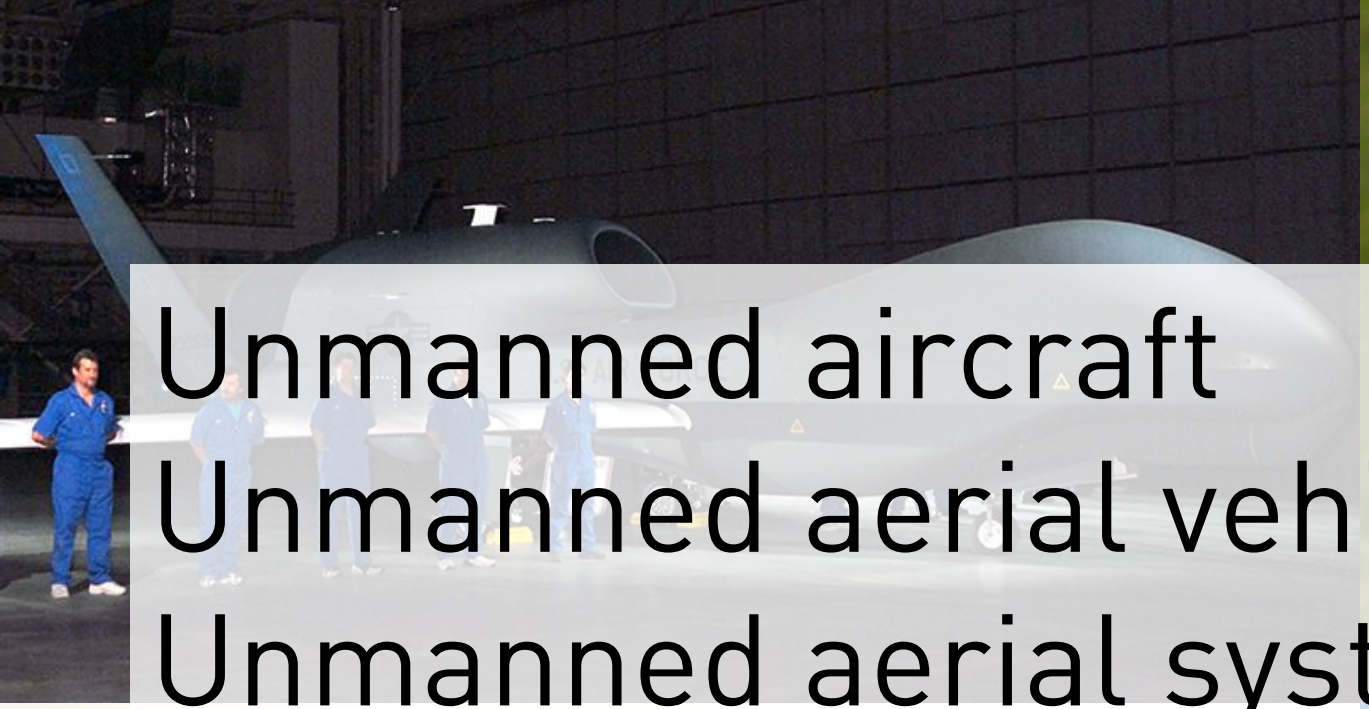
Synergies between icing on wind turbines and UAVs

Dr. Richard Hann / richard.hann@ntnu.no

NTNU

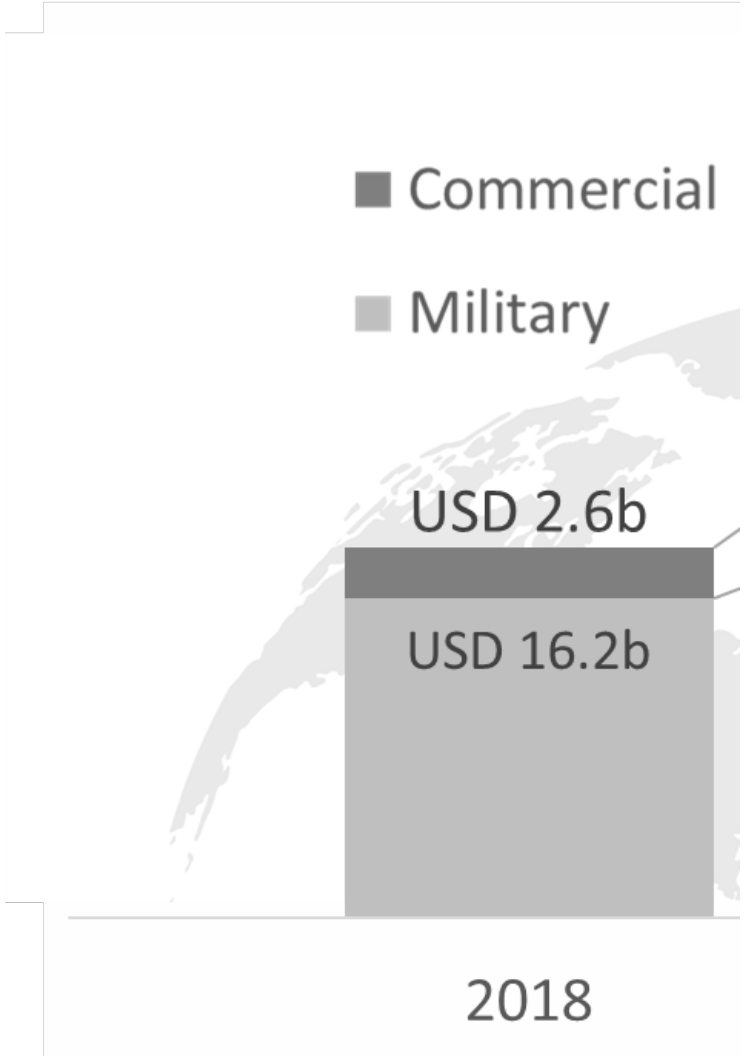

AIR FORCE


zipline

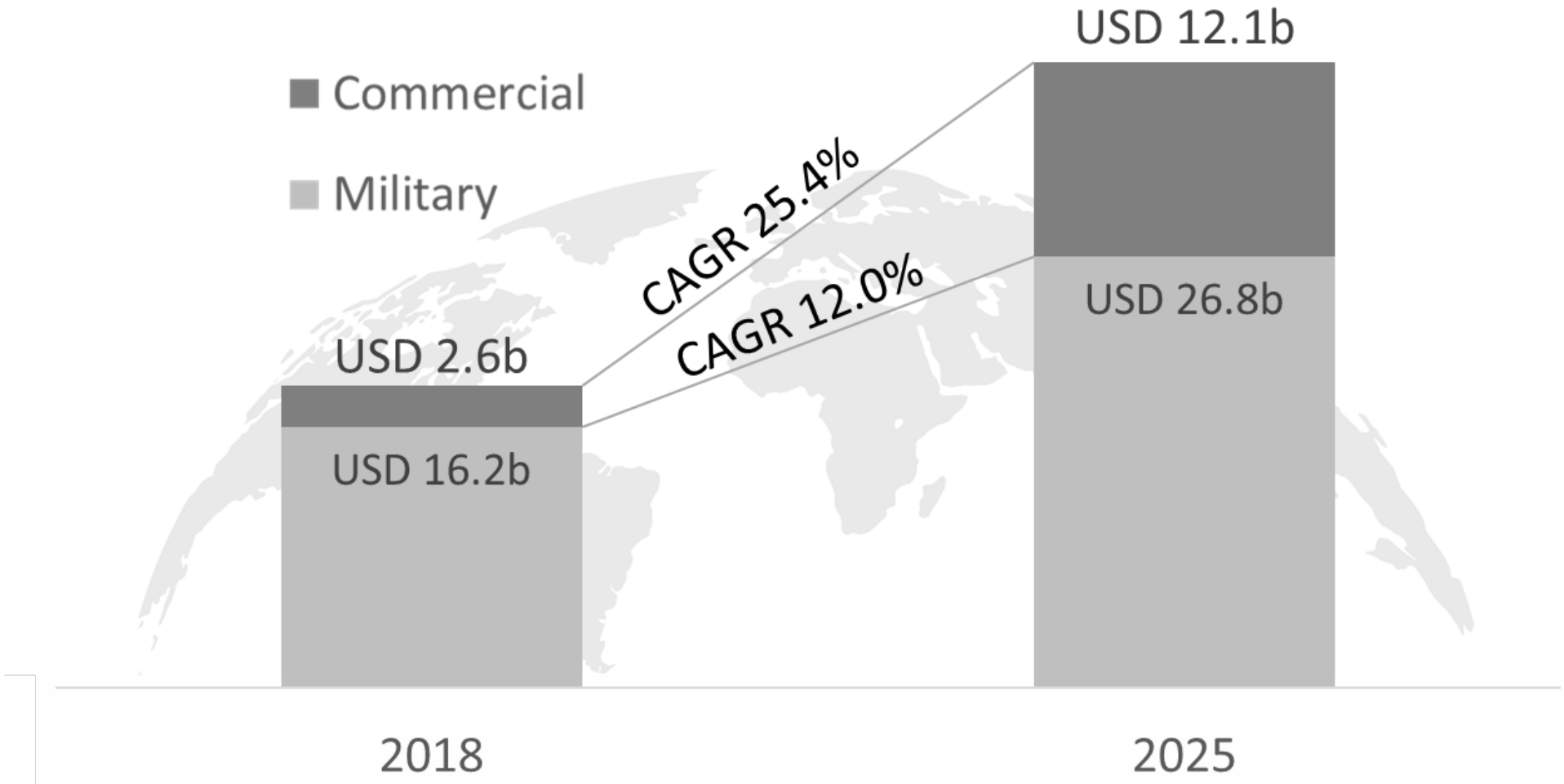


Unmanned aircraft
Unmanned aerial vehicle (UAV)
Unmanned aerial system (UAS)
“Drone”

Global UAV Market



Global UAV Market



Source: Market Study Report LLC & MarketsandMarkets INC

Date: 2018

Civil UAV Applications

- Agriculture
- Construction
- Photography & Film

Civil UAV Applications

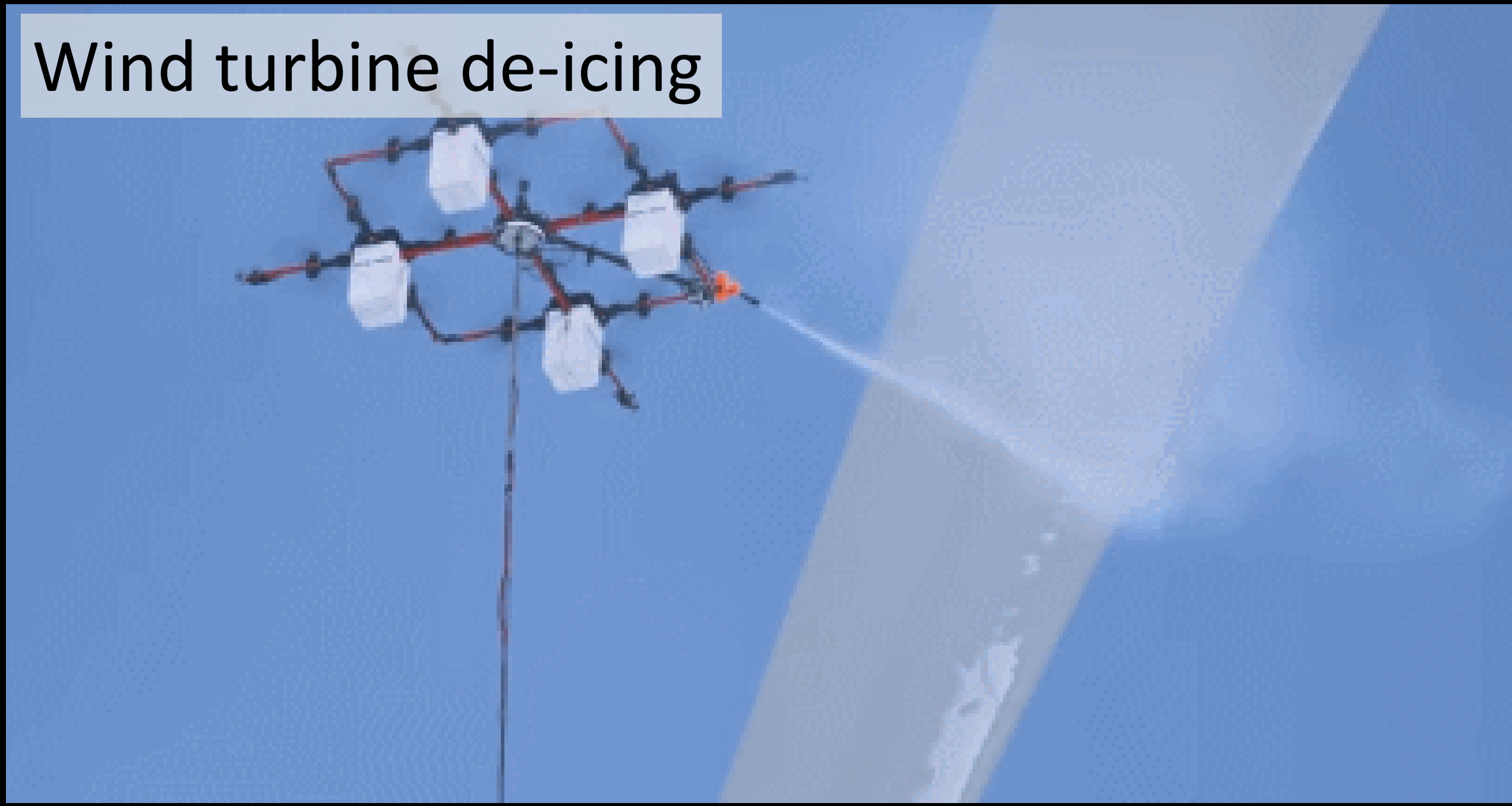
- Agriculture
- Construction
- Photography & Film
- Marine operations
- Arctic operations

Civil UAV Applications

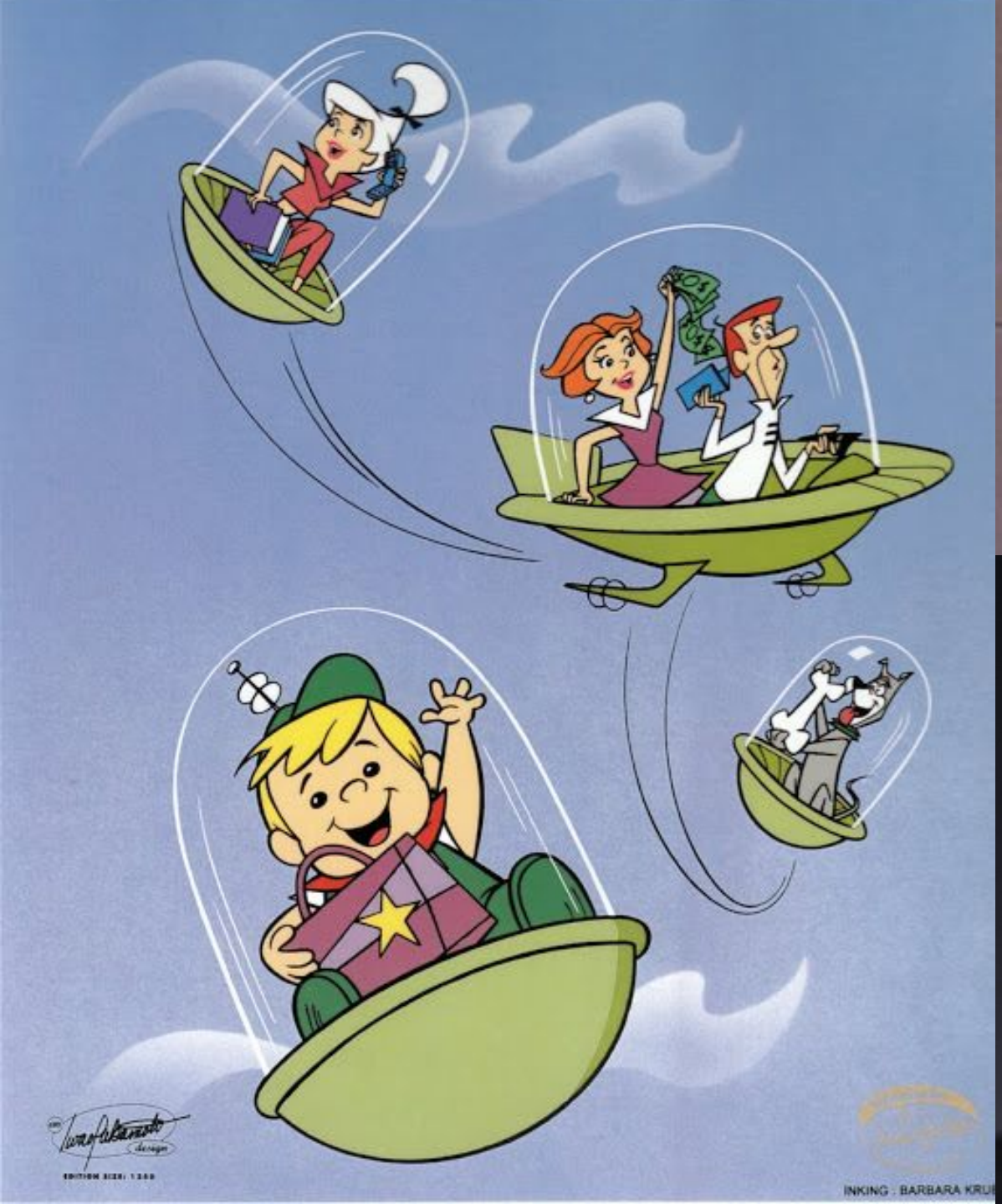
- Agriculture
- Construction
- Photography & Film
- Marine operations
- Arctic operations
- Deliveries
- Urban Air Mobility

Wind turbine inspections

Wind turbine de-icing



Wind turbine de-icing?


INKING : BARBARA KRU


POLICE

NASA Urban Air Mobility

November 2018

URBAN AIR MOBILITY (UAM) MARKET STUDY

CROWN CONSULTING, INC.

ASCENSION GLOBAL

Georgia Tech Aerospace Systems Design Lab

McKinsey&Company

Weather Limitations

	Criteria[1]	Implications	Number of days grounded
Rain/snow	▪ Rain is assumed to ground vehicles when there is more than 1mm of rain paired with temperatures below 32F	▪ Rain is unlikely to ground vehicles unless the temperatures are also at or below freezing point ▪ Technologies may also improve the ability for these vehicles to work in freezing rain	▪ Min: 0 (e.g., Dallas, LA) ▪ Max: ~32 (e.g. Detroit) ▪ Avg: ~5-10
Low temperatures	▪ Temperatures below 32F will likely ground vehicles	▪ Extreme temperatures will likely limit range and potentially ground vehicles due to reduced battery efficiencies	▪ Min: 0 (e.g., Dallas, LA) ▪ Max: ~110 (e.g., Detroit) ▪ Avg: ~35-40
High temperatures	▪ Temperatures above 104F will likely ground vehicles		▪ Min: 0 (e.g., Seattle) ▪ Max: ~45 (e.g., Phoenix) ▪ Avg: ~3-5
Wind	▪ Wind above 25mph will likely ground vehicles	▪ Wind is unlikely to ground vehicles for extended periods of time, but will likely impact accuracy of flying and safety considerations ▪ It is more likely that wind will reduce the range in which vehicles can travel due to increase in battery usage	▪ Days with fastest 2 minutes greater than criteria: – Min: ~8-10 (e.g., Riverside) – Max: ~140-145 (e.g., SF) – Avg: ~55-60

1 Estimates are highly conservative because inclement weather will likely significantly reduce range, and vehicle type (i.e. multi-rotor, fixed wing) may have significant impact on ability to withstand inclement weather.

Source: https://ntrs.nasa.gov/search.jsp?R=20190026762

Weather Limitations

	Criteria[1]	Implications	Number of days grounded
Rain/snow	Rain is assumed to ground vehicles when there is more th[illegible]mm of rain paired with temperat[illegible]	Rain is unlikely to ground vehicles unless the temperatures are also at or below freezing point Technologies may also improve the ability for [illegible]	Min: 0 (e.g., Dallas, LA) Max: ~32 (e.g. Detroit) Avg: ~5-10
Low temperatures	Temperatures below 32F will likely ground vehicles	Extreme temperatures will likely limit range and potentially ground vehicles due to reduced battery efficiencies	Min: 0 (e.g., Dallas, LA) Max: [illegible] Avg: ~35-40
High temperatures	Temperatures above 104F will likely ground vehicles		Min: 0 (e.g., Seattle) Max: ~45 (e.g., Phoenix) Avg: ~3-5
Wind	Wind above 25mph will likely ground vehicles	Wind is unlikely to ground vehicles for extended periods of time, but will likely impact accuracy of flying and safety considerations It is more likely that wind will reduce the range in which vehicles can travel due to increase in battery usage	Days with fastest 2 minutes greater than criteria: – Min: ~8-10 (e.g., Riverside) – Max: ~140-145 (e.g., SF) – Avg: ~55-60

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"Temperatures below 0°C / 32°F will likely ground vehicles… [due to icing]

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Source: https://ntrs.nasa.gov/search.jsp?R=20190026762

Weather Limitations

	Criteria[1]	Implications	Number of days grounded
Rain/snow	▪ Rain is assumed to ground vehicles when there is more than 4mm of rain paired with temperatures below 32F	▪ Rain is unlikely to ground vehicles unless the temperatures are also at or below freezing point ▪ Technologies may also improve the ability for [illegible]	▪ Min: 0 (e.g., Dallas, LA) ▪ Max: ~32 (e.g. Detroit) ▪ Avg: 5-10
Low temperatures	▪ Temperatures below 0°C / 32°F will likely ground vehicles	▪ Extreme temperatures will likely limit range and potentially ground vehicles due to reduced battery efficiencies	▪ Min: 0 (e.g., Dallas, LA) ▪ Max: ~[illegible] ▪ Avg: ~35-40
High temperatures	▪ Temperatures above 104F will likely ground vehicles		
Wind	▪ Wind above 25mph will likely ground vehicles	▪ Wind is unlikely to ground vehicles for extended periods of time, but will likely impact accuracy of flying and safety considerations ▪ It is more likely that wind will reduce the range in which vehicles can travel due to increase in battery usage	

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Weather Limitations

	Criteria[1]	Implications	Number of days grounded
Rain/snow	▪ Rain is assumed to ground vehicles when there is more than 4mm of rain paired with temperatures below 32F	▪ Rain is unlikely to ground vehicles unless the temperatures are also at or below freezing point ▪ Technologies may also improve the ability for [illegible]	▪ Min: 0 (e.g., Dallas, LA) ▪ Max: ~32 (e.g. Detroit) ▪ Avg: 5-10
Low temperatures	▪ Temperatures below 0°C / 32°F will likely ground vehicles… [due to icing]	▪ Extreme temperatures will likely limit range and [illegible]	▪ Min: 0 (e.g., Dallas, LA) ▪ Max: ~150 (e.g. Detroit) ▪ Avg: ~35-40
Wind	▪ Wind above 25mph will likely ground vehicles	▪ Wind is unlikely to ground vehicles for extended periods of time, but will likely impact accuracy of flying and safety considerations ▪ It is more likely that wind will reduce the range in which vehicles can travel due to increase in battery usage	

1 Estimates are highly conservative because inclement weather will likely significantly reduce range, and vehicle type (i.e. multi-rotor, fixed wing) may have significant impact on ability to withstand inclement weather.

> "Temperatures below 0°C / 32°F will likely ground vehicles… [due to icing]

Climate data for Oslo, Norway [hide]

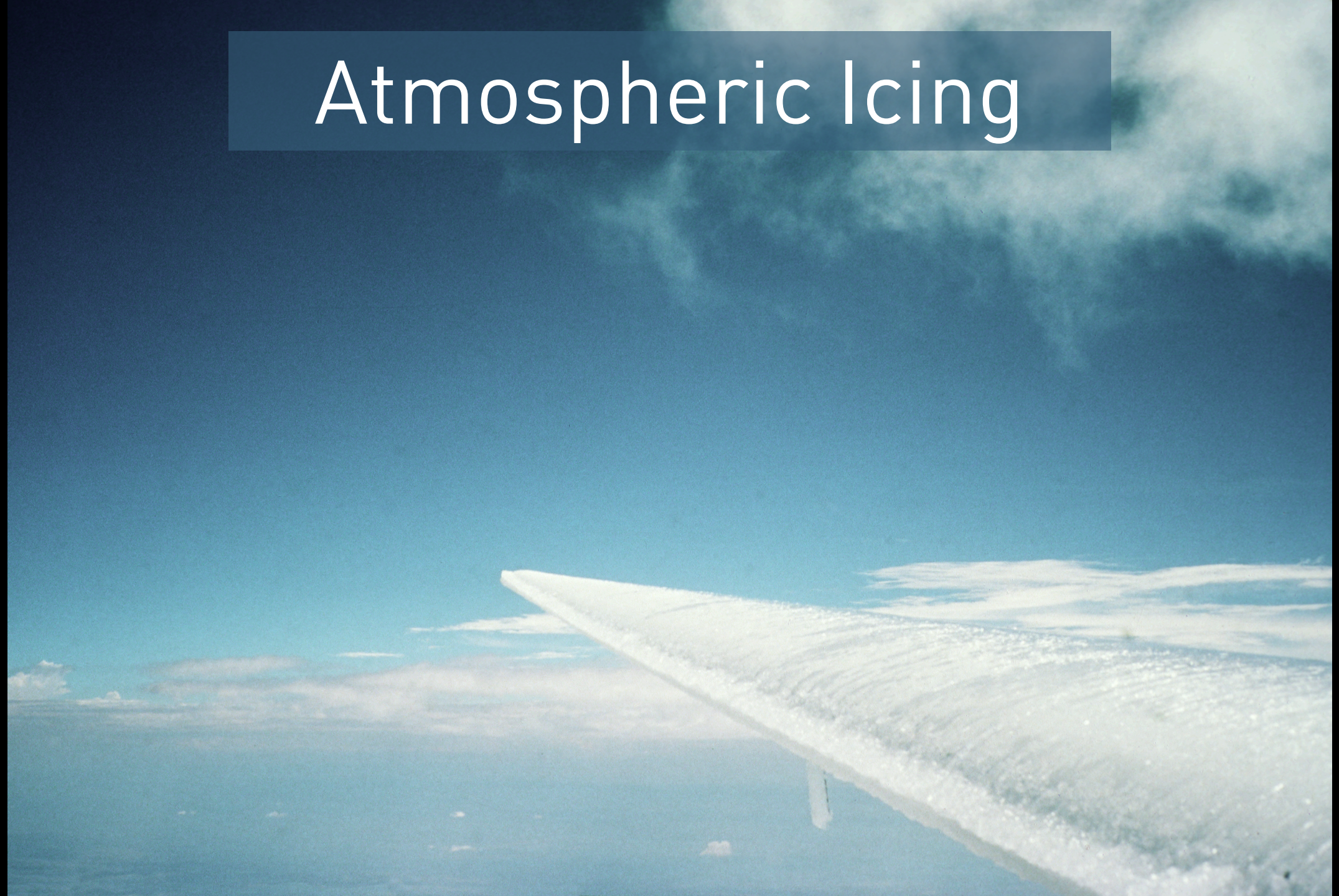
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Daily mean °C (°F)	−3 (27)	−2.5 (27.5)	1.5 (34.7)	5 (41)	11.5 (52.7)	15.5 (59.9)	17.5 (63.5)	16 (61)	11.5 (52.7)	7 (45)	1.5 (34.7)	−3 (27)	6.54 (43.89)

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Source: https://ntrs.nasa.gov/search.jsp?R=20190026762

The icing barrier

Atmospheric Icing

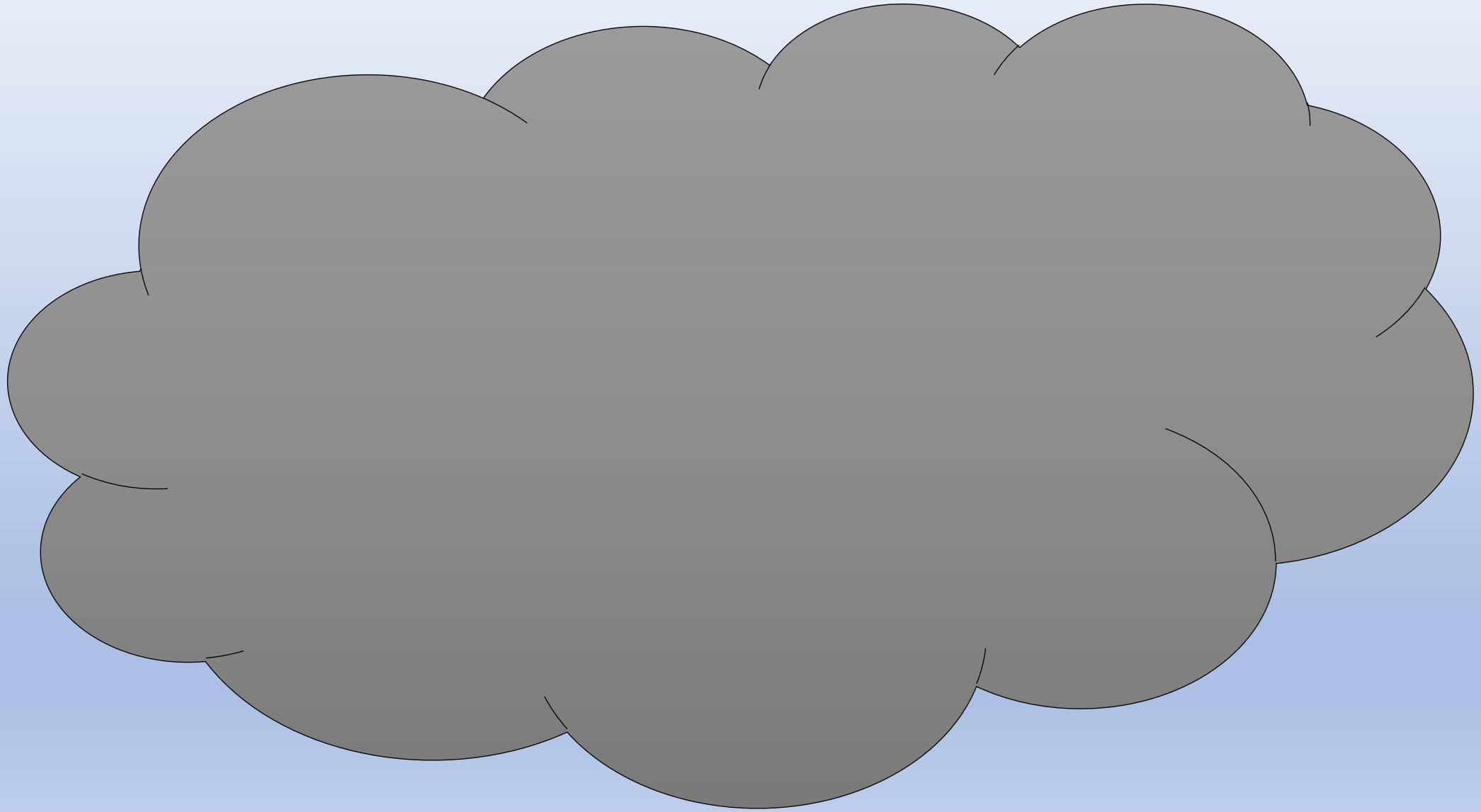


Atmospheric Icing

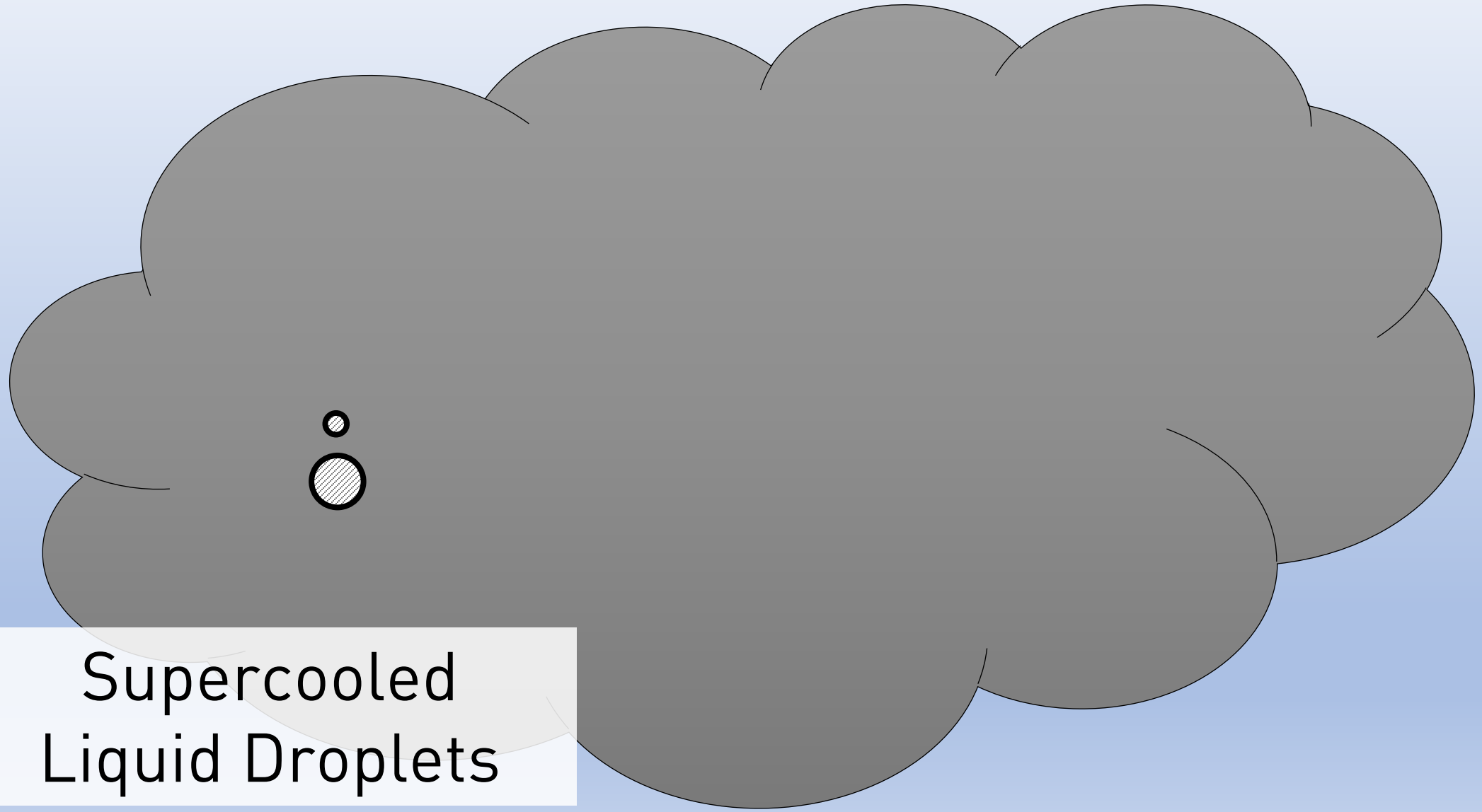
Atmospheric Icing

Atmospheric Icing

Atmospheric Icing

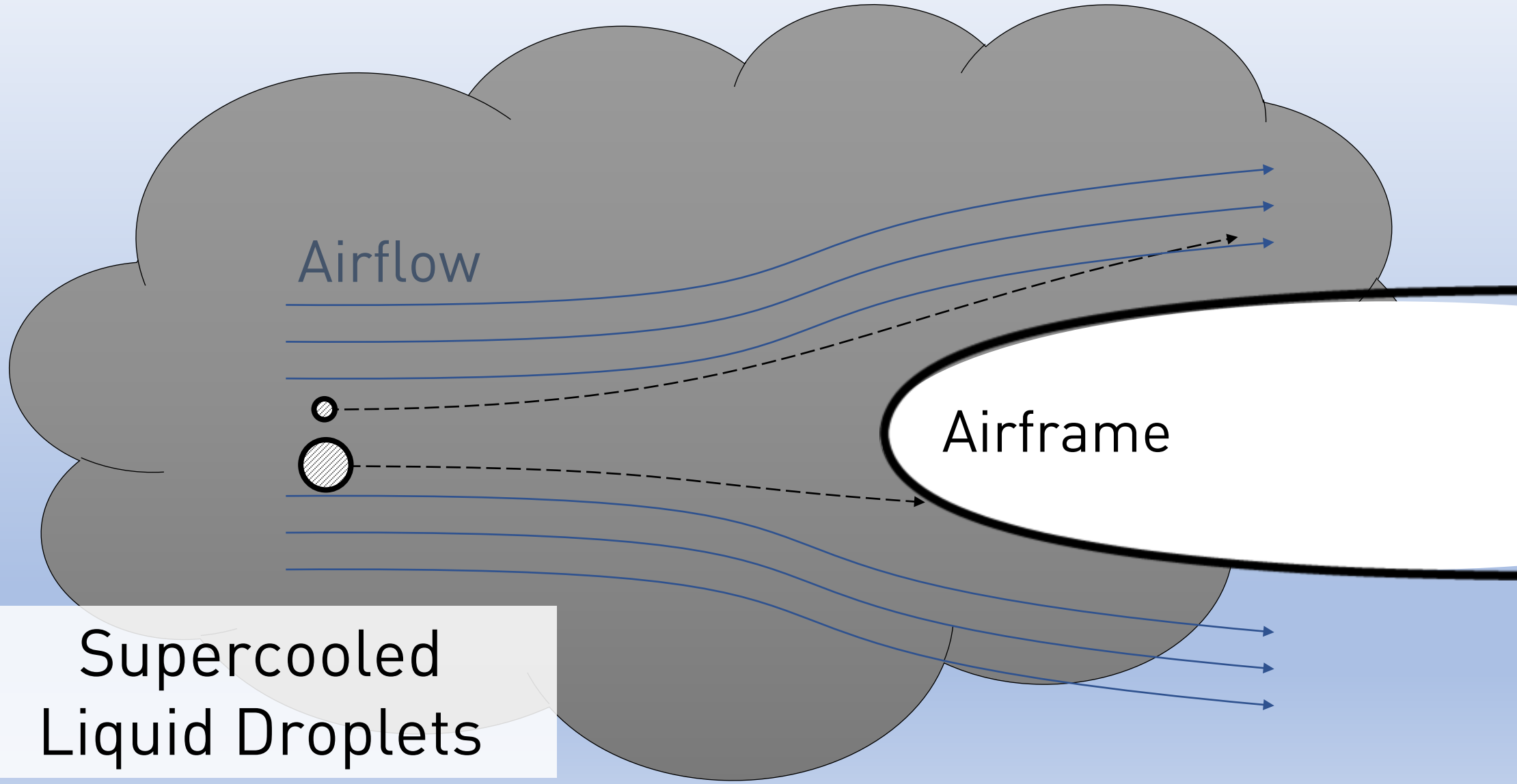


Atmospheric Icing

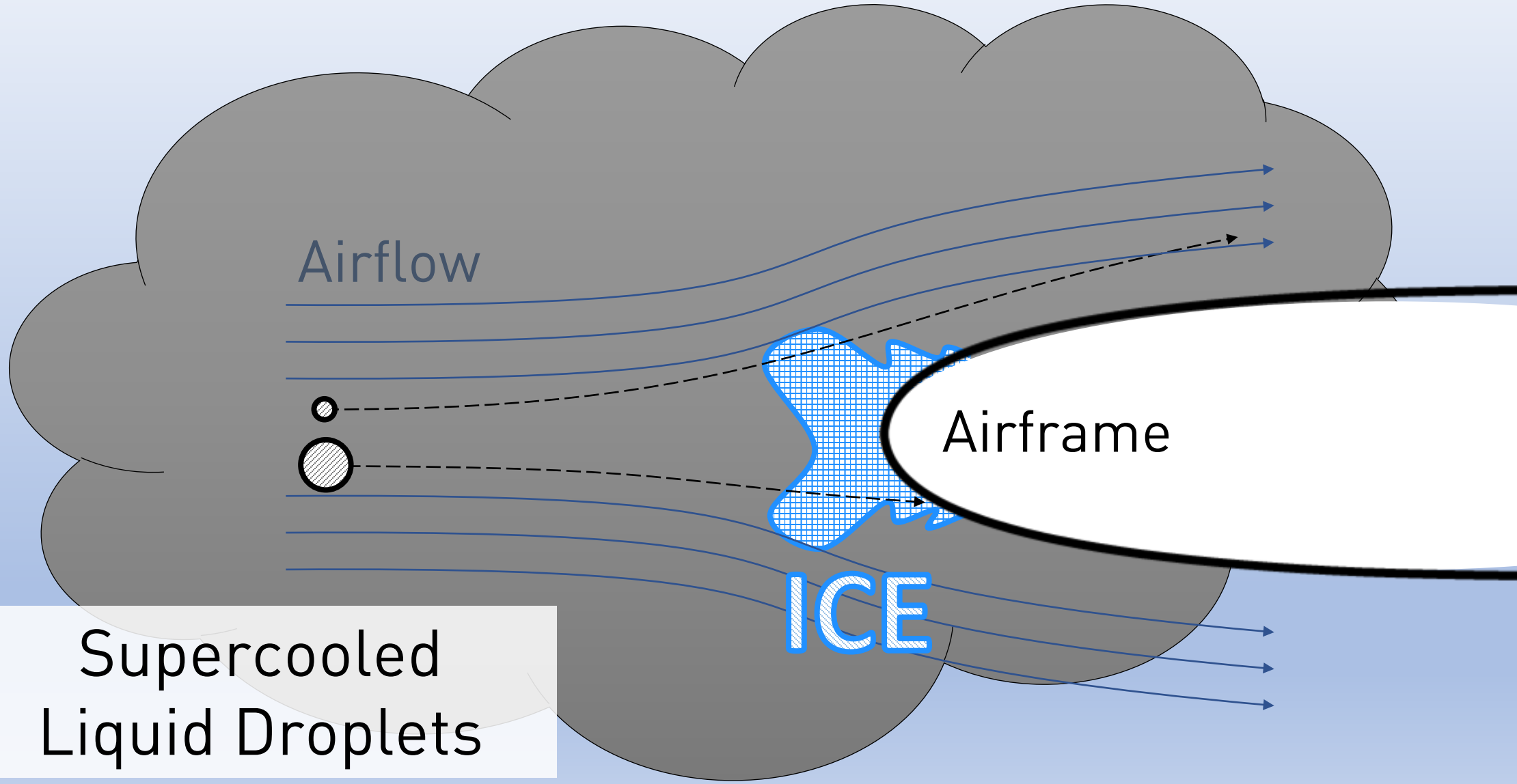


Supercooled
Liquid Droplets

Atmospheric Icing

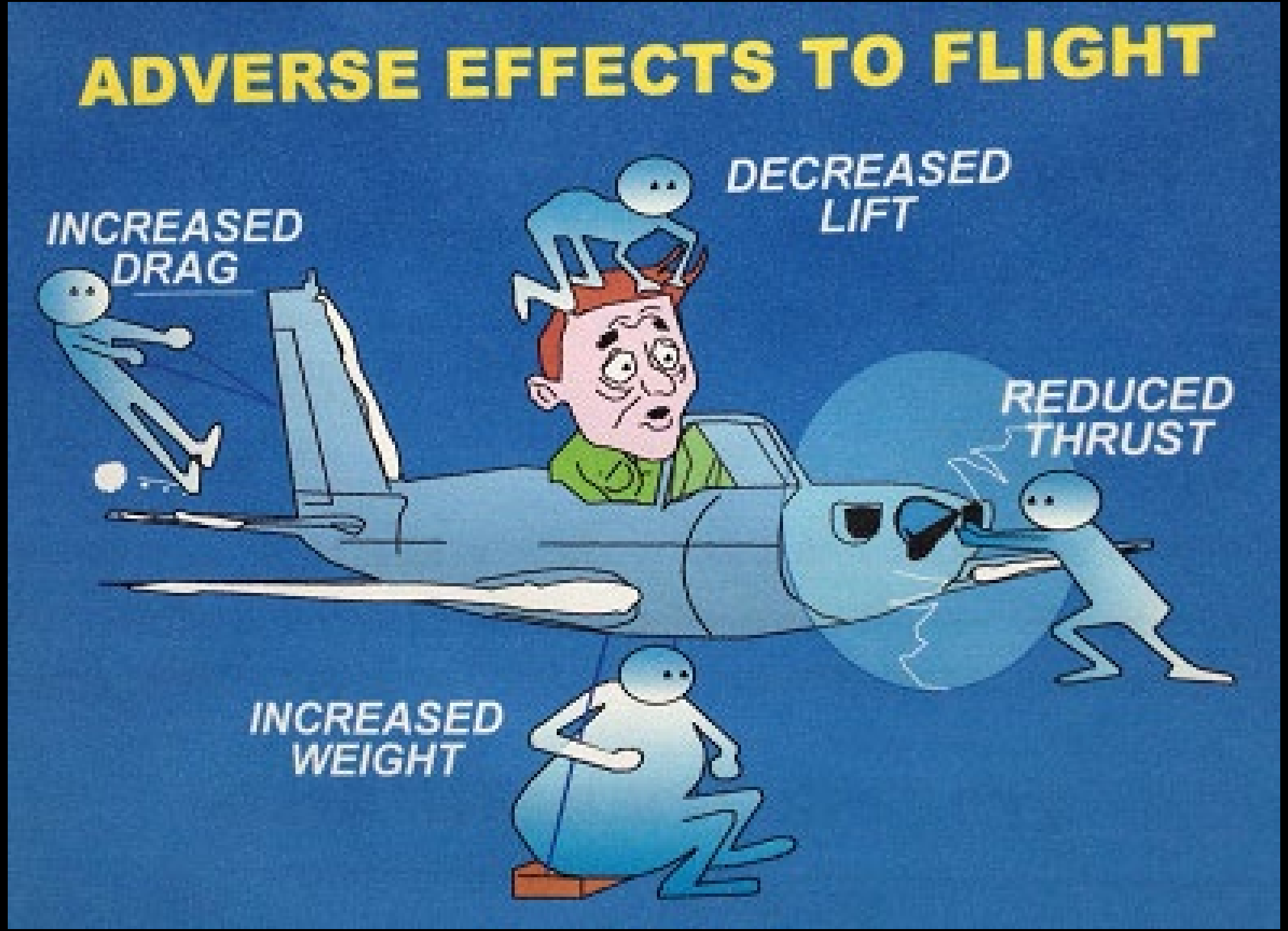


Atmospheric Icing

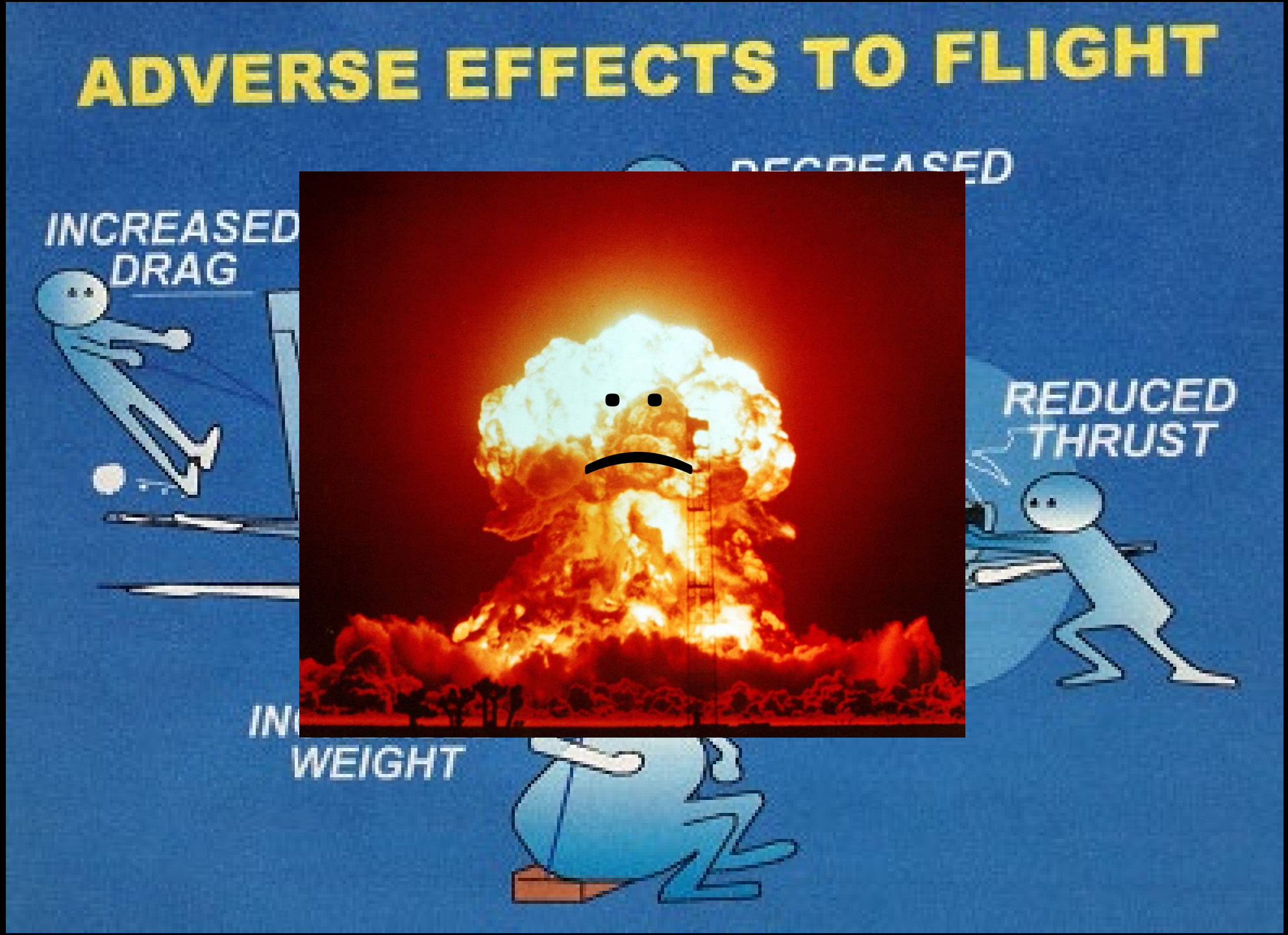



Rime Icing


Glaze Icing

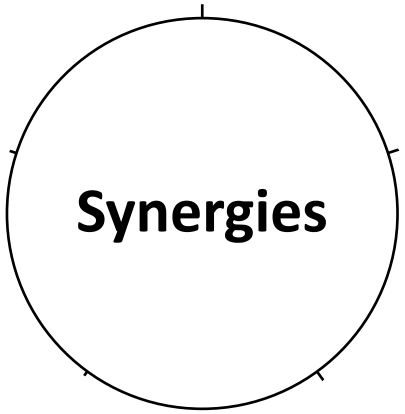

ADVERSE EFFECTS TO FLIGHT
INCREASED DRAG
DECREASED LIFT
REDUCED THRUST
INCREASED WEIGHT

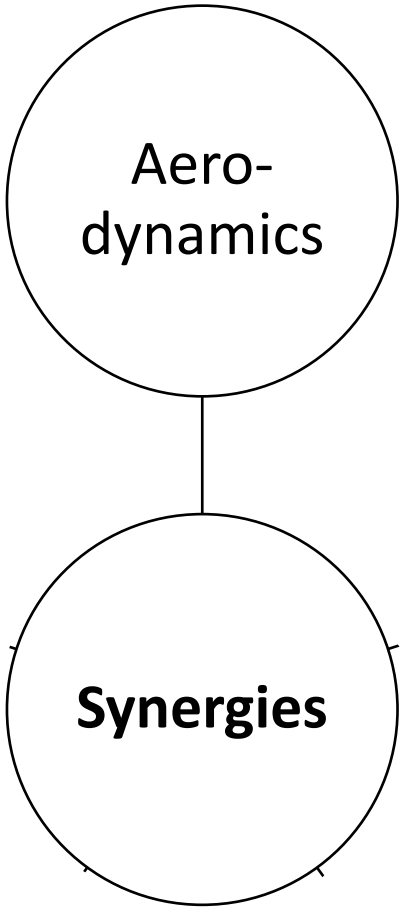
ADVERSE EFFECTS TO FLIGHT

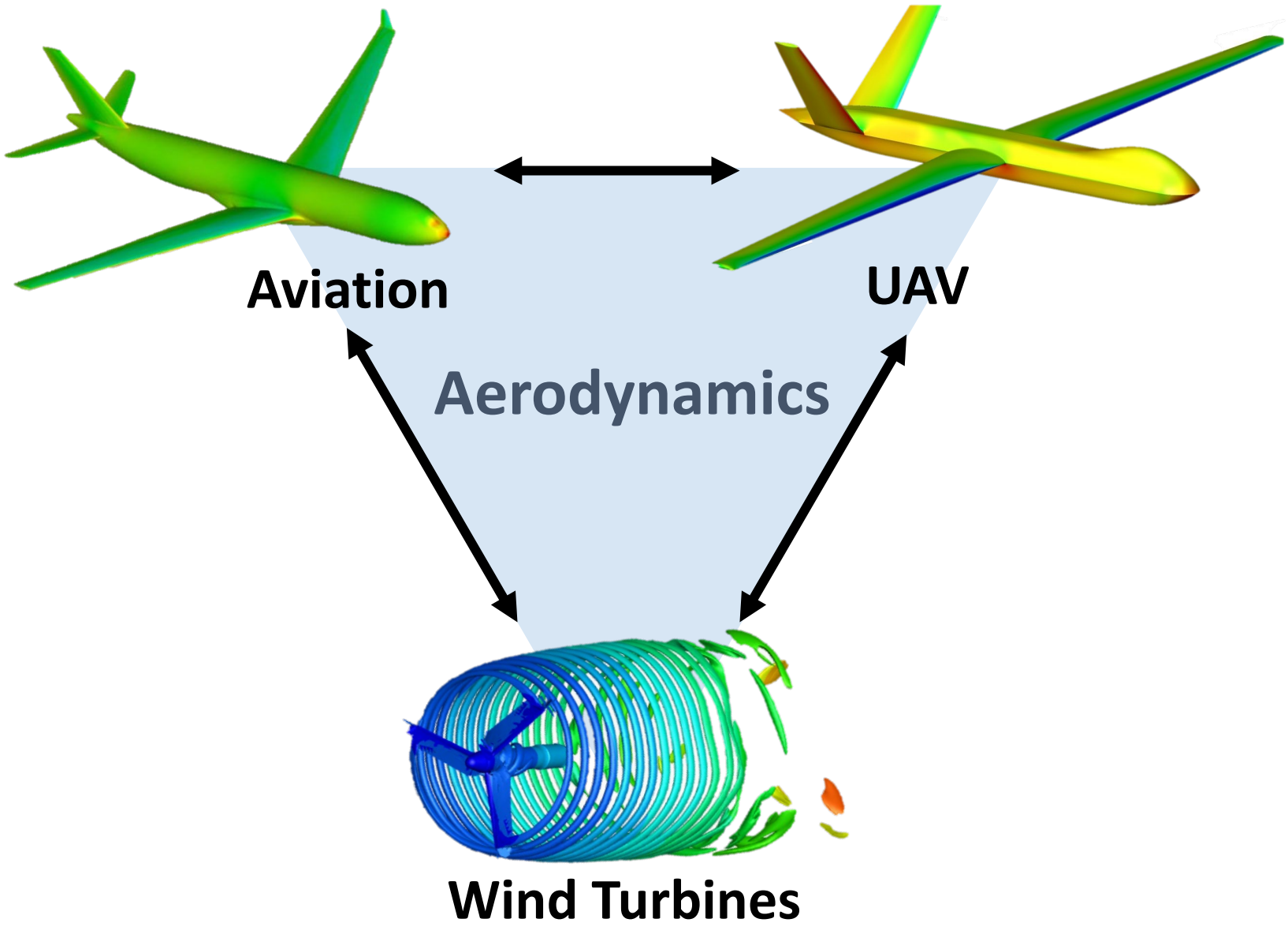


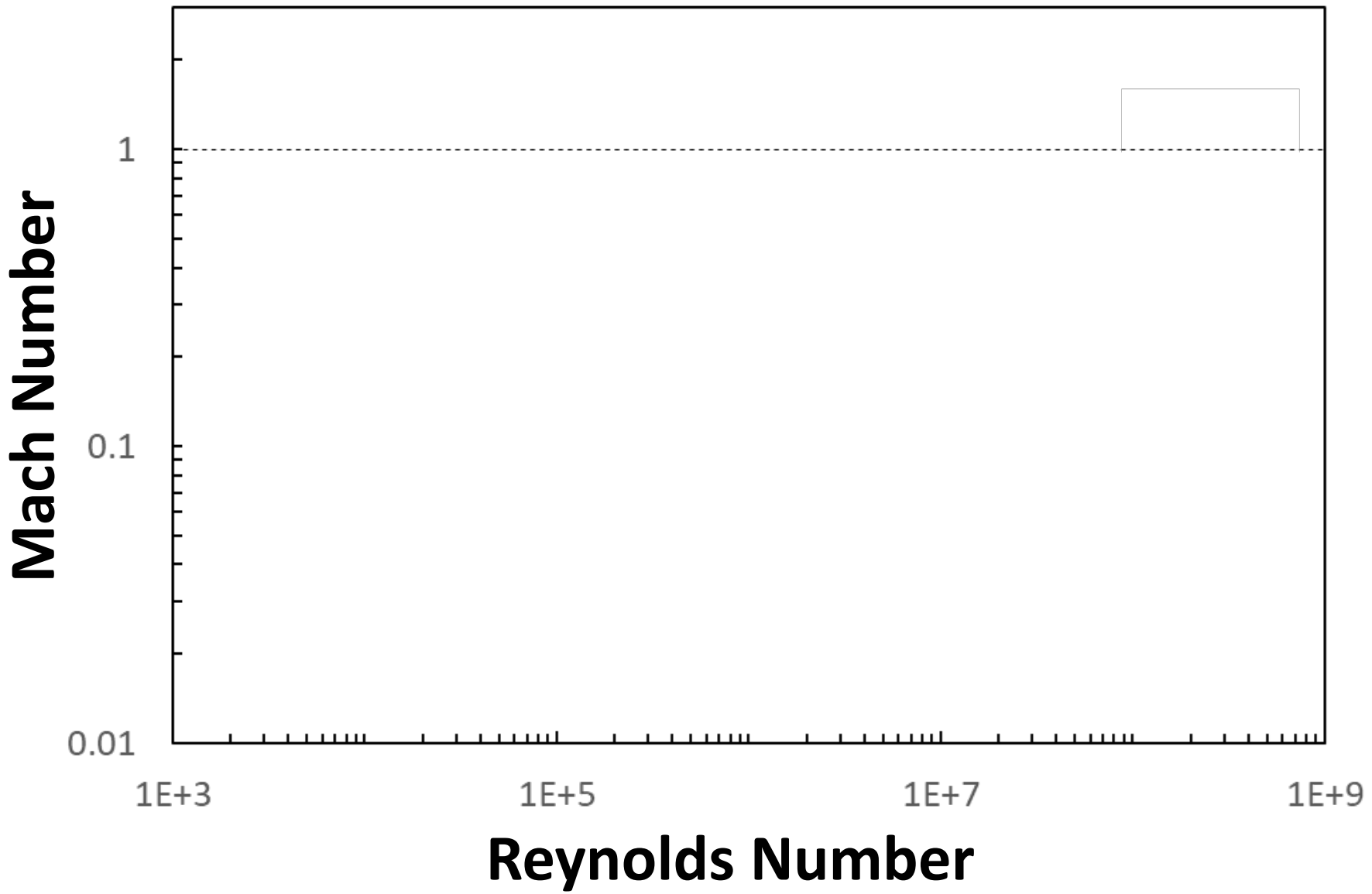
Icing on Manned Aircraft

Cold Climate Wind Energy


Synergies


Aero-
dynamics
Synergies


Aviation
UAV
Aerodynamics
Wind Turbines


Mach Number
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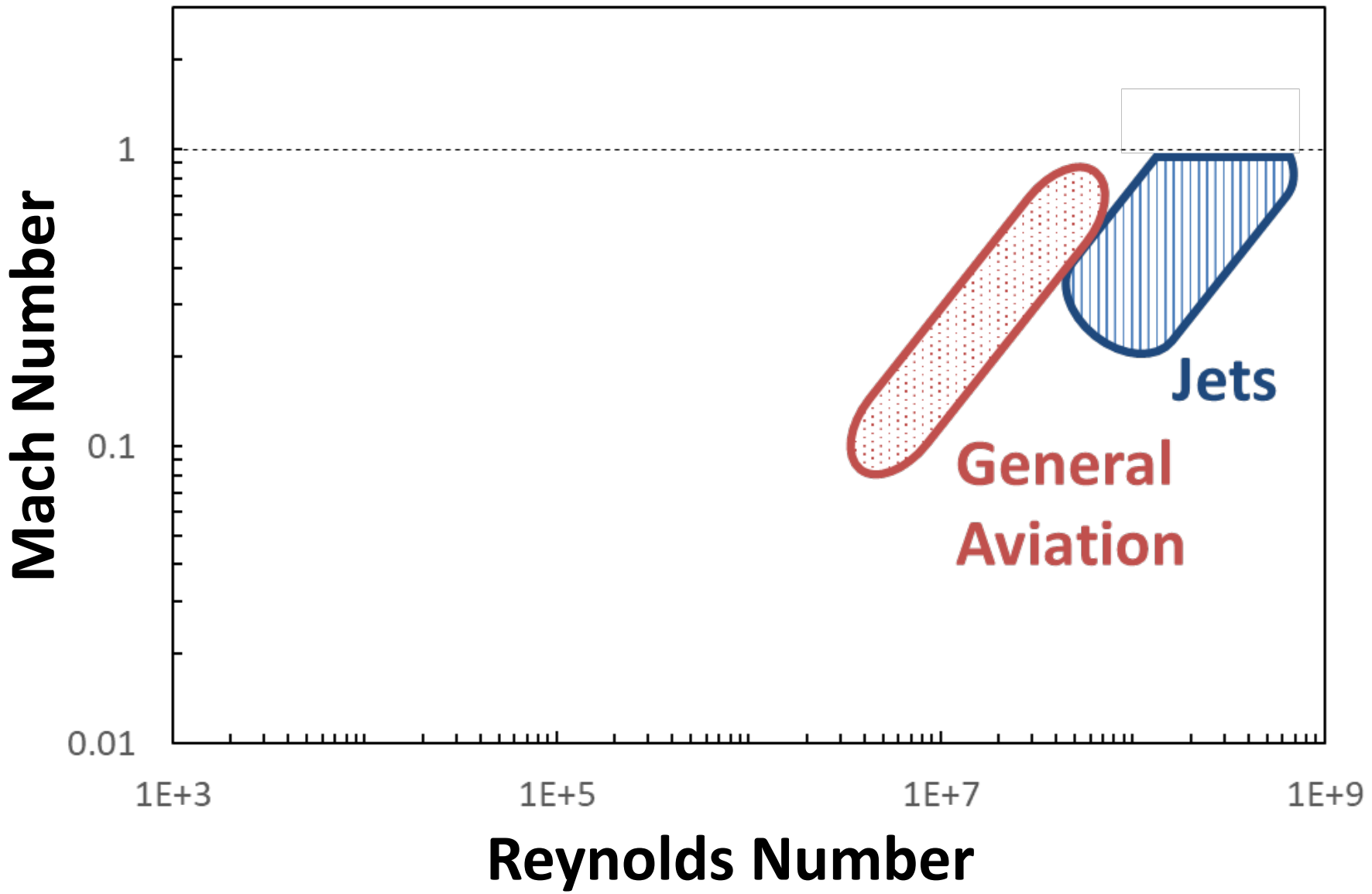
0.1
0.01
1E+3
1E+5
1E+7
1E+9
Reynolds Number


Mach Number
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0.1
0.01
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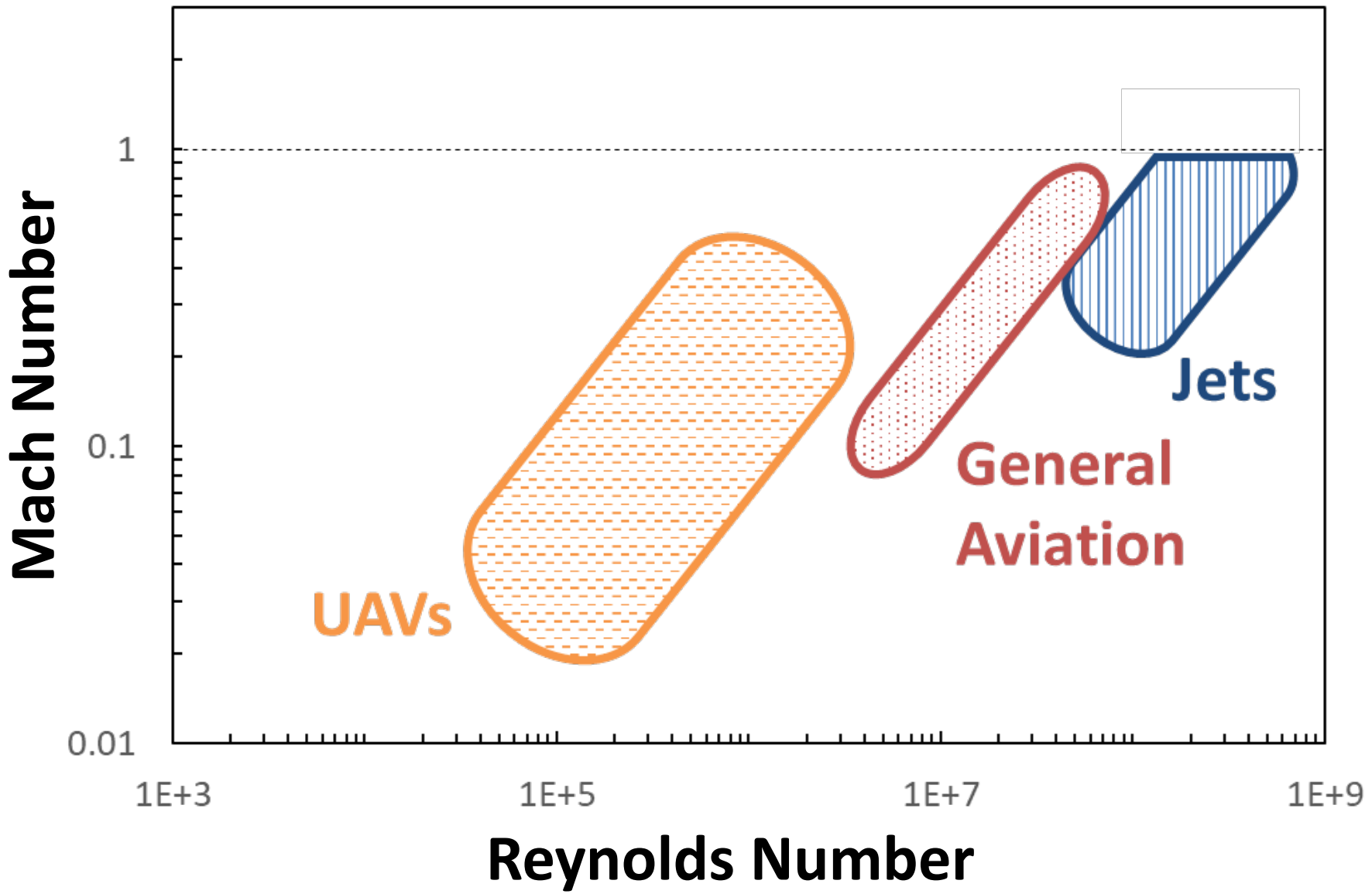
1E+5
1E+7
1E+9
Reynolds Number
Jets
General
Aviation


Mach Number
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0.01
1E+3
1E+5
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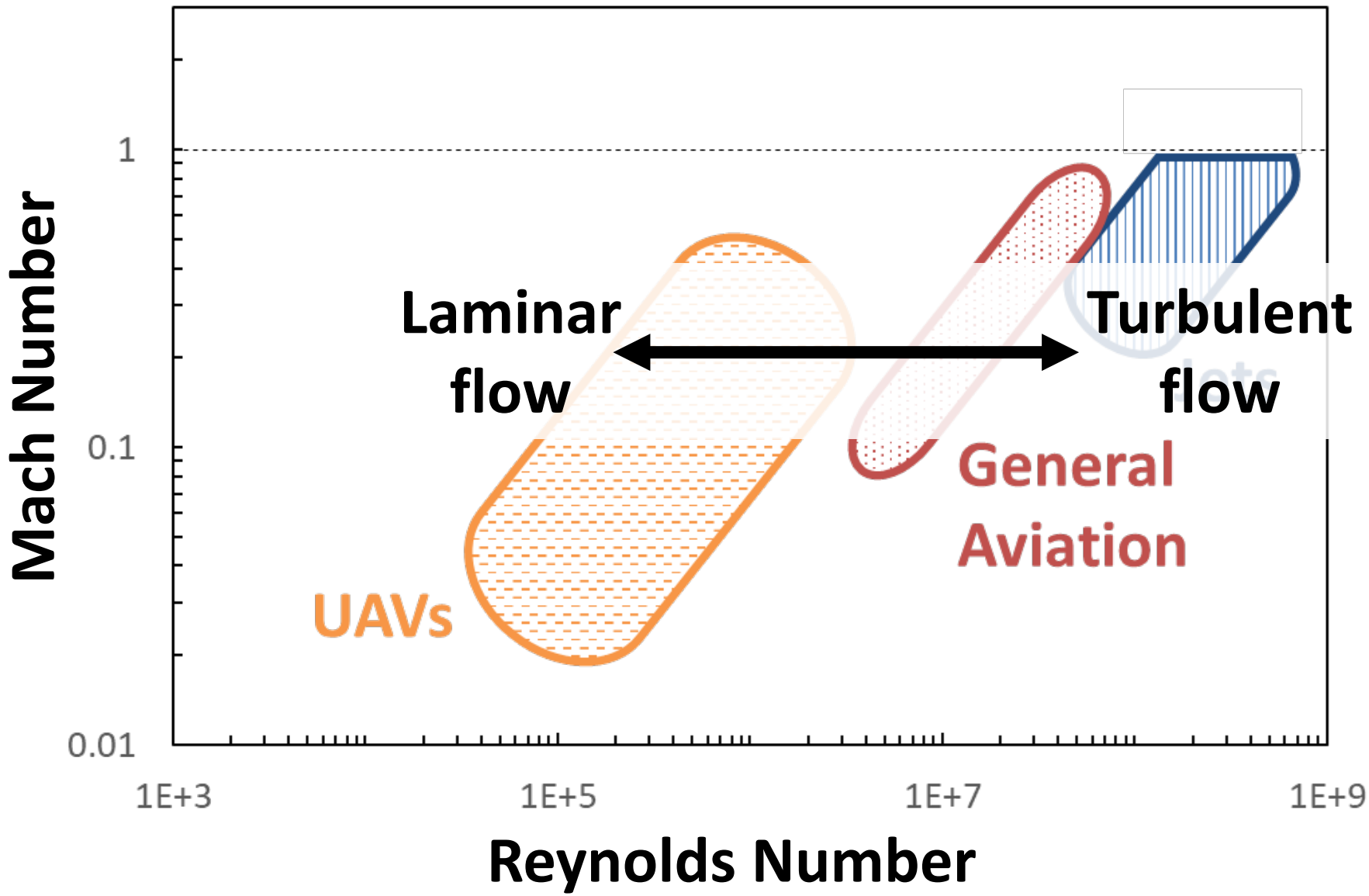
Reynolds Number
UAVs
General
Aviation
Jets


Mach Number
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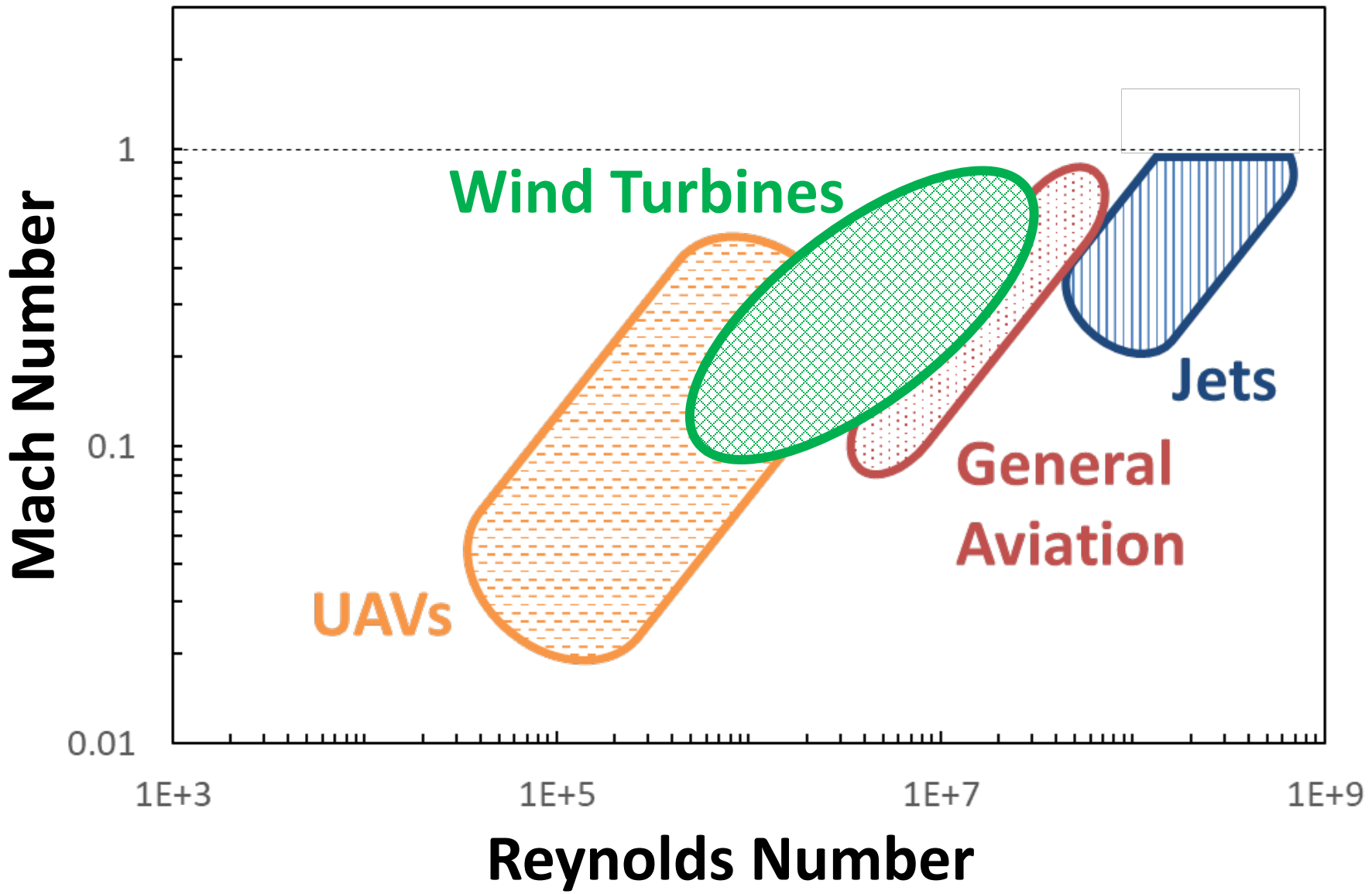
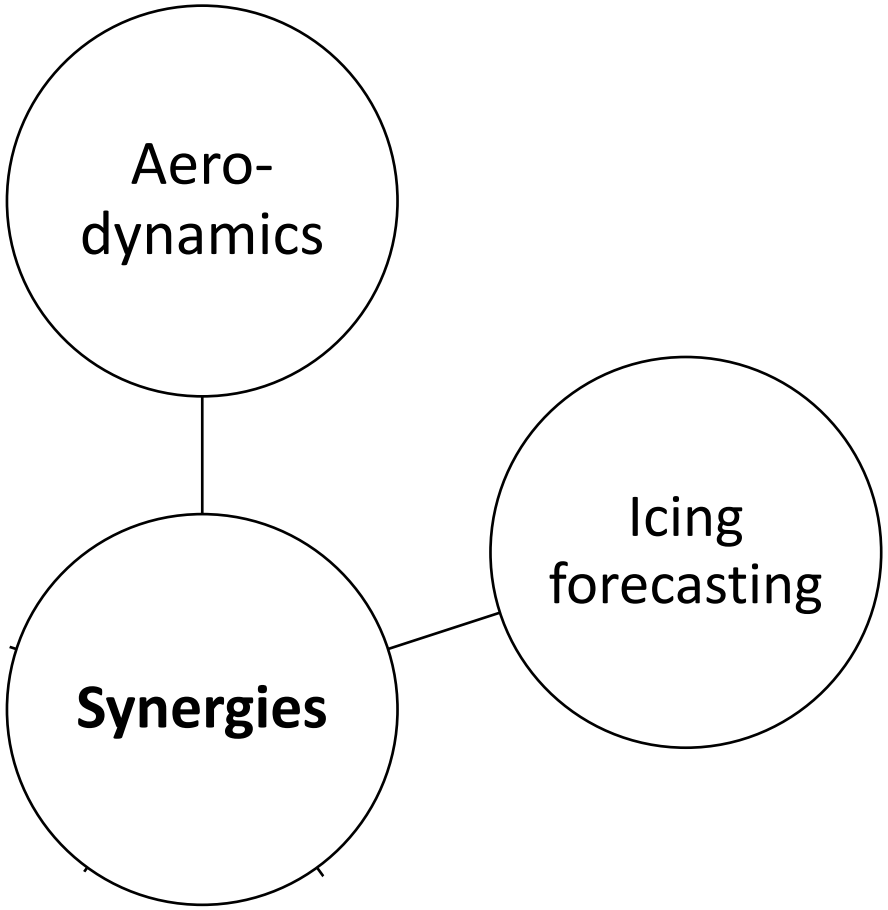
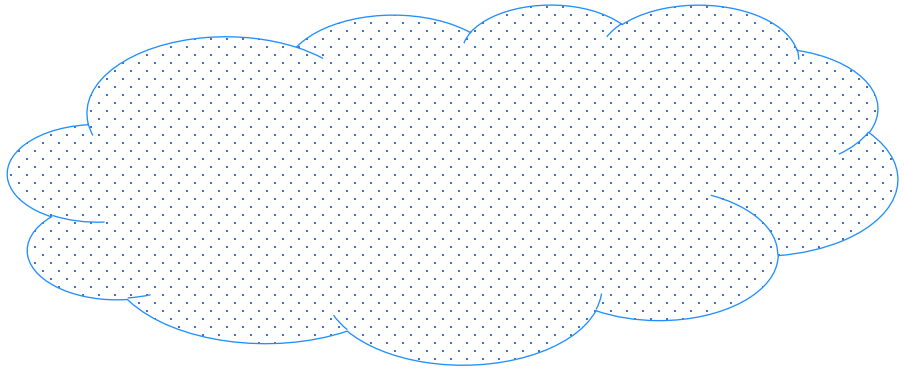
Reynolds Number
Laminar flow
Turbulent flow
UAVs
General Aviation


Mach Number
1
0.1
0.01
1E+3
1E+5
1E+7
1E+9
Reynolds Number
Wind Turbines
Jets
General
Aviation
UAVs

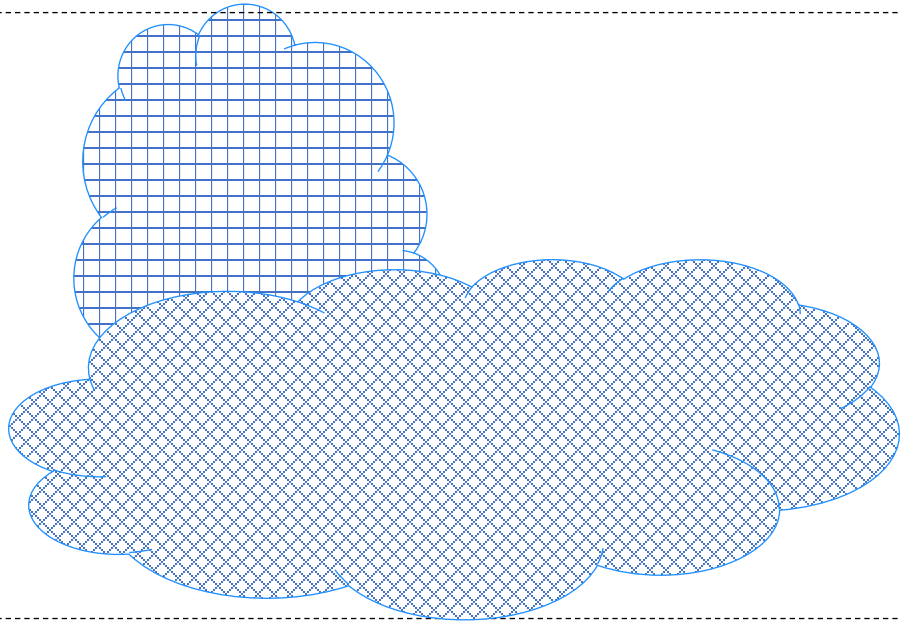
Validation of Numerical Tools

Validation of Numerical Tools

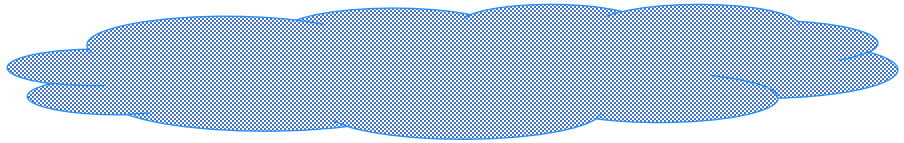

Aero-
dynamics
Icing
forecasting
Synergies



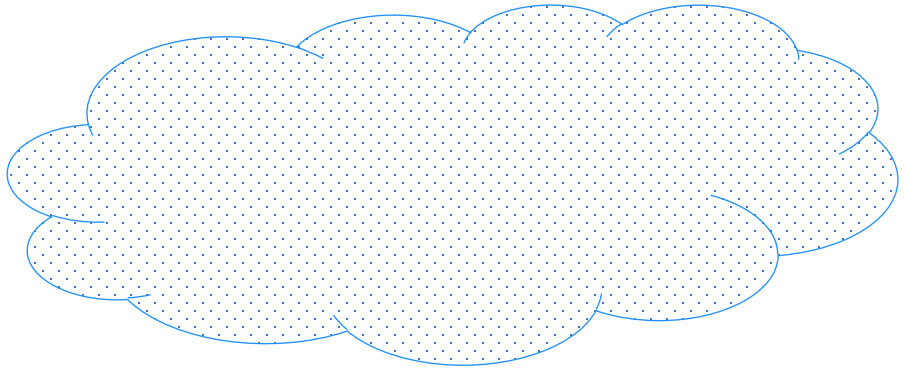
30,000ft



500ft



Ground



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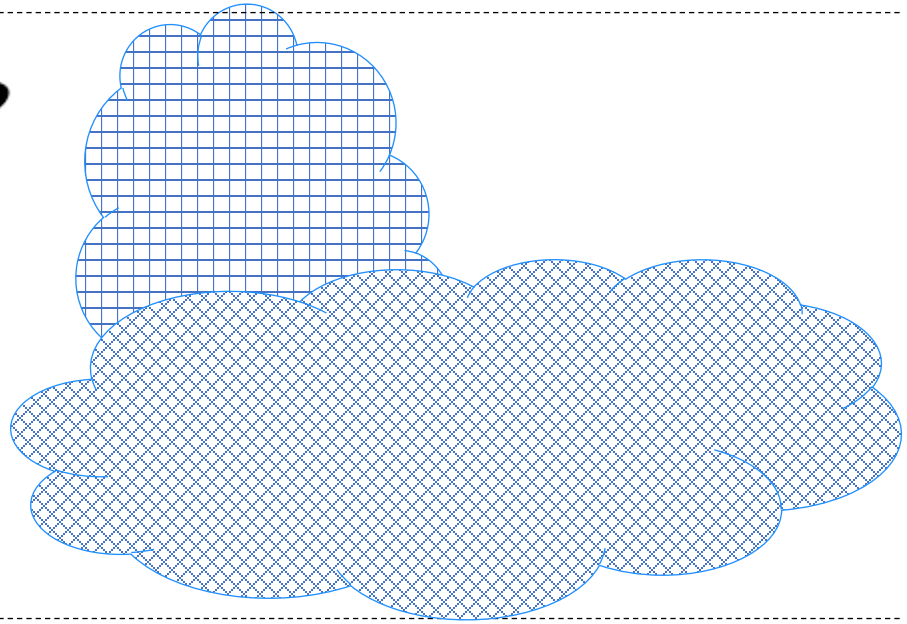
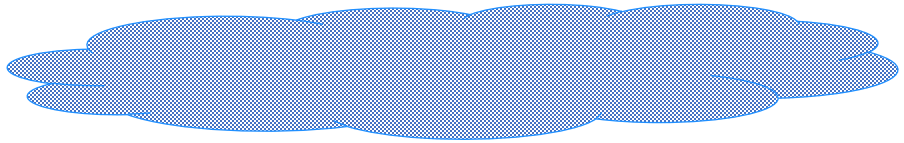
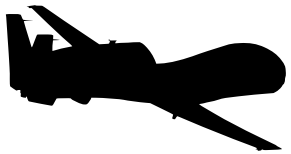
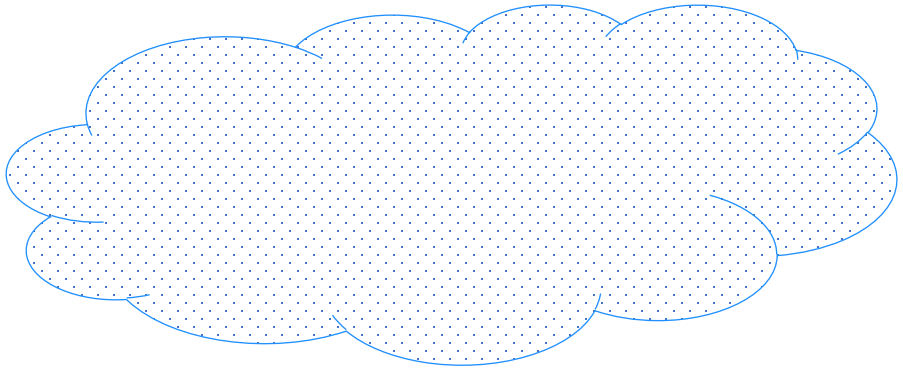


500ft

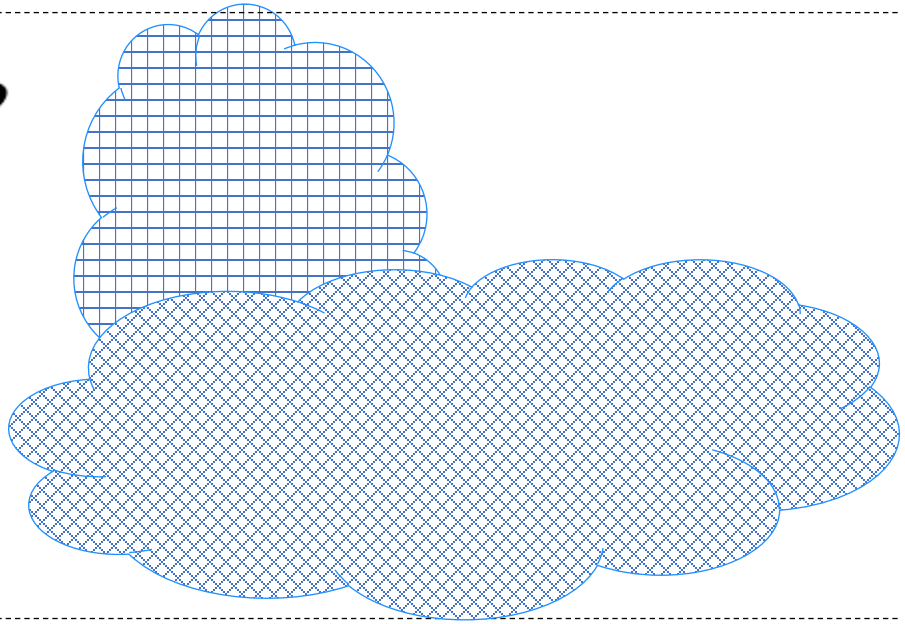


Ground



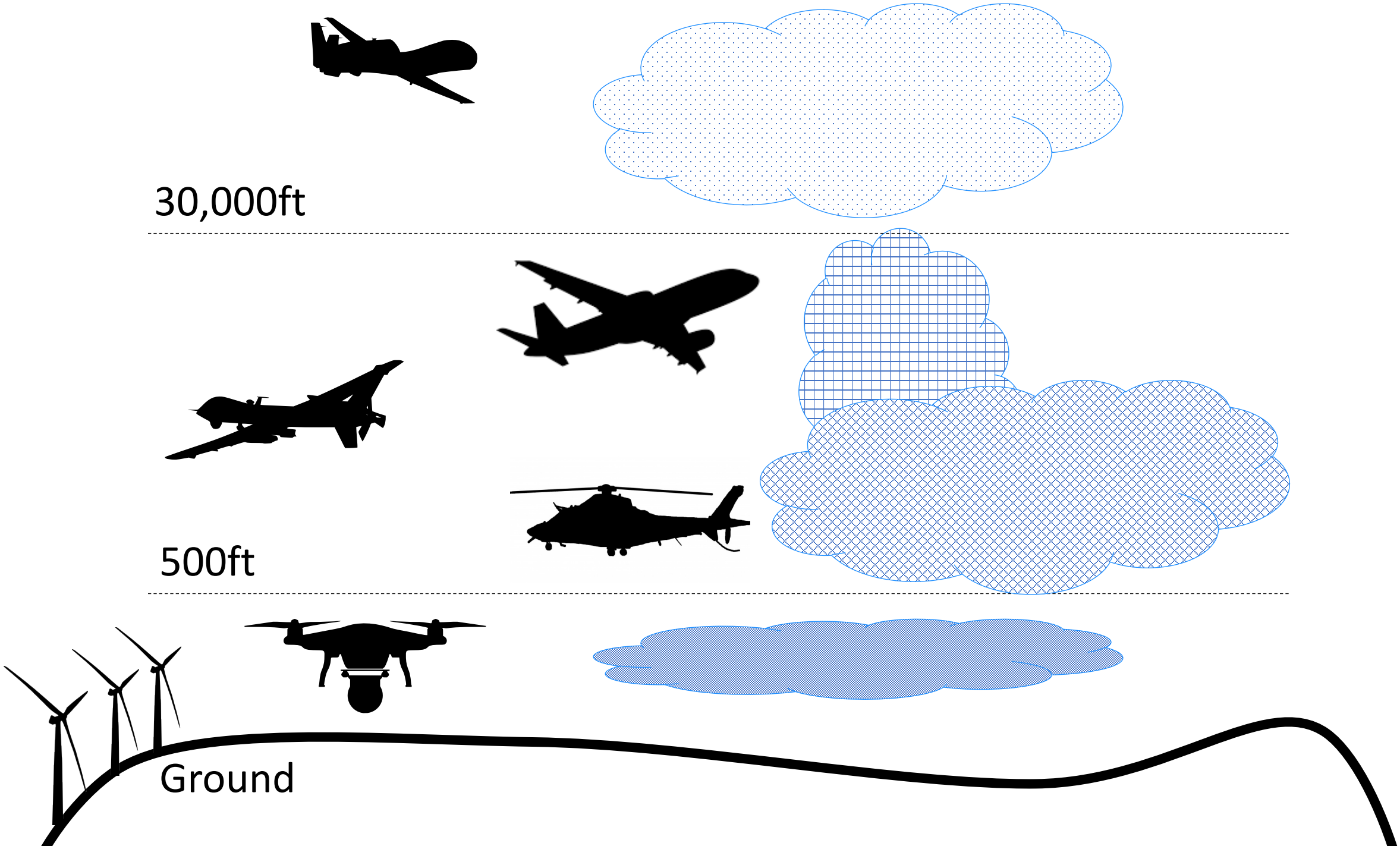


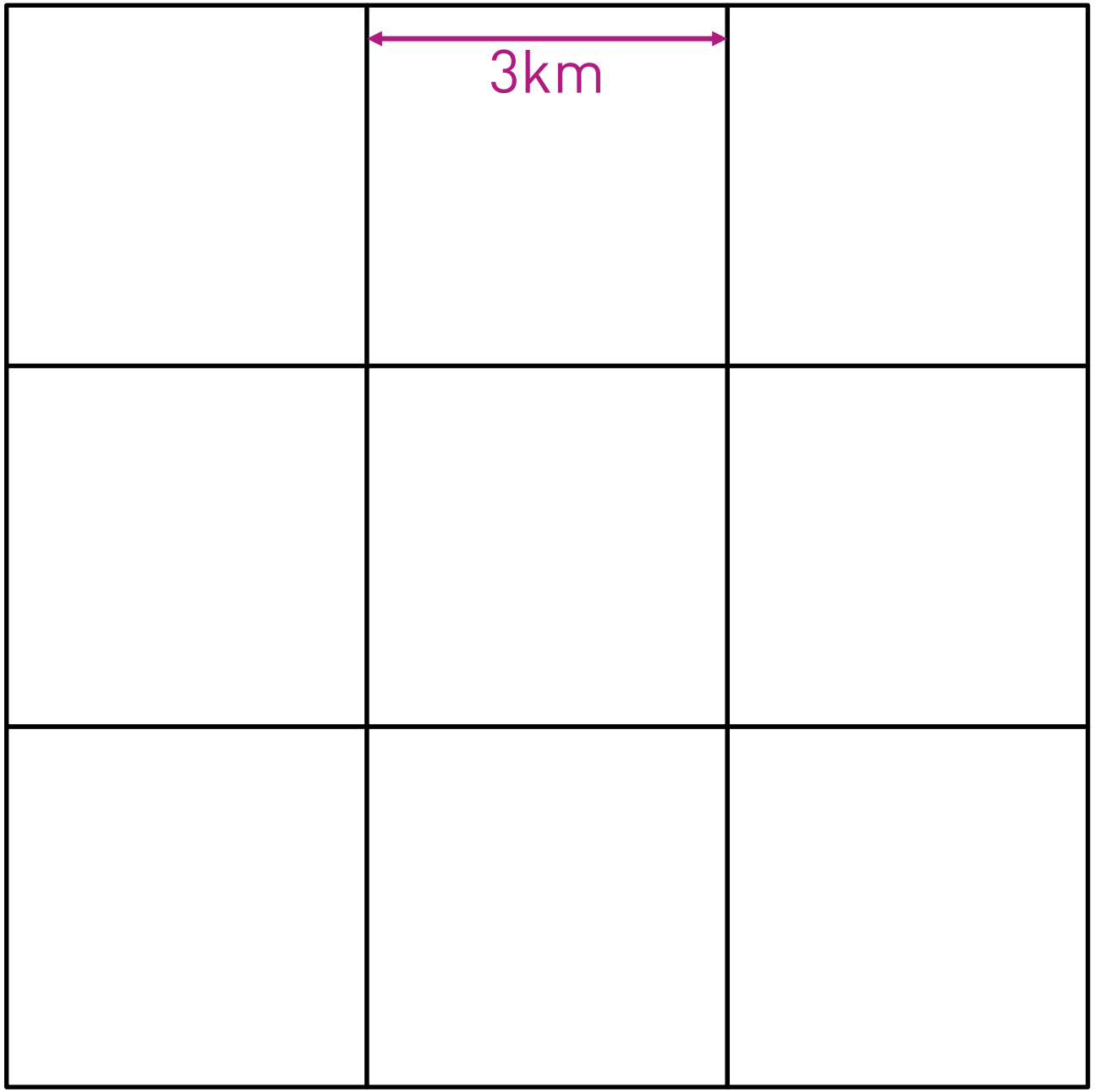
30,000ft

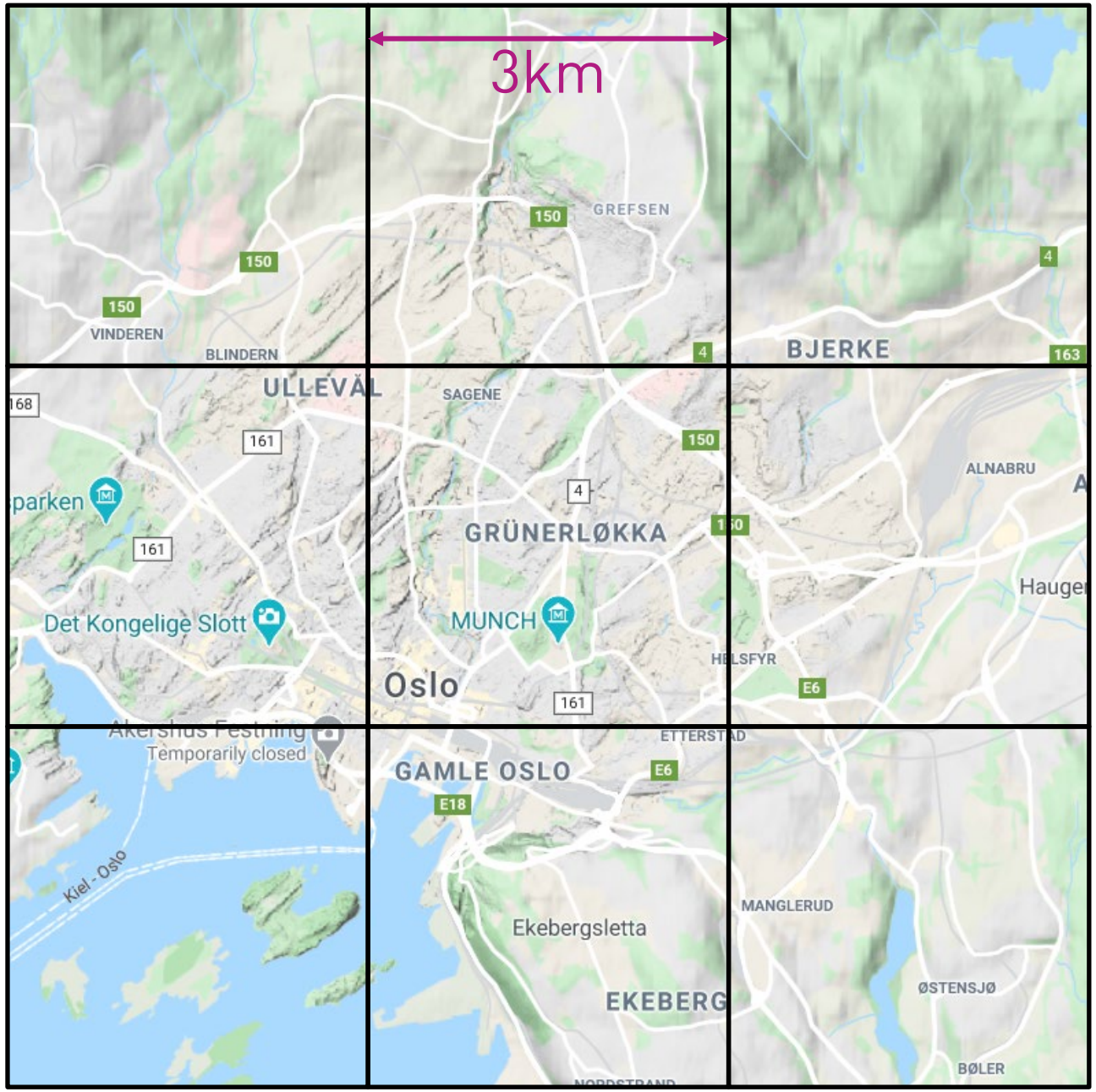


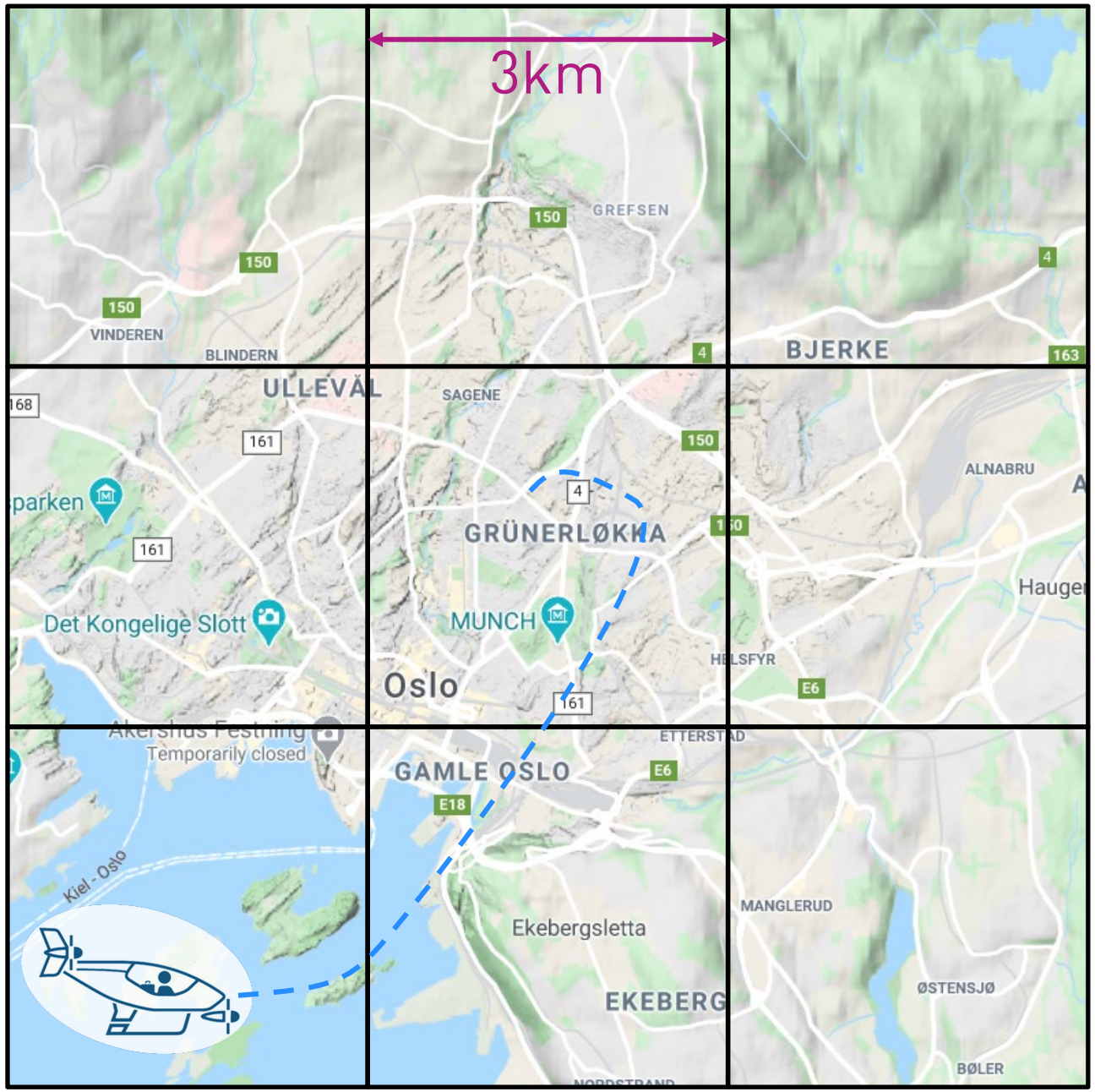
500ft

Ground


30,000ft
500ft
Ground


3km


3km
150
GREFSEN
4
BJERKE
163
VINDEREN
BLINDERN
ULLEVÅL
168
161
SAGENE
GRÜNERLØKKA
MUNCH
Oslo
Det Kongelige Slott
ALNABRU
HELSFYR
E6
Akershus Festning
Temporarily closed
Kiel - Oslo
GAMLE OSLO
E18
ETTERSTAD
Ekebergsletta
EKEBERG
MANGLERUD
ØSTENSJØ
BØLER


3km
150
VINDEREN
BLINDERN
GREFSEN
4
BJERKE
163
ULLEVÅL
168
161
SAGENE
GRÜNERLØKKA
MUNCH
Oslo
Det Kongelige Slott
ALNABRU
HELSFYR
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Akershus Festning
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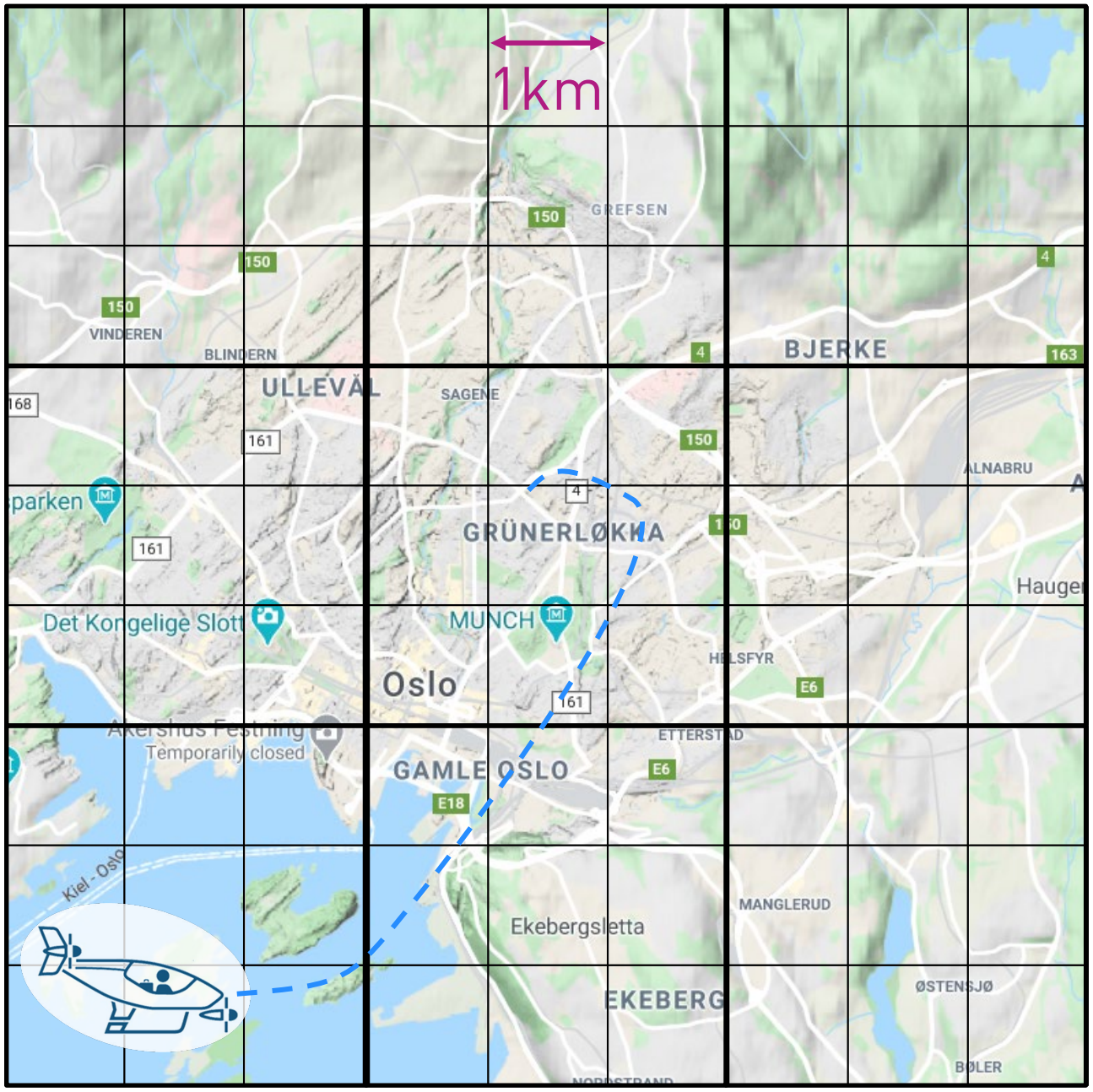
Kiel - Oslo
GAMLE OSLO
E18
ETTERSTAD
Ekebergsletta
EKEBERG
MANGLERUD
ØSTENSJØ
BØLER


1km
GREFSEN
150
VINDEREN
BLINDERN
BJERKE
4
163
ULLEVÅL
SAGENE
168
161
ALNABRU
GRÜNERLØKKA
MUNCH
Det Kongelige Slott
HELSFYR
E6
Oslo
Akershus Festning
Temporarily closed
ETTERSTAD
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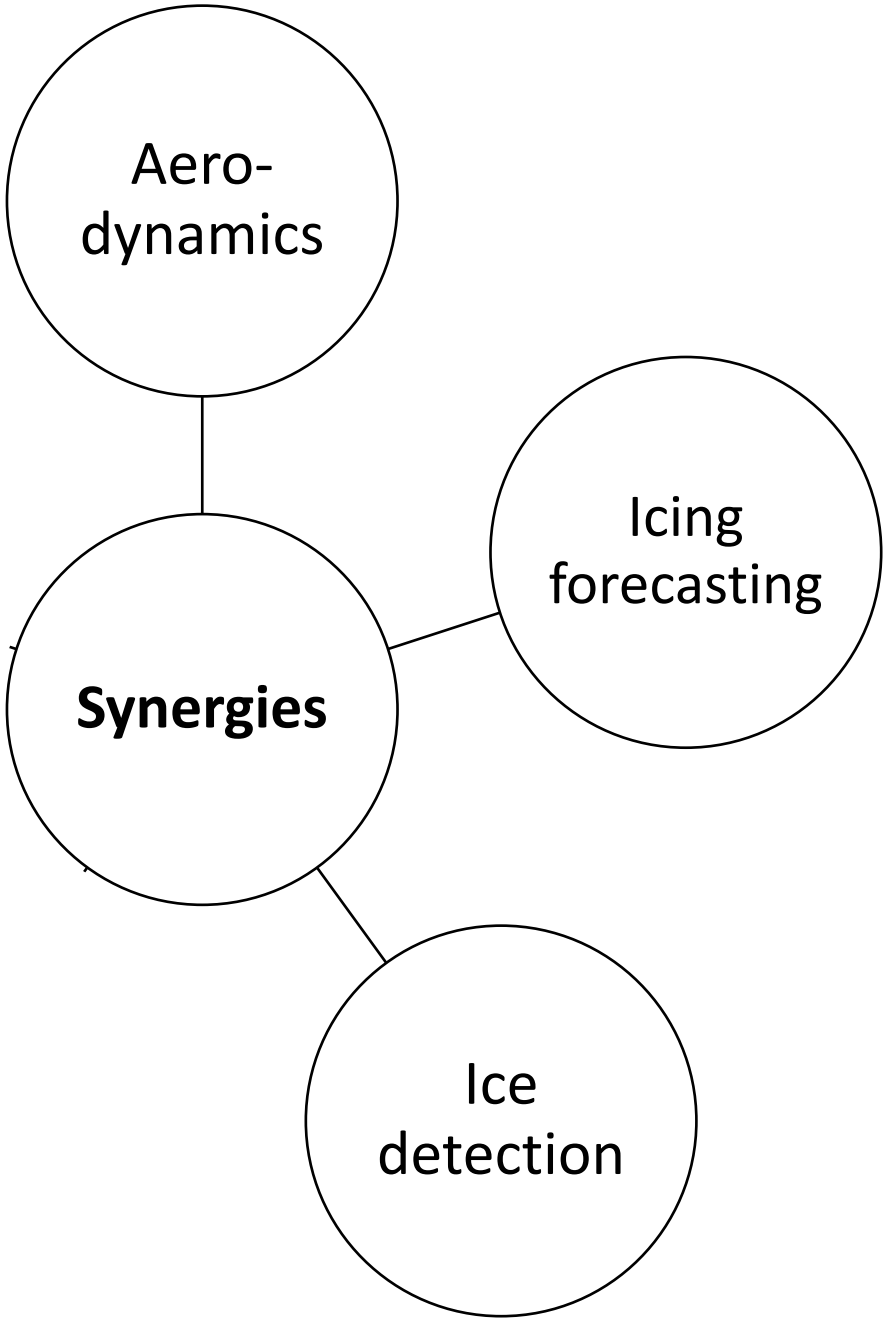
MANGLERUD
EKEBERG
ØSTENSJØ
BØLER

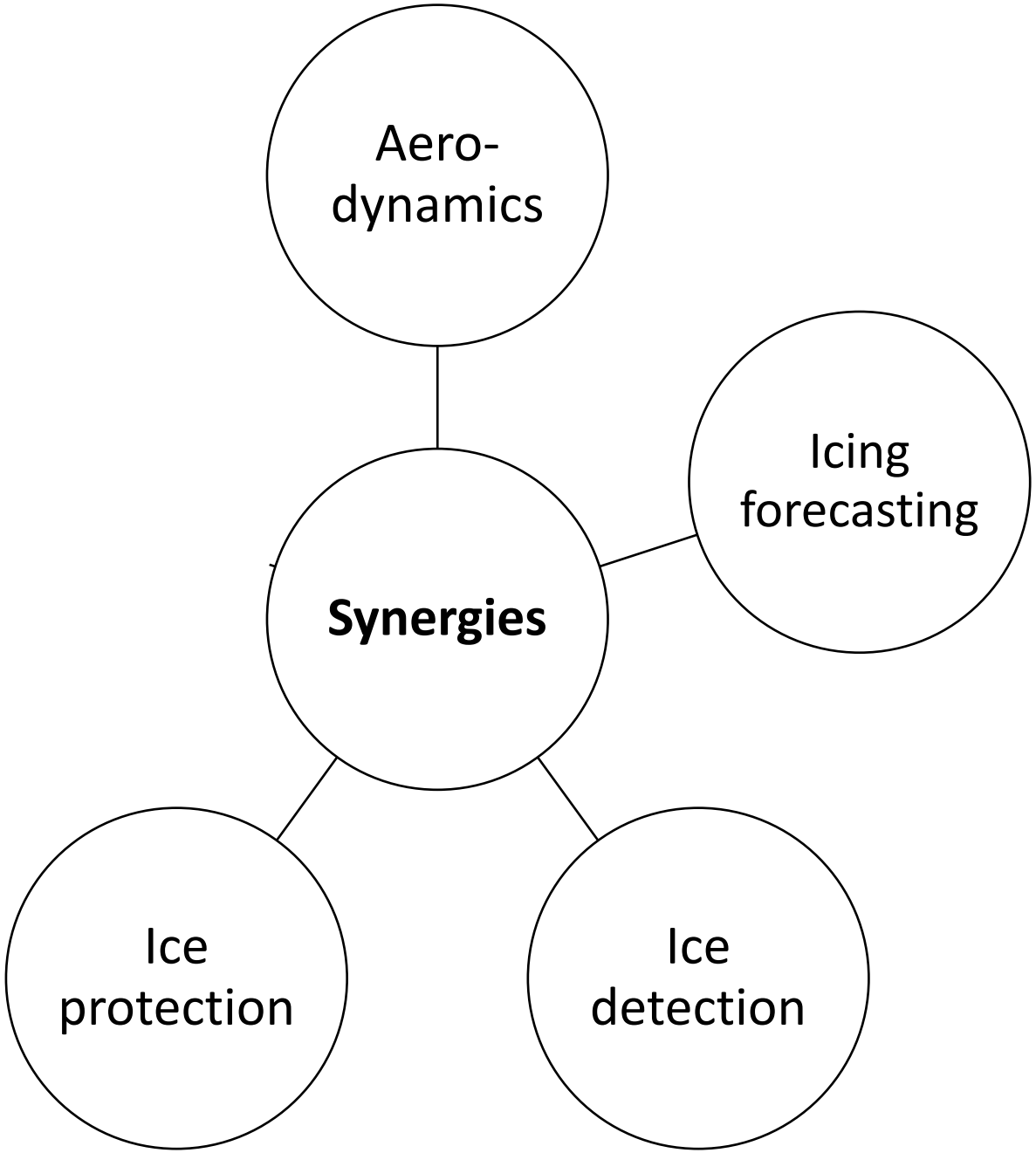

Aero-
dynamics
Icing
forecasting
Synergies
Ice
detection

Requirements

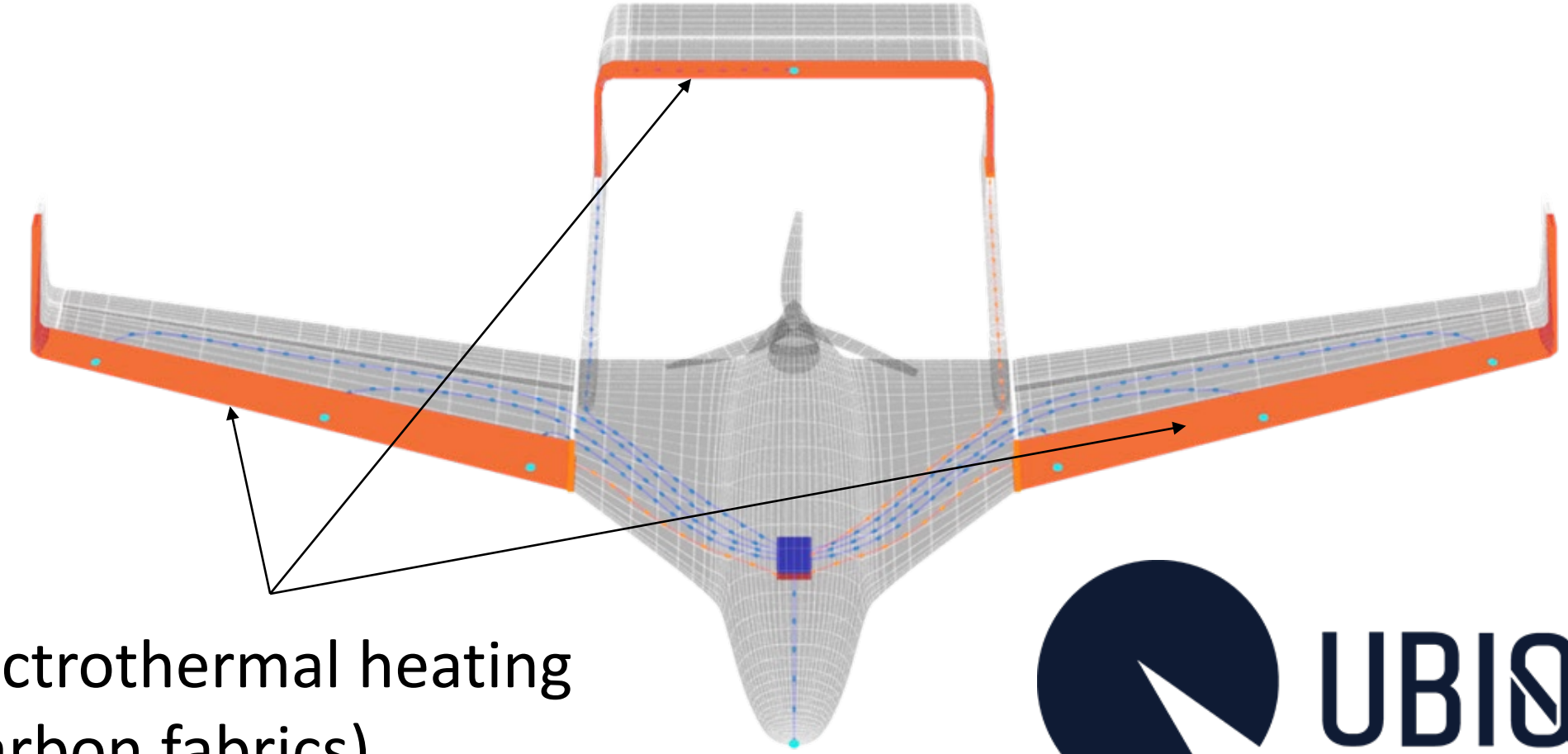
- Autonomous
- Sensitivity
- Accuracy
- Weight

Requirements

- Autonomous
- Sensitivity
- Accuracy
- Weight

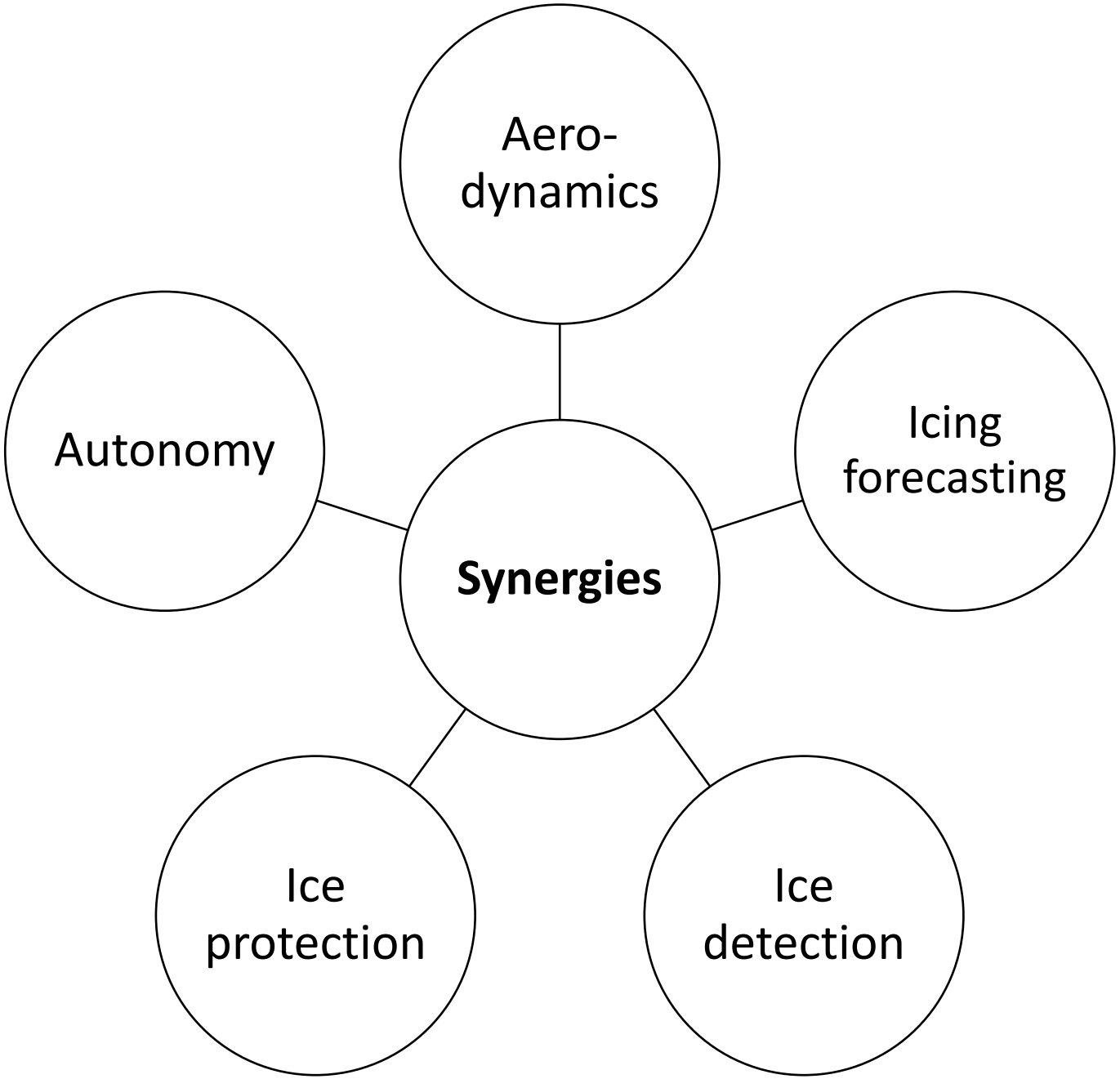

Aero-
dynamics
Icing
forecasting
Synergies
Ice
protection
Ice
detection

Ice Protection System



Electrothermal heating
(Carbon fabrics)

UBIQ Aerospace


Aero-
dynamics
Autonomy
Icing
forecasting
Synergies
Ice
protection
Ice
detection

Smart Algorithms

- Performance based ice detection
- System identification
- Optimized ice protection

Contributions

NTNU

- Icing on UAV propellers
- Ice protection systems
- Low-Reynolds icing simulations
- Icing forecasting for UAVs
- Smart ice detection systems
- Climatological studies

→ UAV Icing Lab (uavicinglab.com)