Pseudosatellites
Disrupting Air Power Impermanence

Michael Spencer

Pseudosatellites

Disrupting Air Power Impermanence

Michael Spencer

© Commonwealth of Australia 2019

This work is copyright. Apart from any use as permitted under the Copyright Act 1968, no part may be reproduced by any process without prior written permission. Inquiries should be made to the publisher.

Disclaimer

The views expressed in this work are those of the author and do not necessarily reflect the official policy or position of the Department of Defence, the Royal Australian Air Force or the Government of Australia. The Commonwealth of Australia will not be legally responsible in contract, tort or otherwise, for any statements made in this document.

NATIONAL LIBRARY OF AUSTRALIA

A catalogue record for this book is available from the National Library of Australia.

ISBN: 9781925062232

Published and distributed by:

Air Power Development Centre

F3-G, Department of Defence
PO Box 7932
CANBERRA BC 2610
AUSTRALIA

Telephone: + 61 2 6128 7041
Facsimile: + 61 2 6128 7053
Email: airpower@defence.gov.au
Website: www.airforce.gov.au/airpower

Foreword

One of the nine characteristics of air power is its impermanence, a limiting factor caused by the temporary nature of conventional air platforms to maintain an influence or effect by their presence. The orbital characteristics of space have a different view of this impermanence. Satellites have an unconstrained overflight of the Earth's surface without the limitations of sovereign borders. However, the orbital mechanics limit the time a satellite can remain over a particular geographic location unless they utilise limited and expensive geosynchronous orbits or a properly configured constellation of satellites.

As outlined in this monograph, significant work is progressing in the development of pseudo-satellites, which can create a persistent effect without the support requirements of traditional air power platforms.

Although not specifically mentioned in the Air Power Development Centre's *Beyond the Planned Air Force*, I believe that this monograph should be considered part of the work on the series as it meets the aim of providing a future-learning analysis of opportunities and disruptors to support air power professionals working a joint operating environment.

Wing Commander Spencer has created an excellent primer that bridges the gap between conventional air power and the development of relatively cheap, short life span, low-orbit micro-satellites. He explains the background, technology, advantages and capabilities that pseudo-satellites bring to users who need access to persistent ISR and/or communications. This will become increasing important to remotely piloted operations to extend Australian-based air power to cover distant and remote operating areas such as the South West Pacific or Antarctica.

I hope that readers of this monograph gain a better understanding of pseudo-satellites and their contribution to making air power an even more potent tool.

GPCAPT Andrew Gilbert
Director
Air Power Development Centre

May 2019

About the Author

Wing Commander Michael Spencer is an Officer Aviation (Maritime Patrol & Response), currently serving in the Air Power Development Centre, analysing potential risks and opportunities posed by technology change drivers and disruptions to the future employment of air and space power. His operational background is with No 10 Squadron as P-3C Orion aircrew. He is the first Australian graduate of the Royal Thai Air Force Air Command and Staff College and the US National Security Space Institute (Space 200), an Australian Institute of Project Management certified project manager and an Associate Fellow of the American Institute of Aeronautics & Astronautics, and completed postgraduate studies in aerospace systems, information technology, project management, space mission systems, and astrophysics. He is the author of "AFDN 1-19 Air-Space Integration" and co-author for the APDC BPAF series handbook, "Hypersonic Air Power."

Acknowledgements

The Air Power Development Centre acknowledges the inputs gained from consultations with Squadron Leader David Burningham on air power doctrine. Additionally, the author acknowledges the support and research contributions provided by Dr David Crisp, Defence Science & Technology Group, during the development of this paper.

Preface

A USER'S PERSPECTIVE

This APDC publication on pseudosatellites is a timely reminder of the intensely dynamic nature of Air Power capability progression in the 21st century and the importance of constantly looking beyond the current project horizon in order to maintain technological advantage over adversaries. Even before the RAAF has taken delivery of our first HALE (MQ-4C Triton) or MALE (MQ-9 Reaper variant) RPAS, we have made our initial steps towards investigating the utility of the next evolution in large unmanned aircraft, the Very High and Very Long Endurance pseudosatellite. In no way a replacement for our next generation RPAS, our manned aircraft or space-based systems, the platforms in the pseudosatellite category serve to compliment, enhance, and indeed multiply many of those current capabilities.

WGCDR Spencer has presented compelling reasons why the RAAF should seriously consider the future pseudosatellite capabilities in our force mix. The advantages they present with regard to persistence are unmatched (other than via expensive space-based systems) and smart planning of a very dispersed pseudosat 'swarm' presents an effective solution for guaranteeing communications/data relay capability, across multiple networks/frequency bands over a very large area, potentially providing another communications option when operating in denied environments.

Current limitations regarding performance (airspeed, rate of climb, endurance) and payload weights are significant. However, as with all evolutionary capabilities, Research and Development efforts into battery technologies, payload/ communications system miniaturisation and improved powerplant performance will inevitably produce significantly more capable pseudosat platforms that should stand not only as complimentary capabilities, but as their own niche capability in many Air Power Roles. I recommend this publication to all with an interest in the diverse range of capabilities that is Air Power.

Gavin Small
Wing Commander,
Remote Piloted Aircraft Systems
April 2019

A LEGAL PERSPECTIVE

The capabilities and efficacy of pseudosatellites threatens disruption to a legal paradigm that is long overdue for evolution. The legal delimitation between airspace and outer space has been obdurately added to the agenda of the Committee on the Peaceful Uses of Outer Space, or its Legal Sub-Committee, every year since 1959 in the vain hope of igniting some impetus among member States to resolve the issue.

Ostensibly, it is difficult to understand why States have been so reticent to support a legal delimitation between airspace and outer space – the altitude at which airspace becomes outer space would seem to be consequential. States enjoy sovereignty in their national airspace (over their land and out to 12nm off their coasts) – they can lawfully prescribe regulation of it, exclude others from it, and enforce their laws within it. But that ends at some indeterminate upper altitude when airspace becomes outer space. Even before Sputnik in 1957, it was conceded among legal commentators, then among States themselves, that the assertion of sovereignty over an infinite column above a State's territory was simply impractical, as well as undesirable. And when Sputnik completed its first orbit on 4 October 1957, overflying many States as it did so, customary international law crystallised almost instantly – or at least far more rapidly than it ever had before. All States accepted as a legal fact that there is no sovereignty, nor any national borders in outer space. The significance of the consequences was immediately apparent to the US government and its citizens – it was not just that the Soviets had the technological capability to 'overfly' – or sustain an orbit over – US territory, but that it was conceded as entirely lawful to do so.

Yet the most common rationale among States for a reticence to support a legal delimitation between airspace and outer space is that such a delimitation is simply unnecessary. The *Convention on International Civil Aviation* does not define the upper limit of airspace, but an annex to the convention does define an aircraft as a machine "that can derive support in the atmosphere from the reactions of the air". This limits the application of air law, and the upper limit of the sovereignty of a State, to the support that the atmosphere can provide to a wing moving through it, or a balloon floating within it. The latter holds the altitude record of 173,900ft, but given that relatively few winged aircraft can or ever have flown above 60,000ft, this is the arbitrary upper limit of 'controlled' airspace – where States actively assert control over the operation of aircraft in their airspace. Conversely, space objects begin to break up once they hit 80km and very few have managed to sustain an orbit below 200km without propulsion (and even then, not for long).

However, this in-between region is not a legal 'no man's land' – if an object is deriving support from the atmosphere, thin as it is above 60,000ft, then it is still an 'aircraft' and still subject to air law and a State's sovereignty. 'Uncontrolled' does not mean 'unmonitored' – States can, will and have asserted sovereignty over aircraft above 60,000ft – notably the U-2 aircraft flown by CIA pilot Francis Gary Powers in 1960. Furthermore (and this is where pseudosatellites become particularly relevant), whatever has been up there above 60,000ft has been relatively transient or impermanent. This applies even to satellites in orbit all the way out to geosynchronous Earth orbit (GEO) at approximately 36,000km. Satellites can endure in space far longer than aircraft, but cannot loiter above a certain spot on the Earth's surface (GEO satellites and constellations address this deficiency). On balance, therefore, States have felt uncompelled to push for a legal delimitation between airspace and outer space and it has seemed wiser to wait and watch as technology progresses.

As WGCDR Spencer discusses, pseudosatellites, like other aircraft and unlike satellites, can loiter above a certain spot on the Earth's surface. Like satellites and unlike aircraft, they can endure. A defining characteristic of satellites is the field-of-view that they offer and this is also a defining characteristic of pseudosatellites. Even at 12nm off the coast of another State, much of the littoral of a State is within the field of view of a pseudosatellite.

Even though it is unlikely that pseudosatellites will, by themselves, offer sufficient impetus for States to support a legal delimitation between airspace and outer space, they join a growing chorus of rationales for States to consider the legal delimitation carefully – and not just from a dry legal perspective, but also from an essential strategic perspective. This paper offers a valuable, practical resource for those seeking to contribute to legal policy debates about the application of air law and space law, especially in the uncontrolled regions above 60,000ft and in international airspace outside 12nm.

Duncan Blake
Wing Commander,
Counsel, Space Law
April 2019

A SCIENCE PERSPECTIVE

It is axiomatic that operations in all domains exploited by militaries are subject to varying forms of attack that can lead to denial, degradation, disruption and/or deception. The ADF, whilst becoming increasingly reliant on services provided by space systems, is recognising the increasing vulnerability arising from threats to space capabilities resulting in increased operational risk. Such threats include: kinetic and non-kinetic attacks on space systems (whether orbital or ground-based components of these system); risks to orbiting platforms from the growth of space debris; and, degradation due to space-weather events.

Space services are becoming sufficiently important that mitigating the risks that arise from such threats is an increasingly important consideration for force design and operation planning. One way of mitigating risks is to have resilience through redundancy. The various pseudosatellite options presented in this report offer potential alternative approaches for achieving the effects offered by orbital platforms. Pseudosatellites, whilst subject to different threats and overall capability pros and cons, can deliver both adjunct effects to extant capabilities as well as a level of replacement of space services providing a degree of redundancy and hence resilience. Having credible resilience through alternative means of providing similar effects can also provide a deterrence effect against adversarial threats to space systems due to the reduced benefit arising from what may be expensive and strategically risky attacks.

As detailed in this report, as well as the military considerations outlined above, there are growing drivers for the development of pseudosatellites in the commercial sector. This is fuelled by technological developments around miniaturisation of sensor, communications and power systems for a range of commercial products. Such technologies are being exploited in small Space 2.0 satellites and are similarly providing opportunities for application the pseudosatellite systems covered in this report.

As threats and technologies evolve, we must always be revisiting our approaches to how we deliver military effects and be willing consider fundamental changes to traditional ways of doing business. Pseudosatellites have the potential to be realised as significant military capabilities given the strategic imperative to achieve operational resilience for key military effects. That commercial developments are leading to the availability of a rich toolbox of technological options available for both commercial and military systems increases the likelihood of the realisation of this vision.

Dr Shane Dunn
Scientific Adviser - Joint,
Defence Science & Technology Group
April 2019

Kneecard Executive Summary

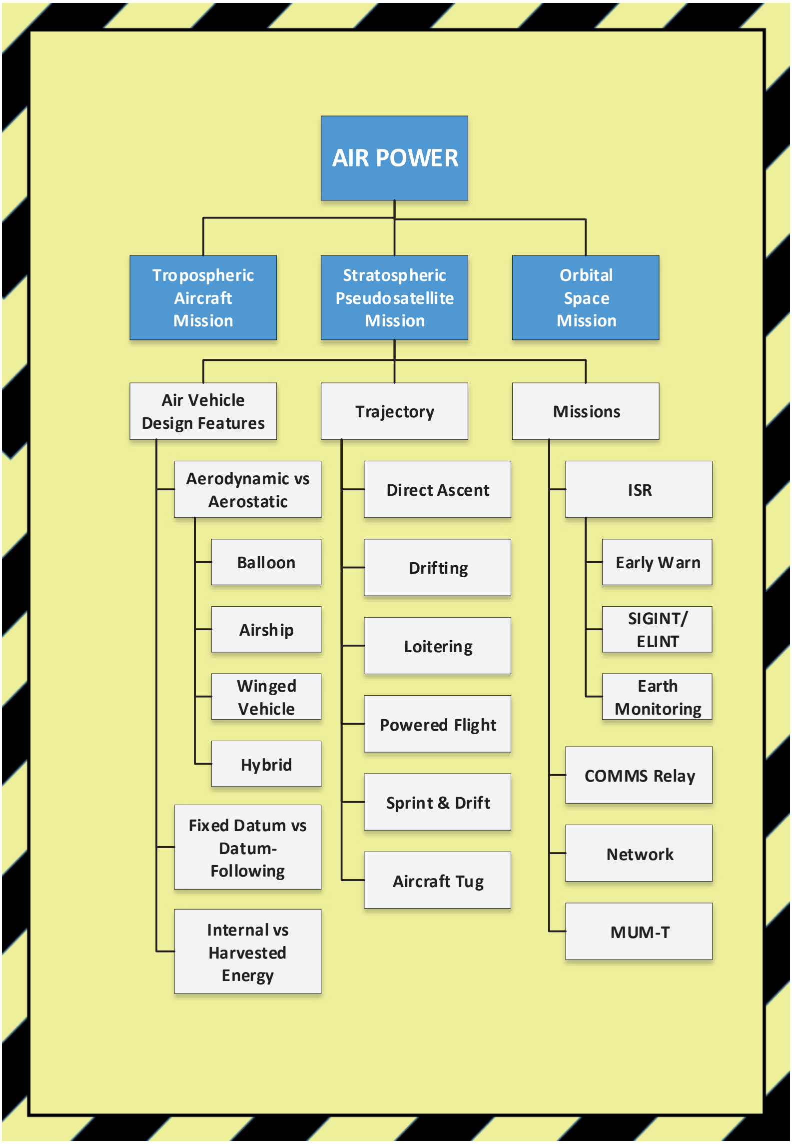


Table of Contents

Foreword .... *iii*

About the Author .... *iv*

Acknowledgements .... *iv*

Preface .... *v*

Kneecard Executive Summary .... *x*

Introduction 1

Air Operating Environment: from Surface to Stratosphere 4

Pseudosatellite Flight Trajectories 8

Pseudosatellite Mission Design Drivers 11

Analysis of Alternatives: Pseudosatellite versus Space Mission 22

Pseudosatellite Vehicle Design Options 24

Examples of Pseudosatellite Designs 27

Comparison of Pseudosatellite Design Features 35

Synopsis of the Potential Military Utility of Pseudosatellites 39

Conclusion 44

Annex A - Case Study: UK Zephyr Flight Trials in Australia 45

Annex B: Abbreviations 48

Endnotes 49

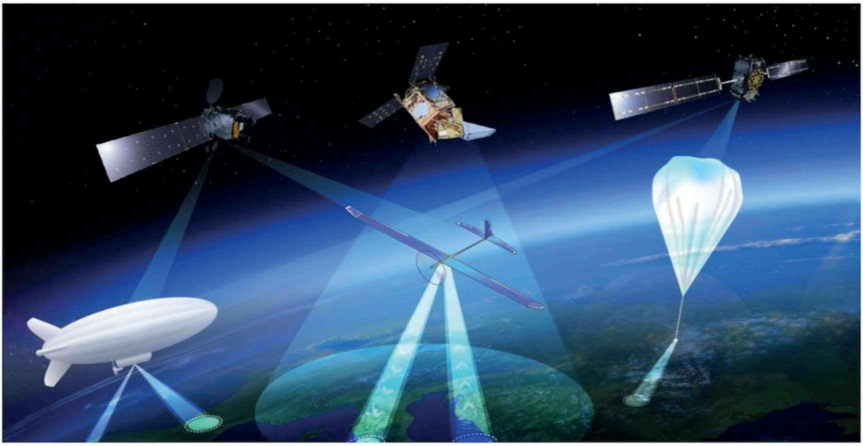
"But above all else, UAS, especially HALE and MALE, have brought a new dimension to the operational theatre, aerial persistence, previously achievable only by cycling multiple manned aircraft through an airborne task, and rapidly running down fleet and crew availability in the process. In one fell swoop, UAS have overcome the lack of an enduring aerial presence over the area of operations – so rectifying one of the long-standing deficiencies of air power."

B Weston,
UAS – *Their Future as ADF Capabilities* (2014)[1]

Introduction

Impermanence is recognised as a limiting characteristic in the employment air power. Air Force doctrine describes impermanence as inherent in air power because of "the temporary nature of an air platform's ability to maintain an influence or effect through its presence".[2] New technology for remotely piloted aircraft systems (RPAS[3]) is enabling the stratosphere to be exploited with low-cost alternatives to complement or substitute for more expensive air and space missions. Pseudosatellites offer new options that are disrupting the impermanence of traditional air power.

New developments in lightweight aerospace materials and structures, and the Space 2.0 technology revolution has miniaturised and made space mission technologies more accessible and affordable. These changes are inspiring the development of new design options for deploying pseudosatellites into the stratosphere. These new designs are resurrecting old and traditional methods such as direct ascent balloons, aerostats, and high-altitude motorised gliders. The stratospheric operating domain also offers new options for exploiting natural forces to shape and steer flight trajectories.



Pseudosatellite design options (ie airship, UAS, stratospheric balloon).[4]

Two endeavours are improving the permanence of air power to deliver better persistence than has been possible with traditional system designs and thus permanent air power effects. These endeavours involve realising high-altitude pseudosatellites (HAPS)[5] that use aerodynamic designs for loitering in the stratosphere, and using renewable energy systems that enable longer endurance missions. The capabilities of pseudosatellites are changing the options for the permanence of air power effects with long endurance airborne systems. They can enable longer and more persistent observations by airborne deployed sensors or longer enduring access to airborne communications relay and networking systems.

A risk of using airborne systems designed for human occupants is that the onstation endurance and permanence are constrained by the human limits of performance and endurance. Surveillance and monitoring activities are well exemplified missions where, to cover a long operational period, planners may need to repeat air missions in an overlapping sequence.

While satellites can exploit the high-ground advantage and improve the availability and permanence of effects to support terrestrial operations, they can be expensive and need to be shared to meed the concurrent demands of many users. Furthermore, the cost of deploying satellites up to geostationary orbit prioritises them in the national interest. While lower costing, lower altitude satellites can support tactical missions, they can be less permanent over a mission area than an aircraft. This is because users need to wait until the satellite orbit coincides with the timeline of the mission objective; it is only available for about 10 minutes as it appears over the horizons before descending below the opposite horizon. The mission may require waiting for multiple passes over several days to accumulate adequate effects from the orbiting space system to support a mission.

The stratosphere is the little-used, upper part of the atmosphere situated above the altitudes that are commonly used for modern military and commercial aviation, but situated below the space environment. Realising new unmanned aircraft designs that can loiter over a mission area for extremely long periods is enabling longer mission durations and disrupting traditional views on the impermanence of air missions. This extended mission duration can gain new benefits in Intelligence, Surveillance & Reconnaissance (ISR), environmental monitoring, and networked communications applications for commercial and military roles, including PNT/navigation services, using the stratosphere to achieve a greater permanence by an air system over a mission area.

Air Operating Environment: from Surface to Stratosphere

The stratosphere is precisely the region of the upper atmosphere that starts at a lower boundary of approximately 23,000 feet at the poles or 65,000 feet at the equator; it extends to an upper altitude of approximately 165,000 feet.[6] The lower boundary of the stratosphere defines the tropopause; the upper boundary defines the stratopause.

Commercial airliners climb to cruise at operating altitudes in the lower stratosphere because, normally, significantly fewer weather storms or turbulence occurs in the stratosphere compared to such conditions caused by convection in the operating altitudes existing below the stratosphere. Conventional heavier-than-air aircraft and weather balloons reach their maximum operating altitudes within the stratosphere. This occurs because the air density that is essential for aerodynamic surfaces to generate lift decreases with altitude from 100 per cent measured at sea level down to about 0.1 per cent at the top of the stratosphere.[7]

The wind in the stratosphere blows in different directions at different altitudes. The predominant wind directions depend on the geographical location and the time of the year (see Figure 1). The southern hemisphere westerly winds are stronger than in the northern hemisphere because fewer high land masses in the southern hemisphere disturb the air and exert a drag force to generate winds in the air.

Near the equator, the stratospheric wind direction alternates between easterly and westerly with a cyclic period of about 28 months, referred to as quasi-biennial oscillation (QBO). Over a period of about one year, the westerly winds gradually weaken and descend in the lower altitude of the stratosphere and are gradually replaced by easterly winds. They also slowly sink and weaken as the westerly winds return with the next change cycle.[8] This variation in wind directions, across different stratospheric altitudes, can be exploited to manoeuvre a balloon along a trajectory to a new location or keep it operating close to a ground datum.

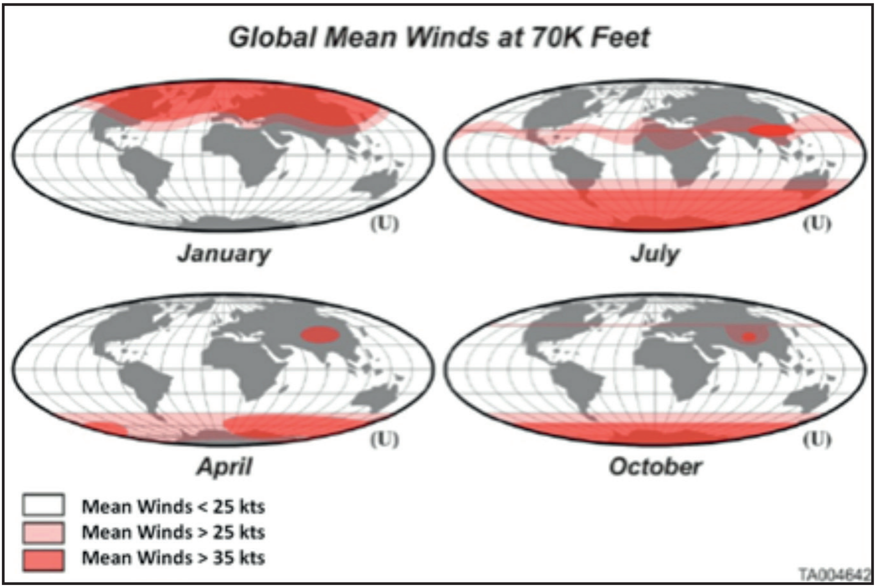


Figure 1. The stratospheric winds change with location and time of the year[9]

In the dense air within the troposphere, the temperature decreases with height so that solar heating of the Earth's surface and other weather conditions that warm the air and cause convection currents to rise and generate turbulent weather. Because the temperature in the stratosphere increases with height (see Figure 2), convection does not occur, thus causing any hot air that might cause turbulence to descend back to the troposphere. The air temperature in the stratosphere, being lower than that caused within the updrafts in the troposphere, means that the stratosphere provides a more stable air environment. It is thus more suitable for operating lightweight and flimsily designed air vehicles with lightweight mission payloads to fly or float on the stratospheric winds.

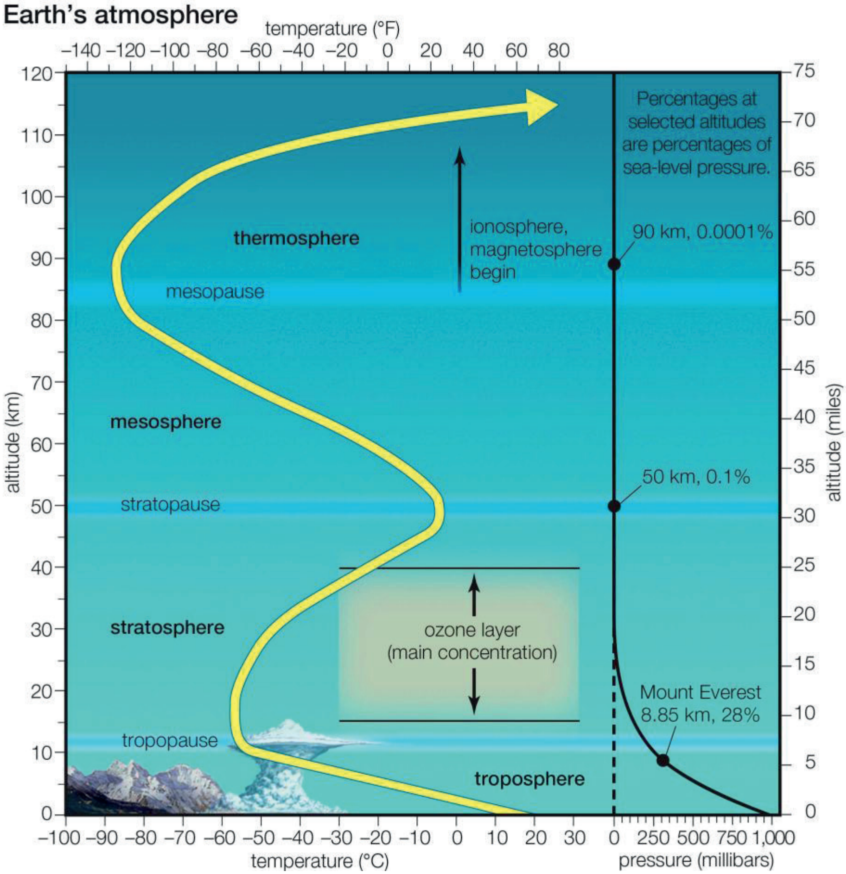


Figure 2. Atmospheric temperature versus altitude[10]

The delicate lightweight structural design, necessary to perform high-altitude long-endurance air missions, is too fragile for launch or recovery without favourable environmental conditions or for air-launch. A high-altitude balloon trail has already demonstrated the launch of a HALE air vehicle into the stratosphere.[11]

While flimsy lightweight designs are suitable for stratospheric air conditions, they are not necessarily suitable for the adverse weather conditions and air turbulence that may exist at the surface, where air missions originate and end. Additionally, the air vehicle must ascend through the tropospheric weather along a slow and steady climb to the stratosphere, with a climb duration measured in hours.

Designing missions employing these lightweight air vehicles needs to consider waiting for favourable weather conditions so that a flimsy air vehicle can slowly and steadily climb to safely transit the turbulent troposphere to the calmer air in the stratosphere. Planning to determine the flight trajectories requires similar considerations about recovery and landing.

Additionally, while the weather effects within the stratosphere may favour lightweight vehicle designs, such conditions in the troposphere may disrupt the line-of-sight between the air platform and the target of observation and/or the ground communications station(s). The benefit of a long endurance mission is that the air platform can loiter until the weather is cleared or slowly manoeuvre to a new location to establish a new line-of-sight around the unfavourable weather.

The risk to the use of solar panels on air vehicles is that sunlight can be obscured by cloud cover; HALE air vehicles operating in the stratosphere will normally be operating at altitudes are above atmospheric haze and cloud cover.

The stratospheric air temperatures can vary between about minus 60 to minus 90 degrees Celsius. Because of changes in altitude and diurnal effects, thermal variations can cause metallic and composite materials to become brittle, cyclically expand and contract, and adversely affect unprotected electronic systems.

Air and space missions face three challenges, each offering both advantages and disadvantages: the first is that the environmental characteristics of the troposphere and stratosphere differ; second are the structural, propulsion, and flight-control systems needed to transit the troposphere from the surface to the stratosphere; and third are that the design opportunities for the terrestrial mission operator and the user of the mission outputs differ for aircraft and space vehicles. Pseudosatellites offer a new range of system design options for air and space for which the combinations of advantages differ.

Pseudosatellite Flight Trajectories

Winged aircraft operations predominantly occur in the troposphere, between the surface and up to about 40,000 feet. To reach their operating altitudes in the stratosphere, pseudosatellites may have to transit airspace that is shared with other air activities.

a. **Direct Ascent/Descent Trajectory**. The simplest way to access to the stratosphere is by using a high-altitude balloon. With favourable environmental conditions, the balloon ascends and descends along a near-vertical trajectory to be recovered within a convenient distance from its launch base.

b. **Drifting Trajectory** describes the flight profile of a balloon system that is not configured with any aerodynamic controls for flight stability or manoeuvre. It is configured only with an aerostatic system to control its ascent, descent and holding altitude. Knowledge of the weather conditions and prevailing wind directions are essential for planning to ascend to the balloon to a specific altitude with a favourable wind. The balloon will then be blown in the desired direction across the mission area and descend into the recovery area (see Figure 3). This cycle is repeated with the same balloon or by using a fleet of balloons to provide overlapping coverage of the mission area as they drift, in a planned mission sequence, to the recovery area.

c. **Aerostatic Loitering over Position Datum**. Knowledge of weather conditions and wind vectors can be used to control the balloon's trajectory by ascending or descending it into different winds that blow the balloon in different directions. This counteracts the unwanted effects of wind on the balloon's location (see Figure 3). There are three popularly used altitude-control systems, depending on the mission's need to maintain a steady altitude:

   (1) By changing the balloon's inflation pressure to control its altitude and maintain a steady altitude.

(2) By maintaining the balloon in a drifting trajectory and accepting the altitude, as it changes with weather conditions, and by maintaining a steady inflation pressure (ie uncontrolled altitude).

(3) Tethering the balloon to the Earth's surface, hooked to a fixed or relocatable ground station or a mobile surface vessel.

d. **Powered Aerodynamic or Aerostatic Flight Trajectory**. Configuring a propulsion system for a winged vehicle or thrusters on an airship will enable controlled flight for different flight trajectories. An air vehicle with a propulsion system can be planned to conduct mission where it might need to loiter over a fixed, relocatable or moving area or datum. Alternatively, it might move across different areas to support different missions over its long-flight endurance.

e. ***Sprint and Drift* Trajectory**. The mass associated with the power generation and energy storage systems required for airship propulsion is an important major design determinant affecting the size of an airship. To save on the mass of the fuel storage and propulsion engine, the airship can follow a sprint and drift trajectory. If the wind and airship speeds are similar, the airship can sprint upwind of the station-keeping datum at high speed during the day, and drifts back with the wind over the mission datum at night.[12]

f. **Aircraft Tug**. A station-keeping aerostat platform could theoretically exploit the opposing wind directions that exist across the east-west wind shear between the stratosphere and the troposphere. A stratospheric airship could harvest energy from the wind-shear to maintain its station by controlling the aerodynamic drag on a tethered aircraft flying below it in the troposphere. The drag on the tethered manoeuvring aircraft would be managed, by changing its aerodynamic shape (eg a redeployable high-drag chute) and manoeuvring, to provide a force that counters the unwanted drift in the floating stratospheric airship.[13]

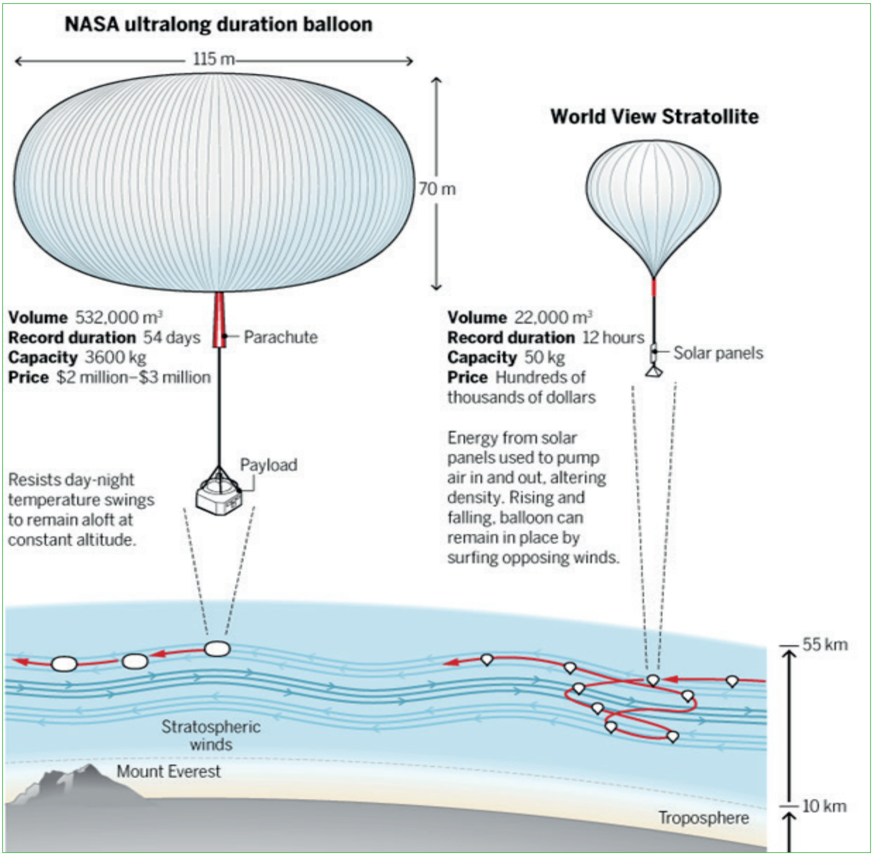


Figure 3. Flight profiles for stratospheric gas-filled lighter-than-air balloons[14]

Pseudosatellite Mission Design Drivers

SPACE 2.0 TECHNOLOGY REVOLUTION

'Space 2.0'-enabled pseudosatellites are disrupting the traditional air power dependencies on space missions. Space 2.0 refers to a change in space technology associated with reducing the size and cost of space mission payloads to increase their affordability and accessibility to space using lower-cost space launch vehicles and microsatellites.[15]

Miniaturising space mission systems has led to the development of smaller mission payloads that have been fortified for the space environment. If a system complies with the standards set for operations in the harsh orbital space environment, it will likely also function correctly in the stratosphere. These small lightweight technologies, originally designed for microsatellite payloads, can now be deployed on small air vehicles, as pseudosatellites, and be suited to use in the stratosphere, which is a milder operating environment than space.

The Space 2.0 technology revolution aimed to make space technology and space access more affordable and, partially, increases the permanence of a mission system by remaining aloft and available on orbit. The mission payload designs of small tactical satellites are optimised to perform at low-Earth orbital altitudes using miniaturised hardware operating with low electrical power. Although the space mission can remain on orbit for about five to 15 years, the mission system is not recoverable for hands-on hardware repairs or reconfiguration; reconfiguration is limited to using uplinked updates for software reconfigurable systems.

Orbital space missions necessarily follow an orbital trajectory, at a fixed speed suitable to the orbital altitude that is fixed relative to the centre of the Earth. The Earth rotates beneath the orbital trajectory, changing the terrestrial user's aspect and access to the orbital space missions, and constrains the permanence of their effects to support a terrestrial mission. Low-Earth orbital payloads may overfly the same fixed point on the Earth only once every few days. This means that they are accessible for up to only 10 minutes as they flyover before descending below the horizon.

TRADE-OFF ANALYSES FOR IMPROVING AIR POWER PERMANENCE

The Air Power Manual identifies a degree of relative impermanence as one of the notable characteristics of air power.[16] Remotely operated and automated pseudosatellite systems offer new capabilities that will change air power employment concepts that are constrained by the traditional capabilities that cannot stay airborne for long, nor can they hold ground in the conventional sense.[17] HALE air vehicles and balloons are providing operations planners with new options for using air power to assert a presence over in and over a mission that was previously only considered possible with traditional force options based on forward deploying troops, warships, and high-end space missions.

The relevance of permanence to an air mission can be viewed as a function of a few measurable and mission-related variables. The trade-offs between the different designs and consequences of rethinking variables may adversely affect other variables or dependent systems.

a. **Operational Responsiveness**. When preparing a new space mission with a short-term plan, a pseudosatellite can be deployed to influence within and over a terrestrial area quickly and inexpensively. The speed and cost are measured by comparing them to those to launch a new satellite into orbit in response to a new mission need. Additionally, a pseudosatellite mission can be replanned and redeployed, much more rapidly and easily than a space mission onto a new orbit to support different mission. However, without airspace control and managed activities conducted in the stratosphere above controlled airspace, the risk of airspace conflicts with other pseudosatellite operators increases.

b. **Coverage**. The coverage of the mission area must be adequate to allow decision superiority over the mission area. This occurs by using a continuously staring sensor or by regularly revisiting areas of the battlespace often enough to prevent an adversary's freedom of action. Coverage can depend on operating altitude and speed, and the frequency of revisiting a mission area. Figure 4 depicts the relative advantage of the operating height for the different types of air vehicle designs regarding the calculated distance to the radar horizon and potential area coverage.

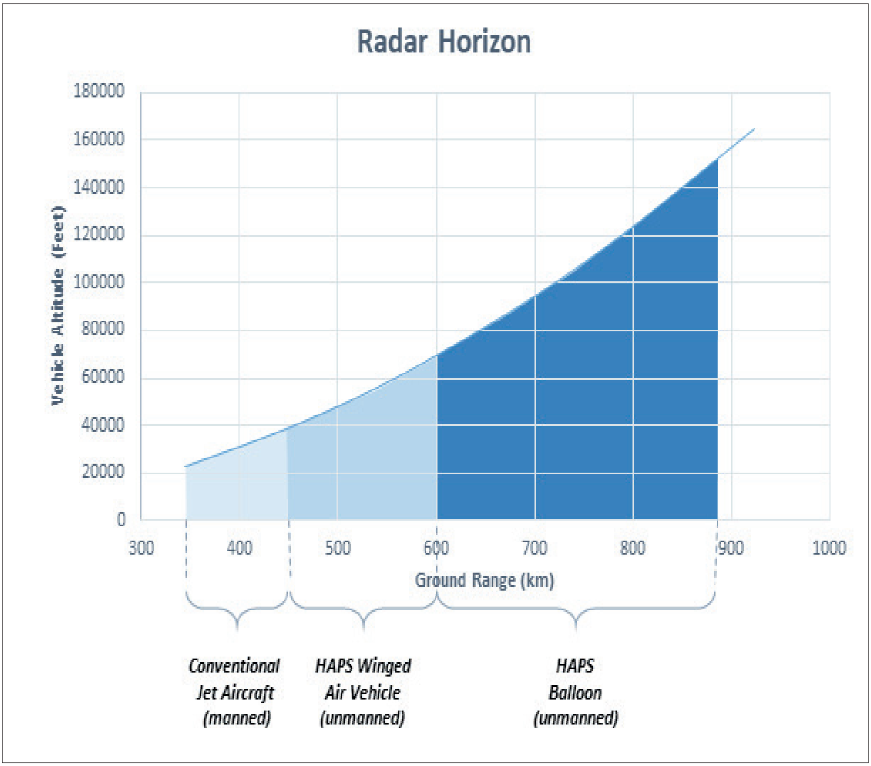


Figure 4. Height versus calculated Radar Horizon distances[18]

At an operating height of 65,000ft, the ground distance to the visual horizon is 500km (270NM) and the radar horizon is 580km (310NM) in favourable environmental conditions

c. **Duration**. Pseudosatellites can be used to achieve new levels of air power permanence. They can provide new long-endurance options for future air power to better support the Joint Force by exploiting the natural forces available in the stratospheric environment that can support air vehicles to remain aloft and manoeuvre. Pseudosatellite designs can offer better mission endurance for less cost than traditionally designed high-end air vehicles that need hydrocarbon fuel-based propulsion systems and a human-controlled flight and mission payload. Note though that, because a pseudosatellite's mission system operation depends on remotely located human operators, the mission duration may be restricted by what human resources are available.

d. **Reach**. The reach is the sum of the air vehicle's operating range from its home base and the effective range of the mission payload. Pseudosatellites have a relatively slower rate of climb and travel speed than conventional aircraft. Mission planners will thus have the advantage of being able to use the long endurance of pseudosatellites to follow a slow-moving mission datum or relocate to a new mission or operation. They will not need to be recovered and refreshed at the home base. Mission planners will feel the disadvantage of needing to prepare many forward locations to be compatible. While the long reach and endurance enables a level of flexibility to change or follow a dynamic mission datum, this may be constrained by the availability and distance to the next nearest recovery site.

e. **Mission Sustainability**. Pseudosatellites are using Space 2.0-systems that are purpose-designed to exploit free and naturally available solar energy to generate power. Additionally, the air vehicles are designed for flight control and manoeuvring based on exploiting aerodynamic forces from the stratospheric winds. Thus, the mission endurance is sustained and extended by accessing freely available and renewable energy sources.

(1) **Solar power**. Solar energy is available during the day to cyclically charge the onboard power cells that are used both during both the day and night, for the propulsion, flight control, communications, and mission systems.

Unlike ground-based solar panels, wing-mounted solar panels cannot be tilted to continuously point directly towards the Sun. Like ground-based solar panels, the airborne solar panel efficiency diminishes when sunlight arrives at an acute angle rather than straight down at 90°.

(2) **Wind power at same altitude**. Weak stratospheric winds blow at difference directions at different altitudes and can be exploited by changing the operating altitude of the pseudosatellite to find a favourable wind to either hold or change a station position, or drift.

(3) **Power of wind shear across different altitudes**. The different east-west winds that exist above and below the tropopause can be exploited by tethering two vehicles. They each operate in the stratosphere and troposphere in winds blowing in opposite directions. While the wind controls the manoeuvre on one vehicle, the drag can be altered on the second to create an equal but opposite effect to the wind blowing on the first vehicle, thus harvesting energy from the operating environment.

f. **Mission Adaptability and Capability Assurance**. Recovering and reusing a pseudosatellite provides opportunities to repair, replenish, reconfigure, and update the capabilities. Their operations are thus more easily assured for their life than a "launch and leave" satellite mission. As well as this assurance, recovering a pseudosatellite assures the user of systems agility. The user can then update or reconfigure the pseudosatellite and/or its mission payload during the mission period and/or its life to respond to changes in the operational environment. Such increased adaptability helps assure that such deployed capabilities can continue to operate with desired effect and permanence.

g. **Trading Off between Endurance to the Mission Area and Endurance over the Mission Area.** In a sense, the ability to remotely operate a long-endurance air mission system that can trade-off between the time spent travelling the long distances to or from a mission area and the time spent over the mission area is, in part, providing new options to improve the impermanence of air power effects in the battlespace.

h. **Flexible Crew Assignments and Locations**. Remotely operated systems are not fully autonomous and are designed to enhance and extend the reach of their control by the same or different mission operators. Unlike for aircraft that are designed to be controlled by their human occupants, remotely operated systems can be controlled by multiple crews, in a seamless sequence of handovers, who are either using the same base location, or a networked connection from a different base, in order to control the pseudosatellite and its mission payload.

TRADE-OFF ANALYSIS: AERODYNAMIC VERSUS AEROSTATIC DESIGN

Aerostatic designs (ie balloons) employ vertical propulsion by using buoyancy to manoeuvre in the vertical plane and exploit natural winds or small thrusters to manoeuvre on a horizontal plane. To propel a wing to generate lift for flight and manoeuvres, aerodynamic aircraft employ horizontal propulsion that is dependent on mechanical energy. Neither design is better or worse than the other; both offer different advantages in different ways and require systems designers to perform trade-off analyses to determine the most appropriate design.

Aerostats can harvest freely available energy from their environment to manage buoyancy and manoeuvres, which can be enhanced by installing propulsion systems or thrusters. However, mission endurance and range then become dependent on the aerostat's manoeuvring capability that is restrict by the amount of onboard stored energy. Better renewable energy systems (eg solar powered propulsion) are increasing range and endurance for both types of pseudosatellite designs.

A different approach to making designs for a maximum payload weight that meets the mission needs is key to an airship increasing its payload-carrying capacity with extra buoyancy. This is easier to achieve than changing the design of a propulsion system for an aircraft.

A pseudosatellite mission is based on a position datum, two of which apply:

a. **Fixed datum** involves aerostat and balloon designs. Whether they are manoeuvrable or tethered, they describe a static mission datum or area.

b. **Following moving datum** involves airships and air vehicles. They are capable of inflight manoeuvres to change their trajectory, can change the mission datum to maintain coverage over a moving target, or change to a new mission. The winged vehicle will be quicker to respond to changes in the mission positions.

For signature management, the balloon envelope of an aerostat is large and capacious. Being physically large provides a large visual signature in daytime and a high infrared signature after being heated by solar radiation in the day or from the Earth at night. The large capacity of the aerostat design also gives it a higher drag coefficient than air vehicles: aerostat drag will advantage missions requiring manoeuvring with the wind and disadvantage missions needing to keep its station position in the presence of wind.

Aerostats can ascend nearly vertically with a better vertical-take-off-landing profile than a winged aircraft that needs to be propelled forward to generate lift, thus necessitating a spiralling climb to reach its operating altitude. Aerostats need a ground station and a small capacity for airspace. However, aircraft need a runway and/or larger airspace capacity between the ground and the mission starting position at altitude.

DESIGNS FOR TRANSITING FROM THE SURFACE TO THE STRATOSPHERIC OPERATING ALTITUDE

A challenge for pseudosatellite designers is to develop a lightweight (ie it tends to be delicate) airframe that can take-off at sea-level and slowly climb through the tropospheric weather and turbulence. Once it reaches its operating altitude in the stratosphere, it reverses that procedure at the end of its mission. Pseudosatellite designs are different to conventional air vehicle used for RPAS, since they need to be more fortified to conduct missions within the more turbulent troposphere because it demands greater flight control authority. With its significantly less turbulent weather and lower density air, operations in the stratosphere need the design of lighter aircraft albeit with lower control authority.

The delicate lightweight airframe structure design, that enables the pseudosatellite to perform high-altitude long-endurance missions in the stratosphere, is unlikely to be air-launched from an aircraft. However, trials have successfully demonstrated launch a pseudosatellite at a high altitude using a balloon.[19]

The pseudosatellite mission is optimised for the size, mass, power needs of the pseudosatellite design, plus its operating altitude and the environmental conditions found in the stratosphere. These aspects are offset against the heavier and strengthened design that needs to cope with all weather and turbulence in the troposphere. This compromise in air vehicle design makes the pseudosatellite mission suitable for launched only when favourable local environmental conditions exist at the surface and in the troposphere.

STRATOSPHERIC OPERATING ENVIRONMENT

Mission durations lasting months instead of hours requires pseudosatellite mission planners to consider diurnal effects and seasonal changes in weather effects. The extent of environmental changes occurring with varying altitude, seasonal weather, and climate can introduce widely differing temperature that may adversely affect the viability of the mission system. For example, temperature variations arising from changing altitudes will affect solar panel charging rates, battery duty-cycles and the battery operating life, and the onboard stored energy that is available for the mission system.

Mission planners will need to consider forecasts for environmental conditions and operations that look forward for periods of days and months.

Under the Chicago Convention, a State has complete and exclusive sovereignty over the airspace above its territory.[20]

In Australia, Class A airspace requirements regulate the flight rules applicable up to 60,000 feet; flight rules and restrictions may apply at higher altitudes as advised by NOTAM.[21]

With less atmosphere above the mission altitude, less protection from radiation hazards is attributed to solar weather and cosmic radiation. This can result in single event upset (SEU) which are triggered by a single energetic particle colliding and ionising a single atom within in an unshielded and non-hardened electrical circuit within the mission system. A SEU can cause a bit flip within a computer memory bit and noise in the charge-couple devices installed in imaging sensor systems. Since the stratopause exists at lower heights over the polar regions and higher latitudes, the radiation exposure hazard for the same mission altitude is worse than missions conducted over lower latitudes closer to the equator.

PSEUDOSATELLITE ACCESS TO SPACE

While pseudosatellites operating in the stratosphere are likely to have clear and uninterrupted line-of-sight access to services from overhead satellites, such available access is determined by the geometry of the pseudosatellite's terrestrial location and the orbiting satellite. Three types of satellite orbits[22] are relevant for influencing the design of any upwards pointing satellite-tracking antenna:

a. **Geostationary Earth Orbit (GEO) satellites at 36,000 km altitude**. GEO satellites above the equator are orbiting the Earth at a rate that coincides with the rotation of the Earth. An observer standing at the equator, beneath the satellite, would observe that the overhead GEO satellites appears to be stationary. Pseudosatellites will depend on GEO satellites for communications and broadcast services.
   Significance to pseudosatellite: antenna design requires an upwards pointing antenna that can find and stare at a fixed location in the sky to maintain a communications link.

GEO satellites are situated above a point on the equator to access a majority of populated areas. Locations at high latitudes near the poles cannot access GEO satellites.

An orbiting satellite cannot be stationary above a fixed ground datum unless it is situated above it at the GEO orbit height of 36,000 km.

Figure 5. Pseudosatellites need to be configured with the right antenna systems to match the designs and orbits of communications and PNT satellites

b. **Medium Earth orbit (MEO) satellites between 2000 to 36,000 km altitudes**. The MEO altitudes are popular for deploying constellations of satellites for Global Navigation Satellites Systems that provide Positioning, Navigation & Timing (PNT) services. Examples include the US Global Positioning System, Chinese Beidou, European Galileo, and Russian GLONASS. These systems use constellations of satellites to assure that most surface locations on the Earth will be able to access a minimum number of satellites to gain PNT solutions. That is, provided the line-of-sight can be established through the surface terrain, obstacles, and is not affected by any adverse weather conditions.

   Significance to pseudosatellite: antenna design requires an upwards oriented omni-directional antenna to receive the PNT signals broadcast from satellites in the GNSS constellations (see Figure 5).

c. **Low Earth Orbit (LEO) satellites between 180 to 2000 km altitudes**. High-resolution Earth observation satellites typically use LEO altitudes with small satellite missions that may also be configured with low-power communications broadcast and relay systems. They circle the Earth at about every 90 minutes and, depending on obstacles and the prevailing weather conditions, are visible to a terrestrial system for about 10 minutes when passing overhead. However, with the Earth rotating under the orbit, the satellite may only appear within the field-of-view of the pseudosatellite every two or more days.

Significance to pseudosatellite: LEO satellites appear as the fastest overhead flying satellites providing only a short access duration when passing directly overhead (eg 10 to 12 minutes) or less when the orbital trajectory is closer to the horizon. This affects mission planning for using the satellite and scheduling to access it.

A critical technology is the design for a manoeuvring vehicle-mounted antenna that can establish and maintain communications with a satellite. SATCOM-On-The-Move (SOTM) allows moving vehicles to share voice communications and data while travelling at varying speeds and manoeuvring (ie changing orientation with respect to the satellite).

The height of the pseudosatellite provides a high-ground advantage. In some circumstances, mission elements on the ground, working in mountainous terrain or complex urban environments may be prevented from being able to access line-of-sight to space support from a geostationary satellite. This applies especially to ground missions conducted in countries located away from the equator, or in mountainous terrain. Such missions have low pointing angles to access the larger geostationary communications satellites. A pseudosatellite that is deployed overhead and dedicated to supporting the local mission area could relay voice and message data, system control signals, and ISR data to the ground mission.

Analysis of Alternatives: Pseudosatellite versus Space Mission

The APDC bulletin, *Pathfinder #225: Lighter-Than-Air and Hybrid Airships*[23] describes the benefits of balloons and airships as air platform options for enhancing air mobility and ISR capabilities. The benefits arise because these options can endure missions better than aircraft and cost less to acquire than orbiting satellites. Pseudosatellites benefit aircraft and space missions by offering them a more readily accessible, affordable, responsive and viable alternative to a high-cost launch event, even if for a low-cost space mission.

Most beneficial is that pseudosatellites on space missions will be operationally responsive and more persistent over a localised area than an orbiting satellite. It may not be readily accessible from locations in the mission area(s) when persistent and dedicated support are needed. Pseudosatellites also require significantly less ground infrastructure, resources, and effort to launch than space missions, and can reuse existing airfields.

Pseudosatellites float like a balloon or fly like an aircraft, in air, carrying mission payloads similar to low altitude orbiting satellites. However, rather than following an orbit trajectory, that regularly passes over a mission area, pseudosatellites can be inserted into the stratosphere to persistently cover for days and months[24] a specific mission area that is located directly below.

The technology and effort needed to deploy a pseudosatellite are significantly less, regarding the cost, resourcing, and scheduling needs that a space launch event needs for inserting a satellite into orbit. The long lead times required to access, schedule, and certify a mission payload for a space launch can be a challenge to operational responsiveness timelines. Similar missions can be performed by deploying the miniaturised mission systems onboard a pseudosatellite, even though they were originally purpose-designed for satellites, with different trade-off benefits and risks. However, once deployed, satellite hardware cannot be recovered for repairs or updates.

Low altitude satellites are purpose-designed to remain in orbit for about six months to a few years, depending on their orbit altitudes and interactions with the dynamic atmosphere and the effects of space weather. Satellites have the advantage of operating at heights that avoid sovereign airspace. Even though the mission endurance of a satellite cannot be matched by a pseudosatellite, the trade-off between choosing to deploy a pseudosatellite over an orbital space mission might be that the orbital trajectory results in the satellite overflying a datum area in a matter of minutes, maybe once only every few days. A pseudosatellite can be deployed to loiter in a stratospheric altitude and remain continuously accessible to a datum area, albeit for a shorter duration than for a satellite on orbit.

Space 2.0 sensors and communications systems that have been designed to function at orbital heights, to observe and communicate with terrestrial sites, are likely to achieve better performance from stratospheric altitudes. Their technology options, in a sense, enable a space mission payload to be deployed into the lower altitudes of the stratosphere, without needing the cost burden of a space launch or waiting for the next available launch schedule. The integration of Space 2.0 technology and stratospheric air missions will provide mission planners with options that can improve the impermanence and operational responsiveness of low-Earth orbital space missions.

Pseudosatellite Vehicle Design Options

Two design solutions categorise pseudosatellites based on the design method used to maintain the altitude for the mission payload:

a. **Aerodynamic vehicle designs** use lift-generating wings and control surfaces to control flight. The winged pseudosatellites use similar onboard algorithms to navigate and loiter within a preferred area,

(1) **Internal power source**. Rechargeable power cells store energy from onboard solar power generators to use when sunlight is not available.

(2) **External power source**. Solar panels are used to convert sunlight into electrical energy.

b. **Aerostatic vehicle designs** use a lighter-than-air gas-filled aerostat or balloon. The pseudosatellite balloon maintains a position close to the specified mission datum location by using predictive models of the winds and decision-making algorithms to decide where and when to move the balloon up or down into different wind layers.

(1) **Tethered airships** are designed for tethered operations from a ground station or sea platform. A tether to a naval ship can provide some protection to the aerostat and provide the option to relocate the mission payload with changes in a mission location.

(2) **Dirigible airships** are normally configured with external thrusters to enable mobility to change and maintain positions in dynamic weather conditions.

(3) **Zero-pressure balloons** are open at the bottom and have open ducts hanging from the sides to allow gas to escape and to prevent the pressure building as the balloon rises. The availability of the stored lighter-than-air gas determines the

maximum flight duration. This gas is released in controlled measures to keep the balloon afloat through the day/night thermal cycle that alternatively heats and cools the balloon.

(4) **Super-pressure balloons** or ultra-long-distance balloons (ULDB) are completely sealed with no open ducts for gas to escape. These balloons will float at a nearly constant altitude. Since gas loss is minimised, ULDBs can fly for longer durations than zero-pressure balloons.

(5) **Infrared (IR) Montgolfiere Aerobots** are designed to fly in the Earth's cold stratosphere with heating from the sun during the day and by trapping heat radiated from the Earth when afloat at night.

The high-operating altitude design enables a wider field-of-view for sensors, increased breadth of coverage for communications, and longer persistence. This is better than possible with traditional air missions but not as good as space missions. However, pseudosatellites offer improved performances over traditional air missions for less cost and effort than a space mission.

Pseudosatellites may carry mission payloads for ISR, communications, networking, and augmented GPS that cover large operating areas with better persistence than conventional aircraft. Pseudosatellites also provide users with better access than low-Earth orbiting small satellites. By flying at lower altitudes than space satellites, pseudosatellites can operate miniaturised sensors that have been fortified for the harsh space environment. They thus provide sharper resolution imagery and signature detections than possible from orbit.

Pseudosatellites can also be configured to function as a communications relay hub for a low-flying swarm or flight of UAS and ground stations. They can provide a line-of-sight communications relay capability that provides persistent coverage when overflying low-Earth orbiting satellites that are only available once per day or a few times per week. Additionally, unlike orbiting space systems, pseudosatellites can be recovered at the end of a mission for repairs, reprogramming, reconfiguration, replenishment, and system upgrades.

High-altitude balloons are used to lift a mission payload into the stratosphere. When the ascending balloon bursts at altitude, the mission equipment parachutes back to the ground in an uncontrolled descent. Aerodynamic pseudosatellites offer new and affordable options to protect and recover the mission payload in a controlled manner.

Examples of Pseudosatellite Designs

Pseudosatellites are currently being developed with sufficient payloads to perform missions for ISR, communications, networking, augmented GPS, and scientific research missions in the upper atmosphere. The following summarises a sample of different pseudosatellite vehicle designs.

a. **NASA standard high-altitude balloons** involve scientific balloons constructed of polyethylene film, using material similar to plastic bags, which is only 0.002 centimetres thick. These very large balloons can carry up to a 3600 kilograms payload, fly up to 140,000 feet, and stay there for up to two weeks.[25]
Status: *Operational at balloon launch stations located around the world, including the NASA Australian Balloon Launch Station (ABLS), operated by CSIRO, at Alice Springs.*[26]

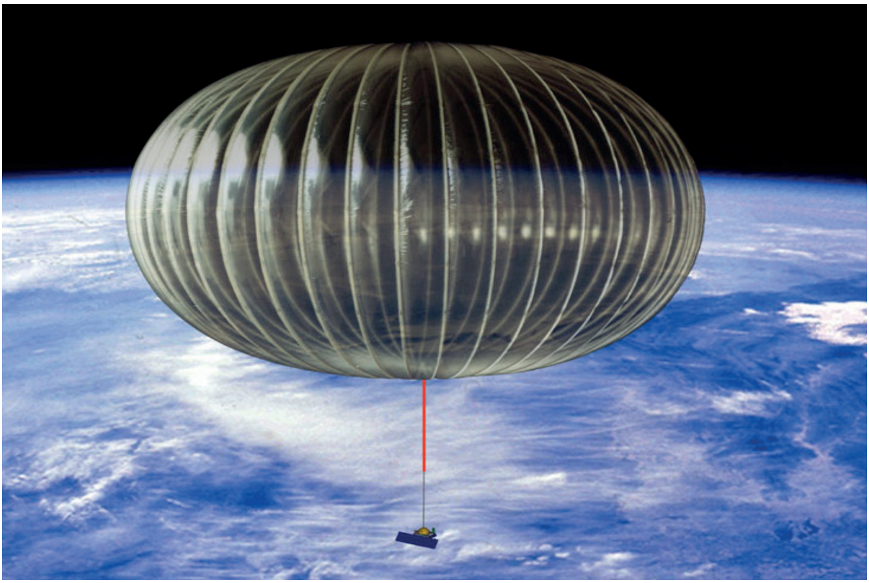


Figure 6. NASA high altitude balloon experiment[27]

b. **Airbus Zephyr**[28] is a winged, solar-powered HAPS design that can make long endurance flights without refuelling. Its purpose is to relay imagery and signals intelligence to groundborne users for less cost and risk than launching and operating an orbiting ISR satellite. Annex A describes the Zephyr trials that were conducted at Woomera, Australia, in 2015 and 2018.
Status: *Currently in production. Australian Government and Airbus cooperative research trials were conducted in Western Australia in 2018.*

Figure 7. Airbus Zephyr-T[29]

c. **Project Loon**[30] is a Google-initiated telecommunications project that formed its own company under Loon LLC in 2018 to extend internet connectivity to remote populations located beyond satellite coverage. Internet smartphones connect users to the network of multiple deployed Loons. Loons use predictive weather models and autonomous control systems to ascend to heights where favourable winds move the balloons in the directions needed to provide network coverage over a specified operating area. The Loons transit the operating area, are recovered, and recycled for relaunch from the original start point, ahead of the weather. They continue the flight sequence and provide continuous uninterrupted internet connectivity. A fleet of balloons is planned to be co-ordinated to ensure that one remains over any specific service area.
Status: Currently in production in US by Google.

Figure 8. Project Loon is proposing to develop a balloon-based Wi-Fi system[31]

d. **Thales Alenia Stratobus**[32] provides intermediary links between satellites and other aircraft, capture higher resolution images within a regional area, and offer another physical layer in the sky for deploying ISR sensors. Solar panels generate power for the electric propulsion system for the aerostat to maintain a stable position in winds up to 90 km/h. The solar energy captured during the day needs to be adequate to power the subsystems. These include propulsion, guidance and control avionics, communications, heating, and mission payload systems, both during the day and night.
Status: Thales Alenia Space is preparing the lighter-than-air Stratobus, for its first flight expected in 2021.[33]

Figure 9. Thales Alenia Stratobus[34]

e. **CNES IR Montgolfiere Aerobot**[35]**(ie Thermal Airship)**, is manufactured with a balloon fabric to exploit the thermal changes in the atmosphere. It does so by generating heat from the Sun during the day and absorbing heat radiating from the warm Earth at night. The thermal radiation heats up air within a large chamber or the balloon envelope to generate buoyancy. The heated air in the balloon's interior has a lower density than the cooler ambient air, thus generating an upward force on the balloon. These balloons generally fly at a constant altitude, albeit differently in accordance with day and night conditions.

NASA is considering options for employing solar infrared mongolfiere aerobots (SIRMA) on exploratory missions to other planets in the solar system.[36]

Status: *French researchers at Centre national d'études spatiales have flown over 40 such balloon missions since the first proof-of-concept was flown in 1977, the longest of which lasted 69 days and encircled the Earth twice. Exploiting a natural heat source negates the need for onboard energy systems and reduces the carbon footprint of the balloon mission.*

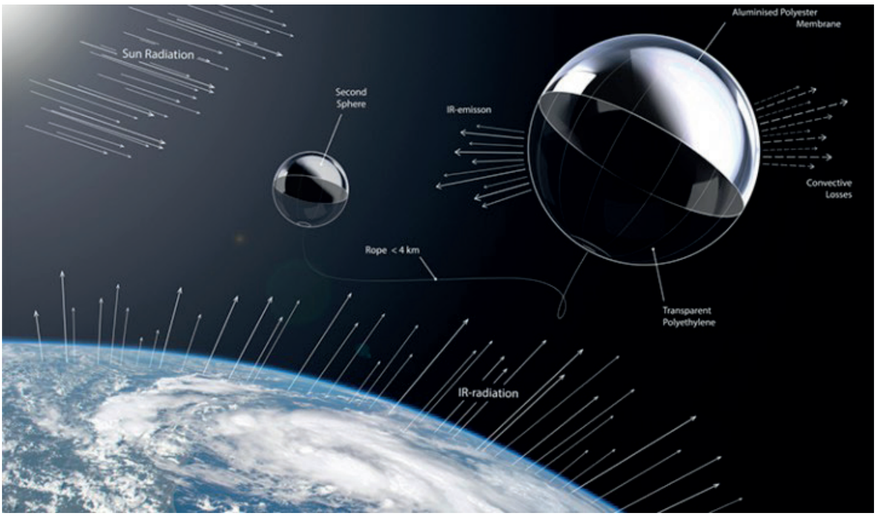


Figure 10. French zero-carbon solar-heated hot-air balloon concept[37]

f. **AlphaLink Space**[38] is a kick-start project promoting an innovative design that deploys multiple, standardised air vehicles, in a coordinated operation. Up to 10 single air vehicles are flown into a formation during which they physically connect themselves to the other vehicles, using flexible joints in their wingtips. They function as a single, large air vehicle with a very long configured wingspan (see Figure 11). The air vehicle's flight control system is designed to perform autonomous wing coupling or decoupling, in flight. The system supports autonomous operation of the joined flight formation when operating as a single large air vehicle. The modular approach can significantly reduce both operations and maintenance costs owing to the AlphaLink being built with standardised aircraft of smaller scale than typical HAP aircraft. The mission risks are also reduced as AlphaLink can keep operating with a partial technical malfunction so that individual aircraft can be decoupled, sent back to a ground station for servicing, and then replaced in the joined formation.
Status: *AlphaLink.Space is a 2017 kickstarter project with projected plans to build a three-vehicle AlphaLink-III by 2022 and a ten-vehicle AlphaLink-X by 2025.*

Figure 11. AlphaLink proposed a design for individually launched air vehicles to fly into a formation and autonomously connect into a single pseudosatellite[39]

g. **Aurora Flight Services (a Boeing Company) Odysseus** is based on a powered high-altitude and long-endurance remotely piloted and autonomously flying, solar-powered aircraft. It is designed for persistent flight at high-altitudes (see Figure 12) to perform climate and atmospheric research. Powered by solar cells and constructed from light-weight materials, it makes zero emissions and can be repositioned and reprogrammed as mission requirements change.
Status: *First Odysseus test flight is planned in 2019.*[40]

Figure 12. Aurora Flight Services Odysseus HAPS[41]

h. **RAAF MQ-4C Triton remotely piloted aircraft system (RPAS)** is a powered high-altitude and long-endurance remotely piloted aircraft (see Figure 13). It is configured with a mission payload of multiple discrete sensor systems. The RAAF Triton RPAS will be operated to perform ISR missions and communicate the mission data directly to users or relay data as a network communications node using a datalink or network. RAAF has planned to acquire Triton RPAS to be home-based at RAAF Base Edinburgh.[42] Depending on crew availability and maintenance support, one RAAF Triton RPA may be flown for up to 24 hours on a mission. It features a persistent operating radius up to 2000 nautical miles (3700 kilometres) and operating altitude ceiling of above 50,000 feet.[43]
Status: *The first Triton RPAS is planned to enter RAAF operational service in 2023.*[44]

Figure 13. MQ-4C Triton remotely piloted aircraft

The RAAF operationalisation of the Triton RPAS will place new demands on the Bureau of Meteorology for weather data and environmental forecasts up to and within the stratosphere.

After the RAAF operationalised the Triton RPAS, the subsequent introduction of any new pseudosatellites by other operators will place new demands on airspace management services to provide information on air traffic in the stratosphere.

Comparison of Pseudosatellite Design Features

Table 1 and Table 2 compare the different options featured in each different modern pseudosatellite design and the well-known U-2 Dragon Lady stratospheric, human-occupied, high-altitude aircraft that has been in US operational service since 1955. These designs do not necessarily represent matured production as the simple nature of the pseudosatellite design, when compared to conventional aircraft and spacecraft designs, are more easily disrupted by technology innovation and the rapidly changing needs of missions and users.

	Original Equipment Manufacturer	Production Date (estimate)	Air Vehicle Design	Launch Trajectory	Size	Operating Weight	Power Source
ABLS @Alice Springs	NASA-owned; CSIRO-operated	Since 1960	Thin-film, helium-filled balloon	Direct Ascent	100 m diameter; 145 m height	2200 kg	configured as needed
Loon	Loon LLC	2017	Helium-filled balloon		15.0 m height	20 kg	renewable solar power charged cells renewable solar power charged cells
Stratobus	Thales Alenia Space	2020	Hydrogen or helium aerostat balloon		33.0 m diameter; 100 m height	5000 kg	
Infrared (IR) Montgolfier	CNES	1977	Hot-air balloon		43 m diameter	95 kg	
Zephyr-T	Airbus Defence and Space	2016	Aerodynamic	Powered spiralling climb	33.0 m wingspan	140 kg	
AlphaLink	AlphaLink Space	AlphaLink-III 2022	Aerodynamic, 3 x vehicles		57.0 m combined wing	474 kg	
		AlphaLink-X 2025	Aerodynamic, 10 x vehicles		215 m combined wing	4000 kg	
Odysseus	Aurora Flight Services (Boeing)	2019	Aerodynamic, 3 x fuselages		74 m combined wing	< 750 kg	
RAAF MQ-4C Triton	Northrop Grumman	Enters RAAF in 2023	Aerodynamic		39.9 m wingspan	14,628 kg	Jet fuel turbine
U-2 Dragon Lady (manned)	Lockheed Martin	1955	Aerodynamic	Powered climb	31.3 m wingspan	18,100 kg	

Table 1. Design features of example pseudosatellites (table shows nominal values).

	Air Vehicle Design	Mission Trajectory	Mission Endurance	Operating Height	Payload Weight	Types of Missions
ABLS @Alice Springs	Thin-film, helium-filled balloon	Drifting	24 hrs direct ascent; 100 days drifting	96,000 to 120,000 feet	1500 kg	Science missions, including terrestrial and space observations
Loon	Helium-filled balloon		100 days drifting	65,000 to 90,000 feet, nominal	15 kg	(notional) ISR, Earth observation, communications and network relay, augmented phone and GPS network, etc.
Stratobus	Aerostatic balloon	Drifting, Loitering, or Flight	1 to 5 years flying/drifting		250 kg	
Infrared (IR) Montgolfier	Hot-air balloon	Drifting	14 to 21 days	90,000 ft day; 65,000 ft night	80 kg	Upper atmosphere science
Zephyr-T	Aerodynamic	Powered Flight	45 days flying	65,000 to 90,000 feet, nominal	20 kg	(notional) ISR, Earth observation, communications and network relay, augmented phone and GPS network, etc.
AlphaLink	Aerodynamic, 3 x vehicles		100 days	> 65,000 feet, nominal	10 kg distributed	(notional) mobile communications for remote locations; surveillance for disaster management
	Aerodynamic, 10 x vehicles		365+ days		450 kg distributed	
Odysseus	Aerodynamic, 3 x fuselages		< 90 days		25 kg	
RAAF MQ-4C Triton	Aerodynamic		24 hours	> 50,000 feet	1452 kg internal	Maritime ISR
U-2 Dragon Lady (manned)	Aerodynamic		12 hours	>70,000 feet	2270 kg	ISR, SIGINT, disaster relief, search & rescue, upper atmospheric research

Table 2. Mission-related features and performances of example pseudosatellite designs (table shows nominal values).

NASA's largest scientific balloon, the ''Big 60", reached the highest recorded, sustainable altitude of 159,000 feet in August 2018.[45]

A Project Loon balloon set the longest duration record by staying afloat for 187 days in March 2015;[46] at altitudes above 70,000 feet.

A Zephyr-S High-Altitude Long-Endurance Unmanned Aerial Vehicle achieved the longest recorded flight endurance of 25 days, 23 hours, and 57 minutes, above Arizona in mid-2018.[47]

A Zephyr high-altitude long-endurance and solar-powered unmanned aircraft reached the highest recorded flight altitude of 70,740 feet in July 2010.[48]

A US Northrop Grumman RQ-4A Global Hawk Southern Cross II recorded the longest distance flown by an unmanned powered aircraft of 13,219.86 km on a non-stop flight to Australia in April 2001.[49]

Synopsis of the Potential Military Utility of Pseudosatellites

Pseudosatellites provide a new capability option that may provide a lower costing alternative to conventional aircraft and spacecraft, to extend the efficacy and efficiency of air power and complement space missions currently being performed in low-Earth orbit. In addition to missions designed for Earth observation requiring weather monitoring, communications, networking, and navigation, other useful applications for militarised pseudosatellites could be: signals intelligence (SIGINT), electronic intelligence (ELINT), and force-disposition and blue-force tracking. Furthermore, a cooperating group of several pseudosatellites could deploy SIGINT payloads to geolocate signals of interest.

COST-SAVING BENEFITS TO FUTURE MISSION DESIGNS

Pseudosatellites, both as aerostatic and aerodynamic designs, can provide cost-savings, when compared to the costs and resources needed for conventional piloted air missions, owing to the following characteristics:

a. Pseudosatellites can be designed to be lightweight, simple, and non-complicated to perform missions at high altitude similar to conventional aircraft. However, their lightweight design does make them fragile and easy to be disrupted by kinetic effects and foul weather.

b. Pseudosatellites can provide a more rapidly deployed and responsive capability than space missions. However, pseudosatellites are more susceptible to damage from the effects of weather, especially when transiting to or from the stratosphere, and conventional air defence systems.

c. Employing miniaturized mission payloads, originally designed space missions, in a stratospheric pseudosatellite can provide better quality sensor data and communications links to terrestrial missions owing to the shorter line-of-sight distances to between the pseudosatellite mission payload and the user element deployed in the air or on the surface.

d. The smaller signatures of the air vehicle designs used for pseudosatellites can make them difficult to be acquired and targeted by conventional guided weapons that are typically designed for much more complicated and expensive aerial targets; aerostat designs will have high infrared signatures due to heating of the capacious balloon envelope. The use of low-power electrical propulsion will also produce a smaller signature when compared to powered aircraft.

e. The communications and control systems for both the pseudosatellite air vehicle and the mission payloads will be critically dependent on the use of the electromagnetic spectrum over long distances. This is likely to expose pseudosatellites vulnerabilities, similar to piloted missions, to non-kinetic attacks from hostile electromagnetic spectrum and cyberspace activities and the foul weather.

f. Pseudosatellites can be introduced that can re-use existing air operations and aviation infrastructure (eg airbases, runways, communications, air traffic control, intelligence analysis, etc), reducing their lifecycle cost when compared to the acquisition of a new conventional piloted aircraft.

g. While their mission life is much shorter than for orbiting satellites, pseudosatellites can improve the permanence of deployed payloads and operate over a mission area with a longer endurance than is possible with traditional air power options, including unmanned aerial vehicles.

h. Pseudosatellites can be designed that exploit the best features from satellite and aircraft mission systems. They may not only have a larger coverage area than terrestrial systems, lower cost than launching and deploying a satellite, but also can be recovered for repairs, upgrades, and reconfiguration more easily than a satellite.

PUSHING TRADITIONAL AIR POWER THINKING INTO THE STRATOSPHERE

Air Force recognises the following nine characteristics of air power.[50] While not listed in order of significance, they can usefully assess the potential military utility of pseudosatellites.

a. **Perspective**. While the high-ground advantage of the stratospheric operating altitude is not as good as an orbital altitude, it is better than for traditional air power that operates in the altitudes below the stratosphere. The pseudosatellite exploits the benefits of both orbital space missions and aircraft missions: terrestrial users can access a space-mission payload deployed to loiter at a high altitude. It could provide better system performance, availability, and access than an overflying tactical satellite.

b. **Speed and Responsiveness**. While the operating speed of the pseudosatellite is poorer than conventional aircraft, this is a trade-off in design than enables better station-keeping to provide steady and lengthy access to terrestrial elements. The speed of response and deployment for a pseudosatellite is quicker than that to arrange the assembly and launch of an orbiting satellite, and costs much less.

c. **Reach and Endurance**. The slow speed but long endurance of the pseudosatellite's performance enables it to traverse long distances, to reach a distant mission area, and to hold station there or follow a moving datum that is associated with a dynamic, changed, or follow-on mission objective. Additionally, the long range and endurance enables the pseudosatellite to wait for foul weather to pass or for it to reposition itself in order to evade the foul weather.

d. **Flexibility**. Pseudosatellites are predominantly air vehicle designs for configured for carrying mission payloads. The payload can be modular to perform different and/or multiple missions concurrently. Additionally, the ability to recover the pseudosatellite provides flexible options to repair, upgrade, and reconfigure the payload to adapt to different mission needs.

e. **Precision**. Pseudosatellites that can operate space mission quality payloads from line-of-sight distances above terrestrial targets that are closer than for overflying satellites. Pseudosatellites will thus deliver effects of better quality and quantity. For example, ISR sensors will gain images with better resolution, and communications relays will achieve better data exchange rates and budget links. Additionally, the far-reaching coverage of the deployed pseudosatellite enables it to support mission elements and enhance their precision by relaying and augmenting satellite navigation and positioning systems.

f. **Dependency**. Pseudosatellites depend far less on supporting ground infrastructure than compared to air and space missions. They do not need long runways and are designed with complicated systems for propulsion, manoeuvring and missions. Pseudosatellite designs can have similar levels of autonomy and independence available in the proven designs for satellites and remotely piloted aircraft systems. Pseudosatellite operations do not depend on continuous human control and can autonomously evade environmental conditions that adversely affect the mission and/or recover to a ground station. This is vital if mission systems begin to fail below the minimum needed to perform the mission. Pseudosatellites can be also deployed to enable or enhance dependent mission elements (eg a communications relay for ground teams deployed into mountainous terrain but shielded from normal satellite coverage).

g. **Fragility** becomes a prominent characteristic of pseudosatellite designs owing to their lightweight structure. In the mix of interdependent design variations, a lightweight but fragile design is a necessary trade-off to improve reach, speed, coverage, and payload carrying capacity. The lightweight designs do suggest that winged pseudosatellites will have a small detectable cross-sectional area and low signature, making it difficult to be detected and engaged by traditional weapons. Aerostats will have a large visual and infrared signature because of the balloon envelope. Both pseudosatellite designs are vulnerable to the damaging forces associated with violent weather and aircraft wake turbulence.

h. **Payload**. The payload capacity results from the trade-offs between the interdependent variables needed to optimise a design that meets the mission need. The Space 2.0 revolution has miniaturised technology that is also used by pseudosatellites to reduce mass and energy consumption and provide options for modular and multi-mission designs. The ability to recover pseudosatellites means that payloads can be services, reconfigured, and replaced.

i. **Impermanence**. All the airpower characteristics mentioned above are interdependent variables in pseudosatellite designs that are modified and traded off against each other to achieve a permanence that is better than with traditional air and space missions (ie low-Earth orbital space mission).

MANNED UN-MANNED – TEAMING (MUM-T)

Manned un-manned-teaming (MUM-T)[51] describes the integration of separate and discrete manned and unmanned mission systems to extend and enhance the capabilities of the other mission systems, such as piloted aircraft. MUM-T is a standardised systems architecture and communications protocol that enables live video and still images gained from the sensor payloads of RPAS to be shared throughout a force. They improve and achieve a common level of battlefield situational awareness, thereby enhancing decision superiority. Pseudosatellites could considered to support, enhance and extend air mission, using any of the different levels of integration for controlling the pseudosatellite mission that suits the mission needs and its workload capacity.

Conclusion

Pseudosatellites are being developed with delicate airframe designs and renewable energy that will be deployed into the little used stratosphere for long endurance missions. They will provide new options for air missions that will modify the impermanence that has restricted traditional air power options.

Pseudosatellites are configured with mission systems that have been reduced in size, mass, energy-usage, and cost, driven by the Space 2.0 technology revolution to develop smaller mission payloads for low-cost space missions.

Pseudosatellites exploit the best features of both satellite and terrestrial communications. For example, an airborne pseudosatellite not only has a larger coverage area than a terrestrial system, a lower cost than a rocket-launched satellite, or a ground deploying terrestrial network with many base stations. Additionally, the use of renewable energy sources with low waste emissions make pseudosatellites environmentally friendly and the ability to land and recover the pseudosatellite makes them upgradeable and repairable, unlike for deployed orbital space mission.

Space missions and pseudosatellites offer different advantages and risks; a trade-off analysis is needed when considering new air options. The orbiting tactical satellite is restricted to flying an orbital trajectory that only passes over the datum area with a frequency measured in days. The pseudosatellite can offer increased permanence to fly a persistent mission over a datum area. The pseudosatellite is also easier and quicker to launch, is recoverable for repair, and can be reconfigured and updated to match agile changes in a benign operating environment.

Deploying pseudosatellites into such an operationally and meteorologically benign environment at stratospheric altitudes enables mission payloads to provide stronger communications signals. They can also provide better terrestrial imagery resolution, with more persistent coverage, than traditional air and space missions.

Annex A - Case Study: UK Zephyr Flight Trials in Australia

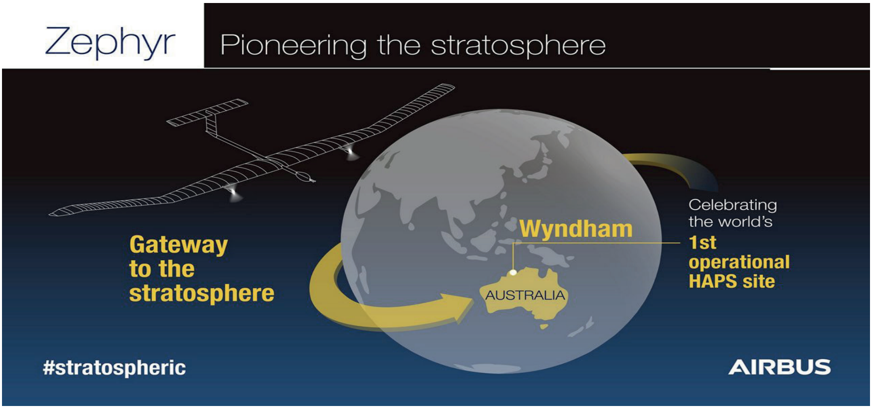


Figure 14 . Zephyr-S was launched from Wyndham to perform stratospheric operations under a joint Australian research program with Airbus[52]

2005 ZEPHYR FLIGHT TRIALS IN WOOMERA, SOUTH AUSTRALIA

In 2005, UK research and technology company Qinetiq conducted flight demonstrations of an earlier version of its lightweight Zephyr-3 HAPS, at Woomera, for the UK Ministry of Defence.[53]

The Zephyr-3 had a 12 m wing span, a total weight of 12 kg and a planned operating ceiling of up to 132,000 ft. The original plan was to lift the Zephyr-3 by a balloon up to 30,000 ft before activating its solar-powered electric motors, before allowing it to be deployed from the balloon. The deployed Zephyr-3 would fly a spiralling climb around the balloon and continue upwards until it reached its planned maximum altitude.

The Zephyr-3 uses electrically powered propellers. During the day, sunlight on the solar panels mounted atop the wings provides the energy to drive the electric motors and charge lithium-sulphate batteries to power the Zephyr through the night, in the absence of solar power.

2018 ZEPHYR-S FLIGHT TRIALS AND HAPS OPERATING BASE IN WYNDHAM, WESTERN AUSTRALIA

In 2016, Airbus opened a new purpose-built ground station at Wyndham Airfield in the Kimberly Ranges, Western Australia, to provide land communications traffic from the Skynet 5 satellite[54] for supporting flight trials for its Zephyr HAPS (see Figure 14). In June 2018, Airbus established the world's first Zephyr-S Solar High-Altitude Pseudosatellite operating base for supporting flight trials conducted with three Zephyr-S solar-powered unmanned aircraft.[55]

After being launched by hand, a pilot situated in a container-based ground station, at the operating base, remotely controls the Zephyr-S until it reaches the minimum altitude necessary to enable the autopilot. Once at that altitude, the autopilot uses GPS to navigate the aircraft between the preplanned waypoints, nominated in the digital mission plan or, when necessary, by the pilot when exercising manual control for manoeuvring the Zephyr-S in flight.

The Zephyr-S is the production version of the earlier Zephyr-7. The total weight is less than 75 kg, it has a 25 m wingspan and, during the Australian trials, was trialled in flights over Wyndham Airfield, at an operating altitude of 70,000 feet. The Zephyr-S design is configured to carry "see, sense, and connect" payloads that shape its mission purpose to support surveillance, Earth observation, and networked communications.[56]

Ground Control Stations are deployed to control Zephyr-S from locations anywhere in the world using Beyond Line-of-Sight (BLOS) networking and communications systems. Zephyr-S is designed to use solar energy as its primary power source. Such energy is also used to charge its secondary batteries during daylight operations to power the HAPS during night. The endurance of the mission, as a single sortie, is planned on a timescale of weeks and months.[57]

Zephyr-S was developed by Airbus Defence and Space as a pseudosatellite to apply potentially to communications and ISR payloads to support civilian operations in precision farming guidance, environmental and security monitoring. Zephyr-S also provides coverage to regions with poor internet access or zero connectivity and to support humanitarian aid and disaster relief missions for civilian and military purposes.

Annex B: Abbreviations

ABLS	Australian Balloon Launch Station (Alice Springs)
BLOS	Beyond Line-Of-Sight
CNES	French Centre National D'études Spatiales
CSIRO	Commonwealth Scientific and Industrial Research Organisation
GEO	Geostationary Earth Orbit
GPS	(US) Global Positioning System
HABLEG	High-altitude balloon launched experimental glider
HALE	High-Altitude Long-Endurance
HAPS	High-Altitude Platform Station or High-Altitude Pseudosatellite
ISR	Intelligence, Surveillance & Reconnaissance
LEO	Low Earth Orbit
MALE	Medium Altitude Long Endurance
MEO	Medium Earth Orbit
MUM-T	Manned Unmanned-Teaming
NASA	National Aeronautics & Space Administration
NM	Nautical mile
PNT	Positioning, Navigation & Timing
QBO	Quasi-biennial oscillation
RPAS	Remotely Piloted Aircraft System
SEU	Single Event Upset
SIGINT	Signals intelligence
SIRMA	Solar Infrared Mongolfiere Aerobot
SOTM	SATCOM-On-The-Move
UAS	Unmanned Aircraft System
ULDB	Ultra-long distance balloon

Endnotes

1 Weston, B (2014). *Unmanned Aerial Systems - Their Future as Australian Defence Force Capabilities*. Submission to Senate Standing Committee on Defence, Foreign Affairs and Trade on 12 December 2014. Online www.aph.gov.au/DocumentStore.ashx?id=936eecd9-df29-4e46-bca3-6355e04299bf&subId=302363. Accessed 5 September 2018.

2 Air Force (2016). *AAP 1000-D The Air Power Manual.* Online at http://airpower.airforce.gov.au/APDC/media/PDF-Files/Doctrine/AAP1000-D-The-Air-Power-Manual-6th-Edition.pdf. Accessed 1 February 2019.

3 *Defined as "A subset of an unmanned aircraft system (UAS), a RPAS is a system consisting of the remotely piloted aircraft (RPA), together with any Ground Control Station (GCS), communications/data links, maintenance, launch and recovery systems. This includes the network and operating personnel required to control the RPAS. A RPAS may also be referred to as a UAS."* AAP 8000-011 Defence Aviation Safety Regulation (DASR). Online at www.defence.gov.au/DASP/Docs/Manuals/8000-011/DASRWeb/index.htm#8570.htm. Accessed 19 February 2019.

4 esa (2017). *Crossing Drones with Satellites: ESA Eyes High-Altitude Aerial Platforms.* Online at www.esa.int/Our_Activities/Navigation/Crossing_drones_with_satellites_ESA_eyes_high-altitude_aerial_platforms. Accessed 21 January 2019.

5 esa (2017). *High-Altitude Pseudo-Satellites,* Space in images. Online www.esa.int/spaceinimages/Images/2017/11/High-altitude_pseudo-satellites. Accessed 5 September 2018.

6 UCAR (2011). *The Stratosphere – Overview*. University Corporation for Atmospheric Research. Online at https://scied.ucar.edu/shortcontent/stratosphere-overview. Accessed 23 January 2019.

7 UCAR (2011). Loc cit.

8 Stanley, S (2016). *Mysterious Anomaly Interrupts Stratospheric Wind Pattern.* EOS, Atmospheric Sciences. Online at https://eos.org/research-spotlights/mysterious-anomaly-interrupts-stratospheric-wind-pattern. Accessed 1 February 2019.

9 Miller, S; et al (2014). *Airships: A New Horizon for Science, February 2014.* Study report prepared for The Keck Institute for Space Studies. Online at http://kiss.caltech.edu/final_reports/Airship_final_report.pdf?bcsi_scan_5e8320feade9cba2=1&bcsi_scan_f3c628fb27335eb8=0&bcsi_scan_filename=Airship_final_report.pdf. Accessed 19 March 2019.

10 ABC News (2016). *Layers of the Earth's Atmosphere.* Online at https://www.abc.net.au/news/2018-02-06/layers-earth-atmosphere-stratosphere-ozone/9401488. Accessed 15 March 2019.

11 Mortimer, G (2015). *HABLEG (High Altitude Balloon Launched Experimental Glider),* UAS News. Online at www.suasnews.com/2015/07/hableg-high-altitude-balloon-launched-experimental-glider/. Accessed 19 February 2019.

12 Miller, S; et al (2014). Op cit. p30.

13 Miller, S; et al (2014). Op cit. p52.

14 Mann, A (2017). *Commercial balloons in the stratosphere could monitor hurricanes and scan for solar storms.* Science. Online at www.sciencemag.org/news/2017/06/commercial-balloons-stratosphere-could-monitor-hurricanes-and-scan-solar-storms. Accessed 31 January 2019.

15 Chong, J (2017). *Better Late Than Never, Australia Heads (Back) to Space. Australian Aviation*. Online at http://australianaviation.com.au/2017/12/better-late-than-never-australia-heads-back-to-space/. Accessed 11 February 2019.

16 Air Force (2016). *AAP 1000-D The Air Power Manual.* Online at http://airpower.airforce.gov.au/APDC/media/PDF-Files/Doctrine/AAP1000-D-The-Air-Power-Manual-6th-Edition.pdf. Accessed 1 February 2019.

17 Ibid.

18 Calculated using the Radar Equation.

19 Hoyle, C (2005). *UK's Zephyr UAV to be tested for military role.* Flight Global. Online at www.flightglobal.com/news/articles/uks-zephyr-uav-to-be-tested-for-military-role-194214/. Accessed 1 February 2019.

20 International Civil Aviation Organisation (2010). *Convention on International Civil Aviation (aka Chicago Convention).* Online at www.icao.int/publications/Documents/7300_9ed.pdf. Accessed 21 March 2019.

21 AirServices Australia (2019). *How Airspace is Managed.* Online at www.airservicesaustralia.com/services/how-air-traffic-control-works/how-airspace-is-managed/. Accessed 20 March 2019.

22 Air Force (2019). *AFDN 1-19 Air-Space Integration.* Air Power Development Centre. Online at www.airforce.gov.au/airpower.

23 APDC (2014). *Pathfinder #225: Lighter-Than-Air and Hybrid Airships.* Online http://airpower.airforce.gov.au. Accessed 5 September 2018.

24 ESA (2017). *Crossing Drones with Satellites: ESA Eyes High-Altitude Aerial Platforms.* Navigation. Online at http://www.esa.int/Our_Activities/Navigation/Crossing_drones_with_satellites_ESA_eyes_high-altitude_aerial_platforms. Accessed 30 January 2019.

25 NASA (2018). Types of Balloons. *Scientific Balloons*. Online at www.nasa.gov/scientific-balloons/types-of-balloons. Accessed 21 January 2019.

26 StratoCat (2018). *ABLS - Australian Balloon Launch Station - Alice Springs. Stratospheric Balloon Bases in the World.* Online at http://stratocat.com.ar/bases/4e.htm. Accessed 21 January 2019.

27 NASA (2003). *NASA Gets Ready to Launch the Largest Super Pressure Balloon Ever Flown.* Online at www.nasa.gov/centers/goddard/news/topstory/2003/0120uldb.html. Accessed 19 March 2019.

28 Airbus S.A.S. (2018). *Zephyr – Pioneering the Stratosphere.* Online at www.airbus.com/defence/uav/zephyr.html

29 Airbus (2019). *Zephyr – Pioneering the Stratosphere.* Online at www.airbus.com/defence/uav/zephyr.html. Accessed 19 March 2019.

30 The Moonshot Factory (2018). *Loon: Expanding Internet Connectivity with stratospheric balloons.* Online at https://x.company/projects/loon/

31 Li, A (2017). *Alphabet deployed emergency LTE to Puerto Rico w/ Project Loon in under a month.* 9TO5Google. Online at https://9to5google.com/guides/project-loon/#posts. Accessed 16 March 2019.

32 Thales Group (2018). *All Articles in Stratobus*. Online at www.thalesgroup.com/en/taxonomy/term/7436

33 esa (2017). Loc cit.

34 Thales (2017). *What's Up with Stratobus? Thales* Group. Online at www.thalesgroup.com/en/worldwide/space/news/whats-stratobus. Accessed 19 March 2019.

35 Hall, J (2012). *Balloon Background.* Online at www2.jpl.nasa.gov/adv_tech/balloons/backgrnd_overview.htm. Accessed 19 March 2019.

36 Hall, J (2012). *Balloons Technology for Jupiter and Saturn.* Online at www2.jpl.nasa.gov/adv_tech/balloons/outer_jupisat.htm. Accessed 19 March 2019.

37 Chardronnet, E (2015). *COP21: maiden flight of the zero carbon hot air balloon.* Online at http://www.makery.info/en/2015/11/30/cop21-le-premier-vol-de-montgolfiere-zero-carbone/. Accessed 19 March 2019.

38 AlphaLink.Space (2018). *Innovative Design.* Online at https://alphalink.space/portfolio/innovative-design/. Accessed 30 January 2019.

39 Cracau, D and Kothe, A (2017). *Project AlphaLink.* Presentation to Space Tech Expo Europe on 26 October, 2017. Online at http://www.spacetechexpo.eu/forums/forum-presentations/. Accessed 30 January 2019.

40 Aurora Flight Sciences (2018). *Media Release: Aurora Flight Sciences Reveals Solar-Powered Autonomous Aircraft Odysseus.* Online at http://auroraliveweb.azurewebsites.net/wp-content/uploads/2018/11/APR-365-Aurora-Announces-Odysseus-Nov-14-2018.pdf. Accessed 4 February 2019.

41 Unmanned Systems Technology (2018). *Aurora Flight Sciences Odysseus unmanned aircraft.* Media Library. Online at www.unmannedsystemstechnology.com/2018/11/high-altitude-solar-unmanned-aircraft-features-ultra-long-endurance/aurora-flight-sciences-odysseus/. Accessed 4 February 2019.

42 Air Force (2018). *MQ-4C Triton Unmanned Aircraft System.* Online at www.airforce.gov.au/technology/aircraft/intelligence-surveillance-and-reconnaissance/mq-4c-triton-unmanned-aircraft. Accessed 17 January 2019.

43 Ibid.

44 Department of Defence (2018). *Media Release: Prime Minister, Minister for Defence & Minister for Defence Industry - Joint Media Release - Strengthening Australia's Maritime Patrol Capability.* Online at https://www.minister.defence.gov.au/minister/marise-payne/media-releases/prime-minister-minister-defence-minister-defence-industry-joint. Accessed 9 December 2018.

45 Salazar, D (2018). *This Giant, Ultrathin NASA Balloon Just Broke an Altitude Record,* Space.com/Tech. Online at www.space.com/41791-giant-nasa-balloon-big-60-breaks-record.html. Accessed 1 February 2019.

46 Muoio, D (2016). *Here's How Google Makes Its Giant, Internet-Beaming Balloons.* Raven. Online at https://ravenaerostar.com/news/here-s-how-google-makes-its-giant-internet-beaming-balloons. Accessed 1 February 2019.

47 Allison, G (2018). *RAF transport Zephyr 'High Altitude Pseudo-Satellite' to Australia for concept trials.* UK Defence Journal. Online at https://ukdefencejournal.org.uk/raf-transport-zephyr-high-altitude-pseudo-satellite-to-australia-for-concept-trials/. Accessed 1 February 2019.

48 Guinness World Records (2019). *Highest flight by solar-powered spyplane (UAV).* Online at http://www.guinnessworldrecords.com/world-records/highest-flight-by-solar-powered-spyplane-(uav)-. Accessed 1February 2019.

49 Guinness World Records (2019). *Farthest flight by an unmanned aircraft (FAI-approved).* Online at http://www.guinnessworldrecords.com/world-records/farthest-flight-by-an-unmanned-aircraft-(fai-approved). Accessed 1 February 2019.

50 Air Force (2016). Op cit. p 131.

51 Woldhuis, D & Spencer, M (2017). *Manned-Unmanned Teaming: "MUM-T's the Word",* The Central Blue, The Sir Richard Williams Foundation. Online at http://centralblue.williamsfoundation.org.au/manned-unmanned-teaming-mum-ts-the-word-donald-woldhuis-michael-spencer/. Accessed 6 December 2018.

52 Airbus (2019). *Zephyr - Pioneering the Stratosphere.* Online at www.airbus.com/defence/uav/zephyr.html. Accessed 21 January 2019.

53 Hoyle, C (2005). *UK's Zephyr UAV to be tested for military role.* Flight Global. Online at www.flightglobal.com/news/articles/uks-zephyr-uav-to-be-tested-for-military-role-194214/. Accessed 1 February 2019.

54 Minister for Industry, Science and Technology (2018). *Growing Australia's space industry capability. Online* at www.minister.industry.gov.au/ministers/karenandrews/media-releases/growing-australias-space-industry-capability. Accessed 21 January 2019.

55 ibid.

56 ibid.

57 ibid.

Pseudosatellites
Disrupting Air Power Impermanence

Commercial and research interests have begun developing balloon and air vehicle system designs for performing missions in the stratosphere that are meant to fly from a few hours to weeks and even months in duration. This monograph seeks to highlight the main differences in the design determinants and likely performances of air and space missions that utilise pseudosatellites.

Pseudosatellites can offer new options for air and space that exploit favourable design features drawn from designs featuring in air and space missions. Whereas the *Air Power Manual* has defined impermanence as a limiting characteristic of air power, the long range and endurance capabilities that are possible with new stratospheric pseudosatellite missions is disrupting this traditional characteristic of air power.

AIR POWER DEVELOPMENT CENTRE - AUSTRALIA -