



AEROSPACE INFORMATION REPORT

AIR6246™

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Landing Gear (Engine Off) Taxi System

RATIONALE

This SAE Aerospace Information Report (AIR) will review, summarize, and discuss challenges facing the new powered landing gear taxi technology currently being developed by various companies and identify the regulations affected and safe failure modes. The report will identify if the existing airworthiness regulations adequately cover the new technology.

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Documents

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1. SCOPE

This SAE Aerospace Information Report (AIR) will review new landing gear (engine off) taxi system technologies currently being developed by various companies and describe the basic design concepts and potential benefits and issues. This AIR will identify the associated systems that could be affected by this new technology. The document will review basic design and operational requirements, failure modes and identify system certification requirements that may need to be addressed. The technology is evolving as this paper is being written and the data present is currently up to date as of 2015.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

ARP1915	Aircraft Tow Bar
ARP4852	Design Specification for Towbarless Push-Back Tow Vehicles
ARP4853	Design Specification for Towbarless Tow Vehicles
ARP5283	Nose Gear Towbarless Tow Vehicle Basic Test Requirements
ARP5284	TLTV - Aircraft NLG Steering and Tractive Force Protection Systems or Alerting Devices - Inspection, Maintenance and Calibration Requirements
ARP5285	Towbarless Towing Vehicle Operating Procedure
ARP5911	Regional Aircraft Towbarless Tow Vehicle - Test Requirements
ARP5916	Design Specification for Regional Aircraft Towbarless Tow Vehicle for Pushback and/or Maintenance Towing Operations

TaxiBot presented their taxi system to the SAE A-5 committee during the SAE A-5 symposium held in Seville, Spain on April 12, 2011. The TaxiBot presentation is available on the SAE A-5 website to A-5 members.

WheelTug gave a presentation at the SAE A-5 Toronto Meeting Towbarless Towing Panel on May 2, 2007 describing their system. Their presentation is available on the SAE A-5 website to A-5 members.

2.2 Definitions

ACI - Airports Council International

APU - Auxiliary Power Unit

ATRA - Advanced Technology Research Aircraft

CBT - Computer-Based training

CG - Center of Gravity

DISPATCH (OPERATIONAL) TOWING - Towing a revenue aircraft (loaded with passengers, fuel, and cargo from the terminal gate/remote parking area, to a location near the active runway. The movement may cover several kilometers with speeds up to 20 mph (32 km/h), with several starts, stops and turns. Replaces typical taxiing operations prior to takeoff and may impose additional fatigue loading on nose landing gear and structure due to numerous starts, stops and turns.

EICAS - Engine Indicating and Crew-Alerting System

EGTS - Electric Green Taxi System

FOD - Foreign Object Damage

FRA - Frankfurt am Main International airport

GPS - Ground Positioning System

GNT - Green Taxi

HKG - Hong Kong International airport

IAI - Israel Aerospace Industries

IATA - International Air Transport Association

JFK - John F Kennedy International airport

LAX - Los Angeles International airport

LGTS - Landing Gear Taxi System

LHR - London Heathrow airport

MAINTENANCE TOWING - The movement of an airplane for maintenance/remote parking purposes (e.g., from the gate to a maintenance hangar). Aircraft is typically unloaded with minimal fuel load.

MBD - Messier-Bugatti-Dowty

MEL - Minimum Equipment List

MLG - Main landing gear

NB - Narrow Body

NLG - Nose landing gear

PUSHBACK - Moving a fully loaded aircraft (up to Maximum Ramp Weight (MRW)) from the parking position to the taxiway. Movement includes: pushback with turn, a stop, and short tow forward to align aircraft and nose wheels. Engines may or may not be operating. Airplane movement is similar to a conventional pushback operation with a towbar.

ROI - Return on investment

SAE AGE-2 - SAE Ground Support Equipment Committee

STC - Supplemental Type Certificate is an FAA approved major modification or repair to an existing certified aircraft

TLD - Tisssm  tal Lionel-Dupont maker of the TaxiBot vehicle

TLTV - Towbarless Towing Vehicle

TPIS - Tire Pressure Indication System

TPMS - Tire Pressure Monitor System

WB - Wide Body

ZRH - Zürich airport

2.3 Websites References

The following websites were used to collect some of the information found in this report.

- Safran Electric Green Taxi System: <http://www.safranmbd.com/systems-equipment-178/electric-green-taxiing-system/>
- Honeywell Green Taxi: <http://honeywell.com/News/Pages/Safran-and-Honeywell-Commence-Electric-Green-Taxiing-System-Testing.aspx>
- TaxiBot: <http://www.taxibot-international.com/#>
- WheelTug: <http://www.wheeltug.gi/>
- Gibb Gear on line news article <http://www.e-lib.co.uk/profiles/forms/?id=18>
- Lufthansa E-Taxi: <http://www.lufthansa-technik.com/etaxi>
- L3 Magnet Motor: <http://www.magnet-motor.de/index.php?id=3&l=1&L=1>
- Crane Hydro-aire: <http://newsroom.craneae.com/2012/07/crane-and-l-3-reach-agreement-to-market-greentaxi-electric-taxi-system/>

2.4 SAE Papers

The following SAE papers provide relevant reference material:

Hainline, B., Sellereite, B., and Swanke, K., "Powered Wheels - A Concept for Parking and Taxiing of Commercial Transport Airplanes," SAE Technical Paper 710446, 1971, doi:10.4271/710446.

Waterman, A., "Energy Conservation Via Airplane Powered Wheels," SAE Technical Paper 751177, 1975, doi:10.4271/751177.

Long, M., "Powered Wheels for Aircraft," SAE Technical Paper 760521, 1976, doi:10.4271/760521.

2.5 Related Presentations

The following presentations provide relevant reference material:

- ACI Europe Green Taxiing Workshop, March 9, 2015 (see SAE A-5 website)
 - o 201503 - ACI Europe workshop - FINAL_egts
 - o ACIGreentaxiWS_WheelTug
 - o IATA Aircraft Taxiing Systems Conference Final V08_EASA
 - o TaxiBot - ACI presentation

- IATA Aircraft Taxiing Systems Conference, February 3-4, 2015 Gables, Miami (see SAE A-5 website)
 - o 2015-atssc-program
 - o Alternative Taxi Considerations David_Paisley
 - o Benefits and first impressions of the in-service evaluation Taxibot Peter_Unger
 - o DERIVING BENEFITS FROM ALTERNATIVE AIRCRAFT-TAXI SYSTEMS Cadmus_Day1
 - o EGTS_Day1
 - o EGTS Jens_Berlinson
 - o E-TAXI win-win for airlines and airports Libor_Kurzweil
 - o IATA_Taxi_Systems_Delta
 - o Impediments to Alternative Aircraft Taxi Systems Paul_Sichko Metropolitan Airports Com
 - o Pilot- Controlled Aircraft taxiing System Bernhard_Weiss Taxibot
 - o TaxiBot_Day1
 - o TaxiBot_Panel_3

3. PATENTS

Appendix A contains a list of published patents that closely relate to the LGTS technology.

4. EVOLUTION OF AIRCRAFT TAXI TOWING SYSTEMS

Traditionally aircraft have been towed using a tow vehicle equipped with a tow bar attached to the nose gear. These towbars usually connect to a pin or lug or axles of the nose landing gear. The tow vehicle and towbar can exert excessive forces and torques into the nose gear and airframe. To protect the aircraft, the towbar usually incorporates a shear pin device, which shears when traction/braking or turning torques exceed design limit load levels. The towbars are designed by ARP1915. The document is maintained by SAE AGE-2.

In the 1980's towbarless towing vehicles were introduced first in Europe. As various companies embraced the new technology the use spread to North America in the 1990s. The towbarless vehicle are equipped with a nose wheel/tire capture mechanism that cradles and lifts the nose gear off the ground to enable towing of the aircraft. The motivation came from limiting personnel involved in towbar activities and towbar connection injuries, and eliminating multiple types of tow bars. It also introduced the possibility of performing dispatch towing to the runway at high speed with the airplane engines off. However this has not become a standard practice due to logistical issues. The towbarless towing vehicles were designed to allow towing various different aircraft using one vehicle. Typically wheel restraining devices capture the specific nose gear tire/wheel assemblies and determine the correct traction/braking/torque fuse settings to safely tow the aircraft.

SAE AGE-2 developed various ARPs to be able to provide some guidance to the industry on key design features and critical testing of the vehicles safety systems to prevent damage to the landing gear or aircraft. The issued ARPs include ARP4852, ARP4853, ARP5283, ARP5284, ARP5285, ARP5911, and ARP5916.

In the early 2000s various companies started working on the next evolution of taxi systems. These can be classified as:

- Pilot controlled towbarless towing vehicles
- Landing gear taxi system (LGTS)
 - o Nose gear wheel mounted
 - o Main gear wheel mounted

This document will review the basic three systems but will focus on the landing gear mounted taxi systems.

With the movement to more electric aircraft various companies started to look at landing gear mounted taxi towing systems as a means to move an aircraft using onboard traction motors that drive the nose or main landing gear wheels directly from aircraft onboard power from the APU rather than the thrust from the main engines. The typical scenario would be to use the LGTS for all pushback and taxi towing operations in lieu of the aircraft's main engines. The aircraft engines would be started just before take-off and would be shut down shortly after the aircraft departs the runway after landing, subject to main engine(s) warm up/cool down times, which are typically 3-4 minutes each (with the exception of the first daily flight and extreme cold temperatures which require longer warm-up times).

5. LANDING GEAR TAXI SYSTEMS ADVANTAGES/BUSINESS MODEL

The focus tends to be consideration of equipping short haul aircraft with the LGTS. Short-haul aircraft typically perform up to 10 flights a day and so spend a considerable proportion of their service lives taxiing on the ground compared with long-haul aircraft. It is estimated that a single aisle aircraft spends 2.3 hours a day taxiing around during 8 to 10 flights a day in a typical airport. In addition, short haul aircraft have shorter route lengths than long haul aircraft, so the fuel penalty of flying additional weight due to an LGTS can be more easily offset by the on-ground advantages.

This new LGTS technology may bring a number of benefits, including:

- A potential saving in fuel consumption. As an example, the Airbus A320 uses two CFM56-type engines which consume 26.45 pounds (12 kg) of fuel per minute at taxiing speed, while the APU consumes only 4.4 pounds (2 kg) per minute. The technology promoters are marketing operational cost savings for the airlines.
- A reduction in CO, CO₂, HC, SO₂, and NO_x emissions due to the main engines being off for most of the taxi operations.
- A reduction in noise and jet blast would make a safer work environment for ground handling personnel. Less noise with the main engines switched off for most of the taxiing operations with only the APU running to provide electric power to the wheel motors.
- A reduction in engine hours per flight.
- A reduction in engine maintenance by limiting foreign object damage.
- An increase in engine flight life due to less use on taxiing portion of the flight.
- An improvement in on-time operations with pushback and go.
- A reduction in tow bar and towbarless vehicles and man power.
- A reduction of ground support personnel with the use of external cameras to aid in pilot controlled moving of the airplane.
- A promised reduction in brake wear due to a reduction of engine idle thrust taxi braking. It has not been determined if the net brake wear is greater using cold brakes versus warm brakes due to engine idle thrust.

- Much more cool-down time after landing event, allowing for faster turnaround. (Sometimes aircraft cannot turn around fast enough because brakes are ridden during taxi, keeping them too hot for takeoff.)
- Between tug damage, tow bar damage, the cost of shear pin replacements (time and money and resources), there is also extensive landing gear damage from use and misuse of tugs, including impact shock forces in normal tug operation, either during hookup or initial pushback procedures.
- Possibility of partial regeneration brake energy recovery.
- Aircraft can move away from the gate when ready which will allow other waiting aircraft to enter. This could increase throughput of gate movement.
- The extra fuel used to carry the onboard LGTS would offset these savings, and would have to be considered in the business model.

5.1 Airplane Taxiing Time

Aircraft taxi time directly relates to fuel burn and cost to the airline.

- Taxi-out time is a function of numerous parameters
- Average taxi-out time today is in the range of 30 minutes
- A specific Taxi-out time could reach more than 42 minutes
- Taxi-out time can reach up to 3 hours during traffic jams

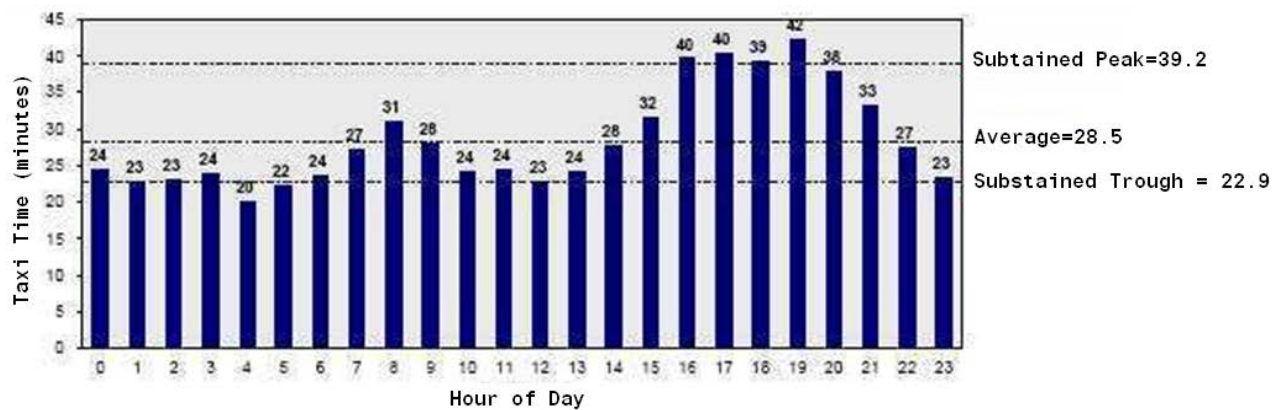


Figure 1 - Taxi-out times (minutes) by hour at New York Kennedy (June 24, 2007)
(Source: TaxiBot SAE Presentation)

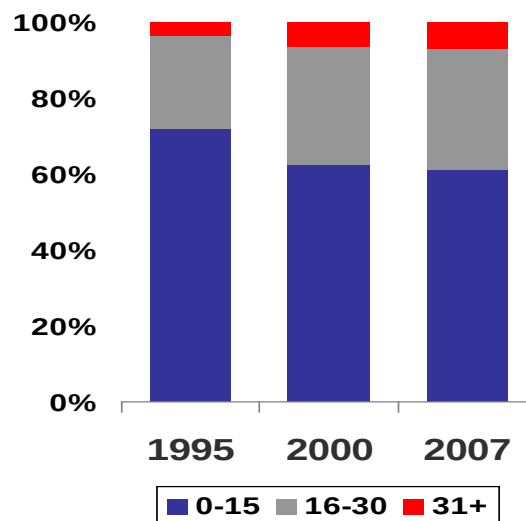


Figure 2 - Taxi-out times (minutes) as % of flights in U.S.
(Source: TaxiBot SAE Presentation)

5.2 Pollution

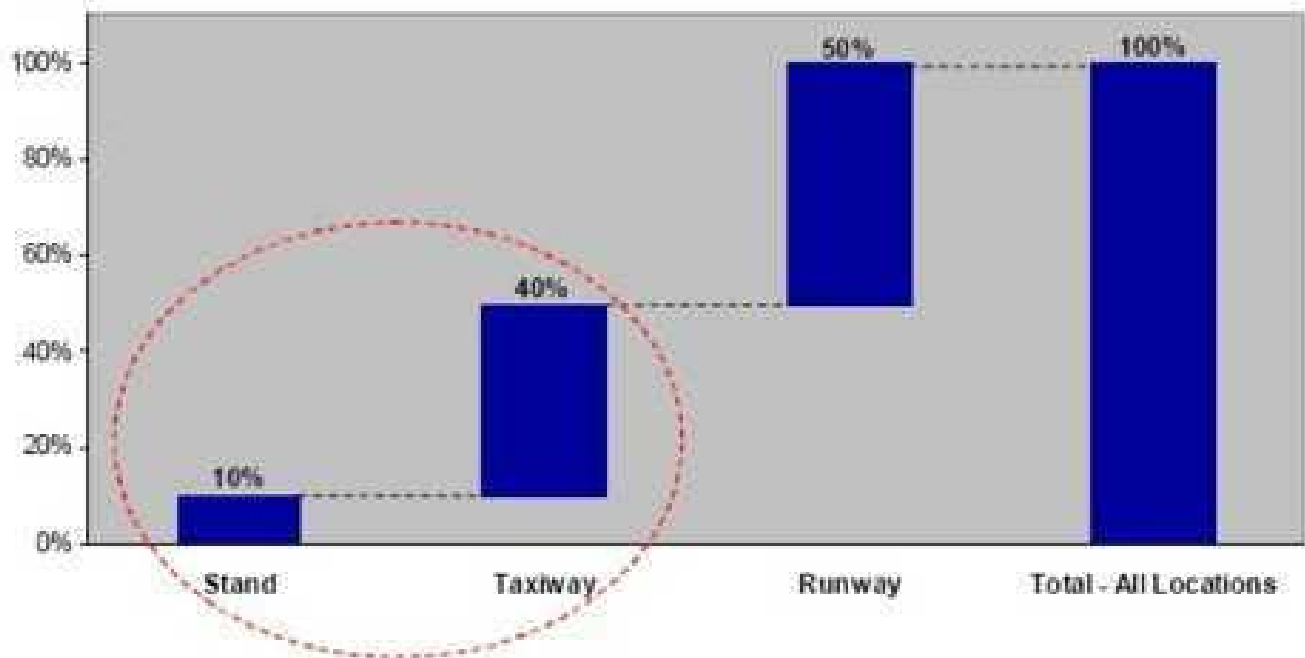
Pollution is a financial as well as an environmental concern. Some of the main points made by TaxiBot (similar to WheelTug and EGTS claims) are:

- The average passenger jet taxiing with engines on consumes on average 227 gallons (860 L)
- Airplane taxiing by tractor consumes 1 gallon (3.8 L) per kilometer
- Average taxiing route in airports is about 3.1 miles (5 km)
- CO₂ emission in the U.S. and Europe in 2011 is estimated at 50 million tons (45.4 metric tons) per year
- Airport noise pollution is also a major factor
- In 2011 Europe introduced a tax for CO₂ emission for domestic airlines
- European Commission is moving forward on applying a CO₂ emission tax to all international flights in the future
- Airplane emission tax rate is \$35 per ton of CO₂ emission in 2007 and is expected to rise in the future.

5.3 Foreign Object Damage (FOD) During Taxi

Taxiing without the main engines running will reduce FOD cost by 50%, since 50% of FOD events are during ramp and taxi operations.

Location of FOD Causing Damage to Aircraft



Source Data: "The economic cost of FOD to airlines," Iain McCreary, Insight SRI, March 2008; UK Civil Aviation Authority Study, Delta Airlines.

Figure 3 - Location of FOD causing damage to aircraft
(Source: TaxiBot SAE Presentation)

5.4 Operational Towing

Operational towing, also referred to as dispatch towing, is towing a revenue aircraft (loaded with passengers, fuel, and cargo up to takeoff weight, from the terminal gate/remote parking area, to a location near the active runway. The movement may cover several kilometers with speeds up to 20 mph (32 km/h), with several starts, stops and turns. It replaces typical taxiing operations prior to takeoff and may impose additional fatigue loads on nose landing gear and supporting structure due to numerous starts, stops and turns.

One of the potential challenges with operational towing with a traditional towing vehicle (with tow bar or towbarless) is that all the loads go through the nose landing gear. As the weight and speed go up, the aircraft momentum has to be reacted by the nose landing gear and tow vehicle. This may impose extra fatigue loads on the nose gear and airframe, which is not desirable.

5.5 Taxi Speeds and Accelerations

It was reported that Israel Aerospace Industries Ltd. (IAI) asked four experienced airliner pilots to record and evaluate 120 taxiing events of commercial flights in 18 different international airports (such as: FRA, JFK, ZRH, HKG, LHR, LAX, etc.) with special measurement and recording equipment.

The IAI cumulative results of all the 120 taxiing events speed and acceleration and pilot comments are shown below:

- Taxiing speed exceeded 20 knots (37 km/h) only in 3% of the taxiing time in all taxiing events
- Taxi speed reached 25 knots (46 km/h) only once.
- Typical and comfortable acceleration rate is not more than 0.02 G
- The maximum acceleration required is 0.03 G for acceleration and 0.06 G for deceleration.

6. DESIGN CONSIDERATIONS

6.1 Design Criteria Objectives

The accumulative results of all the taxi events resulted in some basic requirements and design objectives being generated for the new TaxiBot system:

- Pilot controls operation of landing gear (engine off) taxi system with communication from aircraft ground spotters and/or onboard cameras mounted on the aircraft.
- Push back of aircraft from gate.
- Towing to and from takeoff position with and without passengers aircraft configurations.
- Speeds up to 20 knots (23 mph/37 km/h) forward and 10 knots (11.5 mph/18.5 km/h) reverse.
- Towing on various surfaces and typical slopes and obstacles.
- Accelerate to max speed in 90 seconds
- Accelerate to safely and efficiently cross active runways 0 to 10 knots (0 to 18.5 kph) in 20 seconds.
- Traction forces need to be limited to detect brakes on and/or wheel chocks in place. A safety device needs to be in place to limit the loads introduced into the landing gear and aircraft.
- Maintain strength and fatigue criteria set for landing gear and aircraft interfaces for the LGTS.
- Operate safely over all environmental conditions.
- Failure modes of LGTS should revert to a free spinning wheel.
- Failure mode should not impose strength and/or fatigue loads greater than specified.
- Traditional tow bar and towbarless operations need to be considered if LGTS is not available.
- Less noise at gate.

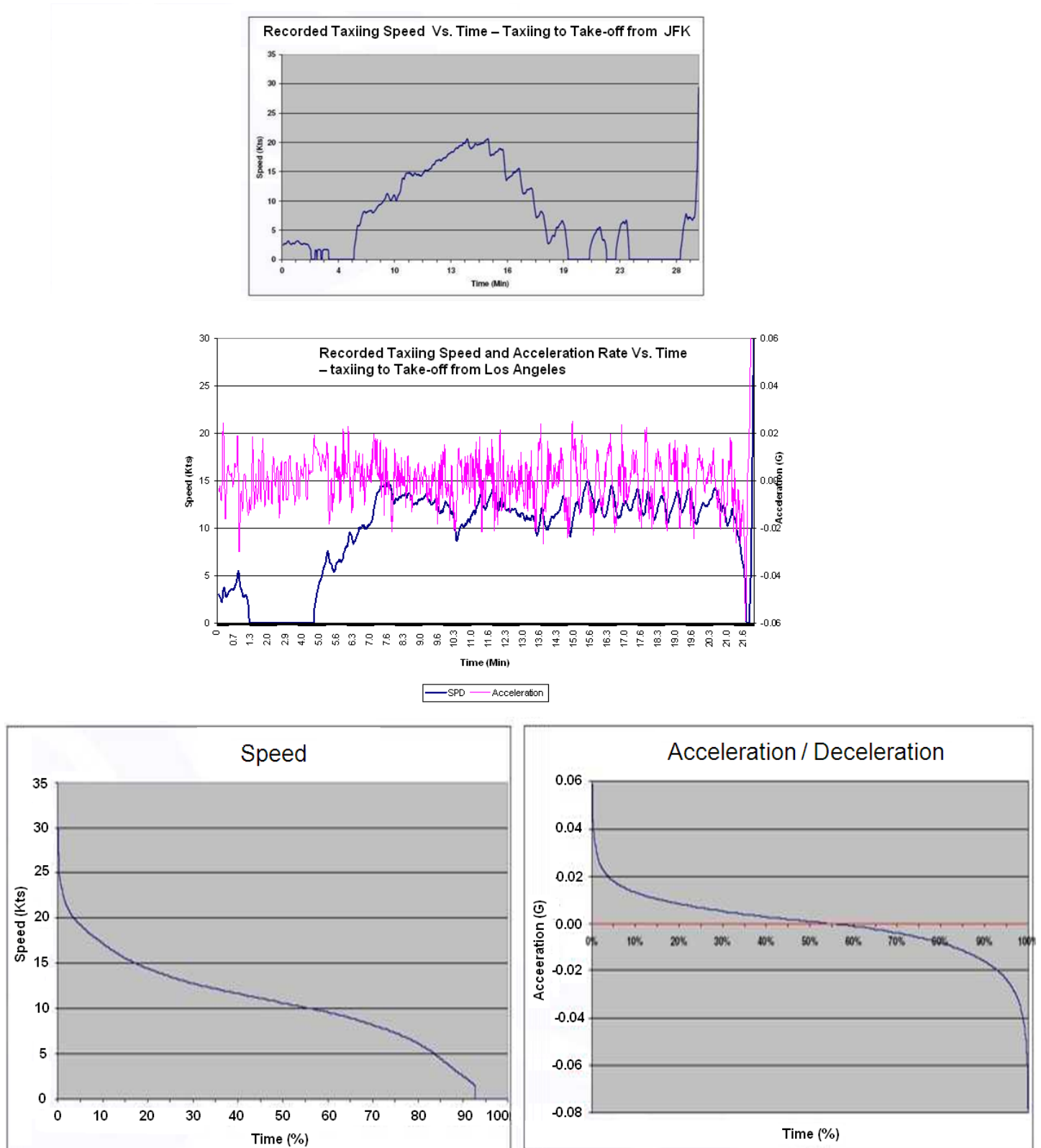


**Figure 4 - Accumulative results of all the 120 taxiing events speed and acceleration
(Source: SAE TaxiBot Presentation)**

- No additional noise during landing
- De-activate system during takeoff roll.
- LGTS needs to be totally compatible with the brake control system and should not interfere with the brake control system's ability to achieve acceptable stopping performance

The testing resulted in IAI and the airframe partner choosing the following design guidelines:

Parameter	Details	Upper Limit	Remarks
• Maximum Taxi Speed	• Straight Taxi	• 20 knots (37 km/h)	•
	• Turn	• 10 knots (18.5 km/h)	•
• Acceleration	• Acceleration	• 0.02 g	•
	• Deceleration	• -0.04 g	• -0.03 may also be marginally acceptable
• Turn Rate	• At least 30 degree change of heading	• 10 deg/s	•

Figure 5 - IAI TaxiBot required taxiing performance

The design objectives appear to be applicable to a MLG and NLG mounted LGTS also.

The SAE A-5 panel discussions generated a list of suggested additional requirements a design may want to consider:

- Some panel members expressed the concern that 10 knots (18.5 kph) in reverse seems quite high, a typical value of about 2 knots (3.7 kph) seems more reasonable to control the aircraft speed in reverse motion, without the use of brakes and taking the risk of a tail down event.
- It was also thought that the LGTS should have a requirement that controls the speed and deceleration in reverse mode to allow smooth decelerations and avoid aircraft tail down events.

6.2 Taxiway Friction and Rolling Resistance

The first obvious difference between the nose wheel and main wheel LGTS concepts is the potential traction force available with the two systems.

- On a typical aircraft the main gears usually support 85 to 95% of the total aircraft weight, leaving about 5 to 15% of the weight over the nose gears. The maximum ground traction force available is generally equal to the weight over a tire/wheel times the friction coefficient. Using the nose gear versus main gear will generally limit the maximum traction ground force available to move the aircraft over obstacles and slippery taxiway conditions.
- For example, if an aircraft weighs W , the typical two nose tires would support on average $0.10 W$. If a coefficient of ground friction of 0.2 is assumed (wet taxiway) between the tires and taxiway then the maximum traction force applied to the aircraft would be $0.02 W$.
- For a two main gear configuration with each main gear having two tires and the four main tires would support on average $0.90 W$. If only two of the four tires are powered to drive the aircraft, that will yield $0.45 W$ supported on those tires. If a coefficient of ground friction of 0.2 is assumed between the tires and taxiway then the maximum traction force applied to the aircraft would be $0.09 W$ before the tires would slip. This would make the main wheel concept superior to the nose wheel concept on providing traction force to move the aircraft. In some taxiway conditions the nose wheel concept could be spinning its tires where the main wheel concept would still be able to generate a traction force able to move the aircraft. The system could limit the extent of spinning tires through traction control.
- Tugs and towbarless vehicles have substantial weight to allow for the traction forces to be applied to the ground in most cases.

- There are appropriate conditions in which one might spin tires - for example, to move snow that is under the tire, and thus increase traction. When an aircraft is rolling, some degree of spin can help it drive under load but with intermittent or partial loss of traction within parameters to avoid excessive tire wear.

Another difference between NLG and MLG LGTS is the capability to control a reverse motion deceleration:

- With a NLG LGTS, a tail down event is less likely since the nose gear braking, to the extent there is traction, does not cause the nose to lift.
- With a MLG LGTS, the deceleration in reverse mode can be controlled by the LGTS since the load on MLG is increasing during deceleration.

6.3 Taxiway Conditions

The design concept would have to consider all the taxiway operational conditions that the system could operate in. These could include the following:

- Dry and clear pavement.
- Rain and ice covered taxiways normally greatly decrease the coefficient of friction available to react the available traction force. Traction force available is generally equal to the normal force times the coefficient of friction.
- Snow covered taxiways decrease the coefficient of friction and increase the rolling resistance of the wheels. Operational limitations might be required in these conditions. Typically using a standard towbarless towing vehicle there is a combined normal force of the weight over the nose gear plus the weight of the tug.
- Uneven pavement, debris and cracks would have to be traversed.
- Slopes between taxiways and crossing active runways, etc., would have to be defined to ensure the LGTS can provide acceptable traction forces to move the entire weight of the aircraft up and over these.
- Hangar thresholds. Step changes between hangars and taxiways usually involve transversing a hangar door rail(s).
- Taxiway contamination can impede the motion of rolling wheels and would need to be investigated as to determine what the LGTS capabilities would be.
- Operational and non-operational temperature ranges. High ambient temperatures can limit the extended use of a LGTS due to temperature build up in the electric motor and wheels/tires. Low temperatures could also have challenges associated with gear lubrication, clutch operation, water freezing contamination, etc.
- Deicing fluid covered surfaces. These fluids can cause lower ground friction coefficients.
- Cold soaked tires. In cold overnight conditions some tires form a D-shape that require additional traction force to start to roll and warm up the rubber to a more compliant state for free rolling.

The LGTS is optional, and as such, does not need to operate in all conditions.

6.4 Nose Gear Geometry

The nose gear geometry could play an important role in the functionality and practicality of mounting a nose gear traction motor in the nose gear wheels. Currently the two major short haul aircraft are the Airbus A320 and the Boeing 737NG family of aircraft. The A320 incorporates a positive caster angle compared to the 737NG with virtually zero caster angle. The result of the A320 caster angle tends to lift the outboard nose gear tire during a hard turn. This could result in the wheel mounted traction drive performance effectivity being cut in half during a hard turn, with one wheel unloaded and free spinning. The WheelTug system is reported to handle this by traction control. During these high degree turns it is envisioned that maximum torque is not required and one wheel traction motor will be able to provide the torque required. The 737NG tires remain flat on the ground during a hard turn.

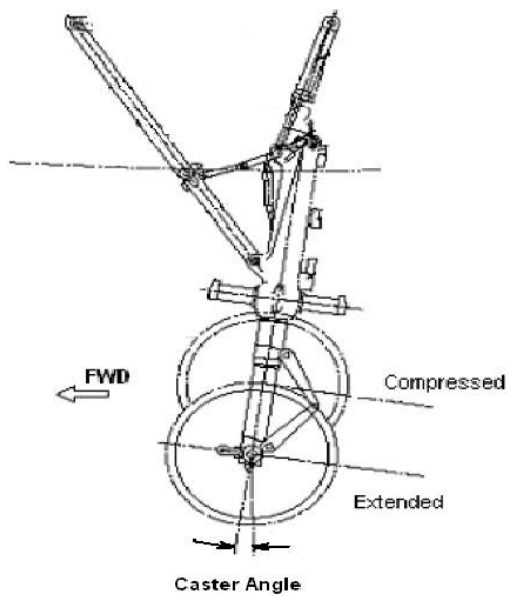


Figure 6 - Airbus A320 caster angle

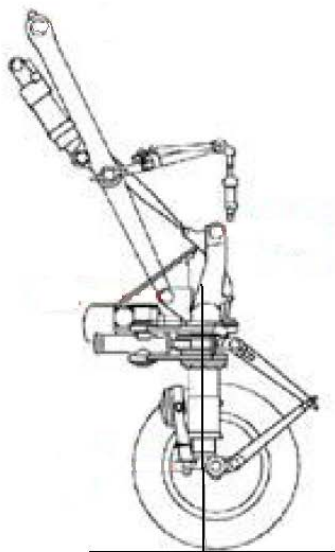


Figure 7 - Boeing 737NG caster angle

6.5 Wheel Mass and Inertia Concerns

The LGTS will be driving a nose or main wheel. That would involve mounting a drive mechanism to the nose or main wheels. This mechanism would add weight and inertia to this driven wheel. This weight may also be off-centered.

For a nose wheel this added weight and inertia could affect the landing gear steering, shimmy stability and spin-up loads generated during landing.

For a main wheel this added weight and inertia would change the landing gear structural natural frequencies, which would affect brake control and shimmy stability.

If only one main wheel is driven on a 2-wheel main gear this may affect brake control tuning and could bring additional challenges.

Increasing the unsprung weight at the end of an axle could affect the natural frequency of the gear which will have effects on landing, steering, shimmy stability and brake control systems.

There is a possibility that a main wheel LGTS could employ a regeneration braking function. This regenerative braking capability would have to be designed for compatibility with the brake control system.

Additional mass at the wheel could affect the ability of the retract actuator to get the gear retracted and/or extended.

The added weight and inertia would also affect spin-up loads generated during landing.

7. CONCEPTS BEING DEVELOPED

There are five main companies that have actively worked on some form of engine off taxi system.

They are divided into three categories:

1. Nose Gear Taxi System

- i) WheelTug
- ii) DLR's A320 ATRA (Advanced Technology Research Aircraft)

2. Main Gear Taxi System

- i) Safran/Honeywell Electric Green Taxi System (EGTS)
- ii) Luftansa/L-3/Hydro-aire e-Taxi

3. Pilot Controlled Towbarless Towing Vehicle. IAI/TLD TaxiBot system

All five initiatives resulted in a proof of concept working prototype. However as of 2014, there are two known companies that are actively working on powered landing gear (main engine off) taxi system concepts. They are WheelTug and Safran/Honeywell teams.

WheelTug prototype work has focused on the Boeing 737NG nose landing gear to develop a powered nose wheel system. WheelTug is also actively working on A320 family NLG solution. The Safran/Honeywell team is working on a main wheel mounted system that is built around the Airbus A320. Both system concepts install electric motor/transmission directly on the landing gear to allow aircraft to taxi with the pilot in control using electric power from the aircrafts auxiliary power unit (APU).

The DLR's A320 ATRA (Advanced Technology Research Aircraft) team built a proof of concept in 2012. However after that the activity has stopped.

The Luftansa/L-3/Crane Hydroaire team also built a proof of concept in 2012. However after that the activity has stopped.

The LGTS concepts can be divided between the nose wheel and main wheel mounted designs. Each offer pros and cons. This AIR presents these concepts and discusses the pros and cons and challenges ahead to certify the new technology.

There is also a hybrid taxi system. IAI, partnering with global ground-support equipment manufacturer TLD, has created the TaxiBot system which involves a semi-robotic towbarless tow tug that is controlled from the cockpit by the pilot. This system has the potential to tow all types of aircraft using towbarless towing vehicles. IAI/TLD TaxiBot initial system work seems to focus on the bigger aircraft where a heavy tug is required to move an aircraft. The team has also done work on the Airbus A320 and Boeing 737 aircraft. The technology is seen as a bridging technology from traditional towbarless towing and fully autonomous aircraft mounted equipment, pilot controlled towing.

7.1 Nose Wheel Traction Concept - WheelTug

WheelTug Plc is a member of the Borealis family of companies. Borealis Exploration Limited, the parent company, was incorporated in 1968. Chorus Motors was incorporated in 1999. WheelTug plc was incorporated in 2005.

The initial concept of a powered nose wheel was reported to have been started in 1994.

WheelTug electric taxi proof of concept prototype was first tested on a Boeing 767 in May 2005. The proof of concept demonstrated that an electric motor and gearing could move an aircraft.

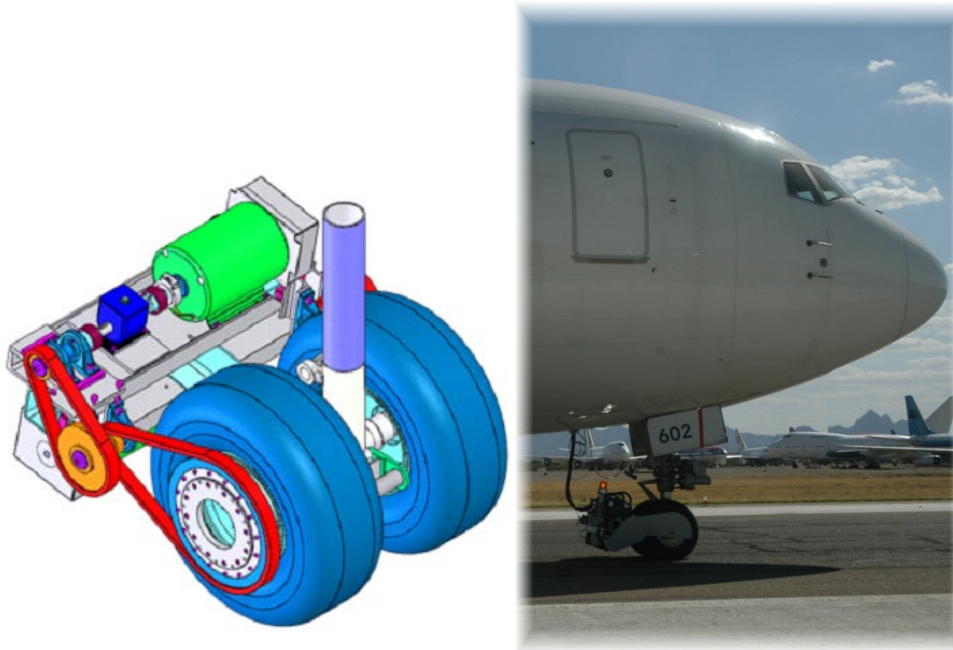


Figure 8 - WheelTug proof of concept testing on Boeing 767 aircraft

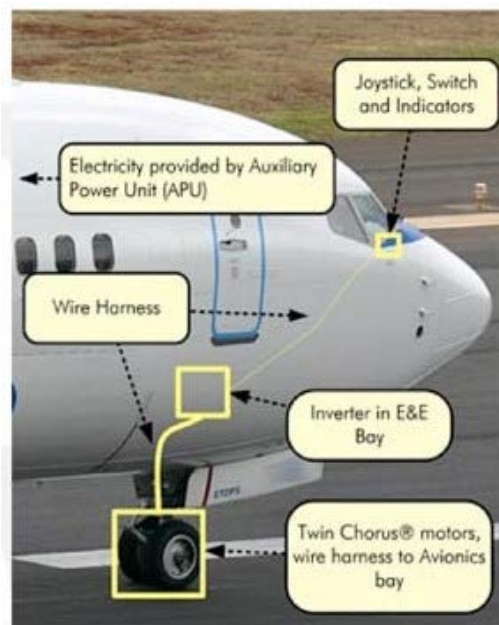


Figure 9 - WheelTug system

WheelTug gave a presentation at the SAE A-5 Toronto meeting during the Towbarless Towing Panel on May 2, 2007 describing their system and activity status. SAE A-5 discussions that followed the presentation focused on some of the challenges with introducing this new technology to an existing aircraft and the impact on the various systems. There were various topics of discussions that ensued.

The following challenges were identified:

- Limited weight over the nose gear limits the maximum traction force available
- APU power availability
- Failure modes and effects
- Providing harness routing for power and signal wires down the gear leg to the axle
- Nose gears are not typically designed for the damage that would result from extensive use in towing and may result in weight addition due to this added towing wheel traction requirement
- Increase weight on the nose gear axle might have effects on:
 - o Retraction actuator system
 - o Landing dynamic spin-up loads
 - o Taxi dynamics
 - o Steering system
 - o Shimmy
 - o This increase in actuator output may result in damage to the gear and structure for both static and fatigue considerations
- Clutch mechanism capable to engage at aircraft taxi speed.
- Speed and deceleration control in reverse mode due to weight transfer to MLG during reverse deceleration which could cause the nose wheel to skid.
- A320 NLG wheel lift on hard turns would lead to loss of traction with ground of outboard wheel. However the normal force is transferred to the inboard wheel. The inboard wheel traction would be provided by only the inboard wheel motor.
- Heating effects on the wheel and tire
- Human safety with high voltage
- New loading of gear and structure, strength and fatigue
- Certification of an existing aircraft
- Water or contamination getting into mechanism and having a frozen mechanism on landing touchdown
- The effects of failure modes on operation and structural loading

NOTE: Most of the above challenges are also present on a main gear mounted system.

In November of 2010 WheelTug conducted additional testing on wet and slippery snow covered surfaces at Prague Airport. The tests were conducted with an aircraft with less than MTOW. Different CG distribution scenarios were also tested including aft CG. The SAE A-5 committee discusses the YouTube video during the panel meeting that followed and came to the conclusion that a fully loaded aircraft would be another good point to test for to ensure the system has enough traction to move an aircraft's main landing gears over a threshold or bump.



Figure 10 - WheelTug torque and traction data gathering testing