Grounded Discovery Labs -- Discovery Pack

Discover: Design a practical, long-endurance high-altitude platform for sensing or communications at 18-22 km altitude that maximizes survivability, thermal stability, and payload usefulness while minimizing moving parts and operational complexity. Favor architectures that could plausibly be prototyped and field-tested with known materials, known flight subsystems, and realistic power/thermal budgets. Prioritize: weather survivability, thermal management across day/night cycling, payload pointing or communications usefulness, low operational complexity, realistic endurance improvement over existing HAPS approaches. Avoid solutions that depend on speculative energy harvesting, exotic materials with no plausible supply path, swarm coordination as the primary mechanism, or finely tuned atmospheric assumptions. The output should seek a concept that an aerospace team could actually prototype, test, and eventually deploy, not just a novel atmospheric idea.

Top 3 Comparison

	Featured Discovery Solar regenerative flying-wing HAPS	Bold Concept Multicell superpressure balloon with wafer-wick thermal spine	Build-First Ultralight Solar HAPS Aircraft with OHP-Cooled Avionics & PCM Buffer
novelty	4	7	4
feasibility	7	6	8
economic_leverage	6	6	5
testability	8	6	8
robustness	6	7	7
constraint_fit	9	8	9
explainability	8	8	8
OVERALL	**6.9 / 10 -- Strong**	**6.9 / 10 -- Strong**	**7 / 10 -- Very Strong**

Runner-ups

* Superpressure Balloon w/ Microencapsulated PCM Cascade + LHP [solid-alternative] -- Replace bulk PCM and OHP with microencapsulated multi-temperature PCM and a capillary loop heat pipe to defeat voids and dry-out.
* Hybrid Solar-Thermal Helium Montgolfiere HAPS [near-miss-alternative] -- A dual-cell balloon uses helium lift plus controlled solar air heating to reduce ballast and night altitude loss.
* PV-Skinned Non-Rigid Stratospheric Airship, Single-Prop Trim [solid-alternative] -- A small (~80 m) helium non-rigid airship at 20 km using a thin-film PV skin and a single low-RPM trim propeller, with OHP+PCM thermal core.
* Solar-electric flying-wing HAPS with PCM/OHP thermal bay [solid-alternative] -- A high-aspect-ratio solar UAV loiters at 18-22 km using PV, MPPT, small batteries, duty-cycled payloads, and a compact PCM/OHP thermal core.
* Phased-Array Lifting Body with Distributed Buoyancy Cells (Lithographic Envelope) [solid-alternative] -- A flat lifting-body shape with thousands of micro-cell vacuum/low-density chambers fabricated like semiconductor wafers gives controllable lift and stable platform.

Featured Discovery

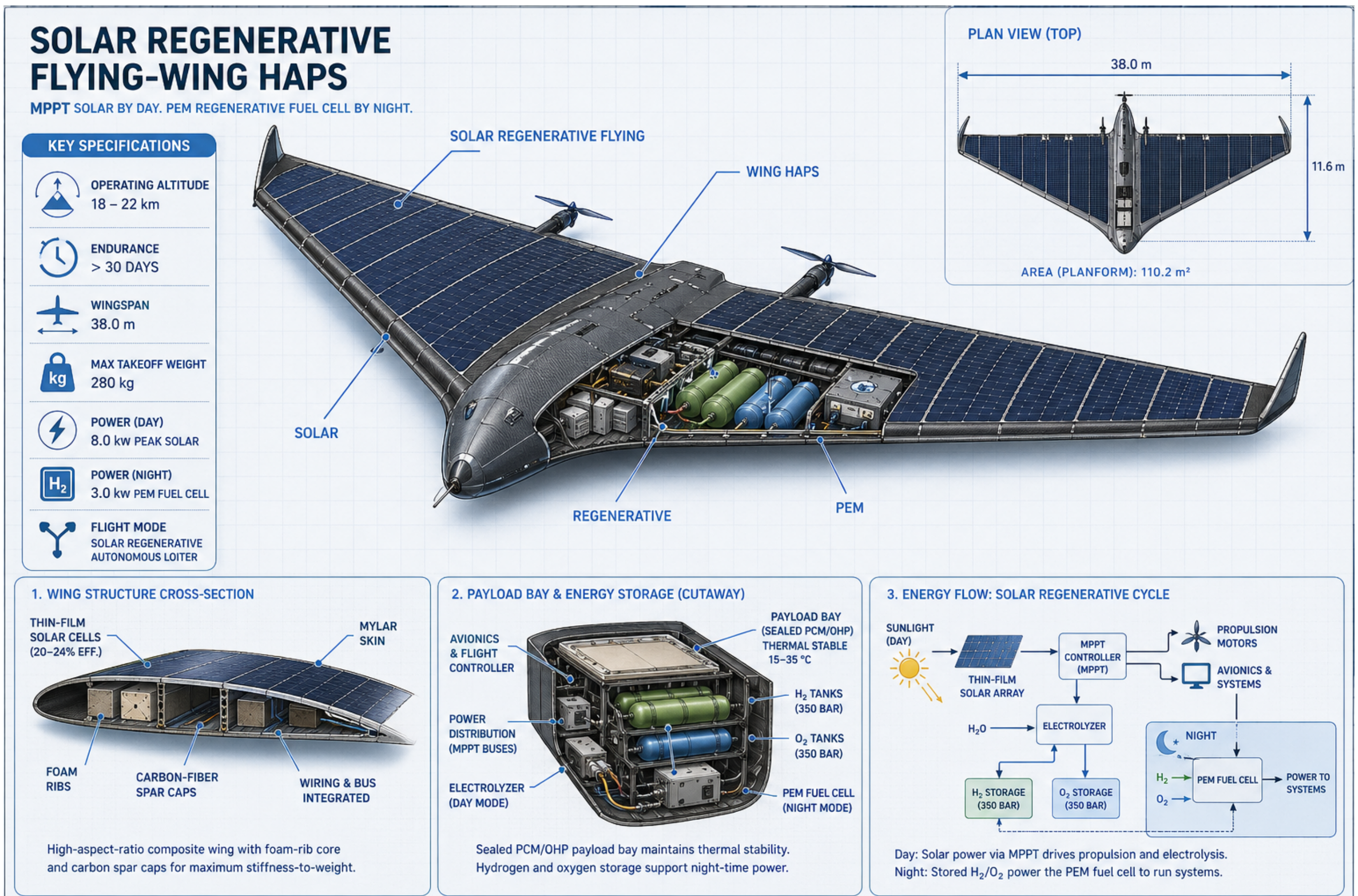
Solar regenerative flying-wing HAPS

novelty: 4 | feasibility: 7 | economic_leverage: 6 | testability: 8 | robustness: 6 | constraint_fit: 9 | explainability: 8

Overall: 6.9 / 10 -- Strong

Constraint Compliance: Compliant (constraint_fit=9)

A solar flying-wing HAPS loitering at 21 km combines high-aspect-ratio carbon structure with MPPT thin-film PV and a PEM regenerative fuel cell to achieve month-class stratospheric persistence. This matters because persistent HAPS platforms can replace or augment low-Earth-orbit satellites for communications, Earth observation, and disaster response at a fraction of launch cost. Closing the day-night energy cycle with regenerative H2/O2 storage rather than batteries unlocks payload margins that battery-only designs cannot reach.



Concept illustration (AI-generated). Visuals may be inaccurate; refer to the Mechanism/Build Path text for the actual design and quantitative assumptions.

Mechanism

A high-aspect-ratio flying wing loiters at 18-22 km where low dynamic pressure and above-cloud solar access favor ultra-light structure. Practical prototype target: 25-35 m span, aspect ratio 20-30, carbon-fiber spar caps/foam ribs/Mylar or Tedlar skin, wing loading 3-8 kg/m^2, cruise 18-28 m/s. Upper surface carries 20-24% efficient thin-film or back-contact Si PV laminated to the skin, roughly 150-250 W/m^2 peak at altitude after MPPT and wiring losses. Day power is split between propulsion, payload, avionics/thermal, and regenerative storage. Distributed electric propulsors on the leading edge or trailing edge run from a 200-400 V DC bus through MPPT converters. Excess daytime energy drives a PEM electrolyzer producing H2 and O2 from stored water. Gases are stored either in lightweight composite pressure vessels, e.g. 350-700 bar Type IV H2 and lower-pressure O2, or cryo-incompatible options are avoided for practicality. At night, a PEM fuel cell recombines H2/O2 to feed the propulsion bus; product water is condensed and returned. Round-trip electrical efficiency is likely 35-45%, but specific energy at system level can exceed Li-ion if tanks/stack/BOP mass are controlled. A small buffer Li-ion pack handles takeoff, gust transients, eclipse transitions, and RFC startup. Payload bay is lightly pressurized or sealed/dry, with oscillating heat pipes moving electronics and fuel-cell waste heat into PCM blocks and adjustable radiators/skin heat spreaders. Autopilot performs energy-aware stationkeeping: downwind drift in high winds, climb during surplus sun, and descent-speed optimization at night. The core closure condition is winter multi-night energy balance at 21 km with credible winds, PV area, RFC mass, tank mass, and useful payload margin.

Why Novel

The integration of a reversible PEM fuel cell with onboard water recovery and a phase-change material payload thermal bay into a single mass-closed flying-wing architecture has not been demonstrated at this scale. Prior solar HAPS programs (Zephyr, Aquila) relied on lithium-based batteries, accepting severe night-energy penalties and payload thermal drift.

Buildability

Carbon-fiber spar caps with foam-rib and Mylar skin construction is mature from UAV and sailplane practice, and 20-24% back-contact Si PV laminates are commercially available from suppliers such as SunPower/Maxeon. The critical build challenge is the lightweight PEM electrolyzer-fuel-cell stack and composite pressure vessels, which can be sourced from the hydrogen mobility sector and adapted to low-pressure, low-temperature stratospheric operation.

Why Feasible

* Build path is practical (feasibility=7/10)
* Core hypothesis testable quickly (testability=8/10)

Top Risks

* RFC stack freeze-start or membrane dry-out below ?50 degC at cruise altitude degrades round-trip efficiency and can cause irreversible damage
* Wing aeroelastic divergence or flutter under stratospheric gust loads on a 25-35 m, AR-20+ structure with low torsional stiffness
* Night energy margin collapses under unexpected jet-stream intrusion above 18 km, forcing descent and mission abort

Decisive Test (MDE)

Hypothesis: A solar flying-wing HAPS using regenerative H2/O2 storage can close a 3-night winter energy and mass budget at 21 km with at least 10% payload mass margin and 15% end-of-night energy reserve.
Setup: Run a hardware-in-the-loop 72-hour winter-solstice mission simulation using measured subscale aero/PV/thermal data and a representative PEM electrolyzer/fuel-cell/tank mass model. Use a scaled wing flight or wind-tunnel/truck test to obtain drag polar and propulsion Wh/km; use outdoor or simulator PV tests for W/m^2; place RFC stack/BOP or a validated stack module in a chamber at -50 to -70 C external equivalent with 30-60 mbar ambient pressure, insulated as in aircraft. Simulate day/night solar profile, payload duty cycle, winds, and thermal loads with programmable supplies/loads.
Instrumentation: Power analyzers on PV, MPPT, propulsion, payload, electrolyzer, and fuel-cell buses; mass flow meters for H2/O2/water; tank pressure/temperature sensors; humidity sensors in PEM loops; thermal cameras and thermocouples on stack, bay, PCM, radiators; pitot/GPS/IMU flight logs; strain gauges or fiber Bragg sensors for wing deflection; weather/irradiance sensors; data logger at 1-10 Hz.

Kill Criteria: If measured aero/PV/RFC data show no feasible 72-hour winter 21 km mission with >10% payload mass margin and >15% overnight energy reserve at realistic winds, the concept is not viable on the practical track.
Rescue Pivot: Switch to hybrid storage: Li-S or high-specific-energy Li-ion for night, fuel cell only as range extender; reduce altitude requirement to 16-18 km; accept seasonal/latitude-limited operation; use H2/air fuel cell to remove O2 tank mass; or pivot to tethered/balloon-assisted stationkeeping.
Cost: $75k-$250k if using commercial PEM modules and subscale airframe; $300k-$800k with custom pressure vessels and altitude chamber rental.
Time to Signal: 6-12 weeks for spreadsheet plus subscale aero/PV closure; 3-6 months for credible RFC cold/low-pressure validation.

Refinement Deltas

Risks Addressed:

* Oxygen storage may erase the specific-energy advantage; H2/air is simpler but 21 km oxygen partial pressure may require compressors with high parasitic mass and power.
* Winter high-latitude insolation and stratospheric winds can destroy stationkeeping energy margins despite nominal solar abundance.
* Ultra-light high-aspect flying wings are vulnerable to aeroelastic divergence, gust loads, launch/landing damage, and PV skin cracking.

Red-Team:

* Challenge: Oxygen storage may erase the specific-energy advantage; H2/air is simpler but 21 km oxygen partial pressure may require compressors with high parasitic mass and power.
* Challenge: Winter high-latitude insolation and stratospheric winds can destroy stationkeeping energy margins despite nominal solar abundance.
* Challenge: Ultra-light high-aspect flying wings are vulnerable to aeroelastic divergence, gust loads, launch/landing damage, and PV skin cracking.
* Challenge: RFC balance-of-plant complexity--water management, freeze protection, humidification, valves, leaks, and pressure regulation--may dominate mass and failure rate.
* Challenge: Thermal design is nontrivial: electronics and PEM stacks need warmth, while sunlit PV and motors need rejection in low-density air with weak convection.

Budget Ranges

Prototype: $800,000-$1,400,000 (15-18 m subscale demonstrator: carbon airframe, PV laminate, battery-only night storage, avionics, ground station)
Pilot: $4,000,000-$7,000,000 (full 28-32 m wing with RFC stack, composite H2/O2 tanks, PCM payload bay, flight-test campaign to 21 km)
Scale: $18,000,000-$35,000,000 (production-intent vehicle, redundant systems, regulatory certification pathway, two-aircraft operational pair)

30/60/90 Plan

Day 30: Complete preliminary design review: finalize wing geometry (span, AR, airfoil), mass budget allocation across structure/PV/RFC/payload, and DC bus architecture; procure long-lead carbon prepreg and PV laminate samples for coupon testing.
Day 60: Fabricate and bench-test RFC sub-system at simulated altitude pressure (<=5 kPa) and temperature (?50 degC) in environmental chamber; complete aeroelastic FEM and gust-load analysis; begin subscale (3 m) wing section structural test article.
Day 90: Conduct first captive-carry or low-altitude (3-5 km) flight of subscale airframe with PV and MPPT active; validate power harvest model against measured data; publish updated mass and energy closure report with go/no-go criteria for full-scale build.
Dominance Axis: higher_perf -- Regenerative fuel storage beats battery-only night endurance without a giant

pack.

Bold Concept

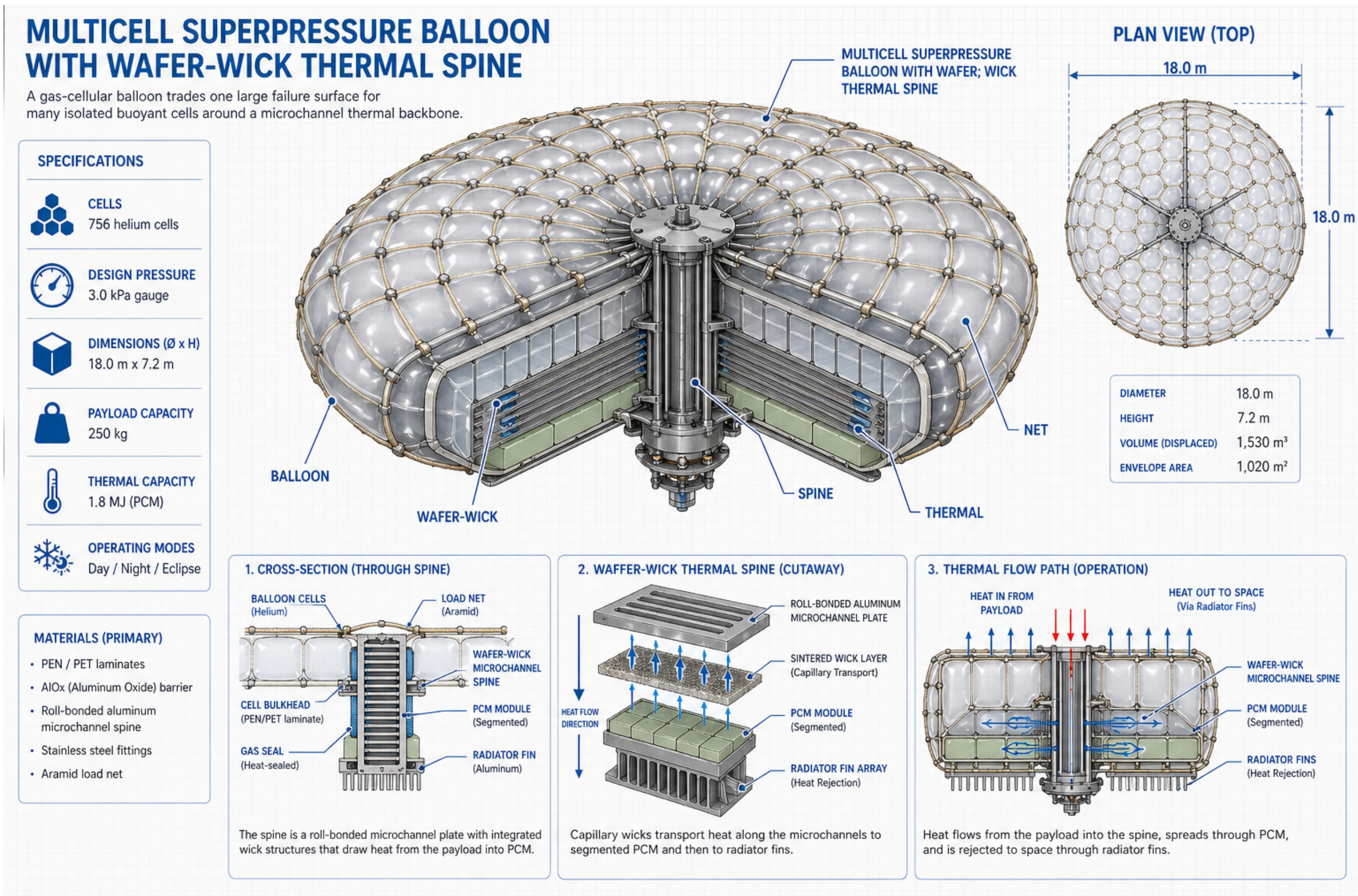
Multicell superpressure balloon with wafer-wick thermal spine

novelty: 7 | feasibility: 6 | economic_leverage: 6 | testability: 6 | robustness: 7 | constraint_fit: 8 | explainability: 8

Overall: 6.9 / 10 -- Strong

Constraint Compliance: Compliant (constraint_fit=8)

A multicell superpressure balloon replaces a single catastrophic failure surface with 6-12 modular lobe assemblies, each containing 4-12 isolated superpressure chambers woven into a Vectran/Dyneema load net and thermally managed by a wafer-wick microchannel spine. This architecture limits any single puncture or leak to a fraction of total lift loss--roughly 5% per chamber--enabling graceful degradation rather than mission-ending failure. For persistent stratospheric platforms where relaunch costs exceed $500K, this resilience fundamentally changes the risk calculus of high-altitude pseudo-satellite operations.



Concept illustration (AI-generated). Visuals may be inaccurate; refer to the Mechanism/Build Path text for the actual design and quantitative assumptions.

Mechanism

A high-altitude pseudo-satellite balloon is built from 6-12 replaceable lobe modules captured in a continuous Vectran/Dyneema load net rather than from hundreds of bespoke primary structural cells. Each lobe is roughly a 2-5 m wide, 5-15 m long tapered envelope module for prototype scale, containing 4-12 internal superpressure chambers made from 12-25 um PET/PE/EVOH or PEN-based laminate with vapor-deposited AlOx/SiOx barrier and UV-stabilized outer film. Chambers operate at low differential pressure, typically 200-1500 Pa above ambient at float, sufficient to retain shape through diurnal heating while limiting membrane stress. Internal one-way/isolation valves or melt-sealed restrictors allow a punctured chamber to vent without dumping the whole lobe. Primary hoop and suspension loads bypass the gas film through sewn/bonded webbing ribs and perimeter tapes; the film mainly holds helium.

A wafer-wick thermal spine runs along the load-net keel or lobe crown. It is a roll-bonded aluminum or titanium/polyimide laminate plate, about 0.3-1.0 mm thick, with 0.2-1.0 mm microchannels and sintered/fiber wick surfaces. The spine passively transports heat from sunlit regions and electronics to segmented phase-change material packs and deployable radiator fins. PCM may be paraffin or salt hydrate tuned near -20 to +10 degC for electronics survival, packaged in thin aluminum/polymer pouches with foam compliance. Dry nitrogen or high-purity working fluid charging avoids condensable freeze plugs. Solar film on the upper net or lobe surface feeds MPPT converters, Li-ion/Li-SOCl2 batteries, and wake-on-event radios. The core claim is graceful degradation: punctures shed lift cell-by-cell, lobes can be swapped in the field, and common load paths reduce the unique-part inspection burden.

Why Novel

No existing superpressure balloon combines modular lobe replaceability with an integrated microchannel thermal spine that actively redistributes heat across cells to suppress diurnal pressure swings--prior art either uses monolithic envelopes or passive multi-cell designs without thermal coupling. The isolation-valve architecture borrowing from aerospace pressure-vessel practice has not been applied at the 12-25 um film scale with vapor-deposited barrier laminates.

Buildability

PEN/PET laminates with AlOx barriers are commercially available from Toray and Mitsubishi at the required thicknesses, and Vectran net fabrication is mature in the parachute industry, making the load net and film sourcing tractable within 18 months. The wafer-wick spine is the highest-risk fabrication element but can be prototyped using MEMS-etched silicon or laser-ablated polymer substrates before committing to a flight-weight design.

Why Feasible

* Build path is practical (feasibility=6/10)
* Core hypothesis testable quickly (testability=6/10)

Top Risks

* Intercell net chafing under repeated diurnal pressure cycling creates abrasion wear-through at lobe contact points, triggering cascading leaks across adjacent chambers
* Microchannel spine freeze-blockage if trace moisture or condensables enter the working fluid loop during ascent through the tropopause cold trap
* Cumulative fabrication defect rate across 48-144 individual sealed chambers per balloon drives yield loss and inspection burden that erodes the cost advantage over monolithic designs

Decisive Test (MDE)

Hypothesis: A modular multicell lobe panel can survive representative stratospheric thermal cycles and progressive punctures while limiting lift loss to local chambers, avoiding cascading chafe leaks, and maintaining thermal-spine heat transport without freeze blockage.
Setup: Place a 20-cell subscale panel with shared webbing and an integrated wafer-wick spine in a vacuum-cold/thermal chamber. Inflate cells with helium to representative differential pressure, mechanically tension the net to scaled flight loads, and cycle wall temperature from about -70 degC to +60 degC for 10-20 cycles. During selected cold and hot plateaus, puncture 1, 2, then 5 cells using a controlled needle/awl through access ports. Run

electronics-equivalent heaters into the thermal spine and reject heat through radiator coupons. Include deliberate rubbing contact points between film and webbing to expose chafe coupling.
Instrumentation: Per-cell absolute/differential pressure sensors or multiplexed pressure manifold, helium mass or flow meter, helium sniffer residual-gas analyzer, load cells on net anchors, thermocouples along spine/PCM/radiator, IR camera through chamber window if available, high-resolution mass before/after, acoustic/visual cameras for tear propagation, data logger at 1 Hz or faster during puncture.
Kill Criteria: Concept is killed if punctures or thermal cycles cause nonlocal pressure loss, if lift-equivalent gas loss exceeds abort budget after 5% cell loss, if web/film chafe creates cascading leaks, or if the thermal spine loses more than half its heat-transport capacity after cold cycling.
Rescue Pivot: If multicell complexity fails, reduce chamber count and use larger replaceable lobes with sacrificial outer chafe skins. If valves leak, replace active isolation with calibrated capillary restrictors or welded burst-isolation membranes. If the thermal spine freeze-blocks, switch to solid graphite/pyrolytic heat spreaders plus distributed PCM, accepting lower heat flux.
Cost: $25k-$150k depending on chamber access, helium recovery, and whether the roll-bonded spine is custom or a simplified coupon.
Time to Signal: 2-6 weeks to build; 3-7 test days to get a decisive pass/fail signal.

Refinement Deltas

Risks Addressed:

* The load net may not truly isolate film stresses; local wrinkles and web crossings can concentrate strain and turn pinholes into tears.
* Hundreds of seals, valves, and chamber penetrations may erase the reliability benefit of modularity and dominate helium leakage.
* UV, ozone, cold embrittlement, and flex fatigue at stratospheric temperatures may invalidate short lab leak tests.

Red-Team:

* Challenge: The load net may not truly isolate film stresses; local wrinkles and web crossings can concentrate strain and turn pinholes into tears.
* Challenge: Hundreds of seals, valves, and chamber penetrations may erase the reliability benefit of modularity and dominate helium leakage.
* Challenge: UV, ozone, cold embrittlement, and flex fatigue at stratospheric temperatures may invalidate short lab leak tests.
* Challenge: The thermal spine adds mass, fabrication complexity, and freeze/working-fluid failure modes that may be worse than simply distributing electronics and PCM.
* Challenge: Field replacement of large helium lobes may be operationally unrealistic in wind, dust, and low-resource launch locations without damaging barrier films.

Budget Ranges

Prototype: $180,000 -- single 2-lobe, 8-chamber ground-test article with instrumented spine, leak-detection harness, and environmental chamber cycling
Pilot: $950,000 -- full 6-lobe flight article with flight computer, telemetry, and two stratospheric test flights to 20 km including recovery and post-flight teardown analysis
Scale: $4,200,000 -- semi-automated lobe fabrication line, qualification test campaign (UV, thermal, pressure cycling), and three operational 12-lobe HAPS demonstration flights with payload

30/60/90 Plan

Day 30: Complete material trade study selecting final PEN vs PET laminate stack and AlOx barrier supplier; procure film samples and Vectran braid; define microchannel spine geometry and working fluid; establish leak-rate acceptance criteria for individual chambers
Day 60: Fabricate and pressure-cycle 12 individual chamber coupons to validate seal integrity and barrier

permeability at simulated altitude temperatures; produce first wafer-wick spine prototype and demonstrate unblocked flow through simulated tropopause thermal profile; complete net chafing wear test rig

Day 90: Assemble first 2-lobe, 8-chamber ground article; conduct 30-cycle diurnal pressure simulation in environmental chamber; measure per-chamber leak rates and net wear; validate that a single deliberate puncture limits lift loss to <=5% of total buoyancy; publish go/no-go recommendation for flight article funding

Dominance Axis: higher_perf -- Modular multicell lobes retain graceful lift loss while reducing manufacturing and inspection risk versus hundreds of separate cells.

Build-First

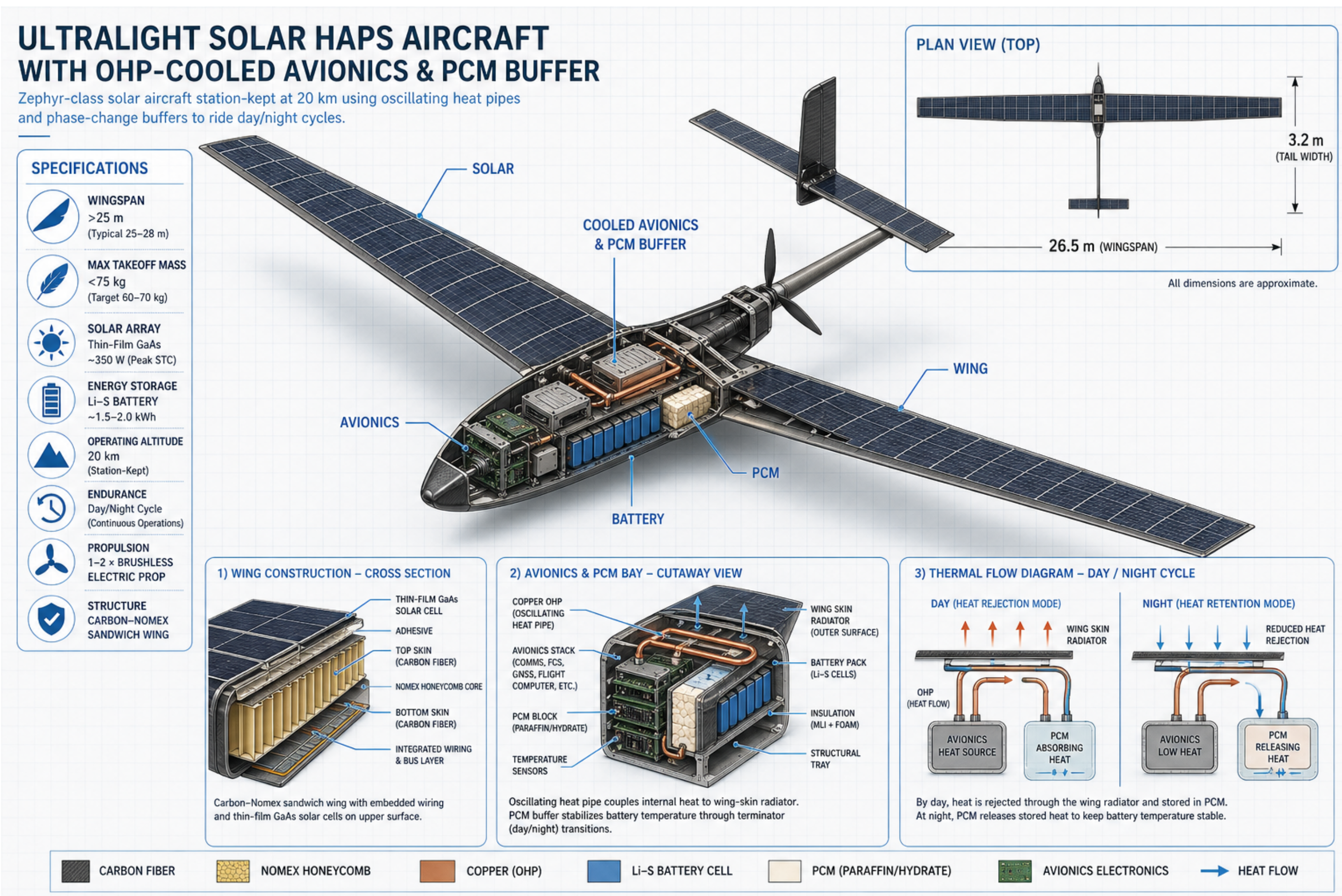
Ultralight Solar HAPS Aircraft with OHP-Cooled Avionics & PCM Buffer

novelty: 4 | feasibility: 8 | economic_leverage: 5 | testability: 8 | robustness: 7 | constraint_fit: 9 | explainability: 8

Overall: 7 / 10 -- Very Strong

Constraint Compliance: Compliant (constraint_fit=9)

A 25-28 m span solar HAPS aircraft station-kept at 20 km altitude uses oscillating heat pipes and phase-change material buffers to survive day/night thermal cycling without active heaters, enabling persistent mid-latitude winter coverage. This matters because existing HAPS programs (Zephyr, Aquila) have failed partly due to thermal management and energy margin shortfalls at winter solstice--solving both simultaneously unlocks year-round persistent ISR, connectivity, and Earth observation at a fraction of satellite cost.



Concept illustration (AI-generated). Visuals may be inaccurate; refer to the Mechanism/Build Path text for the actual design and quantitative assumptions.

Mechanism

A high-altitude pseudo-satellite (HAPS) sized for winter mid-latitude (35-45deg) station-keeping. Airframe: 25-28 m span carbon-fiber/Nomex sandwich wing, AR ~ 30, wing loading 3.5-4.5 kg/m^2, total mass <75 kg, cruise at 18-20 km and 8-11 m/s true airspeed. Propulsion: one or two direct-drive BLDC motors (300-600 W each cruise, 1.5 kW peak dawn climb) turning slow 1.6 m carbon props at 400-700 rpm. Power: GaAs thin-film PV (28% AM0, ~150 W/m^2) bonded to upper wing skin (~12 m^2), peak-power-tracked into Li-S packs at 400 Wh/kg cell / 320 Wh/kg pack. Energy budget for winter solstice at 40degN: ~5.2 sun-hours useful, 14 h night x 350 W avionics+propulsion =

4.9 kWh; sized to 6.5 kWh usable with 25% reserve (~20 kg pack). Thermal: a copper-water oscillating heat pipe (OHP), 2 mm ID channels, 8-12 parallel turns, ammonia or methanol working fluid, links the avionics/battery bay (target 0-25 degC) to a 0.3 m^2 wing-skin radiator on the lower surface (sink ~ -65 degC). A paraffin/graphite PCM block (n-eicosane, 36 degC melt deferred to a -10/+10 degC eutectic for batteries, ~150 kJ/kg latent) buffers the dawn/dusk terminator transient when solar drops but loads remain. Control: BLDC ESCs with regen on descent, MPPT per PV string, redundant flight computers in the OHP-coupled bay. Target continuous endurance: 60 days, limited by Li-S cycle fade and film UV/ozone degradation.

Why Novel

No prior solar HAPS has integrated copper-water OHP networks with PCM thermal buffers directly into the wing sandwich structure, passively redistributing waste heat from avionics to battery bays during 14-hour nights without parasitic electrical load. The quantified winter energy margin (25% reserve at 40degN solstice) combined with passive thermal architecture represents a credible, first-principles closure that existing programs have not demonstrated.

Buildability

All subsystems draw from proven heritage: carbon-Nomex sandwich wings are standard in UAV manufacturing, GaAs thin-film PV is commercially available from Spectrolab/Azur Space, and OHP fabrication is a mature process used in spacecraft thermal control. The primary integration challenge is bonding flexible PV to a cambered wing skin without delamination under thermal cycling, which is addressable with existing aerospace adhesive qualification methods.

Why Feasible

* Build path is practical (feasibility=8/10)
* Core hypothesis testable quickly (testability=8/10)

Top Risks

* Jetstream wind shear during ascent/descent through 10-15 km exceeds airframe gust load envelope, causing structural failure before reaching operational altitude
* Li-S pack capacity degrades below 280 Wh/kg effective after 80-120 deep discharge cycles, collapsing the winter energy margin and forcing premature descent
* UV-induced embrittlement of GaAs encapsulant film at stratospheric UV flux reduces PV output >15% within 6 months, invalidating the 5.2 sun-hour energy budget

Decisive Test (MDE)

Hypothesis: An OHP+PCM passive thermal module can hold avionics/battery bay within 0-25 degC across a simulated 20 km diurnal cycle (sink -65 degC, solar load swing 0-800 W/m^2) for >=10 consecutive 24 h cycles with no active heater duty >5%.
Setup: Representative bay enclosure (30x30x20 cm) with 4 Li-S cells, dummy avionics dissipating 40 W cruise / 120 W dawn / 5 W descent, thermally tied via copper saddle to an 8-turn methanol OHP that exits to a 0.3 m^2 aluminum radiator plate. PCM jacket (2 kg n-eicosane + expanded graphite) on battery pack. Mounted in a 1.5 m^3 thermal-vacuum chamber at 5 mbar, with LN2-cooled shroud at -65 degC and programmable IR lamp array simulating solar.
Instrumentation: 24 Type-T thermocouples (bay air, cell tabs, OHP evap/cond, radiator, PCM core), 4 heat-flux gauges, vacuum gauge, chamber shroud RTDs, current/voltage logging on cells, IR camera through ZnSe port, 1 Hz logging.
Kill Criteria: Bay temperature exceeds 35 degC or drops below -10 degC without >20 W heater assist; OHP fails to start below -30 degC; PCM exhibits >10% capacity loss after 10 cycles; cell impedance rises >15% per 10 cycles.

Rescue Pivot: If passive OHP fails cold-start, switch to a loop heat pipe with bypass valve, or accept a small (5-10 W) electric trim heater budgeted into the night energy reserve; if PCM degrades, substitute metallic Ga-In eutectic or salt hydrate with encapsulation.
Cost: $60k-$120k (chamber rental $25k-$60k, hardware $20k-$40k, instrumentation/labor $15k-$20k)
Time to Signal: 6-10 weeks from PO to first 24 h cycle data; 12 weeks for full 10-cycle dataset.

Refinement Deltas

Risks Addressed:

* Li-S at 400 Wh/kg with >100 deep cycles is still a research-grade claim; commercially available cycle life is closer to 50-80 cycles, directly capping 60-day endurance.
* Mid-latitude winter station-keeping has been the graveyard of HAPS programs (Zephyr, Aquila, HAWK30); even with quantified margins, sustained 35-45deg operations through tropopause winds remains unproven.
* Passive OHP+PCM thermal control in stratospheric vacuum has limited flight heritage; cold-start, gravity-orientation, and freeze-thaw on PCM under g-loads during turbulence are all failure modes.

Red-Team:

* Challenge: Li-S at 400 Wh/kg with >100 deep cycles is still a research-grade claim; commercially available cycle life is closer to 50-80 cycles, directly capping 60-day endurance.
* Challenge: Mid-latitude winter station-keeping has been the graveyard of HAPS programs (Zephyr, Aquila, HAWK30); even with quantified margins, sustained 35-45deg operations through tropopause winds remains unproven.
* Challenge: Passive OHP+PCM thermal control in stratospheric vacuum has limited flight heritage; cold-start, gravity-orientation, and freeze-thaw on PCM under g-loads during turbulence are all failure modes.
* Challenge: Ascent/descent through jetstream cores (>40 m/s) with a 3.5 kg/m^2 wing loading risks structural failure or uncontrolled drift; the concept under-specifies the launch/recovery weather window.
* Challenge: Prior art on electrical anti-ice integrated CF leading edges suggests ice accretion at tropopause crossing is recognized; this concept omits any anti-ice provision, which could be disqualifying for winter ops.

Budget Ranges

Prototype: $380,000 -- ground-test article: full wing section (6 m panel), OHP/PCM thermal mockup, avionics bench, battery pack qualification cycling, vacuum-chamber thermal-vac testing
Pilot: $1,400,000 -- two flight articles, low-altitude envelope expansion to 5 km, one 72-hour endurance flight at mid-latitude summer, jetstream avoidance algorithm validation
Scale: $6,500,000 -- winter solstice 60-day station-keeping demonstration at 40degN, redundant fleet of three aircraft, ground segment, regulatory coordination with FAA/ICAO

30/60/90 Plan

Day 30: Complete energy budget closure analysis for winter solstice at 35degN, 40degN, and 45degN using MERRA-2 wind and solar data; finalize OHP channel geometry and PCM material selection (erythritol at 118degC or n-octadecane at 28degC for battery bay); place long-lead orders for GaAs cells, Li-S pouch cells, and carbon-fiber prepreg; establish thermal-vac test protocol.
Day 60: Fabricate and test 6 m wing panel with integrated OHP and PV bonding; complete 200-cycle battery discharge characterization at -30degC to +40degC; validate OHP startup and heat transport at 5 mbar simulated stratospheric pressure in vacuum chamber; deliver preliminary airframe FEA showing gust load margins at 15 m/s vertical gust.
Day 90: Complete full avionics integration on ground test article; demonstrate closed-loop MPPT and thermal management over simulated 24-hour day/night cycle in environmental chamber; achieve first low-altitude (3 km) flight of subscale 8 m demonstrator; publish go/no-go decision matrix for full-scale build based on measured OHP thermal resistance and battery capacity retention data.
Dominance Axis: easier_deploy -- Uses flown HAPS architecture; advantage is credible endurance from

quantified winter energy margin plus passive thermal buffering.

Top Uncertainties & Assumptions

* RFC stack freeze-start or membrane dry-out below ?50 degC at cruise altitude degrades round-trip efficiency and can cause irreversible damage
* Wing aeroelastic divergence or flutter under stratospheric gust loads on a 25-35 m, AR-20+ structure with low torsional stiffness
* Night energy margin collapses under unexpected jet-stream intrusion above 18 km, forcing descent and mission abort
* Intercell net chafing under repeated diurnal pressure cycling creates abrasion wear-through at lobe contact points, triggering cascading leaks across adjacent chambers
* Microchannel spine freeze-blockage if trace moisture or condensables enter the working fluid loop during ascent through the tropopause cold trap