Immersion Cooling:
Thermal Management for High Voltage UAVs

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High-voltage UAVs make thermal management a design constraint

More power in a smaller airframe concentrates heat in batteries, electronics and propulsion hardware.

Battery packs need narrow temperature control with low cell-to-cell variation.

Power electronics, motor drivers and communications hardware generate high local heat flux.

Fans, ducts and air paths compete directly with payload, range and packaging volume.

Thermal excursions reduce battery capacity, electronics reliability and mission margin.

Design requirement

Remove heat at the source while insulating live high-voltage components and protecting them from the environment.

Single-phase Liquid Immersion Cooling (SLIC)

SLIC directly immerses energized components in a non-conductive dielectric heat-transfer fluid.

Battery pack → Power electronics → Pump → Heat exchanger

Single-phase: no boiling or vapor loop

Liquid: low-pressure coolant circulation

Immersion: no prlotective coatings needed

The fluid carries heat to a radiator, heat exchanger or vehicle skin without compressors, vapor or fan noise.

Why immersion cooling fits compact propelled vehicles:

~1800×

More efficient than air

20 L

can easily cool >1 kW

>3000 ft³

air volume required for similar load

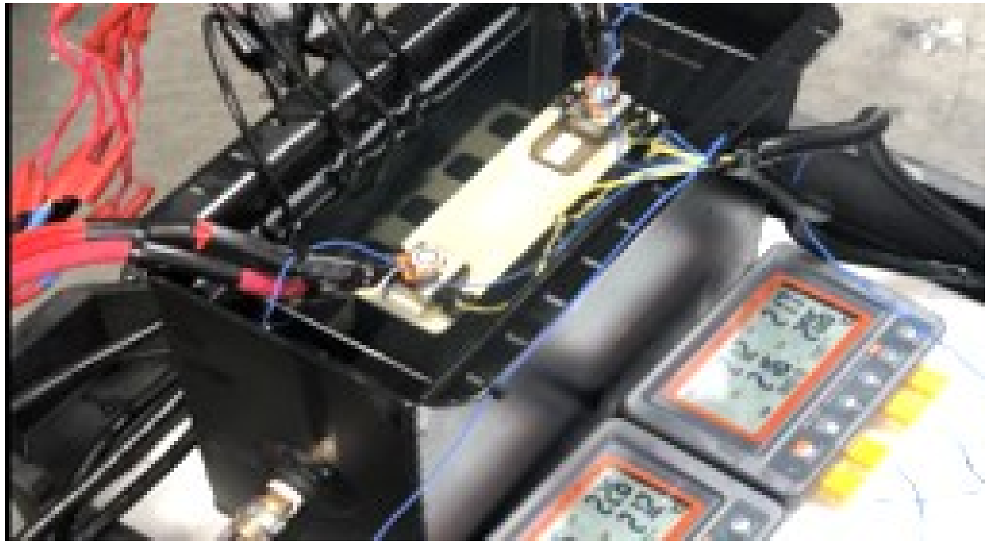
System implications

Higher heat transfer per unit volume

Small pumps and low-pressure plumbing

Direct cooling of cells, bus bars and terminals

Protection from dust, moisture and vibration



Battery test hardware

Battery tests: lower peak temperatures and less swing

Samsung 94 Ah prismatic cells were tested through rapid charge/discharge cycles using air cooling and AmpCool AC-110 immersion cooling.

	Air cooling	Immersion cooling
Maximum temp.	36.7°C	23.1°C
Temperature swing	16.5°C	2.2°C
Average temp.	27.7°C	22.0°C
Relative std. dev.	0.103	0.023

Engineering takeaway

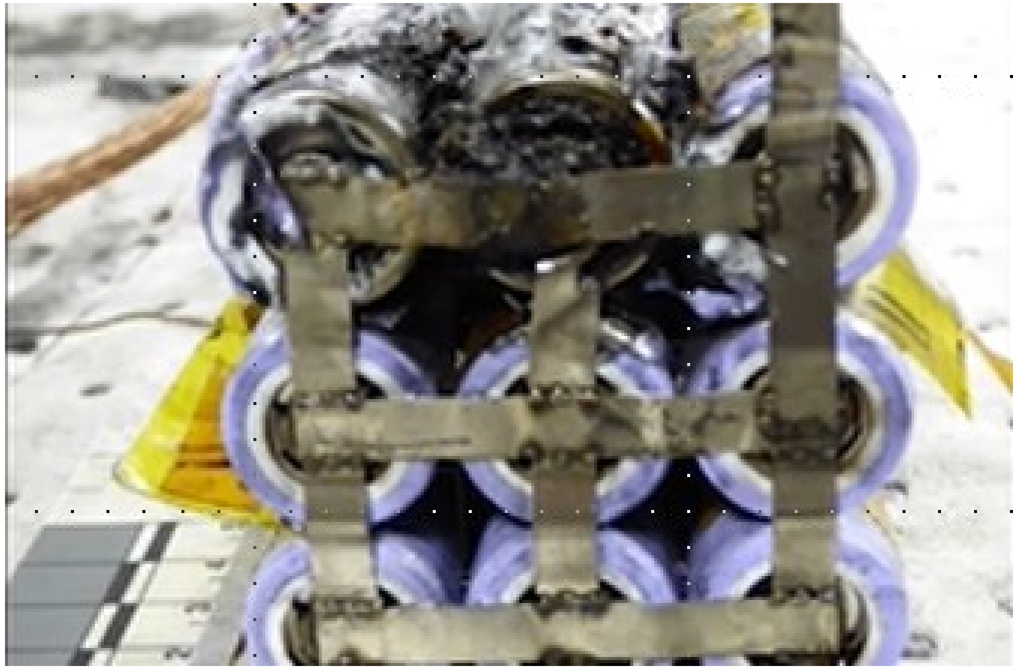
Peak temperature reduced by 13.6°C
Temperature swing reduced by 87%
Average cell temperature about 5°C lower

Lower and more uniform battery temperature improves usable capacity and service life.

Thermal runaway: isolate the failed cell, protect the pack

The safety goal is not only to cool normal operation, but to prevent one failed cell from damaging the neighboring cells.

Air / cold-plate cooled
Propagation damages the pack



Immersion Cooled
Failure contained to the punctured cell

Electronics cooling: less hardware, fewer failure modes

UAV electronics are power-dense and exposed. Immersion cooling combines heat removal with environmental protection.

Motor drivers & BMS
Power switching devices, bus bars and control boards

Enhanced vision systems
RADAR, LIDAR, LEDs, sensors and processors

Communications & navigation
RF amplifiers, processors and antenna electronics

Charging & recovery
High-current leads, terminals and converters

Reliability gains: no fans, less vibration, less corrosion, fewer contaminants and smaller thermal swings.

UAV integration: use the airframe as part of the cooling system

SLIC gives designers flexible heat rejection options while keeping high-voltage components electrically insulated.

Module enclosure

Battery cells
Bus bars and terminals
BMS and sensors

Coolant loop

Low-pressure pump
Small hoses and fittings
Quiet, no vibration

Heat rejection

Radiator or dry cooler
Airframe skin conduction
Heat exchanger interface

A single coolant architecture can cool, insulate and protect batteries, power electronics and propulsion assemblies.

Cooling technology tradeoffs

For high-voltage UAVs, cooling selection must account for heat transfer, electrical safety, packaging and serviceability.

Air cooling	Simple and dry	Low heat capacity; fans and ducting
Water/glycol cold plates	Good heat capacity	Conductive leak risk; TIM and plate complexity
Two-phase dielectric	High heat capacity	Regulatory and Commercial Pressure, toxicity, environmental liability
Immersion Cooling	Direct insulation and high heat transfer	Requires materials and flow validation

SLIC is strongest when heat density, electrical insulation and compact packaging are all requirements.

AmpCool design considerations for aerospace and marinw electrical systems

AmpCool dielectric coolants are designed for batteries, electric motors, power electronics and high-voltage systems.

Electrical safety	High dielectric strength for live assemblies
Thermal range	Wide-temperature operation
Materials	Compatibility testing supports design qualification
Reliability	Protects circuits from corrosion and contamination
Maintenance	Low-pressure components and simple leak detection
Sustainability	Biodegradable, non-toxic coolant approach

Practical development path: heat sources → material compatibility check → flow model → prototype → electrical, thermal and safety validation.

Implementation path for a UAV thermal system

1	**Map thermal loads**	Cells, bus bars, converters, motors and RF electronics
2	**Define electrical limits**	Voltage, creepage, clearances and insulation requirements
3	**Validate materials**	Seals, plastics, wire insulation, connectors and sensors
4	**Prototype the coolant loop**	Flow rate, heat exchanger, pump, venting and leak detection
5	**Test at mission conditions**	Charge/discharge, altitude, vibration, thermal runaway and serviceability

The result is a compact thermal system that also improves insulation, reliability and safety.

Summary: immersion cooling solves multiple UAV design problems

A high-voltage UAV thermal system must be compact, electrically safe, reliable and serviceable.

Thermal

Lower peak temperatures
Uniform cell temperatures
Cooling and warming in one loop

Electrical & safety

High dielectric insulation
Reduced short risk from leaks
Thermal runaway propagation control

Reliability

No fans or ductwork
Protection from dust and moisture
Lower vibration and corrosion exposure

Contact Engineered Fluids to evaluate AmpCool for high-voltage UAV battery, power electronics and propulsion systems.