exhaustless

blue-sky thinking

Proposal to provide additional airport capacity in the long term

Presented to the Airports Commission of the Department for Transport of the United Kingdom

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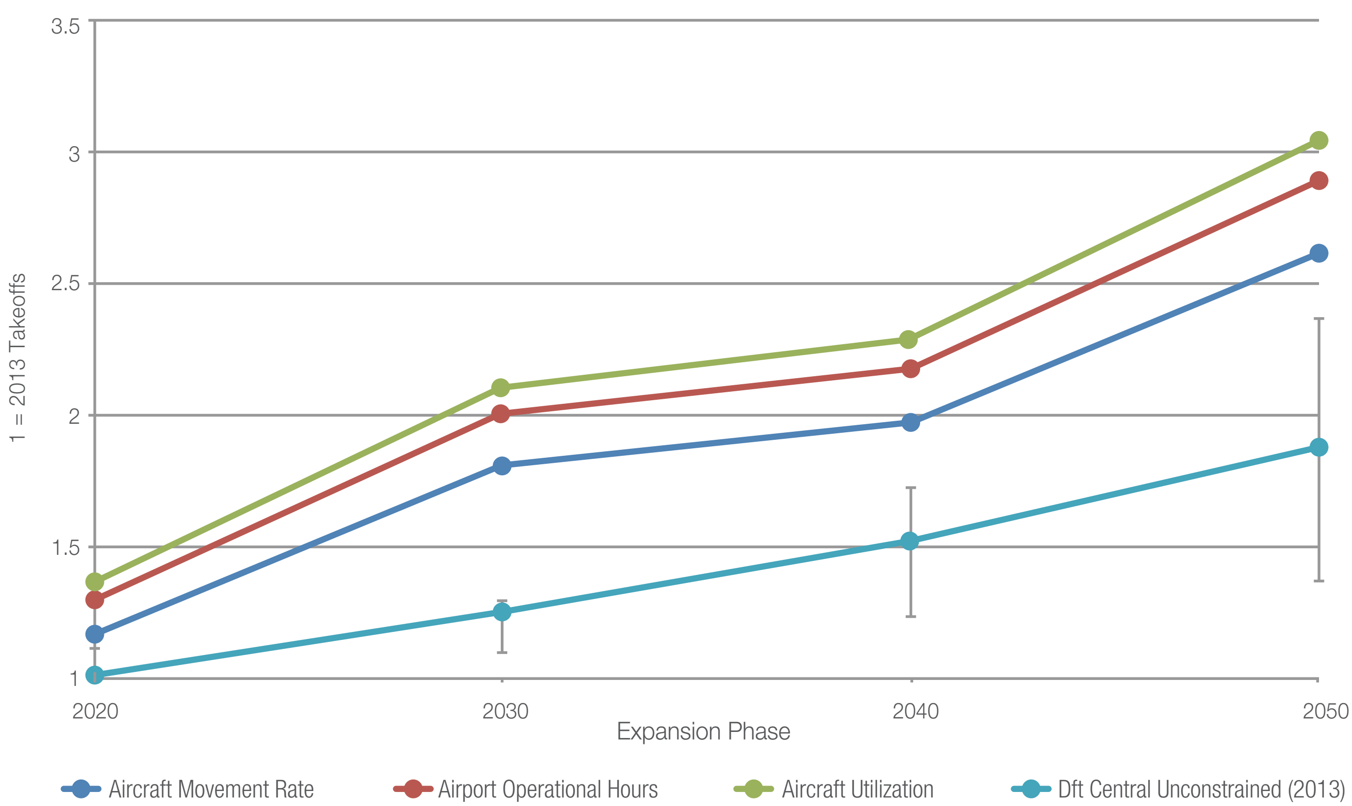
Executive Overview

The UK is at a crossroads; it needs to reduce the environmental impact of air travel, but also meet growing market demand. In fact, both can be accomplished without the need for sprawl. Our vision promises increased capacity and reduced emissions, noise, and pollution from innovations in takeoff operations based on the existing aircraft fleet.

The **Exhaustless Takeoff System (ExTS)** combines existing technologies in an innovative way, using the power from the electric grid to accelerate unmodified commercial airplanes, thereby greatly reducing the amount of jet fuel burned, and noise generated, from takeoff. The system increases the number of takeoffs possible per hour of operation while reducing the distance needed for takeoff, greatly extending flight capacity from existing airport land and infrastructure (See Figure 1 for projected capacity increase). It is a hybrid runway system, rather than a hybrid airplane.

Figure 1: Projected Heathrow capacity increase using ExTS (cumulative effect)



Increased capacity will make Heathrow more accessible to other UK airports and ensure reliable departure schedules needed for serving regional airports, extending the dominance of Heathrow as the European aviation hub. Our proposal provides flexibility to incrementally increase capacity in a four-phase plan. These phases are scheduled to meet contemporary forecasts as the demand emerges and provide sufficient reserve capacity to ensure adequate resilience.

Exhaustless' ExTS helps the UK meet wider economic and legal emission requirements by reducing jet-fuel use during takeoff and climb. Energy production shifts from an import activity to a domestic activity, creating regional jobs at airports where we operate and national jobs where grid-powered energy is produced. Increasing the capacity of takeoff operations with minimal sprawl leverages the extensive existing infrastructure of Heathrow and of greater London. ExTS offers a new era for airports and their cities, in which sufficient supply coupled with reduced noise and pollution eliminates the need for additional airports for the foreseeable future.

No aspect of developing the system is significantly risky in itself; the technologies are used today [redacted] but not in an integrated form. Proving the system will require identifying its optimal operational parameters and verifying its cost. We are asking the UK to commit £200 million to fund the research and development of the system, which will include a proof of concept using scale models and tests of specific items at full scale, to be delivered in twenty-four months. At that time, the viability and cost effectiveness of the system would be assessed and the government can consider its implementation and avoid committing to very risky and high-cost, long-term projects that lead to sprawl and ignore the inherent quality of life issues.

To our knowledge, no other proposal provides the opportunity for Heathrow to gain efficiency, increase capacity, reduce pollution, and reduce sprawl simultaneously. While optimistic regarding the vision of our technology and business model, the work ahead will require significant effort to ensure confidence in Exhaustless' ExTS as a premier solution for Heathrow and the UK.

Exhaustless' ExTS at Heathrow would continue the UK commitment to sustainable urban planning, dedication to environmental goals, and global leadership in innovation by addressing climate goals while opening up the UK to regions of new economic growth.

Learn more from our website at www.exhaustless.com.

The Problems

Today's global economy depends on aviation for connectivity. Airlines are seeking ways to meet the expected growth in demand from rising population, but they are experiencing airport capacity limitations. The UK is exploring how to meet the demand for air travel with consideration to quality of life for those affected by noise, pollution, climate change and sprawl from airports.

Research in the aviation industry focuses upon either turbo-jet engine improvements or flight control software. Expectations from turbo-jet engine researchers suggest that a 1% to 2% increase to fuel economy will likely be the limit of mass aviation technology for the foreseeable future. The magnitude of impact expected from these projects is small relative to the growth in expected market demand. So for our purposes, we assume aircraft technologies are fixed.

Recent court rulings shift the liability of missed flights from passengers onto the chain of travel service providers used during the trip. What previously required nothing but issuing a voucher for future travel to affected customers may now require a refund, plus other reimbursements[1]. These measures, under EU261, have cost one airline more than £1 billion since 2010.[2] These court rulings and the spirit of EU261 show that there is an implied level of service expected by the air travel industry that requires the ability to maintain more precise flight schedules.

Airlines know how to serve more passengers on existing flights with more seats and bigger aircraft. But adding service to new destinations requires more takeoffs and landings. In the past, this need was met by building additional runways at existing airports, or by adding new airports. The challenge is to find the best way to meet the DfT forecast with limited land, limited time, and low impact, leading to a more sustainable airport.

Our Solution

As long as we assume that the energy needs of aircraft must be stored on board, we will be relying on jet fuel for all aspects of aviation for the foreseeable future. However, using energy stored outside the airplane is critical to the solution.

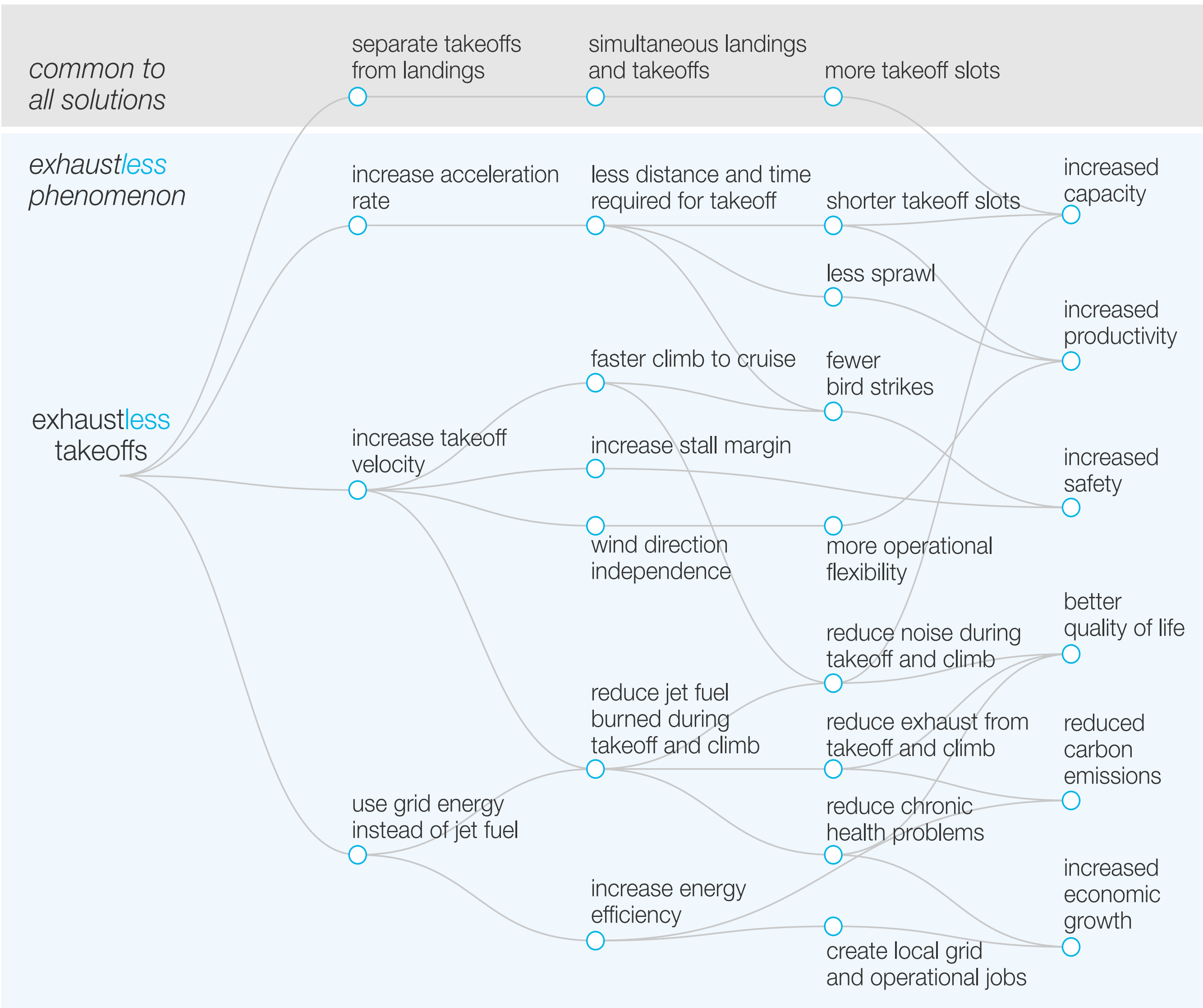
The Exhaustless Takeoff System's (ExTS) patent-pending technology uses stored grid energy to assist takeoffs. It is able to release a greater amount of energy at once, safely increasing the acceleration and velocity of unmodified commercial airplanes and thus decreasing the distance required for takeoff. This reduction in required distance allows physical separation of departures from arrivals without the increase in land typically required. Departures operate from what we call a guideway, requiring about half the length and one-fifth the width of a traditional runway. In other words, it is a *hybrid runway.*

[1]http://www.telegraph.co.uk/travel/travelnews/9627626/Airlines-must-pay-compensation-for-flight-delays.html

[2]http://www.telegraph.co.uk/travel/travelnews/10105801/British-Airways-may-face-compensation-payout-for-delays.html

Changes in the fundamental takeoff process using the grid energy provides a cascade of economic, operational and quality-of-life benefits, each of which will be discussed in further detail throughout this proposal. These benefits are significant; jet fuel burned in takeoff and climb operations is reduced by 43%, which at current Heathrow volume would save 250 million kg of jet fuel[3] and 2% of UK CO_2 emissions from aviation[4]. The installation of just one ExTS would save the UK over 0.5 million $MtCO_2$ ***annually***, as compared to the same capacity using current takeoff methods. See Figure 2: The cascade of benefits provided by ExTS.

Figure 2: The cascade of benefits provided by ExTS



[3]Appendix C provides the calculation of fuel reduction.

[4]Appendix D provides the calculation of 0.7 $MtCO_2$ out of a total of 34 $MtCO_2$ for the UK (from DECC (2013) 2011 *UK Greenhouse Gas Emissions, Final Figures*).

Our Technology

The Exhaustless Takeoff System (ExTS) allows airports to increase the runway throughput, using less land per takeoff with higher energy efficiency. The basic design builds upon proven state-of-the-art electromagnetic linear motors used by the U.S. Navy. Using energy from the electric grid, instead of jet fuel, provides a cascade of immediate benefits for airports and operators at current flight volumes, and provides for capacity to service the much higher volumes expected in the future. Using grid electricity also allows investment in dedicated and renewable sources of power to provide acceleration.

The design allows airports more flexibility in managing their operations by separating takeoff activities onto new *guideways* and routing all landing activities to current runways. The guideways for one system will require 1.8 km x 10 m of land. Two systems can be installed back-to-back and allow almost simultaneous takeoffs in opposite directions, independent of wind direction. The resulting new layout of the airport reduces taxi distances by 50% and reduces the interaction between arriving and departing taxi operations.

Hardware

The Exhaustless Takeoff System (ExTS) integrates three components, which are further explained in this section:

1. Electromagnetic linear motors housed in a guideway and modified for commercial aircraft use and to be powered by the grid;
2. [redacted]
3. [redacted]

Electromagnetic linear motors

Our system relies upon components produced by a group of suppliers [redacted] and is currently manufactured in California. [redacted] Modifications required for use with commercial airplanes include [redacted] These modifications are risk items that will be addressed in the initial stages of development. Exhaustless will partner with a large transportation infrastructure firm to integrate the components and assure the quality and integrity of the overall system.

[5] 1G = 9.8 m/s²

[redacted]

[redacted]

Software

Our logistics service records the takeoffs, [redacted] This data is used for monitoring, regulatory compliance, [redacted]

Description of the operations

Airplanes taxi [redacted] at the centerline of the airport where operators on the ground [redacted] Upon signal from the pilot, the system will be engaged, propelling the [redacted] aircraft down the length of the guideway. [redacted]

Intellectual property

[redacted]

Technical feasibility

With innovation, there is always risk, but the existence of reliable technology that is already in use strengthens the ExTS system. In addition to the current in-use technology, there are new and unique elements:

1. Our design is the first to connect the physics and technology of electromechanical linear motors, [redacted]

The physics and engineering challenges of the design present no unsolvable problems because the science and engineering are based in well-understood Newtonian mechanics, electromechanical energy conversion, and aerodynamics. Forces and pressures involved within our operations are below the range the aircraft experiences during normal operation, and well below those required to meet certification. In fact, our design [redacted] may reduce fatigue upon the wings.

2. The system is similar to that used by roller coasters in that an electromagnetic force is used for acceleration, but at a much larger scale of power. [redacted]

3. [redacted]

4. Historically, designs for assisted takeoff relied upon mechanical linkages connected to reinforced airframes. Our solution does not require modified aircraft. [redacted]

5. The current structural speed limit of aircraft during takeoff is related to weight, runway length, landing gear and tire design. By removing [redacted] we are able to safely increase the takeoff speed.

6. [redacted]

Innovation cycle

The innovation cycle is shortened by the investments [redacted] made recently [redacted] Regardless, there are months ahead of integration and testing of hardware that comes with expected risks. The completion of scale models and proof of concepts is feasible within 24 months.

Risk mitigation

We will mitigate the technical, financial and safety risks by conducting the least expensive and broadest tests that prevent wasted time and capital. By incrementally increasing the weight class of aircraft, Exhaustless will better quantify the risk for the next heavier class. [redacted]
Exhaustless plans to use the [redacted] for experiments and tests in order to minimize cost and time.

Our Business Plan

The Exhaustless Takeoff System (ExTS) will produce a profound improvement to the urban-centric transportation needs of the UK. Our technology creates a way for airports to offer a quantum leap forward to more sustainable aviation, a better passenger experience, and capacity that can grow with demand.

Heathrow annual departure activity at current volumes burns 579 million kg jet fuel, releasing 1.8 million $MtCO_2$ into the atmosphere. In addition to the fuel costs, airlines, airports and cities that burn fuel incur other costs, such as carbon taxes, costs associated with ill health from pollution, and noise mitigation.

Instead, takeoff assistance services using ExTS reduce fuel burn by 43% and providing the cascade of benefits from the Exhaustless Phenomenon (see Figure 2). At current prices the annual fuel savings alone would be £257 million.

Passengers will pay a little more per ticket for a significant reduction in waiting-time at the gate, during taxi and on the tarmac. For less than the amount they pay now for passenger excise taxes, they experience a quality level of service from improved resilience to disruptions, less pollution and noise, and more reliable schedules.

Transactions between Exhaustless and the airport(s) will involve the ExTS manufacturing, onsite construction, installation, acceptance testing, and maintenance. Training of pilots and modification of flight simulators will be additional services contracted between Exhaustless and airlines.

Because the system installation time is much shorter than that of a traditional runway, our solution offers cities the flexibility to procure additional systems, as capacity needs dictate, rather than trying to predict the capacity needs forty years into the future. This prevents the need for such large commitments where risks are high and payoff is less productive capacity.

Capital Asset

Airports will purchase ExTS in the normal course of capital expenditures, through bond-issuances, federal grants, or operating funds of the airport. We estimate that each system would cost between US$4-5 billion, which includes the cost to design, manufacture, and install the system, including the [redacted]. This cost is based on preliminary data; the actual cost may be higher or lower than this. The cost to prepare the land for guideway installation or the cost of additional terminals or ground infrastructure is not included in this estimate.

The airports will charge airlines for the cost of the system as part of its infrastructure fees, which will be passed on to the passenger's ticket price.

Operations

Exhaustless, Inc. will operate and service ExTS. We estimate that each system will require a dedicated team of 20 employees, hired locally, who will [redacted] We will charge the airlines a takeoff fee for each aircraft assisted, [redacted] The price charged will be based upon free market fundamentals.

Flights that use ExTS will reduce the amount of jet fuel required for takeoff and climb by 43%, and benefit from faster climbs, [redacted]. Airlines also benefit from increased hub capacity, increased airport productivity and decreased flight cancellations.

Safety tests will certify when constrained airports may adopt Exhaustless ExTS technology and for which aircraft. However, once certified, regulators may require a certain number of takeoffs or type of aircraft to use the system in order to achieve the desired reduction in noise, air pollution and GHG emissions.

Our Proposal

Our proposal is to install four Exhaustless Takeoff Systems (ExTS) at Heathrow in as many as four discrete phases:

- Phase 1 would meet the current demand as quickly as possible (2020 estimated completion).
- Phase 2 would meet the medium term demand (2024 estimated completion).
- Phases 3 and 4 would be implemented to meet additional cargo and/or passenger capacity when it is needed (2028-2050 time range).

Phase 1, as the inaugural system, has the least impact to the existing infrastructure and surrounding communities. Planning for Phase 2 will be influenced by the experiences from implementing and operating the first system. Capacity at Heathrow at this time may be sufficient for some time with just these two phases. Other airports in the UK or the London regional area, such as Gatwick, may benefit from their own ExTS system in order to address their capacity, noise and pollution problems. The same may be true for other airports that share binding commitments, such as Charles de Gaulle, Schiphol and Frankfurt.

The timing of the deliverability of the first system will be dependent on availability of funding required to complete the research and development. The timelines given assume that the Commission and Heathrow will be committed to the project, and their commitment is expected to generate ample interest in the private market.

We have focused our efforts on developing the system and believe our estimates of those costs to be accurate. We have no expertise in city planning or transportation, so the cost estimates for those activities are very broad and would require thorough analysis from DfT and other experts.

Next we describe the four phases of implementation. The map at Figure 3 shows the footprint of the affected areas.

Phase 1 – NW Quadrant

- **Description:** The first system location would be the northwest quadrant at the current site of long-term parking. Our goal will be to work within the current boundary of the airfield; however, there is a possibility that the tunnel entrance at the Concord Roundabout, perimeter roads and portions of Bath Road would require relocation to the north. In this case, structures in the affected areas would require removal/relocation, including the Thistle, Arora, Holiday Inn, Compass Centre, Revenue & Customs and the police and fire stations. In addition, this scenario would require removing 100 home structures on Pinglestone Close, Zealand Ave and Blunts Ave in the town of Sipson. The Sheraton represents the southern boundary of this scenario and would remain intact.
- **Additional surface transport required:** No additional surface transport requirements are anticipated.
- **Timing:** We estimate that the main risk items of the system could be proven within two years. Full-scale development and testing would follow. Manufacturing, installation, testing and training would take an additional two years; operational in 2020.
- **Total estimated cost:** The estimated cost of the ExTS is US$4 billion, which excludes costs for preparing the site for installation. Adding the site preparation, construction of replacement long-term parking, and relocation of homes and business, we estimate all-in costs of £3.5 billion.
- **Capacity:** **1.3x current level**

Phase 2 – NE Quadrant

- **Description:** The second system location would be the northeast quadrant and would most likely extend beyond the northern perimeter road, south of Bath Rd. The tunnel entrance at the Concord Roundabout would require relocation to the north if that had been avoided in Phase 1. In this case, structures in the affected areas would require removal/relocation, including the perimeter road, Bath Rd., Radisson, Renaissance and HM Revenue and Customs. The eastern perimeter may also require expansion, impacting the long-term parking and hotels in that area. No impact is anticipated to Cranford Rd., which represents the eastern boundary of this scenario.
- **Additional surface transport required:** No additional surface transport requirements are anticipated.
- **Timing:** Assuming planning begins once Phase 1 is online, we estimate the system would be operational in 2024.
- **Total estimated cost:** The ExTS system is estimated to cost US$4 billion. The increased land and infrastructure needs of this phase will be more costly and more disruptive to the local community. Adding the site preparation, construction of replacement long-term parking, and relocation of homes and business, we estimate all-in costs of £4.5 billion.
- **Capacity:** **2.1x current level**

Phases 3 and 4 – SW and/or SE Quadrant

- **Description:** The next two phases will have a larger impact on operations and will require a longer planning timeframe, estimated to begin in 2020. The location of the third system would depend on whether additional cargo or passenger capacity is needed. If additional cargo capacity is needed, we propose relocating and expanding the cargo handling operations to the south and installing a third ExTS in the southwest quadrant. If additional passenger capacity is needed, the system could be installed in the southeast quadrant, dislocating Terminal 4 and potentially some of the homes and businesses to its east.
- **Additional surface transport required:** Roads and security systems may need to be added or modified to accommodate the increased cargo business. More surface transport may be needed if additional passenger capacity is generated.
- **Timing:** Operational as early as 2030 or as late as forecasts warrant.
- **Total estimated cost:** The costs of these phases will depend on the types of capacity needed. We expect that the system costs will increase with inflation, but the additional infrastructure costs are too highly variable because they depend on the type of capacity needed.
- **Capacity:** **Phase 3: 2.3x current level; Phase 4: 3.0x current level**

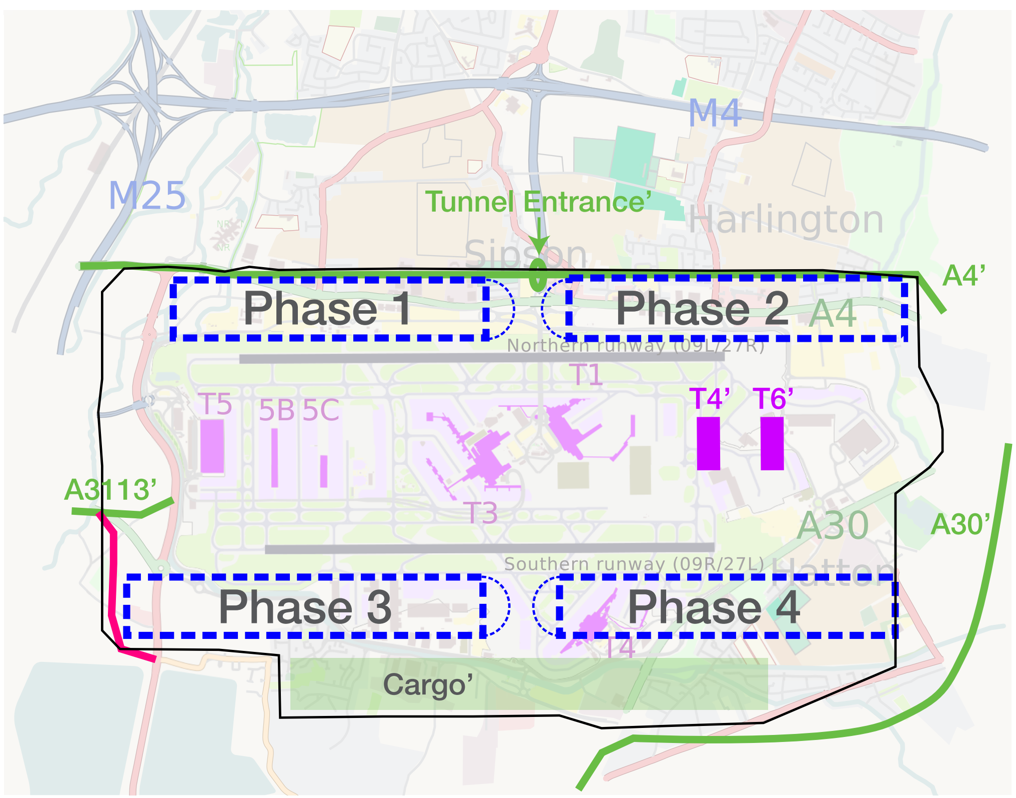


Figure 3: Proposed locations for Exhaustless Takeoff Systems and related changes

Variations

- **Configuration:** We have selected the outer perimeter of the airport as the installation sites of the system in order to minimize the impact to existing infrastructure and also to buffer the outer community from the noise of landing and other airport operations. However, this configuration requires aircraft to taxi across or around the runways in order to reach the guideways. A more efficient configuration may be to build the runways on the outer perimeter and install the systems at the existing runway sight, which would reduce the taxiing time of fully loaded departing airplanes but increase the taxi time of lighter landing airplanes. This option would require more time to implement and would also disrupt current operations until the systems are fully operational. See Figure 4: Alternate configuration with ExTS closer to terminals.

- **Add-ons:** Various additional technology may be beneficial to install [redacted], such as infra-red heaters that could more efficiently de-ice airplanes immediately before takeoff. The costs of these add-ons are not reflected with the system costs.

- **Operations:** It may prove more efficient to dedicate or limit the specific types of aircraft or specific operations of each ExTS. For example, all flights to regional airports, which use short or medium-haul aircraft, would use the same system. [redacted]

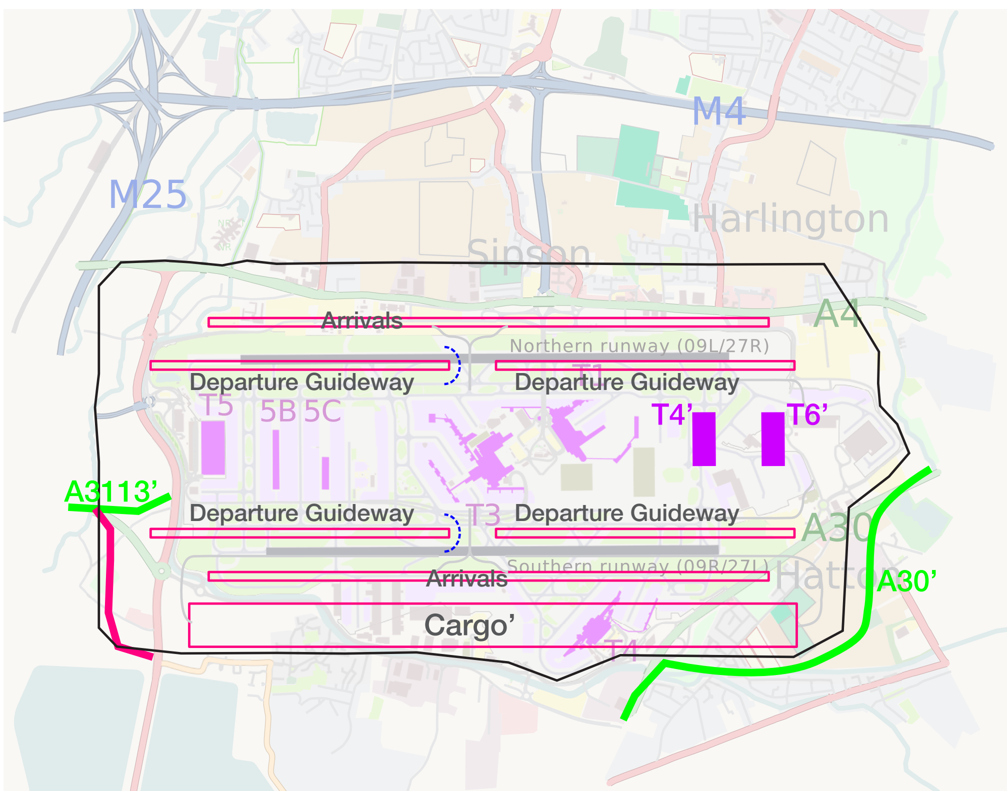


Figure 4: Alternate configuration with ExTS closer to terminals

Comparison of our proposal to other ideas

The main negative of other proposals to the Commission is that they continue to rely upon the technology of pouring concrete and burning fuel, so in many respects they only exacerbate the existing problems of air travel. Below we address some of the main points of divergence of each of these ideas as compared to ExTS:

1. **Take no action:** At first glance, doing nothing may seem like the least damaging option to the local residents, even though it harms the UK by shifting economic growth to other hubs in the European region. However, installing ExTS will reduce the noise and pollution produced by current Heathrow takeoff operations while increasing capacity at reduced noise and pollution levels, so the local communities benefit with jobs and quality of life improvements.
2. **New airport further from the population center:** Building a new airport further from the population center would produce the additional capacity needed to meet demand and provide for economic growth, but because the proposal requires such a large economic investment while threatening existing infrastructure and the environment, it is one of the most risky proposals. Part of that risk is overbuilding to forecasted demand that doesn't materialize. ExTS will utilize the existing infrastructure and allow London to slowly add on the capacity it requires, as the demand comes about, instead of relying on demand forecasts that are 40 years into the future.
3. **Third runway north of existing airport:** While a third runway will provide for medium-term demand forecasts, it will greatly disturb the local community and add further noise and pollution to the surrounding area. ExTS provides the capacity of a third runway but in a much smaller footprint, causing less impact to local residents from the temporary construction, but making long lasting improvements to quality of life metrics. The capacity at Heathrow following Phase 2 implementation would be 30% more than the capacity provided by a third runway.
4. **Extend or reorient Heathrow to the west:** The construction anticipated from these proposals requires moving water reservoirs, tunneling major roads and longer commutes from the center of population. Moving operations 2km to the west requires passengers incur 4km of travel more per trip. Even extending the runways to the west requires extensive construction with disruption to M25 and would deliver more noise to more people by removing the current buffer of the water reservoir. This level of disruption runs counter to policy goals.

We realize that the new technology may be off-putting at first, compared to the comfort of the old technology, however flawed. But people adapt to new technology rapidly; many passengers ride high-speed trains every day and the novelty of the technology wore off quickly with proven safety, familiarity and routine. The same evolution occurred with elevators, as urban high-rise buildings grew ever taller.

Our Executives

[redacted]

[redacted]

[redacted]

[redacted]

Our Response to Specific Airports Commission Questions

Economic factors

Many of the proposals to be submitted to the Commission will provide the capacity to meet growth in demand, leading to an increase in annual trade of £1.5 billion and 32,000 jobs. But only the Exhaustless Phenomenon[6] provides two additional mechanisms of growth. The second mechanism is the cascade of benefits that flows from the technology, enabling reduced carbon emissions, noise, pollution and sprawl to improve the quality of life in urban airport communities; this will provide an additional £1.5 billion annual growth. And the third mechanism is the replacement of the annual cost of 250 million kg[7] of foreign-sourced jet fuel with UK production of grid energy and in assisted takeoff operations, creating local jobs and further investment in the UK. We estimate that every £1 spent will accrue at least £5 in benefits[8].

Impacts on the UK economy

- **Alignment with likely growth in demand:** Our concept provides increased capacity to support the likely growth in demand for air travel, but does so by overcoming limiting factors that govern departure throughput. ExTS increases the departure throughput for Heathrow to 26 departures per-hour per-system installed[9], compared to the 19 or 20 currently available on each runway, [redacted] Peak demand can exceed average hourly departures and still maintain short queues. Phase 1 level of resilience will fade as more of the reserve capacity becomes allocated to everyday flight schedules; therefore we recommend planning Phase 2 expansion soon to ensure reserve capacity can be managed to meet the needs of travelers.

- **Expanded access to areas of international business growth:** Businesses need reliable air service to efficiently compete for markets. Our solution allows airlines to offer flights to more destinations without sacrificing flights to established profitable routes[10]. This is accomplished by expanding capacity an additional two ways:

    1. *Extended hours of operation:* The decrease in noise allows for takeoffs earlier in the morning to serve passengers destined to the east (Russian, India, China), and later at night for those traveling west (Brazil), increasing the hours in each day of airport operation and increasing the working hours available upon arrival of travelling business people.

[6] Figure 2 delineates the Exhaustless Phenomenon.

[7] Appendix C provides the calculation of the reduction in jet fuel.

[8] Appendix B provides our cost-benefit approximation.

[9] Appendix A provides the calculation of this increased takeoff rate.

[10] Currently, airlines offer flights to Brazil, Russia, India, and China from Heathrow, but not Gatwick. We do not anticipate a change in the market forces that shaped this condition, so we focus our proposal towards Heathrow.

2. *Expanding aircraft payload-range:* Because fuel not burned during takeoff is available for use in route, we provide expanded payload-range from existing fleets. Coupled with the increased departure throughput, this will open up new departure slots that can be used for existing or new routes.

- **Facilitation of UK trade:** The expanded aircraft payload-range will also allow freight carriers to use fuel in the value added activity of transporting goods over greater distances using available and unmodified aircraft. At Heathrow specifically, our proposal would better orient the layout of the area used by airfreight handling companies. Figure 3: Proposed locations for Exhaustless Takeoff Systems and related changes shows our recommended expansion to support an ExTS beyond the southern runway to provide operational staging for freight handling as well as the increased takeoffs needed by the forecasted higher rate of trade.
- **Reduced societal costs:** Our concept would reduce societal costs by streamlining the economics of the aviation industry and the tax schemes under review for carbon, noise and pollution. Currently, significant cash flows to jet-fuel supply chains for aviation. After jet-fuel is burned, mitigation efforts including the healthcare and productivity costs of pollution, noise abatement strategies and carbon tax schemes help to offset the environmental impact. Instead, some of this cash flow would be diverted to our operations and used to support local jobs at the airport and electricity providers - no mitigation, offsets or apologies required. The tax savings and profits would continue to fund improvement of UK aviation and airport service quality.

Impacts on the local economy

- **Employment:** Our operations will employ people after construction as well as during the construction phase. People with skills from military and freight operations will operate the ExTS, [redacted] managing the movement of aircraft departing the airport. Ongoing maintenance and upgrades will employ highly skilled and trained engineers and supporting staff. Ongoing engineering research in new materials and technologies will also benefit from proximity to large airports and other UK aviation industry experts. We anticipate that each system could generate 300 sustainable jobs, including airport and airline increases to accommodate the increased capacity. In addition, shorter-term jobs related to construction would include many types of engineers and contractors with specialized construction expertise. On site infrastructure changes needed to support the system could total £1B, which would add to the local economy during construction.
- **Positive impacts on other airports:** By ensuring enough reserve capacity exists at Heathrow, other airports will be able to offer connecting flights into a hub that is streamlined for UK passengers[11]. In addition, the quality of service provided would drastically increase because the reserve capacity would prevent the poor punctuality these flights currently experience at Heathrow.
- **Impacts on business location:** Adding capacity at Heathrow will ensure that the many businesses located in the region continue to have quick access to the hub airport service that is vital to their operations.

[11]This is especially true if the flights are serving people destined or returning from the US and follow a streamlined customs process. Compare this to a flight connecting a US bound passenger connecting through Amsterdam or Frankfurt, where no similar process has been outlined. This could change, but so far doesn't seem to be a priority for other connecting hubs.

- **Increased property values:** Prices for property that surrounds airports will likely increase if noise and pollution are reduced as we expect from ExTS. With the scheduled increased subway connectivity to Heathrow and lower noise, surrounding regions would become more attractive for corporate and residential purposes. Governmental commitment to the noise reduction offered by ExTS would provide the goodwill needed to reach a capacity expansion agreement between Heathrow and the neighboring communities of greater London. We understand the opposition to existing noise (let alone increased noise) and the position of residents near the airport. Our technology provides a more peaceful environment for all the residents by decreasing noise even while expanding capacity.

Consumer impacts

- **Passenger experience:** The improved service level possible from ExTS will benefit consumers by making air travel more predictable and more pleasurable. With less revenue devoted to taxes, fines, and refunds for missed connections[12], airlines may have more flexibility within their operating budgets to offer additional services. We estimate that the cost of the system would increase facility charges by £14 per ticket.

- **Airfreight industry:** The reduction of jet fuel burned at takeoff will extend cargo range (increased cargo capacity, increased flight range, or a combination of the two), reducing the amount of flights required and opening up capacity for the airfreight industry. In addition, the reduced noise may allow for expanded operating hours and for cargo plane takeoffs throughout the night, freeing up departure capacity for passenger planes during waking hours.

Social factors

The Exhaustless solution leads to positive social impacts for the communities surrounding Heathrow, including environmental factors, employment, and construction, which are addressed throughout this document. Because Heathrow has been such a vital part of this community, the relatively modest disruptions that we propose, compared to construction of a new airport in another location, are expected to be in line with city and regional developmental practices and to exceed the local citizen's quality of life expectations.

Climate change impacts

Any increase in capacity leads to climate change effects from increased travel and from the construction operations. Our solution is beneficial for both activities because it reduces the impact of *all* air travel, not just the incremental air travel, and it does so with a smaller expansion footprint.

- **Efficient use of airspace:** Our proposal increases the flights from Heathrow, utilizing the same airspace. In addition, because of the decrease in noise, flights paths will not need to circumvent London, making them more direct and reducing fuel use.

[12]As mentioned above, recent court rulings find that airlines along an entire flight chain are financially responsible for a consumer's delay experienced at any other part of the trip. The potential liability from a snowstorm in London that strands passengers in Paris and prevents them from returning to Los Angeles is too great to ignore and may require ever more insurance protection on the part of airlines. Exhaustless can help prevent the lingering and cascading effects of a snow storm by providing a way to rapidly allow many takeoffs per unit of time and in two different directions from the airport at the same time. This mode of operation may be needed to clear the airport of stranded passengers or provide an evacuation.

- **GHG emissions from construction:** The components of the system will be manufactured in the US and shipped to the UK. Some roads and buildings may need to be destroyed and rebuilt. We will need other experts in those fields to estimate the GHG emissions impact from those activities.
- **GHG emissions from operations:**
  - o *Takeoff and taxi procedures:* If all departures from Heathrow fully utilized ExTS for their takeoff energy, then we estimate that *over 0.7 $MtCO_2$ annual emissions would be eliminated at the airport*[13]. If renewable resources provided this energy from the grid, it could be a net global savings of almost the same amount. This savings from using the system at *one airport* is the equivalent of the entire local savings that the Commission estimates will be generated by constraining the UK airport activity to 2030. And, the commission estimates that all of those savings gained by 2030 will leak to other hubs, so that there would be actually no global savings and therefore no climate change impact. Our solution provides truly global reduction of GHG emissions without the need for constraining activity, and works within the EU ETS framework.
  - o *Cruise:* In the longer term, as more airports utilize ExTS, airplanes that fly exclusively on routes between ExTS-fitted airports will no longer be constrained to engines as currently designed because the power needed for takeoff will be provided by the grid. These airplanes could potentially be altered with smaller, more efficient engines, further reducing the amount of jet fuel burned and noise emitted per flight.
- **Emissions relating to surface access options:** Because ExTS expands capacity at Heathrow, the system does not require additional surface access options above the scope of currently planned high-speed rail.

Local environmental impacts

Local communities are typically against expansion of airports because they bear the largest burden of the negative environmental impacts. Our solution reduces these impacts, improving quality of life for airport communities, and allowing for job growth through minimized expansion of land and maximized expansion of capacity. Next we describe how the Exhaustless Takeoff System (ExTS) provides noise, air quality, and other benefits.

Noise

- Burning less jet fuel (during taxi, takeoff and climb) is one of the advantages our concept provides airports. Because the electro-magnetic linear motors [redacted] employed by ExTS are mostly silent, there is significant potential for noise reduction. Airport users and communities adjacent to airports will benefit from reduced noise intensity levels and duration provided by our design.

[13] Appendix D provides the calculation of CO_2 savings.

- Sound simulations, including various levels of assisted takeoffs, are available at www.exhaustless.com/takeoff-simulations.html[14]. Appendix E provides more detail regarding the noise contours, including a comparative intensity and time exposure plot.
- ExTS provides five ways to reduce the noise experienced during takeoff and climb:
  1. *The faster acceleration decreases the duration of the noise.* The increased acceleration provided by the system reduces takeoff duration to 17 seconds, from 42 seconds. If all departures were to use ExTS for takeoff and full throttle, the shorter exposure time would reduce Leq contours by 6dB; the Heathrow Leq contour currently at 72dBA will be reduced to 66dBA.
  2. *The lower throttle settings at takeoff reduce the noise intensity.* If pilots relied upon ExTS for almost all of the acceleration energy by setting throttle at 30% thrust, the sound reduction would be an additional 8dB to 10dB. Leq contours currently marked 72dBA would be reduced to approximately 56dBA to 58dBA.
  3. *Increasing the distance between the takeoff initiation and the east airport perimeter further reduces the noise intensity experienced by those neighborhoods.* The shorter takeoff distance required allows the takeoff to be initiated from mid-airport and would reduce the eastern portion of the contour by 6dB due to doubling the distance to the engine. Assuming atmospheric attenuation of 4dB/km further reduces the noise by 9.3dB. Thus, the eastern most contour 72dBA Leq would range from 45.7dBA to 47.7dBA, at least for the contribution from westerly takeoffs to the weighted average used to derive the contour. If the number of departures were to double, to 1300 per day, then the eastern most Leq would rise to 48.7dBA to 50.7dBA. This will greatly benefit the Cranford community.
  4. *Higher acceleration increases the Doppler shift experienced by people in front of the aircraft.* This indirectly helps reduce noise further because the rate at which acoustical energy dissipates in the air increases with frequency.
  5. *Increasing the takeoff velocity from 380 km/h to 640 km/h will enable the departing noise to fade faster.*
- In addition, the decrease in taxi times provided by the relocation of takeoff initiation to mid-airport would decrease ground noise. We have not quantified that reduction in our Leq estimates.
- We will need assistance from the CAA to model the remaining portion of Leq contour areas, including the lateral areas. Predicting the full extent of noise reduction will need to include topology of the region and reference atmospheric conditions for typical summer days. In addition the slower fan speed, reduced exhaust velocity, reduced taxi distances and fewer braking events from our layout contribute to noise reductions beyond those quantified and simulated here.
- The decrease in noise allows for takeoffs earlier in the morning and later at night to accommodate distant time zones. We have included a two-hour increase in operational hours per day in our capacity increase estimates.

[14] Appendix F describes the process used to simulate the audio files.

Air quality

- The combustion of jet fuel emits air pollutants, so the reduction of the amount of fuel consumed will directly reduce these emissions. These pollutants impact the health of people that must breathe the local air, the environment by affecting the ozone layer and acid rain, and the beauty of the air related to the level of smog.

- Turbo Jet engine manufacturers measure the amount of certain emissions, such as hydrocarbons (HC), nitrogen oxides (NOx) and carbon monoxide (CO), per gallon of fuel burned. Our estimates of reduced pollutants are based upon data supplied by the engine manufacturers as collected by the International Civil Aviation Organization, (ICAO). Our assumptions include a reduction of takeoff time from 42 seconds to 17 seconds and takeoff throttle of 30% instead of 100%; reduction of climb time from 132 to 80 seconds[15]; and a reduction of idle time before takeoff of 4.8 minutes:

  - o *HC:* We estimate that 1,000 metric tons annual HC emissions from takeoff activities at current capacity would be reduced by 17%.

  - o *CO:* We estimate that 10,400 metric tons annual CO emissions from takeoff activities at current capacity would be reduced by 18%.

  - o *NOx:* We estimate that 13,800 metric tons annual NOx emissions from takeoff activities at current capacity would be reduced by 54%.

- Sulfur oxides (SOx) and particulate matter (PM) measurements are not included in the ICAO data bank, therefore, we do not have estimates for the reduction of these pollutants related to reduced jet fuel.

- Calculation of the impact of these reductions in pollutants to overall air quality will require expertise from the UK government and university researchers.

- The Exhaustless Takeoff System will demand electricity in order to power the system. The source of energy that the power station uses, whether geothermal, wind, nuclear, solar, natural gas, or coal, will determine if there is an offsetting increase of air pollutants, but based on the savings of CO_2 emitted using electricity instead of jet fuel, we believe that any offsetting increase will be negligible. The fact that electricity can be made in large quantities outside of the city reduces the recurring exposure to pollution to the large population within the city.

- A discussion of London/UK power production is outside the scope of this analysis. However, the gain in energy efficiency from using electricity is overwhelming. In addition, effective government regulation exists that monitor and control the pollution produced from the generation of electricity.

[15] Appendix C provides the calculations for reduced pollutants.

Other local environmental impacts:

- **Impact on Heritage buildings:** Our solution would preserve the site of the 15th Century Harmondsworth Barn, neighboring church, and cemetery. Citizens living just north of the current perimeter will likely need to be relocated for safety and minimum distance to trees and potential bird nests. See Figure 5.
- **Impact on bird life:** More flights could increase the number of bird strikes, but there are a few aspects about our takeoffs that could reduce the likelihood of the events. Bird strike data in California shows that most strikes occur during level flight or slow climb. Since aircraft will be traveling faster during initial climb using ExTS, they will spend less time within the altitude range where bird strikes occur[16]. Also, because the engines need not be at full throttle for takeoff and initial climb, the incidence of pulling birds into the engines will be reduced. Further analysis will be required to quantify this impact.
- **Water resources:** The system may require circulating water to cool components after takeoffs. At this time, we anticipate heated fresh water to recycle to storage tanks or into the hot water supply of the airport if cost effective. Adequate drainage of rain and runoff will be needed to protect the electrical equipment, but no chemicals would be added to any water used or pumped from the facility.
- **Flood protection:** The system can be elevated when installed in order to provide flood protection.

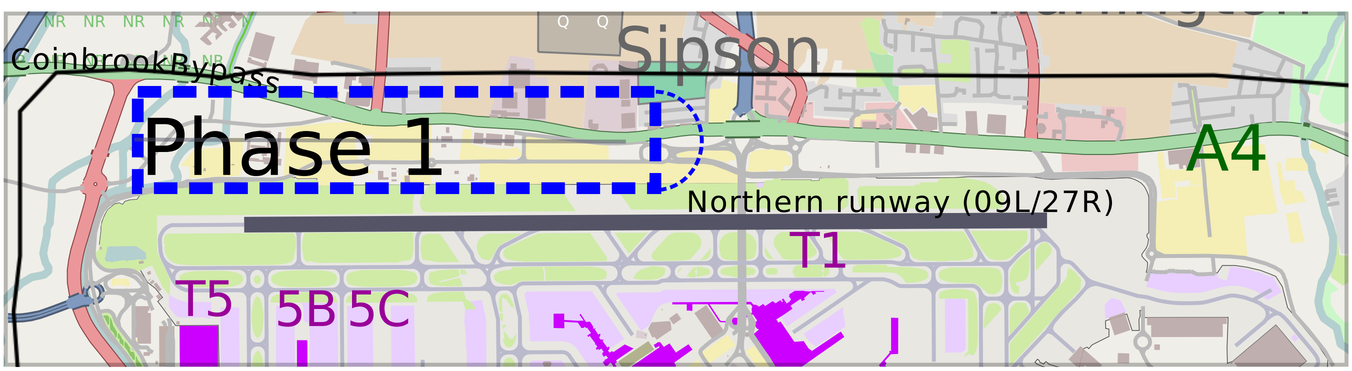


Figure 5: Potential Location of ExTS Phase 1

[16]Higher speeds could allow the engine fan to bare the impact of the strike preventing damage to internal components, but more analysis and data are required.

Accessibility

Accessibility of Heathrow has been factored into the existing London-area surface transport infrastructure managed by the DfT, including the recent tube improvements and the planned HS2 project. This access was planned based on forecasted growth at Heathrow, and we believe will provide sufficient access through Phase 2. Phase 3 may increase airfreight capacity rather than air passenger capacity, which would require different surface transport capabilities. The ability of our solution to increase capacity in stages also provides flexibility to meet the changing surface transport needs in phases, and to maximize the return on invested infrastructure.

Feasibility considerations

Because our concept allows incremental expansion, delivering capacity closer to real-time demand, less capital is put at risk while meeting the determined goals within time, money and technology constraints.

Affordability and financeability

- **Airport infrastructure costs:** Our proposal for Heathrow calls for 4 systems to be installed to fully support demand forecasts of 2050 with sufficient reserve capacity to ensure on-time service and flight-schedule resilience. However, our design allows cities to meet demand incrementally, allowing for more updated traffic figures to determine the location and timing of system installations to best serve airlines. The estimated cost of installing each ExTS system is $4B USD and so costs in today's currency would total $16B if all four systems were to be installed at once. This estimate excludes costs of reconfiguring the airport, which will vary significantly depending on the locations selected for the systems. Other upgrades to improve operating efficiency, such as installing infrared heating [redacted], may be beneficial but are not included in the estimated cost.

- **Surface transport costs:** During the first two northern phases, no additional surface transport requirements are anticipated, although some perimeter roads may need to be relocated. The southern phases require moving perimeter roads and a portion of A30 to make room for additional cargo handling and secure freight access. Terminal upgrades or expansions would occur to the east of Terminal 2 and require under-ground connections to the most appropriate tube station and parking. Expansion of tube access is scheduled for Terminal 2, so it is unclear if this would be in addition to or part of that expansion.

- **Costs associated with mitigating impacts on local communities:** We believe that the benefits of improved quality of life from reduced noise and pollution, coupled with a greater utilization of existing assets, outweigh the disturbances from these infrastructure changes for local communities and will require no mitigation.

- **The commercial attractiveness of the proposal for private investors:** To be very clear, there are two elements of our solution that will attract private investors: 1) the system construction and 2) the takeoff service operation. Our service business model will attract private investment based on its own merits, but private investment will be contingent upon the perceived political stability surrounding the Commission's recommendations; the UK must make a commitment to the project. Revenues from takeoff service will provide sufficient working capital for operations, but infrastructure (takeoff system components, manufacturing, and construction) financing may require government loan guarantees until the technology has a proven track record.

- **How costs will be met:** Industry analysts[17] emphasize that public funding of research and development in aviation technology is vitally important to maintain Europe's leadership position in aviation. Research funding has been directed to incremental improvement of aircraft and engine designs to improve cruise efficiency and reduce noise. Much less emphasis has been given to urban-centric airport development, including new business models for meeting the needs of passengers, airlines, and airports. The most direct way to provide the concept of Exhaustless' ExTS for the UK within the time constraints imposed on the Commission requires a focused financial commitment to accelerated technological development.

  Once integration and safety test results meet specifications, we anticipate that the Airports Commission, elected officials and Heathrow will endorse the system, opening up a market for the product and enticing private investors. Upon approval of our proposal, we expect the following economic impact to each of the constituents:

  - **UK taxpayer:**

    Costs: ExTS System construction costs; CAA engineering and the relocation of the tunnel entrance, government buildings such as HM Revenue & Customs building, and affected businesses and homes. Possibly accelerate construction timeline for mass transit serving Heathrow.

    Benefits: Minimize capital risk by building upon current infrastructure; reduced costs of emissions, pollution and noise.

  - **Airport:**

    Costs: Infrastructure costs of installing the system, including planning and design, on-site scale models, [redacted], offices and communications; airport infrastructure costs such as relocating remote parking.

    Revenues: Increased airport facility charge, estimated at £14 per ticket at current passenger volumes.

[17] http://www.acare4europe.org/sites/acare4europe.org/files/attachment/SRIA%20Executive%20Summary.pdf

- **Commercial investors:**

  Costs: Support needed to deliver and operate the system, including further research, development, design, manufacturing, testing, training, installation and operations.

  Revenues: Operations of the company, including the sale of systems and takeoff service revenue.

- **Airlines:**

  Costs: Takeoff fees.

  Benefits: Decreased fuel during takeoff and climb, [redacted] increased cargo capacity, potentially decreased carbon and other taxes related to improved quality of life metrics.

Deliverability

- **Estimated timescales:**
  - *Design:* Proof-of-concept and scaled model completed in 24 months, and full-scale model completed in an additional 6 months.
  - *Planning processes:* We anticipate that the planning process for Heathrow can begin once the proof-of-concept and scaled models are completed and will take 24 months.
  - *Construction:* Some components of the system, [redacted] will be delivered fully manufactured. The construction for the first system is the least disruptive and could be completed in 24 months. Systems 2, 3 and 4 each include varying amount of airport reconfiguration and infrastructure upgrades. More analysis is needed to determine the minimum lead-time required to reroute roads and/or cargo handling facilities and terminal 4.
- **Impacts on operations during development and construction periods:** For Phases 1 and 2 on the north side, the relocation of long-term parking will need to be managed. Phases 3 and 4 are more extensive and may require an additional terminal and airfreight operations.
- **Legislative issues:**
  - We are unaware of any UK or EU legislation that would require amendment in order to deliver the proposal. Our proposal does not affect any heritage sites.
  - CAA may need to clarify or amend regulations regarding assisted takeoff speeds, and may need to draft new rules related specifically to ExTS, with input from pilots.

Operational feasibility and safety

- **Integration with the overall air traffic system:** ExTS helps streamline air traffic management by separating takeoff and landing operations. In addition, departures transfer more quickly from the airport tower controllers onto the wider air traffic system.
- **Improved safety:** ExTS provides increased safety margins by enabling pilots to takeoff much faster than the aircraft stall speed. This higher velocity also eliminates rejected takeoffs by providing enough velocity for the pilot to circle and land rather than attempt to brake at high velocities with full fuel weight and little remaining runway.
- **Reduced bird strikes:** Risk of bird strikes is reduced due to the faster climb of an assisted takeoff, reduced thrust on runway and climb, and decreased duration spent in bird strike zone.
- **De-emphasis of prevailing winds and weather conditions on takeoffs:** Our system allows more consistent takeoff operations without regard to prevailing winds because we provide takeoff velocities far in excess of aircraft stall speeds. Our concept allows for de-icing just before takeoff using infrared heaters rather than sprayed chemicals given our use of [redacted].
- **Other changes to operations**[18]**:**
  - [redacted] aircraft are prepared for takeoff – [redacted] de-iced and transferred onto the guideway for takeoff.
  - Separation of takeoff from landings via dedicated guideway for takeoff and existing runways for landings.
  - Change flight-path profile to minimize noise during takeoff and initial climb.
  - Change punctuality measurement to really mean takeoff time.

Adaptability to future demand

- **Ability to expand in phases:** ExTS provides for investment in phases to meet demand in a more modular and evolutionary fashion. Independent of increased capacity needs, installation of one or more systems would be beneficial to ensure:
  - Adequate resilience to routine weather events that don't shut down airports but restrict traffic schedules.
  - Faster recovery from system wide weather events that shut down airports.
  - Reduced noise from takeoffs.
  - Reduced GHG emissions and pollution.

[18] Appendix G diagrams some of these airfield operational improvements.

- **Adaptability to/Influence on future developments in aircraft technology:** Our system design handles the mix of size and weight between narrow body aircraft and the super jumbos. Our design is in line with the trend of aircraft that are more carbon fiber based with flexible outer wings. [redacted]

  In addition, as our concept becomes more common at airports across the UK and globally, certain routes may be able to operate with engines more optimized for cruise. In other words, our system may impact the plans of future aircraft design to meet fuel reduction and emission goals.

Summary of risks to deliverability

- **Legal and planning process:** Because our solution has the potential to modestly expand the airport boundaries and displace homes and businesses, there will be legal and planning risks associated with the proposal. Implementing the proposal in phases mitigates these risks, beginning with the least intrusive option and allowing time to more fully develop, plan and assess the need for the later phases.

- **Financing:** The schedule for development of the system requires timely public financing. Once the commission prescribes the first system as the preferred solution (after acceptance of test results), working capital needs of the Company and infrastructure costs to the airport will be met with private financing. The DfT may need to provide loan guarantees for the first system to ensure acceptable finance costs for the taxpayers. Once the first system is operational, ongoing profitability for the airport and airlines will allow continued private financing. In other words, the business model must stand on its own for private financing after the first system.

- **Technical, construction and engineering risks:** The components of the system are already in commercial use, but integrating them into one system does carry some technical risk. We believe the risk is not to its deliverability, but to the schedule and budget, which will be the largest risk borne by public investment. The best way to mitigate this risk is employing the best-qualified engineers, project managers and materials partners and planning transparent deliverables and goals.

- **Operational transition:** The transition to the ExTS system will require thorough pilot, air traffic controller and system operator training and will likely be ramped up over several months; however, the current runway can continue to be used for takeoffs during this training time. We anticipate a gradual transition to full implementation.

Conclusion

We imagine a bright future for aviation in the UK. More than just expanding Heathrow, Exhaustless improves the UK's productivity by introducing 21st century technology to provide an urban-centric airport business model. Beyond a construction project, the Exhaustless Takeoff System (ExTS) aligns with the goals of the UK to reduce urban sprawl, noise, pollution, and emissions while improving safety.

There is no better way to reduce noise and pollution from jet aircraft than to reduce jet fuel use directly. Eliminating 43% of the jet fuel burned during taxi-out, takeoff and climb creates a new relationship between Heathrow and the surrounding communities.

There is also no better way to reduce surface congestion than to prevent the need for employees, passengers, and cargo to commute greater distances to airports. We will increase overall transport throughput by using the extensive transport infrastructure available at Heathrow.

We have invested heavily in our intellectual property because we see a growing market of the world's airports with similar needs. We feel uniquely qualified to meet the UK's schedule and commitments for more sustainable airport capacity, providing the best way to move forward.

With any new technology, there is a tendency to jump to conclusions about its efficacy before data can be gathered and risks quantified. The commission has greatly reduced this possibility by recruiting scientists and engineers to the panel, who will demand evidence-based test measurements instead of conjecture. Extending the current technology limits some risk, but only integrated testing can establish confidence for commercial aviation.

With £200M, the UK will create an option for a cost-effective and productive solution to aviation challenges. The potential payoff for all is too high to wait.

Appendix A: Possible reduction in takeoff queue times – Phase 1

Time is Money PK Formula	Current Process	ExTS Process	Unit
ci	1	1	interarrival variability
cp	1	0.75	process time[a]
Ri	18	18	arrival rate per hour
Rp	20	26	max takeoffs per hour[b]
rho	0.90	0.68	utilization[c]
c	1	1	number of runways / guideways
1/Rp	0.050	0.038	
(Ci^2+Cp^2)/2	1	0.78	
exp	1	2	
exp - 1	1	1	
rho^exp	0.90	0.68	
rho^(exp-1)	0.91	0.77	
1-rho	0.10	0.32	
T	0.45	0.07	time in queue - hours
	27.00	4.35	time in queue - min
I	8.10	1.16	planes in takeoff queue
		84%	**Reduction**

[a] *The reduction in process time is due to independence of landings from takeoffs as well as reduced takeoff time.*

[b] *Calculation of takeoff rate*

	Current Process	*ExTS Process*	*Unit*
[redacted]	-	1.00	minutes [redacted]
Wait to takeoff	2.62	1.00	minutes
Takeoff	0.70	0.28	minutes
Total	3.32	2.28	minutes
Takeoff rate	18	26	per hour

[c] *Utilization rates at various levels of demand*

	Arrival rate	*# of guideways*	*Utilization*
Phase 1	18	1	0.685
Phase 2	18	2	0.343
Phase 2	36	2	0.685
Phase 2	45	2	0.860

These levels of utilization show how we provide resilience by keeping average utilization below 75% and peak utilization below 86%.

Appendix B: Cost Benefit Approximation

Benefits	£ Million
Reduced waiting to takeoff[1]	£400
Increased resilience	£100
Contribution to climate goals	£100
Contribution to domestic energy	£100
Reduced noise	£250
Less land sprawl	-
Less overlap of airspace with other airports	-
Reduced risk of litigation	£50
Decrease in pollution	£500
Sub total	£1,500
Increased Economic Activity[2]	£1,500
Total (each operational year)	**£3,000**
$PV_{BENEFITS}$ of growing perpetuity = $D_0/(r-g)$ = 3B £/(7%-2%)	£60,000

Costs	£ Million
$PV_{MAINTENANCE}$ = 0.4B £/(.07-.02)	£8,000
$PV_{ExTS+Construction}$	£4,000
PV_{COSTS}	**£12,000**
COSTS: BENEFITS	**12:60**

Assumptions

$r_{discount}$	7%
$g_{growth\ rate}$	2%

[1]Waiting to takeoff (Value of Time)

Passengers departing per day	100,000
Avg delay per flight, minutes	12
People-waiting-minutes per day	1,200,000
People-waiting-hours per day	20,000
Value of Time (.85 € to £) [3]	£52
Per day waiting costs	£1,040,000
Annual waiting costs	£379,600,000

[2] *Frontier Economics, Connecting for Growth, 2011. This figure represents potential increase in UK trade imports, and does not include real estate price increases that may result from using ExTS. This volume translates into approximately 32,000 new jobs.*

[3] *http://www.london.gov.uk/mayor/economic_unit/docs/heathrow-economics-study-nov06.pdf*
This Value of Time was based on a 2005 study.

Appendix C: Fuel and emissions savings at Heathrow from adopting ExTS

							Estimate Using Current Methods				Estimate Using Exhaustless Takeoff System						
	ICAO Engine Exhaust Emissions Data (per engine)						Total Fuel/Emissions per Aircraft				Per Engine		Total Fuel/Emissions per Aircraft				
	Power Setting	Time seconds	Fuel Flow kg/s	HC g/kg	CO g/kg	Nox g/kg	Fuel kg	HC g	CO g	NOx g	Time seconds	Fuel Flow kg/s	Fuel kg	HC g	CO g	NOx g	Fuel Reduction
GE90-115B (B777) [a]							2 engines								75% weighting		
Take-off	100%	42	4.69	0.04	0.08	50.34	394	16	32	19,834	17	1.13	38	2	3	1,913	90%
Climb out	85%	132	3.67	0.03	0.07	35.98	969	29	68	34,865	79	3.67	581	17	41	20,904	40%
approach	30%	240	1.13	0.06	1.98	16.50	542	33	1,073	8,943	240	1.13	542	33	1,073	8,943	0%
idle	7%	1560	0.38	4.24	39.11	5.19	296	1,255	11,577	1,536	390	0.38	296	1,255	11,577	1,536	0%
idle - allocate to TO [d]							890	3,774	34,808	4,619	878	0.38	667	2,828	26,086	3,462	25%
LTO total fuel (kg) or emissions (g) calculated							3,091	5,106	47,557	69,797			2,124	4,135	38,780	36,758	31%
Genx-2B67 (B747) [b]							4 engines								25% weighting		
Take-off	100%	42	2.451	0.02	0.17	31.2	412	8	70	12,854	17	0.70	48	1	8	1,498	88%
Climb out	85%	132	2.012	0.02	0.28	17.94	1,062	21	297	19,052	79	2.01	637	13	178	11,428	40%
approach	30%	240	0.701	0.06	2.53	9.58	673	40	1,703	6,447	240	0.70	673	40	1,703	6,447	0%
idle	7%	1560	0.216	0.57	18.95	4.43	337	192	6,386	1,493	390	0.22	337	192	6,386	1,493	0%
idle - allocate to TO [d]							1,011	576	19,158	4,479	878	0.22	758	432	14,364	3,358	25%
LTO total fuel (kg) or emissions (g) calculated							3,495	838	27,615	44,326			2,453	678	22,639	24,224	30%
Weighted Average of Engine Types															100%	Total	
Take-off							399	14	41	18,089			41	1	4	1,809	90%
Climb out							992	27	125	30,912			595	16	75	18,535	40%
approach							575	34	1,231	8,319			575	34	1,231	8,319	0%
idle							306	989	10,279	1,525			306	989	10,279	1,525	0%
idle - allocate to TO							920	2,974	30,896	4,584			690	2,229	23,156	3,436	25%
LTO total fuel (kg) or emissions (g) calculated							3,192	4,038	42,572	63,429			2,207	3,269	34,745	33,624	31%
Heathrow Annual LTO Cycles [c]			250,428			% Total Fuel	Annual Fuel/Emissions					% Total Fuel	Annual Fuel/Emissions				Fuel Reduction
Take-off						13%	99,920,772	3,505,992	10,267,548	4,529,992,092		2%	10,267,548	250,428	1,001,712	453,024,252	90%
Climb out						31%	248,424,576	6,761,556	31,303,500	7,741,230,336		27%	149,004,660	4,006,848	18,782,100	4,641,682,980	40%
approach						18%	143,996,100	8,514,552	308,276,868	2,083,310,532		26%	143,996,100	8,514,552	308,276,868	2,083,310,532	0%
idle						10%	76,630,968	247,673,292	2,574,149,412	381,902,700		14%	76,630,968	247,673,292	2,574,149,412	381,902,700	0%
idle - allocate to TO						29%	230,393,760	744,772,872	7,737,223,488	1,147,961,952		31%	172,795,320	558,204,012	5,798,910,768	860,470,608	25%
LTO total fuel (kg) or emissions (g) calculated						100%	799,366,176	1,011,228,264	10,661,220,816	15,884,397,612		100%	552,694,596	818,649,132	8,701,120,860	8,420,391,072	31%
TO total fuel (kg) or emissions (g) calculated							578,739,108	755,040,420	7,778,794,536	13,419,184,380			332,067,528	562,461,288	5,818,694,580	5,955,177,840	
Reduction of takeoff fuel/emissions													43%	26%	25%	56%	

a) Archived datasheets, Version 18, GE Aeroengines, *7GE099 - GE90-115B DAC (27.01.2012).pdf* http://easa.europa.eu/environment/edb/individual-engine-datasheets.php
b) Archived datasheets, Version 18, GE Aeroengines, *11GE139 - GEnx-2B67 TAPS (27.01.2012).pdf* http://easa.europa.eu/environment/edb/individual-engine-datasheets.php
c) Airports Council International Annual Traffic Data – Movements: http://www.aci.aero/Data-Centre/Annual-Traffic-Data/Movements/2010-final

Appendix D: Calculation of annual CO_2 savings - Heathrow

	Current Method	Exhaustless	Savings	% Savings	Unit
	99,920,772	10,267,548	89,653,224	90%	annual kg fuel - TO
	248,424,576	149,004,660	99,419,916	40%	annual kg fuel - Climb
	230,393,760	172,795,320	57,598,440	25%	annual kg fuel - Idle allocated to TO
	578,739,108	332,067,528	246,671,580	43%	annual kg fuel[a]
x	2.20462	2.20462	2.20462		lb/kg
/	6.84	6.84	6.84		lb/gallon
=	186,535,060	107,029,636	79,505,424		gallons fuel
x	9.75	9.75	9.75		kg CO_2/gallon[b]
=	1,818,716,838	1,043,538,956	775,177,882		kg CO_2
=	**1,818,717**	**1,043,539**	**775,178**	**43%**	**metric tons CO_2 - current capacity**
	3,637,434	**2,087,078**	**1,550,356**		**metric tons CO_2 - 2x current capacity**
		15%			**increase of CO_2 from current method to 2x with ExTS[c]**

[a]*See Appendix A for calculation of fuel useage*

[b]*http://www.theclimateregistry.org/downloads/2012/01/2012-Climate-Registry-Default-Emissions-Factors.pdf*

[c]*With ExTS, doubling departures from airport increases annual CO_2 emissions from takeoff and climb by 15% relative to current levels.*

Appendix E: How Exhaustless ExTS reduces noise for departing aircraft

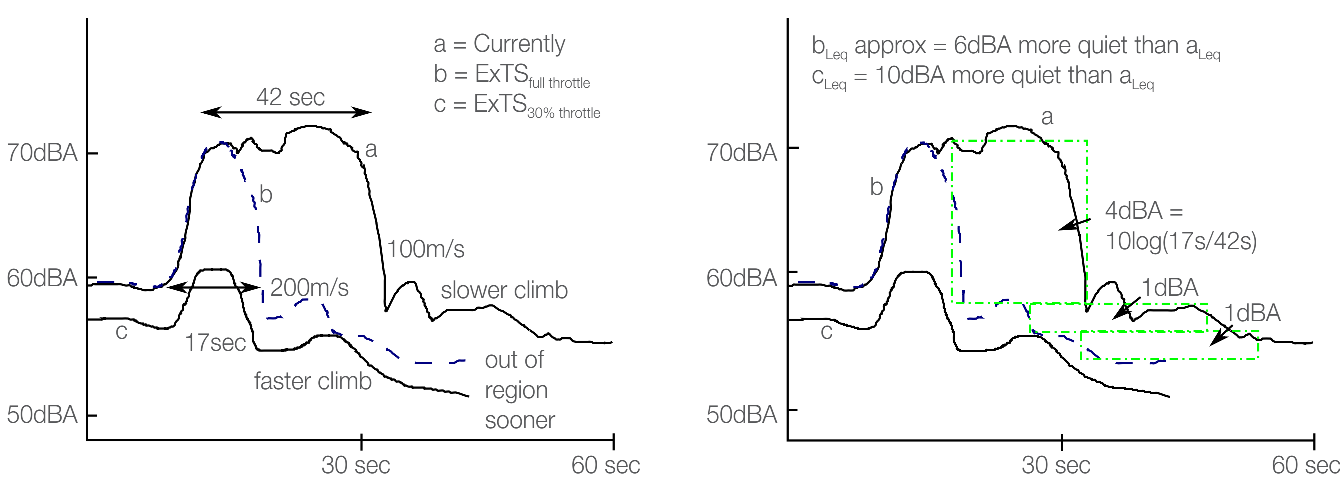
Using grid-power to accelerate aircraft reduces the thrust that must be provided by the onboard engines during takeoff and climb. The relationship of noise versus thrust produced for similar engine types shows an 8dB drop at 40% thrust and 10dB drop at 30% thrust. Late model geared turbofan designs already make reductions in fan speeds to take advantage of this relationship, but our system provides the same benefits to all aircraft without waiting for current fleets to be replaced over the coming decades. (Also, since many of the large aircraft have sizable turbofans today, it is unclear how much larger and slower these fans can operate on current product designs).

The distance to the engine from the edge of the airport also changes with our design. The distance from Cranford to the current start of takeoff measures 1.3km. Our concept moves the start of acceleration to the west of the tunnel road which doubles the distance and provides an additional 3dB drop in noise plus any dissipation provided by the air and ground.

Increased Doppler shift from higher acceleration will depend upon location, but this brings up an interesting point. The faster acceleration produces higher frequencies for those locations in front of the aircraft by roughly 1.3x using 100m/s and 200m/s as the typical speed of the aircraft at takeoff without ExTS and with ExTS, respectively.

Our design also reduces overall airframe noise during takeoff. [redacted] Drag from the slats and flaps are much lower in our configuration because the higher takeoff velocity provides enough lift without increasing wing area. Noise from the boundary layer flowing around the airframe, the empennage, wing fairings and related vortices will increase compared to slower takeoffs, but these items are all designed to produce the least drag possible since they are part of the drag experienced during cruise. [redacted] We have been unable to find literature on the level of airframe noise at different slat and flap settings.

Figure 6 shows how ExTS would reduce noise intensity and duration providing two scenarios. (These plots were created to help engineers understand and quantify potential noise reduction, but for how these scenarios would sound to humans, please see the audio files simulating takeoffs for each of these scenarios.) Scenario ‘a’ represents a typical takeoff as experienced using jet-fuel for acceleration. Scenario ‘b’ shows the same airplane using ExTS while maintaining full throttle during takeoff. Scenario ‘c’ shows the reduction provided by relying upon ExTS for most of the energy needed during acceleration with reduced throttle to 30%.



Rectangles are areas of reduced noise

Figure 6: Changes to noise duration (left) and intensity (right)

Appendix F: Process to simulate noise reduction from using ExTS

The following list of steps describe the process applied to an audio file to simulate the noise reductions provided by Exhaustless:

1. Simulations were made using Audacity version 2.0.3 with mp3 add-on.
2. On Mac OSX computers, audio must be passed through a virtual device. See: http://www.wikihow.com/Record-Application-Audio-With-Soundflower for how to configure Soundflower to record audio from streaming media.
3. An audio file was recorded from YouTube video of Aircraft Taking off from Heathrow.
4. Left and Right audio tracks truncated to the first three takeoffs.
5. Center of each takeoff was truncated to produce 17-second takeoff.
6. The entire audio track was amplified by -10dB to simulate the difference between full throttle and 30% throttle
7. Frequency increased by 1.3 to simulate the additional Doppler shift that would occur from the increased velocity over the 17-second takeoff.
8. The trailing portion of the audio after the peak noise level was faded from 0 to -3dB to simulate the effect of the airplane leaving the runway at higher speed.
9. The start of each takeoff was faded-in from -3dB to 0dB to simulate the affect of the throttle moving from idle to 30%.

Figure 7 shows the Doppler shift as the aircraft accelerates during takeoff. Since acceleration is constant (velocity increases throughout the takeoff) the shift is an increasing frequency perception in front of the aircraft; but the shift to higher frequency is more pronounced using the Exhaustless Takeoff System (ExTS). Near takeoff, frequencies are nearly doubled from those currently observed. The higher absorption of the increased frequencies by the air and ground are not modeled in our audio simulations. The precise terrain and atmospheric conditions will require effort by CAA to apply their acoustic models to estimate new noise contour lines as they have in the past. Their model would need to incorporate new takeoff acceleration rates and adjust assumptions regarding airframe noise levels.

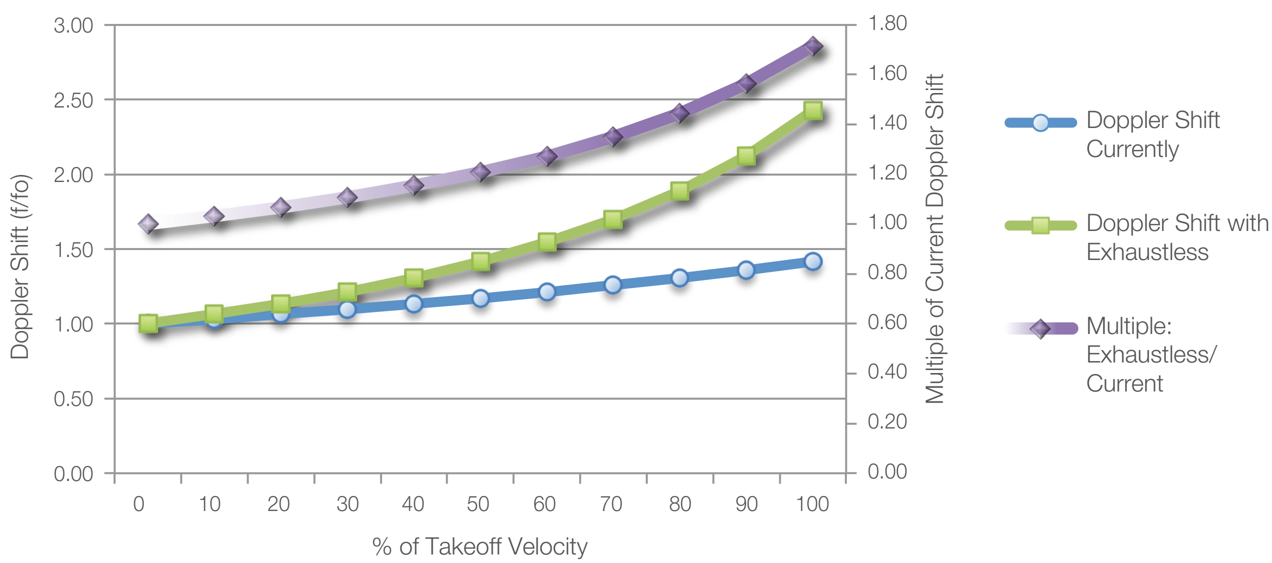


Figure 7: Change in Doppler shift In front of aircraft from using ExTS

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