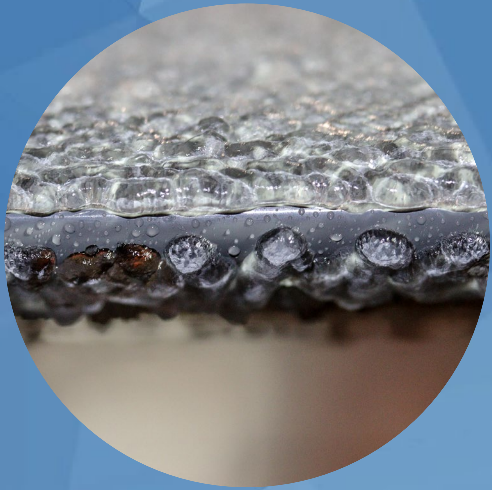
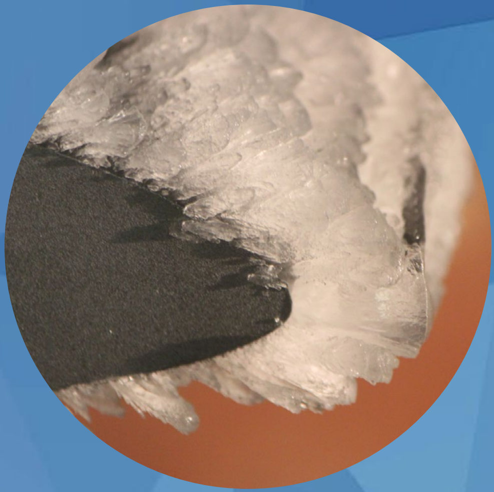
# ICING ON UAVs

Richard Hann / richard.hann@ntnu.no





NTNU
Norwegian University of Science and Technology

UBIQ Aerospace

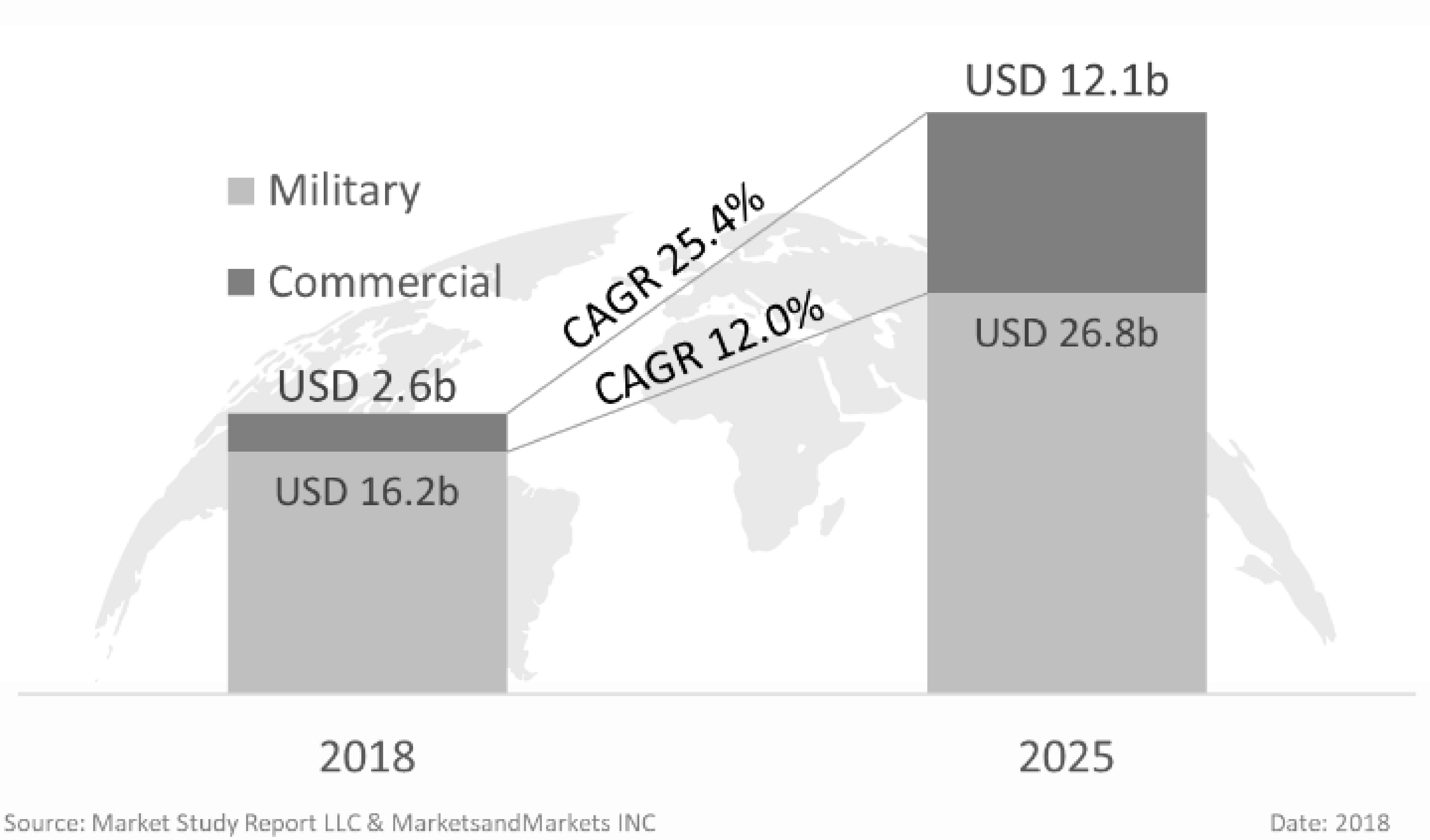

Richard Hann
PhD at NTNU
Icing expert
Unmanned aerial vehicles
Wind turbines
Drones in the Arctic
UBIQ Aerospace

# drone noun

/droʊn/

: an unmanned aircraft or ship guided by remote control or onboard computers

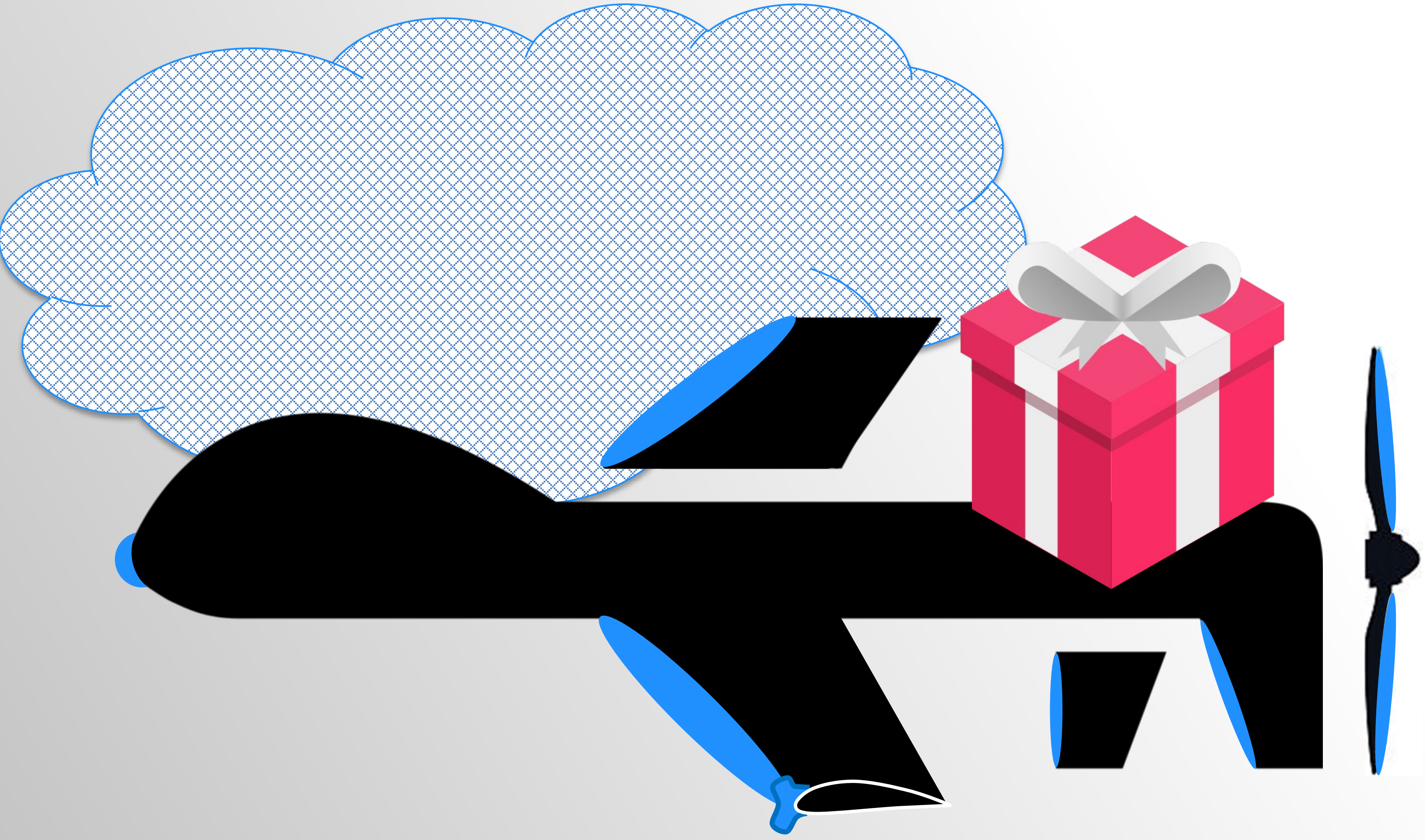
# Global UAV Market

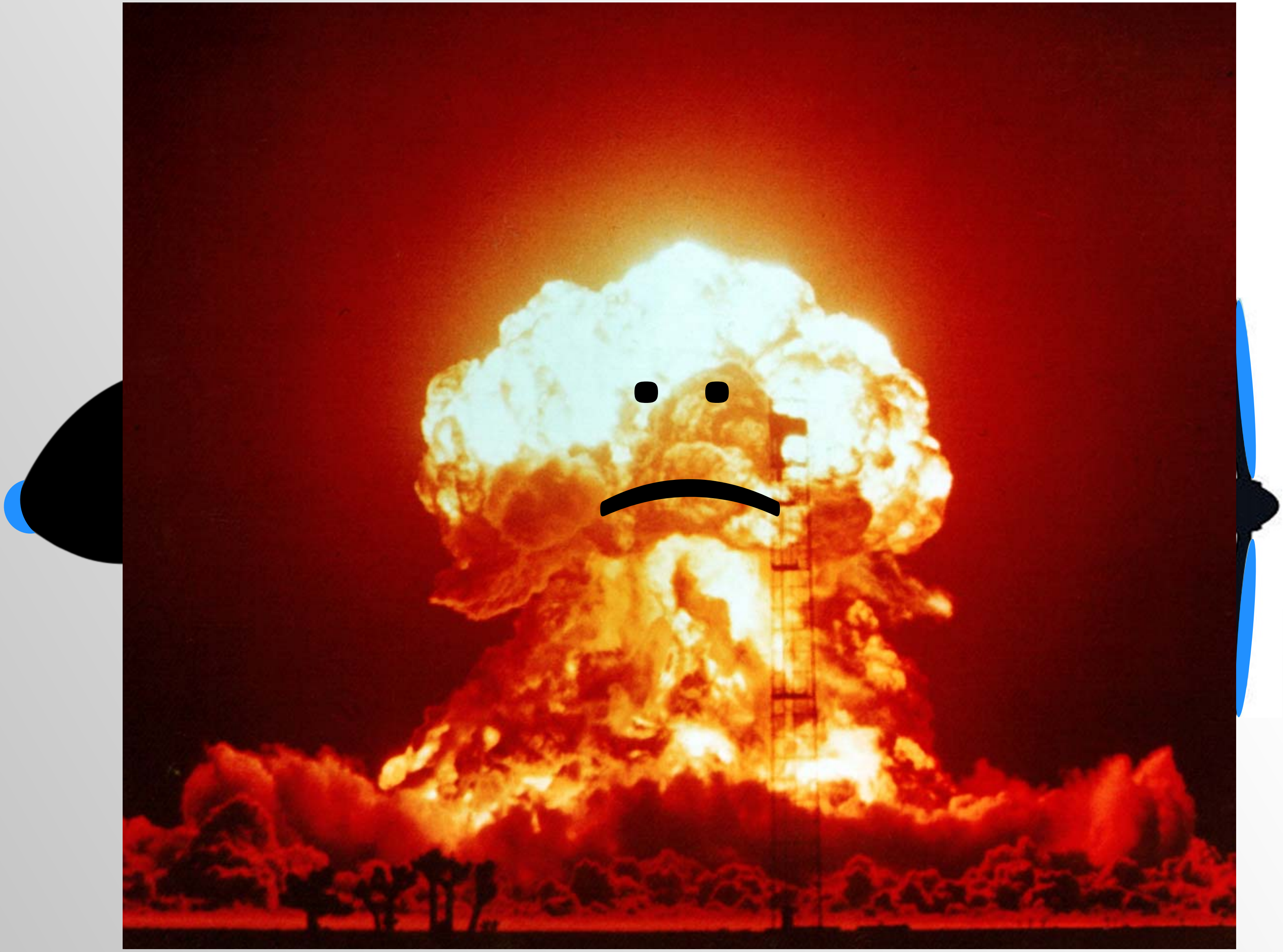


# Civil UAV Applications

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


PACKSET
M
M
DHL
DHL
md4-1000
DHL
DHL

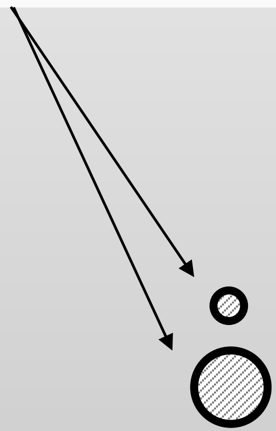




# ATMOSPHERIC ICING

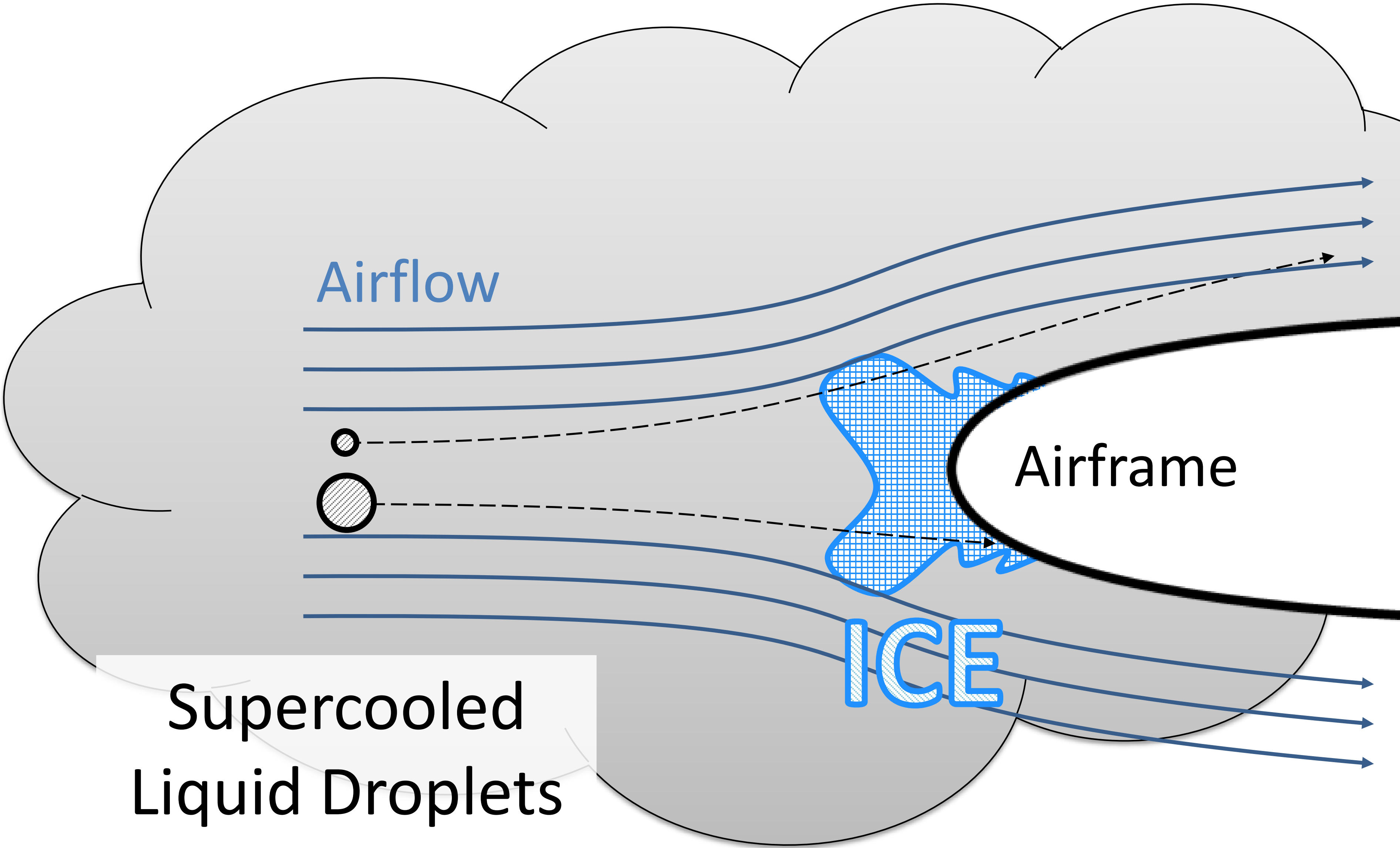
MVD: Median (drop) volume diameter

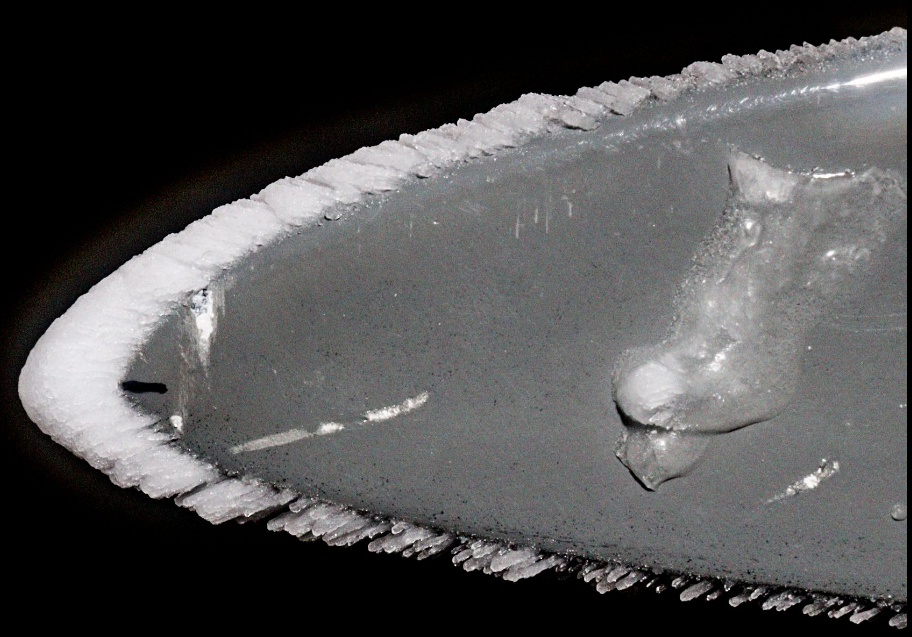
LWC: Liquid water content



Supercooled Liquid Droplets

# Atmospheric Icing





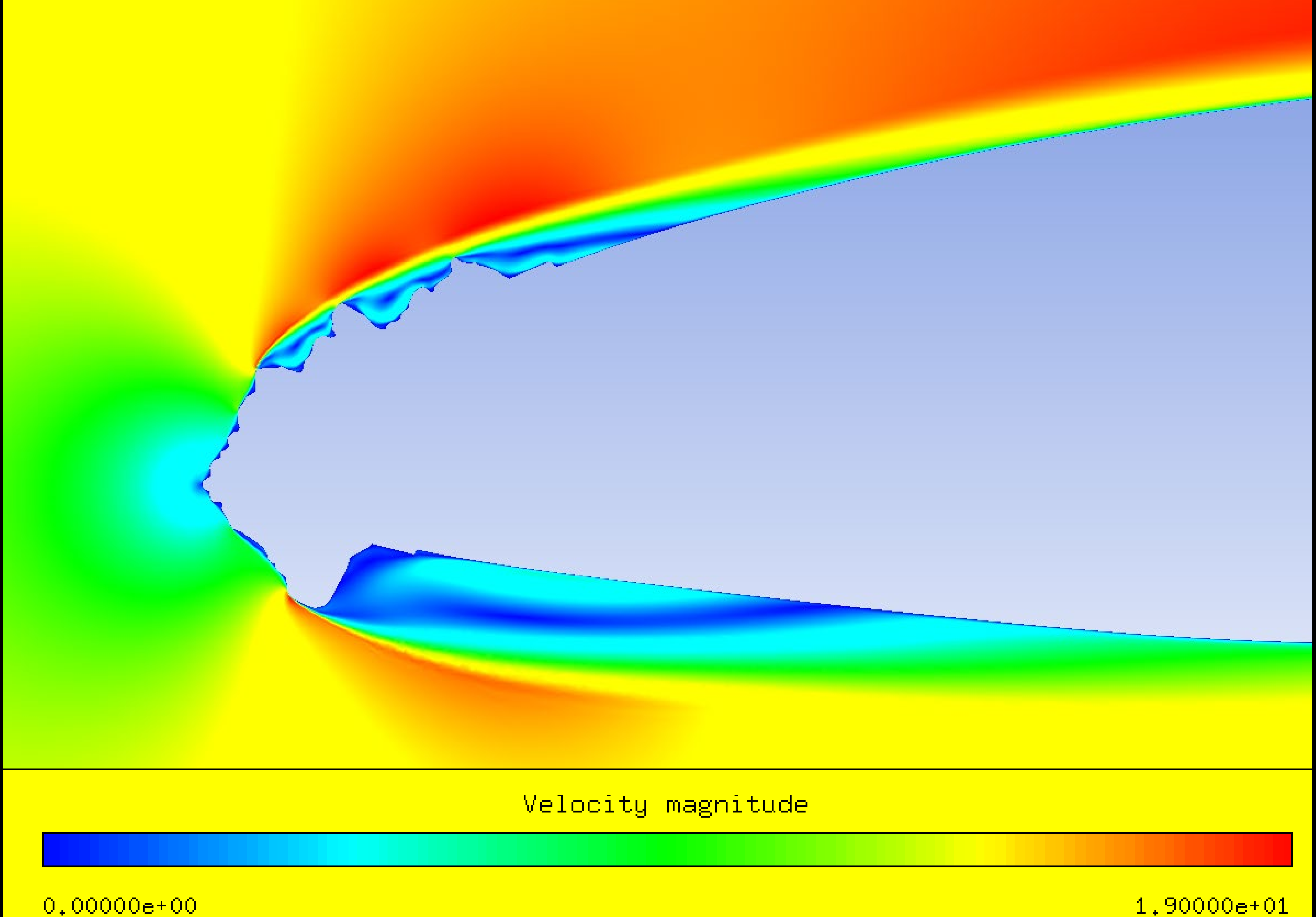
Rime: T<<0°C

Glaze: T≈0°C

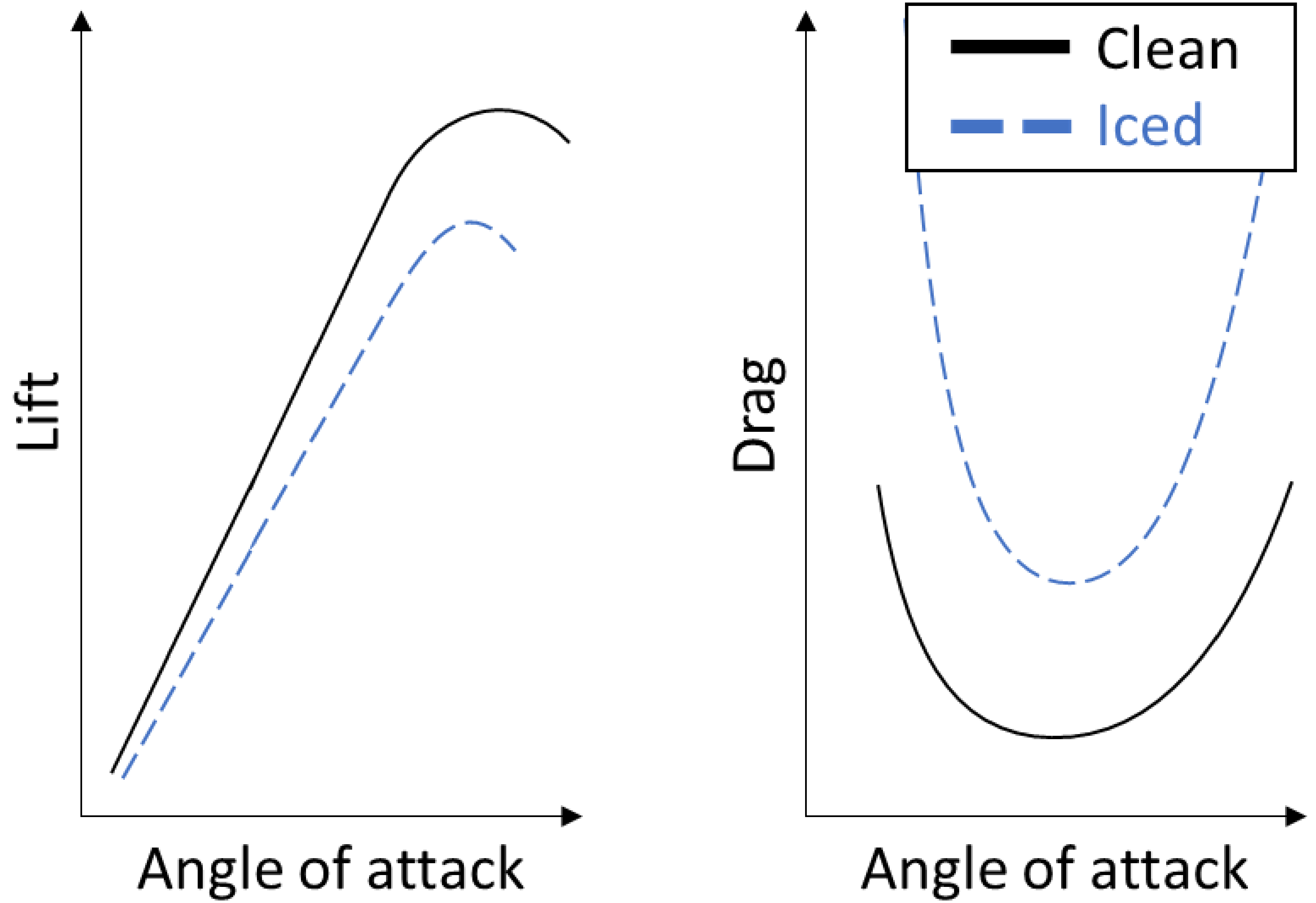

Rime Icing


Glaze Icing

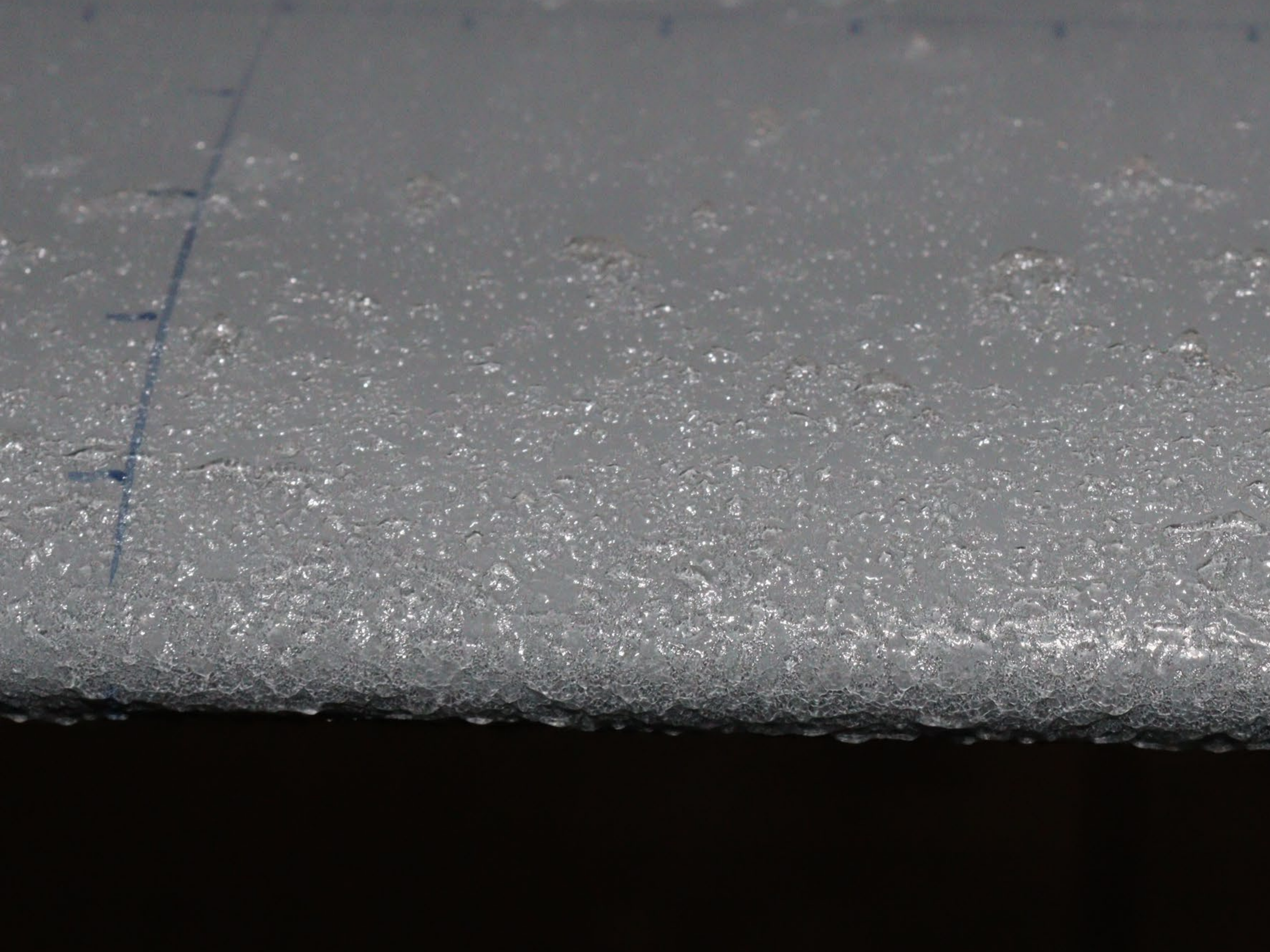
# ICING EFFECTS



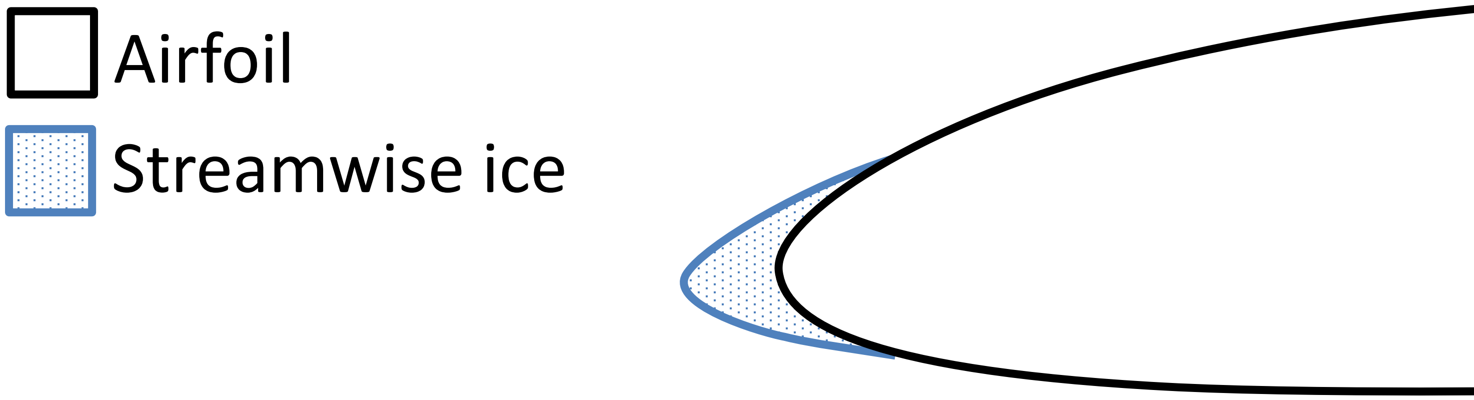
# ICING EFFECTS



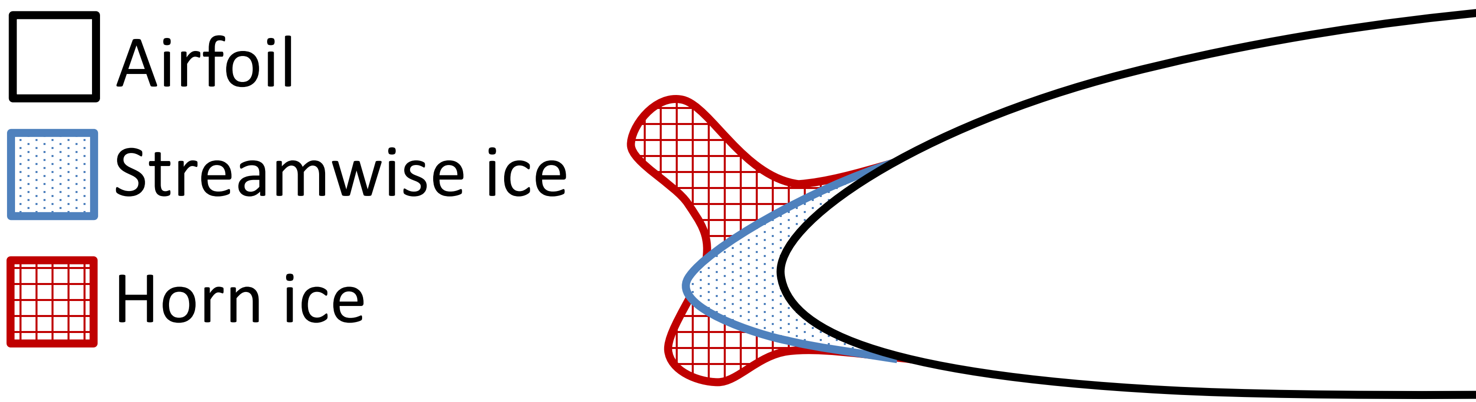
# Ice Morphologies



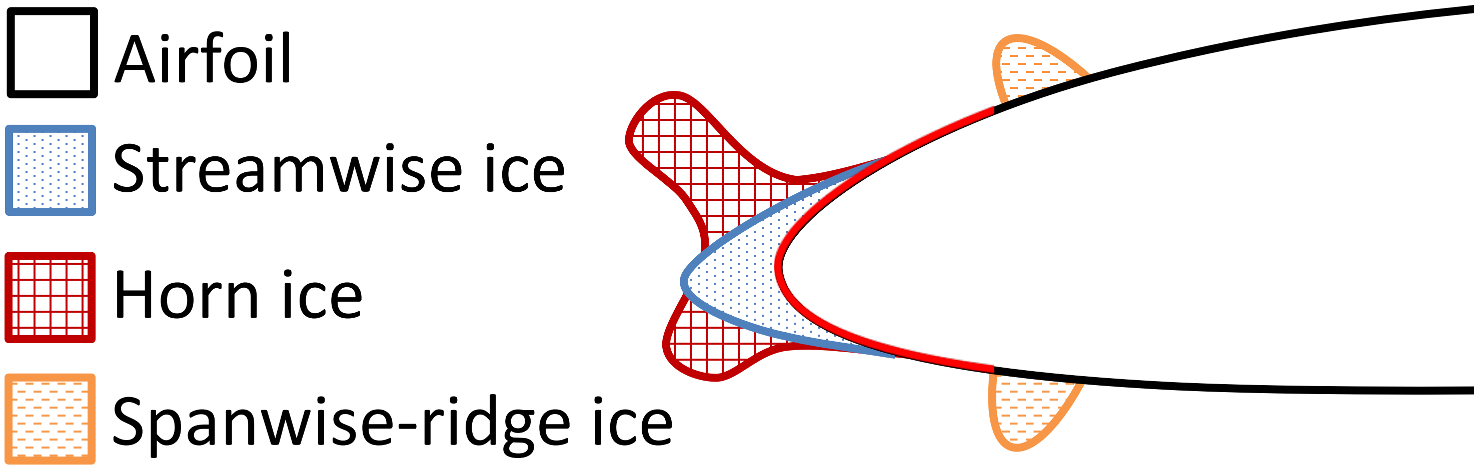
# Ice Morphologies

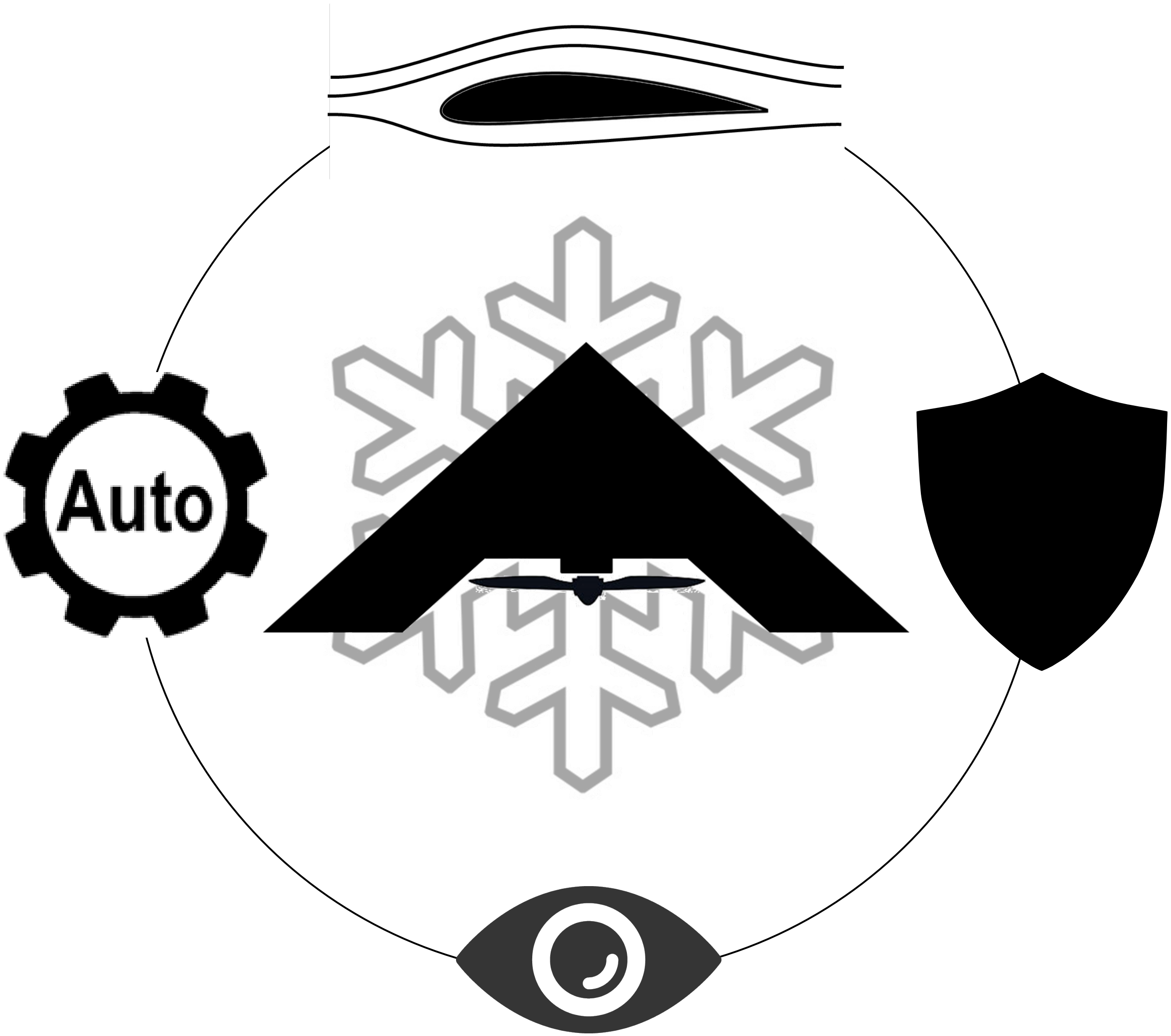


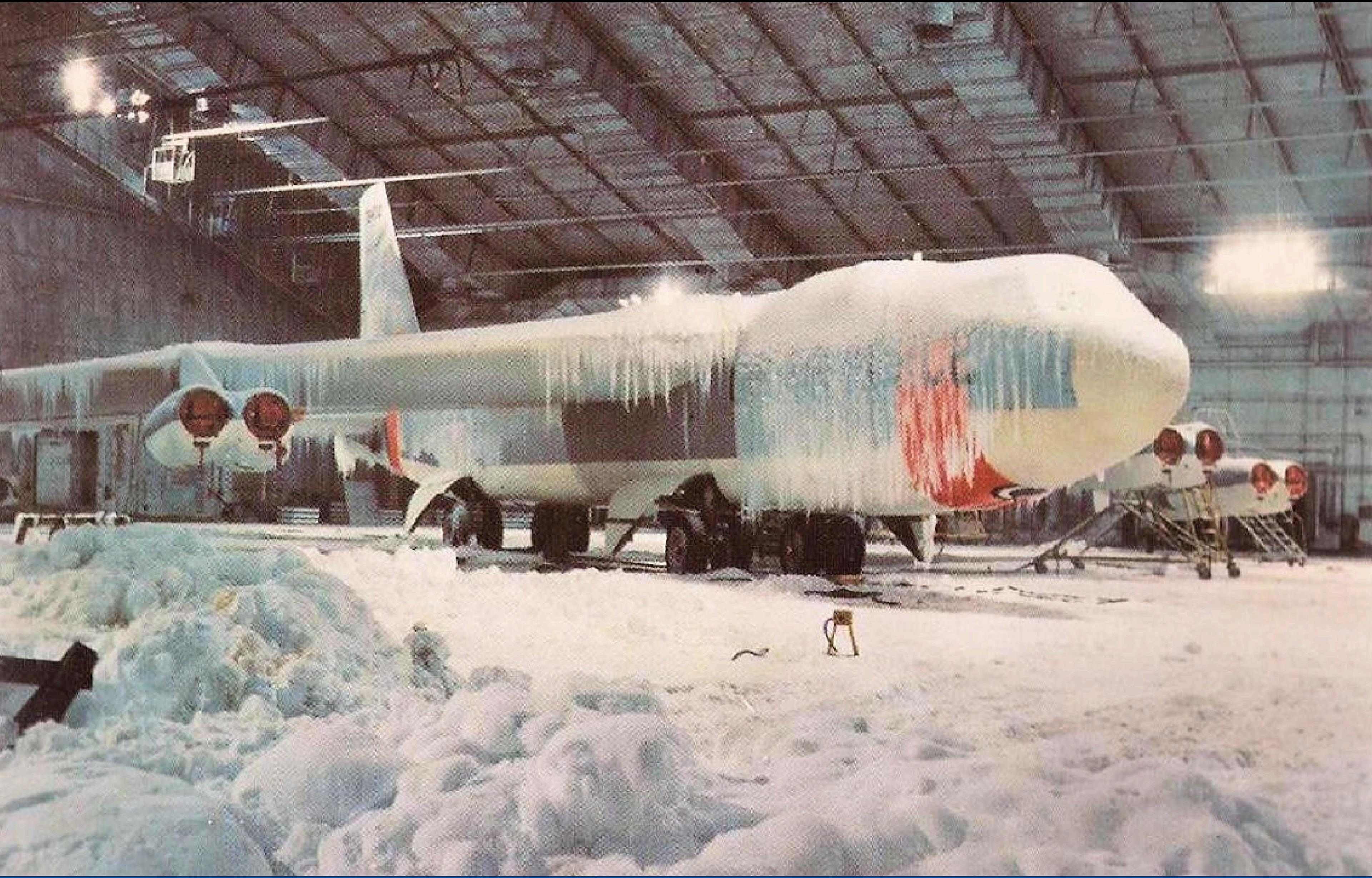
# Ice Morphologies



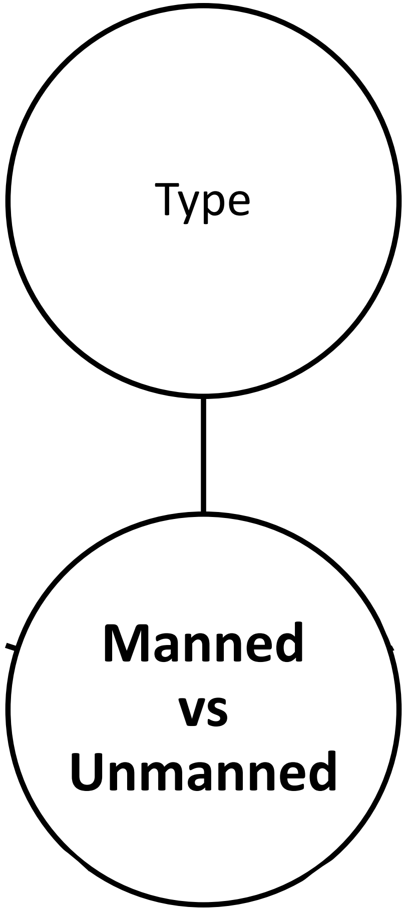
# Ice Morphologies

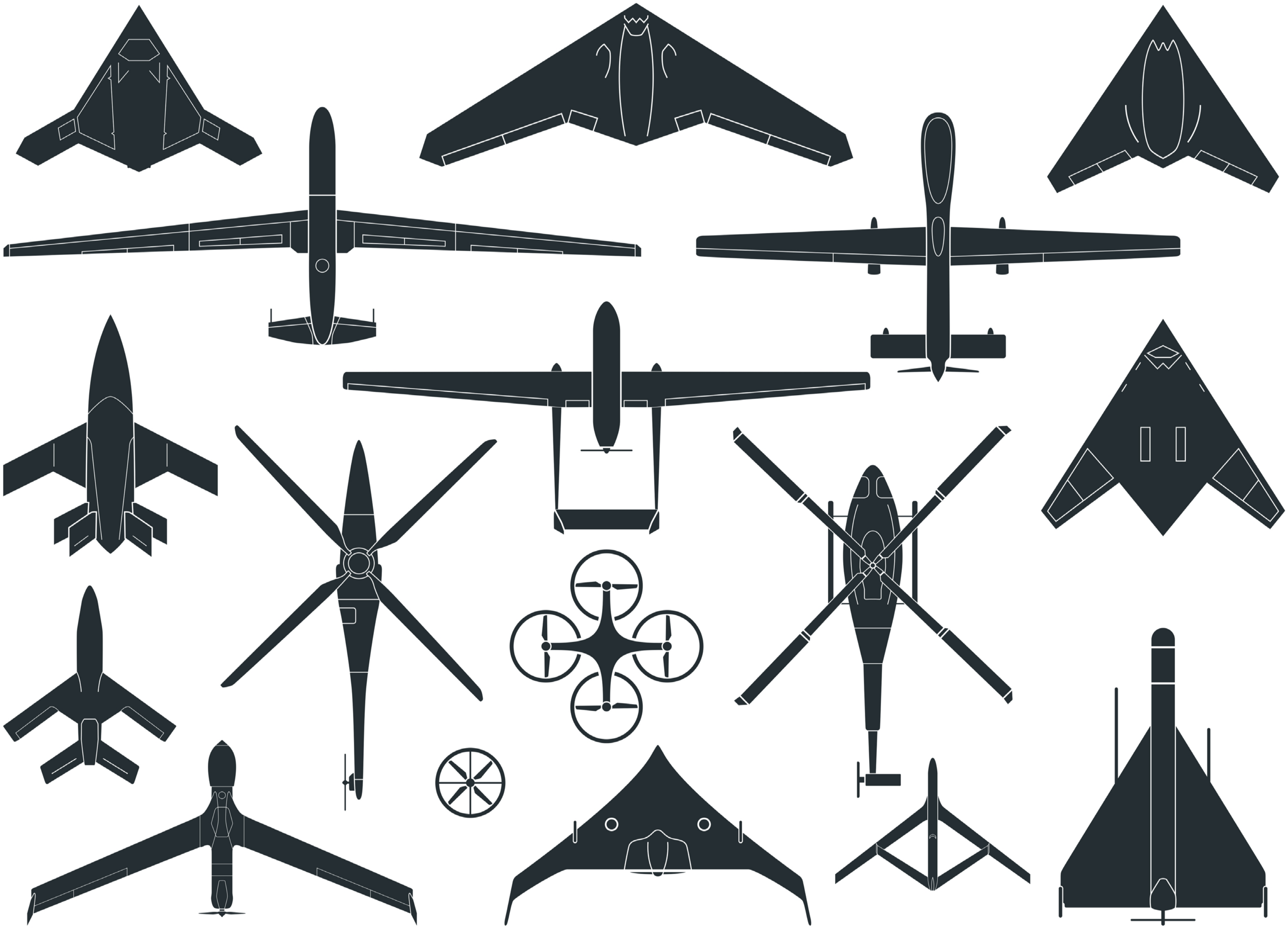



Auto

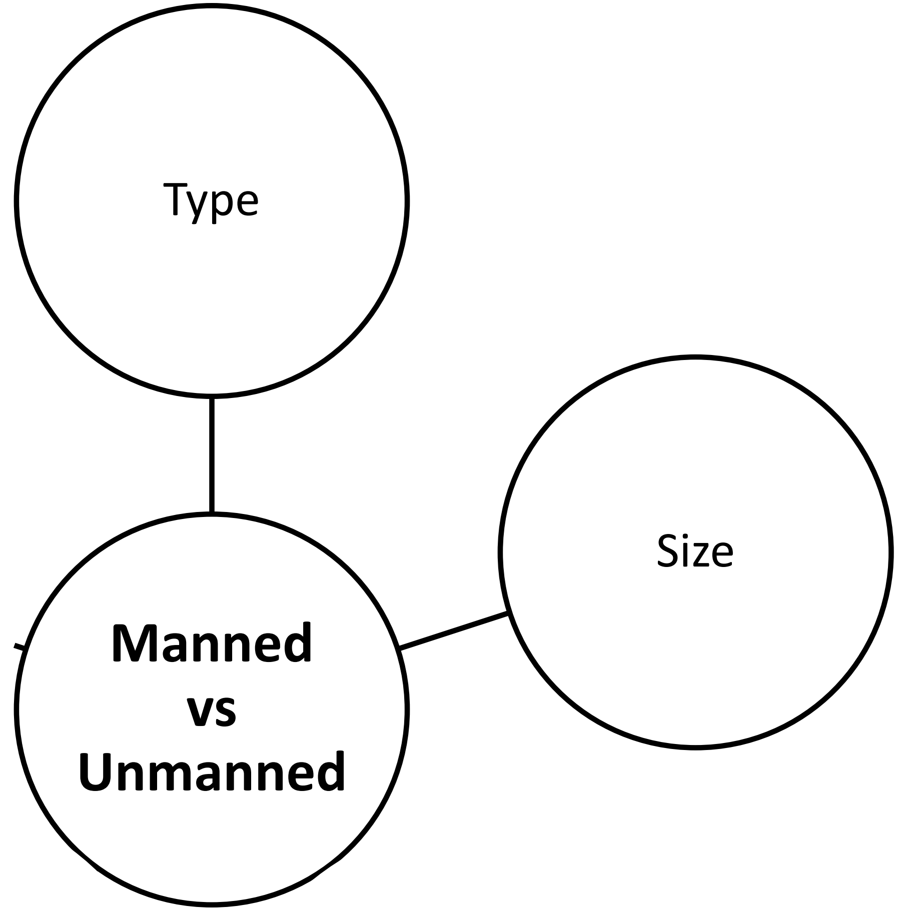


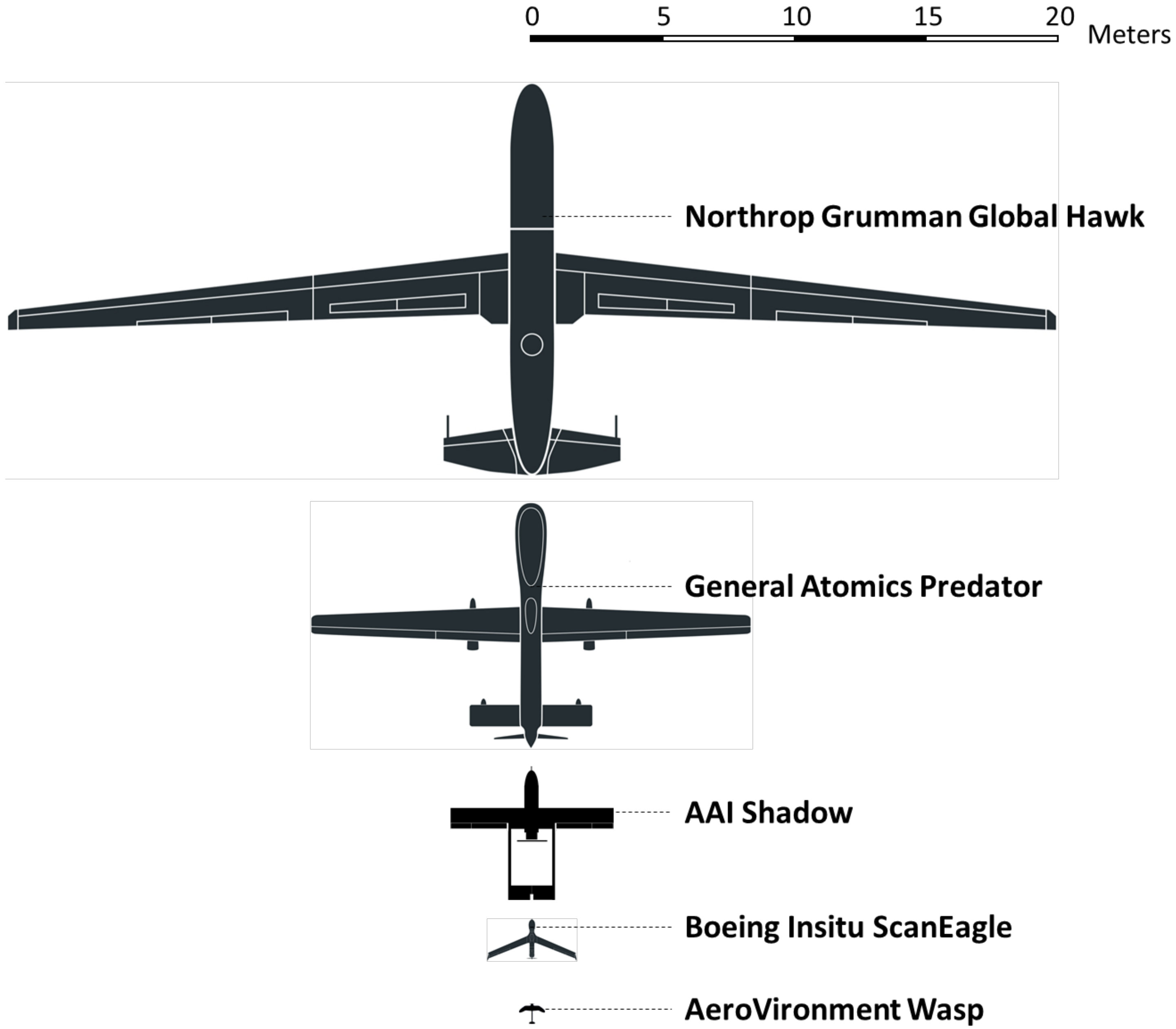
**Manned**
**vs**
**Unmanned**


Type
Manned
vs
Unmanned



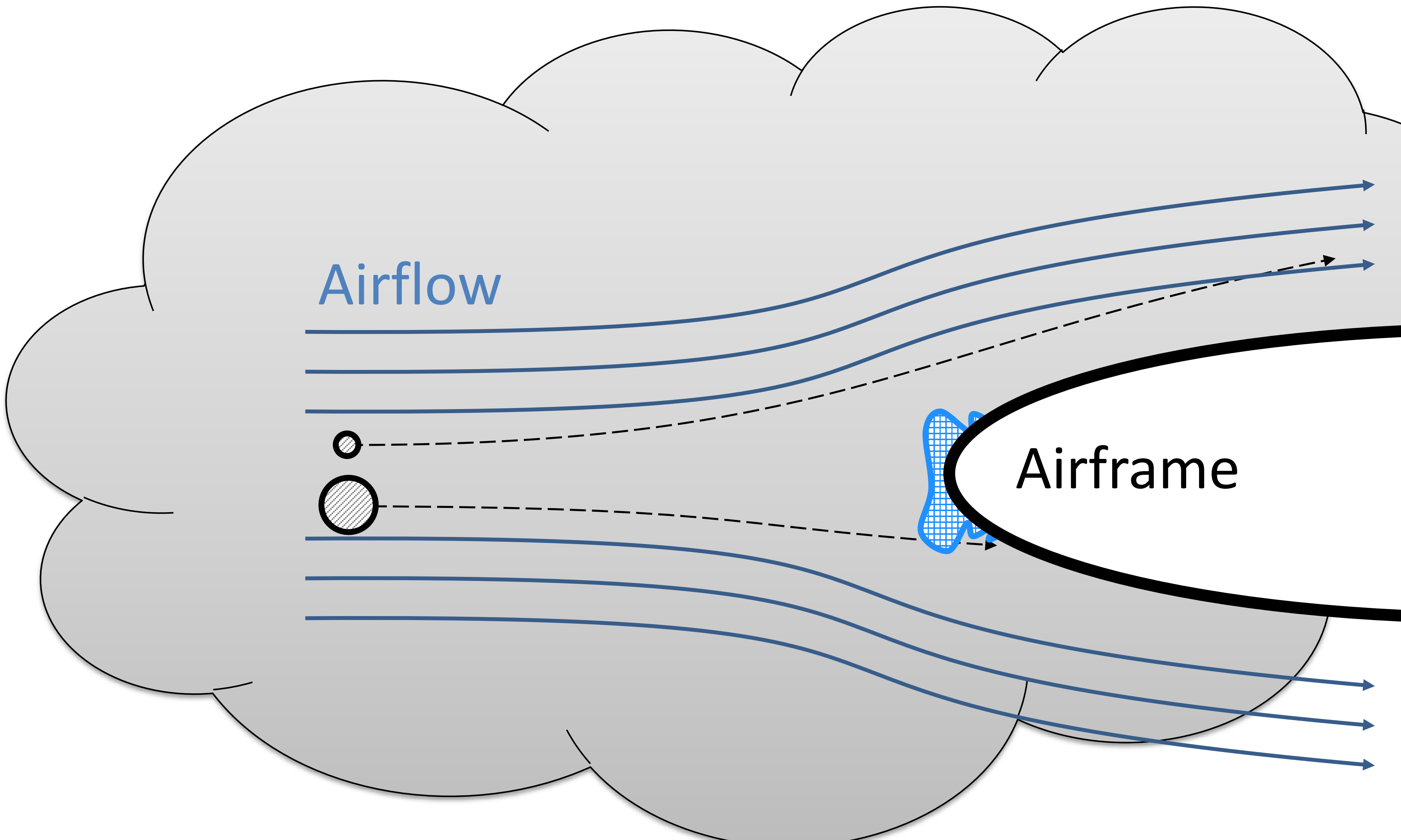

Source: Meteomatics


Type
Size
Manned
vs
Unmanned

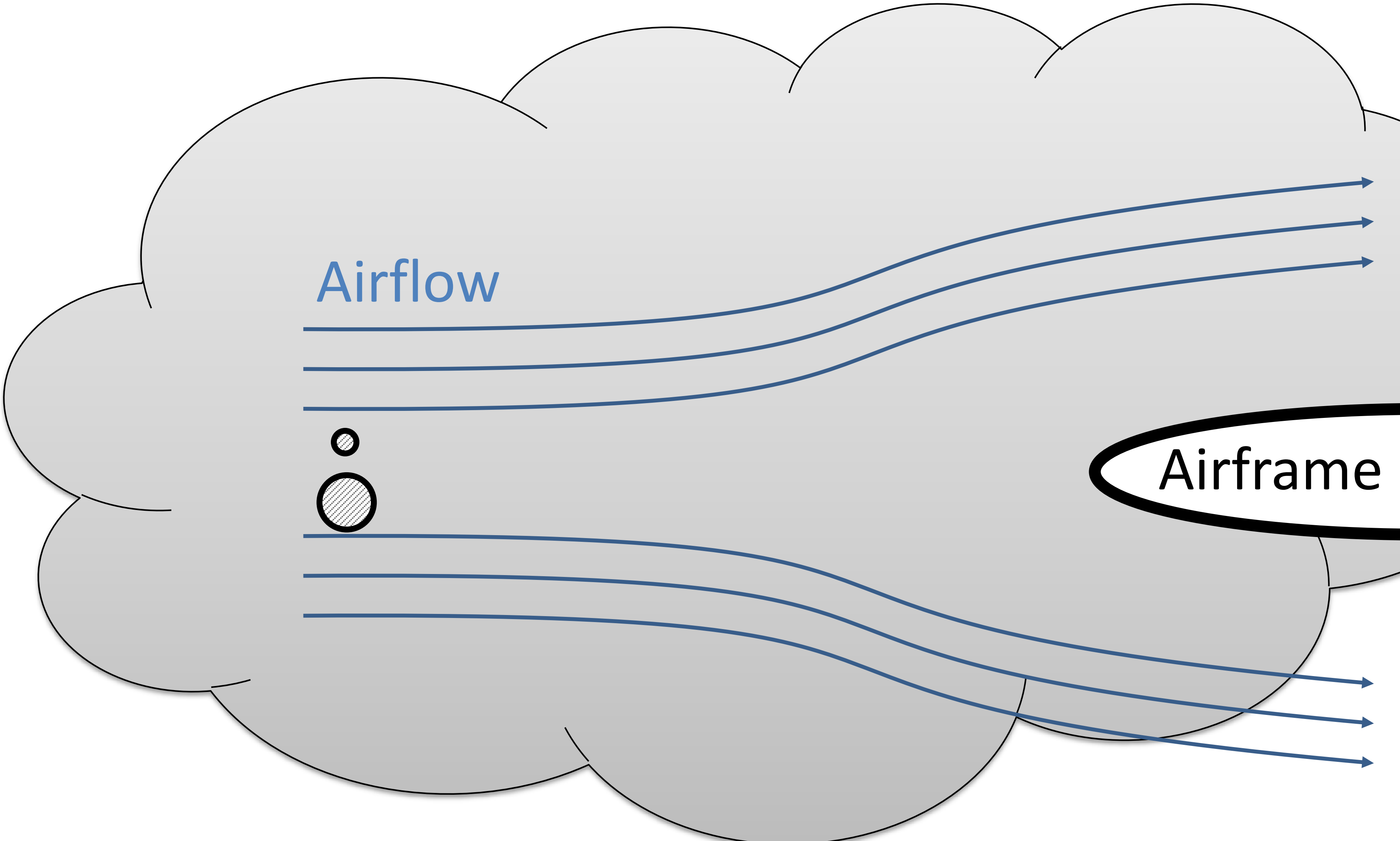


0
5
10
15
20
Meters
Northrop Grumman Global Hawk
General Atomics Predator
AAI Shadow
Boeing Insitu ScanEagle
AeroVironment Wasp

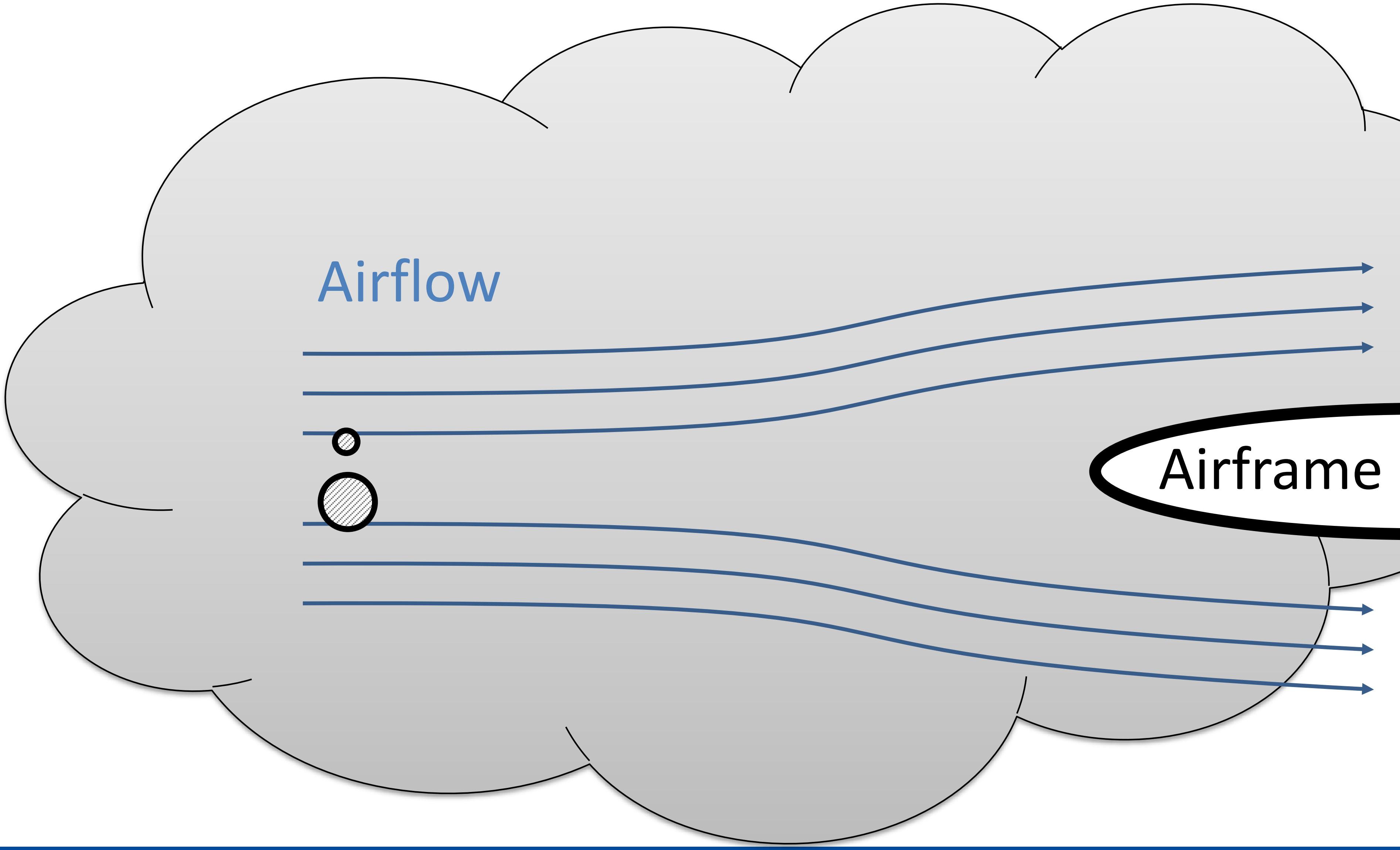
# INFLUENCE OF SIZE



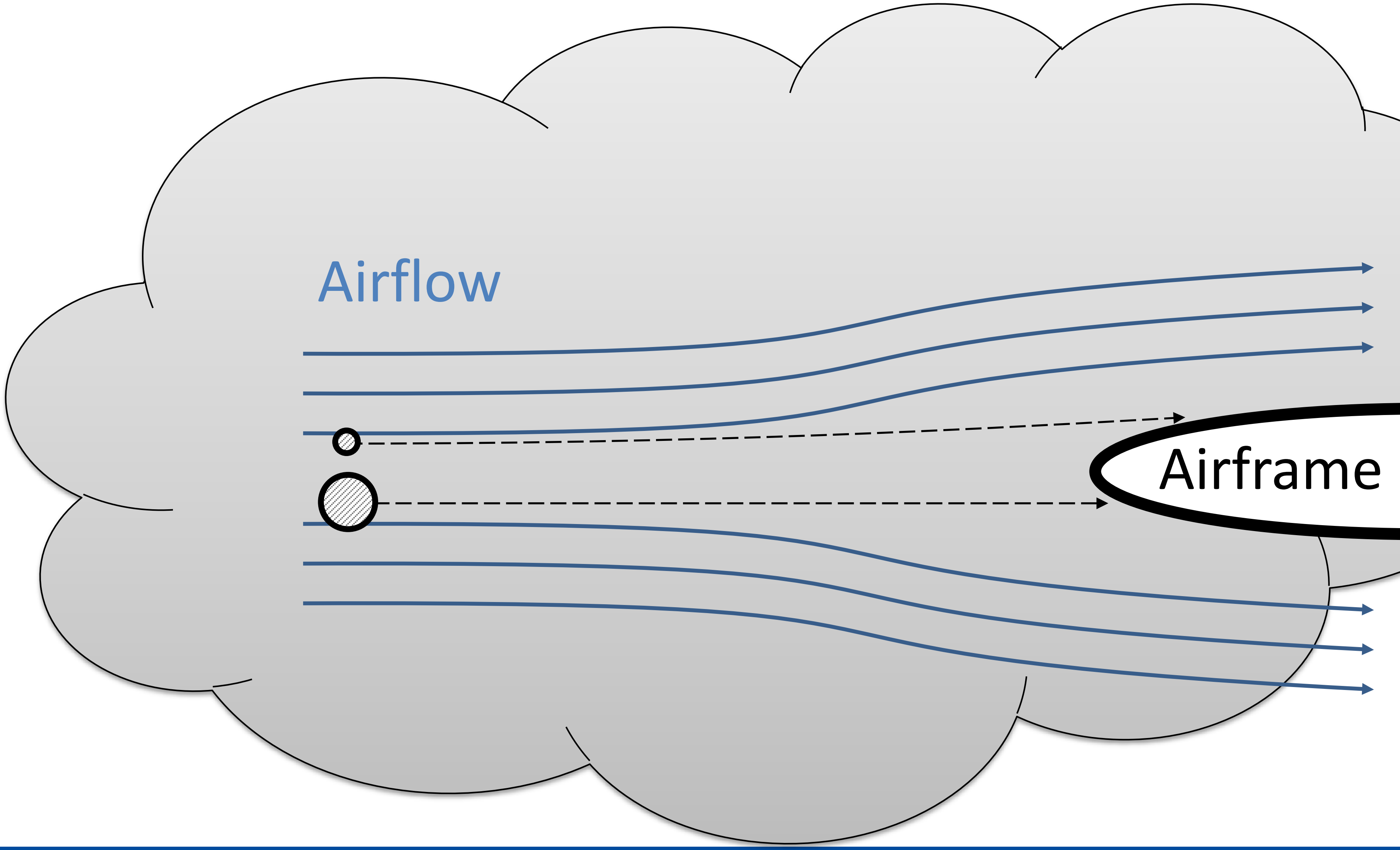
# INFLUENCE OF SIZE



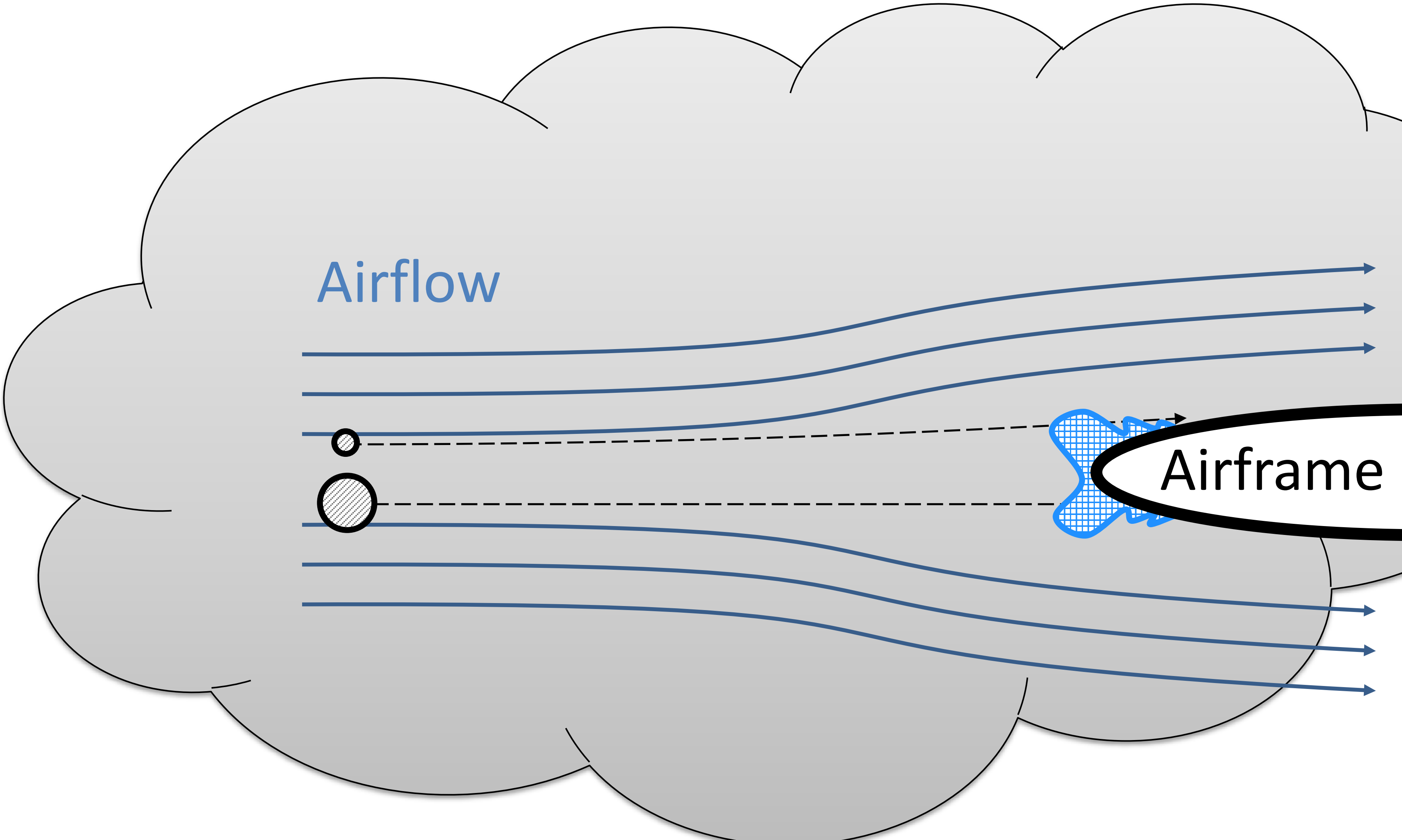
# INFLUENCE OF SIZE

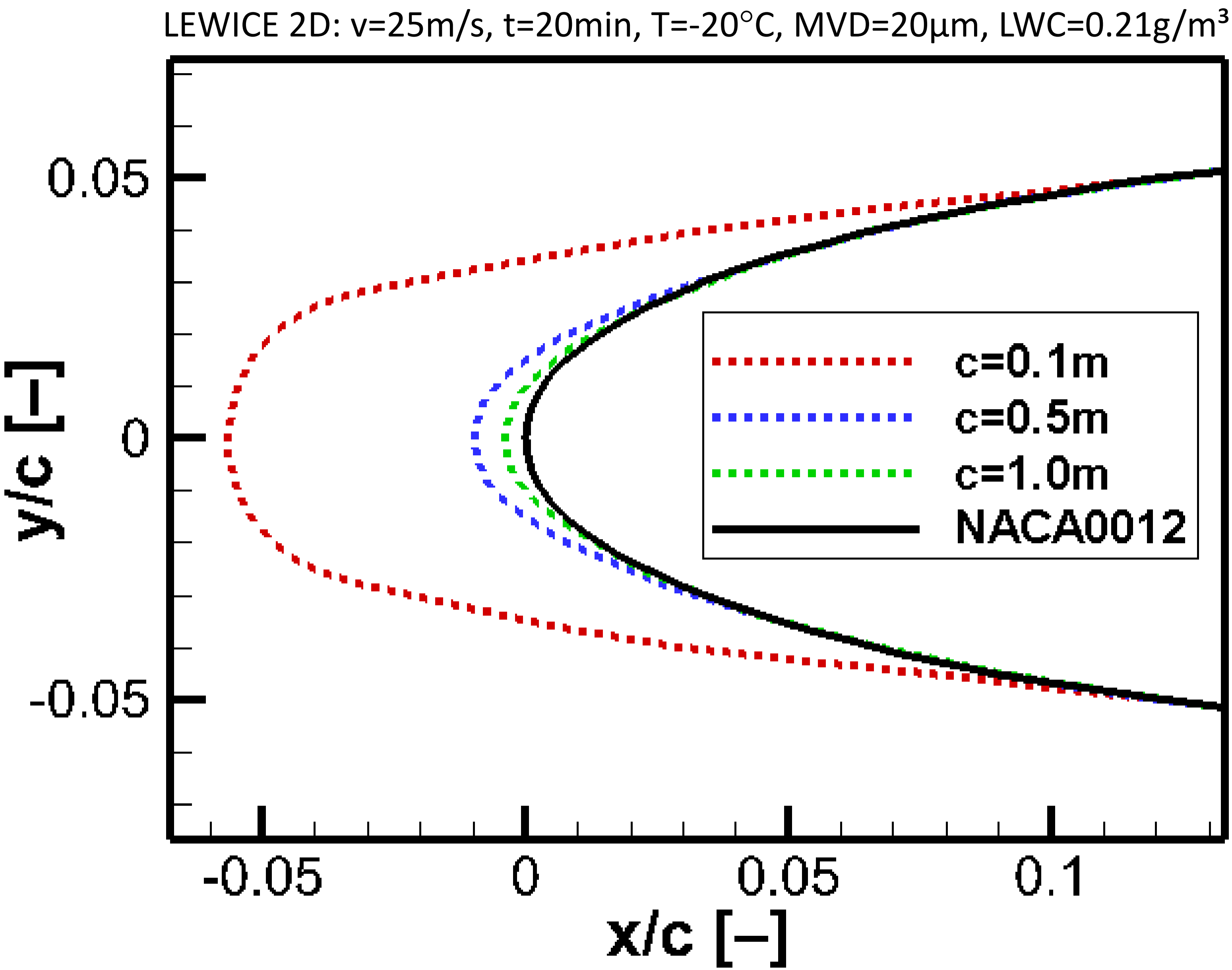


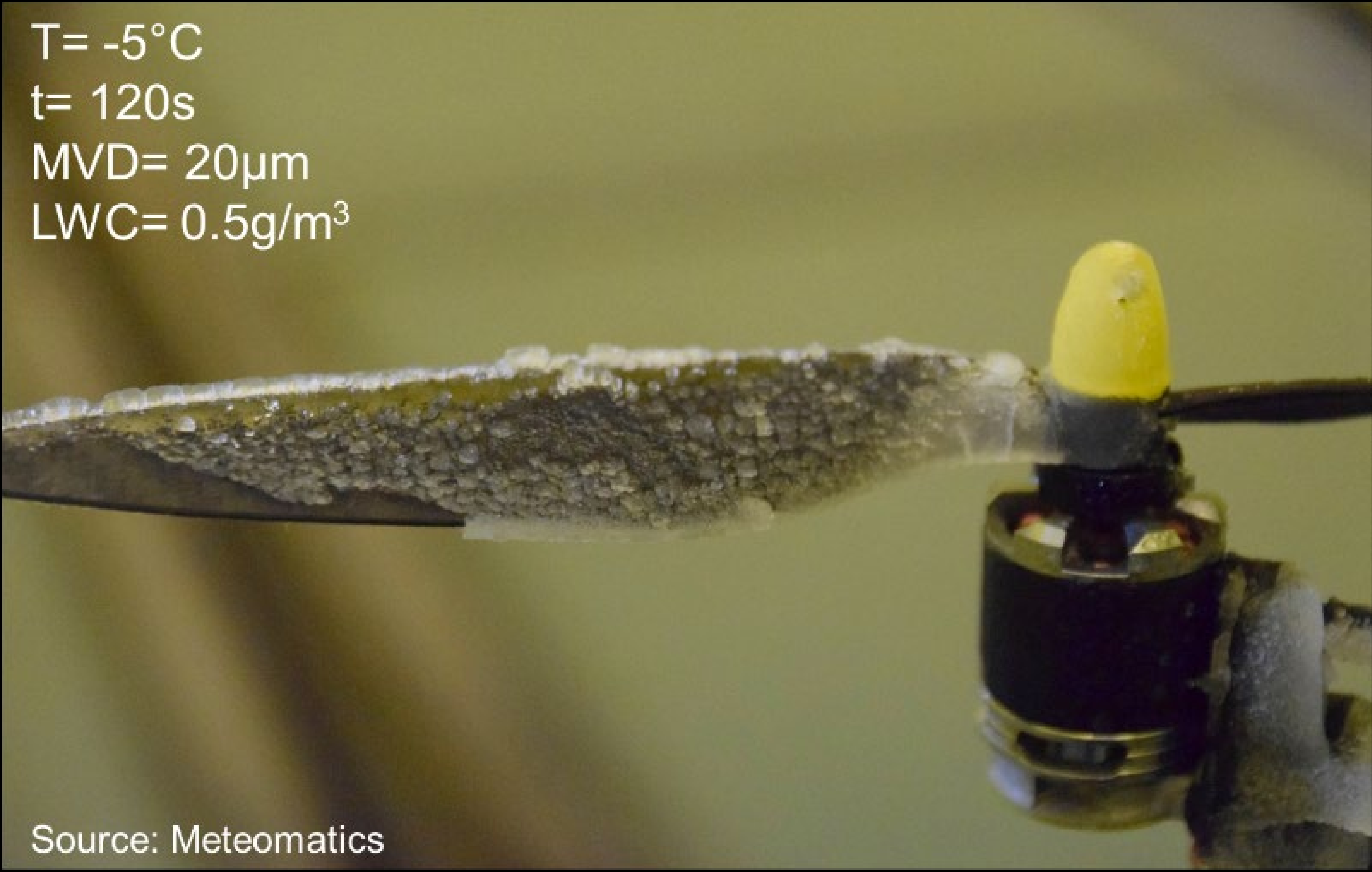
# Influence of Size

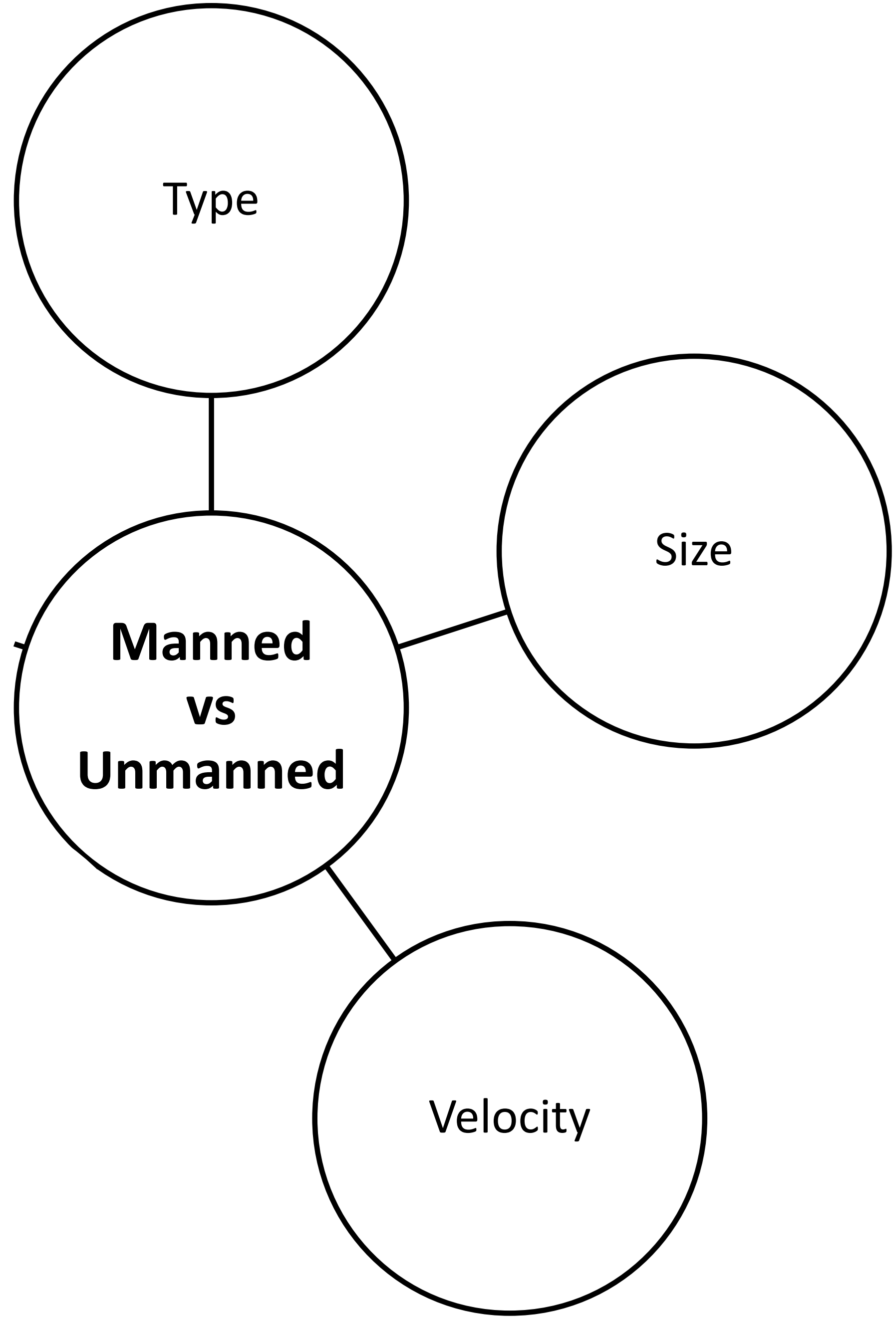


# INFLUENCE OF SIZE

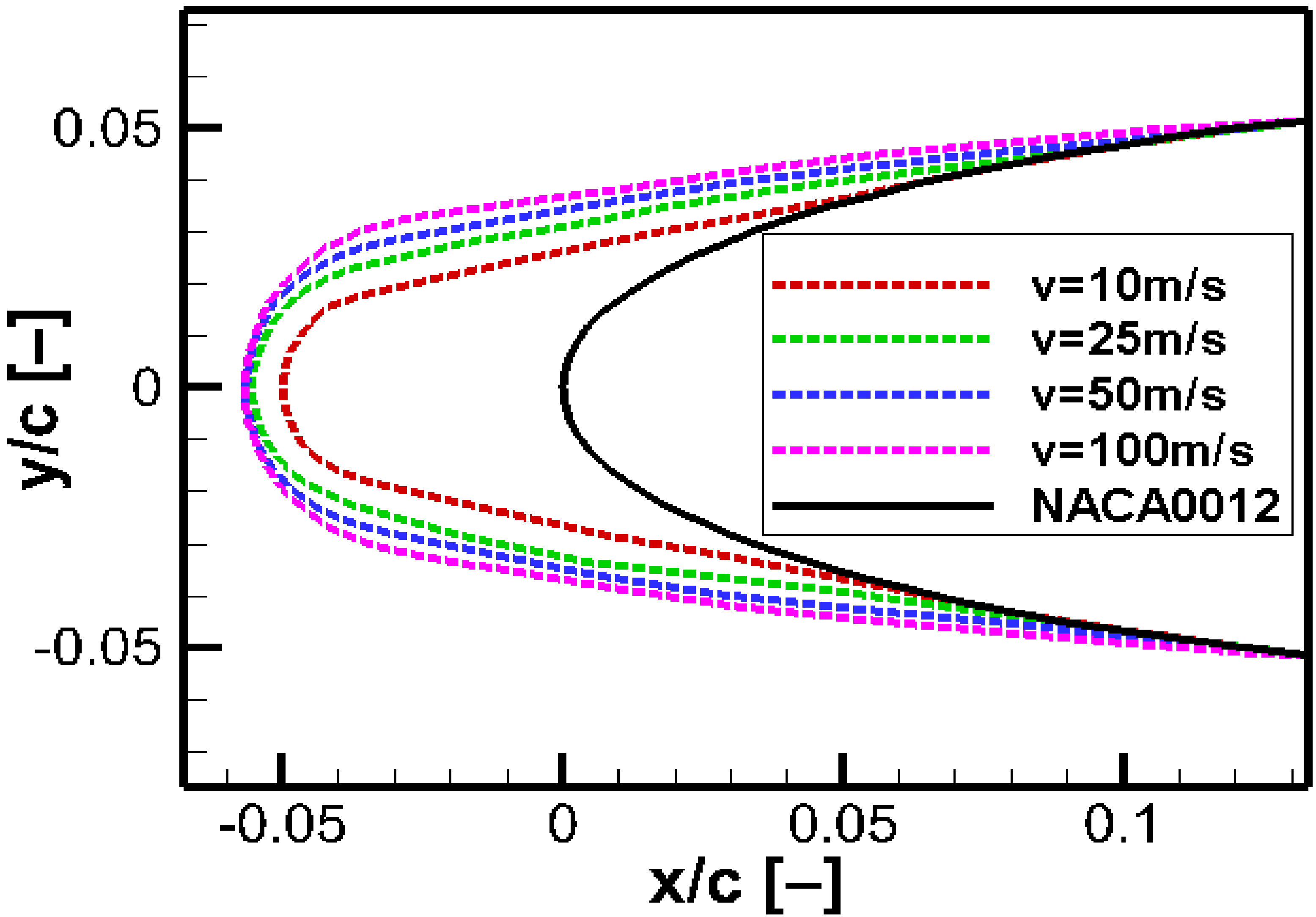


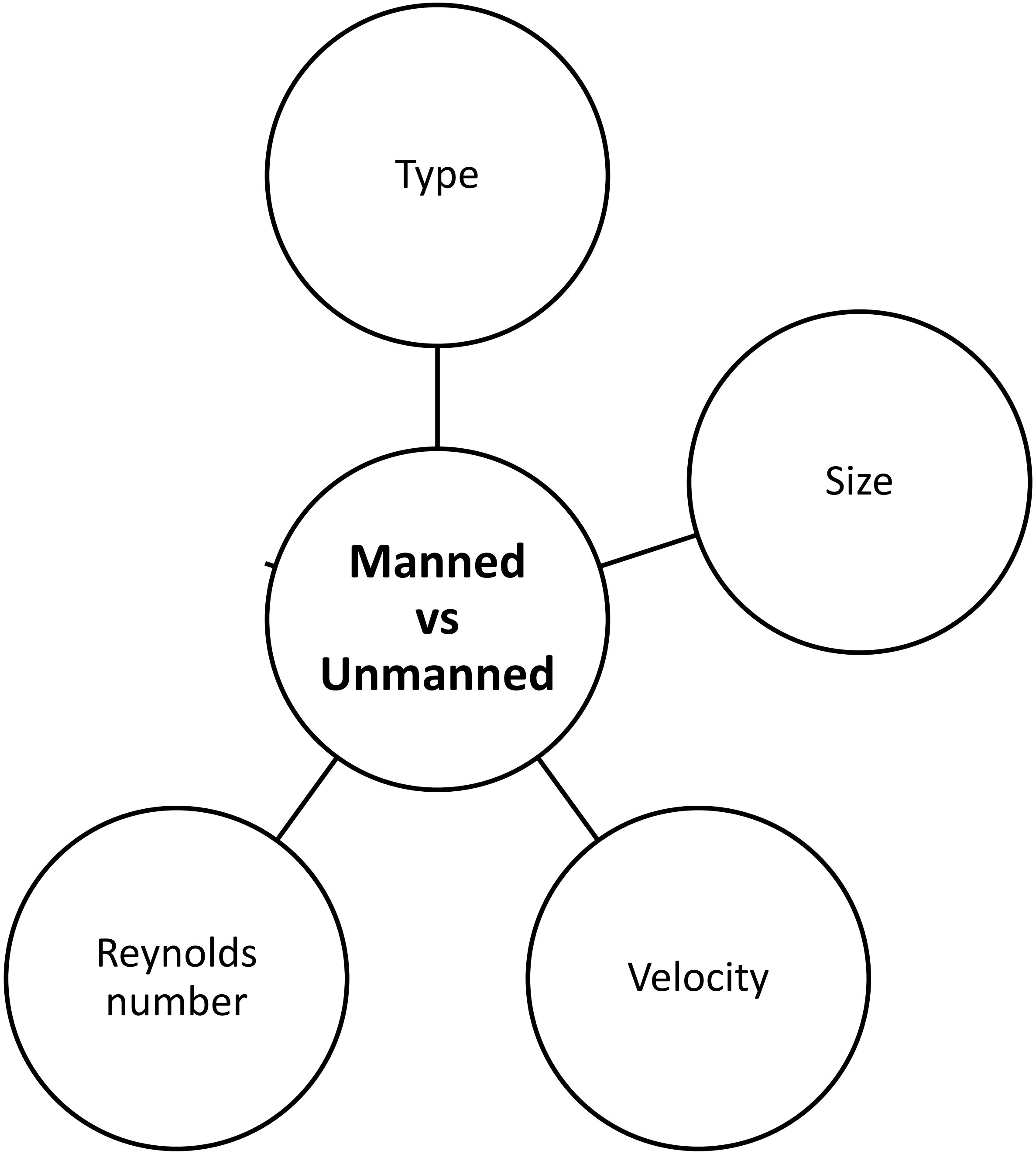

LEWICE 2D: v=25m/s, t=20min, T=-20°C, MVD=20μm, LWC=0.21g/m³
0.05
0
-0.05
y/c [–]
-0.05
0
0.05
0.1
x/c [–]
c=0.1m
c=0.5m
c=1.0m
NACA0012

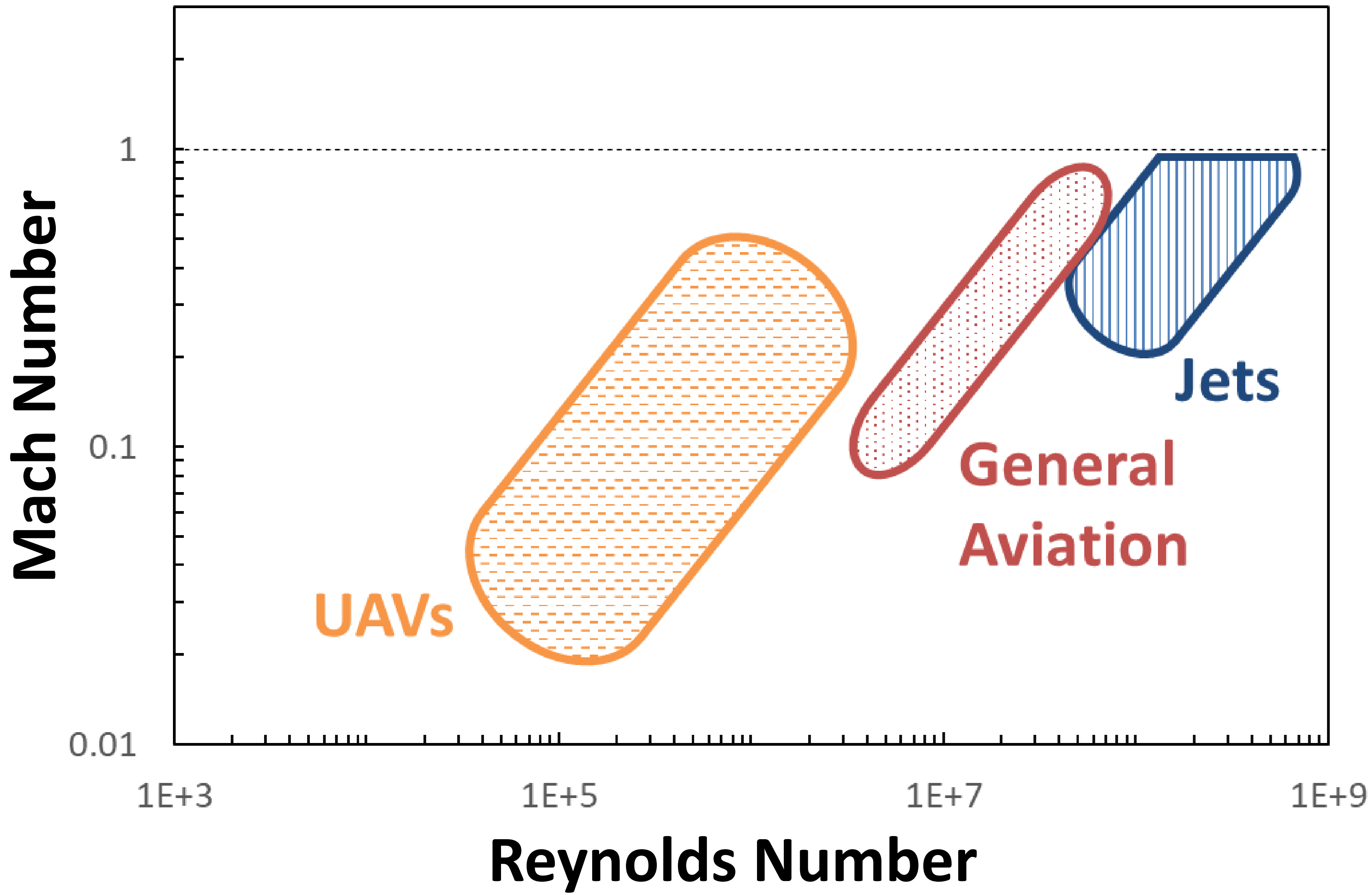

T= -5°C
t= 120s
MVD= 20µm
LWC= 0.5g/m3
Source: Meteomatics

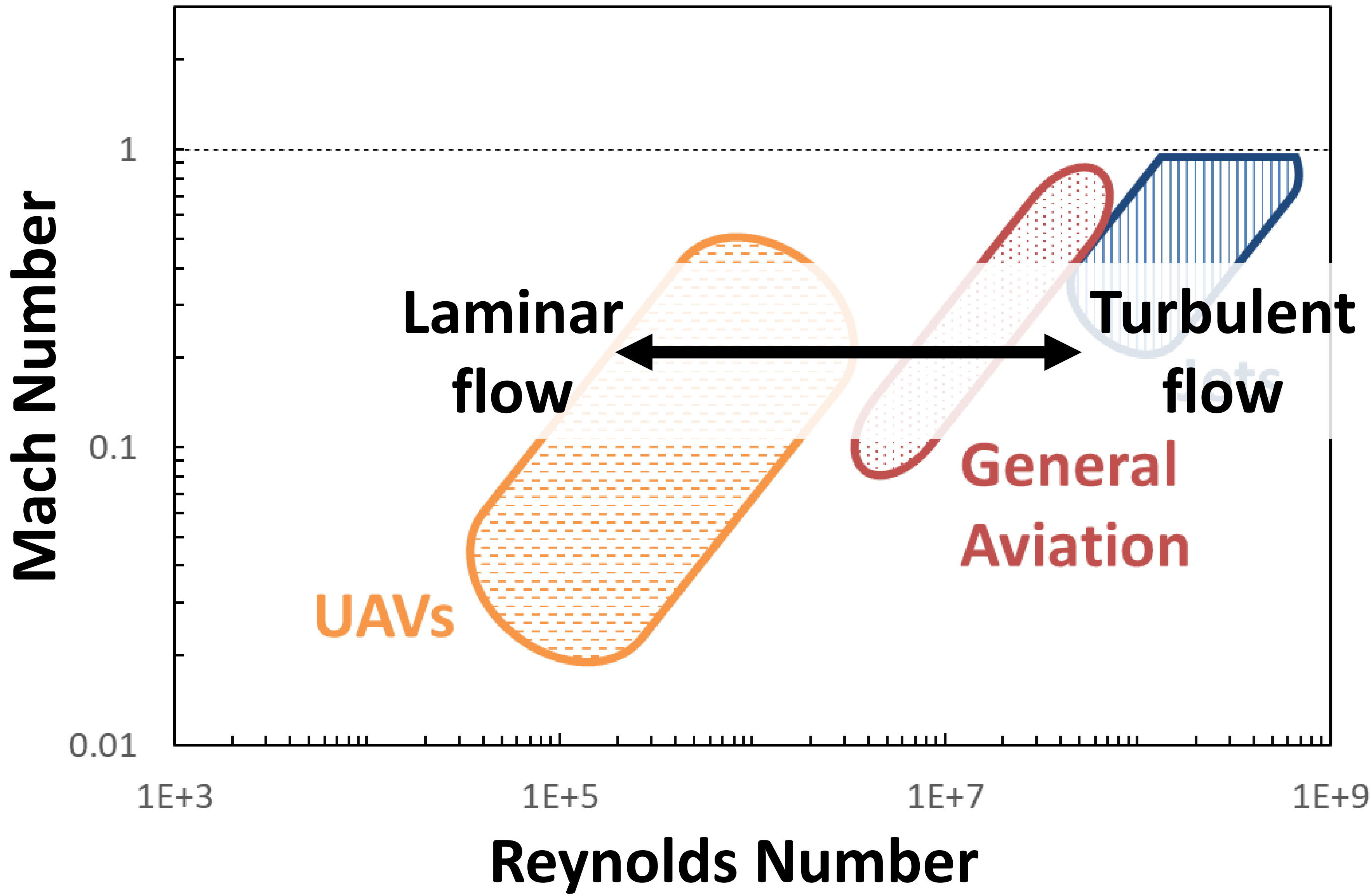

Type
Size
Manned
vs
Unmanned
Velocity

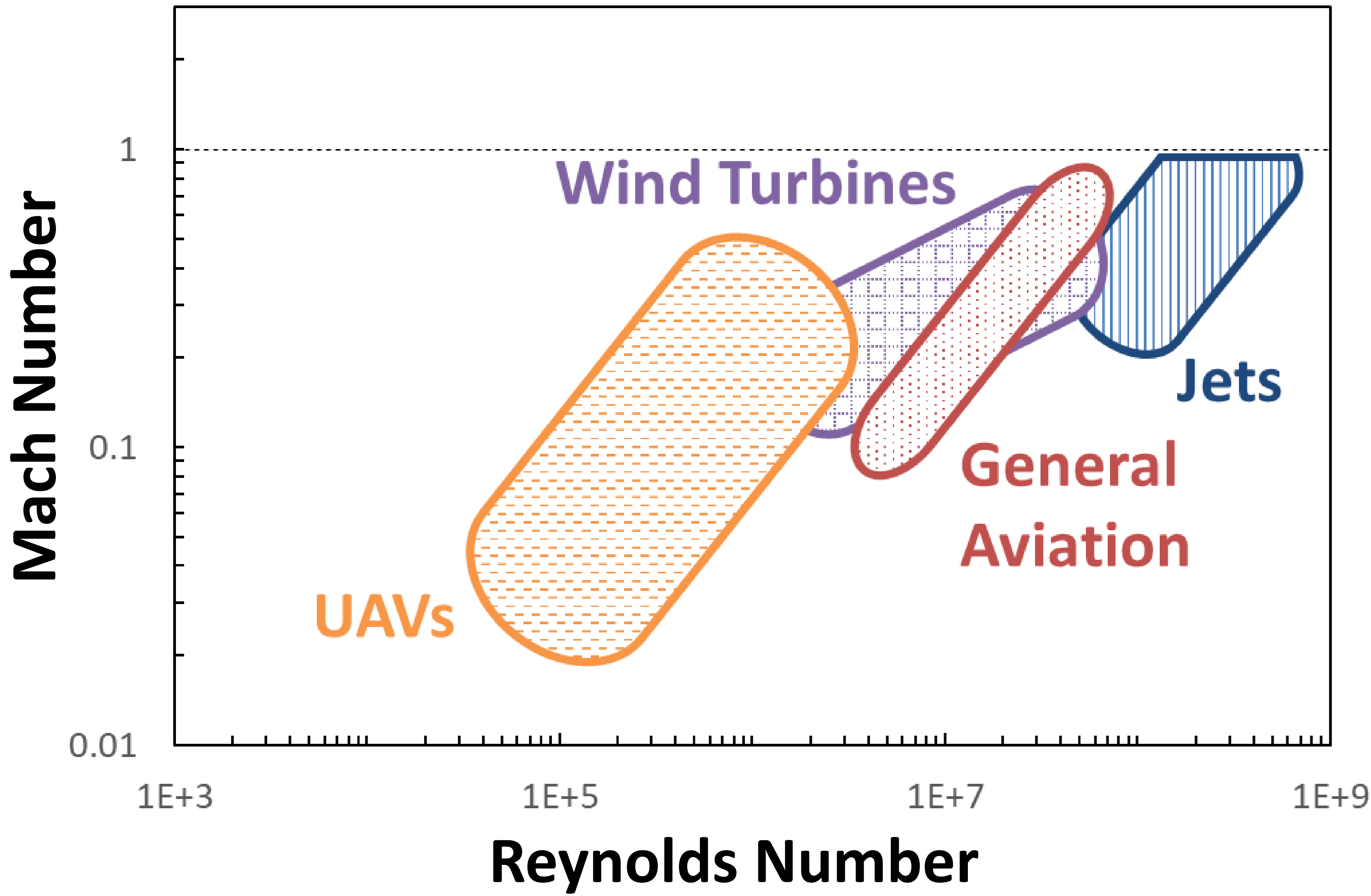
LEWICE 2D: c=0.1m, T=-20°C, MVD=20µm, LWC=0.21g/m³

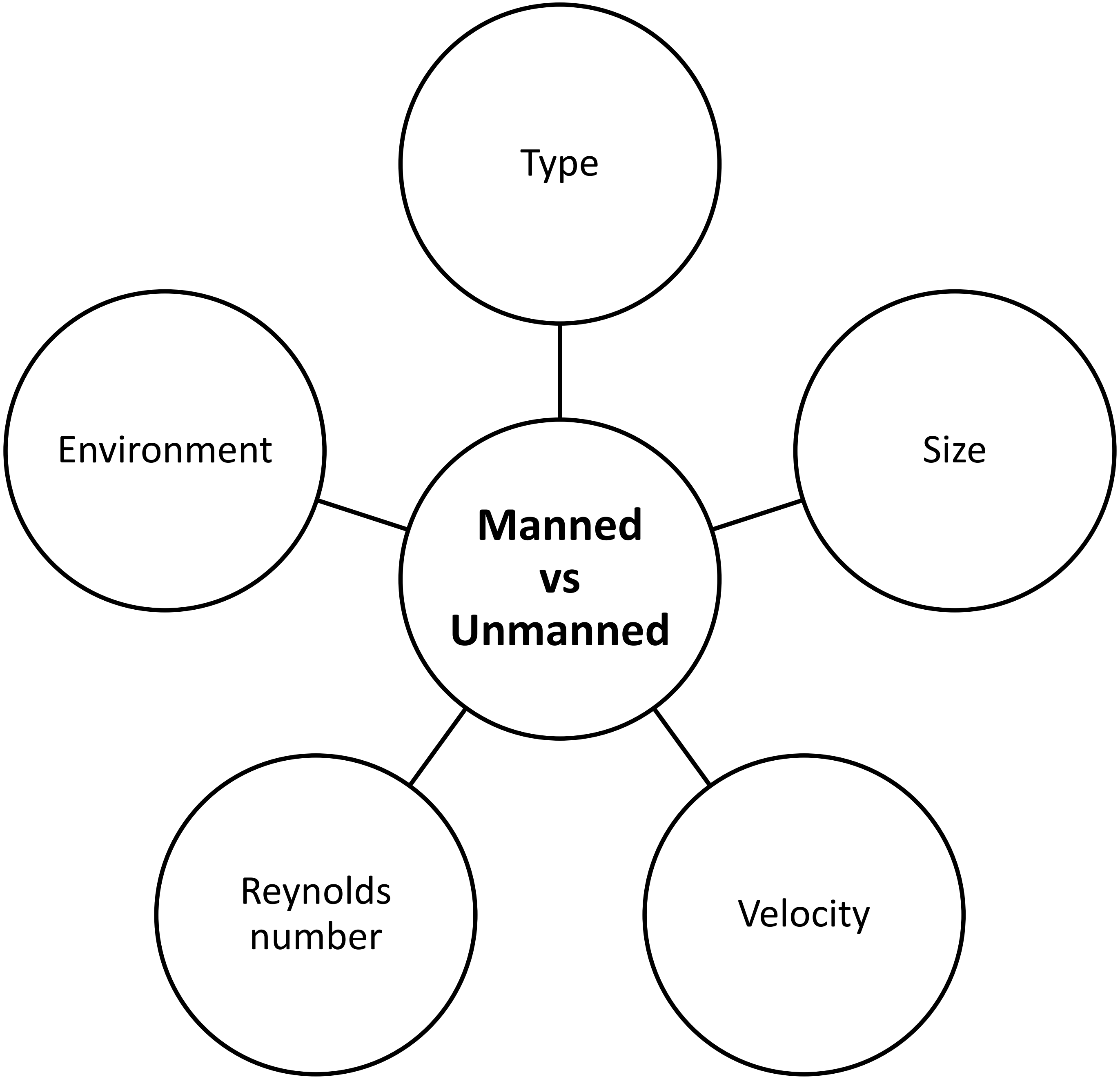


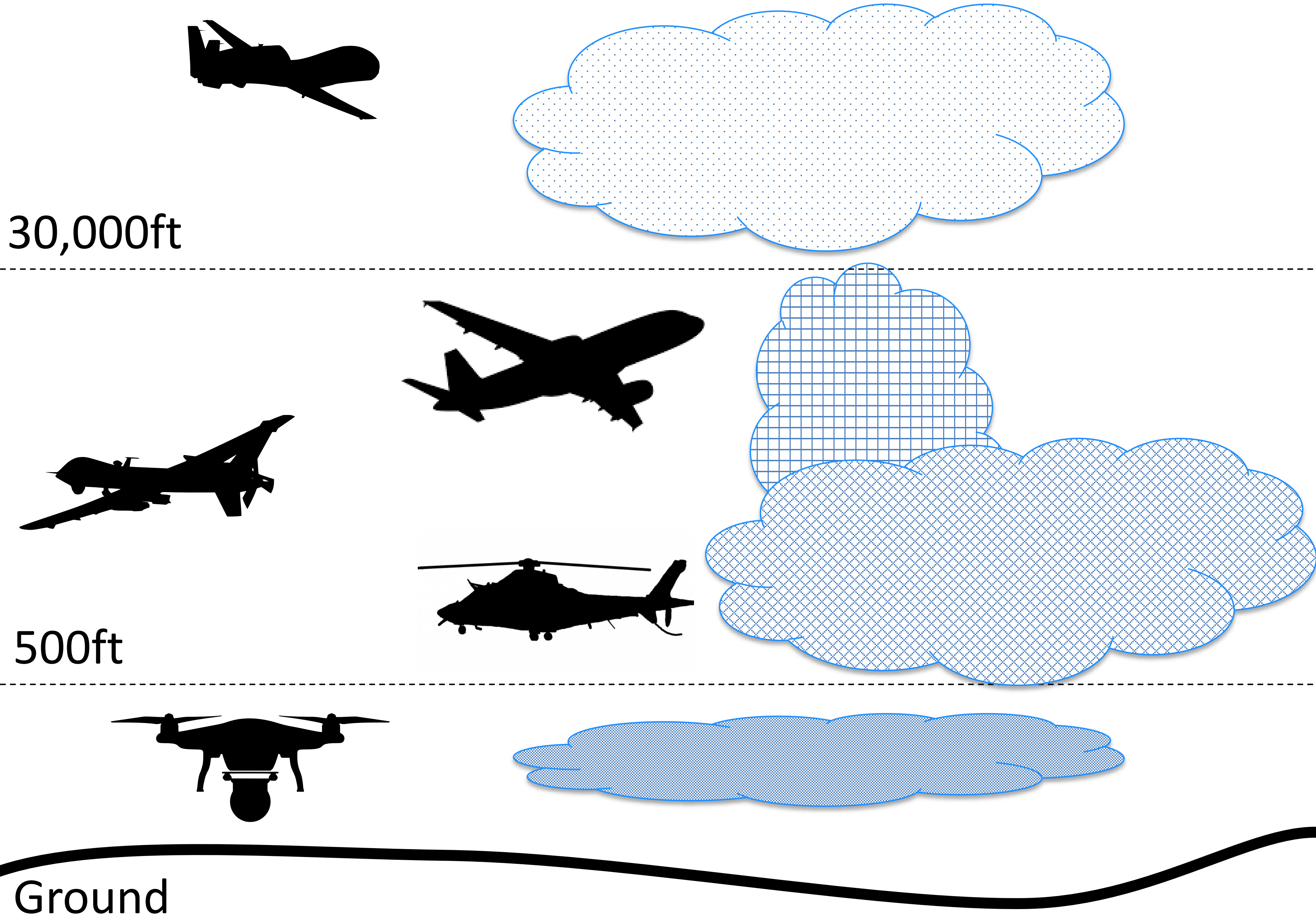

Type
Size
Manned
vs
Unmanned
Reynolds
number
Velocity


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


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

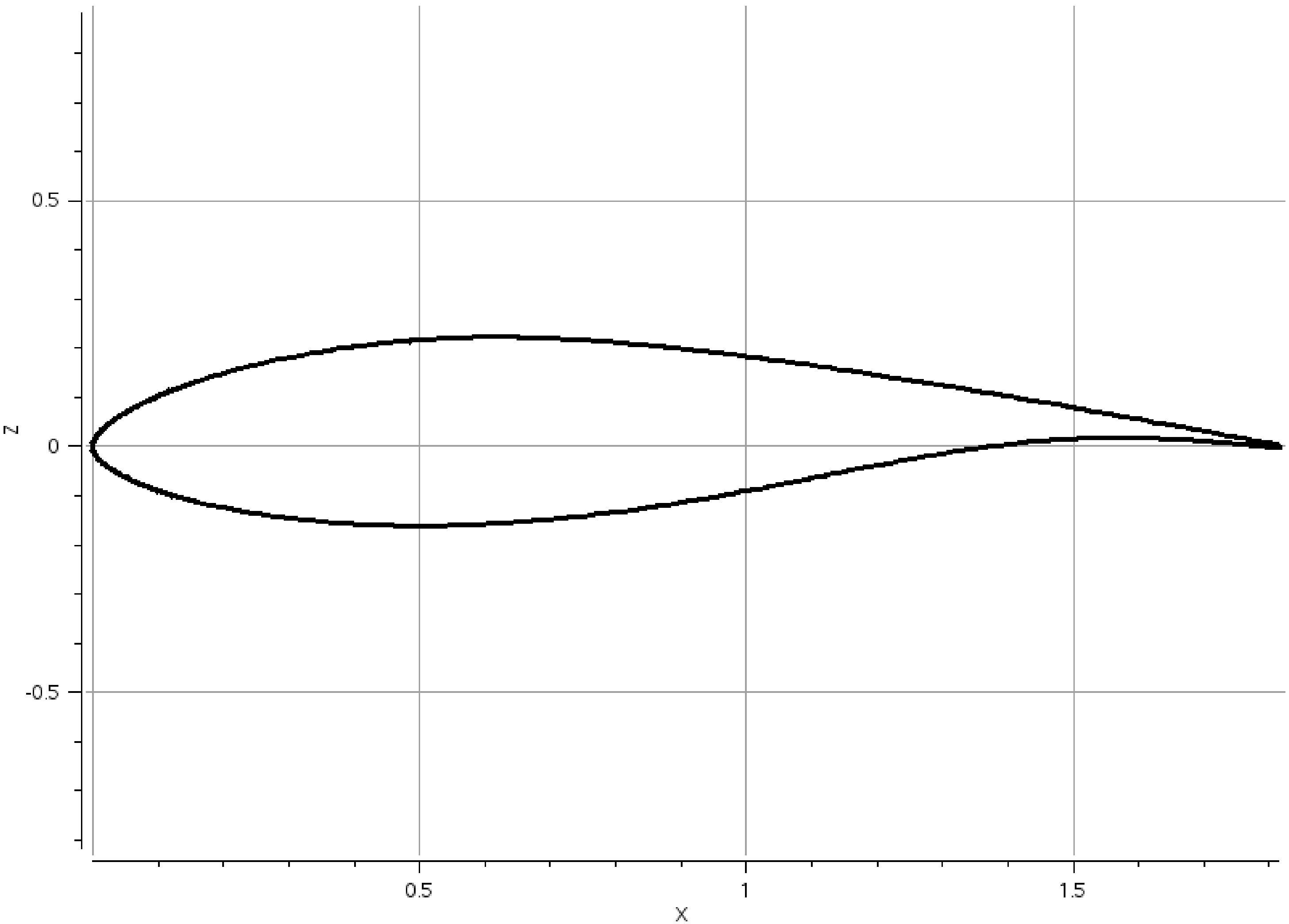

Type
Environment
Size
Manned vs Unmanned
Reynolds number
Velocity



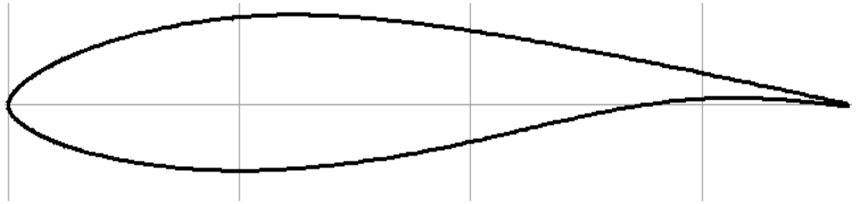
30,000ft
500ft
Ground

# Icing Simulation

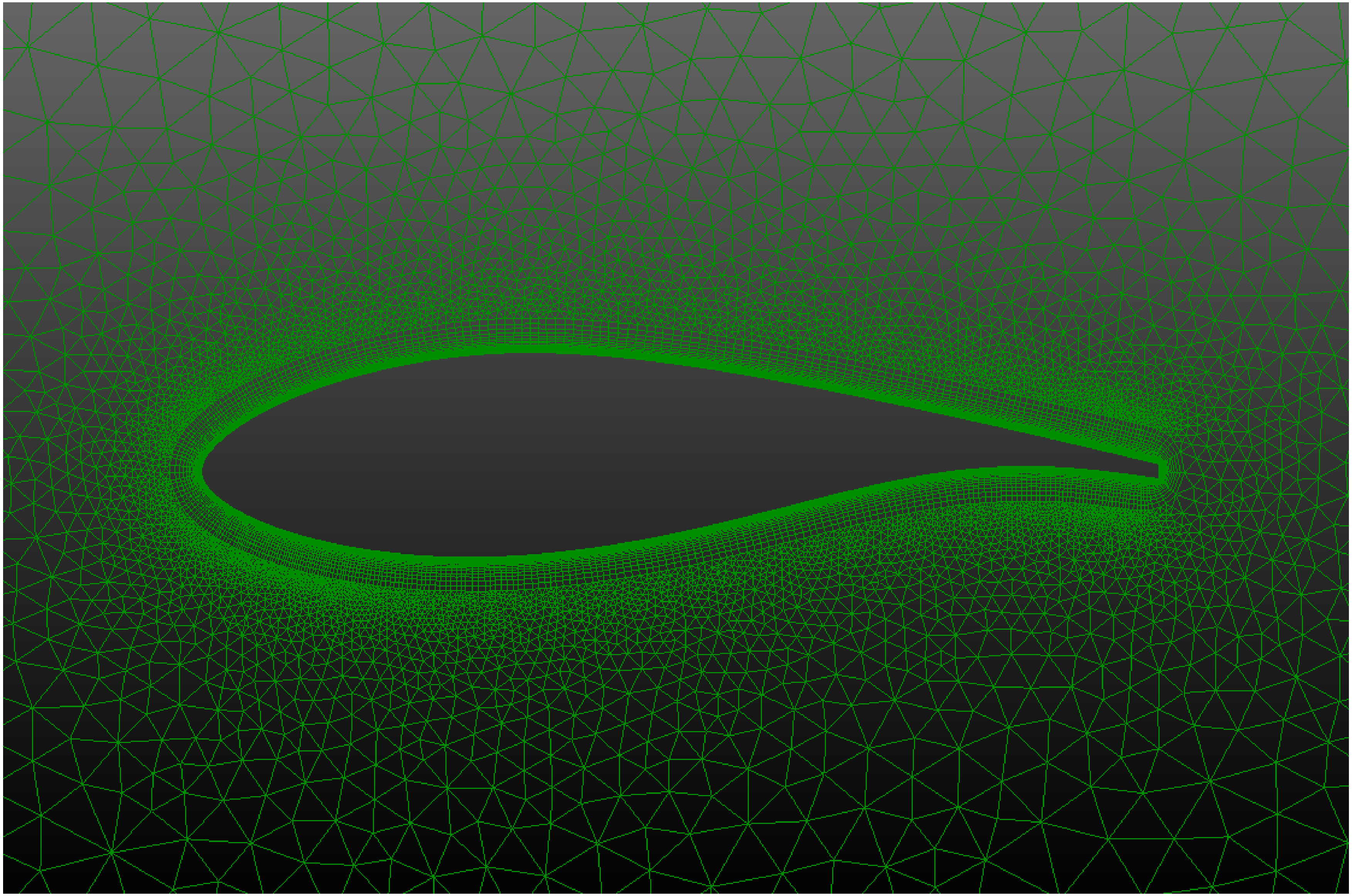
# Airfoil geometry



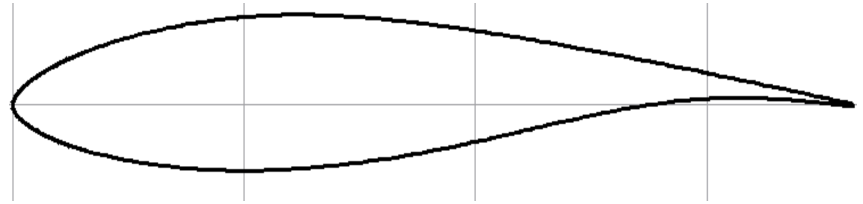
Airfoil geometry



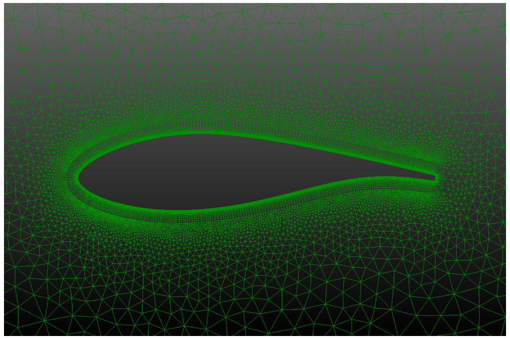
# Mesh



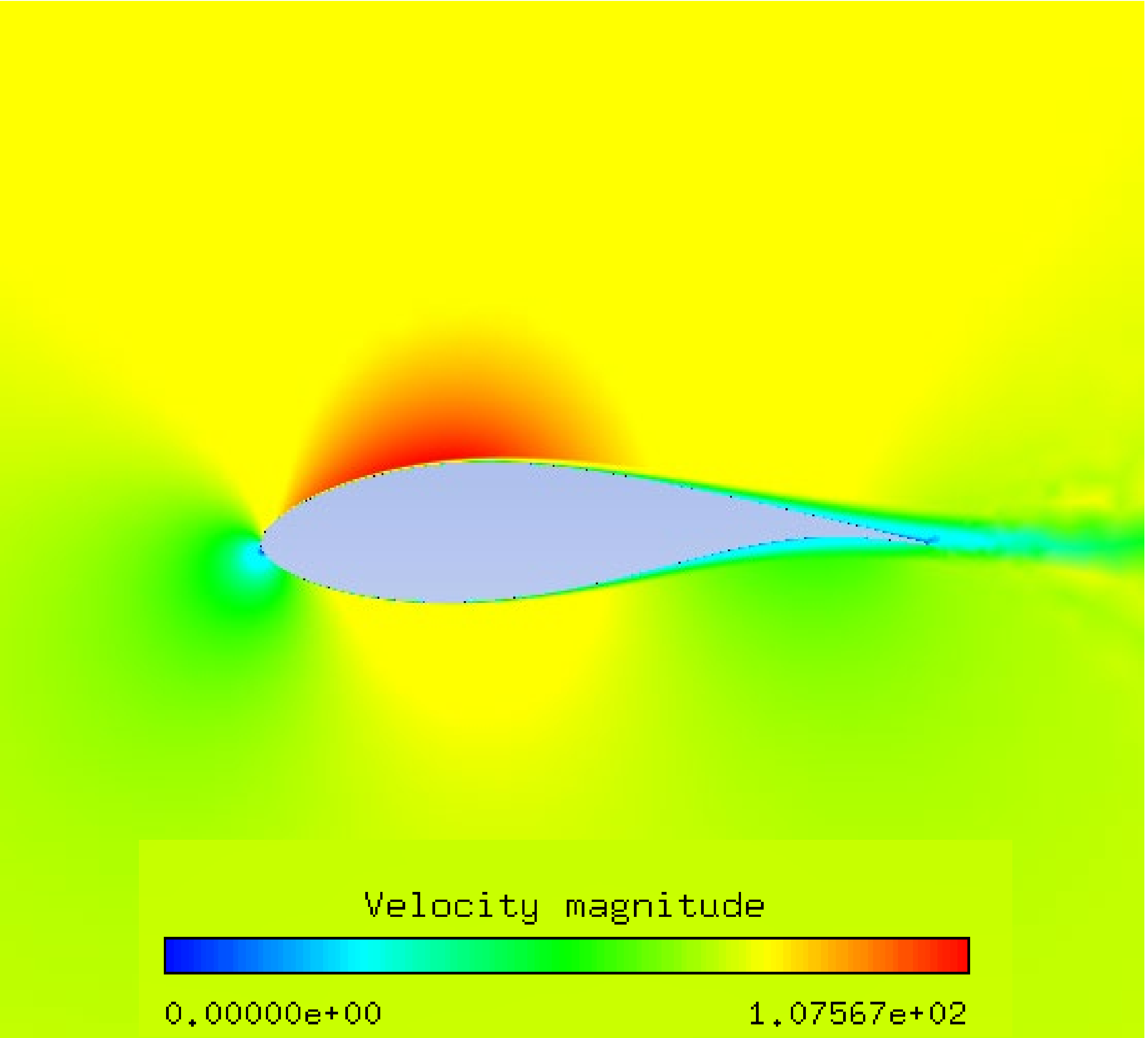
Airfoil geometry



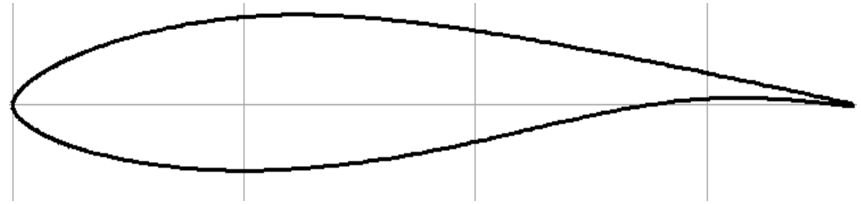
Mesh



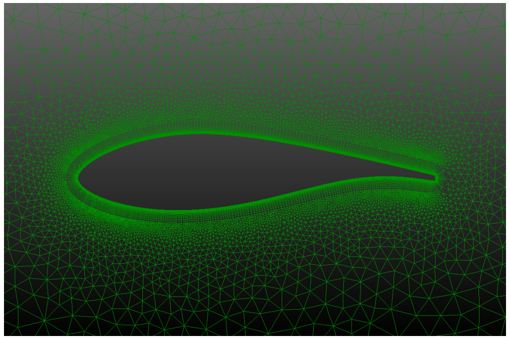
# Flow solution



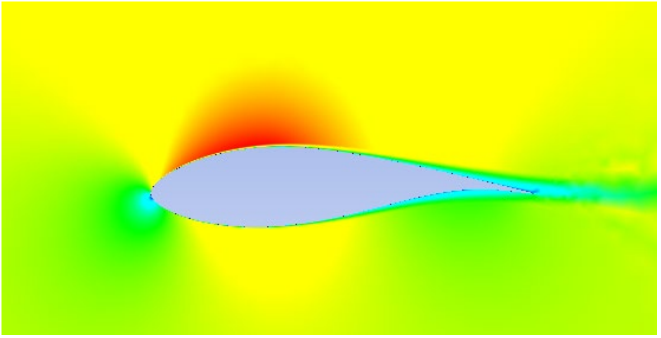
Airfoil geometry



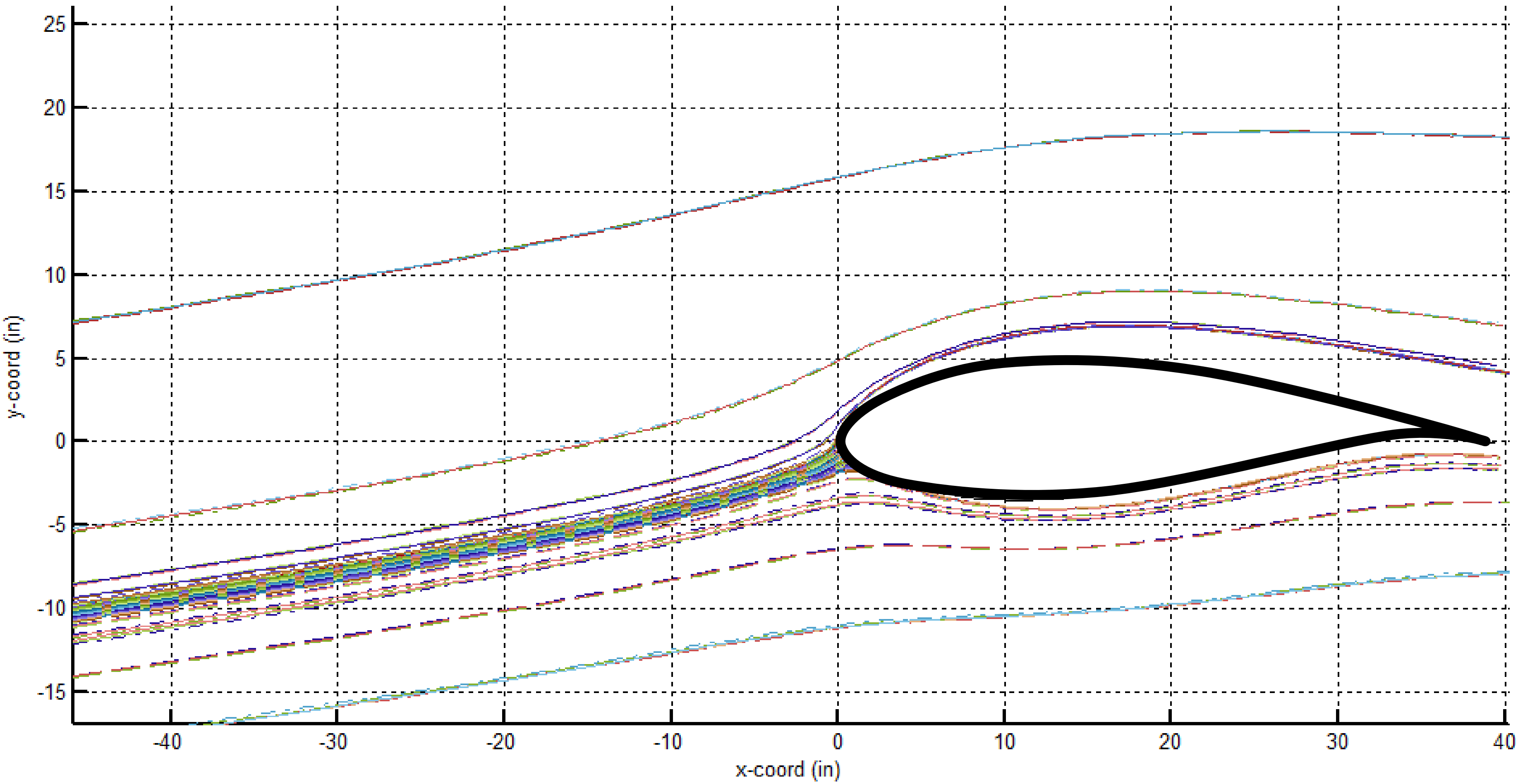
Mesh



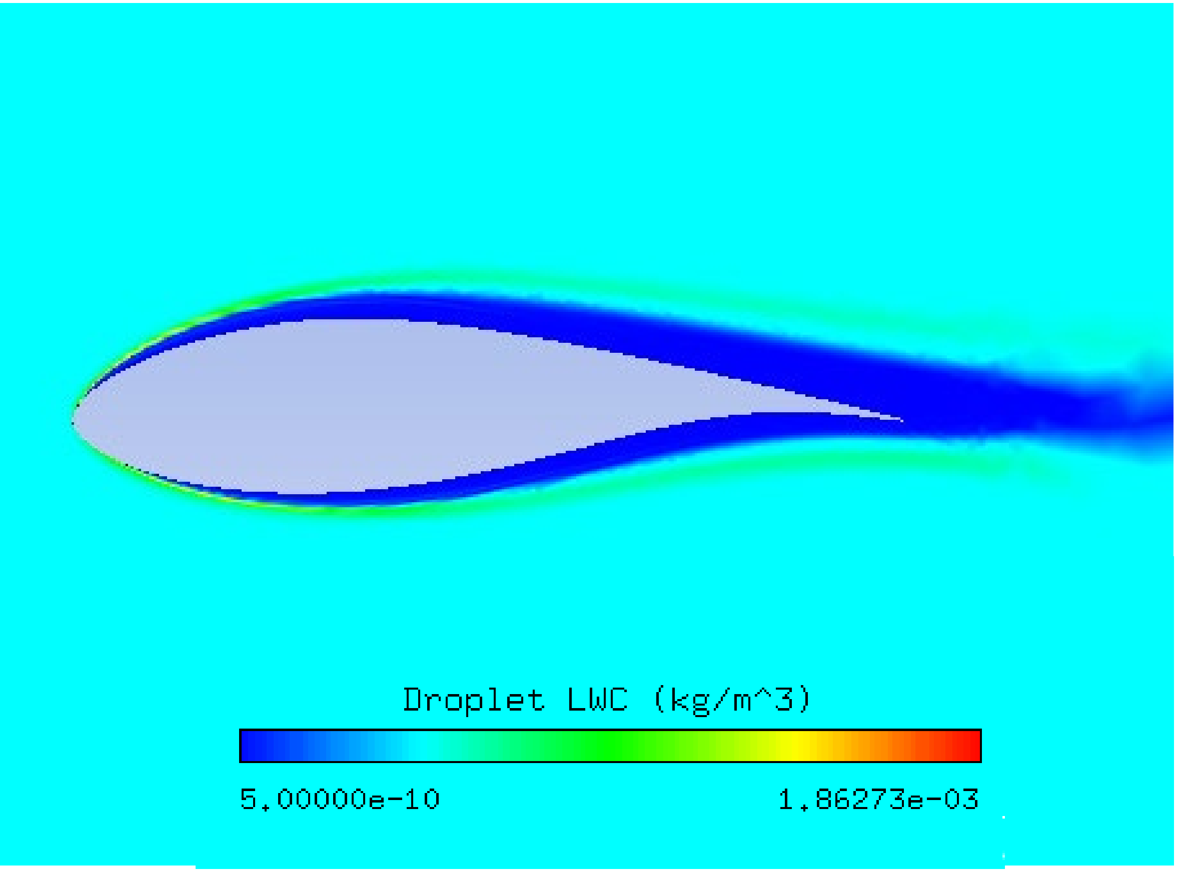
Flow solution



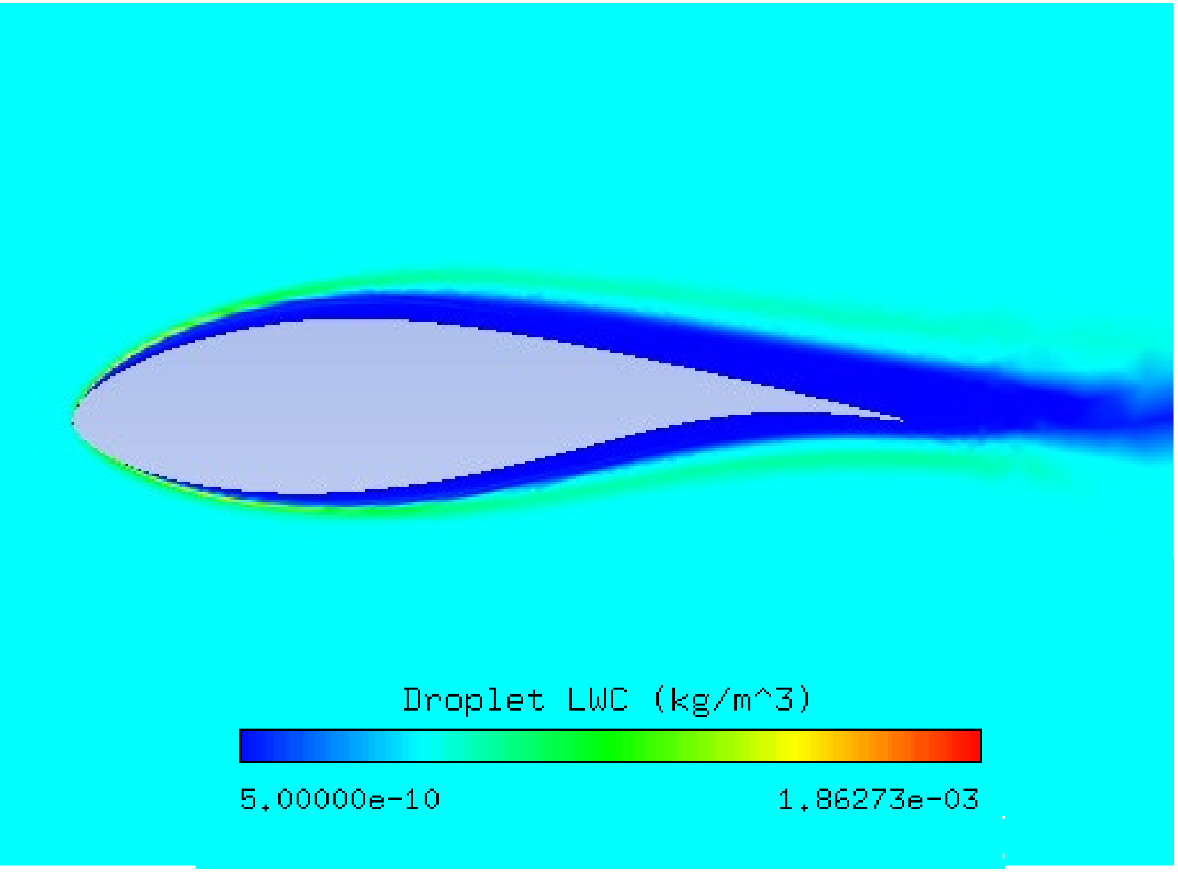
# Droplet solution

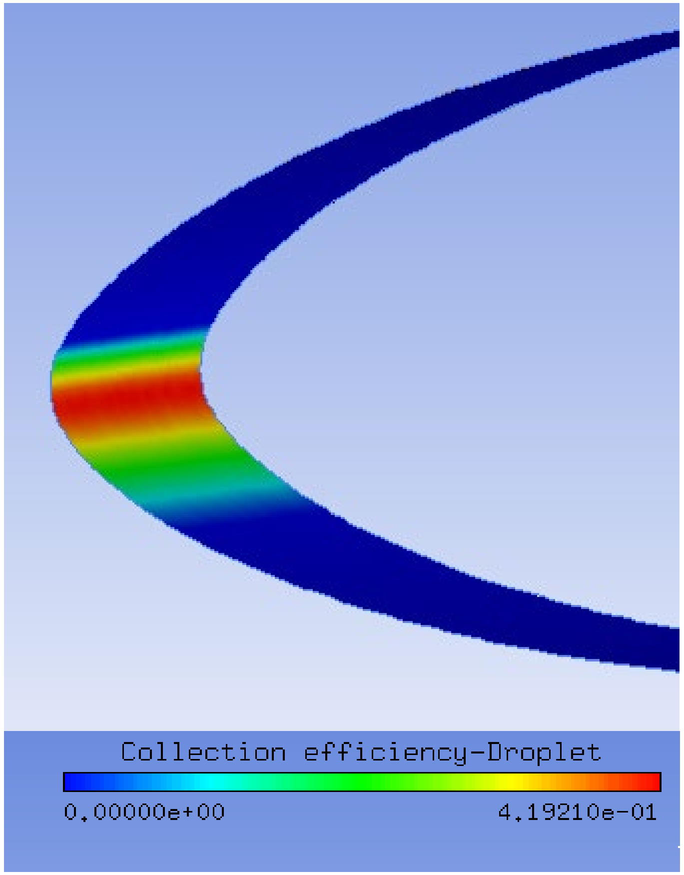


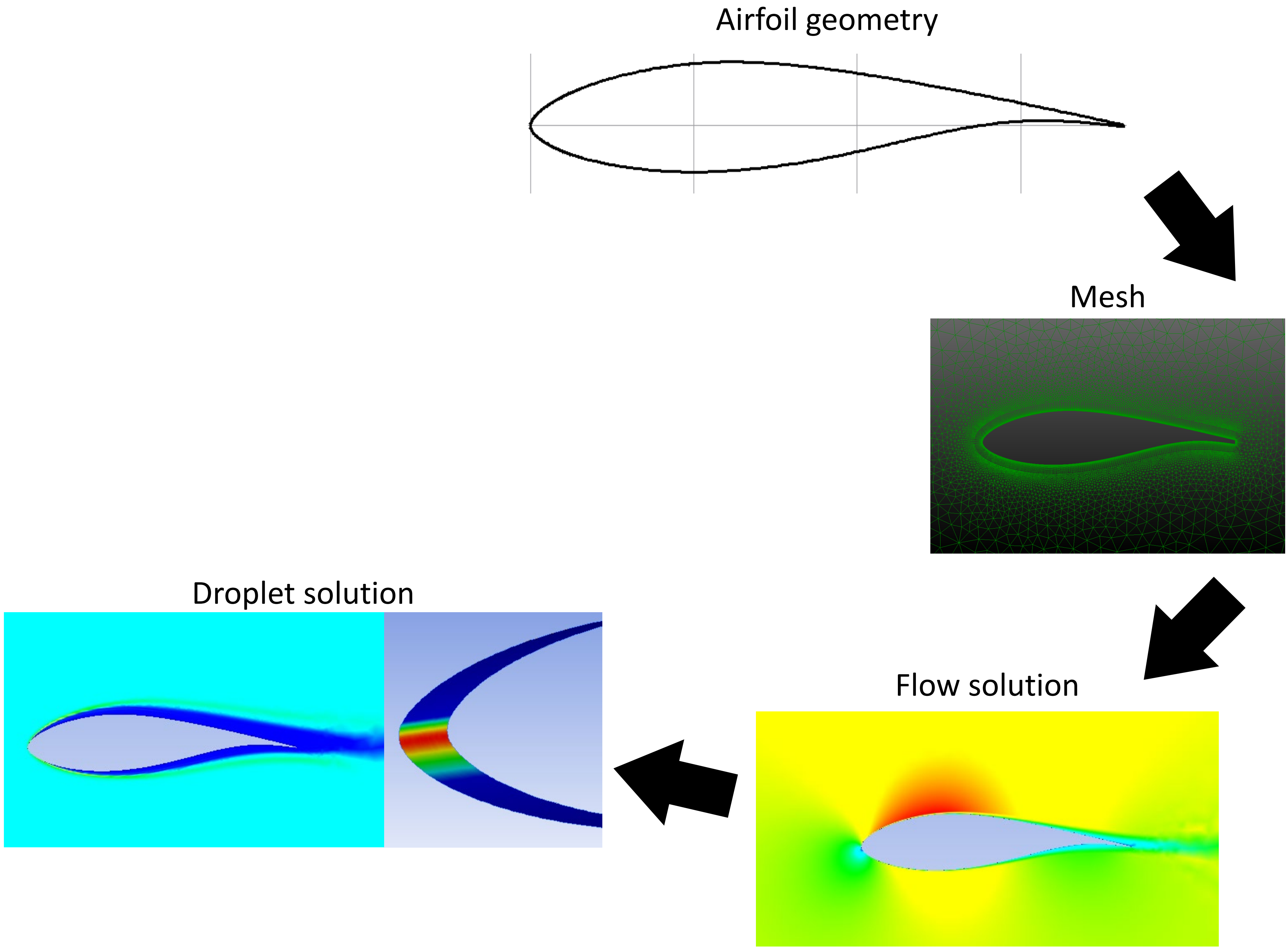
# Droplet solution



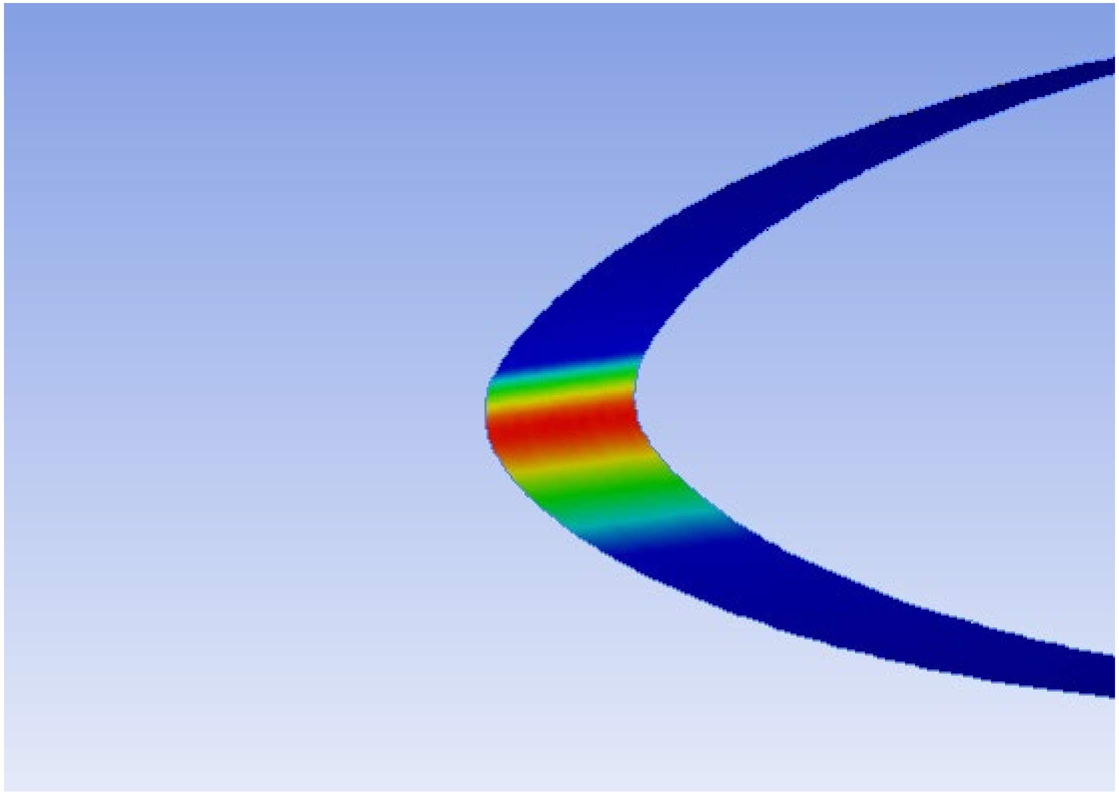
# Droplet solution



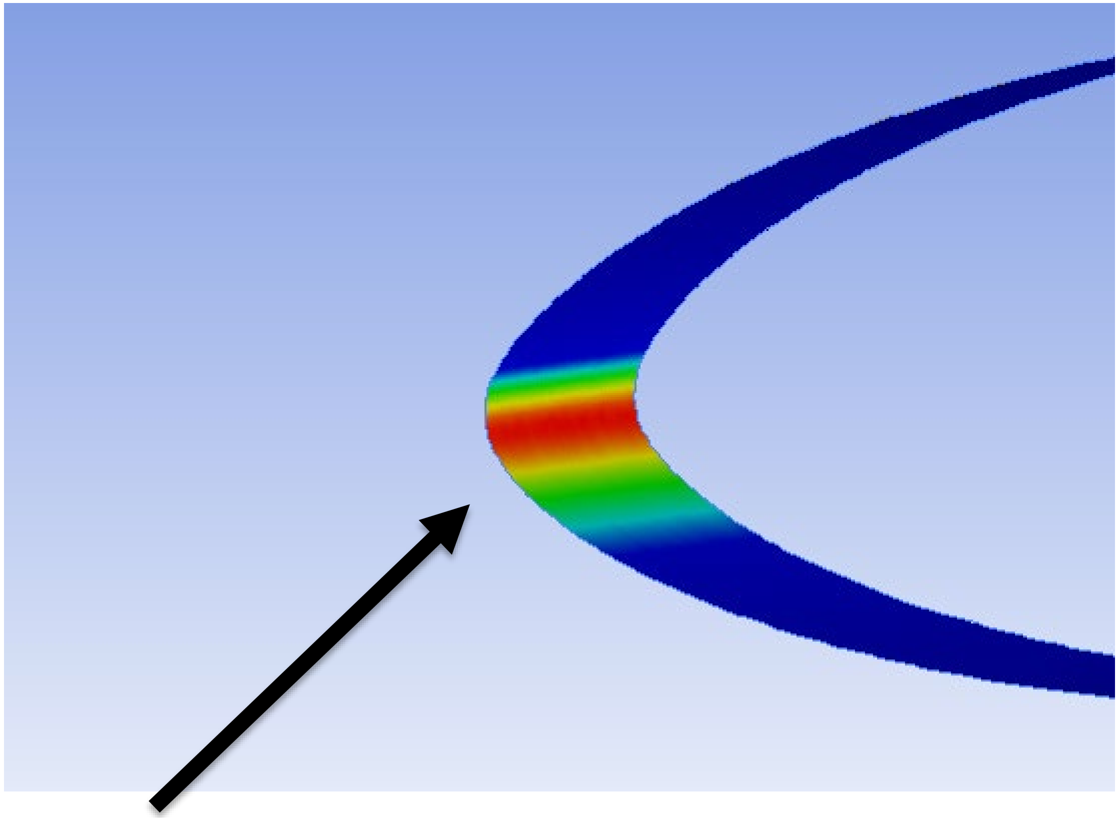




Airfoil geometry
Mesh
Flow solution
Droplet solution

# Collection efficiency

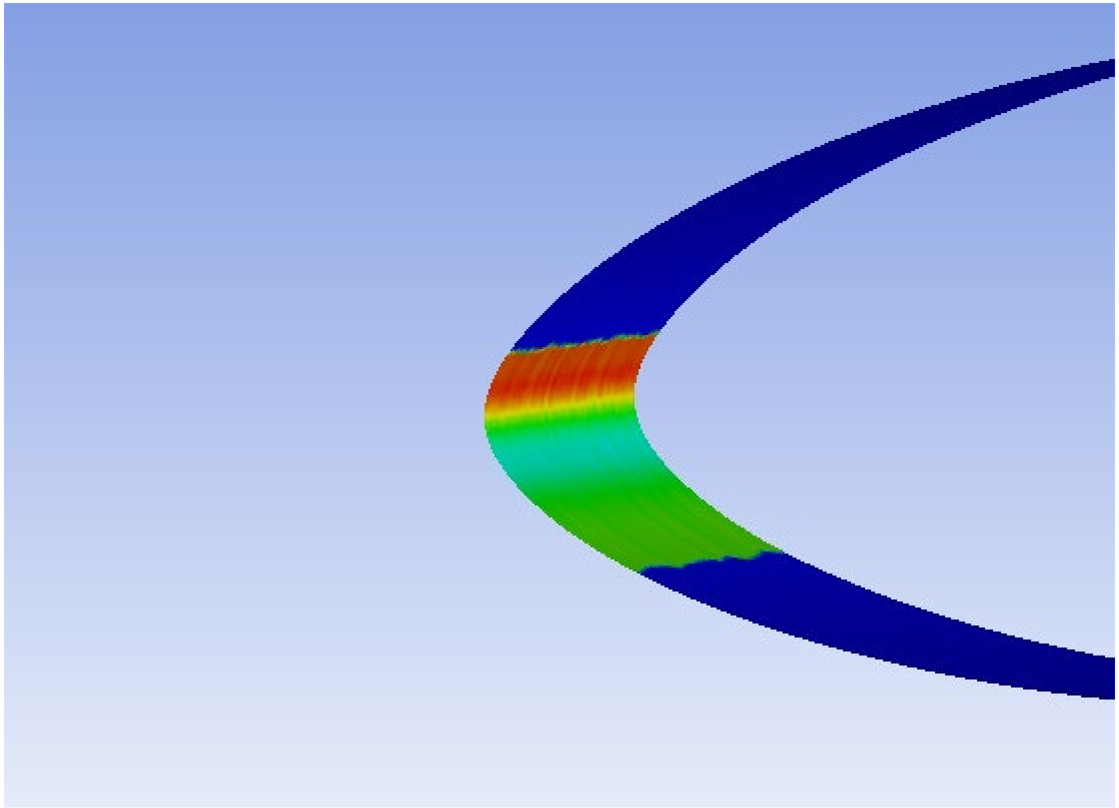


# Collection efficiency

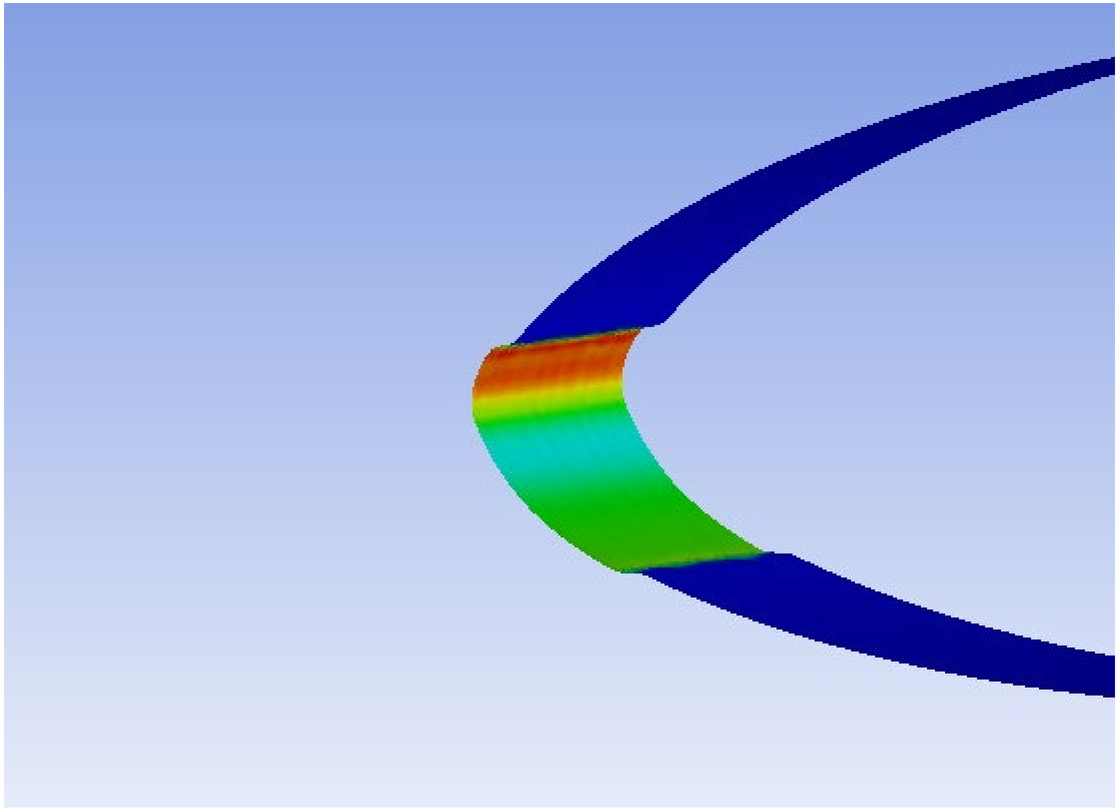


Energy & mass calculations (Messinger model)

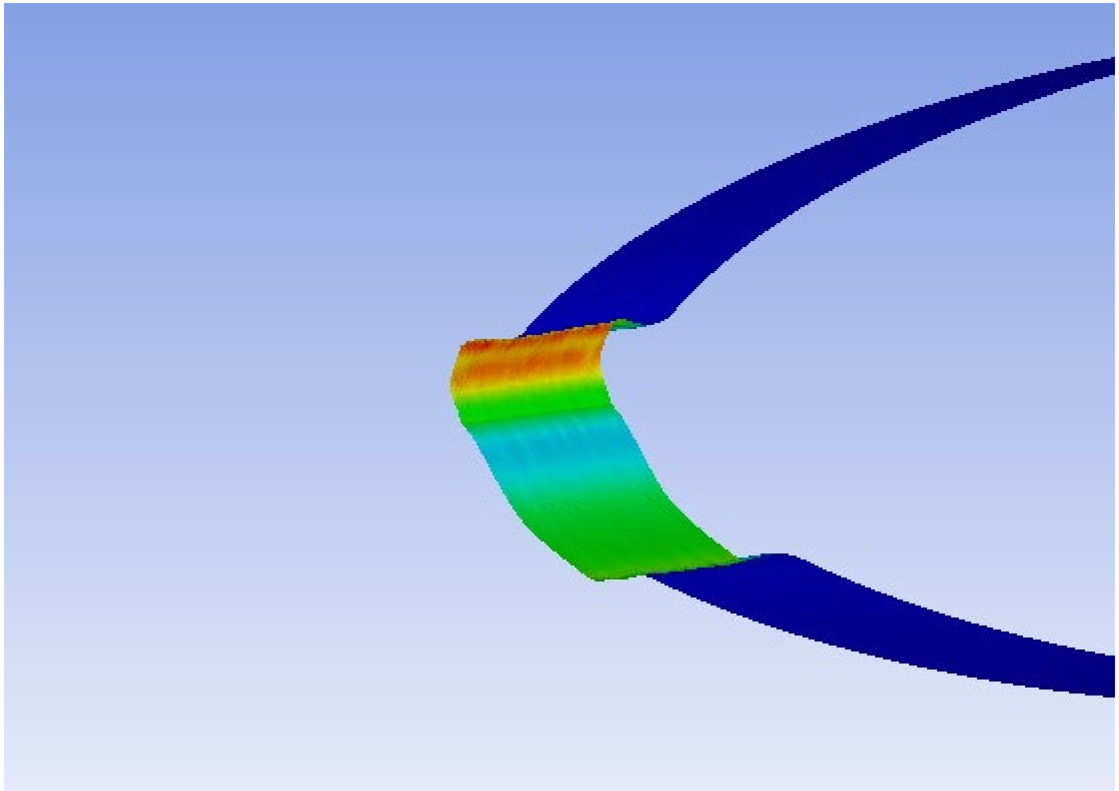
# Ice growth (t=1)



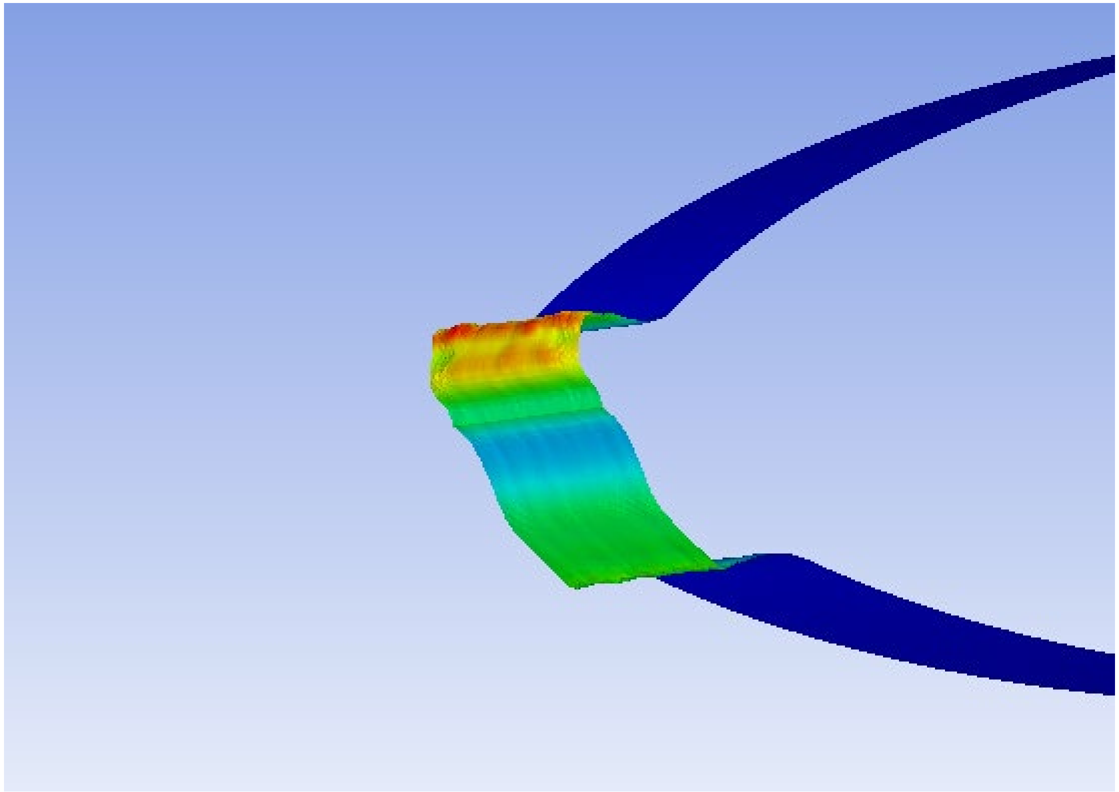
# Ice growth (t=2)

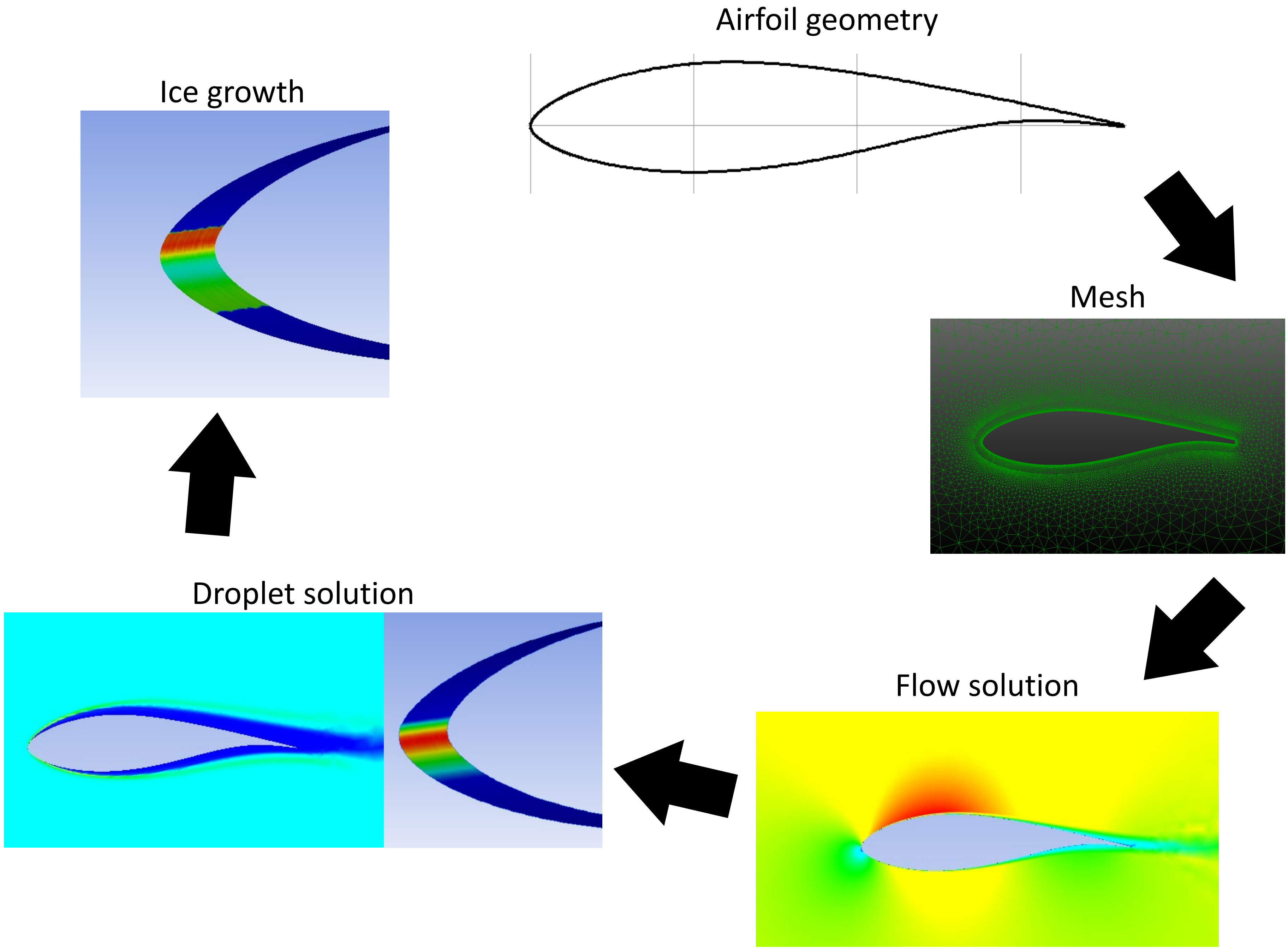


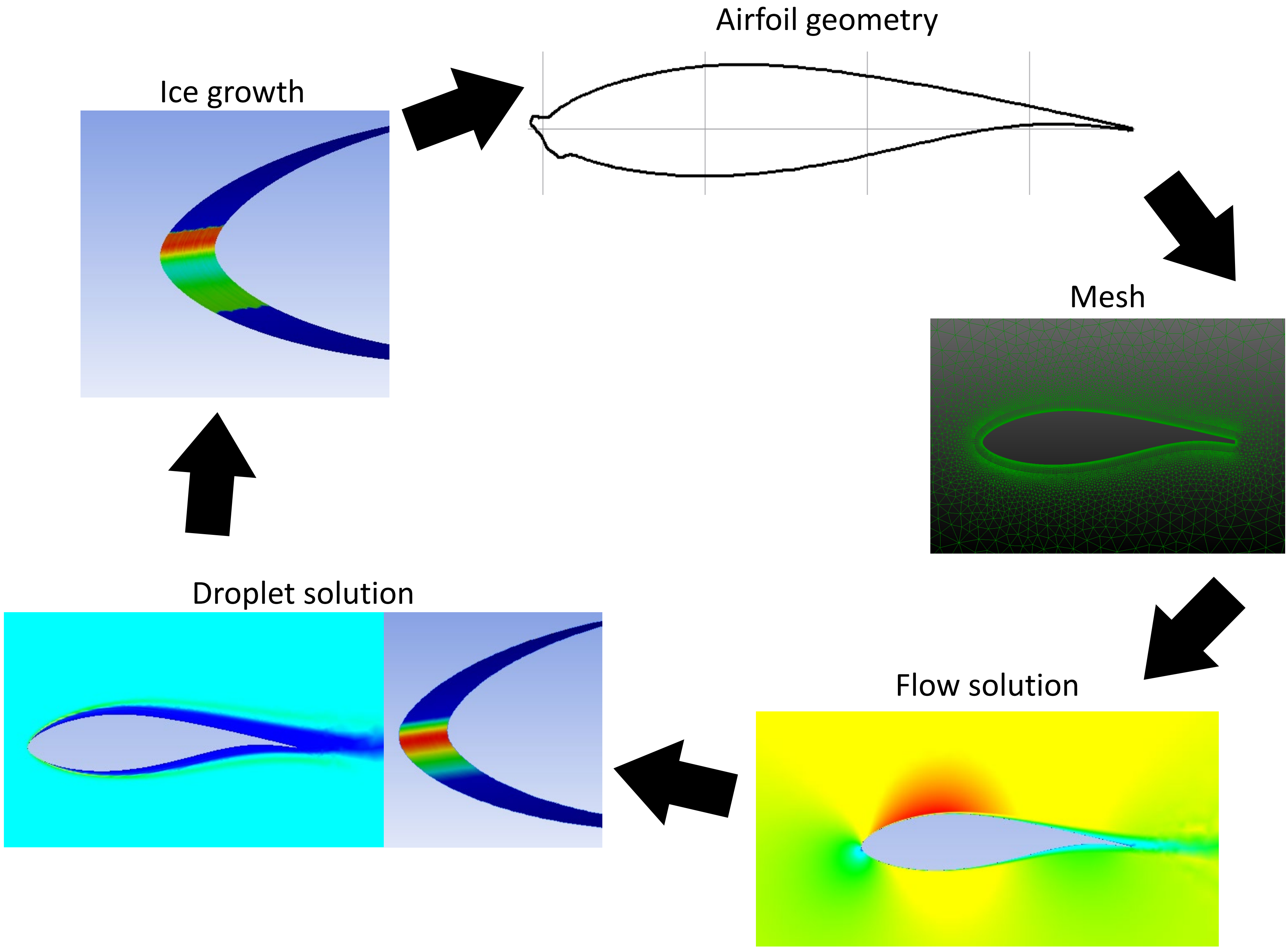
# Ice growth (t=3)

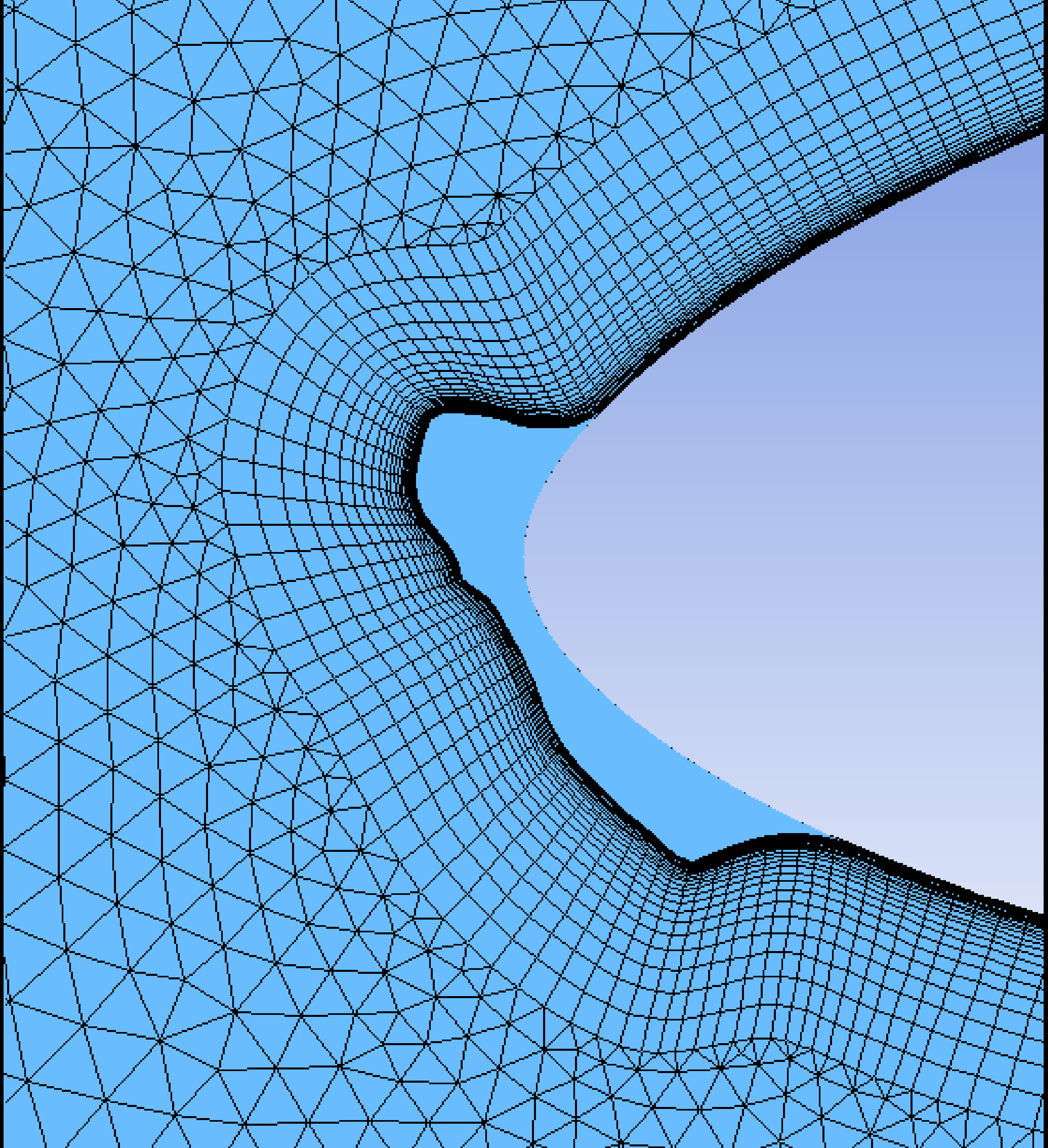


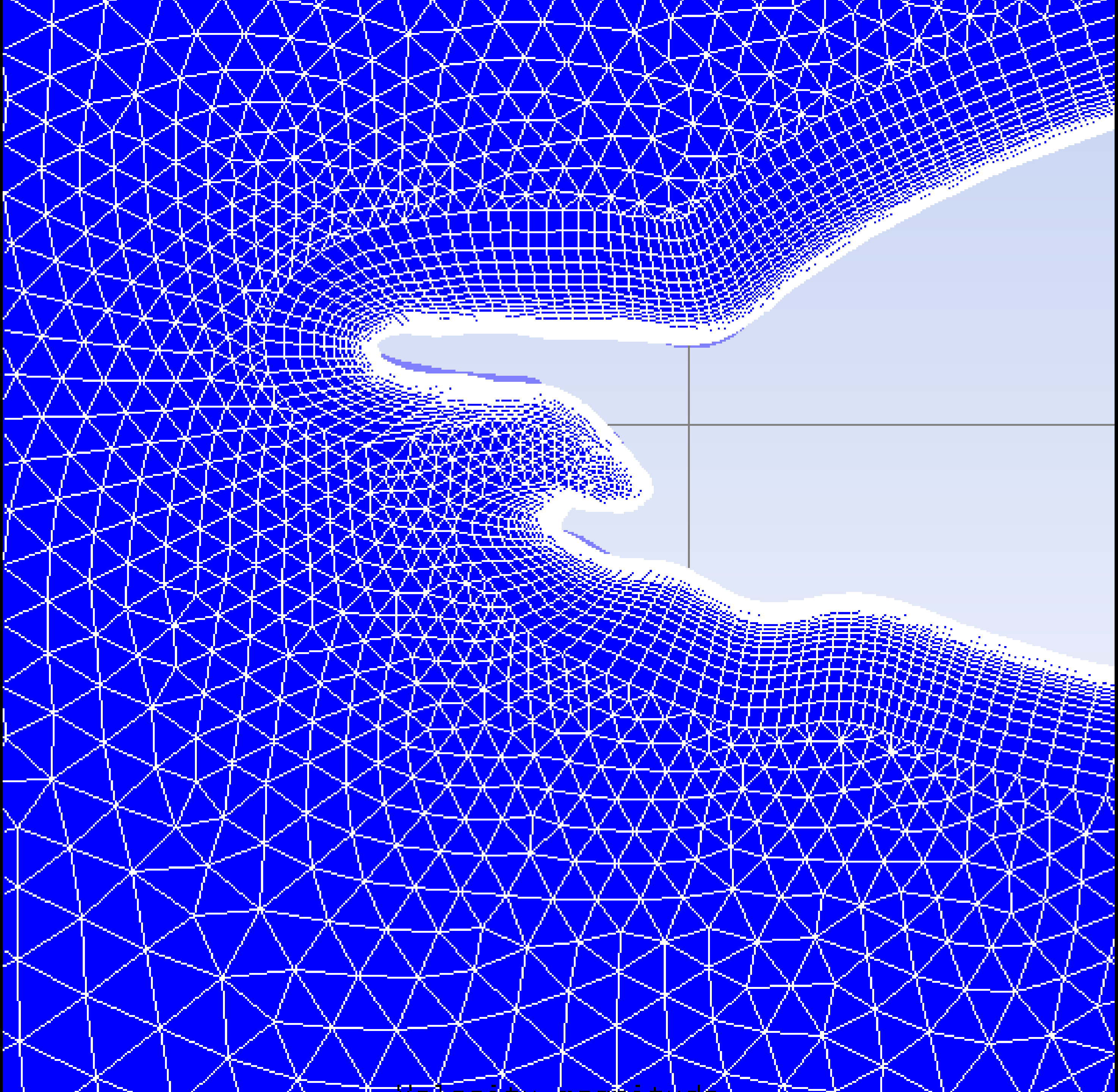
# Ice growth (t=4)



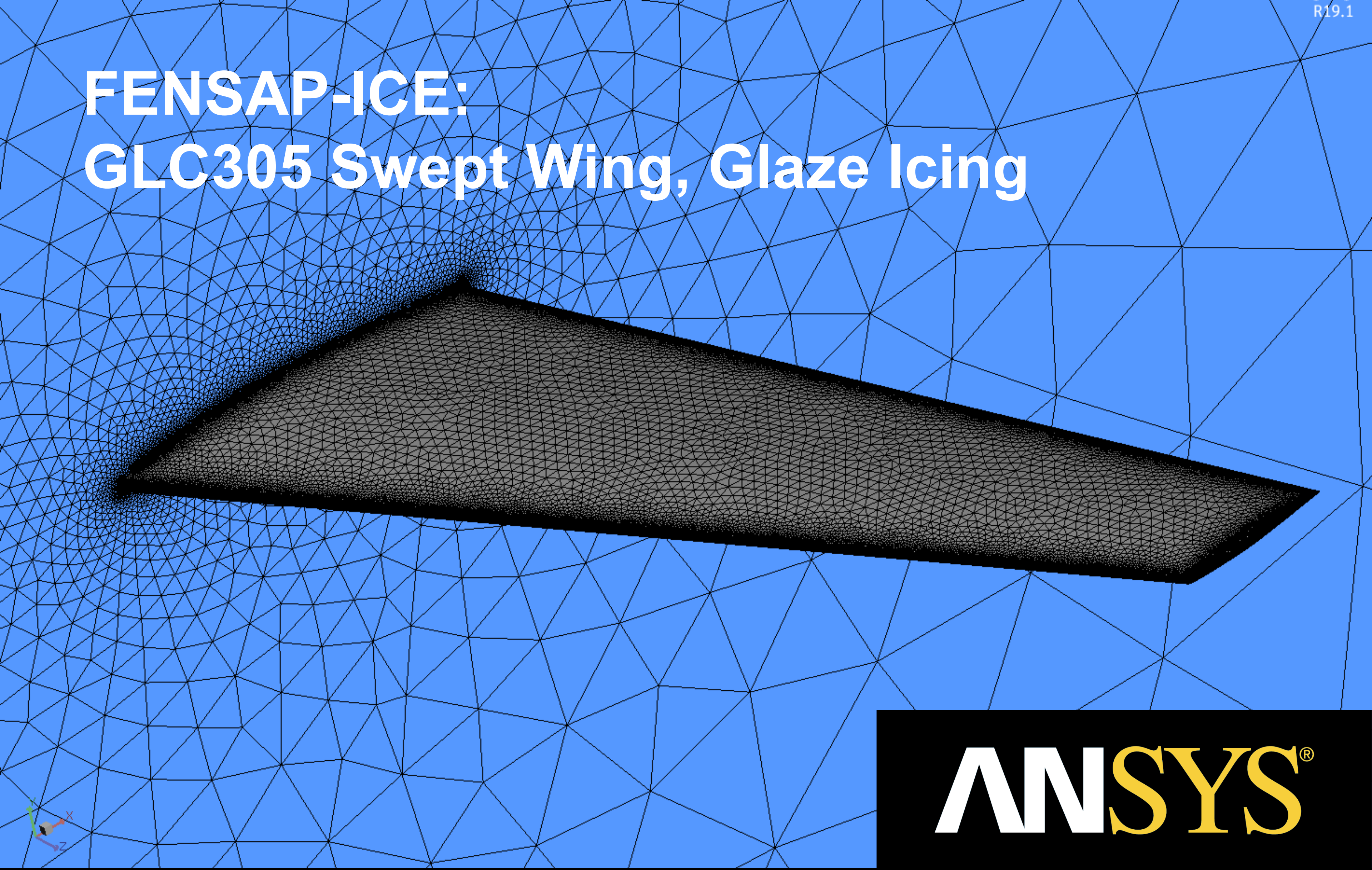

Airfoil geometry
Mesh
Flow solution
Droplet solution
Ice growth


Airfoil geometry
Mesh
Flow solution
Droplet solution
Ice growth

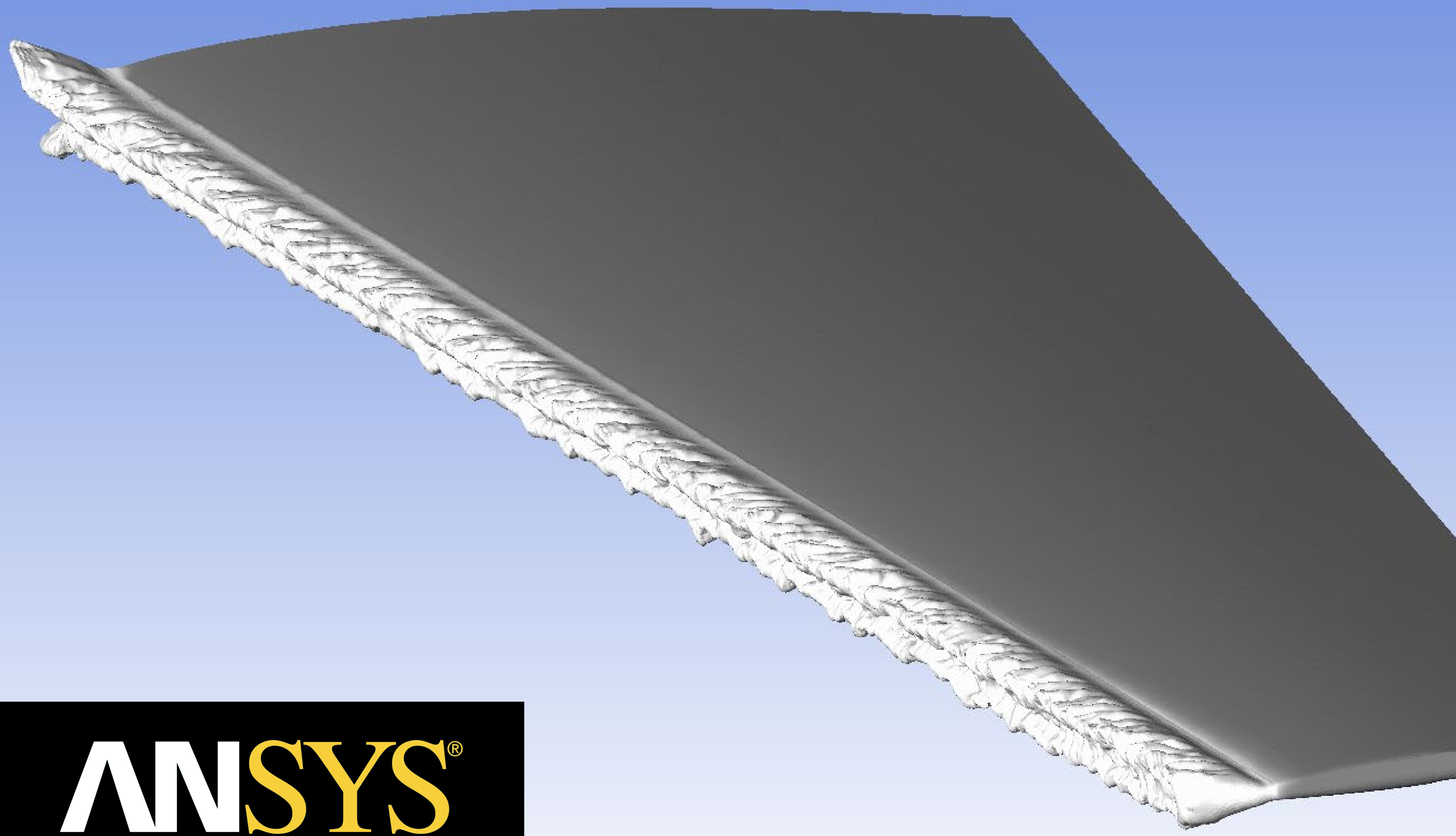




# FENSAP-ICE:
# GLC305 Swept Wing, Glaze Icing

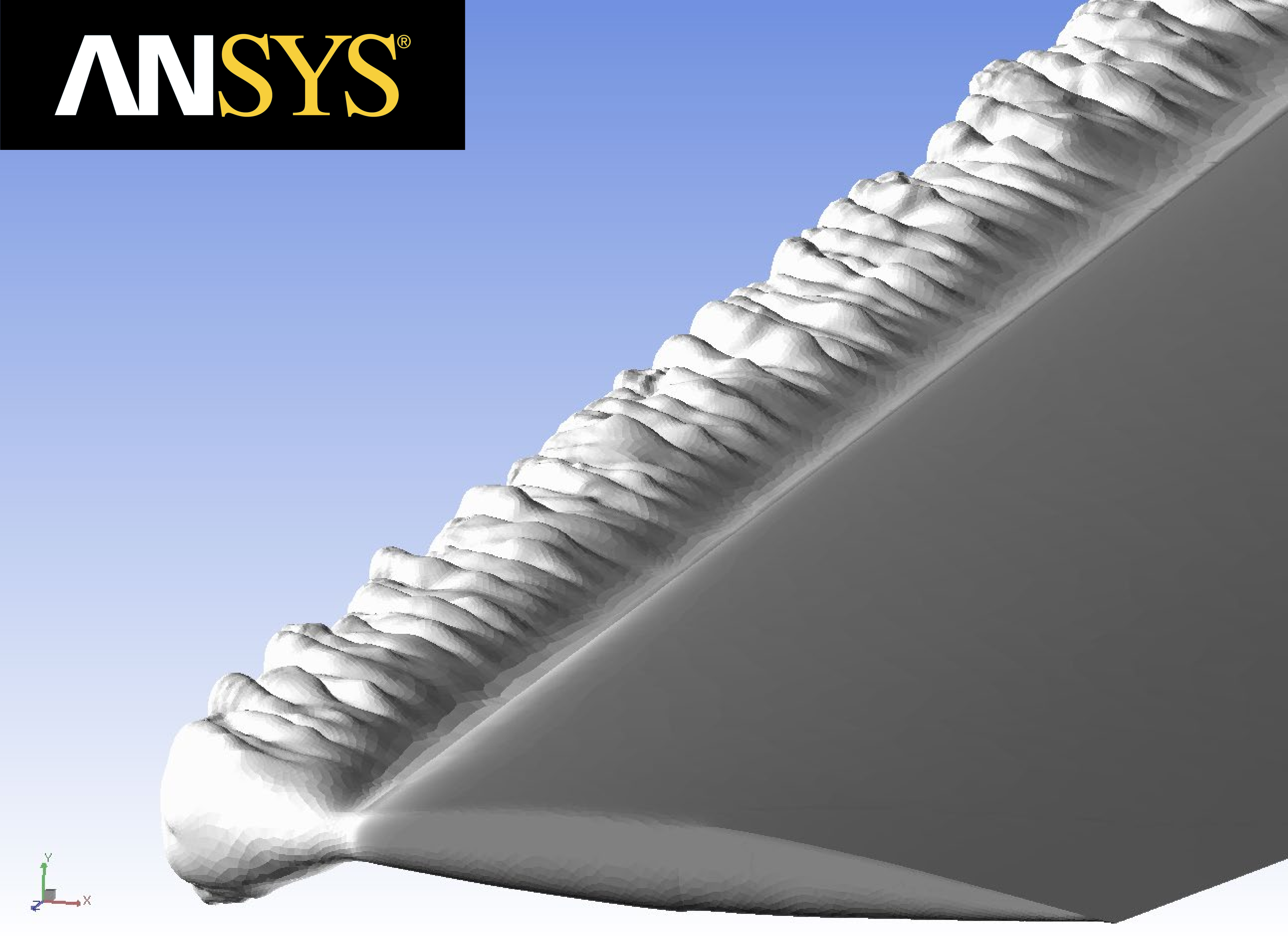


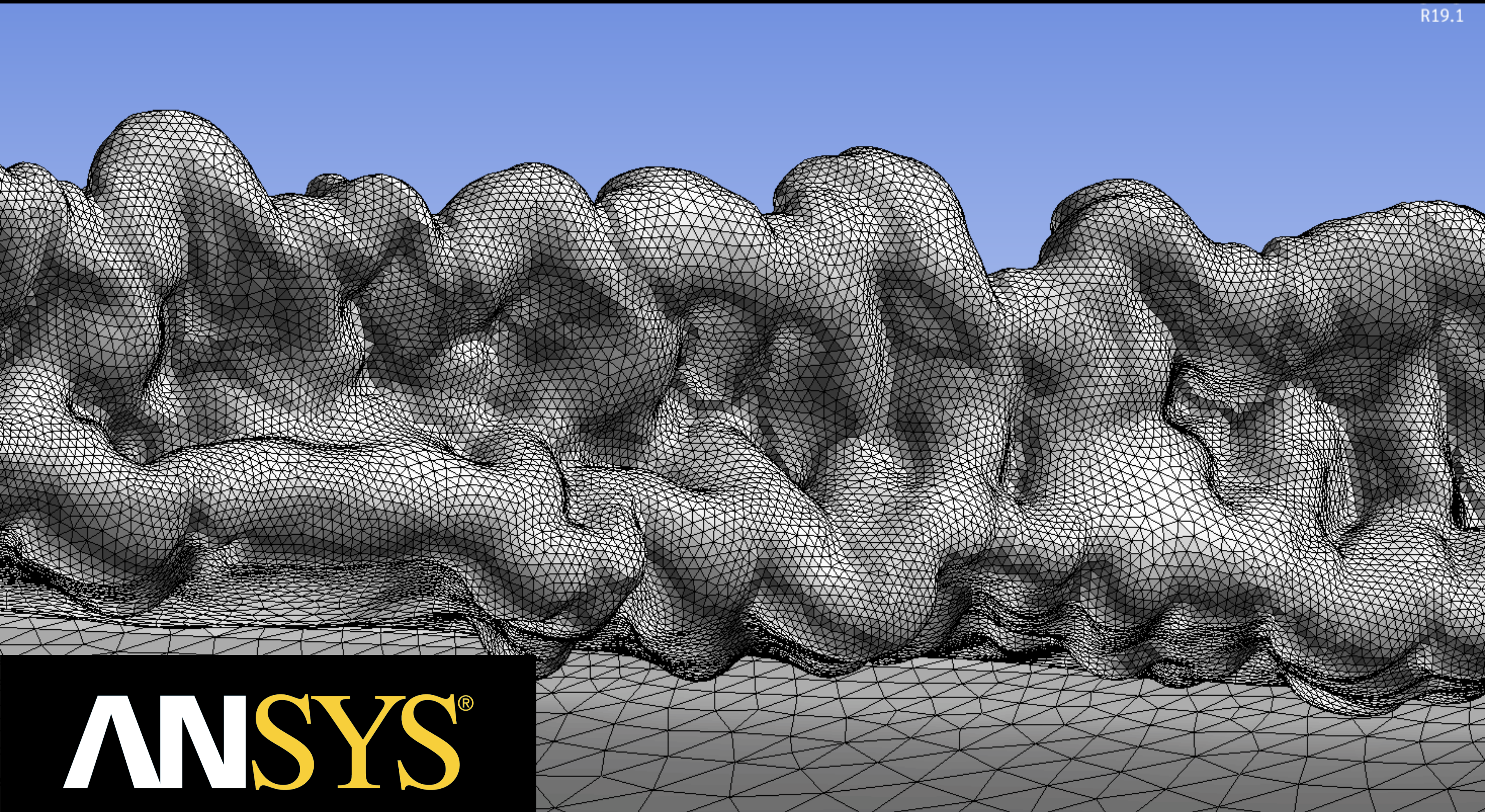

ANSYS®

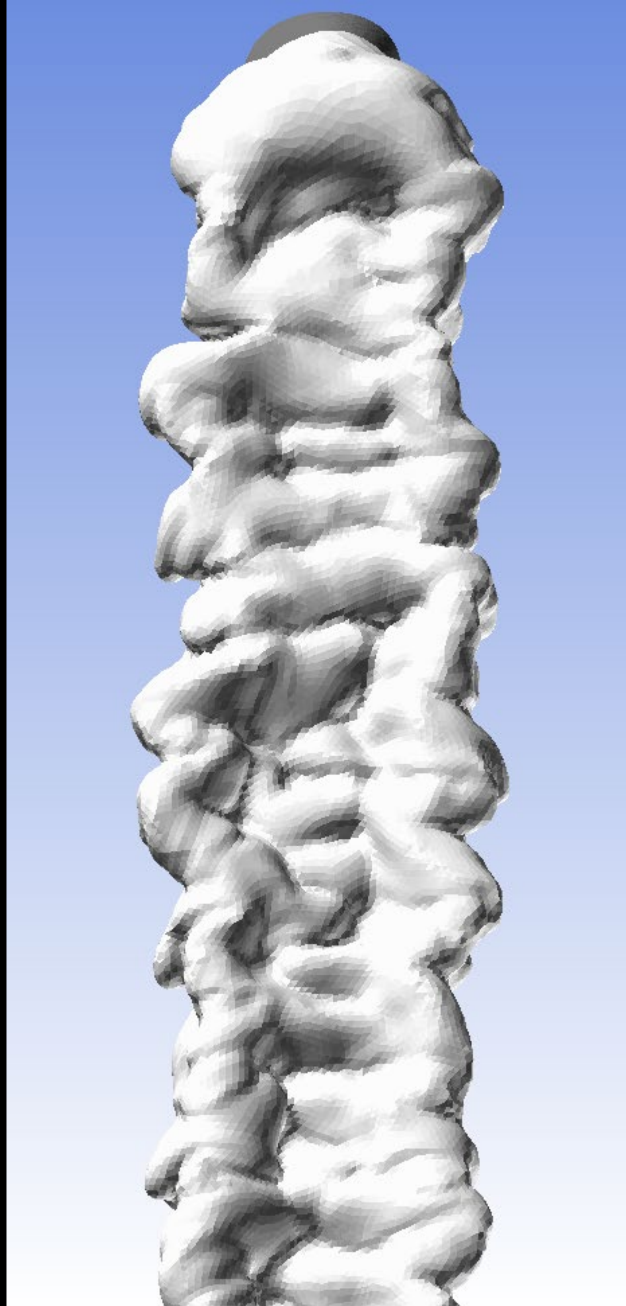


ANSYS®

ANSYS®

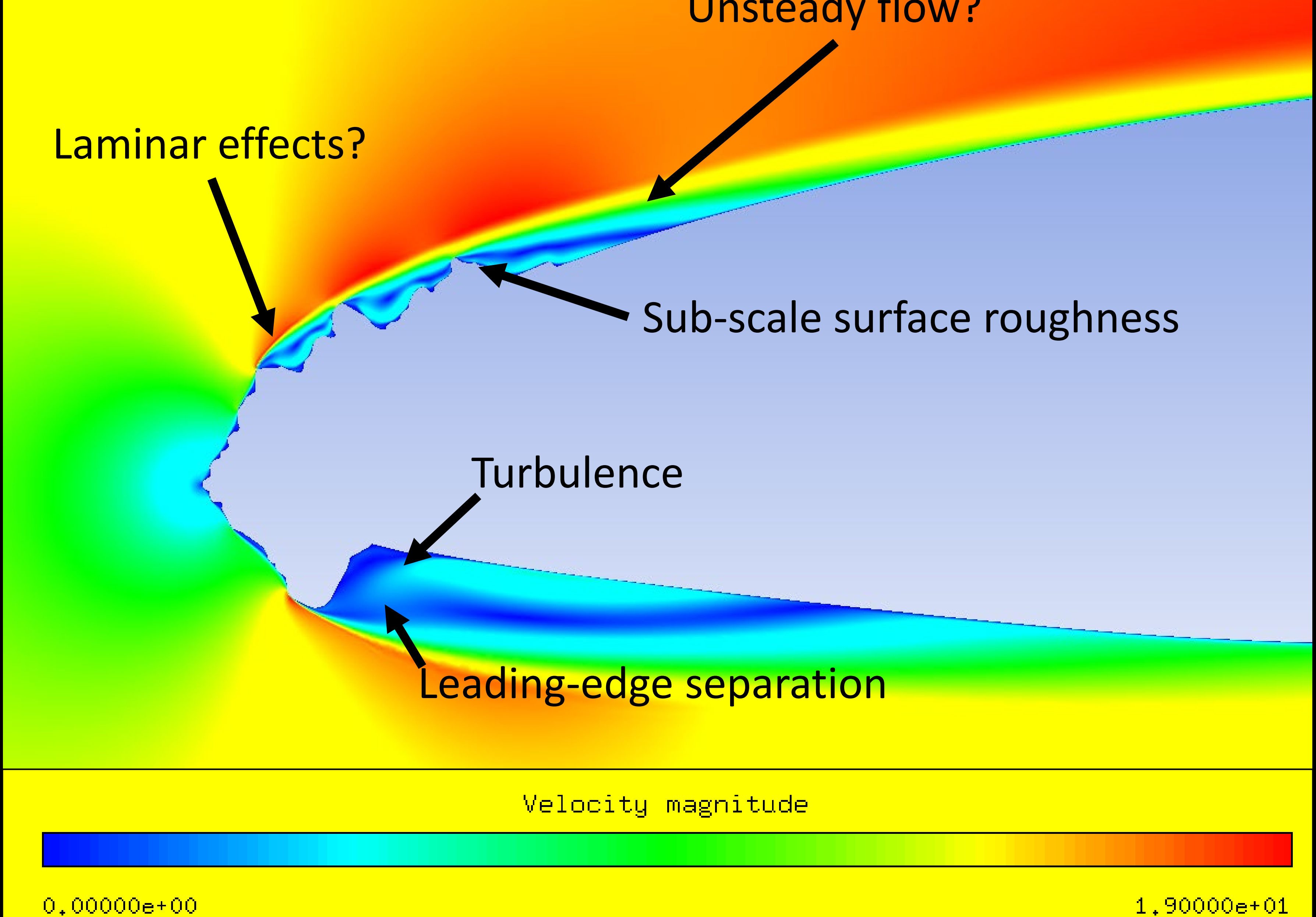



R19.1
ANSYS



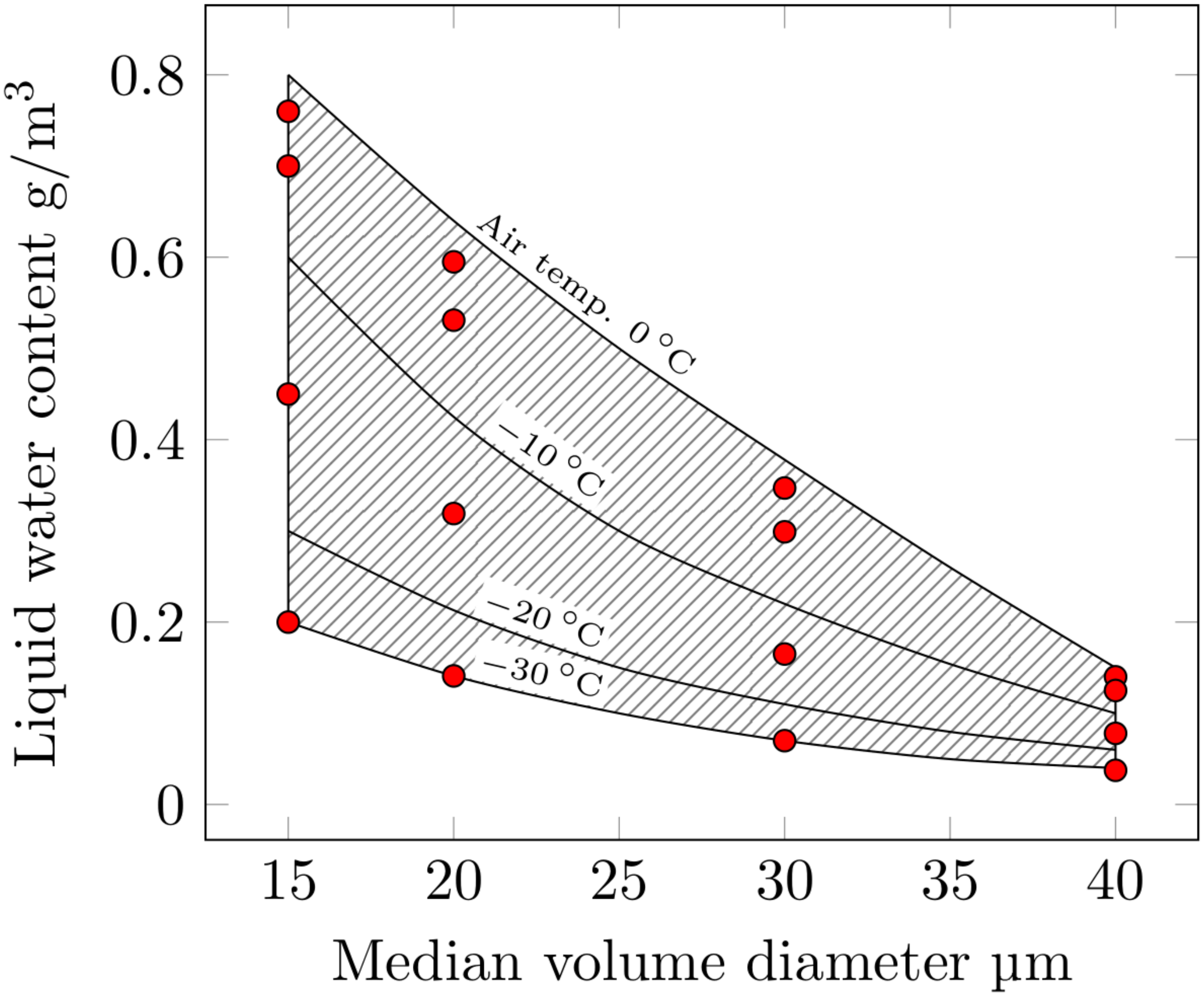

IRT-
CS22

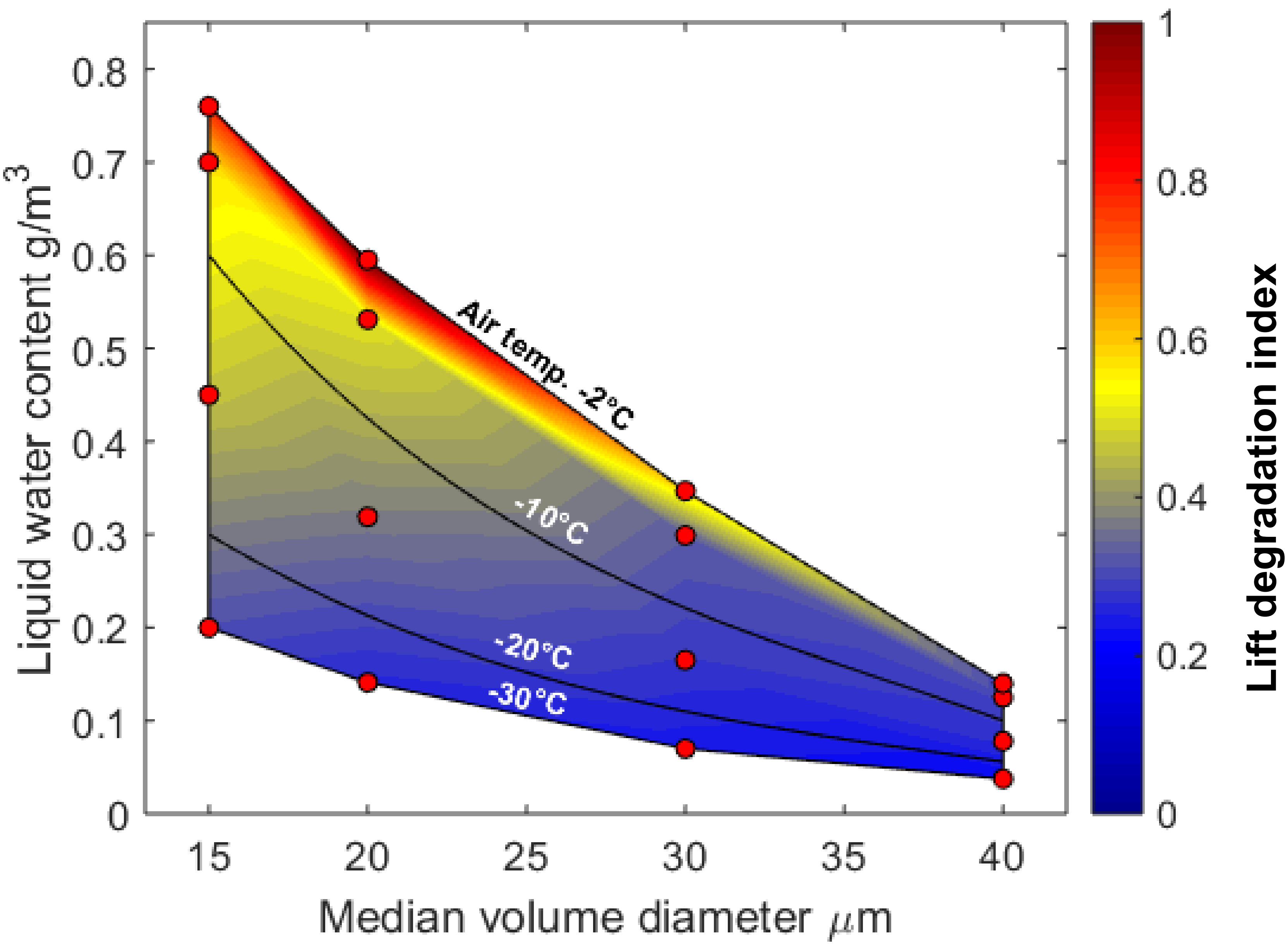
# ICING EFFECTS




Simulation → Icing wind tunnel → Flight tests

# CFR 14, Part 25, Appendix C icing envelope



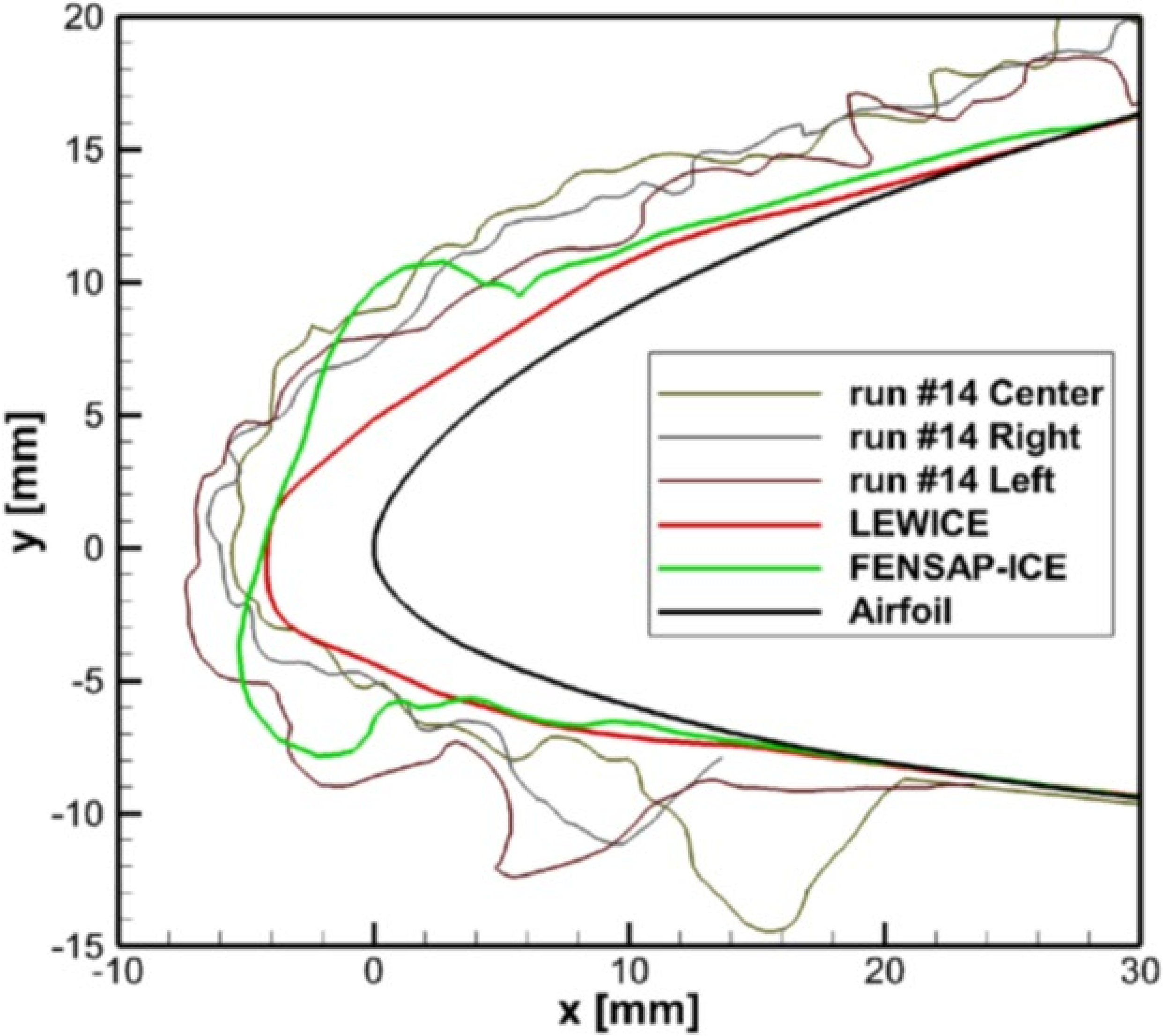

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Liquid water content g/m3
15
20
25
30
35
40
Median volume diameter μm
Air temp. -2°C
-10°C
-20°C
-30°C
1
0.8
0.6
0.4
0.2
0
Lift degradation index

„A toolbox alone, does not make a handyman!“

- German proverb

# MISSING

# LOW-REYNOLDS VALIDATION



y [mm]
x [mm]
run #14 Center
run #14 Right
run #14 Left
LEWICE
FENSAP-ICE
Airfoil
20
15
10
5
0
-5
-10
-15
-10
0
10
20
30

# Next Up…

- Overview paper*
- Validation Database
- Icing Protection System Energy Requirements
- Icing on Propellers

*SAE Edge Report: "Unsettled Topics in UAV Icing" est. Q1 2020

# Conclusions

# Conclusions

- Icing is a severe hazard for UAVs.
- Severity depends on UAV type, mission, icing environment, …
- Icing may be more severe for UAVs than for manned aircraft.
- Mature icing simulation methods exist but lack validation for UAVs.
- Tailor-made icing protection systems for UAVs are required.

# Questions?

richard.hann@ntnu.no