to the main gear steering system of the B747, the B777 and the A380 incorporate a steering mechanism of the aft axis of the six-wheel main gear bogies (s. Fig. 13 for A380). Again, the steering functionality is solely designed here to prevent the aft tyres from scrubbing during narrow turns and cannot be applied at higher speeds or in flight.

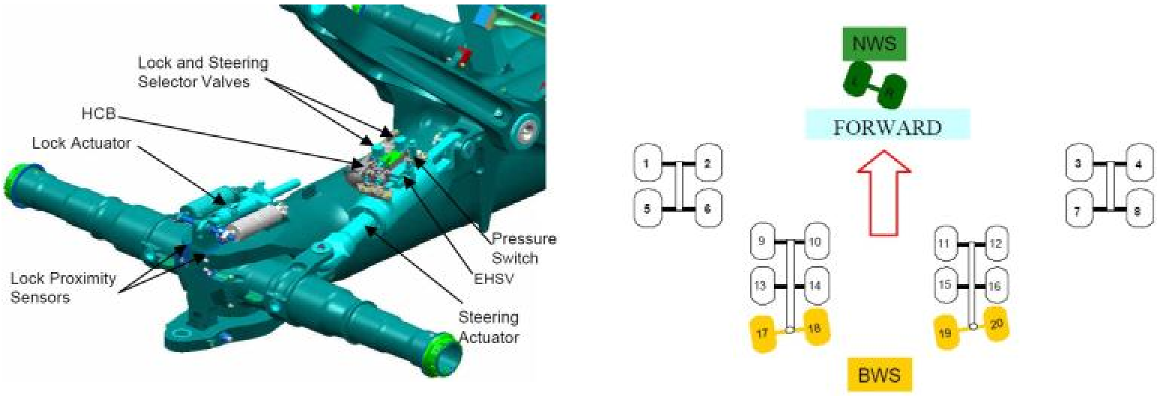

Figure 14: Actuated aft axis of main gear of A380 for improved ground handling [7]

All the above mentioned active systems are not designed for crosswind assistance and are not available in flight. Nevertheless, these examples show that it is possible in principle to actuate main gears. Also, it shows that the necessary actuation effort is affordable in terms of additional weight for the actuation system, even if it is only for prevention of tyre scrubbing.

The only aircraft with steerable main gears designed for crosswind assistance are the B-52 and the C5-A. These aircraft possess manual assistance systems, which are explained in the following sub-section. Automatic crosswind assistance systems still not exist today. However, there exist some patents and as the focus of the research of DLR Institute of Flight Systems in the framework of Future Sky Safety P3 is on automatic systems, these are mentioned in the subsequent sub-section following the description of the manual systems.

2.2.3.1. Manual Systems

The only aircraft equipped with an active manual main gear steering system for crosswind landings are the C5-A and the B-52. However, the C5-A was only equipped with steering functionality for crosswind landings in early days [8]. The in-flight application of the main gear steering for crosswind landing assistance was soon removed and the main gear steering functionality was only used for ground handling improvement, similar to that of the B747.

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The only aircraft still incorporating a steerable main landing gear for crosswind landings is the B-52. Figure 14 shows a crosswind landing in crabbed motion. It is obvious in the figure how the aircraft rolls along the runway still with a crab angle and with the wheels all aligned with the runway. The crosswind landing steering functionality of the main gear is necessary for the B-52 due to its design. As can be seen in Figure 14, the very limited wing tip clearance would not allow a de-crab manoeuvre under strong crosswind conditions without risking a wing strike. Another issue which made a crosswind landing assistance necessary is possibly the tandem configuration of the undercarriage of the B-52.

Figure 15: Crabbed landing of B-52 under crosswind conditions [Picture: Mike Hall]

Figures 15 and 16 show the principle of the B-52's crosswind main gear steering. Via the crosswind crab position indicator (1 in Fig. 16) and the crosswind crab control knob and indicator (2 in Fig. 16) the pilot can manually set the steering angle of all four bogies so that the wheels are aligned with the ground track whilst the aircraft flies in crabbed motion. As can be seen in Figure 7 the desired heading is the new neutral position of the wheels for steering. For ground manoeuvring the wheels can be steered to angles of +35° and -55° with maximum crab angle applied [9].

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The crosswind landing system of the B-52 has no automatic control functions. It solely allows the pilot to touch down with a crab angle. Ground control of the aircraft, compensation for gust etc. has to be performed by the pilot like in every other aircraft with fixed main landing gears by applying rudder.

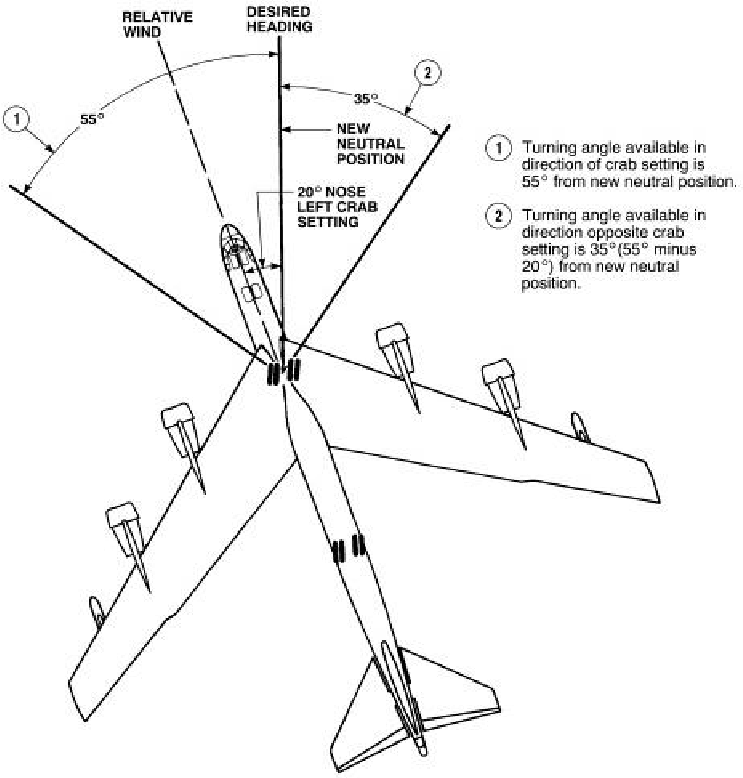

Figure 16: Turning angles available with maximum crosswind crab setting of B-52 [9]

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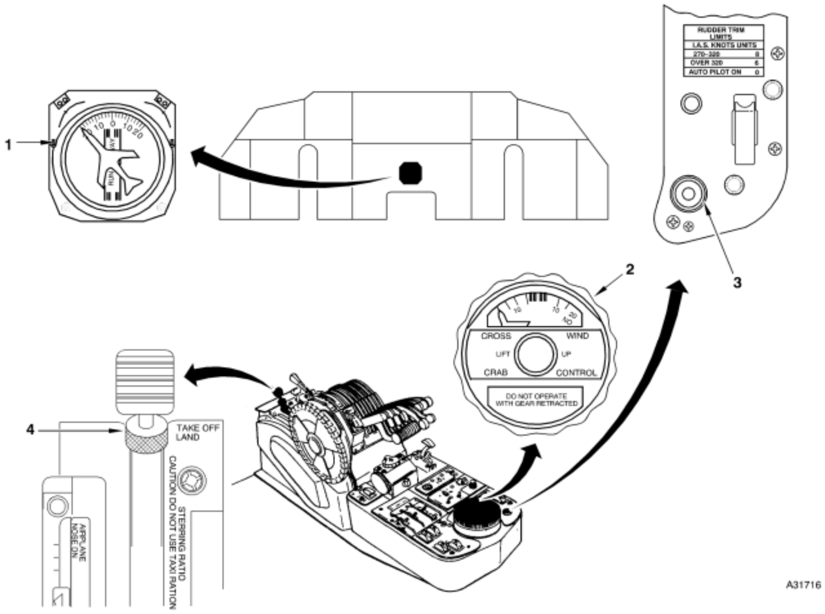

1 CROSSWIND CRAB POSITION INDICATOR
2 CROSSWIND CRAB CONTROL KNOB AND INDICATOR
3 CROSSWIND CRAB CONTROL CENTERING BUTTON
4 STEERING RATIO SELECTOR LEVER

Figure 17: Steering and crosswind crab controls and indicators at B-52's flight deck [9]

2.2.3.2. Automatic Systems

The biggest disadvantage of manual systems as previously described is that the settings are static and in case of any change in wind speed or direction these settings need to be adjusted manually by the pilot. If corrections were not taken and the landing gear crab angle is different to the actual crab angle, the pilot has to compensate for it after touch-down by applying rudder, steering the aircraft manually on ground like a conventional aircraft with a fixed main gear.

Therefore, any automatic system, which automatically adjusts the steering angle, in flight as well as on ground, would be a benefit compared to a manual system like on the B-52. In case of changes in wind speed or direction such an automatic system would automatically align each wheel so that the aircraft always touches down without any necessary control action to compensate crosswind. The only control input the pilot needs to do is for guiding the aircraft on the runway but not for crosswind compensation.

The big advantage of an automatic system is that it could be used for additional applications besides crosswind operations, such as improved ground handling. In case that each wheel can be steered separately, the turn radius can be varied arbitrarily, the aircraft could be moved sideways or turned on the spot if necessary. This might not be necessary for present aircraft; at least the lack of existence of such a system proves a lack of demand today. However, as mentioned before, such a system might be beneficial or even necessary for possible future aircraft with a nonconventional layout, such as aircraft

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with high aspect ratio wings or blended wing bodies. For aircraft with a large wing span it could also be beneficial to have the possibility to park sideways. This way the limiting parking box's width could be adhered even if the wing span is bigger than the width of the parking position.

Steerable main landing gears making use of automatic systems for crosswind landing assistance are currently not available for transport aircraft. However, there exist some patents claiming inventions for steerable main landing gears for crosswind assistance and aircraft guidance on ground.

Boeing has a patent on a "method, system, and computer program product for controlling maneuverable wheels on a vehicle" [10], claiming a system providing a steering radius selection and a crab angle selection, as well as compensation for crosswind during landing and take-off of an aircraft (s. Fig. 17).

DLR has two similar patent, claiming a "device for stabilizing the guidance of a vehicle" and a "control device for aircraft" [11][12]. Both patents deal with a system that incorporates steerable main landing gears in order to automatically control and guide an aircraft during landing and take-off under crosswind (s. Fig. 18).

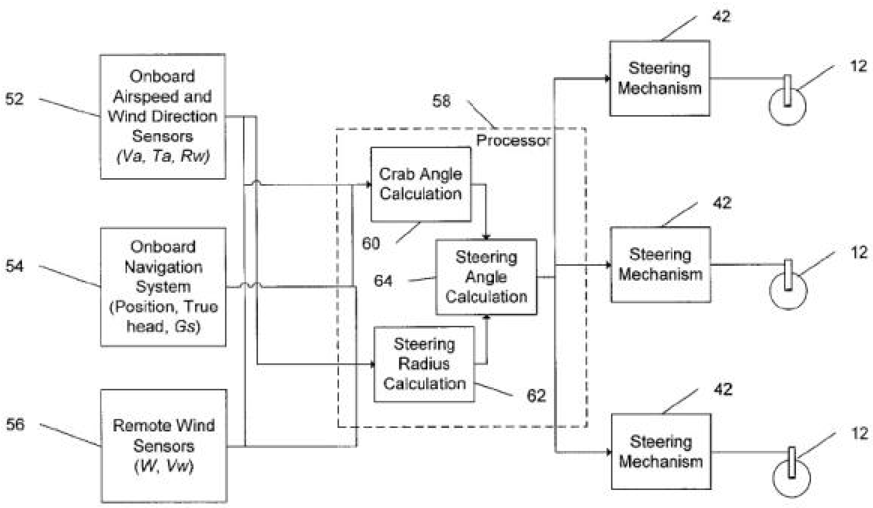

Figure 18: System architecture as claimed in Boeing's patent [10]

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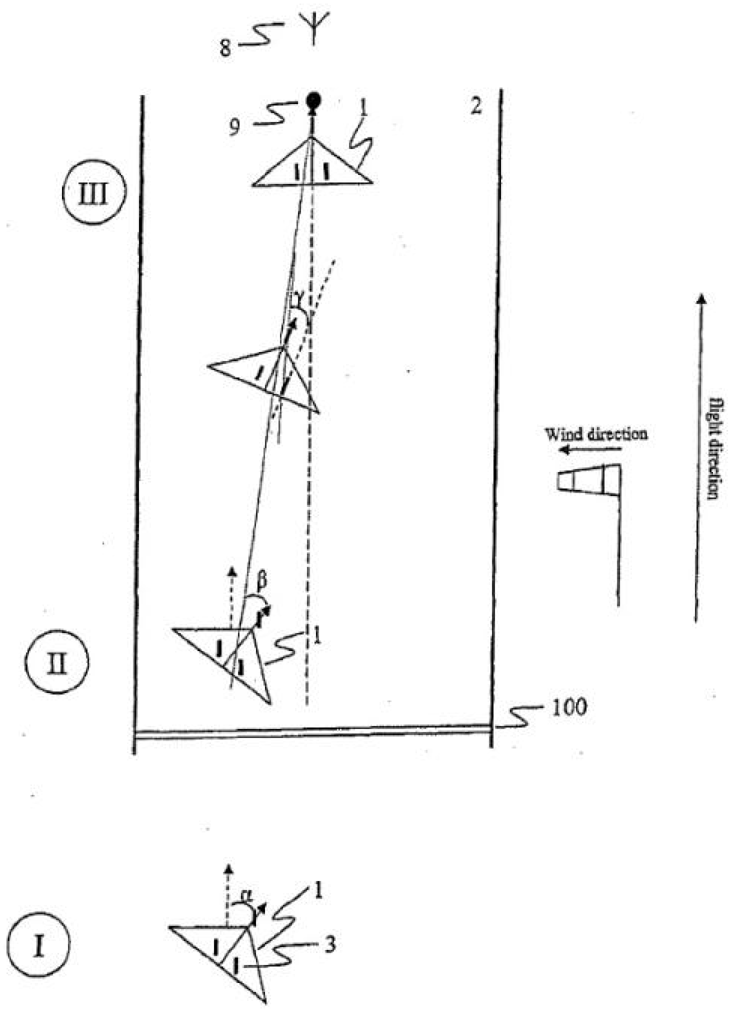

Figure 19: Crosswind landing as claimed in DLR's patents [11]

3 AIRPORT INFRASTRUCTURE

Runway safety is the main policy focus for the prevention of runway excursions as indicated by the European Action Plan for the Prevention of Runway Excursion (EAPPRE). However, while risk is generally defined as the product of a probability of an occurrence by its severity of consequence it would have on the infrastructure/equipment/people concerned, the main focus of all regulation and action plan over the last years has been the probability aspect. Such a philosophy has turned out to bring constantly declining results over the history as shown by the ASTER report[3]. Consequently, and in accordance with the philosophy that has dominated over the course of the last decades, the existing technologies and methods mainly focus on the reduction of probability. Factors influencing excursion probability are briefly discussed in the first sub-paragraphs below. Those probability influencing-factors that an aerodrome operator can control can include instrument approach system availability, available runway length and width, runway markings, texture, friction characteristics, runway condition and the reporting thereof. The risk factor of severity can be influenced by the aerodrome operator through the provision of obstacles, runway dimensions, runway end safety areas, runway strips and alternatives to the full provision of these characteristics, such as arresting systems. Probability and severity factors are addressed in ICAO and State annexes, documents, rulings, guidelines and advisory circulars as to standards and recommended practices, however, historically, many means of compliance are listed for aerodrome operators to satisfy the intent of the guidance. The industry is evolving as recommended actions from multiple accident investigations and studies begin to flourish and risk analysis and safety management systems are emerging to justify the use of these new concepts and measures.

3.1. Runways surface control/analysis

Successful runway surface control and analysis is a culmination of many facets working in concert to provide the aerodrome and aircraft operators the best surface possible from which to conduct the safest operation. Keeping the runway clear of contaminants such as snow, water, ice, slush or rubber along with proper painting and marking ensures that the tire to pavement interface allows for maximum braking capability of the aircraft. It also allows the pilot to maintain proper alignment with the runway upon visual contact on the approach through touchdown, rollout and taxiing to the gate. An additional consideration for the aerodrome that directly influences the friction capabilities of the

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[3] **http://www.transport-research.info/Upload/Documents/201003/20100310_120301_24152_Aster%20 Consolidated%20Final%20Report.pdf**

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runway is the pavement micro/macro texture and grooving. The condition of the underlying pavement directly influences the adhesion qualities of contaminants such as precipitation and rubber.

3.1.1. Contaminant removal on runway

Regulators in EASA, similar to US FAA and other States, provide Acceptable Means of Compliance (AMC) and Guidance Material (GM) to aerodromes for planning, coordination and execution of inspections and actions for daily operations and during significant weather situations. For winter operations, GM calls for an Aerodrome Snow Plan. According to GM1 ADR.OPS.B.035 of EASA AMC/GM TO ANNEX IV, Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Authority, Organisation and Operations Requirements, 27 February 2014, the Aerodrome Snow Plan should include:

1. the Snow Committee members and the person in charge of the snow clearance operation, with a chain of command giving a breakdown in duties;
2. methods of communication between aerodrome operations, air traffic control, and the Meteorological Office;
3. the equipment available for snow clearance. This should include equipment for ploughing, sweeping, and blowing snow;
4. priority of surfaces to be cleared, and clearance limits for aircraft using the aerodrome;
5. collection of information for SNOWTAM and dissemination of this information;
6. designated snow dumping or melting areas to avoid confusion during the actual clearance operations;
7. an alerting system in order that sufficient warning is given to all bodies concerned;
8. the manpower available, including staff for equipment maintenance arrangements for shifts, and call out procedures;
9. deployment of equipment and tactical approaches to be used;
10. general principles to be followed in deciding when to close runways for snow clearance and designation of management personnel authorised to make the decision;
11. methods of assessing and reporting the surface conditions; and
12. criteria for the suspension of runway operations

Prior to or following any runway clearing operation, the assessment mentioned in step 11 above typically involves a visual inspection to report the runway surface condition to include depth/type of any existing or remaining contaminant, width and time of last clearing operation, any de-icing or anti-icing chemicals involved and time applied as well as a possible assessment of runway friction by Continuous Friction Measurement Equipment (CFME). This information is then formatted in a report or SNOWTAM for dissemination as listed in step 5 above. There are newer methods on the horizon to conduct and report runway conditions that will be covered in section 3.1.X.

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Regulatory authorities such as EASA, Transport Canada (TC) and the US FAA establish guidelines for the frequency of evaluating runway friction (runway rubber buildup), acceptable friction levels and recommendations for the minimum frequency for conducting runway rubber removal. These regulatory authorities develop their recommendations largely based on recommendations from ICAO. Although there may be minor differences between the guidance provided by the various regulatory authorities, they are all very similar to the guidance provided by the FAA in Advisory Circular AC 150/5320-12C. Mostly, this is due to the fact that much of the early research into runway friction and the effects of rubber deposits was conducted in the United States. This led to the development of the ICAO recommendations and FAA guidance.

Rubber is typically the contaminant that is most likely to affect the friction on the runway in the long term. Typically, experience shows that 7kg (15lb) of rubber are left on the runway after the landing of a 747 and the figure can double with the Airbus double deck A380. Accumulation of rubber on a runway will negatively affect both the braking capability of an aircraft and its lateral controllability.

The frequency of rubber removal is generally recommended by state guidance based upon aerodrome traffic count over a period of time. From FAA AC 150-5320-12C, Table 4-1 is shown for illustration purposes.

TABLE.1 RUBBER DEPOSIT REMOVAL FREQUENCY

NUMBER OR DAILY TURBOJET AIRCRAFT LANDING PER RUNWAY END	SUGGESTED RUBBER DEPOSIT REMOVAL FREQUENCY
LESS THAN 15	2 YEARS
16 TO 30	1 YEAR
31 TO 90	6 MONTHS
91 TO 150	4 MONTHS
151 TO 210	3 MONTHS
GREATER THAN 210	2 MONTHS

There have typically been four methods to remove runway rubber: water blasting, chemical removal, shot blasting, and mechanical means (including sandblasting, scraping, brooming, milling, and grinding). Generally, only water blasting and chemical removal are used solely for the removal of rubber deposits. Shot blasting, milling and grinding are only used when the friction level of the runway surface

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needs to be improved and rubber removal alone will not meet acceptable levels of friction due to deterioration of the micro, as well as the macro-texture, of the runway surface. In past years shot blasting was used for rubber removal, but because of its retexturing effects, damage to the joint structures and runway markings, and its cumulative effects on runway deterioration it is no longer used solely for rubber removal. Retexturing, resurfacing or replacing a runway surface are all considerations for a runway that cannot be brought to acceptable friction levels through rubber removal. Scraping and brooming a runway surface to remove rubber deposits is not normally done for that purpose, but is a byproduct of snow and ice removal. No single runway rubber removal method is superior to all others in improving runway friction. All four methods have proven themselves to be successful "tools" in the runway friction improvement "toolbox". Aerodrome operators must evaluate their specific requirements, runway age and condition, climate, traffic, and local laws and regulations, while selecting the tool or combination of tools that best fits their specific runway friction improvement needs.

Rubber removal, chemical products

Traditionally, chemical agents were used in the process of removing the rubber accumulated on the runway. The ACRP synthesis 11[4] of the US Transportation Research Board lists the following as advantages of the chemical removal of runway:

- Minimal potential for pavement damage because rubber is softened before it is removed.
- Ability to use existing in house maintenance equipment and personnel
- Process speed: range from 900 to 1950 yd²/h (743 to 1641m²/h)
- Biodegradable and environmentally benign chemicals

The basic process for chemical removal of rubber is spraying a detergent agent liberally on the surface to be treated in an area small enough to be kept wet for the soaking period recommended by the manufacturer. The surface is then agitated usually with a runway broom equipped with a combination of metal and plastic bristles to scrape free the loosened rubber deposits. In some cases, low to medium pressure water is used in place of the runway broom. After a second agitation, the surface area is flushed with water to remove the chemicals and the rubber residue. Depending on the location and the environmental sensitivity of the area the water and the rubber residue is either left to run off of the runway sides and into the adjacent environment or it is vacuumed up and disposed of in an approved manner.

[4] http://onlinepubs.trb.org/onlinepubs/acrp/acrp_syn_011.pdf

Rubber removal, high pressure water

The other method most employed by aerodromes is high pressure water usage or waterblasting. Waterblasting is a process that removes rubber by using water pumped through a device at a specified high pressure. The water is directed at the surface through specialized high pressure nozzles, usually made from ceramic to withstand the high pressure without excessive wear. In most devices, the high-pressure water is supplied through a circular head, normally around thirty-six inches in diameter. One or more of these heads are typically mounted in front of, or to the side of, a parent vehicle that contains the high pressure pump and water supply, and in some cases the vacuum system and waste water receptacle. The nozzles under the head rotate to create a water scrubbing motion. In some other devices the nozzles are located in a liner pattern that travels back and forth across a track in front of or behind the vehicle. Regardless of the design, the unit moves slowly along the runway surface to be cleaned.

Although no specific specifications have been developed, in general, the following classifications apply; "high pressure" (2,000 psi to 15,000 psi) – (2003 Transport Canada specifications limit pressures on this type to 5,000 psi (35 MPa) on asphalt runways and 7,000 psi (48 MPa) on concrete surfaces and typically use about 30 gallons of water per minute) and "ultra-high pressure" (pressures >15,000 psi up to 43,000 psi. These systems typically use about 8 gallons of water per minute). These high pressures are normally supplied at a very low water volume.

Some devices have self- contained vacuum systems that vacuum up the residual water and removed rubber deposits. New technology is reported to be reprocessing the water for reuse in order to extend the time that the equipment can remain on the job between water servicing.

The noted advantages of waterblasting include:

- Speed of the system and the ease of getting on and off of the runway
- Improved friction on the macro and micro-texture of the pavement
- Perceived environmental-friendliness over the use of chemicals

3.1.2. Continuous Friction Measurement Equipment (CFME)

An adequate friction is necessary when it comes to bringing an aircraft to a stop. Would it be in the scenario of a landing or in case of rejected take off, the interface between the aircraft tires and the runway is the one most straightforward and necessary factor to monitor. In almost all cases of runway excursions, the friction between the aircraft and the runway has come to be a critical factor in the consequences of the happenstance.

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CFME is used to monitor the conditions of the runway for an airport to determine whether the runway needs maintenance such as re-pavement, rubber removal, or to be cleared of snow or ice. Over time, the skid resistance of a runway degrades and CFME is used to quantify this resistance or friction for pavement maintenance and operation safety.

To clarify the purpose of CFME use, FAA Circular 150/5320-12C section 3-7 states "All airports with turbojet traffic should own or have access to use of CFME. Not only is it an effective tool for scheduling runway maintenance, it can also be used in winter weather to enhance operational safety (see AC 150/5200 30)." Clarifications are also provided in Section 1-5 corresponding to reservations about the practical use of CFMEs readings and their transfer to the pilots. These reservations are related to a misleading risk due to the difficulty to harmonize the available technologies on the market and to dispose of a common-scale of friction coefficient. Furthermore, ground measurements apparently do not sufficiently correlate to real braking performances of aircraft. Those difficulties are compounded by time-instability of the reading provided by CFMEs. It explains why recommendations are made to put the emphasis on continuous friction measurements for maintenance purposes. Note that on-going the recent proposal of amendments of ICAO Annex 14 even requires not to report friction coefficients in case of runways which are wet or contaminated by standing water, slush and wet snow.

The Federal Aviation Administration (FAA) recommends the use of CFME to monitor runway friction conditions for maintenance purposes, clearing actions, and trend reporting (whether the condition of the runway is improving or getting worse). CFME measurements are not capable of indicating aircraft braking performance. A task force led by the FAA reported in 2005 that they had found no direct relation between runway friction measurement and aircraft performance. In fact, the algorithms used in the applied braking performance of an aircraft are complex enough that finding a correlation between runway friction and braking performance has not been successful. However, the indications from the CFME are instrumental in the decision of airports to downgrade the runway and/or in some cases to temporary close it for cleaning and/or snow plowing operations. Statistical use of the data also helps airports anticipate and plan maintenance activities. In the recent years, patents have been filed to measure and report runway friction from aircraft using the runway. The use of those patents will be investigated further in the second stage of this study.

There are various kinds of CFME which use different friction measuring methods from each other, which result in differing reported friction coefficients over the same pavement. Each device, however, is capable of producing repeatable measurements.

Three friction measuring methods are commonly used: locked wheel, fixed slip ratio, and side force. Locked wheel is only applied on highways and excludes runways. The fixed slip ratio method uses a linkage mechanism to rotate the friction measuring tire rotating at a target slip ratio. The side force

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method uses a yawed tire (yawed at a target angle relative to the direction of travel) to achieve a target slip ratio to measure the coefficient of friction.

Both methods are advantageous because both are continuous measurements. The physics are well understood for both continuous friction measuring methods. The disadvantages, however, depend on device's configuration. The fixed slip ratio method requires a robust system of gearing down the drive wheels' speed such that the friction measuring wheel achieves the target slip ratio. The fixed slip ratio gearing down system adds complexity to the device and requires more maintenance compared to the yawed wheel device. The yawed wheel devices tend to be simpler than the fixed slip designs but their physics are a bit more complicated.

Two CFME configurations are commonly designed: integrated and tow-behind. The integrated devices use a host vehicle as a platform for the friction measuring wheel while the tow-behind devices use a towable trailer containing the friction measuring equipment. Integrated devices use the host vehicle's suspension and mass to stabilize the friction measuring wheel, and the tow-behind use independent suspension systems to support the friction measuring wheel. Currently, various ASTM standards exist for different CFME configurations. The FAA and ASTM are developing standards for CFME to reduce variations between different CFME and harmonize the measured coefficient of friction.

From a technical point of view, all the devices reviewed here capable of measuring the runway coefficient of friction and the FAA AC 150/5320-12C lists all the approved devices. The various advantages and disadvantages between the methods and configurations make it difficult in judging which one is the best CFME. From the airport's point of view, the economics, ease of use, and maintenance seem to be the big factors in determining which CFME to acquire.

Similar guidance and recommended procedures for the use of CFME in EASA member States can be found in the RUNWAY FRICTION CHARACTERISTICS MEASUREMENTAND AIRCRAFT BRAKING (RuFAB) FINAL REPORT, VOLUME 1 – SUMMARY OF FINDINGS AND RECOMMENDATIONS, submitted in response to contract: EASA.2008.C46, March 2010, submitted by BMT FLEET TECHNOLOGY LIMITED, George Comfort. There are four volumes to the RuFAB report containing Summary of findings and recommendations, Documentation and taxonomy, Functional friction and Operational friction and RCR. Discussed throughout the volumes is the need for CFME harmonization, global taxonomy and recommendations to put the findings of the US FAA Takeoff and Landing Performance Assessment Aviation Rulemaking Committee (TALPA ARC) and the ICAO Friction Task Force (FTF) through assessment and adoption.

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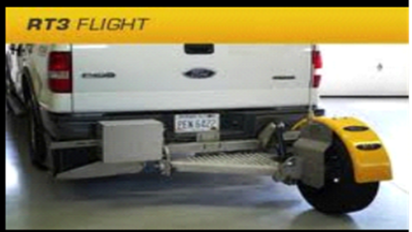
Device	Picture	Device	Picture
NORWAY - TWO		DYNATEST (HFT)	
ASFT		Mu-METER	
SAAB SARSYS		HALLIDAY RT3	
NAC DFT		PENN DOT ICC E274	
DYNATEST (RFT)			

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	**IMAG**

Figure 20: Examples of CFME

3.1.3. Pavement Condition and Markings

The pavement condition allows for the runway to minimize the effects of contaminants on braking action and runway friction. According to ICAO Circular 329 Draft, Runway Surface Condition Assessment, Measurement and Reporting, this is accomplished through proper surface drainage (shape and slope), Tire/ground interface drainage (macrotexture) and Penetration drainage (microtexture). As previously stated, the pavement qualities in combination with proper pavement maintenance in snow/slush/ice/frost removal, rubber removal and removal of other such as sand, dust, mud and oil will greatly improve runway surface conditions for better aircraft braking. Also according to ICAO Cir 329, the most important aspect of the pavement surface relative to its friction characteristics is the surface texture. The effect of surface material on the tire-to-ground coefficient of friction arises principally from differences in surface texture. Surfaces are normally designed with sufficient macrotexture to obtain a suitable water drainage rate in the tire/road interface. The texture is obtained by suitable proportioning of the aggregate/mortar mix or by surface finishing techniques. Pavement surface texture is expressed in terms of macrotexture and microtexture. However, these are defined differently depending on the context and measuring technique the terms are used in. Furthermore, they are understood differently in various parts of the aviation industry. Doc 9137, *Airport Services Manual*, Part 2 — *Pavement Surface Conditions* contains further guidance on this subject. Although ICAO provides general guidance (various parts of ICAO Aerodrome Design Manual Doc 9137 and 9157) on the smoothness and bearing capacity of runway, the efficiency of some features such as runway grooving is not standardized across the world. Rainfall on runway surfaces with good drainage has a lesser effect on aircraft performance. Grooved runways and runways with porous friction course surfaces fall into this category. However, there comes a time when the drainage capabilities of any runway exposed to heavy or torrential rain can be overwhelmed by water, especially if maintenance has been neglected. The primary purpose of grooving a runway surface is to enhance surface drainage and tire/ground interfacial drainage. Natural drainage can be slowed down by surface texture, but can be improved by grooving, which provides a shorter drainage path with more rapid drainage. Grooving adds to texture in the tire/ground interface and

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provides escape channels for dynamic drainage. In order for a surface to be considered for wet grooved runway aircraft performance, the saw-cut grooves must meet tolerances set by the State for alignment, depth, width and center-to-center spacing.

Runway resurfacing is generally accomplished at intervals based on baseline friction assessments of the runway surface, slope changes or change in drainage characteristics. Microtexture is reduced by wear and polishing. Macrotexture is reduced and lost as the voids between the aggregate are filled with contaminants. This can be a transient condition, such as with snow and ice, or a persistent condition, such as with the accumulation of rubber deposits. Comprehensive guidance on methods for improving the runway surface texture is available in Doc 9157, *Aerodrome Design Manual*, Part 3 — *Pavements*, Chapter 5.

Runway markings and painting also require inspection and attention to detail. Runway markings play an important role in helping the pilot properly identify runway and taxiway centerline, edges and distance remaining as well as first identifying the proper touchdown zone during the visual part of the landing. Additionally, runway markings help provide runway designation outside of the cockpit and without reference to the navigation charts. Each marking and painting on the airfield and runway play an important role in ensuring safe operations. If any of these markings are obscured, safety is potentially compromised. Uncertainty of location on the runway can lead to incursions and excursions. Additionally, improperly marked runways can create confusion for a pilot on approach due to an incorrect aimpoint or line-up on centerline. Again, mis-marked or obscured painting can lead to disastrous consequences.

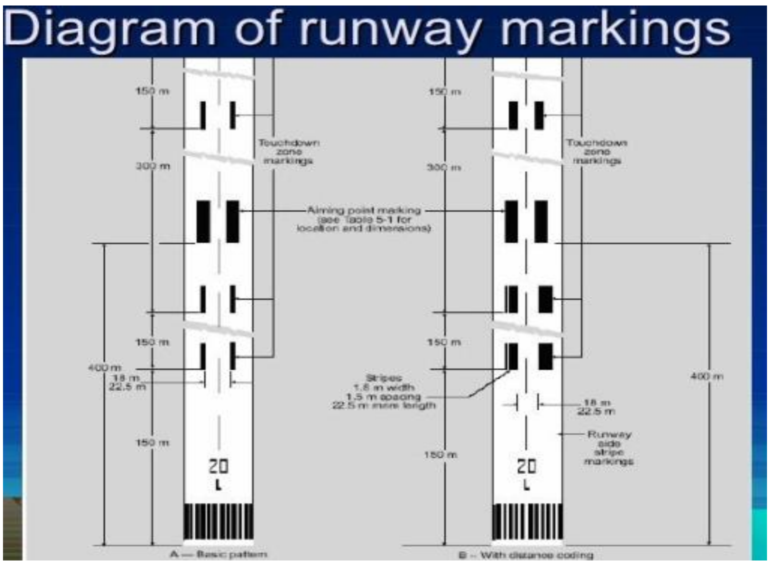

Figure 21: Diagram of runway markings

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3.1.4. Runway surface condition and monitoring:

Takeoff And Landing Performance Assessment Aviation Rulemaking Committee (TALPA-ARC) and the ICAO Friction Task Force (FTF)

In 2007, the FAA formed an aviation rule making committee to analyse takeoff and landing performance assessment methods. The FAA's Takeoff and Landing Performance Assessment Aviation Rulemaking Committee (TALPA ARC) released a set of guidelines for runway condition reporting and developed the Runway Condition Assessment Matrix (RCAM) in 2009. There were two winter trial periods (2009-2010 and 2010-2011) with airports and aircraft operators participating for validation of the methods agreed upon by industry participants in the ARC. The RCAM is now part of FAA AC 91-79A, Mitigating the Risks of a Runway Overrun Upon Landing, dated 9/17/2014. TALPA ARC comprised of FAA personnel, Part 121 pilot and engineers, Part 139 operators, aircraft manufacturer performance engineers, professional pilot organizations such (ALPA, SWAPA, APA), CFME manufacturers and other industry safety organizations. The committee made the following recommendations:

- Develop common language on runway condition assessment and reporting;
- Develop common definition of performance assumptions between manufacturers on landing airborne distance, assumed braking, and terminology;
- Base performance data on reasonably attainable parameters ;
- Develop a method for operators to compute operational landing performance even if manufacturers do not supply appropriate data.

The cornerstone of the TALPA ARC result is the so-called Runway Condition Assessment Matrix (an example of this matrix is shown in the Figure below from AC 91-79A). This is the communication tool allowing the airport operators, aircraft operators, aircraft manufacturers and regulators to work with a common understanding and definition of the issues involved in non-dry runways. The matrix is the tool for the airport runway inspector to relate his observations and measurements of the runway condition to terms that the aircraft manufacturers can use to compute aircraft performance. FAA leads for TALPA ARC guideline implementation have indicated that, beginning in the 2016-2017 winter season, RCAM will be the only allowable method of reporting runway condition. Numerous documents have been or in the process of being revised for this rollout.

The ICAO Friction Task Force (FTF) submitted their recommendations over the past two years to the ICAO Air Navigation Commission (ANC). ICAO released State Letter AN 4/1.1.55-15/30, dated 29 May 2015 for proposed amendments relating to the use of an enhanced global reporting format for assessing and reporting runway surface conditions. The comment period closed on 28 August 2015. From that State Letter, the proposals developed by the Friction Task Force of the Aerodrome Design and Operations Panel (ADOP) to amend the Standards and Recommended Practices (SARPs) in Annex

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14 — *Aerodromes*, Volume I — *Aerodrome Design and Operations*; the *Procedures for Air Navigation Services (PANS) — Aerodromes* (PANS-Aerodromes, Doc 9981); Annex 3 — *Meteorological Service for International Air Navigation*; Annex 6 — *Operation of Aircraft*, Part I — *International Commercial Air Transport — Aeroplanes* and Part II — *International General Aviation — Aeroplanes*; Annex 8 — *Airworthiness of Aircraft*; Annex 15 — *AeronauticalInformation Services*; and the *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444) relating to improvements in assessing and reporting runway surface conditions. The Commission authorized the transmission of these proposals to Contracting States and appropriate international organizations for comments.

The State Letter further explains, "The origin of the concept of a global reporting format stems from the operational need of having one reporting format crossing state borders. A flight crew should not need to relate to various reporting formats. As a basis for such a global reporting format, the United States FAA-initiated Take-off and Landing Performance Assessment – Aviation Rulemaking Committee(TALPA ARC) approach was chosen since this approach establishes the common and performance-relevant language between aerodrome, aeroplane manufacturer and aeroplane operator and was already used in aeroplane performance manuals provided by the major aeroplane manufacturers.

The term "runway condition report" (RCR) is used in the interim period in Annex 14, Volume I and in the PANS-Aerodromes for the global reporting format until such time as the AIS is transformed to AIM, together with the restructuring of Annex 15 and a new term/acronym may be developed. The output from the global reporting format is an information string resulting from an assessment process using procedures described in the PANS-Aerodromes."

Similar to TALPA ARC guidance, as defined by ICAO, a runway condition code (RWYCC) is reported to the flight crew as a result of an assessment of the runway surface condition by the runway inspectors using the runway condition assessment matrix (RCAM) and associated procedures in the PANS Aerodromes. The RWYCC reflects the effect on aircraft stopping performance of water or naturally occurring contaminants on the runway surface. With this information, flight crew can compute the necessary stopping distance of an aircraft under the prevailing conditions based on performance information provided by the aeroplane manufacturer. The RWYCC is reported for each runway third intended to be used.

Because of recommendations in the RuFAB Final Report, it is expected that EASA will follow the proposed guidance in the ICAO State Letter. The new guidance supplied and due to be implemented via FAA and ICAO coupled with emerging on-aircraft technologies, could provide a vast improvement in safety for runway surface condition monitoring and reporting for both aerodrome and aircraft operators alike.

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9/17/14 AC 91-79A
Appendix 1

TABLE 1-1. OPERATIONAL RUNWAY CONDITION ASSESSMENT MATRIX (RCAM) BRAKING ACTION CODES AND DEFINITIONS

Airport Operator Assessment Criteria		Control/Braking Assessment Criteria	
Runway Condition Description	**Code**	**Deceleration or Directional Control Observation**	**Pilot Reported Braking Action**
• Dry	6	--	--
• Frost • Wet (Includes damp and less than 1/8 inch depth of water) ***Less than 1/8 inch (3mm) depth of:*** • Slush • Dry Snow • Wet Snow	5	Braking deceleration is normal for the wheel braking effort applied AND directional control is normal.	Good
-15ºC and Colder outside air temperature: • Compacted Snow	4	Braking deceleration OR directional control is between Good and Medium.	Good to Medium
• Slippery When Wet (wet runway) • Dry Snow or Wet Snow (any depth) over Compacted Snow ***1/8 inch depth or greater of:*** • Dry Snow • Wet Snow ***Warmer than -15ºC outside air temperature:*** • Compacted Snow	3	Braking deceleration is noticeably reduced for the wheel braking effort applied OR directional control is noticeably reduced.	Medium
1/8 inch depth or greater of: • Water • Slush	2	Braking deceleration OR directional control is between Medium and Poor.	Medium to Poor
• Ice	1	Braking deceleration is significantly reduced for the wheel braking effort applied OR directional control is significantly reduced.	Poor
• Wet Ice • Water on top of Compacted Snow • Dry Snow or Wet Snow over Ice	0	Braking deceleration is minimal to non-existent for the wheel braking effort applied OR directional control is uncertain.	Nil

Operational RCAM Version 2014.1

Note: The unshaded portion of the RCAM is associated with how an airport operator conducts a runway condition assessment.
Note: The shaded portion of the RCAM is associated with the pilot's experience with braking action.
Note: The Operational RCAM illustration will differ from the RCAM illustration used by Airport Operators.
Note: Runway condition codes, one for each third of the landing surface, for example 4/3/3, represent the runway condition description as reported by the airport operator. The reporting of codes by runway thirds is expected to begin in October of 2016.

Figure 22: Runway conditions assessment matrix

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3.2. Environmental conditions/analysis

3.2.1. 3.2.1 Weather and Airfield condition reporting

Weather and airfield condition reporting are mainly provided by:

- Sensors: X-band Radar and Lidar (not yet available on all airports but requested by ICAO for Wind-Shear and Wake-Vortex)
- Weather Forecast Models (Resolution should be improved until 500 m)
- Mode-S Downlink (available on almost main european countries; could be replaced by ADS-B downlink of MET data)

In the following figures, we illustrate availability of Radar/Lidar data with respect to weather conditions, and their complementarities with Mode-S and (High Resolution) Weather Forecast models.

Especially, at high altitude or in foggy conditions, Radar/Lidar data are not available and data are provided by Mode-S EHS and High Resolution Weather Forecast Model.

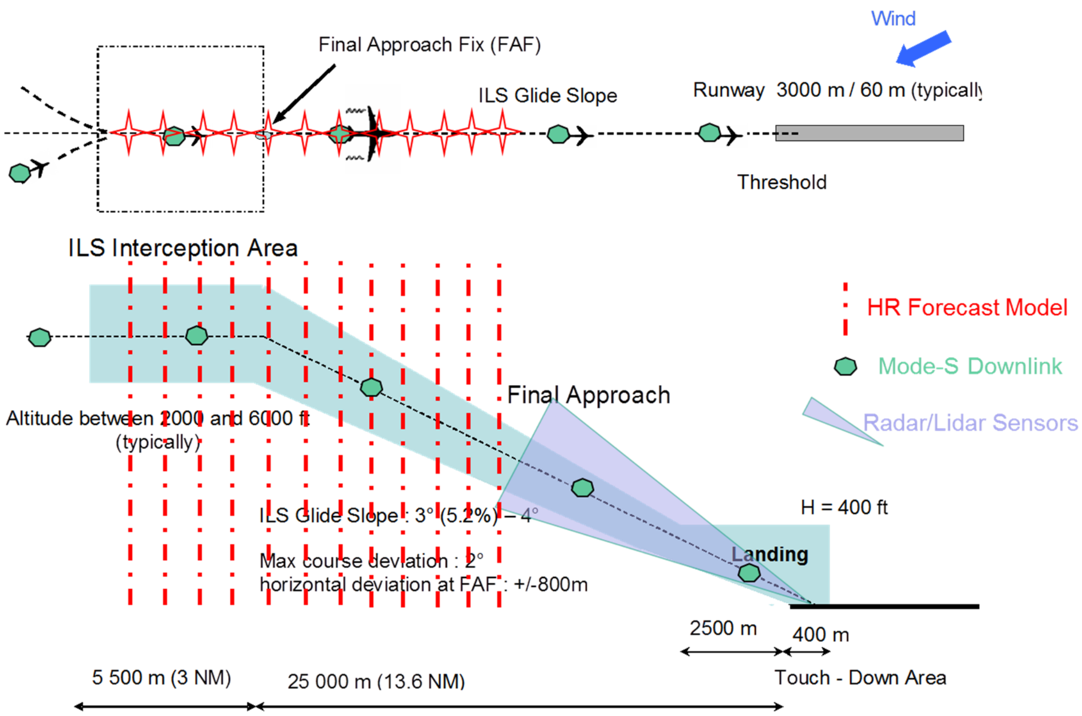

Figure 23 : Spatial localization for different sources of information

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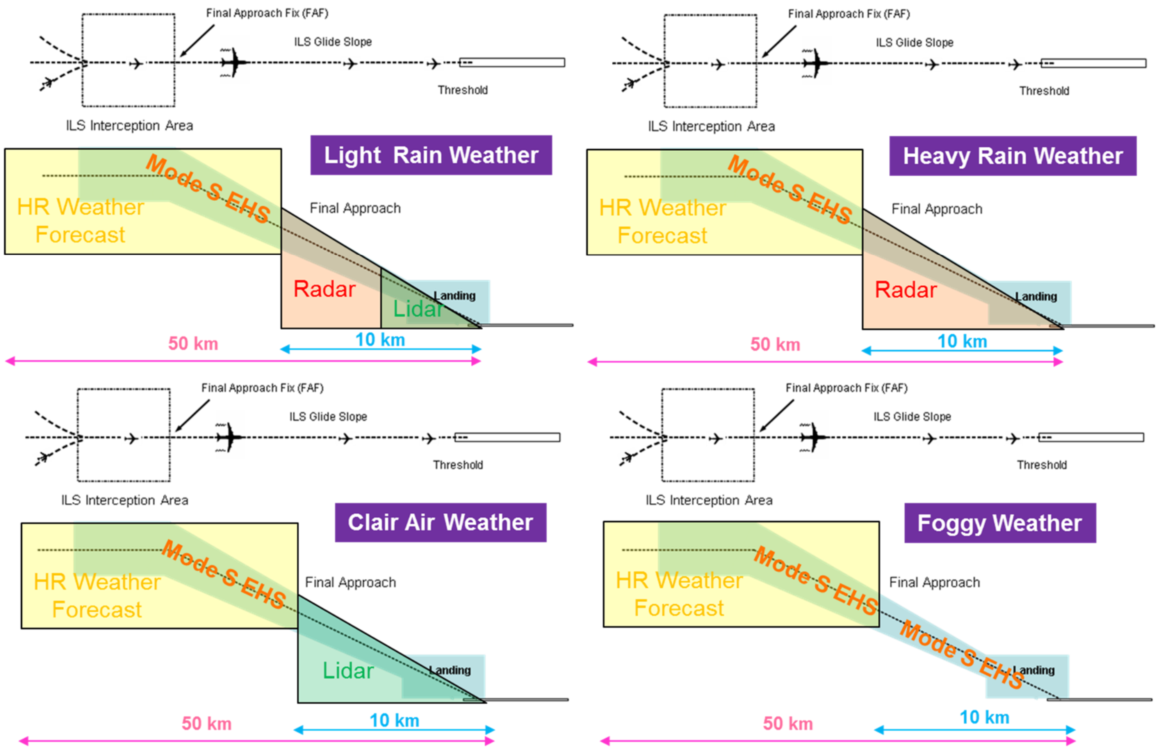

Figure 24 : Availability for different sources of information in different weather conditions

We give in the following figure available wind assessment accuracy and future accessible accuracy:

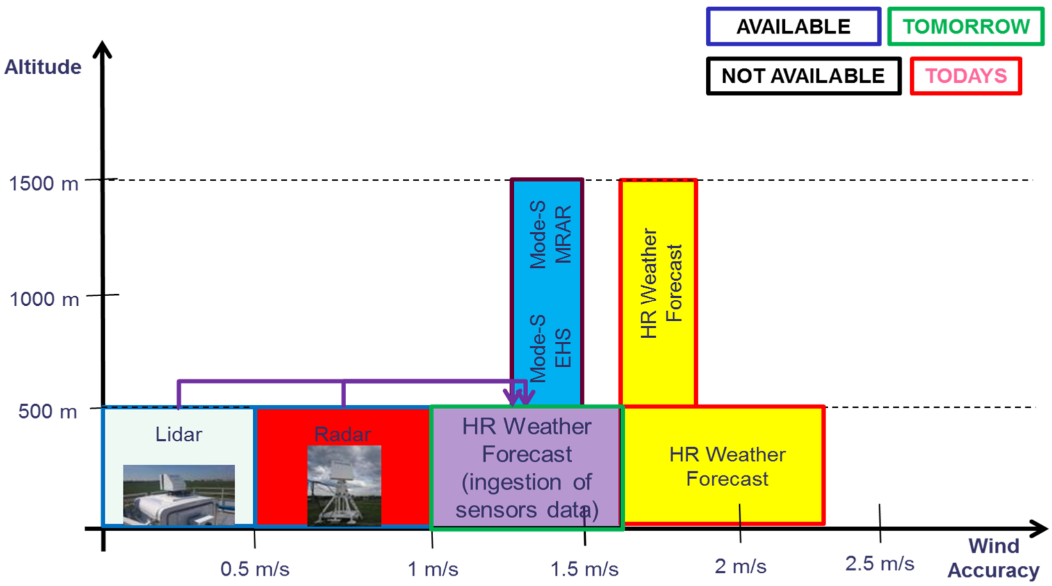

Figure 25 : Wind accuracy available at different altitudes

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3.2.2. Runway Strip, Runway Safe Area, RESAs...

As appearing over the course of this document, the main paradigm influencing the regulations and actions related to the risk of runway excursions is to affect the probability of occurrence. This fact is easily explained by the reality of air transportation. Not only is the prevention of any occurence always the favored option. Also, the best and safest way to ensure the safety of two airplanes in the sky is to keep them apart from each other. Similarly, the best regulation against controlled flight into terrain (CFIT) is to maintain the distance between the airborne aircraft and any terrain.

However, as all measures aimed at preventing a runway excursion may fail to reduce the probability to a non-occurring fact, distances around the runway have been standardized to reduce the severity of a possible runway excursion. In fact, contrary to other accidents in aviation, runway excursions are in principle survivable as long as the integrity of the aircraft is maintained and no obstacle are met.

Although the regulation differs slightly between various countries, the concept of having an area free of obstacle around and beyond the runway is universally accepted.

Runway Strip

According to the annex 14 of ICAO, a runway strip is defined as "a defined area including the runway and stopway, if provided, intended:

- to reduce the risk of damage to aircraft running off a runway; and
- to protect aircraft flying over it during take-off or landing operations."

As seen in here, the description covers the reduction of probability to the airborne aircraft as well as reduction of severity to the aircraft on the ground.

This area should as much as possible be free of any obstacle for the purpose cited above. Depending on the category of the airport, the flights that it is capable of accepting and the size of the runways, many standards and recommendations are made in the ICAO Aerodrome Design Manual concerning longitudinal and lateral distances, grading, slope as well as bearing capability of the area.

While dimensions vary, the role of the runway strip is clear and the ability of that area to preserve the integrity and sustain an aircraft in an overrun situation an important factor. ICAO in "ADM Part 1, runways" states that the area should be "graded in such a manner as to prevent the collapse of the nose landing gear" . Moreover, protection of an aircraft in an overrun situation would require that the surface should be able to sustain the weight of the aircraft. For that purpose, ICAO recommends that the area "be prepared to have a bearing strength of California Bearing Ratio value of 15 to20".

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It is reported that this level of ratio is extracted from a recommendation Boeing made related to the landing of aircrafts on soft ground terrains during the Viet Nam war and might require an update. However, as the only recommendation made by an aviation authority , it is interesting to note that several countries in Europe are keen on respecting this value while others disregard it as nothing more than any recommendation from the UN organization that ICAO is.

Stopway

Included in the runway strip, the stopway is "A defined rectangular area on the ground at the end of take-off run available prepared as a suitable area in which an aircraft can be stopped in the case of an abandoned take-off" according to the ICAO definition. As such it is one of the areas that have an impact on the performance calculations of the aircrafts as it is affecting the Accelerate-Stop Distance Available (ASDA).

Runway End Safety Area

"An area symmetrical about the extended runway centre line and adjacent to the end of the strip primarily intended to reduce the risk of damage to an aeroplane undershooting or overrunning the runway" has been the focus of much attention over the recent years. Indeed, however rare it was to see runway veer offs not protected within the width of the runway strip, a large amount of runway excursions are ending outside of the strip beyond the end of it. Therefore, Runway End Safety Areas also known as RESAs are an essential element in the mitigation of the consequences of overruns.

In fact, values extracted from the ICAO ADREP database brought the ICAO to report[5] that "*whatever the length of RESA provided, a study of data on runway overruns suggest that the standard distance of 90m would capture approximately 61% of overruns, with 83% being contained within the recommended distance of 240m. Therefore, it is recognized that some overruns would exceed even beyond the 240m RESA distance.*"

This area has been the focus of a lot of attention after that authorities worldwide have been trying to push towards an increased length when, instead, airports are indeed in favor of a longer runway whenever possible. Often, airfields have been built with natural (terrain, rivers, oceans...) or artificial (roads, railways...) obstacles close to the end of the runway when not literally on the water. Consequently, any retroactivity of the

[5] ICAO Proposal for amendment AN 4/1.1.52-11/41

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regulation and lengthening of the Runway End Safety Area or RESA often occurs a large amount of money; money that is seen by the airports as nothing more than a cost, often a high one.

Moreover, the legitimacy of using past occurring events to predict future overruns is subject to controversy, particularly when factoring in the impressing improvements of technologies that have been made as well as the many variables linked together and leading to an overrun.

Consequently, the Transportation Research Board and the FAA have been conducting research programs. ACRP report 3[6] "Analysis of aircraft overruns and undershoots for Runway Safety Areas" (2008) later followed by ACRP report 50[7] "Improved models for risk assessment of Runway Safety Areas" in 2011 are covering at length the area past the runway strip often referred to as "Runway End Safety Area". More recently, the National Aerospace Laboratory of the Netherlands (NLR) have conducted an extensive research "RESA study" for the European authority which results are expected to be published in the coming weeks.

Also, in Europe, the coming increase of role by EASA has brought to light the many difference variances that airports and regulators had taken towards the basic ICAO regulations. In fact, European travelers are facing a very different level of safety when flying from one country to the other. Similarly to the situation depicted related to the runway strips, some European countries are those where the dimensions are well respected or aimed for while others are being reluctant to enforce the standard distances and/or bearing ratios that are recommended in order to mitigate the consequences of an overrun.

EASA, with the push for standard ICAO regulation is willing to create a "level playing field" where the rules are as little prescriptive as possible and a "performance based" assessment is realized. Patrick Ky, Executive Director of EASA is however showing little acceptance for the airports and countries where the global ICAO standards are not respected. In June 2015, in Airport business magazine, a publication with tight links to Airport Council International or ACI, Patrick Ky states that "[EASA is] simply enforcing the global ICAO standards, and those airports [that are opposing the new regulation] were just not in compliance with those, which [he doesn't] think is right"[8].

It is also important to note that EASA is facing a real challenge in the application of the rule. Contrary to the FAA or most other aviation authorities, EASA is to date a pan European authority. The responsibility

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6 http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_003.pdf

7 http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_050.pdf

8 http://www.airport-business.com/2015/06/easa-spreads-wings-reaching-europes-airports/

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of EASA towards the airports is only partial as, to date, national CAAs are responsible for the application of the regulation over their own territory. Moreover, the European mandate and European rule making frame a very restrictive and prescriptive rule when it comes to use of public funds for airport related infrastructure.

Consequently, the improvement of RESAs in Europe, although fundamental to the reduction of severity and therefore of risk, is difficult to implement. More generally, all investments related to airport safety are viewed as nothing more than a cost by the airport while the European authority does not have the mandate to enforce a prescriptive law nor the funds that other authorities such as the FAA would have to finance the projects.

Runway Safe Area

Specific to the FAA, the runway safe (or safety) area covers most of the areas previously discussed. It is defined as "a defined surface surrounding the runway prepared or suitable for reducing the risk of damage to airplanes in the event of an undershoot, overshoot or excursion from the runway". The dimensions are defined in the FAA Advisory Circular 150/5300- 13, "Airport Design".

3.2.3 Runway overrun mitigation measures

In the early 1990s, the FAA started working towards what has turned out to be the most successful overrun mitigation measure to date. In the course of a mandate aimed at improving the safety at airport that did not have the required or recommended distances previously mentioned, the FAA engaged in the development of alternative methods to improve the safety when a full RSA was not available. Also, aware of the constantly increasing cost for prevention of runway excursions as the probability nears zero, the efforts of the FAA have turned out to be extremely cost efficient with the creation of a severity reducing (thus risk reducing) system that have been installed at over 100 runway ends ever since.

Arrestor beds are generally built as a passive system installed beyond the end of the runway. Built over a surface able to support the weight of an aircraft that would be overrunning the runway and tailor fitted to each and every single runway end, the arrestor beds are made of a material that will decelerate the overrun reliably and along a predicted performance curve without creating damage to the aircraft.

Initiated in the US, the arrestor beds have gained international recognition. In the recent years, ICAO then EASA have updated the regulations thus acknowledging the safety adding value of the arrestor beds to accept the installations of those within the runway strip.

One of the main obstacle on the way of the generalization of a cost effective severity reduction systems today is the equivalency of performance. As mentioned above, international guidance refers to distance

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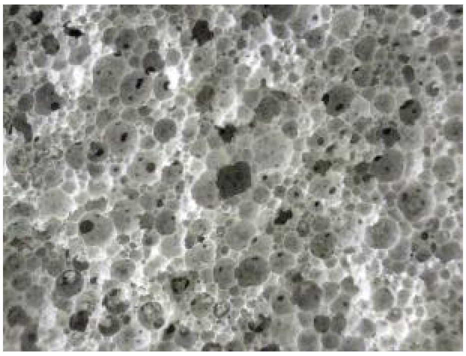
at and around the runways based on their capacity and dimensions. The performance calculated with the arrestor beds are, however, measured in knots.

In its initial guidance, the FAA indicated that an arrestor bed offering a performance at or above 70 knots for all aircrafts on the runway would be accepted as equivalent for a 1000ft (304.8 meters). Such equivalence was primarily built on empirical values. When confronting studies of the FAA and ICAO, it was found that roughly the same percentage of overruns would be caught within the area of a 240meter RESA as the percentage of aircraft exiting the runway at a speed of 70 knots or less. Also,the FAA also indicated that a minimum value of 40 knots would be considered for financing in the scope of the Airport Improvement Program. The authorities to date have generally accepted the equivalence of 70knots performance for a recommended 240 meter RESA past the runway strip. However, the question of equivalency of performance for the Standard RESA of 90 meters has not yet been addressed and several airport seek a clear frame to the regulation.



Two different technologies nowadays co-exist with the long time used and proven cellular cement and a more recent silicon foam glass. While the initial generations of EMAS has been tested at length with a long list of requirements and several aircraft tests, some companies without any prior aerospace experience have recently entered the market or are on the verge of doing so with products with a high degree of similarity or, in some cases, completely different technologies. It is being reported that the authorities are considering imposing most constraining performance demonstrations prior to accepting the installations of those more recent systems in Europe.

Recently, both EASA and the FAA have announced and promoted a change towards a performance based environment where the metrics will be a level of safety and prescriptive rules the exception rather than the norm. With their modular structure and precise performance measurement calculation, the arresting systems, already inherently performance oriented, may prove to be instrumental in the achievement of a safer, better level of safety. The coming steps required will be to define the required levels of safety, means to reach it and investigating the steps and timeline for implementation.

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4 AIRPORT/AIRCRAFT INTERACTION

4.1. DATALINK: Current network topologies

In order to communicate the current runway condition to flight crew before landing, Air Traffic Control (ATC) needs means to provide this information to aircraft. This section depicts the current existing means. Up to now, Voice communication through ACARS VHF radio is preferred way of communication.

Three types of networks are under operation today in the aeronautical world for aircraft – ground communications:

- ACARS (Aircraft Communication Addressing and Reporting System) used for AAC/AOC/ATC
- ATN (Aeronautical Telecommunication Network) used for ATC
- IP (Internet Protocol) used for AAC/AOC (mostly aircraft IT systems)

Depending on the aircraft type, area of operation, and airline, some or all of the above mentioned network technologies are supported.

Traditional Aeronautical Datalink Service Providers (DSPs) such as SITA and ARINC provide ACARS and ATN connectivity services.

IP air ground connectivity can be provided by traditional DSPs, or by standard telco operators (3G operators). Thus, this section will not focus on this specific network.

These three technologies will in the frame of future ATM (Air Traffic Management), migrate/include an IP connectivity solution for ATM.

4.1.1. ACARS

ACARS cockpit data link avionics are installed on approximately 10,000 air transport aircraft and approximately 4,000 business and government aircraft.

ACARS is used by flight operations applications that are hosted in the ACARS avionics unit and is connected to a Multi-Function Control and Display Unit and a cockpit printer that provides input/output to pilots. The ACARS unit is also used as an air-ground router by other airborne systems including the Flight Management system and aircraft system monitoring systems called Digital Flight Data Acquisition Units or Central Maintenance Computers. The ACARS unit communicates with ground networks via various radio systems, always including a VHF radio, and optionally also satellite avionics and/or an HF data radio. Passenger and Cabin application systems can share the use of the satellite avionics if they are installed. In the following, a high level view of end to end ACARS architecture is presented.

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Subnetworks:

The following subnetworks are used by ACARS service:

- VHF (Very High Frequency) :
  - VDL (VHF Digital Link) mode 1/A (POA : Plain Old ACARS)
  - VDL (VHF Digital Link) mode 2 (AOA : ACARS Over AVLC)
  - HFDL (High Frequency Data Link)
- Inmarsat Satcom Data2
- Iridium SBD (Short Burst Data)

VHF and HF subnetworks are operated by the ACARS service providers (DSP), while Inmarsat satellite service is operated by Inmarsat (and ground telco partners), and Iridium Satellite service is operated by Iridium.

In some countries, the VHF/VDL subnetworks are operated by the local ANSP (Air Navigation Service Provider).

Aircraft communications use of Inmarsat satellite links

Aircraft have been able to carry out voice and data communications via the Inmarsat satellites since around 1990, when these satellites were expanded from their original function of providing services to ships.

The number of aircraft equipped to use the Inmarsat aeronautical service today is approximately 2,000 air transport aircraft and another 1,800 business jets or government aircraft. The aircraft using the Inmarsat aeronautical service each month generate a total traffic of approximately 9 million kilobits of ACARS data link messages and 200 thousand minutes of voice calls.

The original Inmarsat Aeronautical service provides two service modes, circuit mode supporting voice communications (or a 2.4kbit/sec modem-to-modem data/fax communications) and packet mode supporting "always-on" data communications.

Aircraft data link using HF Radio

The move of aircraft communications from voice to data has motivated some operators of HF radio ground stations to install "HF datalink" (HFDL) computers that enable them to transport ACARS communications.

The vendors of aircraft HF radios have added corresponding capability to support ACARS and it has been installed by a few airlines. The new HF avionics radios can switch between voice and data mode

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using the same aerial, but they are required to give voice communications precedence over data link, which limits the HFDL availability. A limited number of aircraft are using HF data link and it has been found to provide better availability than HF voice on the routes over the Poles beyond the 80-degree North/South limit of Inmarsat satellite coverage. The HFDL capacity is limited by the frequencies available in the HF band. The allocation of HF frequencies to data link has required a very complex co-ordination process and the system will quickly reach the limits of available capacity.

ACARS Iridium satellite air-ground link

ACARS avionics have since 2007 begun to be linked to avionics that use the Iridium satellites which fly in low earth orbit and allow avionics to be lighter and less costly. These ACARS messages are being sent in Iridium Short Burst Data (SBD) transmissions. SITA has implemented a gateway between the ACARS service Processor and the Iridium SBD server to provide the service via Iridium.

ACARS over VDL

The Air traffic Control community defined the ICAO VDL standard to transport ATN air-ground communications but ACARS communications can also use the VDL link. Following discussion of the options for ACARS use of VDL, the AEEC Data Link Users Forum in January 1999 adopted as the standard interim architecture “ACARS over AVLC” (AOA).

In the VDL AOA architecture, aircraft use the AEEC 618 protocol over the ICAO VDL standard AVLC link providing 31.5-kilobit per second capacity. Aircraft using VDL AOA obtain increased capacity over the VHF link but can only exchange messages in the same ACARS AEEC 618 formats used over the existing VHF analog link.

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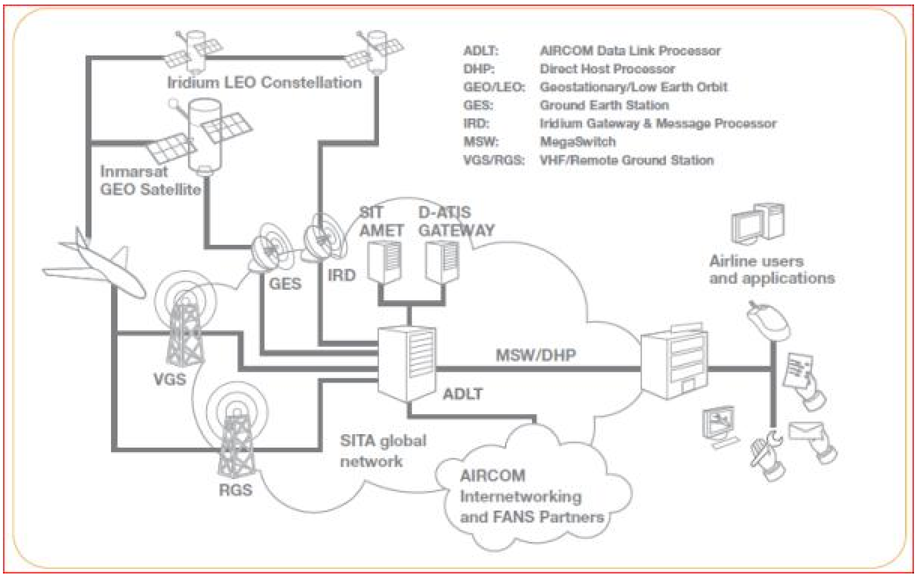

Figure 26: Crosswind Landing Techniques [2]

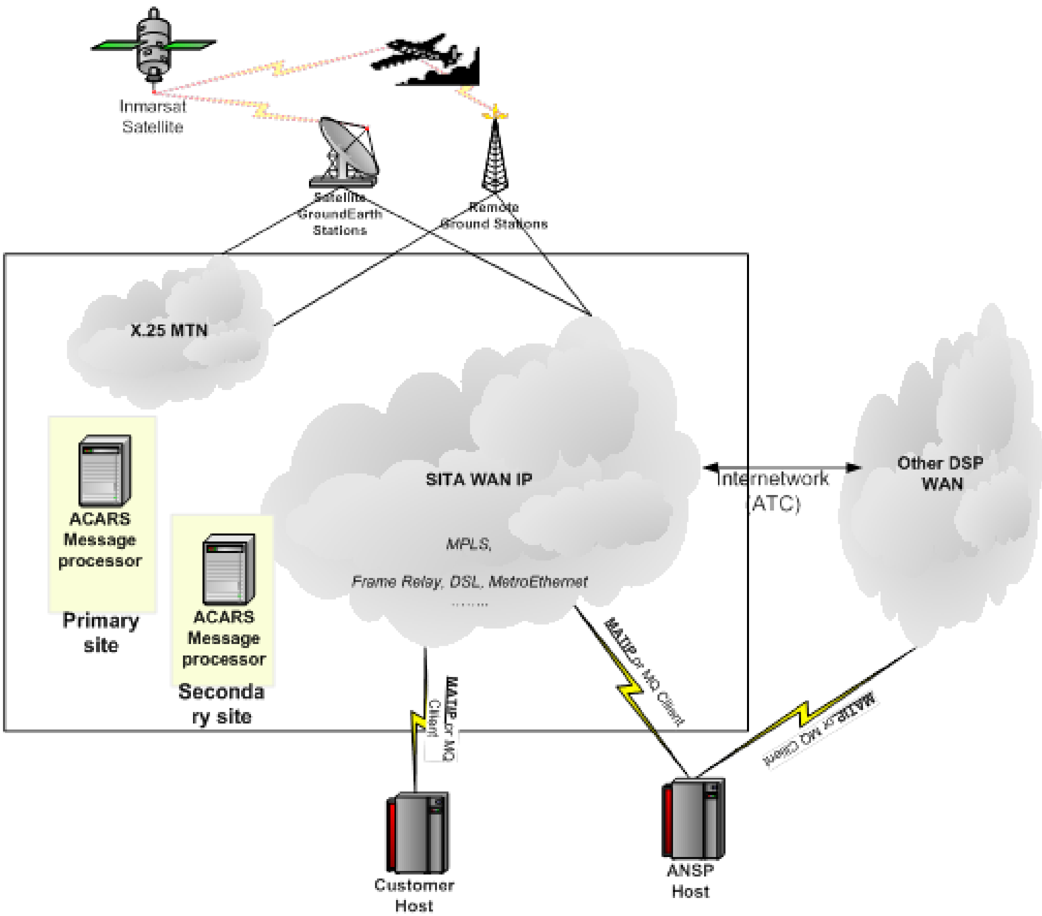

Figure 27: Overview of SITA ACARS network

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4.1.2. ATN / OSI

ATN (ATN/OSI) End-to-End Protocols

The ATN and data link standards specify protocols using the logic and terminology of the International Organization for standardization (ISO) model for Open systems Interconnection (OSI). The ATN standard covers Upper Layer protocols used in end systems but this document focuses only on the ATN transport and network Layer Protocols. The ATN standard specifies ATN applications use of ISO 8073 Connection Oriented transport Protocol (COTP) over the ISO 8473 Connection Less Network Protocol (CLNP). The COTP protocol provides a message delivery acknowledgement over the CLNP protocol which handles the actual message exchange between the ATN users systems. The ICAO ATN standard specifies a unique addressing scheme to be used in the CLNP protocol which has two formats:

- ANSP systems: ISO country code, city code, terminal identifier
- Airline systems: ICAO airline code, city code, terminal identifier

The ATN CLNP messages are handled by routers that interconnect air-ground (mobile) sub-networks and terrestrial subnetworks. The routers establish a routing information base using ATN routing protocols, primarily the ISO 10747 Interdomain Routing Protocol (IDRP).

The ATN routing protocols establish a CLNP routing information base, which is updated as the system establishes subnetwork connections to other ATN systems. Airborne ATN routers maintain a routing information base indicating which connections are available over air-ground data link sub-networks.

<u>Subnetworks:</u>

Currently the only approved subnetwork in use by ATN service is:

- VHF :
    - VDL mode 2

ICAO VHF air-ground digital link (VDL) Mode 2

The ICAO VHF Digital Link (VDL) Mode 2 standard was developed following the 1990 ICAO Communications Divisional meeting that recognized the value of specifying the use of the Aeronautical VHF channels for data communications. The 1990 ICAO Communications Divisional meeting also reserved the 4 channels 136.900, 136.925, 136.950 and 136.975MHz for data communications worldwide. Following that meeting, the ICAO Air navigation Commission created the Aeronautical Mobile Communications Panel (AMCP) to develop the VDL standard.

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The validated VDL Mode 2 standard was presented to the AMCP at its fourth meeting in March 1996, which recommended that it be included in Annex 10. The ICAO member states accepted this recommendation by agreeing to its inclusion in Amendment 72 to Annex 10.

The ICAO VDL Mode 2 standard specifies the use over the VHF link of a D8PSK (Differentially encoded 8-Phase shift Keying) modulation scheme providing a data rate of 31.5 kbits/ second compared to the VHF ACARS rate of 2.4 kbits/second in the same channel width of 25 kHz.

The VDL Link Layer protocol specifies for media access control to the VHF channel the same Carrier Sense Multiple Access (CSMA) algorithm as for classic VHF ACARS. However, the VDL CSMA will provide better performance than the VHF ACARS CSMA by using a VHF Data Radio to process the CSMA function.

The combination of the VDL D8PSK scheme and its CSMA algorithm makes the link reach saturation at a data load of 10kilobits per second, compared to the classic VHF ACARS maximum effective link capacity of 300 bits per second.

The “Aviation VHF Link Control” (AVLC) protocol provides a link for the transport of binary data between an aircraft and a ground station. AVLC is a variation of the ISO High Level Data Link Control (HDLC) protocol, designed specifically to handle the use of VHF channels.

4.1.3. Datalink Synthesis

Different types of data links are recalled here:

- Satellite: handling A/G communications via satellite (based on at least safety and operational consideration, the satellite system used for ATS/AOC services can be different from the one used for AAC/APC services).
- Terrestrial: handling A/G communications via a direct radio link between aircraft and ground and A/A communications (at least point-to-point communications).
- Airport: handling A/G communications via a direct radio link between aircraft and airport infrastructure (the general use is for aircraft on ground).

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Data Link type	Data Link technology	Frequency band
Terrestrial	HF Data Link	In-use: 2.8-22 MHz
Terrestrial	VDL Mode 2	In-use: 118-137 MHz
Satellite	L-band AMS(R)S (safety)	In-use: 1545-1555 MHz (space-to-earth), 1646.5-1656.5 MHz (earth-to-space)
Terrestrial	LDACS 1/2	Allocated & not in-use: 960-1164 MHz
Airport	AeroMACS Airport	Allocated & not in-use: 5091-5150 MHz

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5 CONCLUSIONS

This inventory of current developments and new initiatives to reduce runway excursions has described:

- On board means to stop the aircraft (avionics system: avionics means for alerting & awareness, automation systems for pilot, procedure).
- Airport infrastructure: runways surface control/analysis, environmental conditions/analysis.
- Airport/aircraft interaction: communication/measurements means for critical data, consolidation of onboard data with airport data.

A literature and patent survey on crosswind assistance systems was conducted. The survey showed that in early decades of aviation the crosswind landing capabilities of tail dragger aircraft was improved by using castering wheels. The renunciation from the tail dragger design and the introduction of the present front wheel steering improved the situation under crosswind operations and lessened the risk of a ground loop in case of an inappropriate landing under crosswind. Nevertheless, even today crosswind contributes to runway excursions during landing and take-off to a significant amount. Any crosswind assistance would inevitably improve flight safety. Furthermore, the introduction of steerable main landing gears could be a necessary technology for possible, nonconventional future aircraft designs, in order to enable crosswind operations. An automatic system that assists the pilot during crosswind landings by automatically adjusting the steering angle of each wheel does not exist today.

Existing ROPS (Runway Overrun Prevention System) and BTV (Brake-To-Vacate) systems, with their main capabilities, have been described.

Available sources for weather characteristics, such as Cross/Head/Tail Winds and EDR (Eddy Dissipation Rate), have been described. These available sources have been investigated in the EC FP7 Project UFO.

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