Unlocking the Stratosphere®

Stratospheric Operations and Research Symposium (SOaRS)
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What makes the stratosphere so difficult?

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A new company Unlocking the Stratosphere®

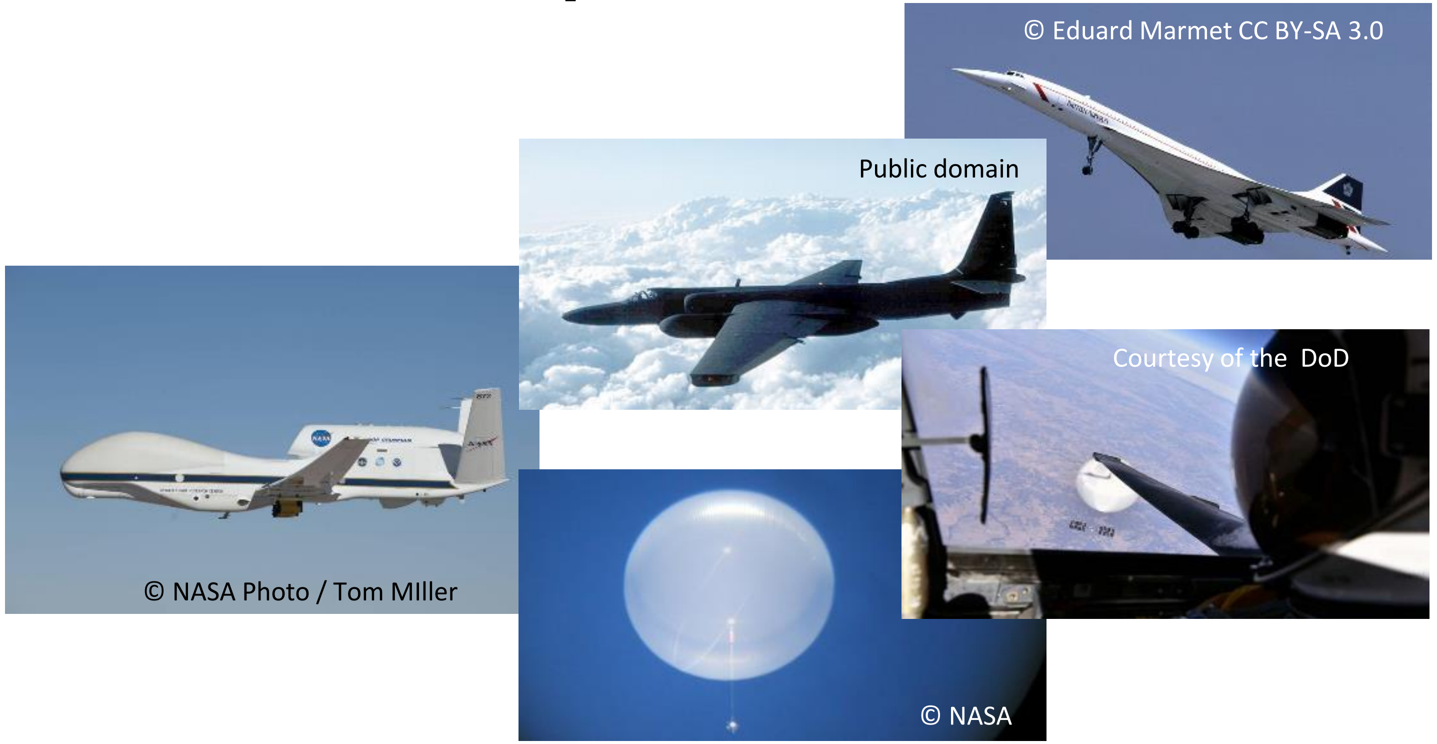
- Voltitude specialises in high altitude platforms, applications, and payloads.
- Our technology enables services from the stratosphere which are available globally and year-round.
- We are focused on complimentary systems of lighter-than-air and fixed-wing stratospheric technologies.

Paul Stevens CEng, MInsP, MPhys.

- CEO of VOLTITUDE LTD.
- Former Head of Design for Zephyr HAPS at Airbus.
- Over 25yrs of HAPS & UAS design and operating experience.

What makes the stratosphere so difficult?

Is it difficult?



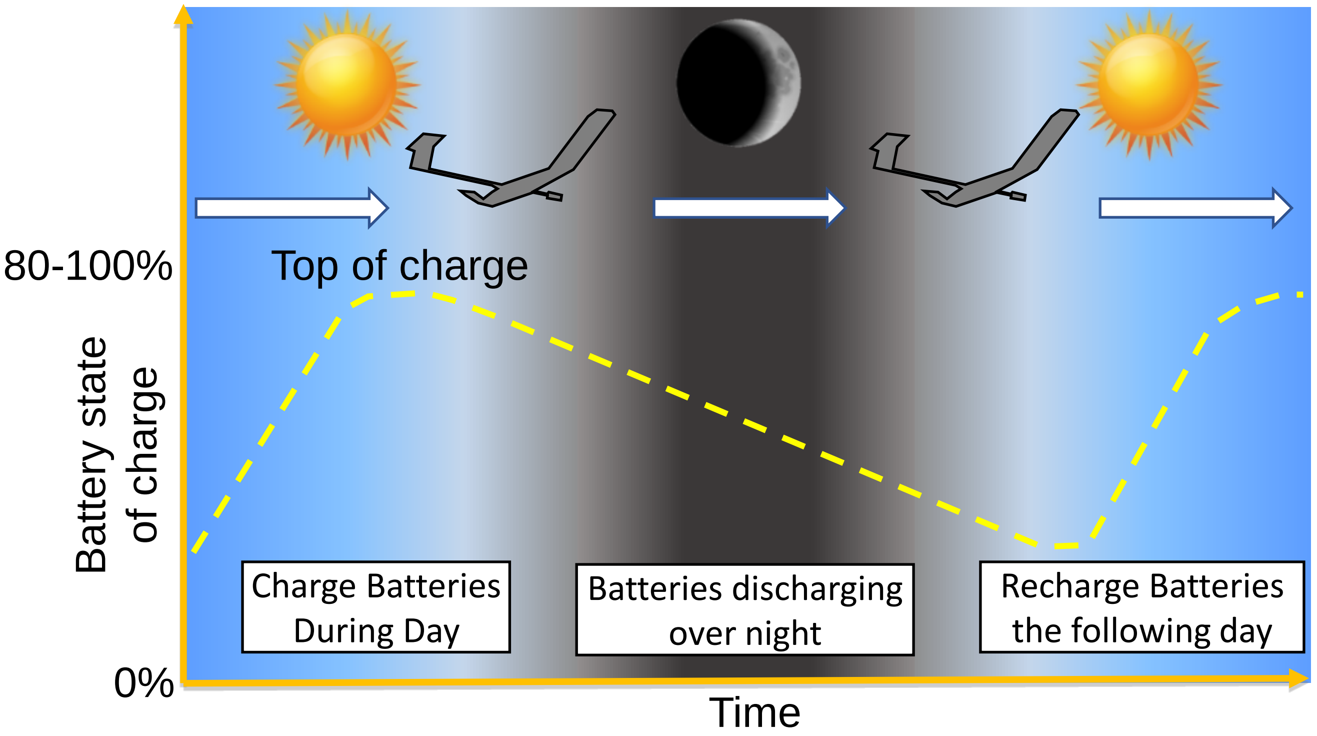
High Altitude Pseudo Satellites (HAPS)

My talk is regarding the technical challenges facing long endurance Solar Electric Fixed-Wing UAS.

“Perpetual” Solar Powered Flight

Fixed wing HAPS are ultra-lightweight Solar Electric Aircraft with very low power required to cruise in the stratosphere:

- During the day high efficiency PV array converts solar energy into electrical energy.
- During the night the system flies on electrical energy stored in high capacity rechargeable batteries.

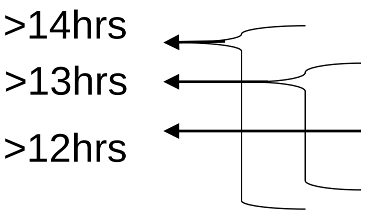


The HAPS Energy Budget

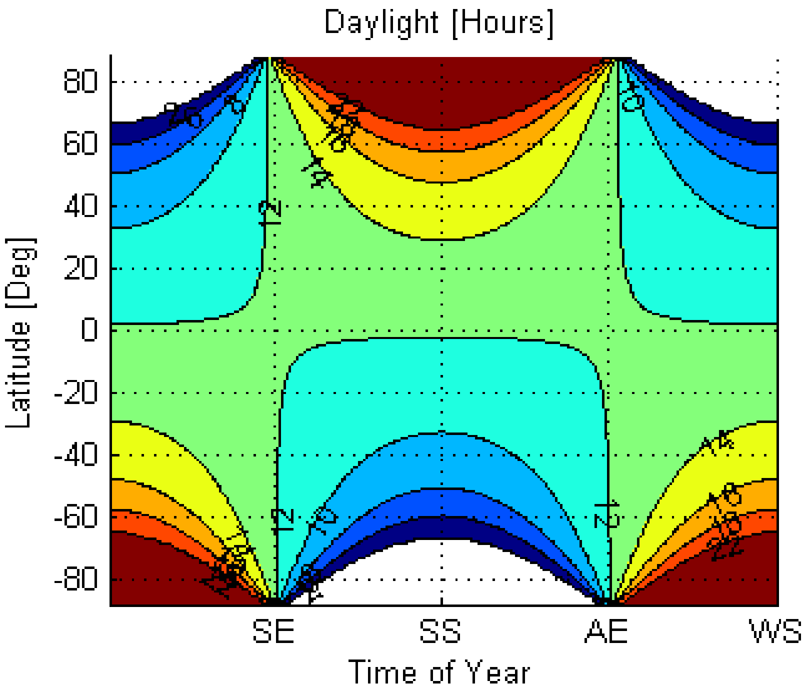
Total energy collected and stored during the day	≥	Total energy consumed overnight

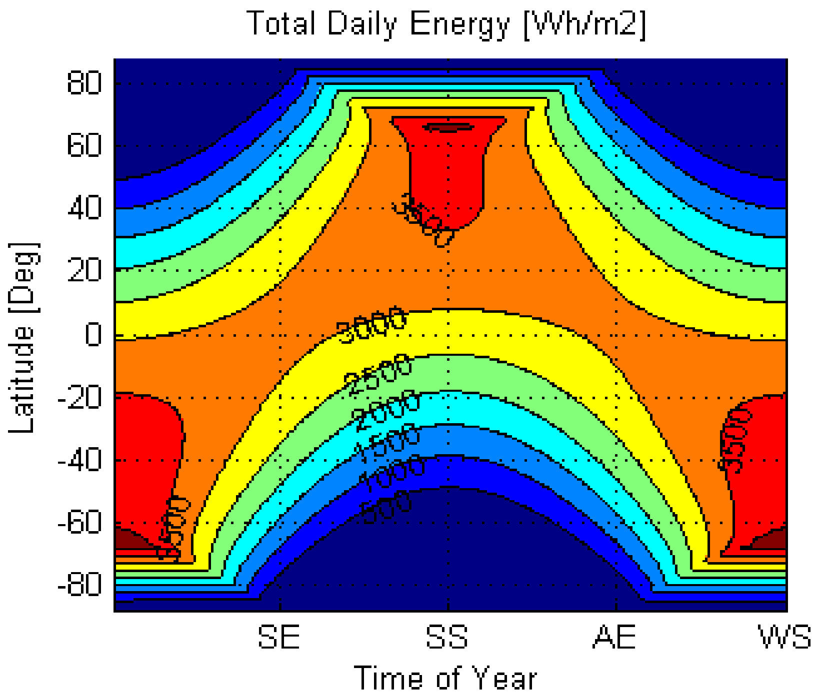
Clearly easiest when the days are long and nights are short i.e., seasonal capability.

But what about year-round?



Length of **winter night** at 0°, 20° and 30°





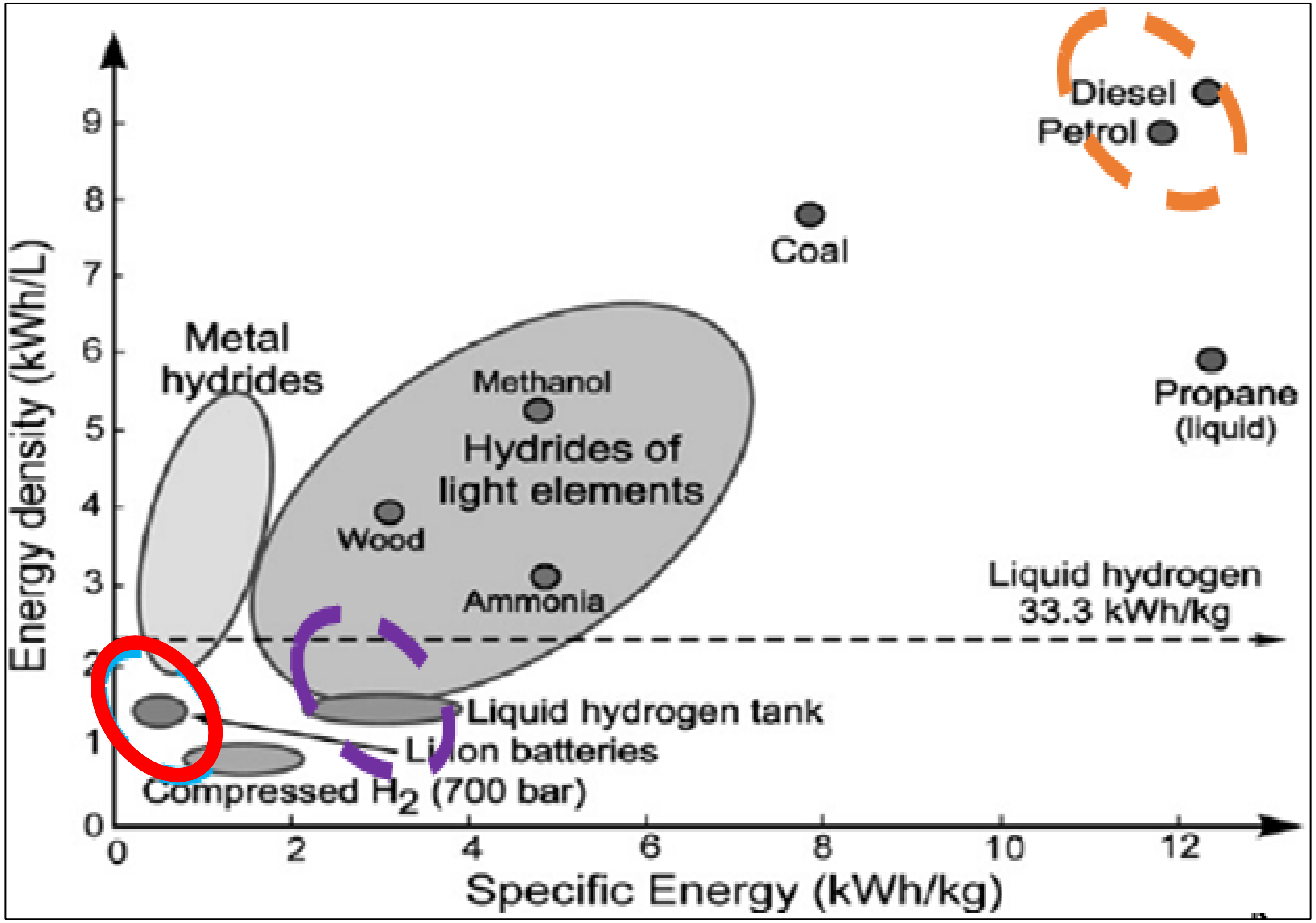
The HAPS Energy Storage

The highest specific energy density rechargeable batteries in the world are <500Whrs/kg

25 times lower than aviation gas.

What about other options?

- ➢ What about regenerative fuel cells?



The Solar Energy Challenge

How can we design a plane which flies for >14hrs between refuelling when limited to fuel which has 25 times lower specific energy density than aviation gas.

$$Drag = \frac{1}{2}\rho \boldsymbol{V^2} S C_D, \; Power = D \times \boldsymbol{V}$$

$$\boldsymbol{Power \; \alpha \; V^3}$$

E.g., $6ms^{-1}$ increase by 2x to $12ms^{-1}$

Power increase= $\frac{\mathbf{12^3}}{\mathbf{6^3}}$ = **8x** More power for **2x** increase in speed

<u>Fly slowly to minimise drag and power and have the largest aspect ratio possible to offset induced drag.</u>

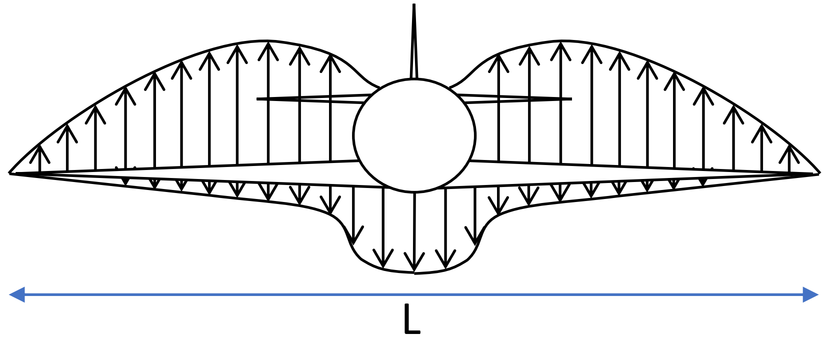
Lightweight with low wing loading

Human powered flight: E.g., 1979 Gossamer Albatross II

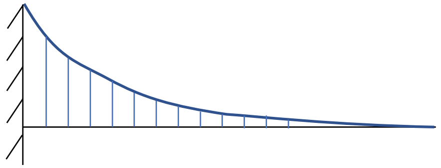
Requires ~300W of power to cruise at sea-level.

How large can solar electric UAS be

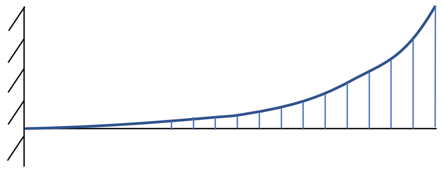
‘Conventional’ Aircraft



$$Moment_{Max} = -\frac{qL^2}{6}$$



$$Deflection_{Max} = \frac{qL^4}{30EI}$$



Large central mass supported by wings.

- Deflections α $Span^4$
- Bending Loads α $Span^2$
- High strength and stiffness requirements for the structure, which get more demanding the larger the aircraft is.

- The cubic law of mass increase with wingspan

The Great Flight Diagram

The great flight diagram is useful to understand **what is possible in the history of aviation**, including manned, unmanned and flying animals.

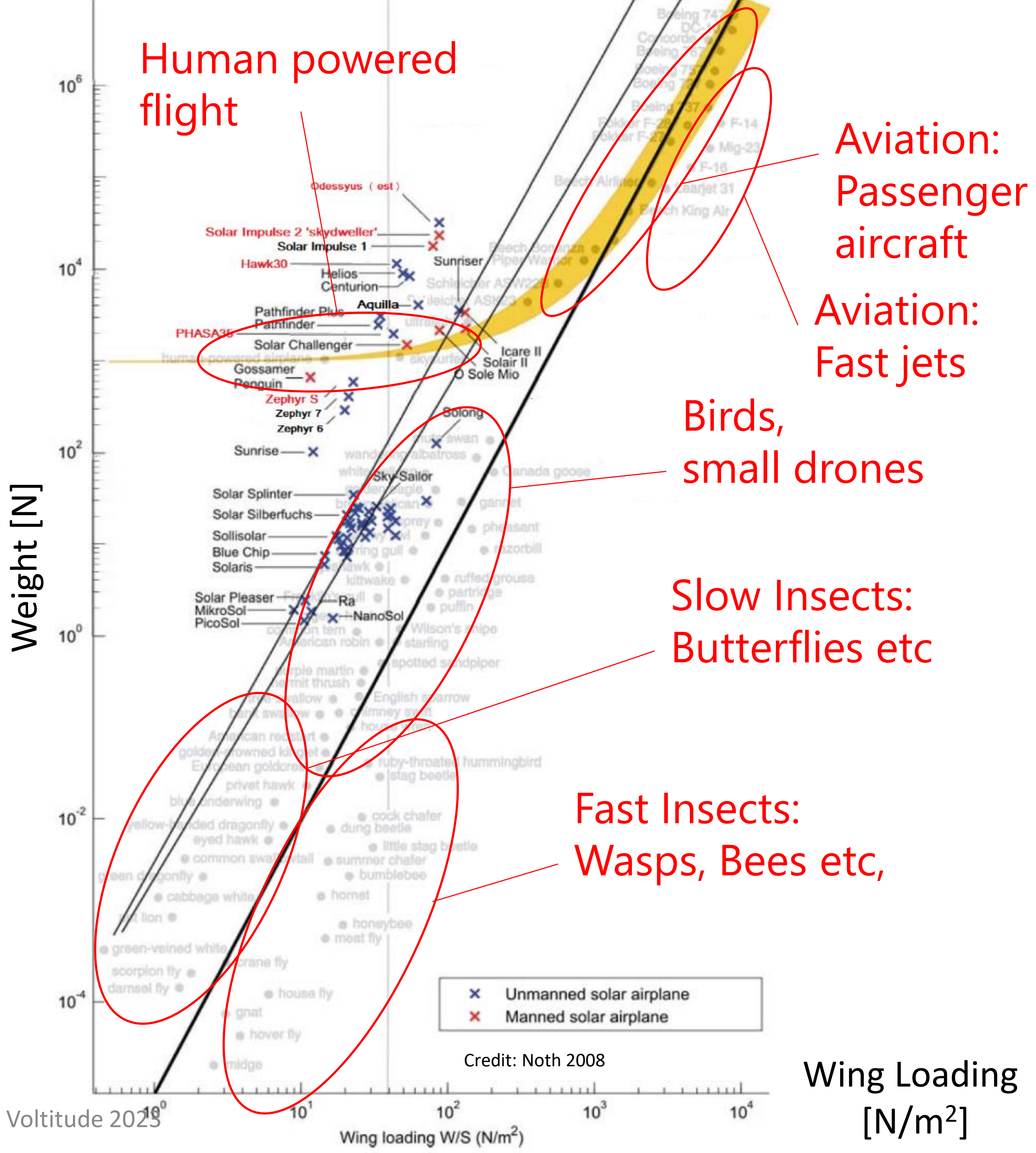
So why does this fit occur?

Right hand limit:

- Cubic law of scaling (length, width, height scale at the same time)
- Square law of scaling for flight loads for normal aircraft configurations.
- the structure gets heavier and no fuel exists with high enough specific energy to offer a useful endurance.

Left hand limit:

- Flying system is too fragile.



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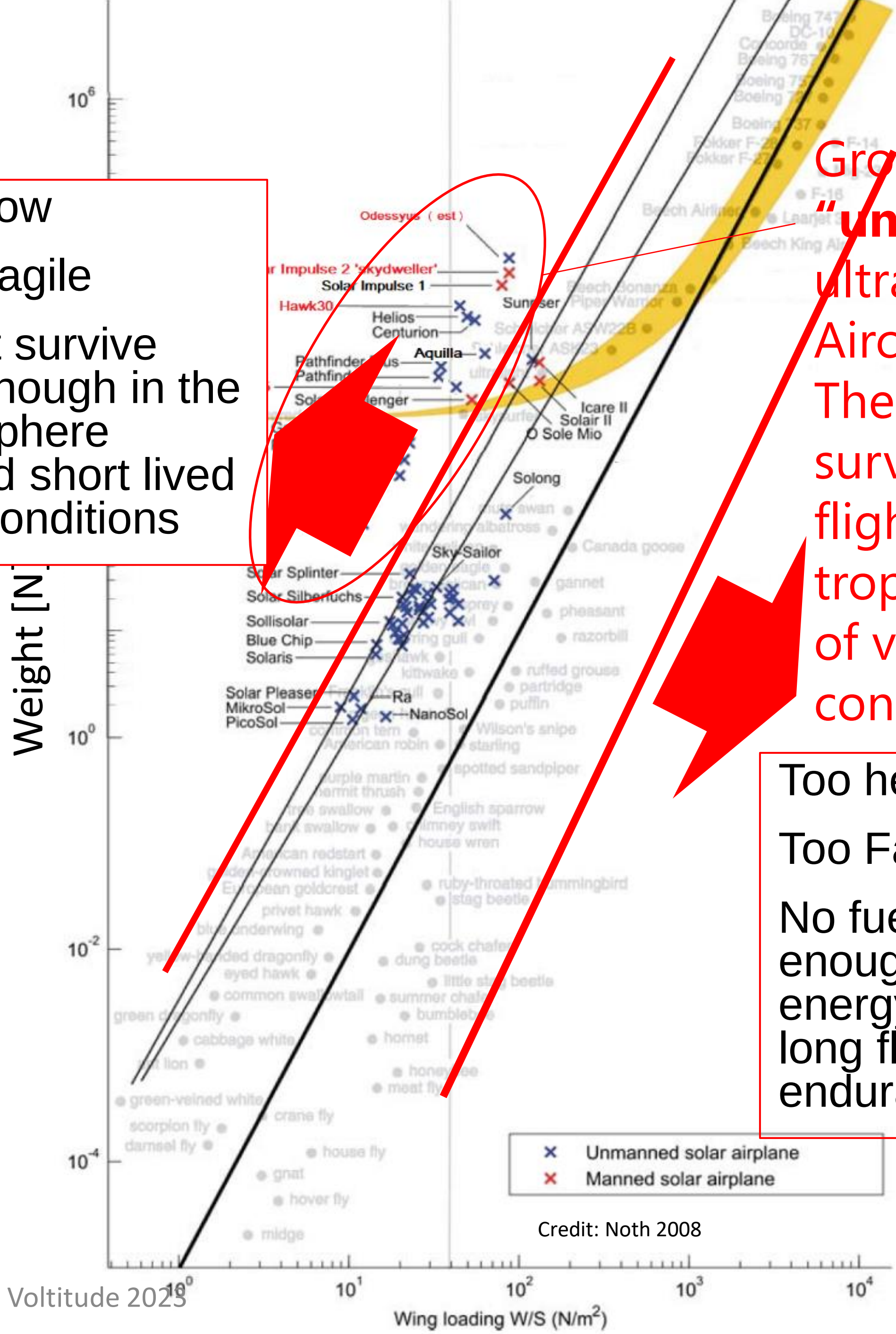
Too Slow

Too Fragile

Do not survive long enough in the troposphere beyond short lived calm conditions



Group of **“unnatural”** ultra-efficient Aircraft. These can not survive prolonged flight in the troposphere outside of very calm conditions

Too heavy

Too Fast

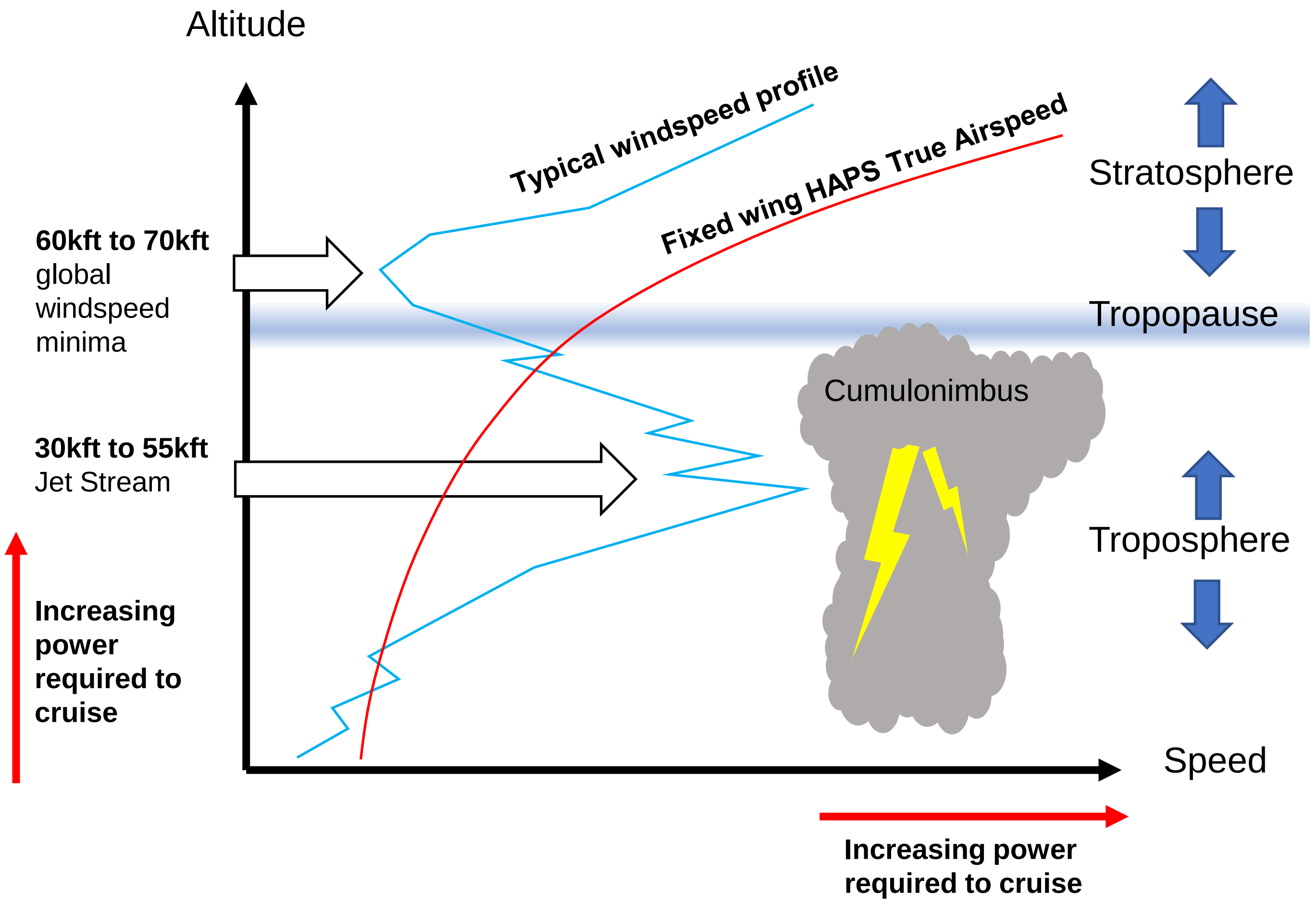
No fuel with high enough specific energy to provide long flight endurance

Wing Loading [N/m^2]

Characteristics of the Stratosphere

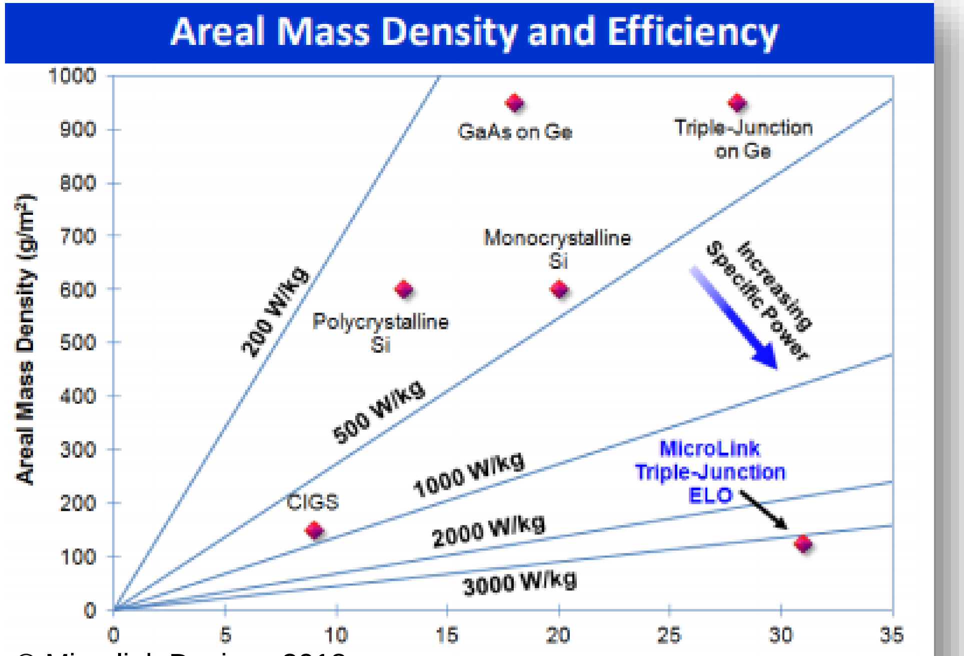
The stratosphere takes its name from the "stratified" layers of air that exist within it and is characterised by extremely little vertical air movement.

- The stratosphere is a very calm and benign environment for aviation.
- This is in stark contrast with the often-turbulent conditions associated with strong convection systems and large vertical movements of air in the troposphere.



Key Enabling Technologies

1. High specific energy density **rechargeable batteries**:
   - >420 Whr/kg for HAPS with wing loading <2.5kg/m2
   - Limiting factors
     - Battery cycle-life defines flight endurance.
     - Battery specific energy density defines longest survivable night.
2. High efficiency **solar array**:
   - Specific power density >1500W/kg (encapsulated strings).
   - High efficiency >30%.
   - Encapsulated string is adhered directly to flying surface.
   - Limiting factor – array performance at low solar elevation angles



Key Enabling Technologies

3. Aerostructure - Lightweight, low drag with exceptionally low wing loading - Ultra-thin walled composite structures.

- New "Spread Tow" carbon fabrics push back minimum gauge thickness challenges allowing new lighter structures.

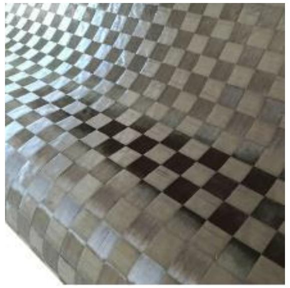
4. Efficient electric propulsion system - >90% of all stored electric power passes through the propulsion system.

5. Better weather data and weather forecasting – for safer operations

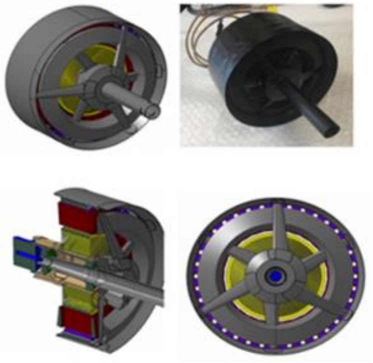
- Particularly stratospheric conditions **above violent tropospheric features** such as tropical storms, strong jet streams and frontal systems.

6. Expansion of the operating envelope - without detriment to performance in the stratosphere.

- Technologies which make lightweight aeroelastic structures less vulnerable to gusts and turbulence, without adding significant mass.



Spread tow fibres offer <50gsm fabrics



"Carbon e-motor" Offers lower mass and higher efficiency.

© Formtech Composites Ltd

Biggest technical challenge to delivering regular and reliable services:
Availability of Launch and recovery windows

Year Round and Seasonal Markets

HAPS: fixed wing solar electric offer accurate station keeping and navigation capability:

- Year-round between the mid-latitudes.
- Seasonal coverage at higher latitudes.

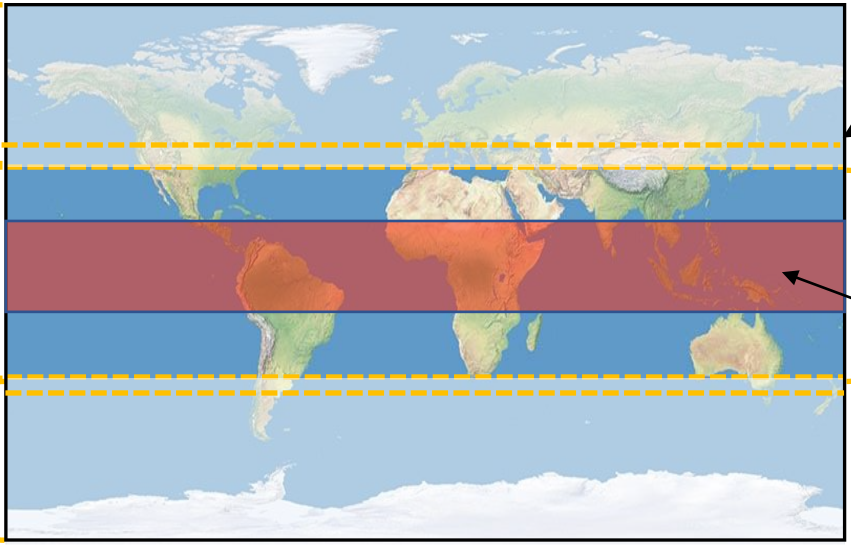
Requires **Expansion of the operating envelope** to deliver commercial services from the stratosphere.

Fixed wing HAPS coverage

Seasonal cover

Year round

Seasonal cover



3. low elevation angle solar array might increase this to $\pm40^{o}$ to $\pm45^{o}$ Latitude

2. Future Battery (>500Whr/kg) $\pm35^{o}$ Latitude = Coverage >80% of world population

1. Current battery capability (420Whrs/kg) Coverage $\pm20^{o}$ Latitude = ~35% Earths Surface

Summary - Challenge

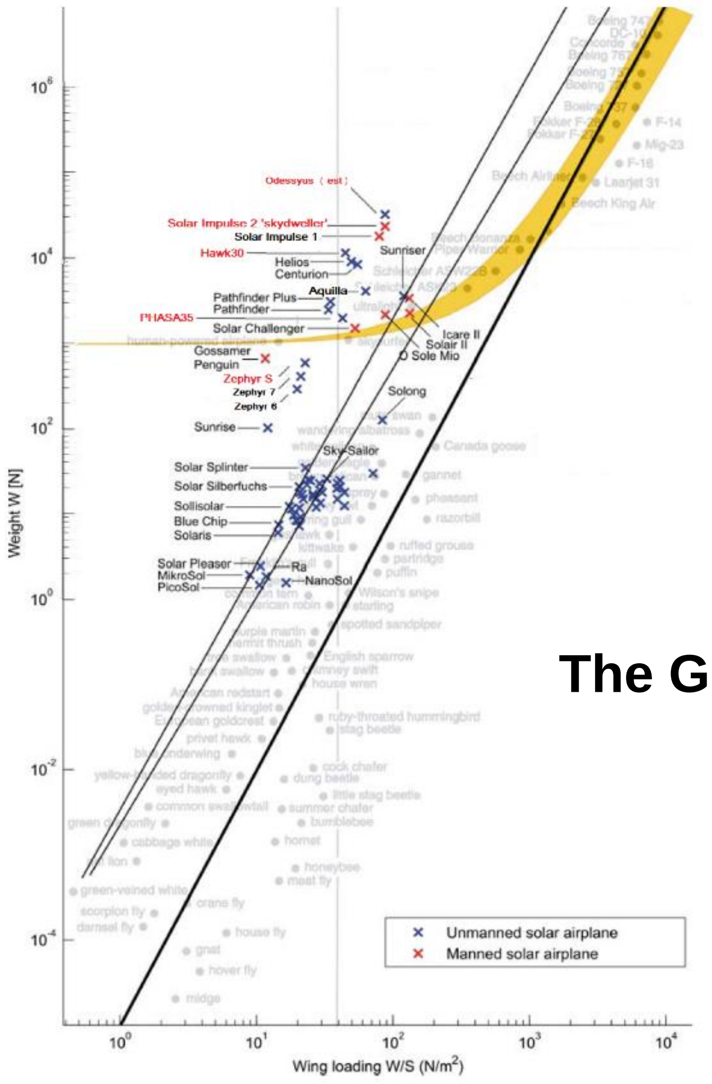
- Solar powered fixed-wing HAPS must fly through the night on stored energy before recharging on solar power in the day time.
- Specific energy density of rechargeable batteries ~25times less than aviation gas
  - → **HAPS must fly with very low power to cruise**
  - → **results in slow flying aircraft, very vulnerable to turbulence and gusts**
  - → **safest calmest conditions for such aircraft exist in the stratosphere**
  - → **challenge getting to and from the stratosphere through the hazardous troposphere - limiting availability for launch and recovery**
  - → **this availability problem gets worse the larger the HAPS aircraft**

Summary - Solutions

- Fixed wing HAPS can operate in the stratosphere over equatorial regions, year-round on currently available battery technology **– if designed to balance the energy budget.**
- **Ultra-long endurance** helps to **mitigate** lack of **launch and recovery availability**, but vulnerability to gusts is still the biggest challenge to offering regular routine services from the stratosphere.
- Having **better weather forecast data helps operate HAPS more safely**, it does not make them more available.
- **Availability will only increase** if the next generation of fixed-wing HAPS benefit from **technologies which expand their operating envelopes.**

Until Next Time

Questions



The Great Flight Diagram
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