



# eTaxi Taxiing aircraft with engines stopped

The idea to taxi aircraft without the main engine thrust is not recent. When Aerospatiale's (one of Airbus' founder partners) design office provided its conclusions on a study for "motorised wheels for autonomous taxiing for a 76 tonnes subsonic aircraft" back in 1977 (figure 1), the technology and oil prices were not at today's high level, making this idea a "must" to offer. As part of Airbus' commitment to continuously improve

its products and develop environmental-friendly solutions, Airbus' Research and Technology programme has revisited this case with various solutions in the recent years. Today's improved technologies considering more electrical equipment power over the equipment mass ratio, higher reliability figures and fuel prices together with a longer taxi time, are making an onboard solution for autonomous taxiing more and more attractive.



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## eTaxi for which aircraft?

Aircraft taxiing is today performed through the use of engine thrust. On twin-engine aircraft, one or the two engines are used while taxiing, depending on the operator's policy and operational conditions.

The eTaxi system offers:

- Taxi-out and taxi-in with all engines stopped capability,
- A total aircraft autonomy allowing the aircraft to "pushback" without any tractor.

The eTaxi system is an onboard solution. This means that there is some significant hardware to be installed on the aircraft, consequently some weight to be added.

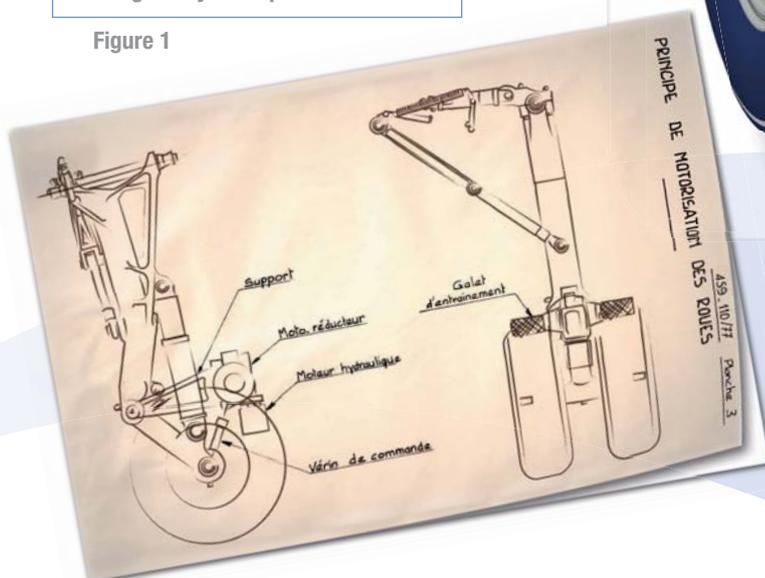
This explains why such a technology is only considered for short and medium range aircraft, and not for long haul flights in which the aircraft would burn the fuel saved on ground, in flight.

So it is intended to propose eTaxi as an option available for the A320 Family fleet, only.

Airbus is working with the objective to propose both forward fit and retrofit.

Motorized wheels' principle designed by Aerospatiale in 1977

Figure 1



## eTaxi system and TaxiBot

While eTaxi is an on-board solution, TaxiBot is a product that enables aircraft taxiing with engines stopped and APU running, using a diesel-electric tractor controlled by the aircraft's pilot through his regular controls (tiller and brake pedals).

When taxi-out is completed, TaxiBot is disconnected from the aircraft Nose Landing Gear by the TaxiBot driver, who then drives back the vehicle to the apron. Unlike eTaxi which is specific to A320, this concept of tow-bar-less towing aims at the capability to tow all types of aircraft with more than

100 seats (both Airbus and non-Airbus types).

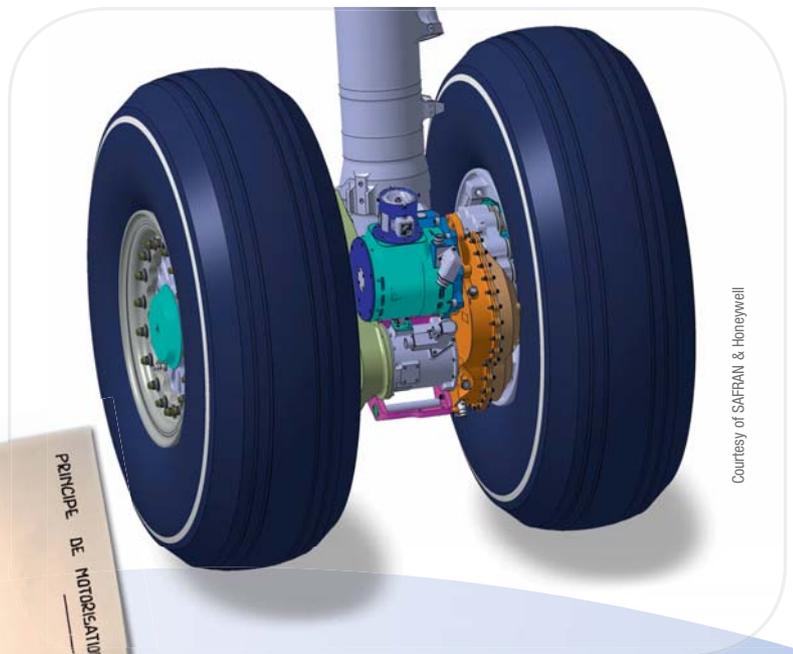
It will target a deployment on the major airports where such concept makes sense.

There will be two TaxiBot variants: One for single-aisle aircraft (Narrow-Body TaxiBot) and the other for twin-aisle types (Wide-Body TaxiBot).

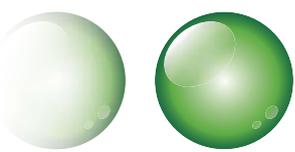
The first prototype is currently in test phase at Châteauroux (France), with an operational test under real conditions to be conducted at Frankfurt am Main Airport (Germany) in spring 2013.

eTaxi electric motor and transmission installation on Main Landing Gear

Figure 2



Courtesy of SAFRAN & Honeywell



### On-going testing

**Airbus testing:**

Airbus is using the APTV (Accelerated Pavement Testing Vehicle) so-called the “Turtle” (figures 3 & 4), in an A320 configuration, to measure key sizing parameters. Amongst them, the simulation of the “breakaway” forces needed to move the aircraft with almost “square tyres”, to test the phenomenon after a long stop. This “Turtle” vehicle has been used for the HTPT (High Tyre Pressure Testing - read FAST 48 magazine) but the Main Landing Gear beams have been displaced and the weight adjusted to correspond to

the Landing Gear configuration, to MTOW, and centre of gravity of an A320. The “MOSART” (Modular Simulator for Airbus Research Tests) simulator is used by flight test pilots to evaluate the most appropriate eTaxi control device. More than five different manoeuvrability concepts (HMI – Human Machine Interface) have already been tested.

**Partners’ testing:**

Major partners have already pre-evaluated some concepts. They are now assembling prototypes for full scale testing.

## eTaxi system performances and architecture

Whereas eTaxi system performances and characteristics are still under construction and refinement, some key design objectives are emerging.

### TAXI-OUT AND TAXI-IN OPERATIONS

Studies have been conducted to propose the best operational compromise between the eTaxi performance (speed, acceleration, aircraft weight, external conditions, etc.) and the sizing (hence additional hardware weight onboard).

Airbus is aiming to achieve a performance requirement for taxi speed of 20kts (knots).

This speed is fully compatible with airport ground traffic and does not impact taxi time, whether the aircraft will be equipped, or not, with the eTaxi system. This has been confirmed after having conducted ground traffic simulations in several major airports.

The Turtle

Figure 3



An acceleration capability of 0 to 20kts in 90 seconds is considered as fully sufficient from an operational view point, as well.

#### REARWARD (“PUSHBACK”) OPERATION:

The rearward operation is a key feature offered by the eTaxi system. The pilot controls the backup of the aircraft from the cockpit thanks to an onboard device, at a maximum speed of 3kts.

#### ETAXI SYSTEM ARCHITECTURE

The eTaxi system includes electrical motors and their associated power electronics, electrical power protections, wires, cockpit control devices and control laws.

Large air cooled electric motors are integrated in between the Main Landing Gear wheels.

These electric motors are sized to provide the required torque to move the aircraft (breakaway force due to “square tyre effect” as simulated in figure 4) and to insure the required acceleration and taxi cruise speed in most conditions (taxiway slope, adverse wind, etc.).

The choice of the Main Landing Gear versus the Nose Landing Gear is to allow the eTaxi operations in all usual operational cases (i.e.: On wet taxiways, at MTOW (Maximum Take-Off Weight) and at the rear centre of gravity location). A Nose Landing Gear solution would provide a limited traction capability due to a weaker vertical load on this gear.

The power electronics which supplies and controls the electric motors is air cooled and installed close to the Main Landing Gear bay, requiring no cargo space.

The eTaxi system is fully controlled from the cockpit. Additional control means, indications and warnings are added for the pilot’s control and awareness, during the eTaxi phase.

The eTaxi control laws shall be integrated in the aircraft avionics. Various solutions are investigated (e.g.: Dedicated control unit or eTaxi control software can be hosted into the existing computer, such as the Braking and Steering Control Unit - BSCU).



#### definition

**Power electronics** is the application of solid-state electronics for the control and conversion of electrical power in order to drive the electric motor at a variable rotational speed. Hence, power electronics converts electrical power (at frequency and voltage levels) from aircraft electrical network to the electric motors.

Test installation for torque measurement on the Turtle

Figure 4



## Where does the electric power come from?

The technical and commercial electrical needs are still ensured and the bleed power is still available for the Environmental Control System (ECS). Several operational options and design solutions can be considered:

### Base eTaxi solution

Keeping today's APU, both engines stopped but accepting reduced performance. Using the existing APU (Auxiliary Power Unit) with its actual generator of 90kVA (kilo Volt Ampere) is the favourite and simplest solution to go for a minimum change.

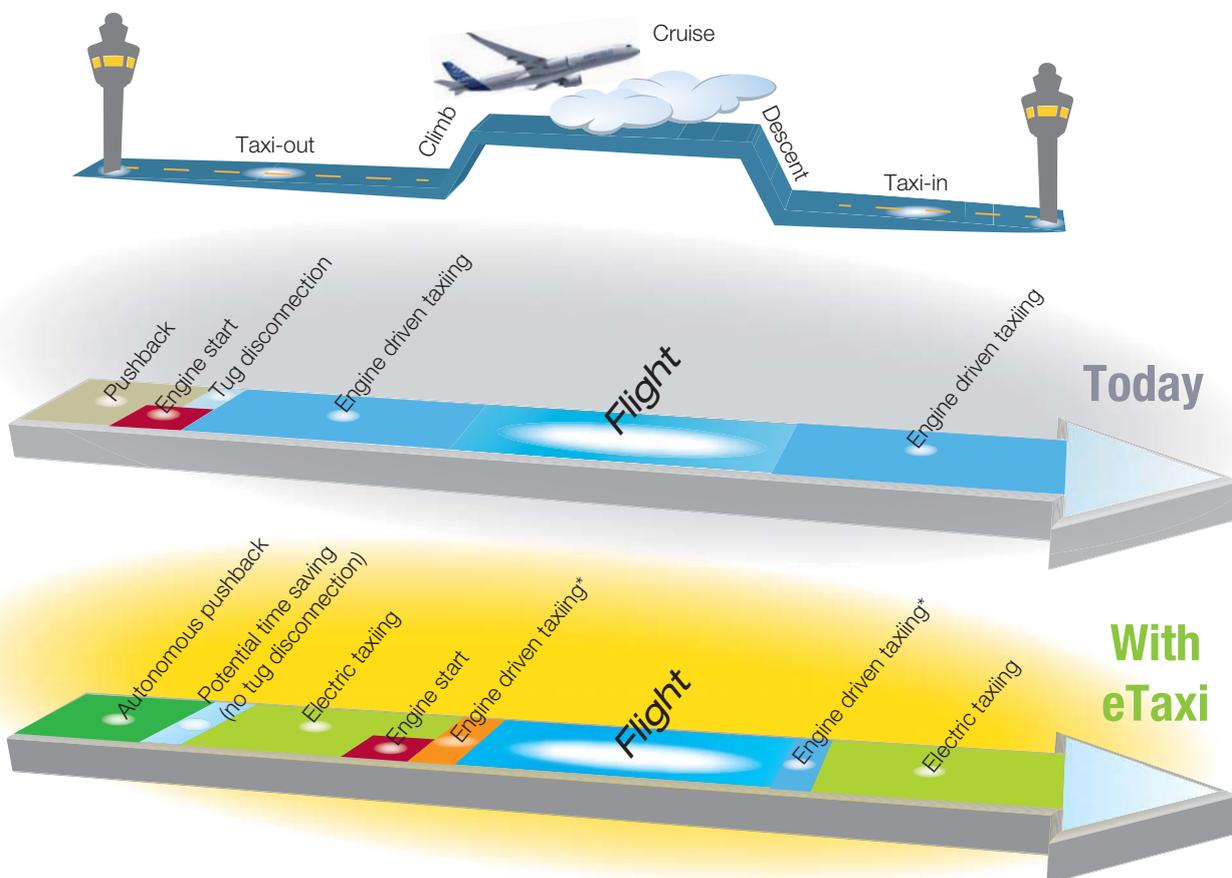
However, the taxi performance with both engines stopped cannot be the nominal one in all conditions. While acceptable on many airports, it may not be sufficient at large airports with long taxiways as there is not enough electric power to supply both, the normal electrical loads and the eTaxi system for a full performance. As an example, an A320 at MTOW (Maximum Take-Off Weight) of 78 tonnes would only reach a maximum speed of 12kts. The performance is, of course, better for a lighter aircraft of 69 tonnes at 13.5kts.

### Hybrid eTaxi solution

Keeping today's APU, one engine at idle benefitting from a full performance. By still keeping the existing APU and APU generator ON, one engine can be kept at idle during the eTaxi operation.

Usual flight operations versus eTaxi

Figure 5



(\*) Engine warm-up and cool-down phases

This solution offers all the required electric power for a full performance (20kts on A320 at MTOW) as the engine IDG (Integrated Drive Generator) and APU generator are used together to supply the aircraft normal loads and eTaxi system. Nevertheless, there is still a significant fuel saving with this solution (even compared to usual single engine taxiing) due to the engine thrust of the aircraft not being used to accelerate - the acceleration being taken in charge by the eTaxi system. Obviously, there is still the full benefit of the “autonomous pushback” done with both engines stopped and with the APU only.

**Full eTaxi solution**

Modified APU with a new APU generator. The only way to get a full eTaxi performance with all engines stopped in every conditions (notably taking in consideration the aircraft weight) is to increase the APU generator

sizing and in consequence, to adapt the APU. Trade-off studies are still on-going by Airbus for an APU modification, aiming to increase, or not, its available electric power.

**eTaxi operation**

**NO TUG TO WAIT FOR PUSHBACK**

By switching the eTaxi push-button ON with the APU running, the pilot activates eTaxi and configures various other systems.

The Yellow hydraulic circuit (figure 6) Electrical Motor Pump (EMP) which is electrically supplied by the APU generator, provides the required hydraulic power for the nose wheel steering and for alternate braking (the Power Transfer Unit is turned off).

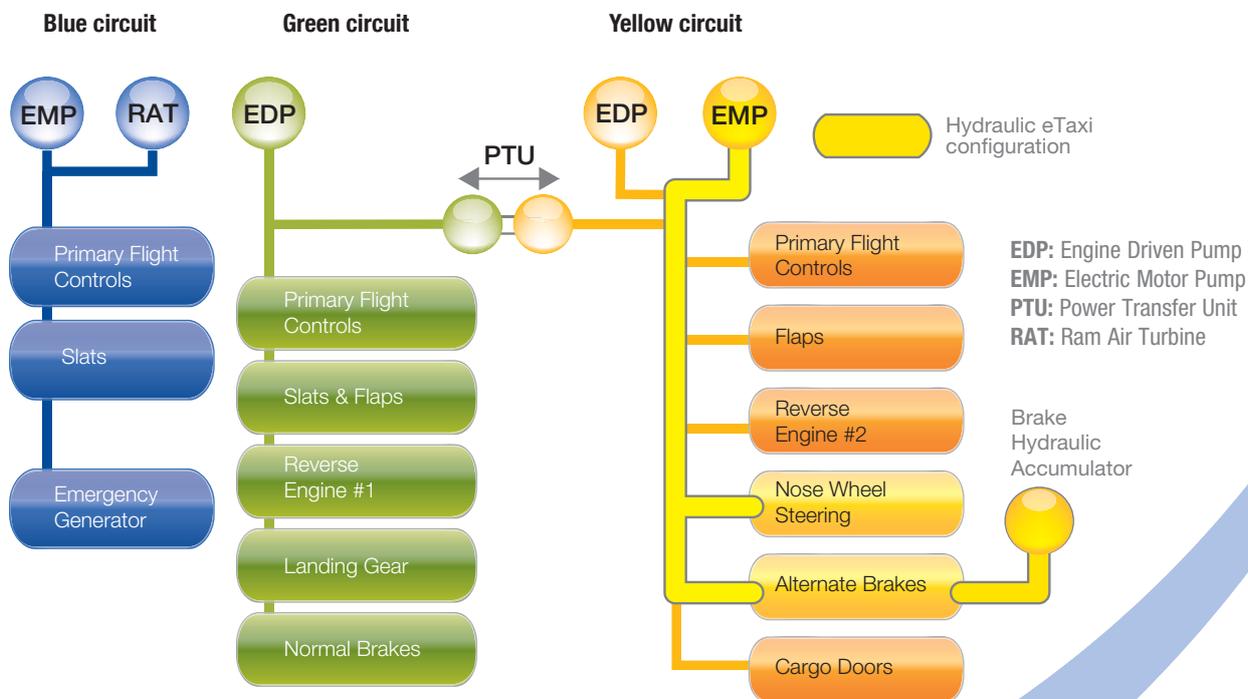
Then, the pilot is ready to backup the aircraft guided by one or two marshallers.

**d** definition

**Aircraft marshalling** is the signaling and communication between the ground handling personnel and pilots. The usual equipment of a marshaller is a reflecting safety vest, a helmet with acoustic earmuffs, gloves or marshalling wands and handheld illuminated beacons.

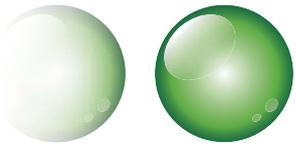
**Three independent hydraulic circuits on the A320 Family**

Figure 6



These three circuits supply several systems such as flight controls, high-lift, landing gear extension/retraction, braking, etc. The Green circuit supplies the normal braking system while the Yellow circuit supplies the alternate braking and nose wheel steering. Yellow alternate braking is backed-up by the brake hydraulic accumulator, in case of Yellow hydraulic system failure.

Note: The nose wheel steering has been powered by the Yellow hydraulic circuit system since the MSN 1939.



### Average taxi time from Airbus study

A320 Family in-service statistics  
12 months fleet average  
(April 2012)

- Average flight duration: 1.8 Flight Hours (FH)
- Average daily utilisation: 8.9 FH/day
- Average taxi time: 20 minutes (0.3 FH/flight)

In average, an A320 spends more than 15% of its time taxiing.

### TAXI-OUT

When the backup operation is completed, the pilot may immediately proceed to the eTaxi forward phase without waiting for the tractor's disconnection.

The pilot uses the eTaxi control device from the cockpit to accelerate and the usual brake pedals to slow down or stop the aircraft. It also allows switching off the electric motor power supply to gently decelerate the aircraft without using any brakes at all.

As the engines must be started 4 to 5 minutes prior to take-off for warm-up, the eTaxi system is designed to allow the engine start-up while eTaxiing the aircraft. The eTaxi system automatically disengages when both engines are ON or above 20kts.

Remark: In case of Hybrid eTaxi (i.e. With one engine at idle), the aircraft operation will be very similar to the existing single engine taxi operations.

The main difference is that acceleration control is done only by using the eTaxi control device in one case, and by using the engine thrust control lever in the other case.

### TAXI-IN

The engines are switched-off after landing, the pilot exits the runway, the APU is started and the eTaxi mode is switched ON. There is no need to stop the aircraft to engage the eTaxi mode.

Depending on whether the high thrust has been applied or not during the reverse thrust, it may be required to wait approximately three minutes to let the engines cool down before switching them off.

Finally, the aircraft is electrically driven up to the gate, with no need for tug, which may be mandatory when local restrictions prohibit the engine use close to the apron.

### eTaxi reduces fuel burn

Taxiing and queuing penalize the optimisation of an aircraft's performance. A short and medium range aircraft may spend from 10 to 30% of its time on taxiways (statistics based on 35 major European airports, absorbing 50% of European departures). Consequently, aircraft of these ranges burn up to 10% of their fuel on ground.

Fuel burn reduction on ground depends on several parameters such as:

- Reference scenario (today's operation): One or two engines taxi-out/taxi-in,
- Taxi-out and taxi-in duration,
- Taxiing: Number of stops and starts.



Estimated fuel savings with eTaxi

Figure 7

Block fuel = Trip fuel + Taxi fuel

**Trip fuel**

The eTaxi system adds some weight; however the impact on block fuel is limited.  
On a 500 NM flight, +400kg\* represents an additional 16kg fuel burn.

\* Weight non-contractual

**Taxi fuel**

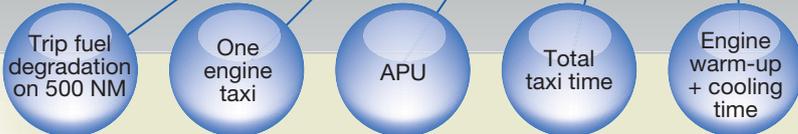
Configuration	Fuel Burn Rate
<b>Today</b>	
2 engines taxi	12.5 kg/min
Single engine taxi + APU	9.5 kg/min
<b>eTaxi</b>	
Hybrid eTaxi (one engine at idle + APU)	7 kg/min
Full eTaxi (APU only)	2 kg/min

**Block fuel**

**Block fuel saving**

Case of Full eTaxi versus single engine taxi

Fuel saving = 16 kg - ( 9.5 kg/min - 2 kg/min ) x ( 20 min - ( 5 min + 3 min ) ) = **- 74 kg**



Remark: Tractor disconnection saving time not included.

Full eTaxi	versus	two engines taxi	-110 kg
Full eTaxi	versus	single engine taxi	<b>-74 kg</b>
Hybrid eTaxi	versus	two engines taxi	-50 kg
Hybrid eTaxi	versus	single engine taxi	-14 kg

Block fuel saving

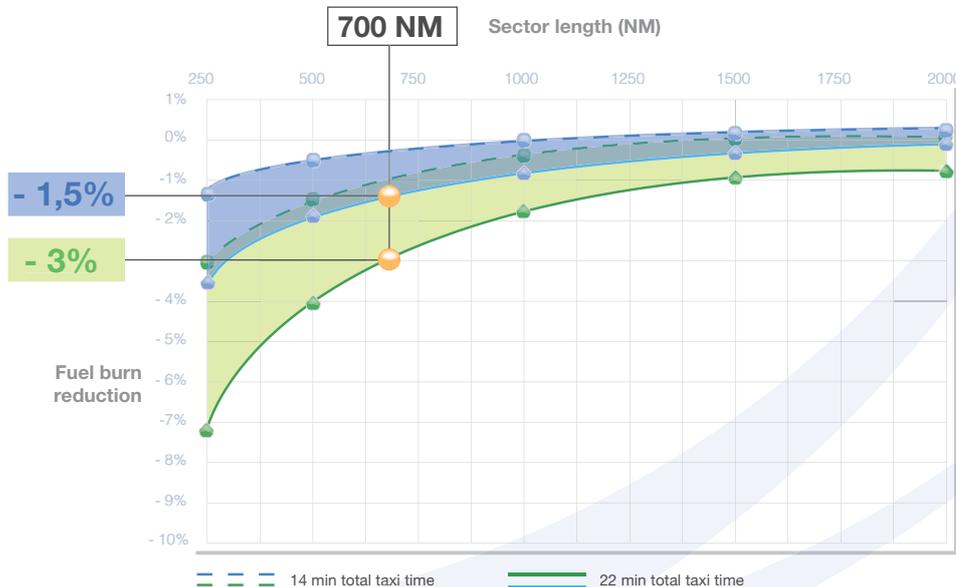
Example of A320 with CFM56-5B4/3 (similar results with IAE):

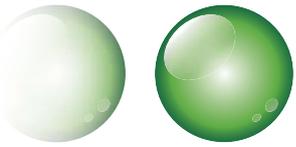
- 500 NM (Nautical Mile) flight
- 20 minutes for taxi-out plus taxi-in
- 5 minutes considered for engine warm-up and 3 minutes for engine cooling

Hybrid eTaxi offers about 1.5% fuel burn reduction\* for typical A320 sector and taxi time

Full eTaxi offers about 3% fuel burn reduction\* for typical A320 sector and taxi time

\* versus 2 engines taxi





## Expected eTaxi benefits

By allowing the taxi with the main engines stopped, the eTaxi solution brings a direct fuel burn reduction and:

- A major reduction in ground emissions (CO<sub>x</sub> and NO<sub>x</sub>),
- Noise reduction on ramp with obvious benefits for ground staff,
- More autonomy versus airport infrastructures (no waiting for tug, no tug to pay for),
- Overall flight time savings by eliminating time disconnecting the tug after pushback,
- Less use of wheel brakes during taxi as there is no engine residual thrust, leading to potential brake wear reduction,
- Less risk of engine ingestion of damaging debris (Foreign Object Damage - FOD) and no engine jet blast blowing close to the gate,
- Improved safety for ground staff,
- High precision manoeuvring (no engine spool-up lag and inertia).

Evidently, the use of eTaxi does not impair aircraft operation capabilities and passenger comfort.



### CONTACT DETAILS

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## Conclusion

The eTaxi (electric taxiing) system is a very promising system that provides aircraft autonomy, reducing the use of engines during the taxi operations. It leads to substantial fuel savings while reducing emissions.

Airbus is actually investigating, in close collaboration with several industrial partners, different architectures and technologies for the best possible integration at aircraft level. A fully mature solution which preserves the recognized A320 Family Operational Reliability (OR) is targeted. Airbus is using all its available development, tests and certification resources to converge toward the most optimized solution.

eTaxi must be easy to install, remove, operate, and also easy to maintain.

In the long term, another generation of eTaxi will likely emerge with the next generation of short-medium range aircraft. As an example, we already know that eTaxi may offer many additional functionalities and benefits, when fully integrated in the aircraft design from the beginning. This is especially true when we consider the more electrical aircraft architectures which are being studied by Airbus, targeting a more efficient aircraft. The "More Electrical Aircraft", or even in the future the "All Electrical Aircraft" concepts, are aiming to make the electrical power the main or sole source of on-board power for flight controls, high-lift, the Environmental Control System, wing anti-ice, etc. This would allow the hydraulic and bleed systems' deletion.