Perpetual Flight - atmospherically powered, long endurance flight

PROGRAMME THESIS

v1.0

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CONTEXT

This document presents the core thesis underpinning a programme that is currently in development at ARIA. We share an early formulation and invite you to provide feedback to help us refine our thinking.

This is not a funding opportunity, but in most cases will lead to one — sign up **here** to learn about any funding opportunities derived or adapted from this programme formulation.

An ARIA programme seeks to unlock a scientific or technical capability that

+ changes the perception of what's possible or valuable
+ has the potential to catalyse massive social and economic returns
+ is unlikely to be achieved without ARIA's intervention.

This programme thesis is the starting point for a potential ARIA programme. It is the foundation around which the programme team will build a full programme.

We aim to launch the programme funding call in late 2025, pending approval.

PROGRAMME THESIS, SIMPLY STATED

An overview of the programme thesis, accessible & simply stated

In 1957, Sputnik marked the beginning of a new kind of infrastructure, one that operated above the Earth. Since then, satellites have transformed the modern world, enabling global communication, positioning, and Earth observation. But space-based infrastructure carries deep limitations: putting new hardware into orbit typically takes five years or more, and once launched, it is immutable and follows a trajectory that cannot easily be changed. The distance to Low Earth Orbit imposes hard physical constraints — on latency, resolution, power, and persistence — that no amount of engineering can fully overcome.

A new layer of infrastructure, operating persistently within the atmosphere, could overcome these constraints. For an atmospheric alternative to viably integrate with or replace satellites, it would appear we need a way to keep aircraft aloft for months at a time. Existing approaches — using fossil fuels, solar power, or lighter-than-air vehicles — have so far proven too limited, fragile, costly, or impractical to deliver persistent flight at scale.

Nature signals that atmospheric energy may be the key. The albatross and the frigatebird extract energy from wind gradients and thermal lift to sustain flights of several hundred kilometres, even over oceans and at night [30]. They show atmospheric energy is harnessable. With advances in sensors, autonomy, and predictive weather models, aircraft could be able to detect and harvest atmospheric energy more effectively than any bird, potentially at far higher altitudes. Atmospheric energy harvesting has the potential to enable cost competitive, long endurance platforms. These could deliver many of the services of today's satellites, but with vastly greater flexibility, speed, and precision; improving performance by one or more orders of magnitude.

ARIA's Perpetual Flight Programme will bring together enabling hardware, weather modelling, and autonomous flight robotics to develop the foundational capability for aircraft to remain aloft for months. In parallel, the technical and economical viability of different enabled applications – possibly including centimeter scale positioning, low latency communication, and real-time analytic imaging – will be iteratively co-developed with the maturing flight capability.

This programme is derived from the ARIA Opportunity Space: [Scoping Our Planet](#).

PROGRAMME THESIS, EXPLAINED

A detailed description of the programme thesis, presented for constructive feedback.

Satellite services have become indispensable to modern life, underpinning navigation, global communications, weather forecasting, disaster response, and scientific discovery. The ability to place sensing, communications, and positioning systems in orbit has created tens of trillions of pounds in value and transformed how we live and work.

Much of the utility of satellites comes from their line-of-sight access to large areas of the Earth's surface, something terrestrial assets like cell towers cannot achieve. Yet the vast distances involved mean that signals to and from satellites are subject to a fundamental power penalty that scales with the square of the distance, leading to significantly narrower link budgets (see box below). Distance further imposes an irreducible latency as signals travel to outer space and back. Signals also get distorted by the atmosphere, in particular in the ionosphere. As the demand for real-time data, ubiquitous connectivity, and persistent situational awareness grows, these constraints represent a performance ceiling that is rapidly being approached.

This programme thesis posits that the logical and necessary evolution of our global infrastructure is the creation of a persistent atmospheric layer. The pull for such a solution has driven major advances in High-Altitude Pseudo-Satellites (HAPS). Lighter-than-air platforms like Google Loon connected hundreds of thousands of users worldwide [2]. Solar-powered fixed-wing aircraft such as Airbus Zephyr have set endurance records of several weeks [3], evidence that long-endurance atmospheric platforms are technically feasible, even if they still face major blockers preventing their commercial viability. The significant investments in HAPS to date underscore that such capabilities are seen as disruptive, rather than merely incremental improvements.

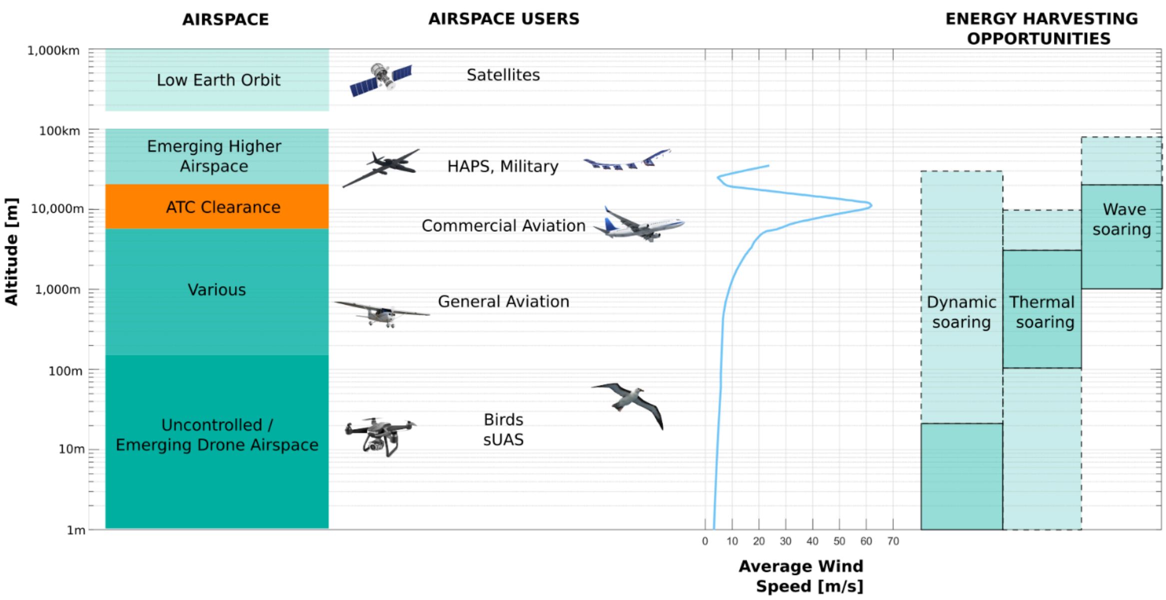

Figure 1: Chart showing atmospheric layers, the aircraft that frequent them, and atmospheric phenomena that have been demonstrated (boxes) or could potentially be harnessed (dashed boxes) for sustained flight. Among these, thermal soaring in the lower atmosphere is the best understood. Dynamic soaring, a method to extract energy from wind shear perfected by birds like the albatross, has yet to be achieved by autonomous aircraft. It remains uncertain whether the wind regimes of the middle atmosphere (~10-90 km elevation) support it. Stratospheric gravity-wave soaring has been achieved to an altitude of 23 km, but our current understanding and models are insufficient for their reliable prediction and exploitation.

Existing HAPS platforms face significant limitations. Lighter-than-air vehicles struggle to hold station, making consistent coverage difficult and leading to low utilisation [2]. Solar-powered HALE (high altitude, long endurance) aircraft require vast photovoltaic surface areas, have extremely low wing loading and ultra-light structures, leaving them vulnerable to structural failure except in the calmest conditions [3]. Even the most advanced solar HALE platforms are constrained by the availability of sunlight at higher latitudes [5] and by battery cycle limits at lower latitudes, capping missions at a few months [3]. Aircraft amortisation dominates operational costs, with 1 in 4 missions ending with aircraft loss [7].

Atmospheric energy as a power source is underexplored. While HAPS development has attracted billions, funding to investigate how aircraft could harvest energy from the atmosphere has been two orders of magnitude smaller [8]. And yet, atmospheric energy is abundant, and its exploitation for flight proven: In the lower atmosphere, many birds routinely obtain 90% or more of their flight energy from the air itself [9]. Albatrosses, for example, can traverse thousands of kilometres without flapping by extracting energy from wind shear over the ocean.

Most of our knowledge about how aircraft can exploit atmospheric energy comes from the lower atmosphere (See Figure 1 above). Software allowing gliders to autonomously detect and center thermals and other forms of lift has been published. We understand the manoeuvres referred to as *dynamic soaring* to exploit the energy from wind shear [1]. Exploitable conditions of wind shear may exist near jets at altitudes extending into the stratosphere. Also in the middle atmosphere, gravity waves (oscillations that occur when stable atmospheric layers are displaced) can generate vertical motions of a few metres per second, see Figure 2 below. Sailplanes have used such waves to climb to heights of 23 km [10].

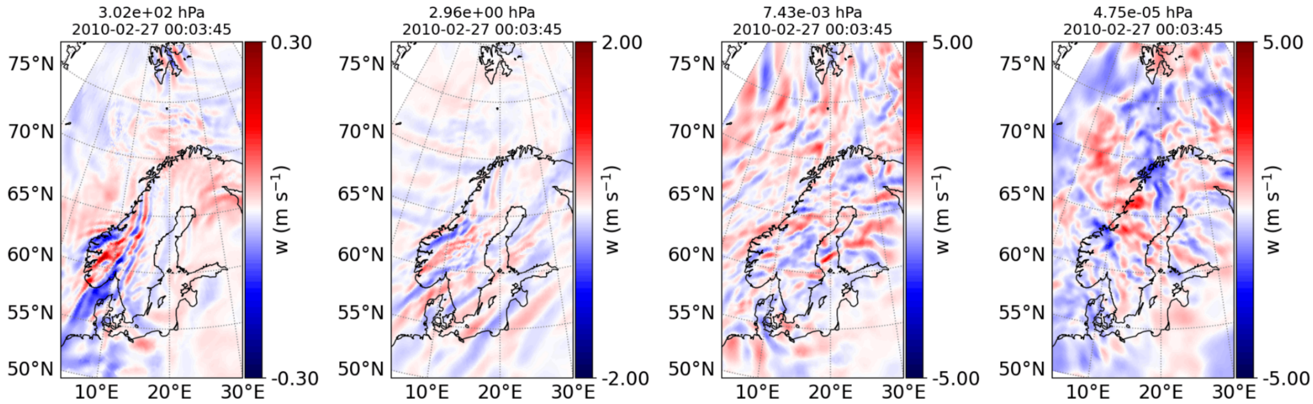

Figure 2: Modelled animations (pdf gives a snapshot in time) of gravity waves, showing vertical velocity maps at ~9 km, 30 km, 40 km and 45 km altitude as a function of time over 24 hours. Gravity waves could be used by aircraft to gain altitude. They are abundant in the middle atmosphere. The distance between individual patches of lift is estimated to be of the order of tens to hundreds of km, while the distance between areas of strong horizontal wind shear are estimated to be of the order of single to hundreds of kilometres. [11 - Figure courtesy of Martin Kupilas & Dan Marsh at Leeds University].

For today's solar HALE, two determining design elements —PV array size and battery weight fraction— are driven by their critical reliance on diurnal solar energy. Some of the described atmospheric phenomena persist through the night. This opens the possibility for aircraft to overcome the need for large battery fractions, large PV arrays, and low structural integrity. Rather, they might rely primarily on atmospheric energy, harvesting and storing surplus when available. The bill of materials for manufacturing such aircraft would be significantly reduced. More importantly, it would also remove the primary endurance constraints, potentially unlocking year-long missions, with an order of magnitude fewer aircraft failures.

Atmospheric platforms, airborne for months at a time, would be flexible and fast to deploy, and outperform orbital systems in latency and resolution. Like satellites before them, we expect their most valuable applications to emerge once the infrastructure exists.

If successful, this programme will develop long-endurance aircraft with flight endurance of over one year and cost reductions of an order of magnitude. This achievement could enable a layer of digital infrastructure between earth and satellites, offering 10 – 100× improvements in precision. This could not only

transform navigation and sensing, but also create groundbreaking capabilities enabling new industries outside of our current imagination.

Surpassing the hard limits of space infrastructure

Persistent aircraft operating within the atmosphere could offer an opportunity to outperform orbital systems in multiple critical dimensions — speed of deployment, responsiveness and persistence, and data quality. They combine the advantages that make satellites valuable with the agility and proximity of terrestrial systems.

Unlike space systems, atmospheric platforms could deploy new hardware payloads within weeks rather than years, and would not require very large constellations to serve a given geography. The list below gives an overview of some of the constraints that atmospheric platforms could overcome.

+ Latency: The time required for a signal to travel at the speed of light to outer space and back is a significant barrier for time-critical applications. This delay is a fundamental impediment to real-time robotic control, high-frequency trading, and certain distributed computing architectures. An atmospheric platform reduces this travel time by more than an order of magnitude compared to LEO.
+ Resolution and Power: Communication link power scales inversely with the square of the distance ($1/r^2$), so it takes roughly 600× more power to transmit a signal from Low Earth Orbit to the ground than from the middle atmosphere, with a massive effect on link budget, bandwidth, and hardware (See next bullet). Optical resolution scales linearly with altitude, so a platform 25× closer achieves ~25× finer ground detail with the same optics. Both effects allow significantly smaller, lighter, and cheaper hardware to achieve the same performance.
+ Link Budget, Bandwidth & Hardware: Orders of magnitude stronger signals from stratospheric platforms reduce the need for high-gain antennas and high transmit power, allowing higher-bandwidth links to ordinary devices such as phones [16].
+ Atmospheric Disturbance: Signals to and from satellites must traverse the entire atmosphere, making them vulnerable to degradation from interactions with the atmosphere and its weather. An airborne platform is not subject to the full thickness of the atmosphere in its connections with the ground below. Similarly, observation applications may benefit from reduced atmospheric optical distortion and cloud obscuration.
+ Design: Unlike satellites, atmospheric platforms experience less exposure to cosmic radiation and avoid the thermal management challenges of operating in

a vacuum [12]. This can make it easier to use robust, commercially available electronics. New challenges arise above the lower atmosphere, where designs must account for extreme temperatures, low pressure, and high UV levels.

+ Rapid Deployment & Persistence: Atmospheric platforms could avoid the 5-year lead times and immutability of space hardware. Furthermore, they can loiter to persistently serve a target region.

Constraints overcome by atmospheric platforms relative to satellites.

WHY IT'S WORTH SHOOTING FOR

Two high-value use cases that exemplify the potential value of long endurance airborne platforms are Measurement (near-term) and PNT (Positioning, Navigation, and Timing) in the longer-term. Both address pressing capability gaps and offer the potential for outsized economic and societal returns.

Measurement (including Earth Observation)

+ **In-situ atmospheric measurements**
  Persistent, targeted in-situ measurements at altitude in data-sparse regions such as the oceans and the Southern Hemisphere are a likely route to improving weather and climate forecasts [13, 14]. Forecast improvements translate directly into economic value by enabling better decision-making in sectors such as agriculture, logistics, and disaster response. Long endurance high altitude platforms could deliver thus far unavailable measurement data such as in-situ sampling of aerosols and thermodynamic profiles. These could help resolve one of the most important uncertainties in climate science: aerosol-cloud interactions. This "aerosol-cloud problem" is a leading contributor to uncertainty in climate sensitivity estimates aerosol-cloud problem [15]. Reducing this uncertainty even modestly, could unlock societal and economic benefits worth trillions of pounds through improved climate projections and better-targeted mitigation and adaptation strategies.

+ **Persistent Earth observation**
  Satellites have revolutionised Earth observation, but revisit times, observation geometry, and latency impose hard limits. An atmospheric layer operating continuously over a region could deliver real-time, persistent coverage, at an order of magnitude higher resolution. This would enable applications ranging from continuous monitoring of dynamic features such as illegal fishing, wildfires, glaciers, or volcanic activity to ultra-responsive imaging for disaster response or security operations.

Positioning, Navigation, and Timing (PNT)

Providing positioning, navigation, and timing —ultimately a communications application— is an example of the impact digital infrastructure on long endurance aircraft could have.

Table 1 below compares the cost scaling of investments into terrestrial, satellite, and HAPS infrastructure to provide better services like communications or PNT. Unlike terrestrial or LEO infrastructure, HAPS have the potential to continuously cover a region with a low number of additional nodes in a constellation.

[Rough orders of magnitude]	**Terrestrial infrastructure**	**HAPS infrastructure**	**LEO infrastructure**
Transmission radius of a node	1 km	100 km	1,000 km
Cost to add a node	£100,000 (incl. permitting & real estate)	£10 million (incl. aircraft and ground station)	£1 million (incl. sat, launch, & ground station)
Investment to increase regional coverage (e.g. England)	£10 billion (+100,000 nodes)	£60 million (+6 HAPS)	£2 billion (+2,000 sats)

Table 1: Comparing rough order of magnitude cost scaling for providing better connectivity to a region via terrestrial, HAPS based, and satellite based services [16].

For the use case of PNT, medium Earth orbit (MEO) satellite-based legacy systems such as GPS and Galileo have hit their practical performance ceiling, typically providing few metres accuracy under optimal conditions. This is insufficient for most autonomous vehicle applications.

Precision is degraded by the signal distortions in the atmosphere/ionosphere, and errors scale with the time of flight for signals to overcome the 20,000 km from MEO to Earth. More precise PNT with better coverage would unlock enormous value [17], for example by enabling autonomous vehicles to precisely orient themselves. Large investments are being made to provide "PNT as a service": a paid, higher quality PNT offered by the private sector. Performance increases can be achieved by addition of terrestrial infrastructure, by using LEO satellites (LEO is 40x closer than MEO), and by hybrid approaches. The cost scaling follows the pattern shown in Table 1. While the cost scaling of LEO constellations is favorable for providing global rather than regional coverage, the performance scaling achievable with LEO satellites is limited by physical limits, to the detriment of coverage in urban canyons and indoors.

A high-altitude, airborne PNT overlay, at least an order of magnitude closer to the user than satellites, could deliver faster convergence, lower latency, and significantly better coverage —advantages that follow directly from the much larger link budget of atmospheric platforms— especially in urban environments. This could potentially translate into 10 – 100× gains in precision for users within coverage, with greater resilience against jamming and spoofing. Such a capability would directly benefit applications where precision is critical, including autonomous transport, precision agriculture, automated construction, and emergency response.

WHY NOW

We appear to be approaching the point where atmospheric power could enable long endurance aircraft. At the same time, the market is ready for the services it could bring.

1. **AI is transforming weather prediction**

A new generation of AI-driven models can forecast at unprecedented resolution and update in minutes. They are approaching the ability to predict the location and strength of wind shear and lift — the atmospheric energy sources this programme seeks to exploit. This could allow planning flight trajectories maximizing energy capture. Interestingly, these models perform best when fed with fresh data from parts of the world that are sparsely observed today a gap autonomous vehicles could fill in a virtuous two-way loop (K-better data ⇄ better forecasts).

2. **Beyond GPS' ceiling: Unlocking new industries with higher-resolution PNT**

Global Navigation Satellite Systems (GNSS) now provide metre-scale accuracy for most users. Higher precision is possible today, but only with costly, regional augmentation systems that are slow to converge and not universally available. Many emerging sectors, from autonomous transport to precision agriculture, are constrained by this limit. Airborne PNT could deliver 10–100× greater precision, more quickly, and at a lower cost than satellite augmentation.

3. **Resilience in an uncertain future**

GNSS signals and other satellite services are increasingly subject to jamming, spoofing, and unintentional interference [18]. Long endurance aircraft could be the enablers of a resilient, affordable, sovereign, and superior service for the British Isles.

4. **Small, powerful payloads**

Once large and power-hungry communications and sensing payloads can now fit in the palm of a hand. Chip-scale atomic clocks, compact free-space optical terminals, software defined radios, and miniaturised sensors mean that even small aircraft can deliver high-value services.

WHAT WE HOPE TO ACHIEVE: GOALS & METRICS

By developing the technology to harness atmospheric power for long endurance flight, this programme aims to drop the hourly operating cost of long endurance aircraft by an order of magnitude with respect to the state of the art. By breaking the reliance on solar power, the primary blockers of endurance are removed, while at the same time enabling dramatic increases in aircraft survivability.

Programme success will be measured by the fraction of atmospheric to total consumed power for a flight of 1-month endurance. By the end of this programme, successful Creators are expected to have demonstrated achievement of the **Threshold** requirement, with a compelling plan to achieve the **Goal**.

	State of the art	**Threshold requirement**	**Goal**
Atmospheric energy share over a 1-month mission *(Fraction of total energy supplied by atmospheric sources)*	<10% Today's solar High Altitude, Long Endurance (HALE) aircraft rely on solar energy. Some use atmospheric energy opportunistically, when lift is encountered in non-threatening conditions	>60% Covering >60% of energy needs through atmospheric energy allows parting from legacy solar aircraft design with enormous wing surface and low wing loading	>90% Covering >90% of energy needs through atmospheric energy removes the battery as an endurance blocker and cost driver
Implication	Solar aircraft have very large wing area and very low	This is expected to enable a significant increase in gust	Without batteries as a blocker, flight endurance well over

	wingloading, making them fragile. High performance solar cells and battery technologies make up the majority of aircraft cost and do not exhibit favourable cost scaling.	tolerance. Aircraft loss rates are expected to drop to 1 in 20. Reduced battery reliance allows smaller, lower-energy density, higher-cycle life batteries to be used.	1 year appears feasible. Gust tolerance can be increased even further.

The table above shows threshold and goals for atmospheric power usage. By comparison, birds like Albatross use atmospheric power (primarily wind shear) to cover >90% of the energy required to keep them aloft. The middle atmosphere is expected to contain both lift in the form of gravity waves and wind shear, potential sources of energy that could be harvested.

Estimated cost per hour for existing fossil fuel UAVs and existing high altitude long endurance (HALE) platforms in relation to the programme threshold and goal[1].

+ **Fossil-fuel long-endurance UAVs** (e.g., ScanEagle, fully burdened): ~£1,000/hr
    - ~20% of cost is hardware amortization
+ **Solar HALE** (e.g. Zephyr): ~£7,000/hr
    - ~85% of cost is aircraft amortization; 1 in 4 aircraft lost on ascent/descent
    - ~70% of aircraft cost is battery & PV array
    - Battery degradation primary limiting factor capping endurance to 2 months
+ **Perpetual Flight** Threshold: ~£500/hr
    - <25% of cost will be aircraft amortization; loss rate improved to 1 in 20
    - Battery degradation removed as primary blocker to endurance
+ **Perpetual Flight** Goal: ~£100/hr
    - <20% of cost will be aircraft amortization; loss rate improved to 1 in 200
    - Learning curve further drops aircraft cost
    - Regulation enables multiple autonomous aircraft per operator

For reference, the estimated hourly costs for satellites (on a per satellite basis) are listed below. Direct 1:1 comparison with the programme's cost threshold and target values is difficult as these values do not account for the (mission specific) precision or quality of

[1] Rough order of magnitude estimates by programme team and industry experts.

the services rendered, or the (mission specific) required number of aircraft/satellites in a constellation.

+ **Basic LEO satellites:** ~£100-500/hr
    - ~20-60% of cost is hardware amortization
+ **Basic MEO satellites:** ~£2,000-5,000/hr
    - ~50-80% of cost is hardware amortization
+ **GNSS satellites (critical infrastructure in MEO):** ~£13,000-18,000/hr
    - ~30-50% of cost is hardware amortization

Cost Hypotheses

If solar powered propulsion could be supplanted by atmospheric energy to gain altitude and possibly recharge batteries (for example by using propellers as wind turbines), this could enable:

+ **Gust-tolerant aircraft with larger structural margins** (remove nocturnal energy gap, reduce wing area, reduce battery mass fraction, increase wing loading) → improve loss rates from to below **1 in 20**
+ **Remove batteries as limiting factor for endurance** → missions could be stretched **>1 year**

This could **drop costs by an order of magnitude** toward ~£500/hr making it commercially viable in niche applications such as persistent earth observation, in-situ measurement, or emergency communications.

+ Reducing a long endurance aircraft's hourly operating cost below £1,000/hr would make its operation profitable for niche applications. This could be achieved by supplanting solar energy with atmospheric energy.
+ Reducing a long endurance aircraft's hourly operating cost towards £100/hr would open up a large market of services. This could be enabled when regulation allows multiple aircraft to be overseen by a single operator.

Initial adoption in high-value niches would enable technology maturation, ultimately unlocking further cost reduction, thereby enabling many more applications.

WHAT ARE WE EXPECTING TO FUND

The programme's Technical Area (TA) efforts run in parallel, and their numbering (TA1, TA2, TA3) reflects technology maturity levels. TA1 will focus on developing game-changing enabling technologies. TA2 will form the core of the programme with the main efforts of system development, integration, and testing. TA3 will focus on future emerging applications (TA3). Proposers can apply for a single or several TAs.

TA1: Enabling Technologies

Technologies to predict, detect, and exploit atmospheric sources of energy could be game-changers for achieving long endurance flight. TA1 is a set of risky bets, of which 1 - 3 are expected to mature into impactful technologies that can be integrated into TA2 to radically improve endurance. TA1 will have several decision points at which downselects will reduce the number of funded teams to the most promising.

TA1 developments should aspire to provide TA2 Creators with tools to efficiently overcome some of the biggest challenges of the programme. These might include helping stratospheric aircraft find and exploit the nearest areas of exploitable lift from gravity waves.

Examples of enabling technologies could include

+ Sensing technologies to detect lift or wind shear at a distance [25]
+ More capable aircraft, for example
    - that possess birdlike agility to sense and/or respond, extracting energy from gusts, or
    - suited for energy harvesting in the stratosphere
+ Systems for storing harvested energy for later use when atmospheric sources are lacking
+ Rapidly updating air flow models that enable flight trajectory planning, and updating those trajectories to include energy extraction manoeuvres. These models would predict time and place of atmospheric phenomena (e.g. waves, wind shear, lift) of interest. Developing such models could require bespoke measurement campaigns.
+ Autonomous aircraft control systems that have the precision required to exploit atmospheric energy sources
+ Adaptations for high altitude that are not incremental, but disruptive in nature. This could include advanced aerodynamic concepts and electronics
+ Miniaturization of sensors, transmitters & clocks that enable small aircraft to perform valuable tasks in communication & sensing
+ Advanced collision avoidance architecture

TA2: Integration and Testing

We expect to fund TA2 teams to develop atmospherically powered, long endurance flight. Proposals should show a plan to demonstrate the achievement of the threshold requirement (>60% atmospheric power share over a 1 month flight) within the programme, and a road map to achieving the goal (>90% atmospheric power share over a 1 month flight) in the future, in support of at least one use case of their choice. For inspiration, a by no means exhaustive list of possible use cases is provided below.

TA2 teams are expected to plan for integration of novel technologies or tools developed under TA1 in later phases of the programme. TA2 will also have decision points at which downselects will reduce the number of funded teams to the most promising.

Driven by the assumption that making a newly designed UAV airworthy, and establishing efficient flight testing operations takes years, we are recommending that TA2 teams plan to leverage an existing, proven airframe they can modify, along with access to suitable testing infrastructure and established processes for rapid flight testing. Lower TRL efforts can be funded under TA1. TA2 Creators are encouraged to plan integration of the most promising developments of TA1 during the advanced phases of the programme. This approach appears better suited for achieving disruptive breakthroughs given the short, four-year timeline of the programme. Exceptions may be considered if the described concerns are addressed in a compelling manner: Such teams should clearly demonstrate they have the expertise to design aircraft and bring them to airworthiness, including establishing suitable flight testing and improvement campaigns. They should present a compelling plan that aligns with the programme's goals and timing.
While this thesis assumes that the goals of this programme are easier to achieve in the middle atmosphere than in the lower atmosphere, the programme is open to proposals making a compelling case for other altitude ranges.

To be successful, a team will typically require interdisciplinary skillsets including:

+ Weather modelling and prediction
+ Remote aircraft testing and operation
+ Aircraft modeling and simulation
+ Autonomy and robotics
+ Payload technologies relevant to the use case

Smaller teams lacking some capabilities are encouraged to collaborate to bridge these gaps. The programme team is open to helping facilitate such collaborations.

Teams are welcome to propose testing and demonstration environments of their choice, keeping in mind that test & evaluation protocols will be based on conditions typically encountered in the UK's geographic vicinity.

Successful proposals will explain which atmospheric phenomena they intend to exploit, and explain the technologies they will develop or integrate to do so. For the use cases of their choice, they are expected to outline the characteristics of their development. Such characteristics could have the following format (example values are given for illustration purposes):

Altitude: upper atmosphere Atmospheric phenomena targeted: gravity waves, wind shear Payload weight: <10 kg Payload power draw: <40 W Stationkeeping: 200 km radius around a defined point Endurance: > 30 days

Example of what the characteristics for a use case may look like. Proposers are encouraged to define their own characteristics based on use cases of their choice.

The maturity at the end of the programme is expected to be sufficiently high for further pursuit without ARIA funding (be that through commercial viability, the ability to raise venture capital or other forms of funding, or a maturity sufficiently high to become a government-funded programme).

Examples of use cases TA2 teams could choose to work towards could include:

Digital Infrastructure

+ Low-latency communications: Providing a stratospheric backbone for 6G networks or serving as a direct relay for high-frequency trading, where microseconds of reduced latency translate into significant financial advantage
+ High precision PNT: Augmenting or providing Positioning Navigation and Timing for critical infrastructure, autonomous robotics, and novel industries.
+ Ubiquitous IoT: Acting as a persistent "macro base station" for wide-area IoT networks like LoRa, enabling smart agriculture, logistics, and environmental monitoring in remote areas without terrestrial infrastructure

Climate & Earth Science

+ Real-time atmospheric science: Loitering in specific atmospheric regions, such as within stratocumulus clouds, to gather in-situ data crucial for resolving major uncertainties in climate models. The region of the atmosphere above 30 km is sometimes colloquially referred to as the 'ignorosphere' for our lack of knowledge about it.
+ Precision earth observation: Conducting continuous, high-resolution monitoring of dynamic geological features, such as glaciers or volcanoes, or tracking greenhouse gas emissions (e.g., CO_2, methane) at parts-per-million accuracy

+ Wildfire management: Providing early detection of wildfire ignitions and real-time data streams to coordinate suppression efforts

Societal Resilience & Security

+ Livestock-borne epidemic monitoring: Using video based early detection of avian flu, swine flu, and rabies in livestock could save billions and prevent the next pandemic
+ Persistent situational awareness: Providing an unblinking eye over areas of interest for maritime surveillance against piracy or illegal fishing without the predictability of satellite passes or the logistical footprint of conventional UAVs
+ Drone Detection: Serving as a high-altitude sensor platform to detect and track rogue drones over critical infrastructure or high-value assets
+ Disaster Response: Rapidly deploying to disaster zones to provide emergency communication services when ground infrastructure is destroyed, a task currently performed by temporary towers or short-endurance drones

This list is for inspirational purposes and is not exhaustive. It contains examples with different timelines of achievability, ranging from a few years to 20+ years. Potential Creators are invited to use their own experience and judgement to select their target use cases.

TA3: Developing applications for tomorrow's world

Viewing long-endurance flight capability as potentially as impactful as satellite technology or the first computers connected to ARPA-net, TA3 will explore and frame enabled applications of the world beyond 2030. TA3 Creators are expected to anticipate the intercept of the outcomes of this programme with the trajectories of novel emerging technologies that could be combined in a disruptively valuable manner. They are expected to pursue visionary concepts that have the potential to deliver radical value to society. Over the course of the programme, they are expected to study the technical and commercial viability of their vision, and work with TA2 Creators to understand the gaps and blockers standing in the way of achievement. Over the course of the programme TA3 will also have decision points at which downselects will reduce the number of funded teams to the most promising.

TA3 Creators' plans should work towards establishing target product profiles, define constellation sizes for the foreseen missions, and plan for navigating regulatory environments.

TA3 Creators may be large or small organizations or even individuals, possibly enlisting the support of subject matter experts to fill critical skill gaps. Creators could include technology developers, service providers or industry experts with experience in relevant applications such as communications solutions, aerial imagery, PNT or other advanced sensor or photonics solutions.

TA2 Creators should feel a strong incentive to collaborate with TA3 Creators, as a successful TA3 Creator could unlock a new and untapped future market for the technology developed by this programme.

Teaming and collaboration

We expect Creators to be very open to collaboration with other Creators, provided these are not in direct competition. During the course of the programme, successful Creators in TA2 are expected to increase their potential by collaborating with Creators from TA1 (integrating emerging enabling technologies to increase capability) and TA3 (increasing the commercial value of the platform technology).

ASPECTS STILL TO FIGURE OUT

1. What about fossil-fueled, long-endurance aircraft?

~20 hour endurance can be achieved with fossil fuels, yet such platforms have not unlocked fundamentally game-changing applications, perhaps with the exception of warfare. Does this mean long-endurance flight serves little benefit?
Why would atmospherically powered, long-endurance flight be more useful - does increasing endurance from days to months make a big difference? Will future developments of sensors, compute, telecommunications, positioning, navigation & timing change the equation, making flying platforms indispensable?

2. Is the atmosphere a sufficiently abundant, reliable, and predictable energy source?

Answering the question of the abundance (not to mention predictability) of favorable atmospheric conditions has been a challenge. This is in part due to the lack of established metrics to quantify such conditions in a satisfactory way. More surprisingly, it appears that the necessary data is unavailable due to lack of study.

a. How abundant are conditions enabling sustained flight (e.g. gravity waves and wind shear) near the tropopause and above (See Figure 1)?
b. What kind of convection is caused by anthropogenic heat sources? Likely highly turbulent, streams of small, hot bubbles (rather than coherent natural thermals)[2].

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[2] Over the next decade we expect a sharp increase in waste heat being dumped into the atmosphere by human activity (e.g. air conditioning, data centres, ocean going vessels). We know that

How high do they rise under given conditions? What kind of aircraft could exploit them?

c. How much energy needs to be harvested and stored to reliably sustain an aircraft through the times when favorable conditions are absent? How is that best performed? Is power beaming or photovoltaics required as ancillary power?

3. Best use

This thesis assumes that among the most impactful use cases for atmospherically powered, long endurance aircraft are measurement in the near term, and PNT in the longer term.

+ Certain measurement tasks, such as targeted in-situ sampling of the middle atmosphere, are not feasible today by other means. Such data could materially improve weather and climate models, driving value through increased forecast precision.
+ PNT is used as an example of the digital services these platforms could provide, and the scaling laws they follow. PNT is an interesting example, as atmospheric platforms could enable 2 orders of magnitude improvement. Also, the time appears ripe for mitigating reliance on single external parties to provide such a critical service [22].

More work is required to understand whether these two examples are the most impactful use cases, and whether this impact could uniquely be delivered by atmospheric platforms as opposed to alternative future means.

4. Airspace integration

The integration of autonomous aircraft with legacy air traffic presents two main challenges. The first pertains to development and testing, the latter to adoption into service once mature. TA2 (and potentially TA1) will be faced with the former, probably conducting testing in segregated airspace. TA3 will consider the latter, taking into account potential future regulatory developments.

5. Aircraft scale

The ability to extract energy from the atmosphere – kinetic energy in the case of dynamic soaring, potential energy in the case of static soaring – appears to be highly scale-dependent. This scale dependence opens up a relatively unexamined design space: What appears as turbulence to one size aircraft might appear as segregated zones of lift and sink to a much smaller aircraft [22]. As technological advances drive down the size, weight, and power of sensors, control, and communications hardware,

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localized atmospheric heating causes convection, but know little about what kind of aircraft could exploit such phenomena.

the need for large aircraft is relaxed. Aircraft of smaller scale may benefit from so far unexplored opportunities to harvest energy both in the lower atmosphere (e.g. exploiting anthropogenic convection) and middle atmosphere (e.g. jet streams, the wind shear they cause [23], and gravity waves [21]).
The possibility that small scale aircraft could operate collaboratively — exploiting atmospheric energy in concert, much like migratory birds or teams of paraglider pilots [28,29] — has seen little focused investigation, yet might be a further significant enabler of long endurance flight.

THEORY OF CHANGE

Long-endurance atmospheric platforms have the potential to dramatically exceed satellites as infrastructure enabling digital services. If the value rendered by satellites is an indicator, trillion pound industries could be the result.

Harnessing atmospheric energy is a vastly underexplored resource, despite its potential to be the missing enabler of long endurance flight: Observing birds suggests this resource could enable very long flights, and recent advances in weather modelling, robotics, AI, and control might give us the capability to approach bird-like efficiency in extracting energy from the atmosphere. Furthermore, the dramatic reduction in Size, Weight, and Power (SWaP) of sensors and transmitters mean that even small aircraft could render important, high-value services.

The area of atmospherically powered aviation remains largely neglected, possibly due to the long timelines (10—15 years) for full impact and the regulatory hurdles, especially around airspace access. This programme has the goal to enable Creator teams to drop the hourly operating cost of long endurance platforms to below the threshold[3] at which commercial viability is achieved in niche, high value applications. The learning curve from these niche applications, combined with future regulatory change enabling single operators to manage multiple autonomous aircraft, will drive further cost reduction to a level where long endurance platforms become competitive with satellites, especially if coupled with payload technologies that benefit from or are non-impacted by distribution across multiple aircraft.

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ENGAGE

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Success in the programme requires multidisciplinary teams. For groups or individuals needing assistance in building these teams, you can register your capabilities and missing expertise to ARIA's teaming tool via the feedback form linked above, allowing us to support matching with other registered teams.