Brake-to-Vacate system

The smart automatic braking system for enhanced surface operations

The Brake-To-Vacate (BTV) is an Airbus innovation in pilot aid to ease airport congestion and improve runway turnaround time. The BTV system, which will be available on the A380 (2009) and A320 Family (2012/2013) as an option and on A350XWB basically, helps reducing taxiing time at busy airports by optimizing the runway occupancy time and lowering braking energy while maximizing passenger comfort. The BTV system, which is designed by a multi-disciplinary team (avionics, flight controls and auto-flight, landing gear, flight tests, aircraft performance and human factors) under the scope of a multi-programme project, allows pilots to select the appropriate runway exit during descent or approach preparation. The Airbus-patented innovative system uses the GPS (Global Positioning System), Airport Navigation, Auto-Flight and Auto-Brake Systems to regulate deceleration, enabling the aircraft to reach any chosen exit at the correct speed in optimum conditions.

Fabrice VILLAUMÉ
Multi-Programme Project Leader
Airbus Systems Engineering

Final approach on LFBO 32L runway with S10 exit selection for BTV

The project began in 1998 via a PhD thesis. Following a feasibility phase until 2001, it completed a prototype phase on an A340-600 prototype in 2006, with a first test flight in April 2004 under various operational conditions. These preliminary demonstrations were performed within a research framework. A successful flight test in March 2005 has been performed in real-time conditions at Charles de Gaulle Airport in Paris. The industrialization began on A380 in October 2006 with a first test flight in May 2008.

To better understand what is the BTV system, this article will highlight the current use of the already existing auto-brake system and its impact on aircraft operations, the evolving airport operation context and will detail the Airbus BTV operational answer.

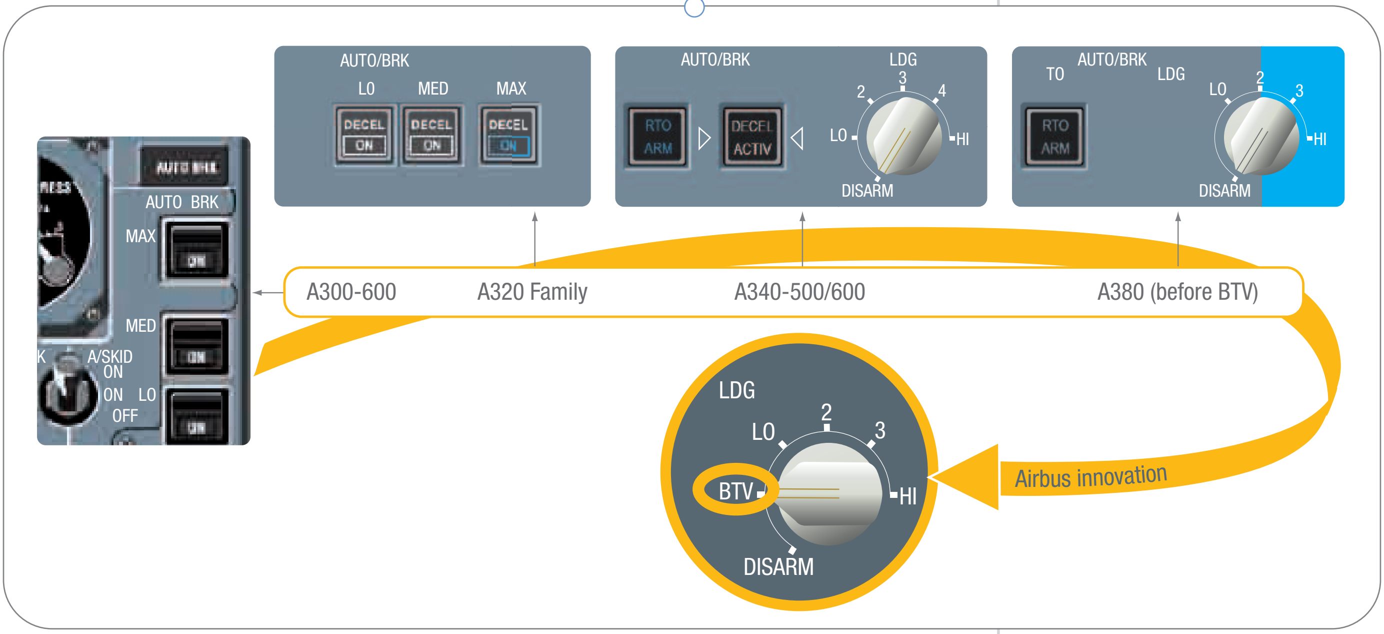
The automatic braking system at landing: Historical perspective of evolution

Automatic braking system, also called auto-brake system, is a type of automatic wheel-based hydraulic brake system for advanced airplanes (Airbus, Boeing, etc.). In order to keep the pilot free to perform other tasks, the auto-brake has been designed to control, robustly and rustically, aircraft longitudinal deceleration during rollout and down to full stop. The automatic deceleration control roughly starts at the nose landing gear impact with an onset transition ramp for comfort.

Since the A300-600 model, auto-brake modes are selectable for landing using either LO and MED, which provide low and medium fixed deceleration control. In order to give more operational flexibility, A340-500/600 models are fitted

Automatic braking systems on Airbus aircraft

Figure 1



with an auto-brake system enriched by five fixed deceleration modes through a new rotary switch: LO, 2, 3, 4 and HI (see figure 1). The A380 is fitted with a four-modes auto-brake system (LO, 2, 3 and HI).

In everyday operations, analysis shows that the auto-brake system cannot be adapted to each landing situation, which has specific touch-down characteristics (position and speed) with respect to the desirable exit taxiway foreseen by the crew (type, position and speed).

The use of the auto-brake system is recommended when the pilot's workload is high, and has become since the year 2000, Airbus recommended Standard Operating Procedures (SOP) at landing, but there are some drawbacks:

- Firstly, onset nose high on some models would be stronger than the pilot would wish,
- Secondly, brake pedals override includes discomfort, as the pilot has frequently to brake more... to brake less, causing frequent assymetric braking.

Since the A380 models, a smooth and symetric system has been introduced by allowing auto-brake system disconnection through the Auto-Thrust Instinctive Disconnection button located on the thrust levers,

- Thirdly, associated to crosswind operations, it may induce on some models assymetric braking, which helps lateral control, but has a negative impact on Turn Around Time (TAT): There is more braking energy on the more loaded wheels, so those brakes get to reach higher temperatures and need more time to cool down before the next departure,
- Finally, it is highly recommended to reduce as much as possible the number of brake pedal applications during landing roll to limit carbon brake wear.

Additionally, current auto-brake system shortcomings at landing are magnified with its systematic use. Everyday use leads to reach the desired exit speed too far or too short from the desired exit.

The only way to improve this situation is the pilot's compensation by overriding the auto-brake system at the right time. The override decision criterion then depends on the pilot's feelings, view and experience inducing an everyday very limited brake optimization. In low visibility conditions (crew blindness), the pilot cannot compensate the classic auto-brake system blindness, being blind himself. In that operational case, auto-brake MED deceleration level or equivalent is mostly used, bringing the aircraft at low speed in the middle of nowhere. Then, the pilot taxies on the runway until...
…an exit literally appears!

The auto-brake system control principle is a closed-loop control on deceleration. Hence, more reverse thrust results in less braking, but without shortening landing distance. At first sight, this is really beneficial by reducing brake energy. Nevertheless, this everyday situation increases the risk of runway end overrun in case of long flare on short runways; even if the pilot selects, as committed, the maximum reverse thrust.

In terms of Human Machine Interface, the pilot, through the DECEL light extinction does a simplistic auto-brake system monitoring when current deceleration is 20% below the target deceleration:

- The DECEL light might be extinguished at high speed on slippery runways while auto-brake system is operating normally,
- A partial improvement has been introduced on A340-500/600 by adding an ACTIV light in order to confirm the correct operation of the auto-brake system. Nevertheless, it will not help the pilot in achieving an intended exit or in preventing a possible runway overrun.

An evolving airport operation context

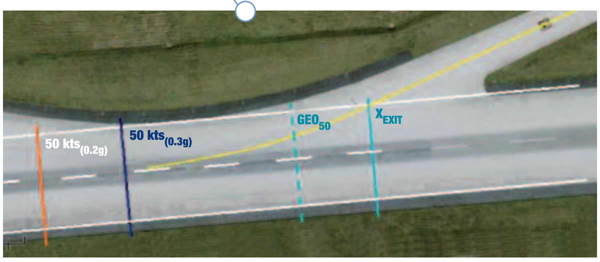
Innovative solutions are urgently required because congestion is already a serious issue at some airports. A minority of airports generates the majority of demands, and these airports are already operating at their maximum throughput for sustained periods of time. Among other topics, the ongoing SESAR (Single European Sky for Air Traffic Management Research) project focuses on making best use of airport airside capacity based on the available infrastructure, because new constructions are in many instances strictly limited by political and environmental constraints. The airport's airside system capacity is significantly influenced by the runway capacity, which should be considered as key determinant for the overall intake. It has the potential to significantly reduce the total amount of delays at airports. This will in turn reduce the requirements for the airport's development, the impact on the environment and its resource use.

Among the wide spectrum of runway capacity elements, reducing the time spent by aircraft on the runway is one of the most important issues.

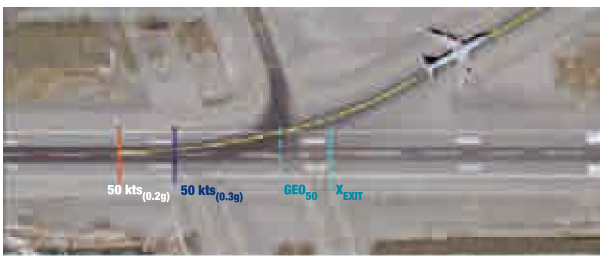
information

Synthetically, current
auto-brake system
drawbacks (induced by its useful rusticity) are, in everyday averations, an approximate optimization achieved by the pilot (i.e. too high deceleration followed by too long speed taxi on the runway), a partial awareness of the estimated and measured braking distance, a lack of flexibility with respect to operational constraints and an 'Airport Navigation' unawareness.

BTV is capable of high speed turn off



Depending on exact geometry, taxiway exact angle, turn radius and RWY width, aircraft can be at 50 KTS with yellow line having slightly started to turn



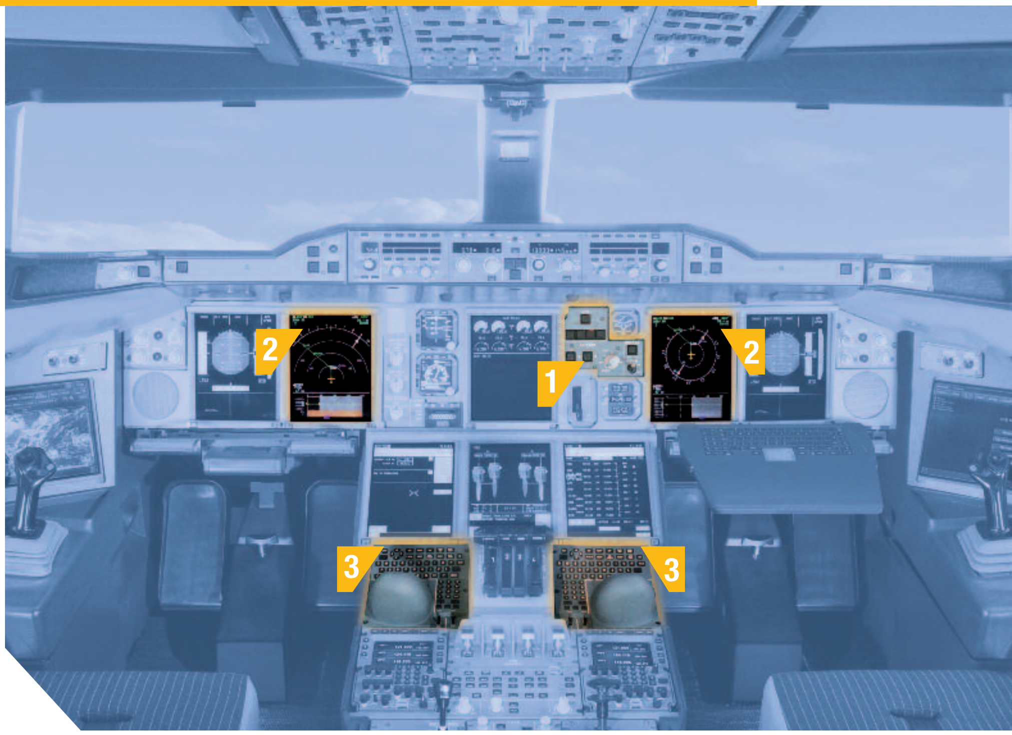
High speed turn off angle slightly steeper than 30°, with 45m wide runway (in Nice - France exactly 30°)

This does not alter the fact that Runway Occupancy Time (ROT) is inextricably linked to other issues such as wake vortex separation minima and minimum separation standards for both arrival and departure. Minimizing the separation between arriving and departing traffic is equally crucial in reducing ROTs. Even environmental aspects, such as use of preferential runways, etc., may also have an impact on occupancy time.

Studies have shown that depending on the traffic mix (various aircraft types), runway capacity can be increased between 5% (in the case of single-runway airports) and 15% (multiple-runway airports) by reducing ROTs. A remarkable example is the 19% capacity increase achieved over a period of three years on the single runway at Manchester, U.K.

It should be stressed that increasing runway capacity by minimizing runway occupancy is a matter of seconds per operation. Indeed, aircraft that unnecessarily occupy the runway for additional seconds potentially provoke delays of at least one order of magnitude greater, (i.e. close to the minute or worse). If this develops into a domino effect, then overall system capacity will be reduced, causing losses of slots. On the other hand, the saving of a few seconds per movement can represent an important capacity increase. Enhancing runway capacity is not necessarily a matter of seeking absolute minimum occupancy time but rather one of achieving consistent performance, thereby building up the confidence of pilots and controllers, which is necessary to optimize runway capacity.

Finally, in case of low visibility, the runway capacity is drastically reduced due to lack of the operational guarantee between the pilot and the controller, inducing an important increase of safety margins added to everyday separation between two consecutive aircraft.



1 Control using Auto-Brake existing selector.
BTV instinctive disconnection using A/THR existing instinctive disconnection button.

2 Independent display on existing Navigation Display (ND)

3 Selection using existing Key Board Control and Cursor Unit (KCCU)

An operational answer: The Brake-to-Vacate function

It becomes natural to imagine an enhancement of the existing classical auto-brake system at landing which aims at reaching optimally a desired exit, by adding a new auto-brake mode (with the same activation/disconnection principles).

Brake-to-Vacate system design objectives can be expressed to:

- Ensure the best possible braking management at landing from main landing gear impact to runway exit vacation,
- Develop a crew intuitive selection, monitoring and termination of the BTV system,
- Propose a seamless and natural integration with: In-flight landing distances assessment during descent/approach preparation and execution, Runway Overrun Prevention and Warning Systems (ROP and ROW) below 500ft until aircraft runway vacation, Airport Navigation during taxi,

information

Synthetically, regarding present runway operations, current **on-board systems** cannot help improving runway capacity; therefore, runway capacity is not optimized and is drastically reduced in low visibility conditions.

- Ensure a safety improvement by increased crew situation awareness achieved with the in-flight landing distance computation continued on final approach and ground roll, even with low visibility operations,
- Ensure a safety improvement with the implementation of a brand new runway overrun prevention device covering most frequent cases on non-contaminated runways; feature which is also generalized to all other classical auto-brake modes. The description of BTV integrated brand new Runway Overrun Prevention (ROP) system and display of operational landing distances, will be the object of two specific articles in July and December 2009 in the editions of Safety First magazine.

BRAKE-TO-VACATE GENERAL OPTIMIZATION PRINCIPLES: AIRCRAFT SIDE

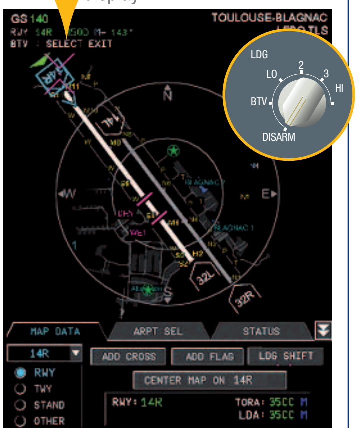
In more details, 'the best possible braking management at landing', targeted by the BTV system, considers the most robust and simple compromize which guarantees to vacate at the assigned exit, optimizes the brake energy

BTV configuration

1

BTV configuration must be done in PLAN mode / ZOOM range. The FMS runway is 14R. Runway selection with click on QFU.

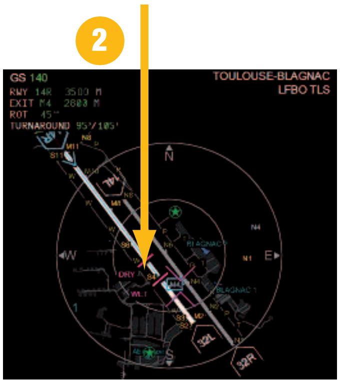
Selection of airport navigation display



Selection of BTV runway

2

Exit selection with click on exit label according to aircraft performance, runway condition and destination gate.

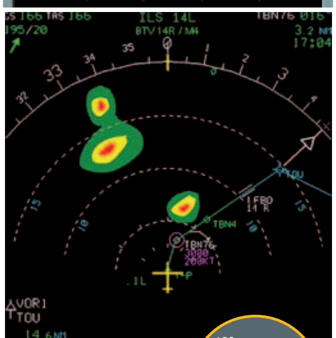


Exit selection

3

BTV arming by ABRK rotary switch. Runway LDA must be cross-checked with charts.

BTV arming



Confirmation message

regarding the current operational constraints, minimizes the runway occupancy time and improves the passenger comfort.

In an operation, the optimum exit selection depends on multiple criteria and constraints that can only be known in their full complexity by the pilot and the air traffic controller:

- Optimum braking energy (complex as function of taxi, of requested Turn Around Time (TAT), of noise abatement procedures preventing maximal reverse thrust usage out of safety needs),
- Minimum number of brake applications,
- Minimum runway occupancy time,
- Best exit for taxi duration.

A short exit selection can obviously produce lower runway occupancy time than a far exit, but with higher brake energy and Turn Around Time. At the end, no automatic selection of the optimum exit is possible.
Then, for an exit selected by the pilot, the BTV system guarantees that simultaneously the lowest brake energy and runway occupancy time are reached. For this, BTV system delays braking as much as possible, applies the maximum possible braking at the latest possible time while reaching the exit at suitable speed. But a design compromize has been found in order to respect the passengers' comfort constraints by fixing maximum level of deceleration and variation of deceleration over time, during the landing roll. Moreover, a special attention has been paid to the BTV deceleration profile computation regarding the visual perception of the pilot associated to late braking in the case of a selected exit close to the runway end.

To help the exit selection chosen by the pilot, the BTV system proposes a dedicated interface providing intuitive information to assist the selection of an optimum exit and to monitor BTV operation. This dedicated interface provides also a predicted and guaranteed ROT (Runway Occupancy Time) and an estimated TAT in a sense of brake cooling time (assuming thrust idle or maximum reversers' usage as per Standard Operating Procedures indication).

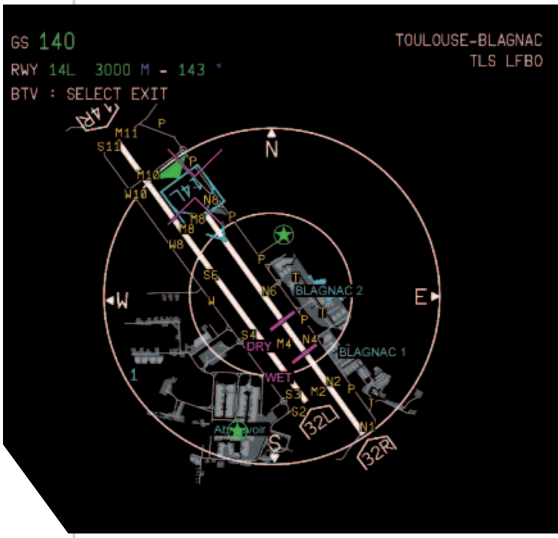
Nevertheless, the selection of the 'optimum' exit remains the pilot's responsibility. These indications then help the crew on the optimal thrust reversers' usage strategy during the landing roll on dry runway.

BRAKE-TO-VACATE GENERAL OPTIMIZATION PRINCIPLES: ATM (AIR TRAFFIC MANAGEMENT) SIDE

The main principle is to use efficiently the runway occupancy time reduction allowed by BTV-fitted aircraft in the whole traffic converging on the considered air-port; particularly, it takes benefit from the knowledge of the effective and guaranteed runway occupancy of the BTV-fitted aircraft using the 'runway resource'.

Then, the followed dedicated arrival procedure is today imagined (still under study with the ATM community):

- Since the 'approach' controller manages the BTV-fitted aircraft, the pilot and the controller agree on the in-service landing runway and exit taxiway, which depends on several points as the airport layout configuration, aircraft landing performances, airline operational procedures and all other current landing conditions,
- The pilot (or in the future the aircraft itself) communicates the predictive runway occupancy time, which will be guaranteed,
- The 'approach' controller manages arrivals considering separations to be respected and the forecasted arrival time on the landing runway threshold.



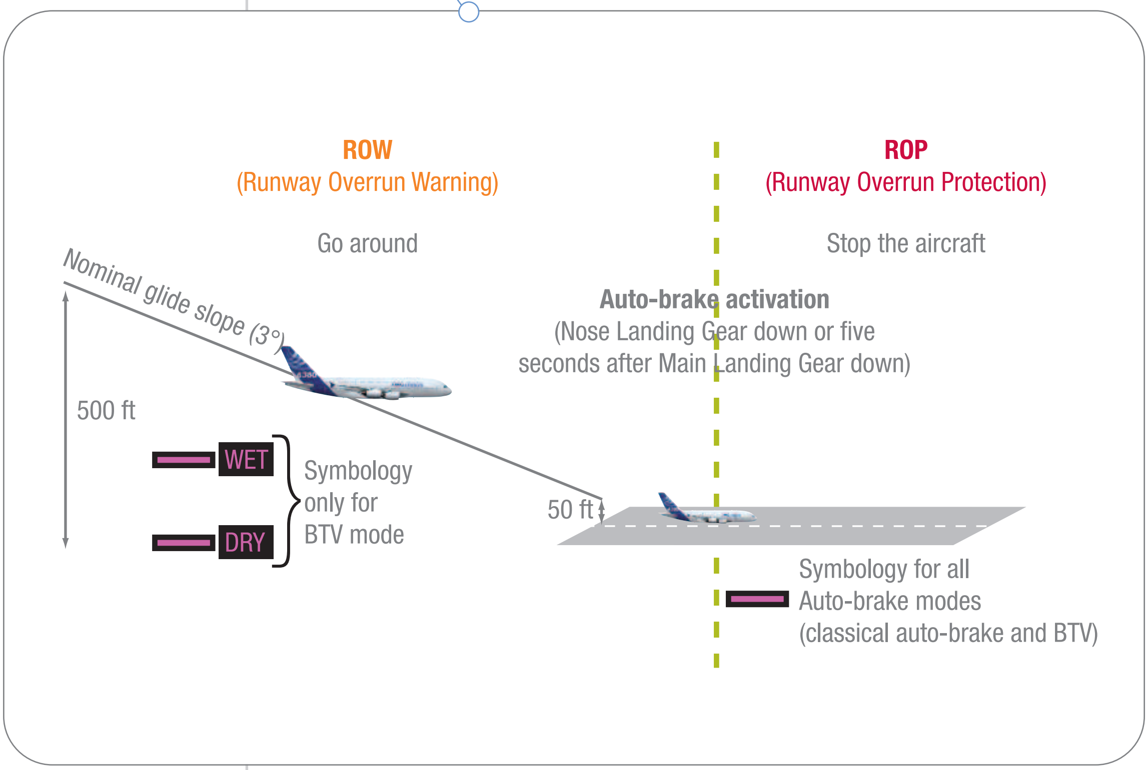
The results of this sequencing task is the location of all aircraft in final approach in order to optimize the arrival flow with respect to the runway occupancy time, but also allowable minimal separations (radar and wake vortex). Also, it results in managing forecasted separation in time on a given future position on the approach trajectory (runway threshold),

- Once the aircraft is established in final segment, the 'tower' controller monitors approaches so that the forecasted timing is respected (in the future, the aircraft itself will be able to manage these constraints),
- The 'tower' controller gives the landing clearance with respect to its own conviction that the runway will be vacated on time.

The operational management of mixed traffic (BTV-fitted and non-BTV-fitted aircraft) is obviously much more complex. Nevertheless, it remains consistent. In this case, conservative forecasted runway occupancy time would overestimate known mean values with a sufficient margin to take into account uncertainties (like it is practised today). For non-specialized runways (used simultaneously for takeoff and landing), the arrival timing has to be also optimized; a takeoff can immediately follow the vacation of the previous just-landed aircraft and then take benefit of the time saved.

In addition to the operational and safety gains foreseen above, the immediate consequence is the minimization of strong constraints, which allow the improvement of admissible cadences. The induced ATM operational gain is based on the increase of runway technical capacity. This gain is particularly remarkable in case of low visibility conditions because standard separation can be reached thanks to BTV system (within the limits of sensitive radio electric protection zone constraints). The runway occupancy time can be then the same as in case of good visibility operations because low speed evolution on the runway is reduced

BTV system



to its minimum. Moreover, as the runway occupancy time of the previous aircraft is known and respected, a certain number of go-around manoeuvres (due to non-cleared runway) will be avoided.

The reduction of the time spent on the runway can be translated by an operation time gain for the airline. It could be negligible for an isolated aircraft but important for a fleet. The most visible gains will be obtained on the delays reduction occurring during airport saturation periods. Operation gains can then be magnified by a network effect when considering sets of platforms that are interconnected with local BTV induced gains. They will be also sensitive to 'a hub effect' due to an important part of fitted aircraft.

Eventually, the airport manager will benefit from a declared improved operational capacity without doing expensive investments (additional and/or exit runway building, etc.).

CONTACT DETAILS

Fabrice VILLAUMÉ
Multi-Programme Project Leader
Airbus Systems Engineering
Tel: +33 (0)5 61 18 63 50
Fax: +33 (0)5 61 18 25 38
fabrice.villaume@airbus.com

Conclusion

Brake-To-Vacate (BTV) is an Airbus development effort for improving the pilot's management of the approach and landing phases. The well known GPS and the new on-board airport map database has permitted this innovation. Tangible value will be brought to our customers by:

- Reducing brake wear and temperature,
- Using less and even removing brake fans,
- Relieving maximum thrust reversers' usage on dry runways,
- Reducing noise level on ground, fuel consumption and gas emission,
- Controlling Turn Around Time before landing (guarantee for the next departure slot),
- Improving passengers' comfort during landing roll,
- Avoiding missed exit situations,
- And, minimizing runway occupancy time.

BTV system is coupled to a Runway Overrun Prevention system, also called ROW/ROP. This Airbus patented solution offers a comprehensive and efficient answer to the runway excursion risk at landing.
It can then be seen as a major safety enhancement feature. Through the minimization of the runway occupancy time, BTV helps also to reduce significantly the exposure time to a runway incursion risk.