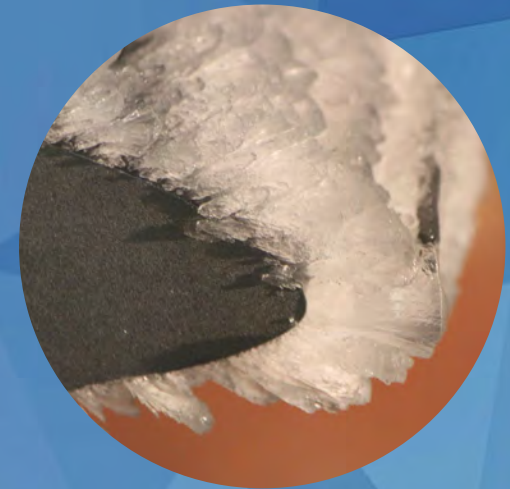


ICING ON UAVs

Richard Hann / richard.hann@ntnu.no



A man with glasses and a beard, wearing a blue and green puffer jacket and dark pants, stands in a vast, flat, brownish landscape. He is holding a white drone controller. In the background, a large, snow-capped mountain rises under a cloudy sky. To the left, a small blue building is visible. The overall scene is an Arctic or high-altitude environment.

Richard Hann

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

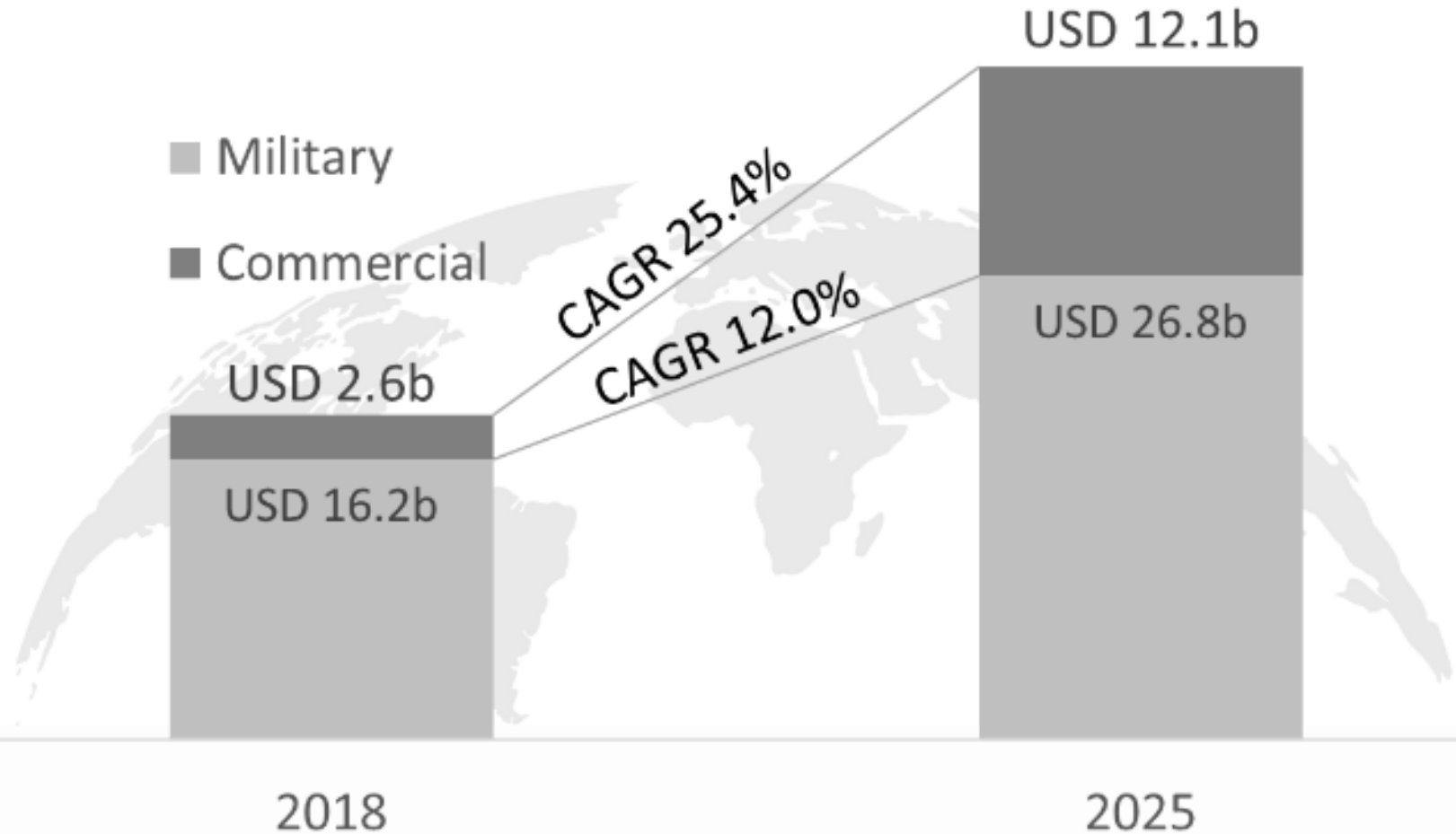
drone

noun

/ˈdrɒn/

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

GLOBAL UAV MARKET



Source: Market Study Report LLC & MarketsandMarkets INC

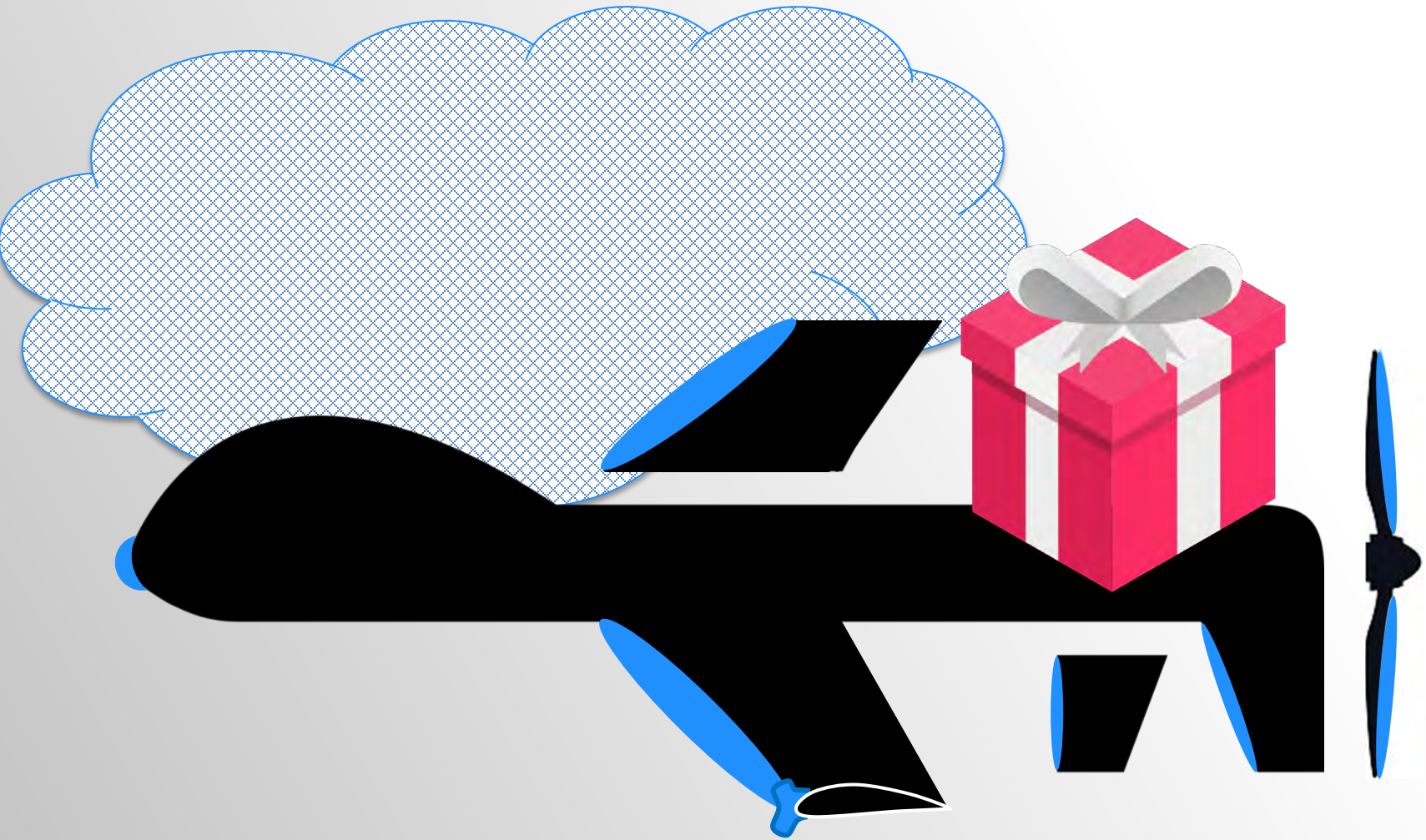
Date: 2018

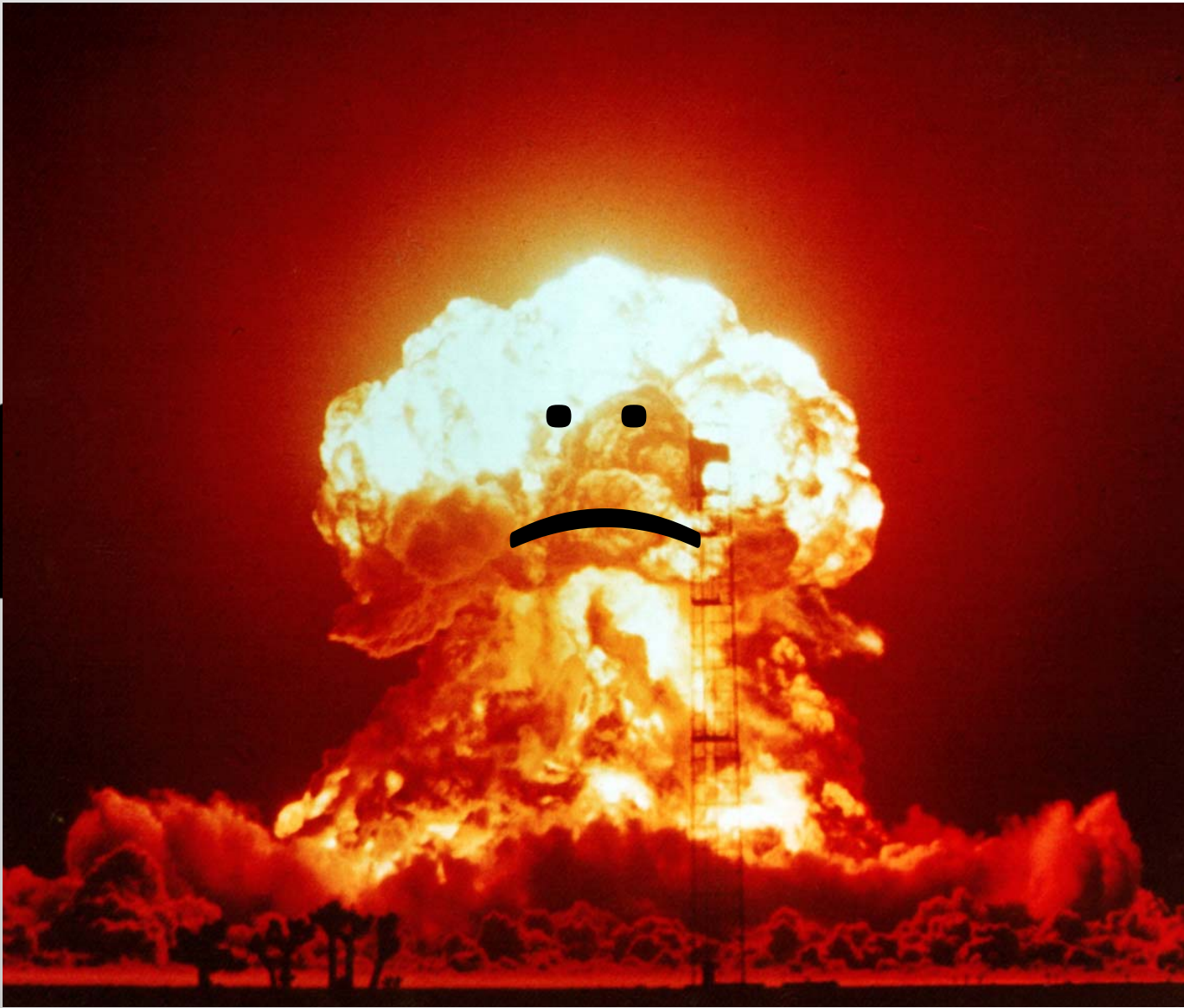
Civil UAV Applications

A white quadcopter drone is shown in flight, hovering in the air. In the background, a construction worker wearing a yellow hard hat and an orange safety vest is visible, looking towards the drone. The setting appears to be a construction site with a steel framework.

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



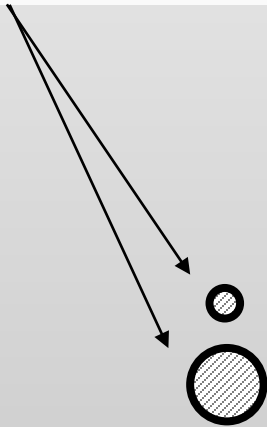




ATMOSPHERIC ICING

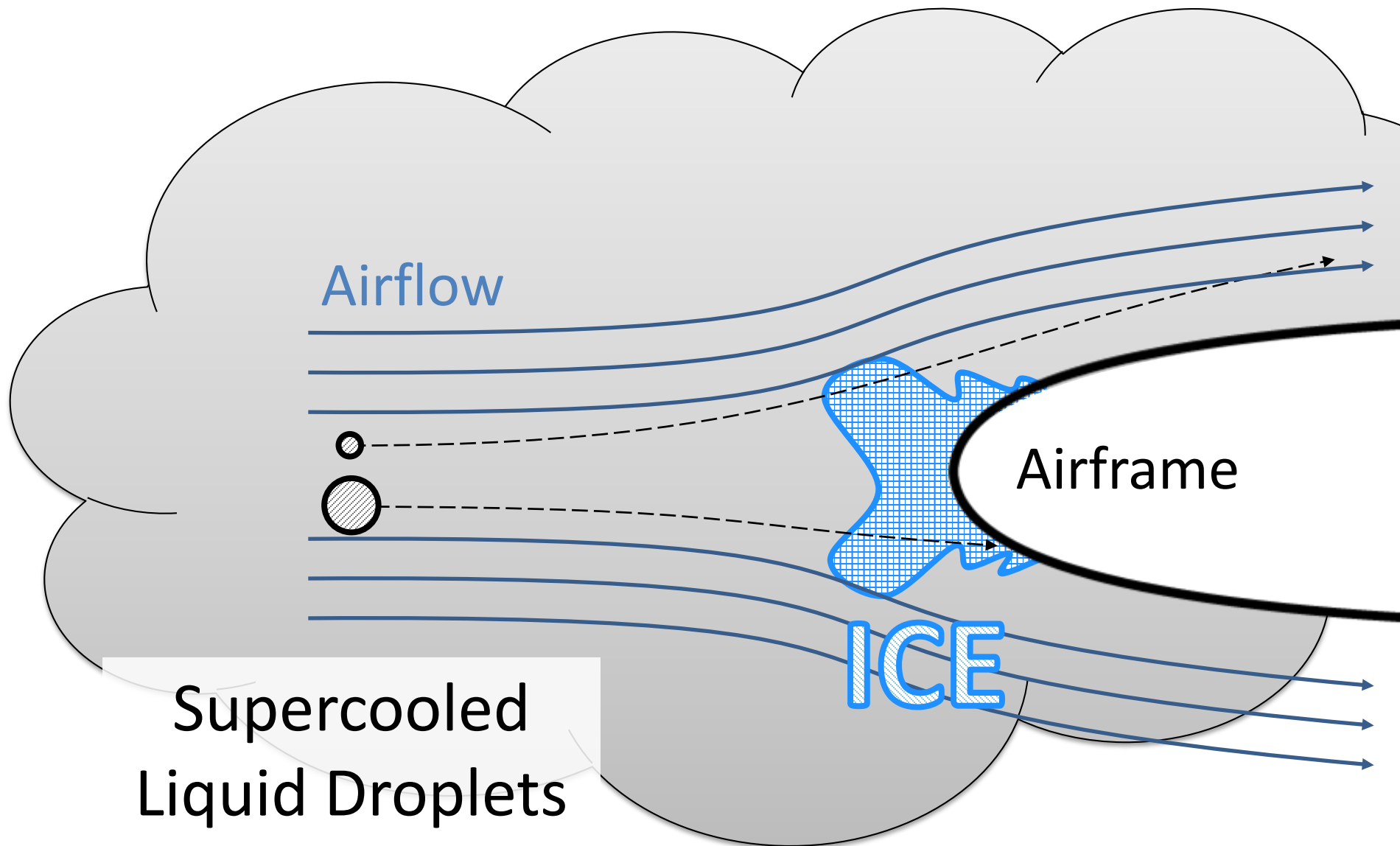
MVD: Median (drop) volume diameter

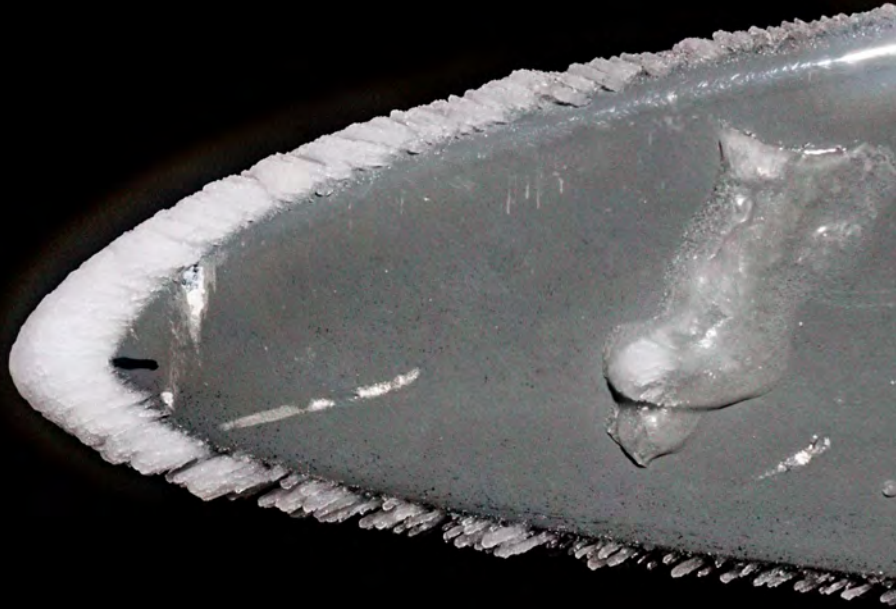
LWC: Liquid water content



Supercooled
Liquid Droplets

ATMOSPHERIC ICING





Rime: $T \ll 0^\circ\text{C}$



Glaze: $T \approx 0^\circ\text{C}$

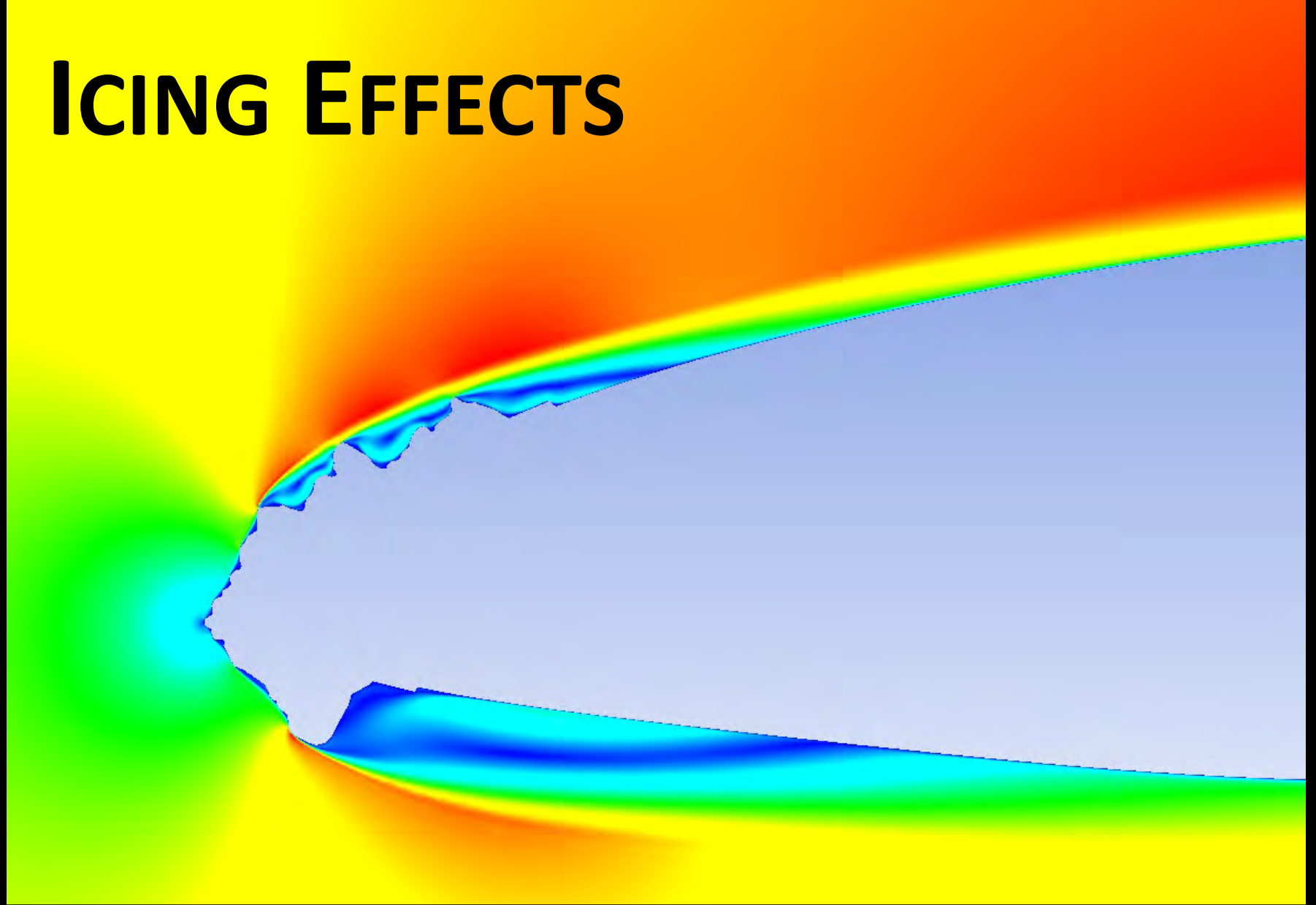
Rime Icing



Glaze Icing



ICING EFFECTS



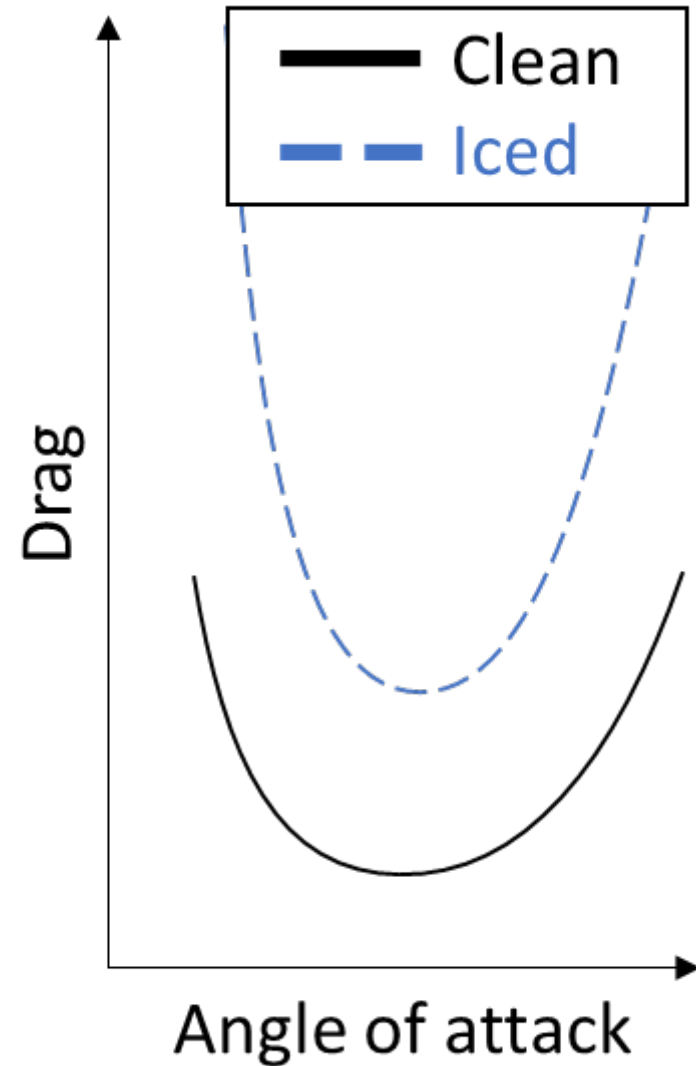
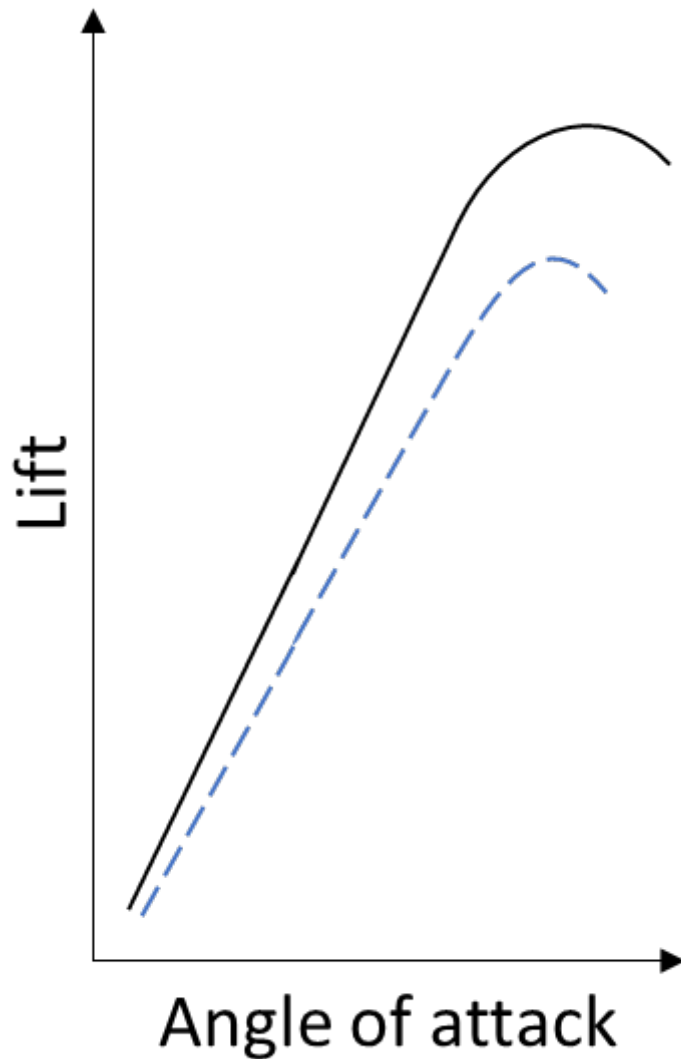
Velocity magnitude



0.00000e+00

1.90000e+01

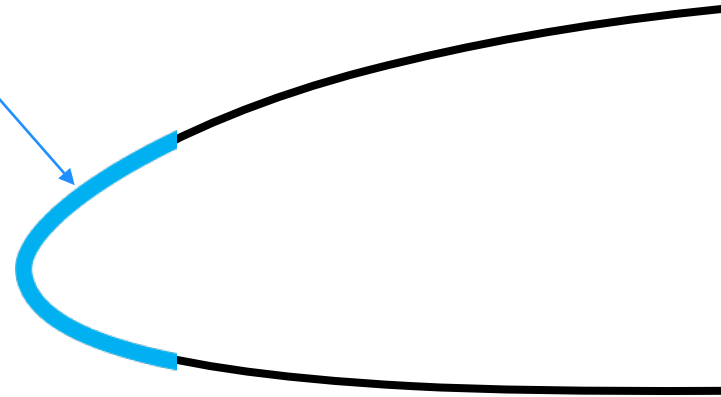
ICING EFFECTS

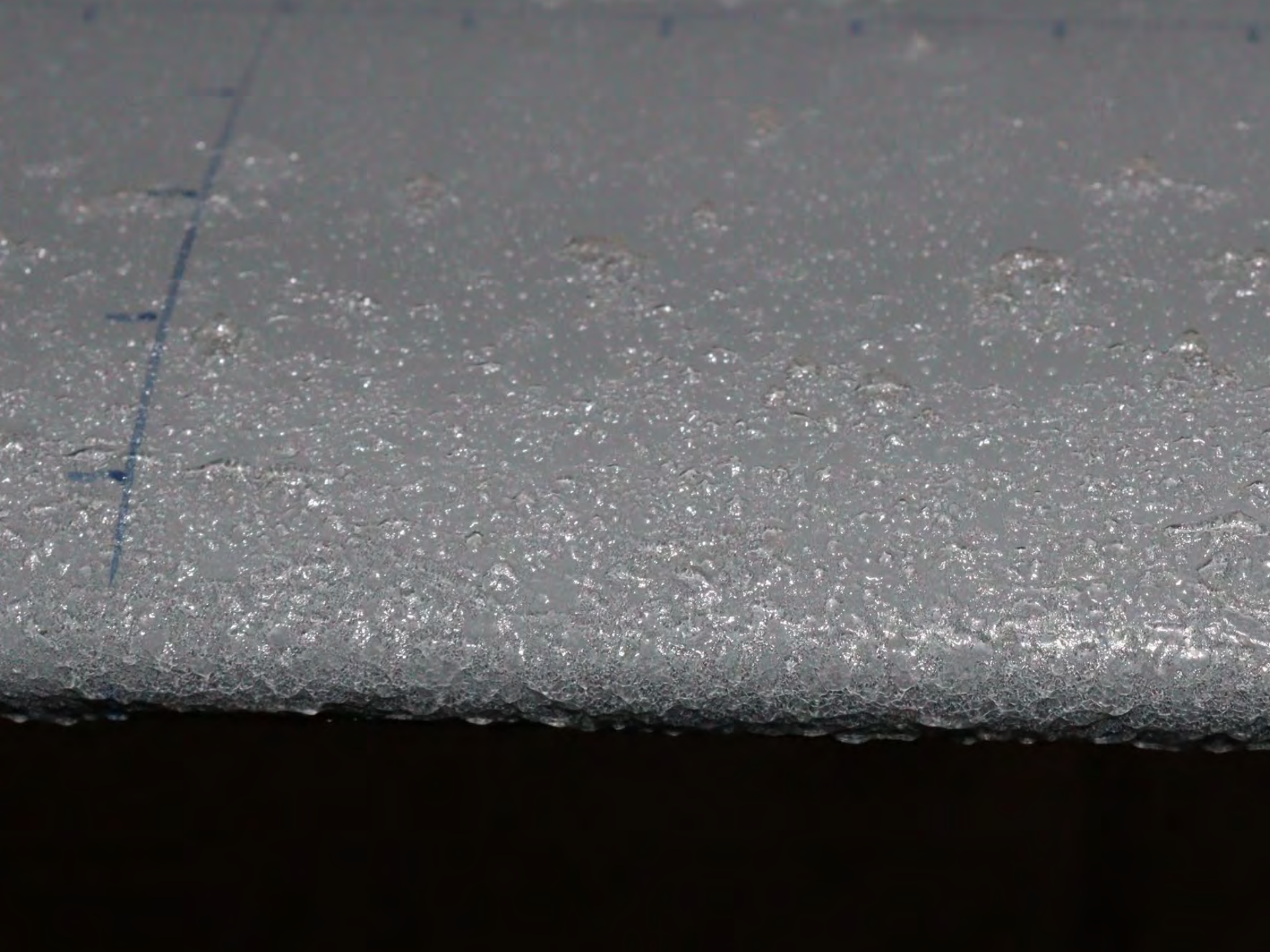


ICE MORPHOLOGIES



□ Airfoil

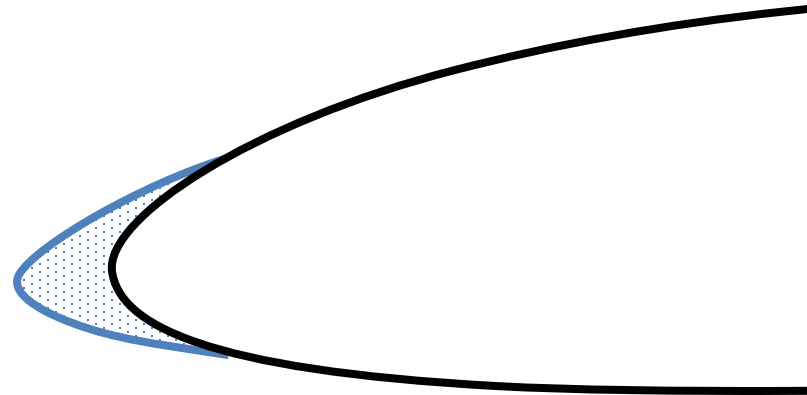
Surface roughness








ICE MORPHOLOGIES

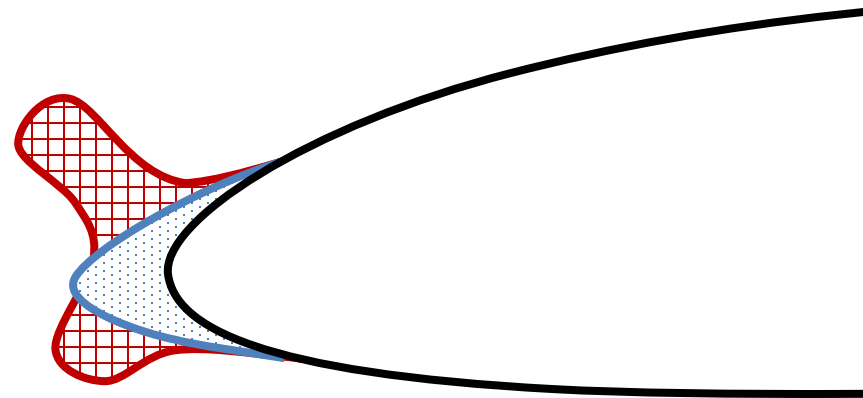
-  Airfoil
-  Streamwise ice









ICE MORPHOLOGIES

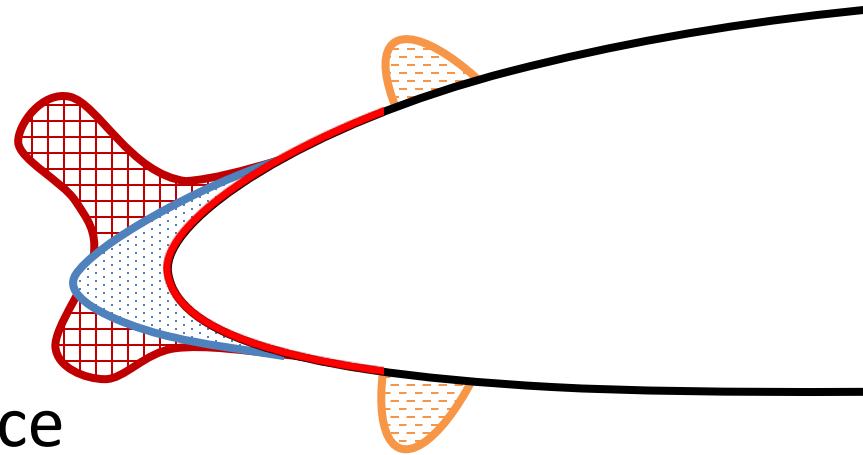
-  Airfoil
-  Streamwise ice
-  Horn ice

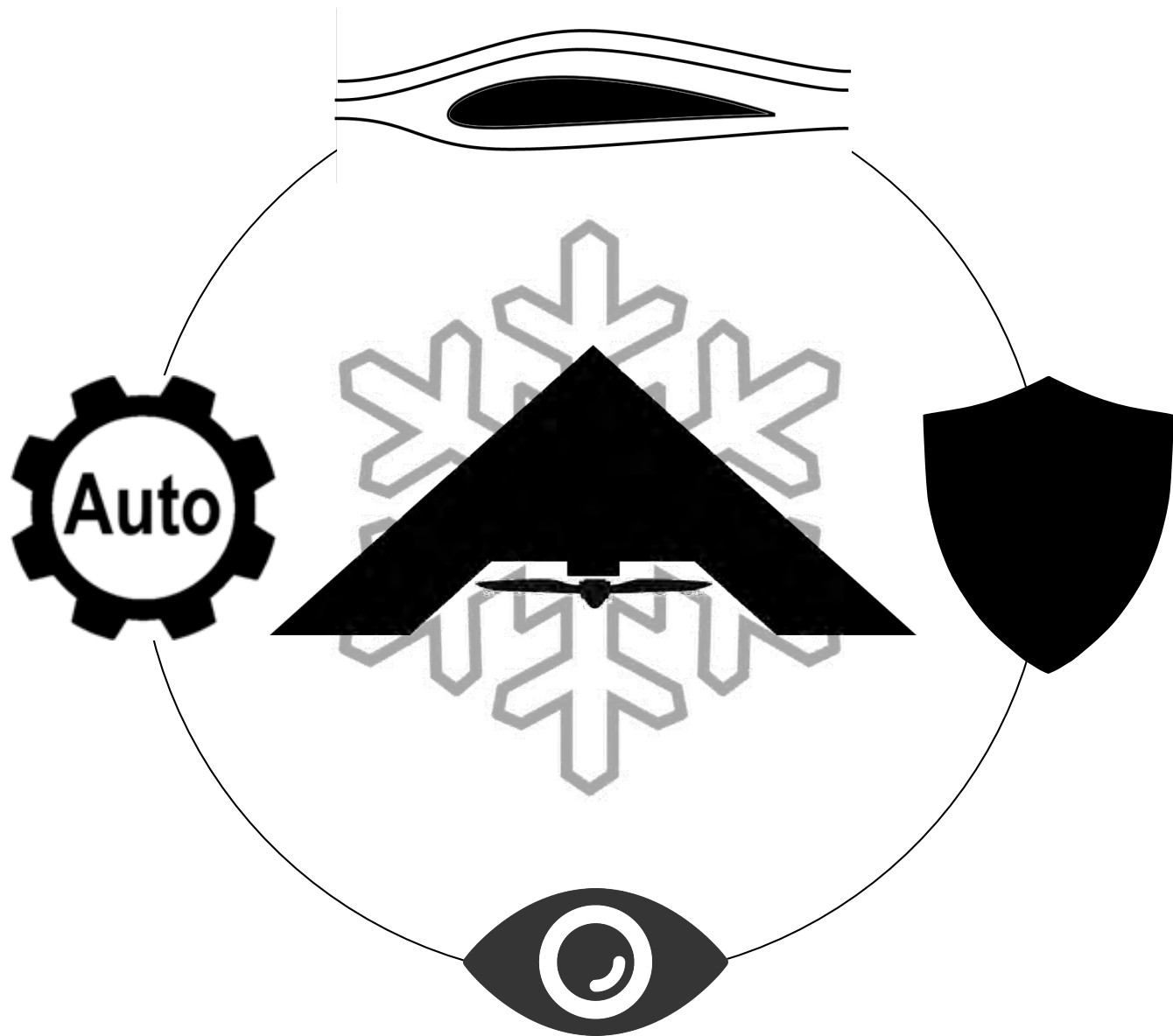




ICE MORPHOLOGIES

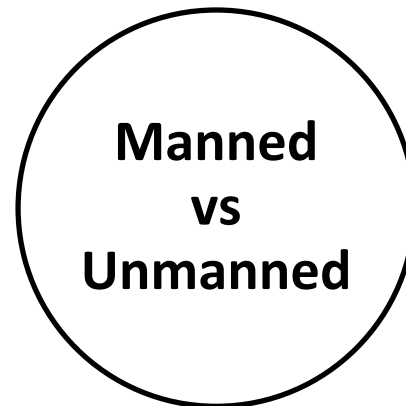
-  Airfoil
-  Streamwise ice
-  Horn ice
-  Spanwise-ridge ice



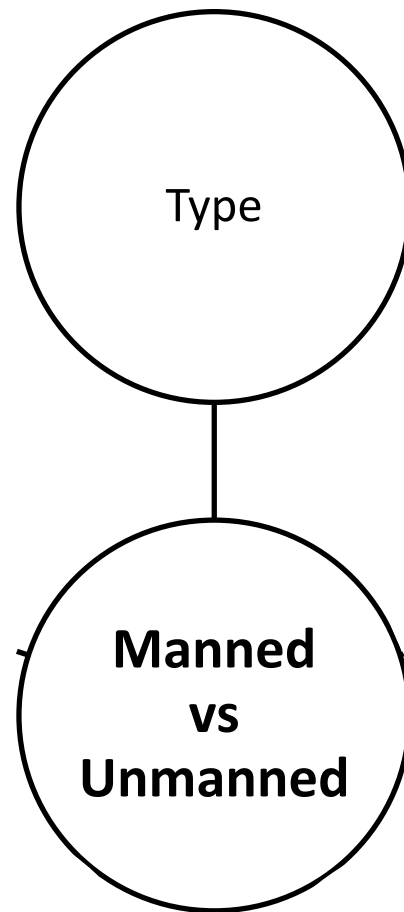


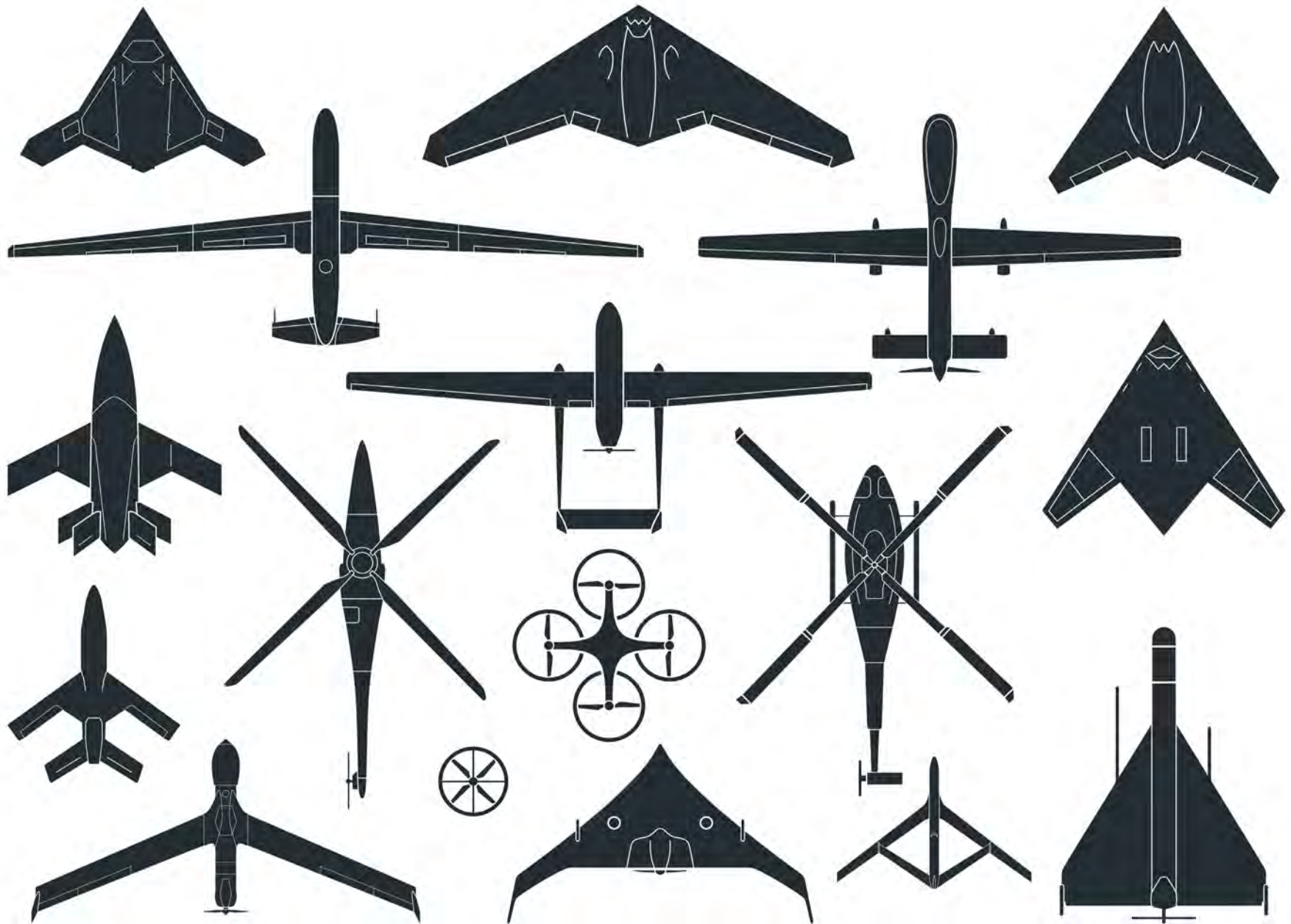






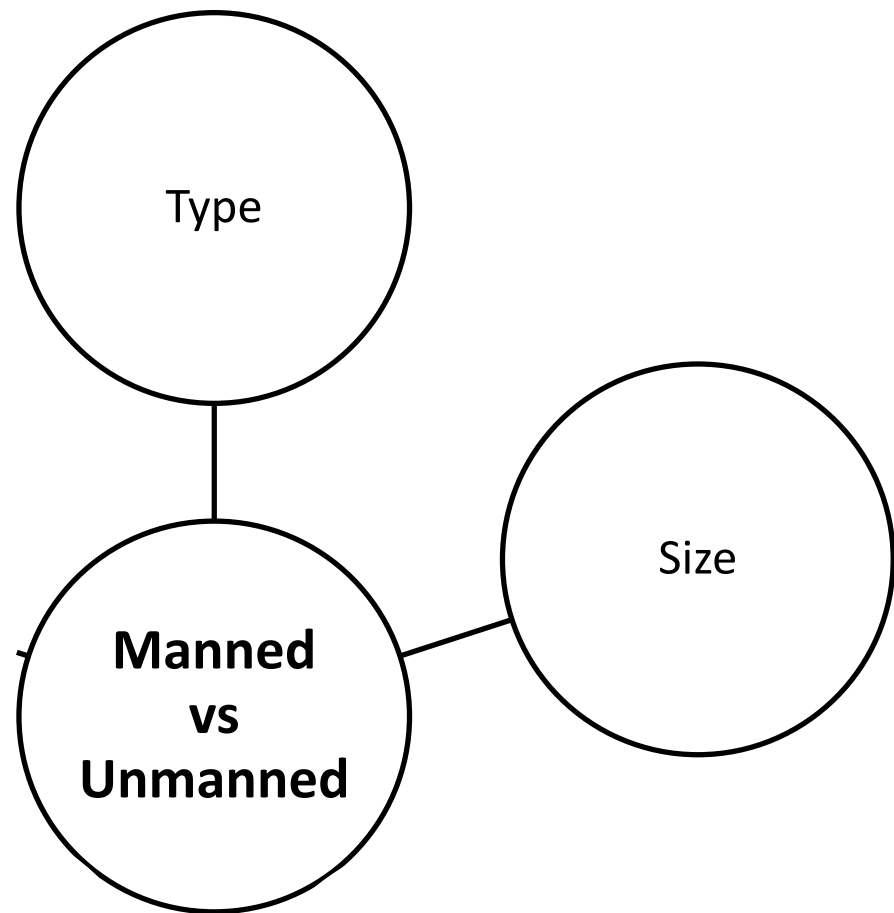
**Manned
vs
Unmanned**



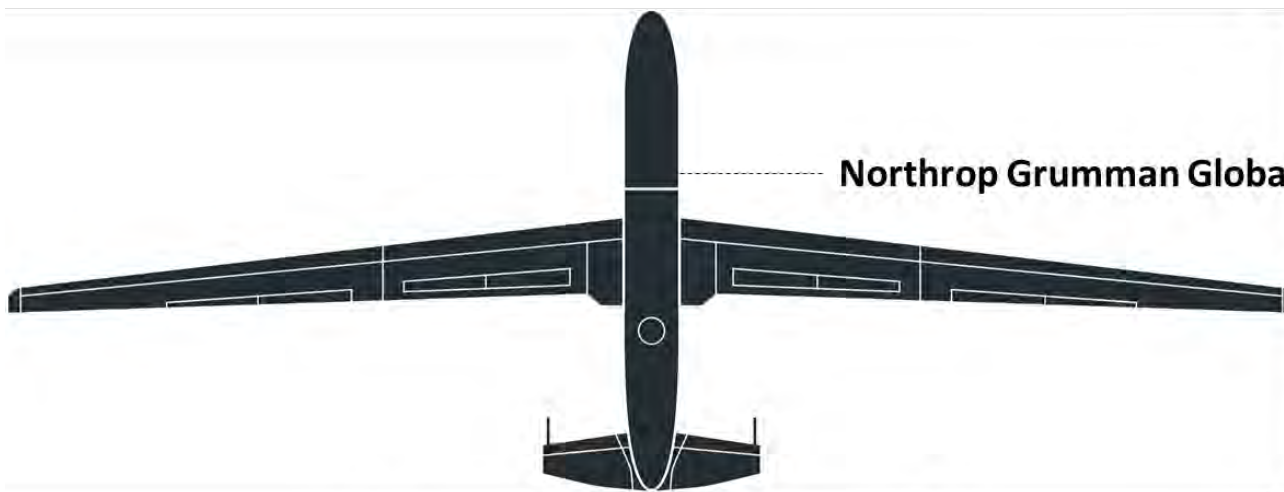




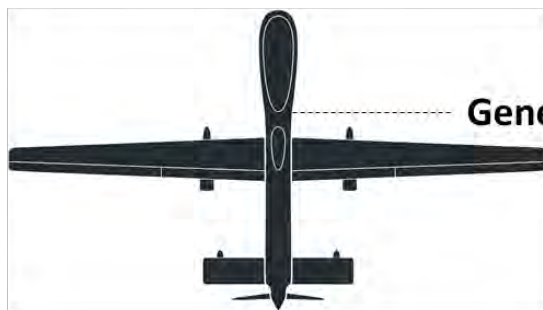
Source: Meteomatics



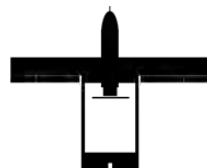
0 5 10 15 20 Meters



Northrop Grumman Global Hawk



General Atomics Predator



AAI Shadow

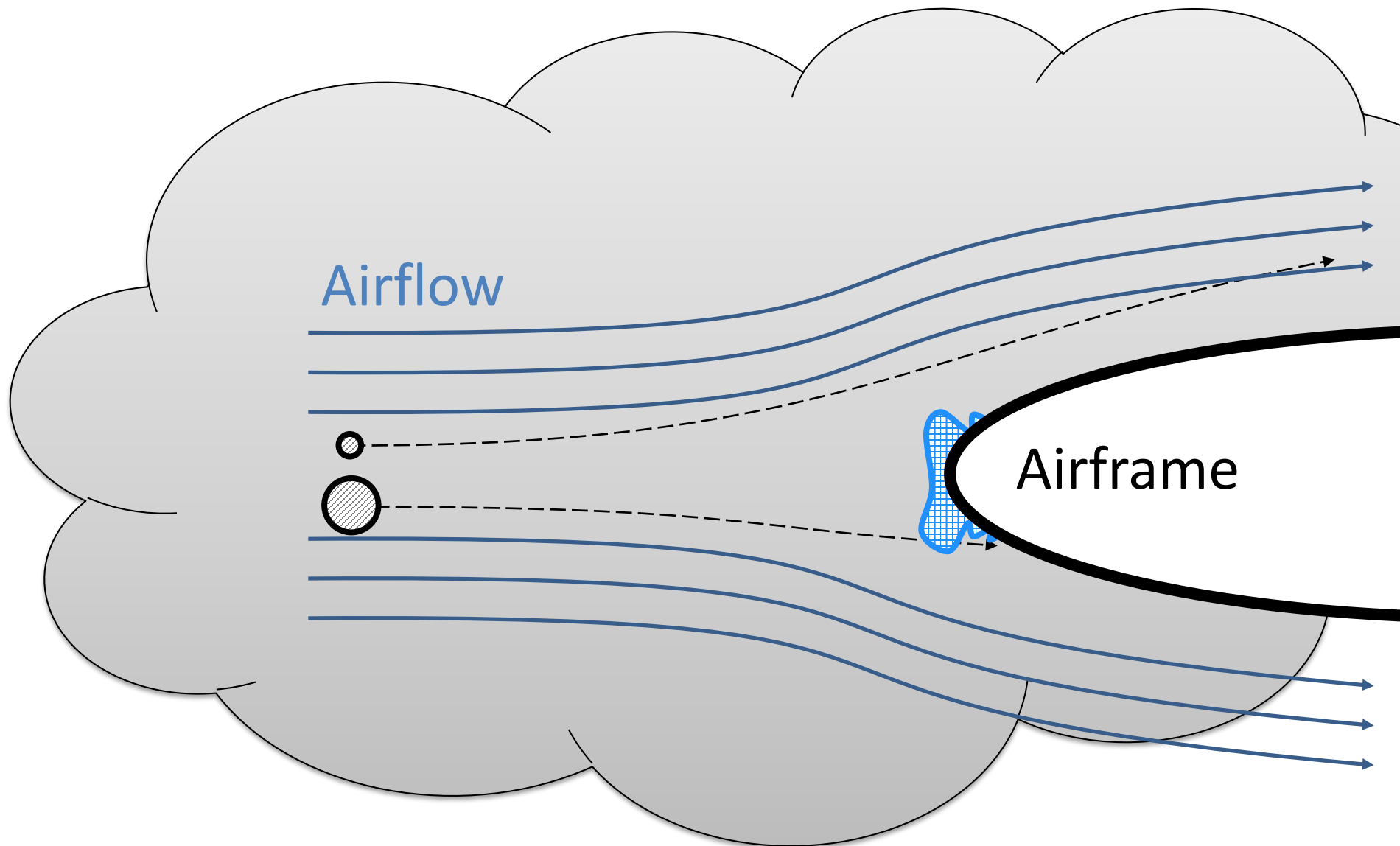


Boeing Insitu ScanEagle

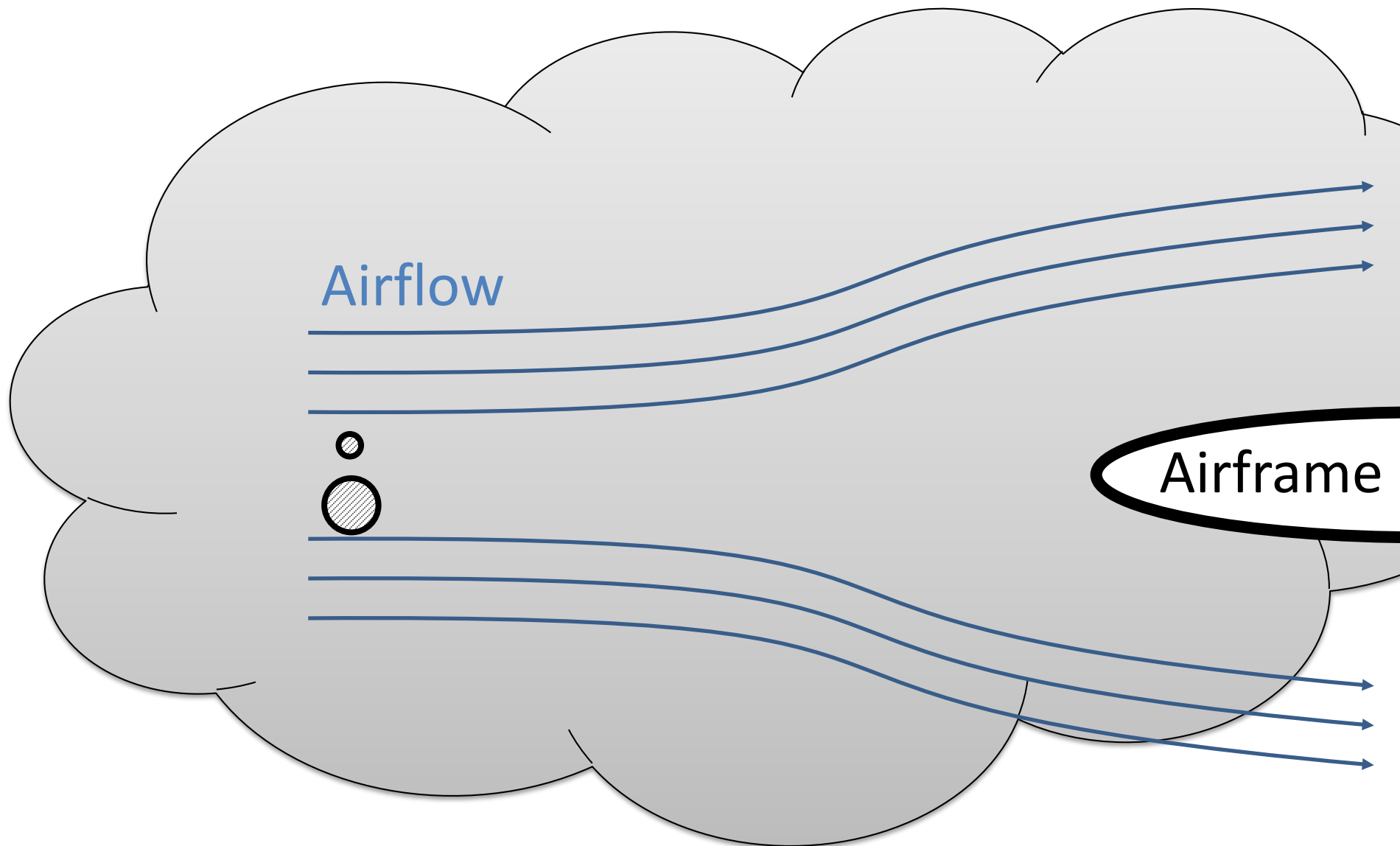


AeroVironment Wasp

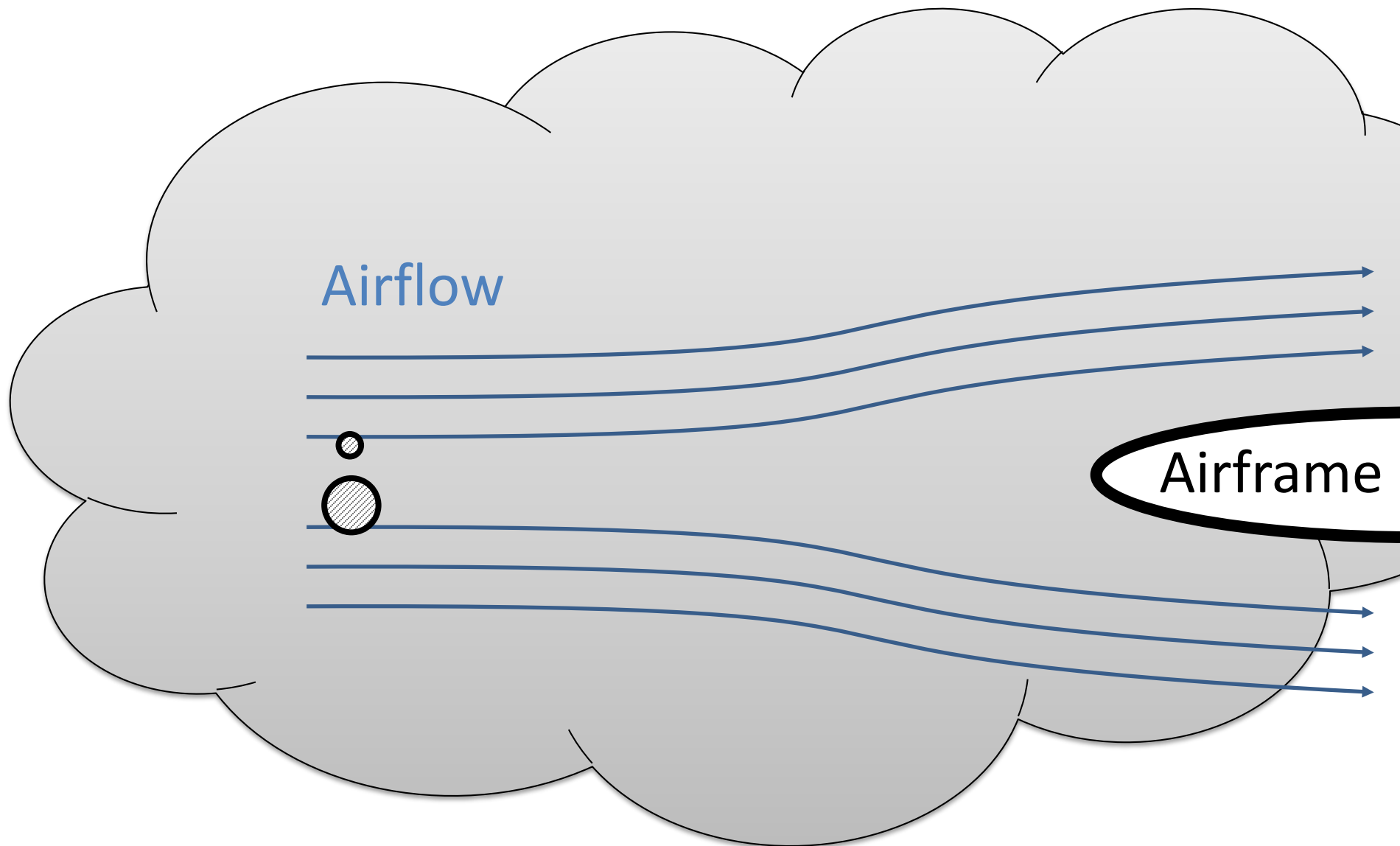
INFLUENCE OF SIZE



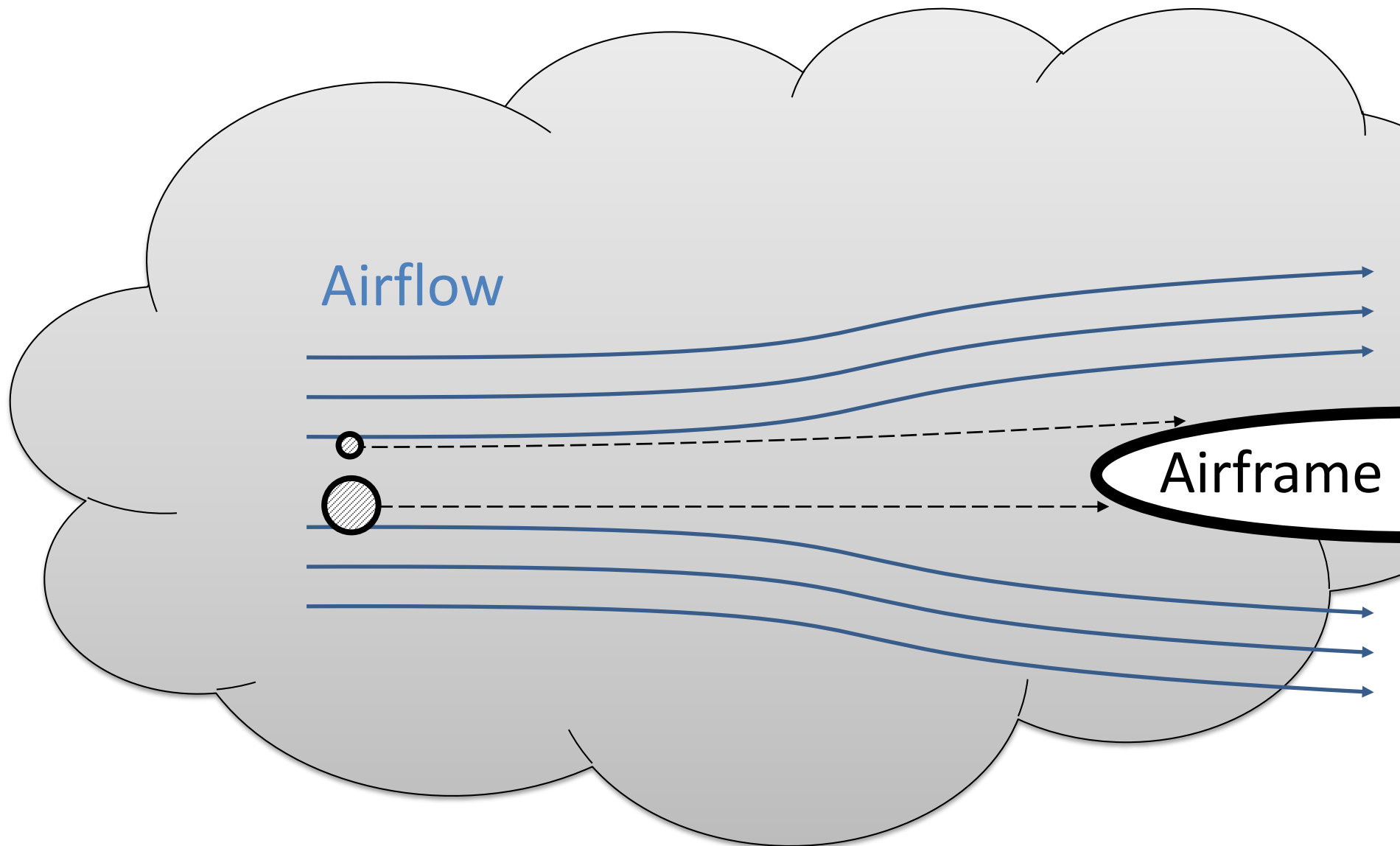
INFLUENCE OF SIZE



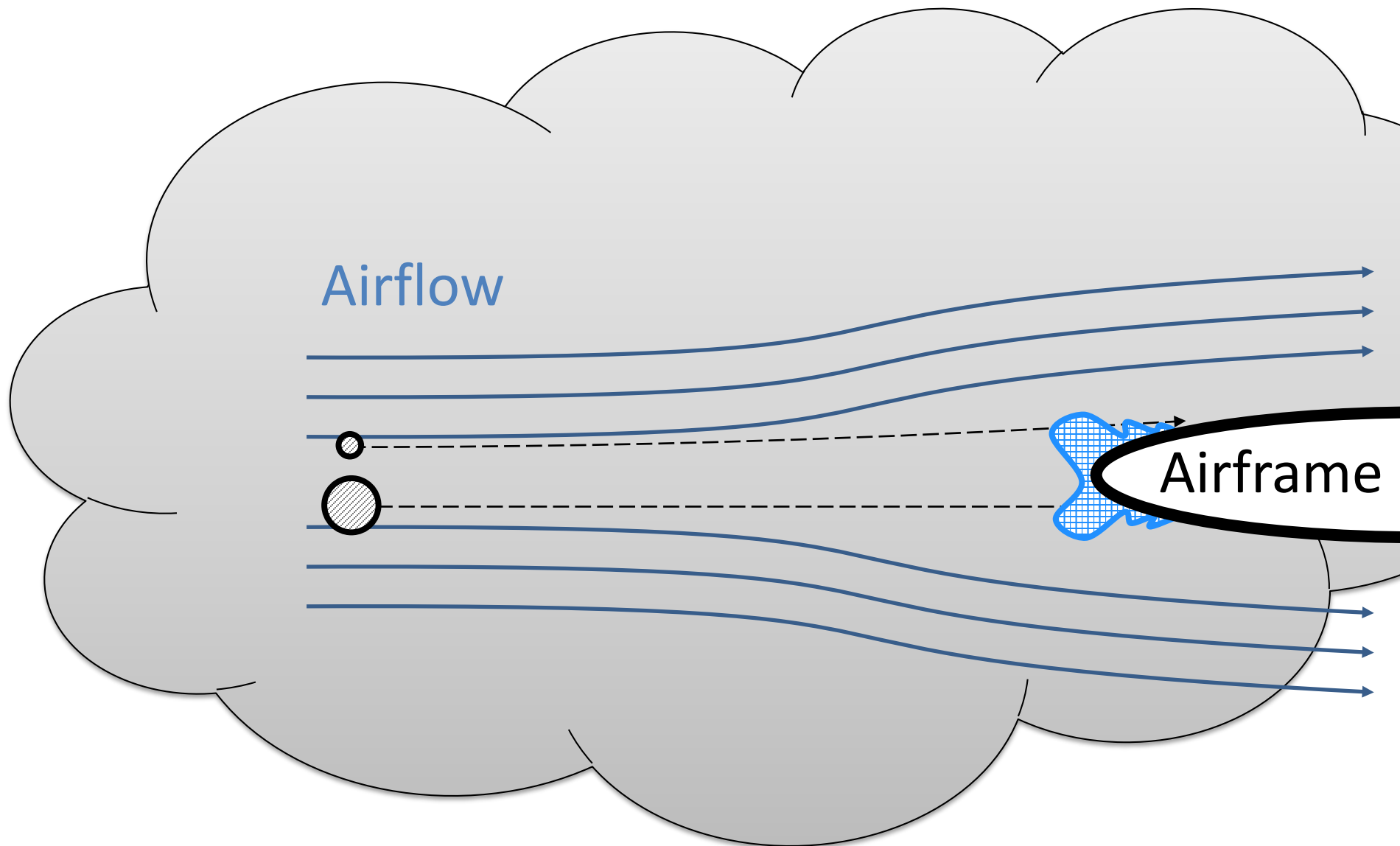
INFLUENCE OF SIZE



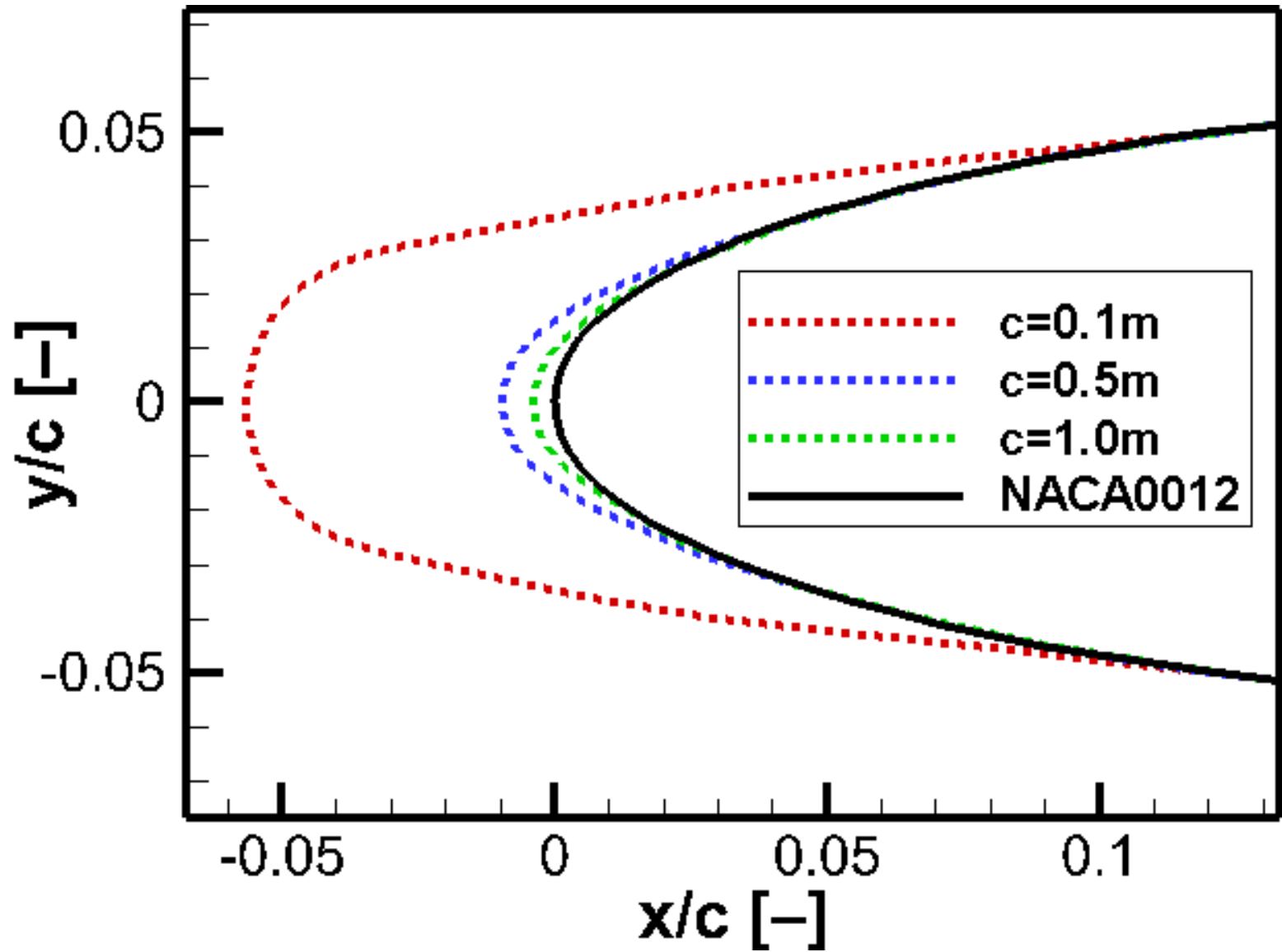
INFLUENCE OF SIZE



INFLUENCE OF SIZE



LEWICE 2D: $v=25\text{m/s}$, $t=20\text{min}$, $T=-20^\circ\text{C}$, $\text{MVD}=20\mu\text{m}$, $\text{LWC}=0.21\text{g/m}^3$



$T = -5^{\circ}\text{C}$

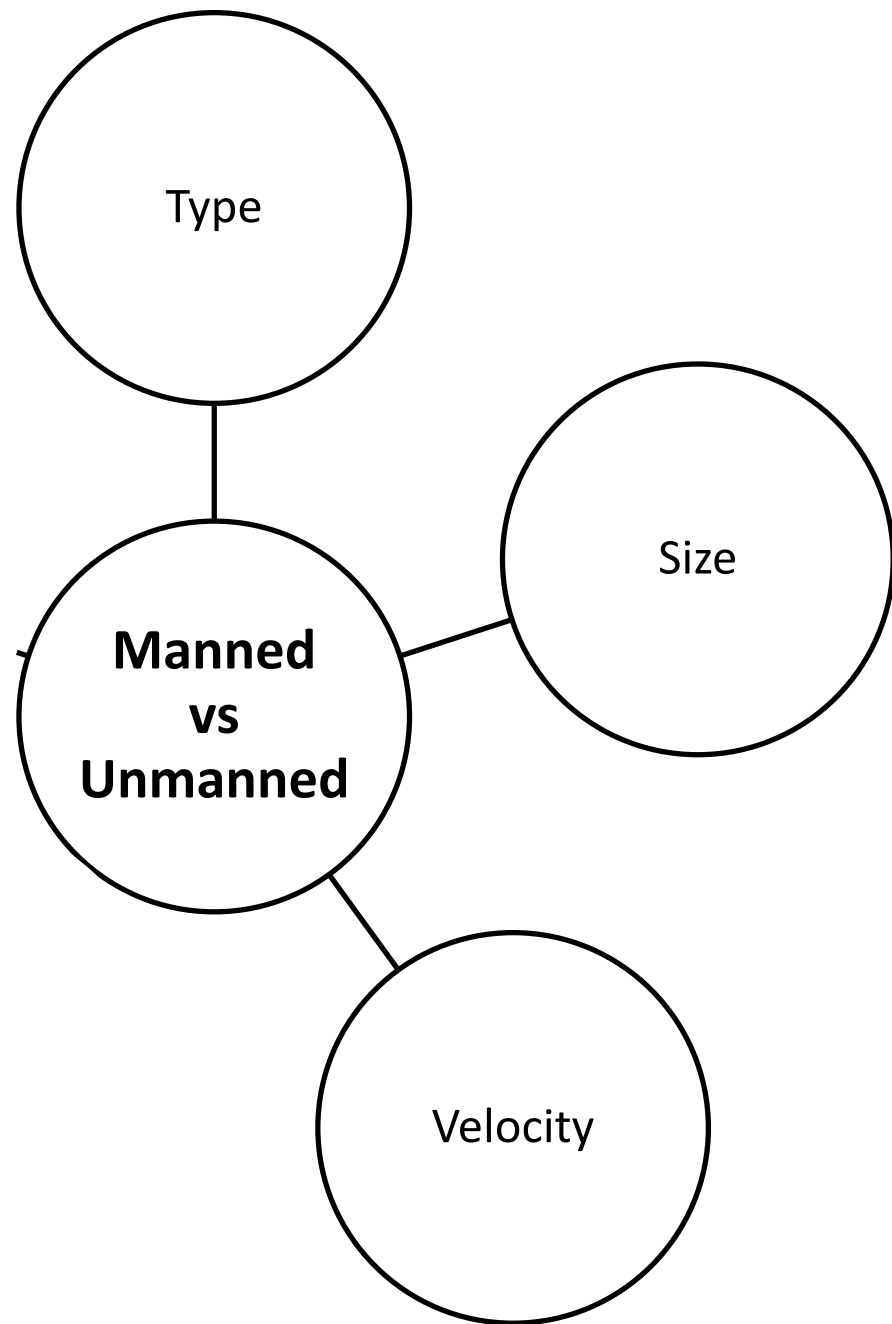
$t = 120\text{s}$

$\text{MVD} = 20\mu\text{m}$

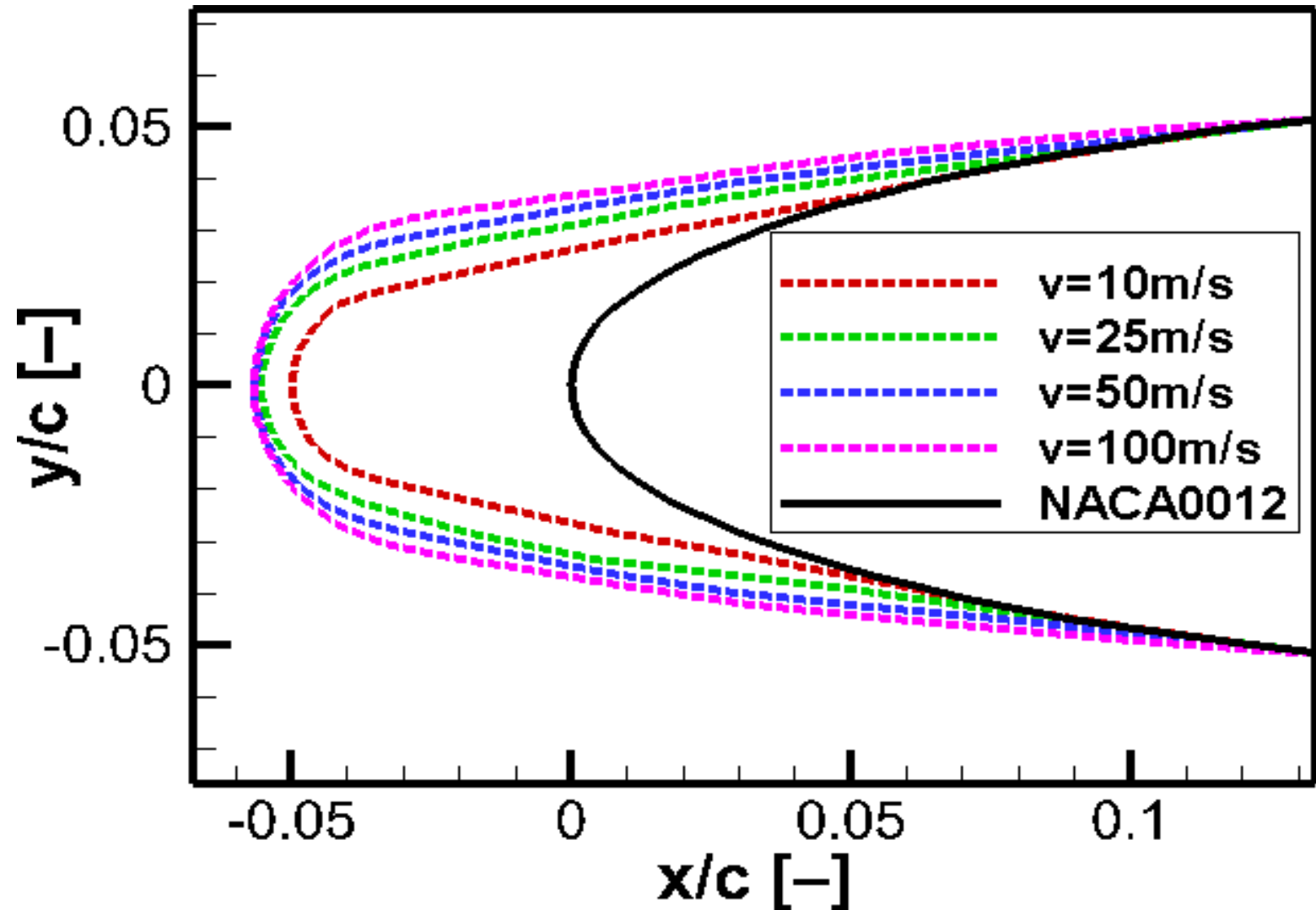
$\text{LWC} = 0.5\text{g}/\text{m}^3$

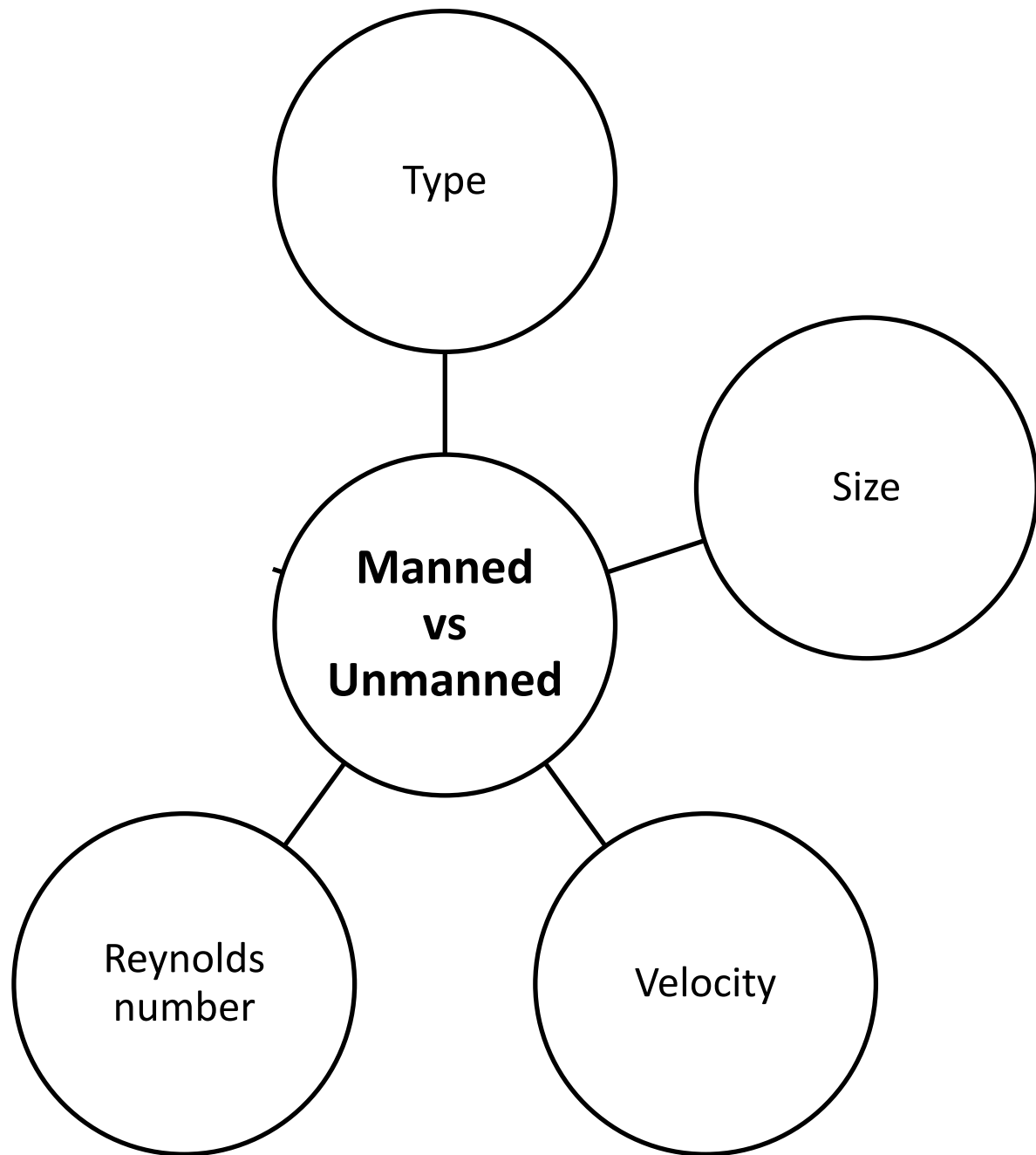


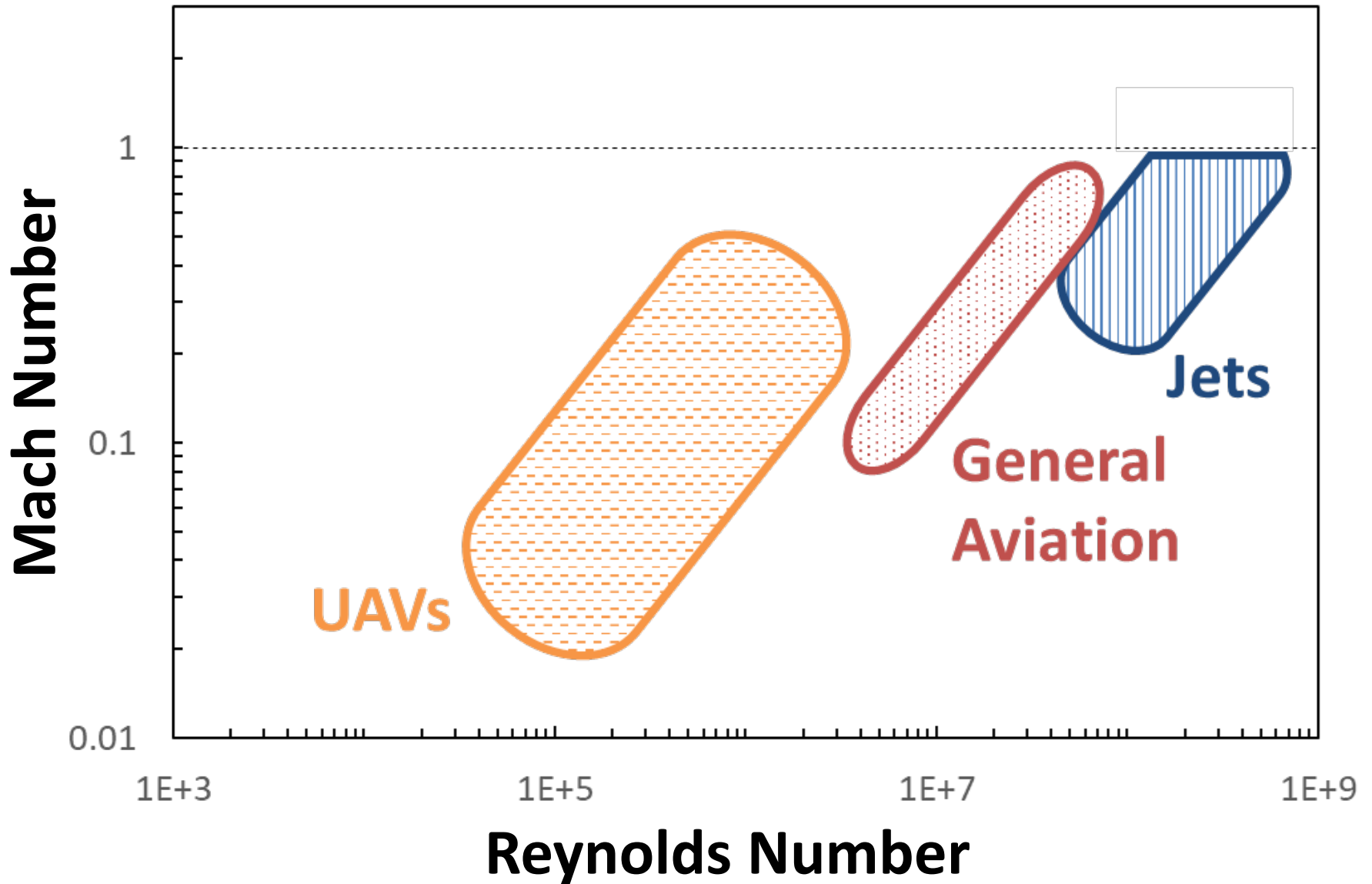
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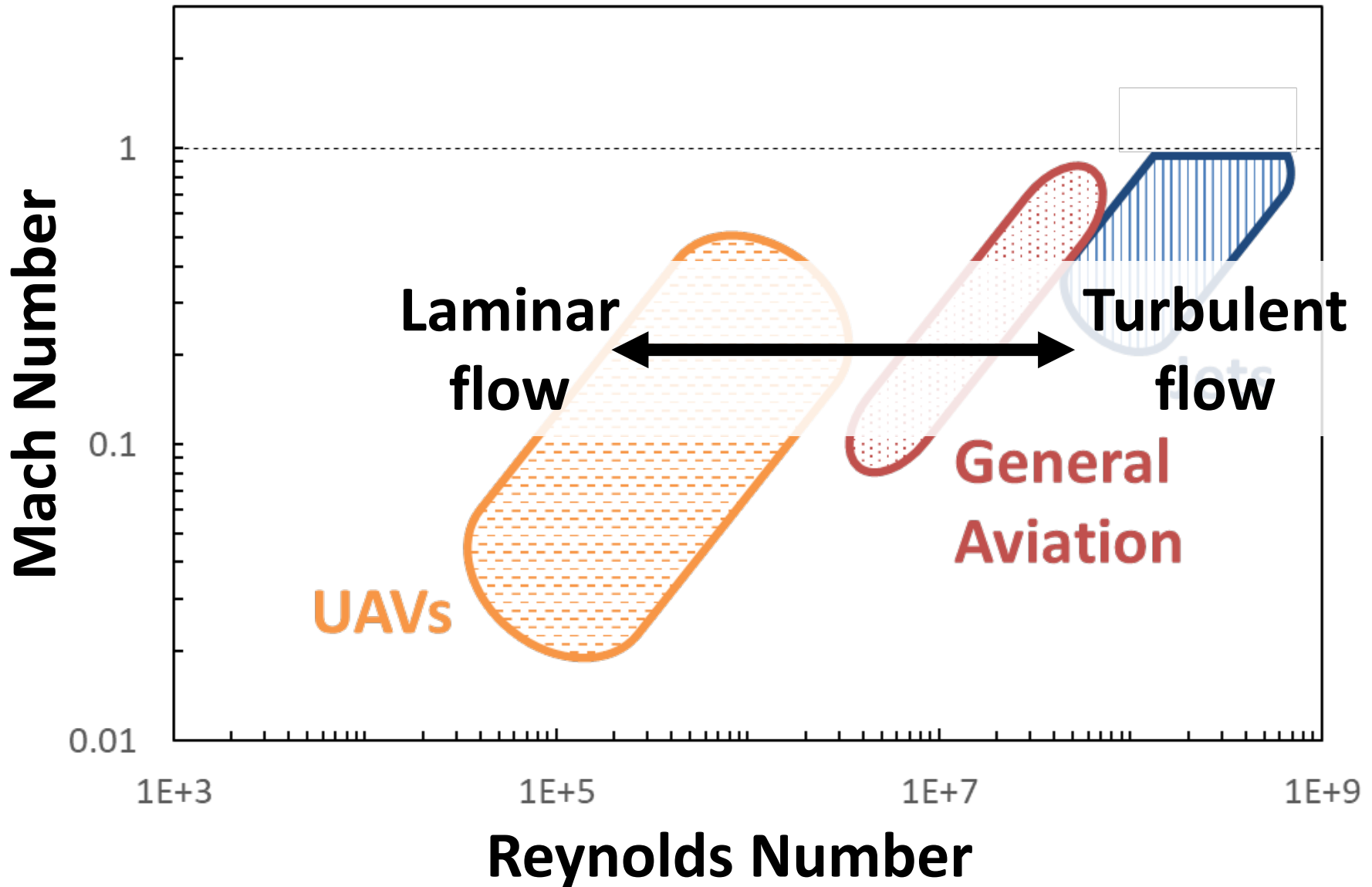


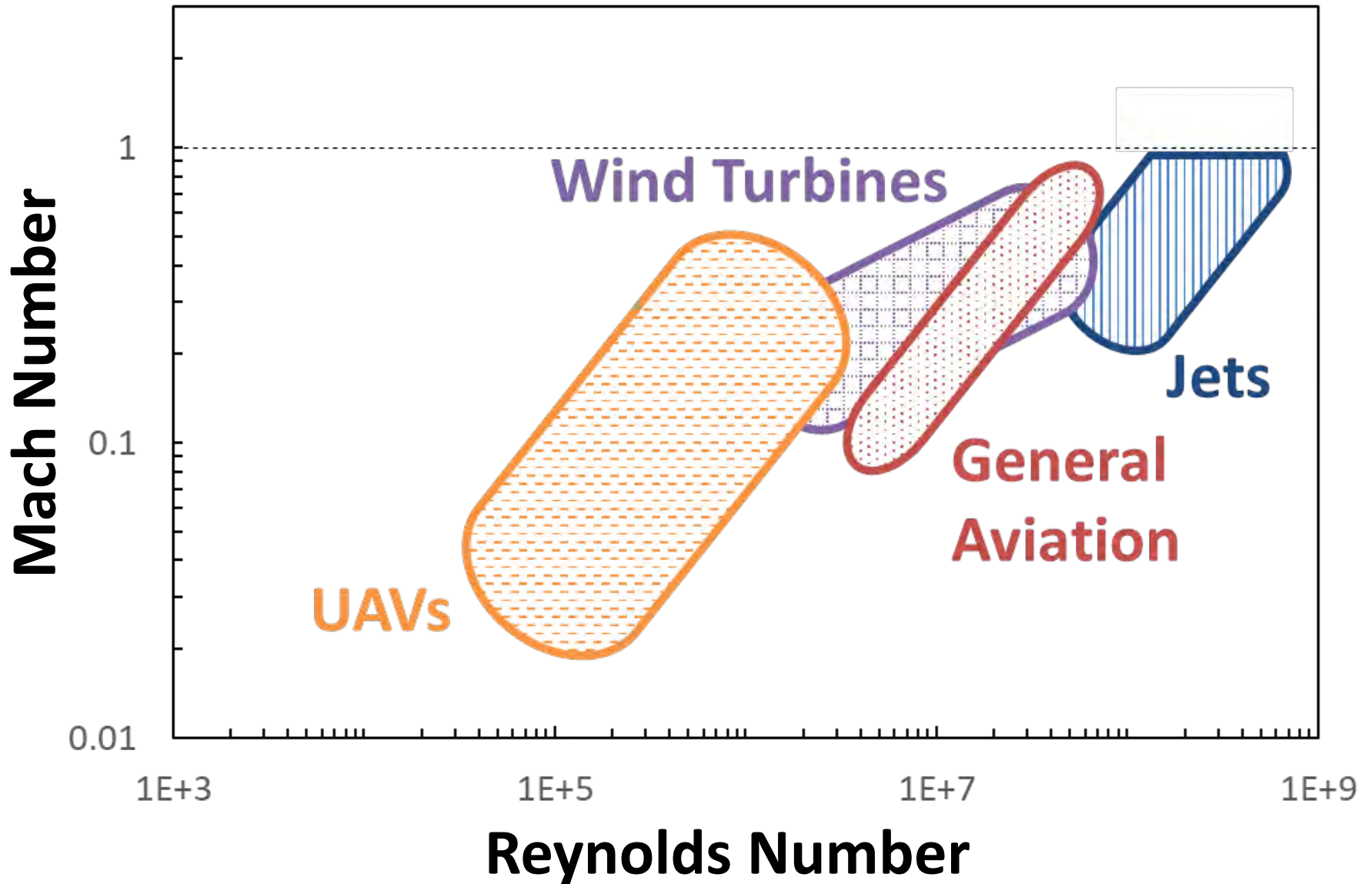
LEWICE 2D: $c=0.1\text{m}$, $T=-20^\circ\text{C}$, $\text{MVD}=20\mu\text{m}$, $\text{LWC}=0.21\text{g/m}^3$



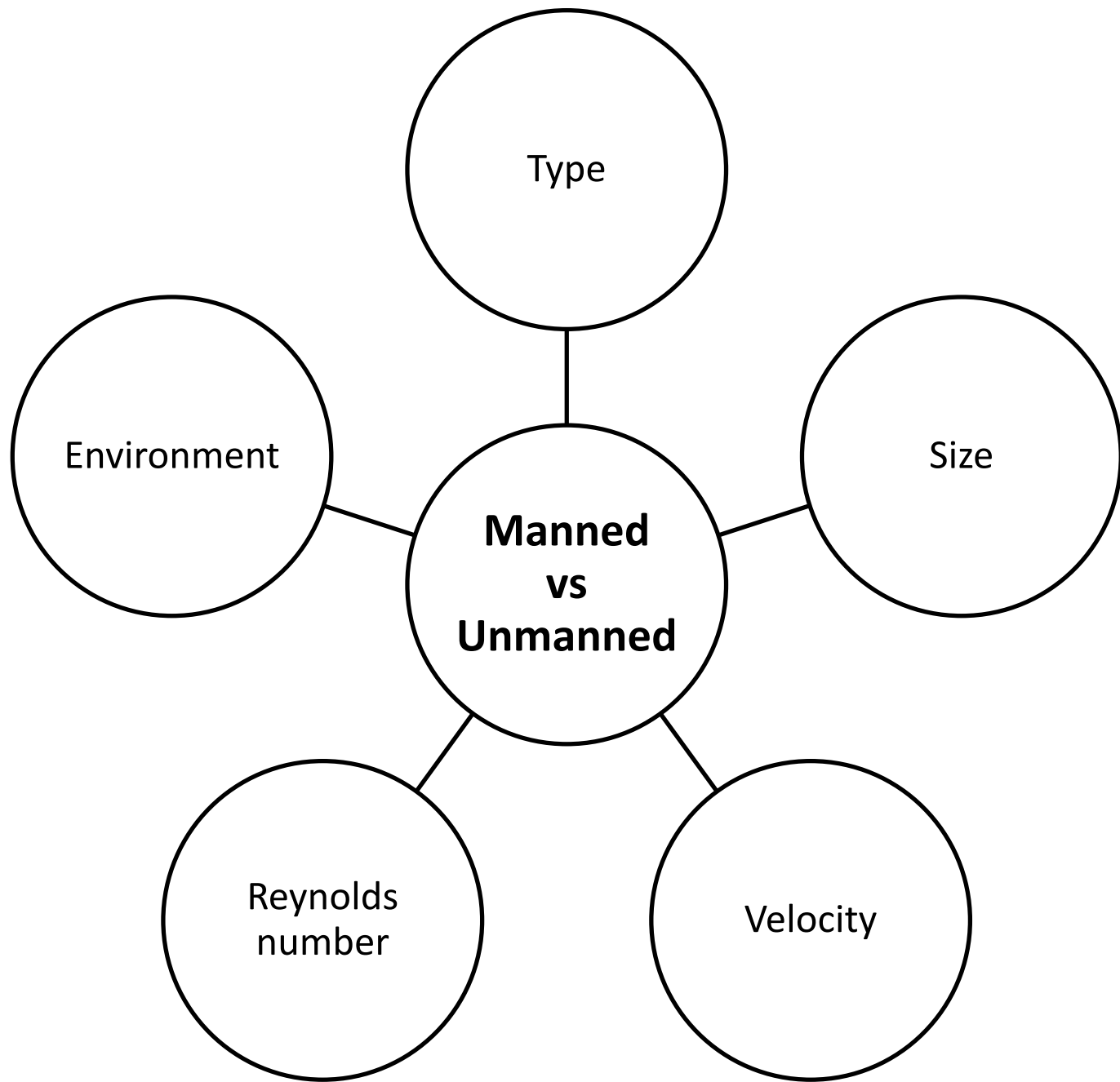


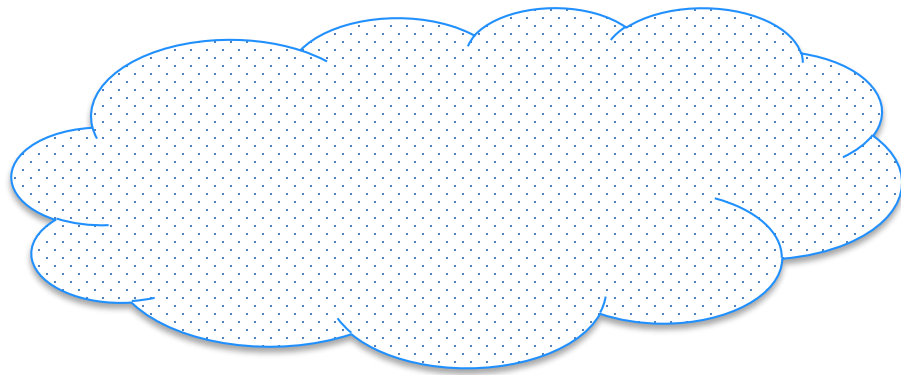
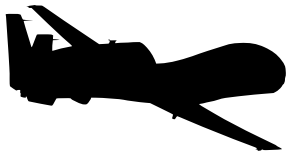




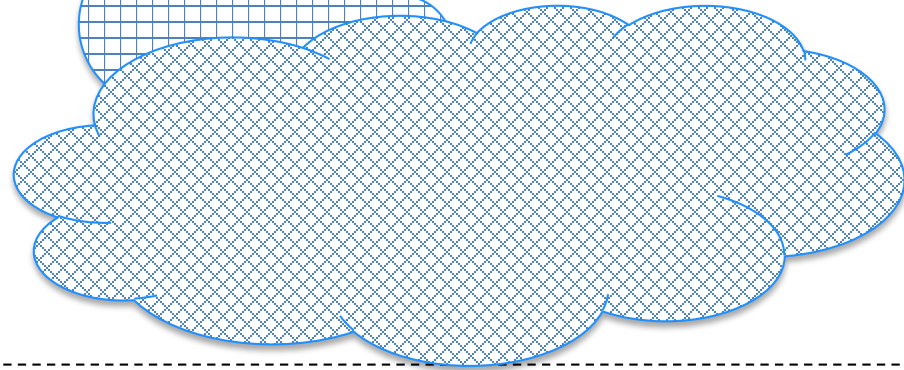
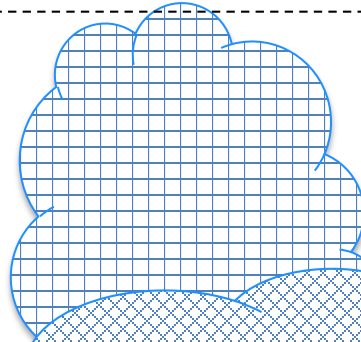








30,000ft



500ft



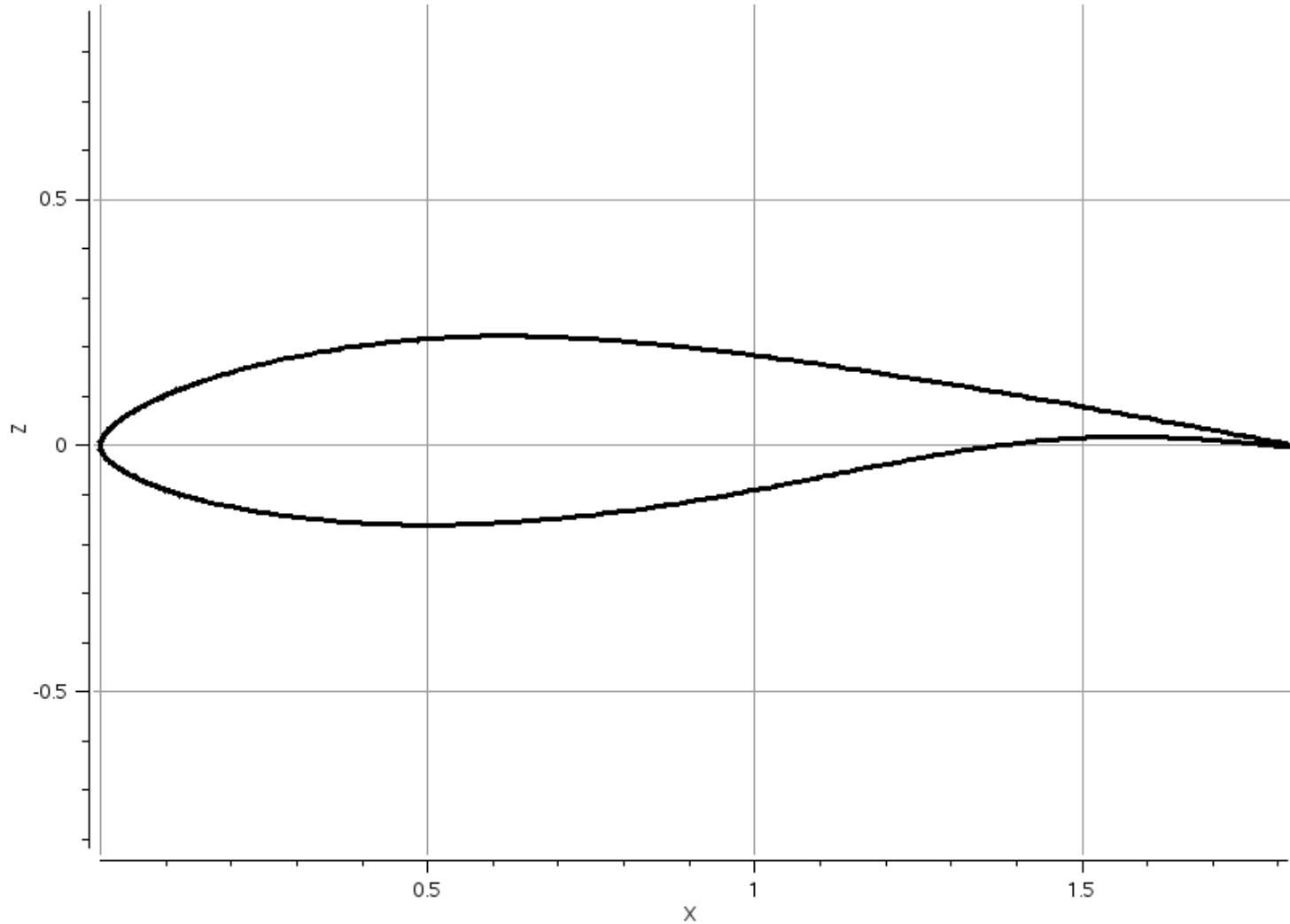
Ground



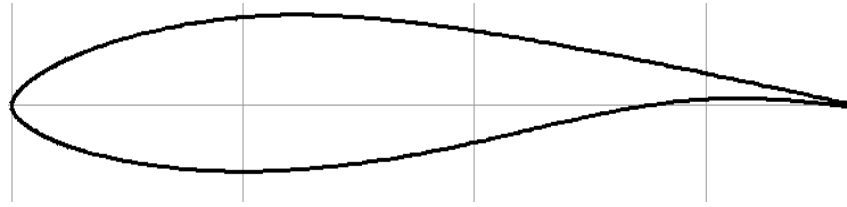


ICING SIMULATION

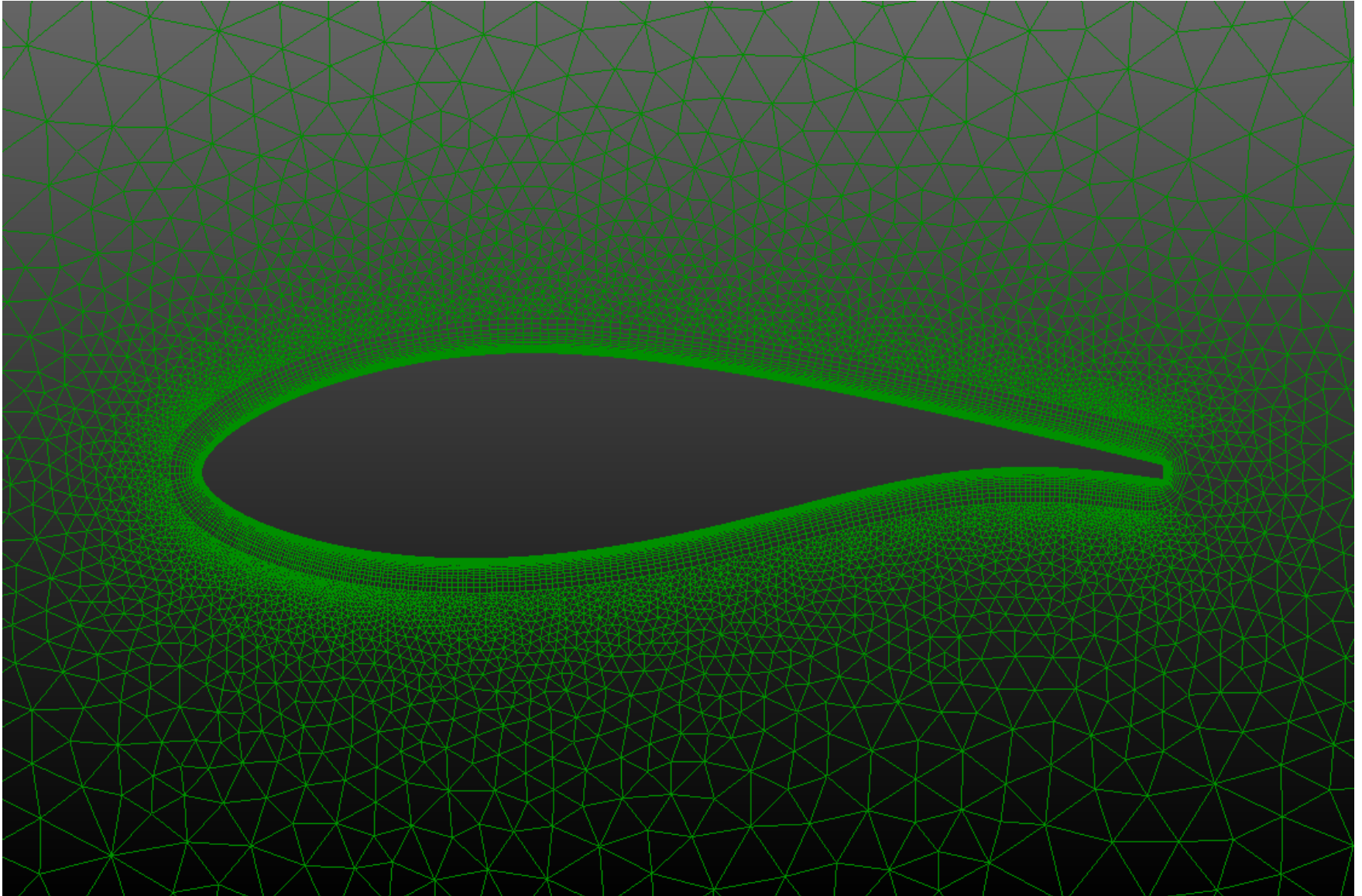
Airfoil geometry



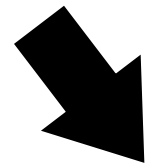
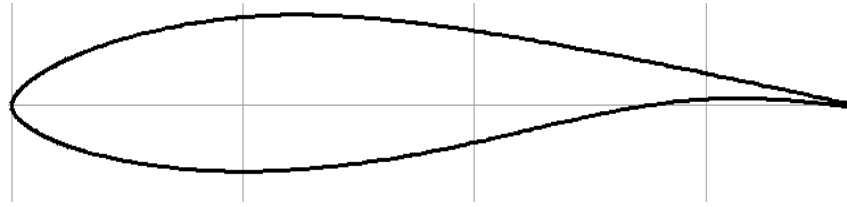
Airfoil geometry



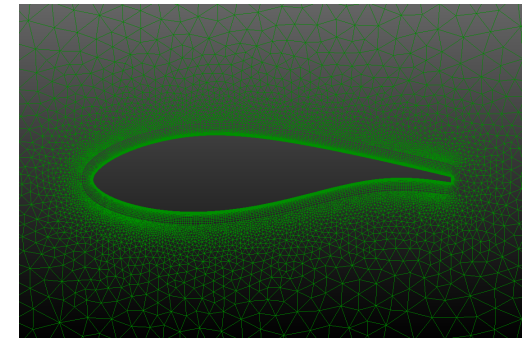
Mesh



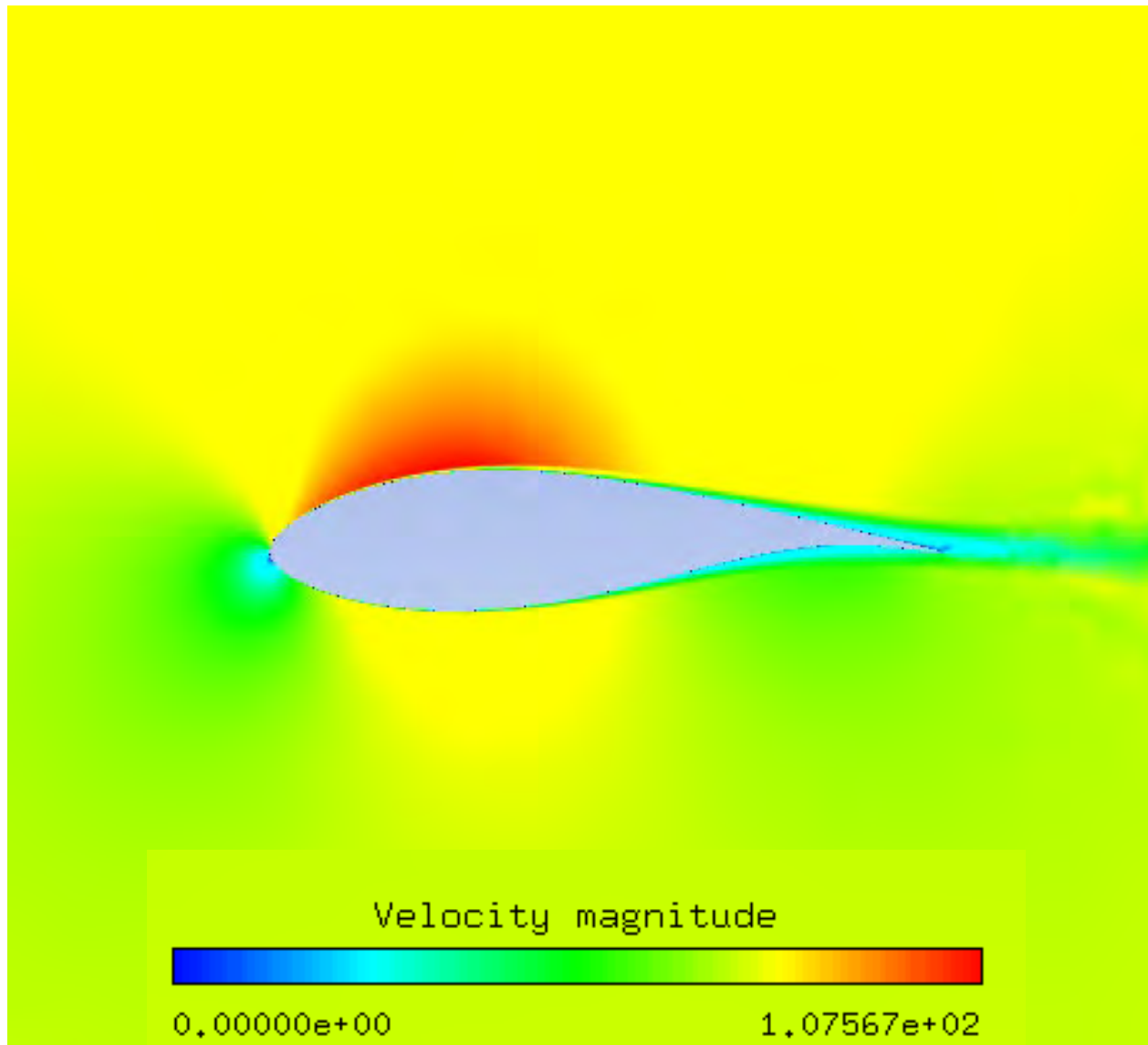
Airfoil geometry



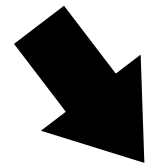
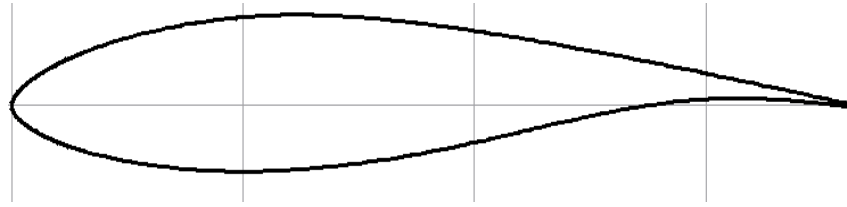
Mesh



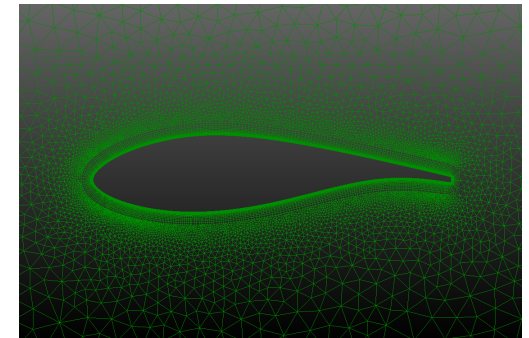
Flow solution



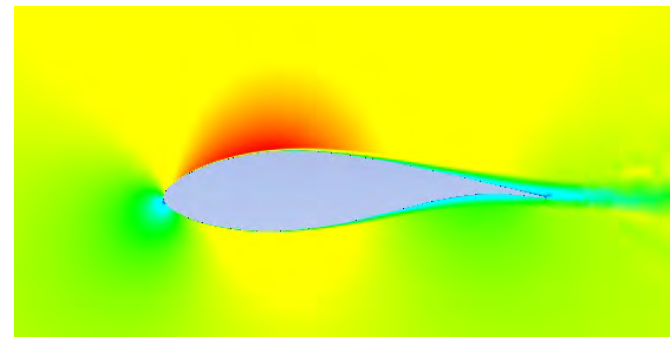
Airfoil geometry



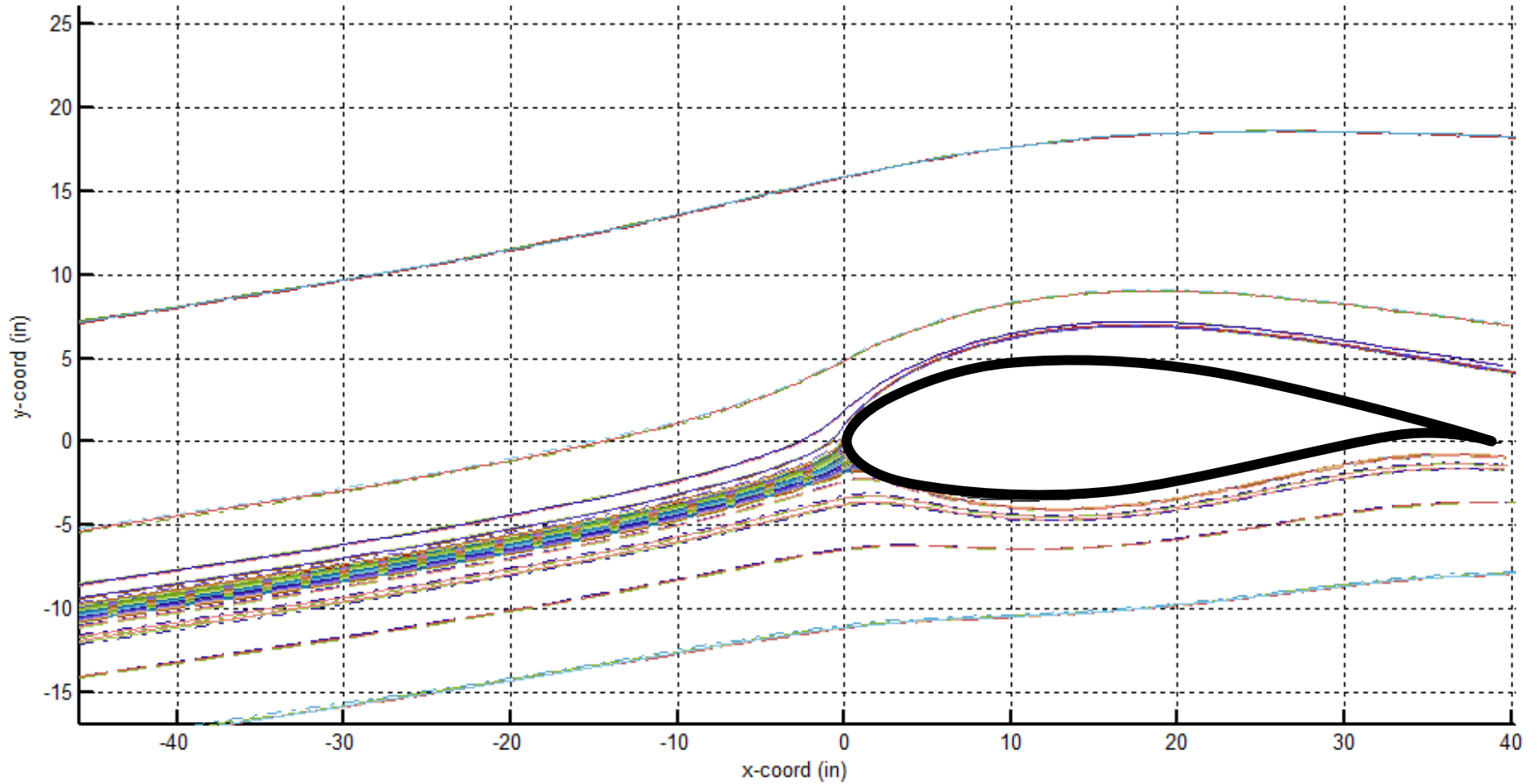
Mesh



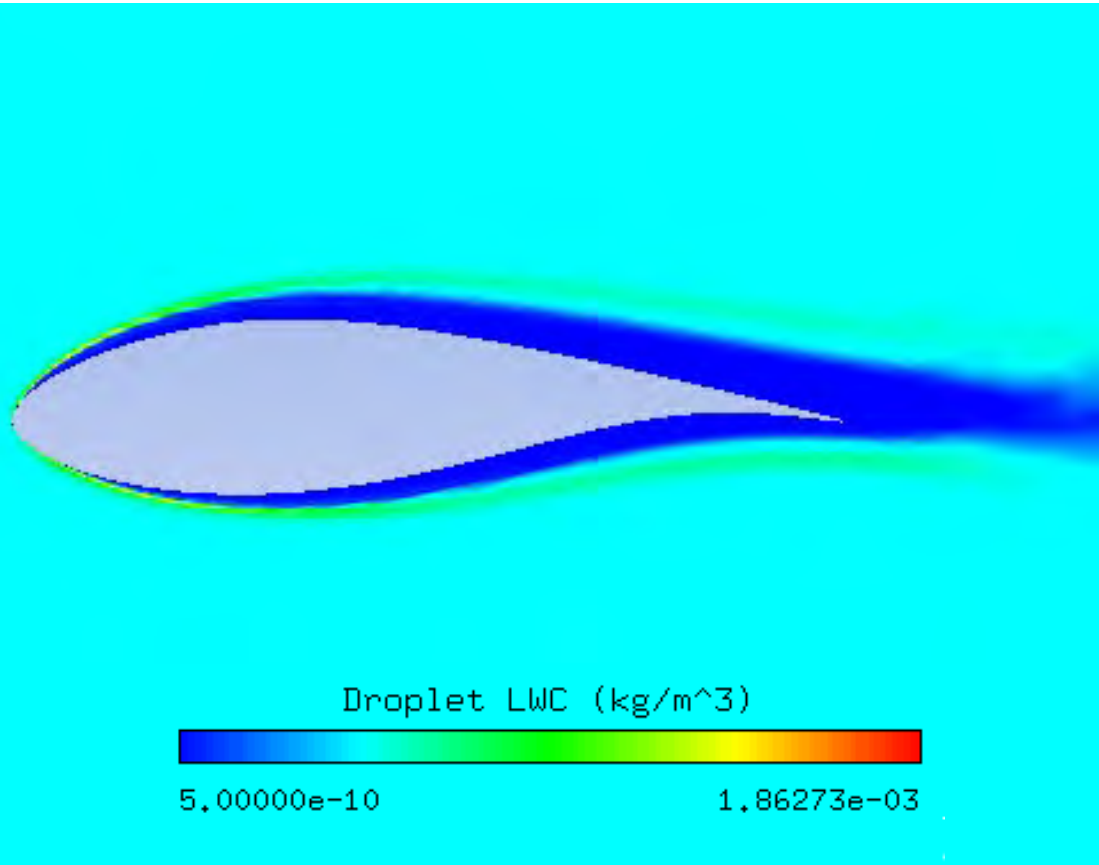
Flow solution



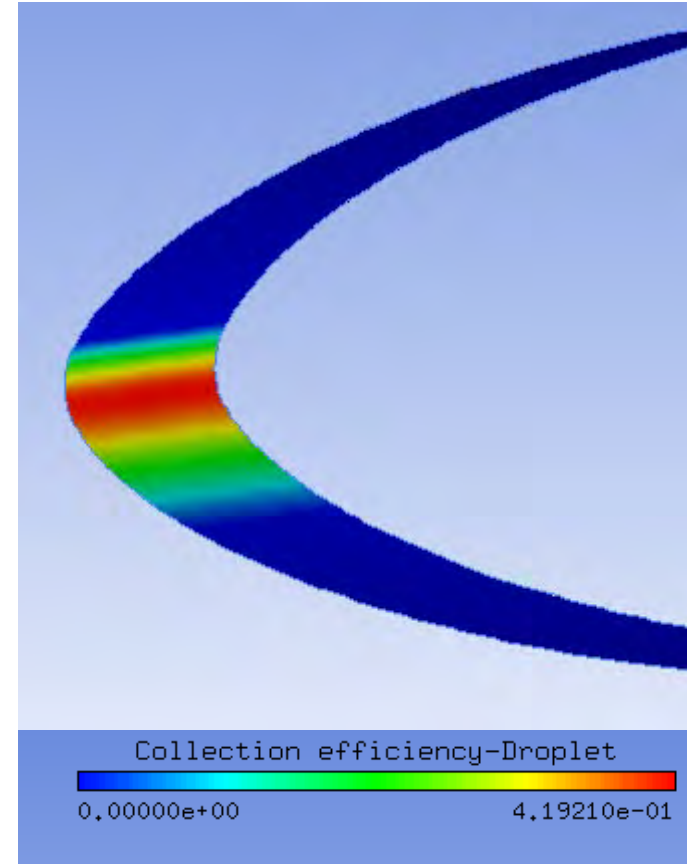
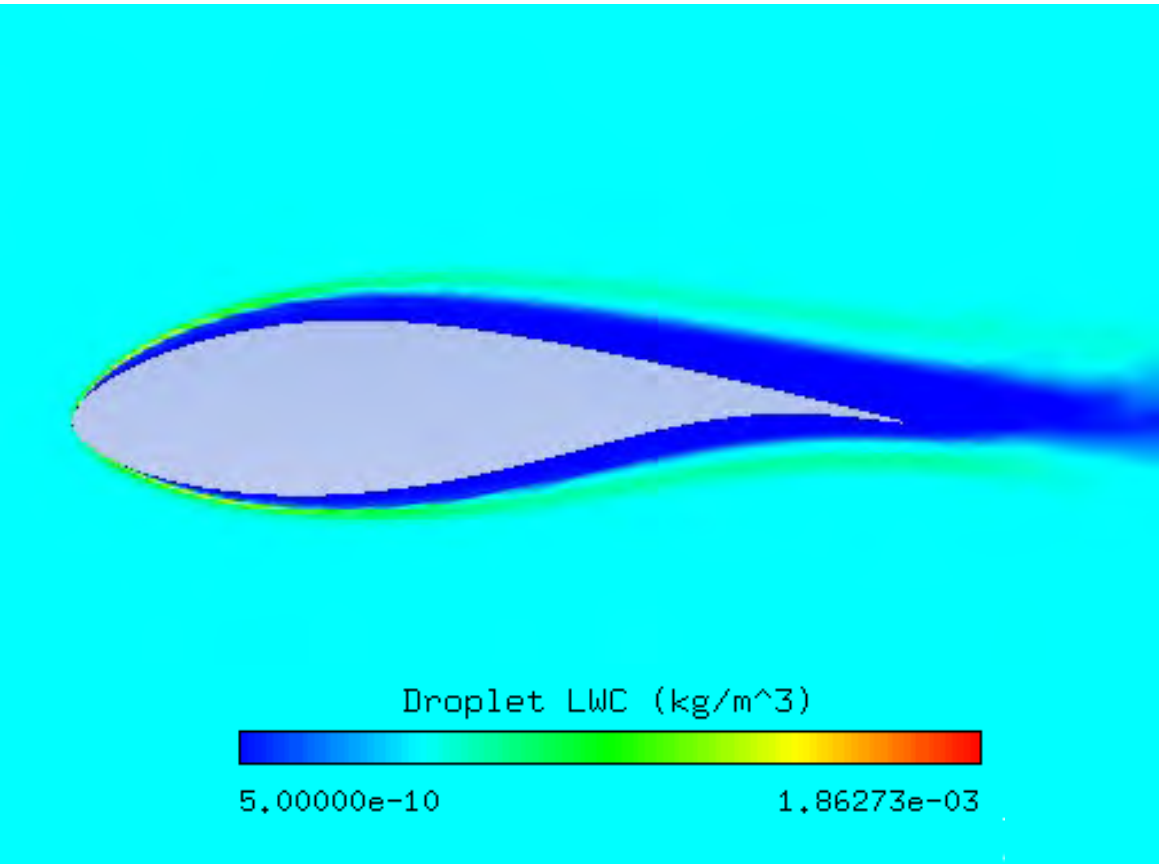
Droplet solution



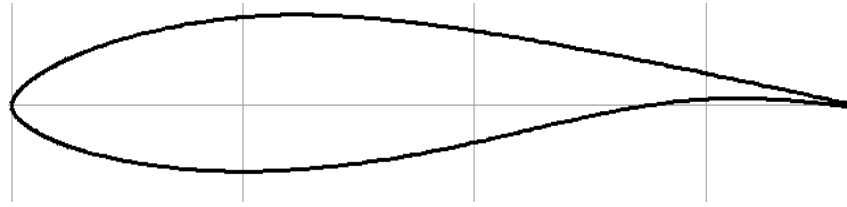
Droplet solution



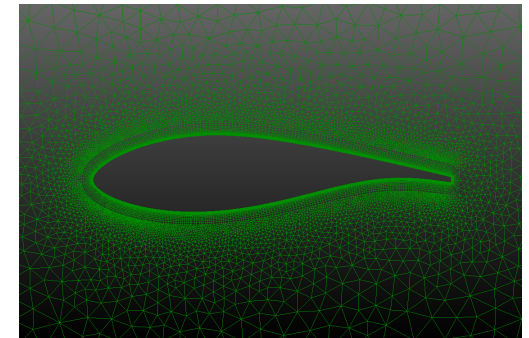
Droplet solution



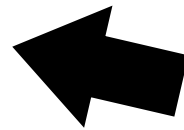
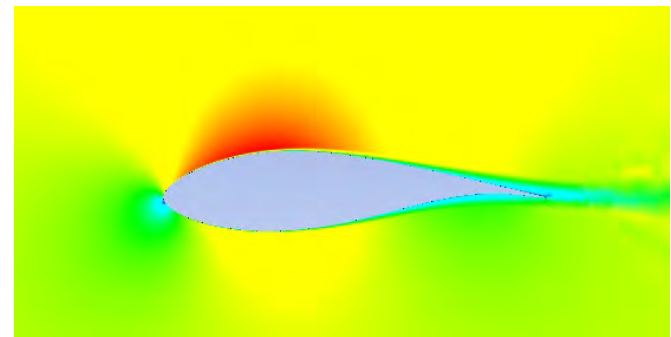
Airfoil geometry



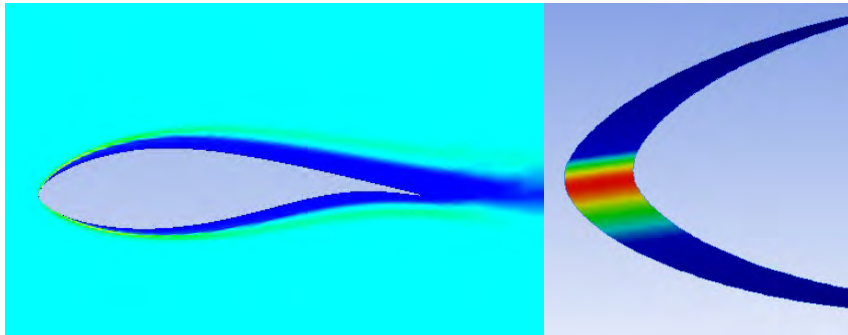
Mesh



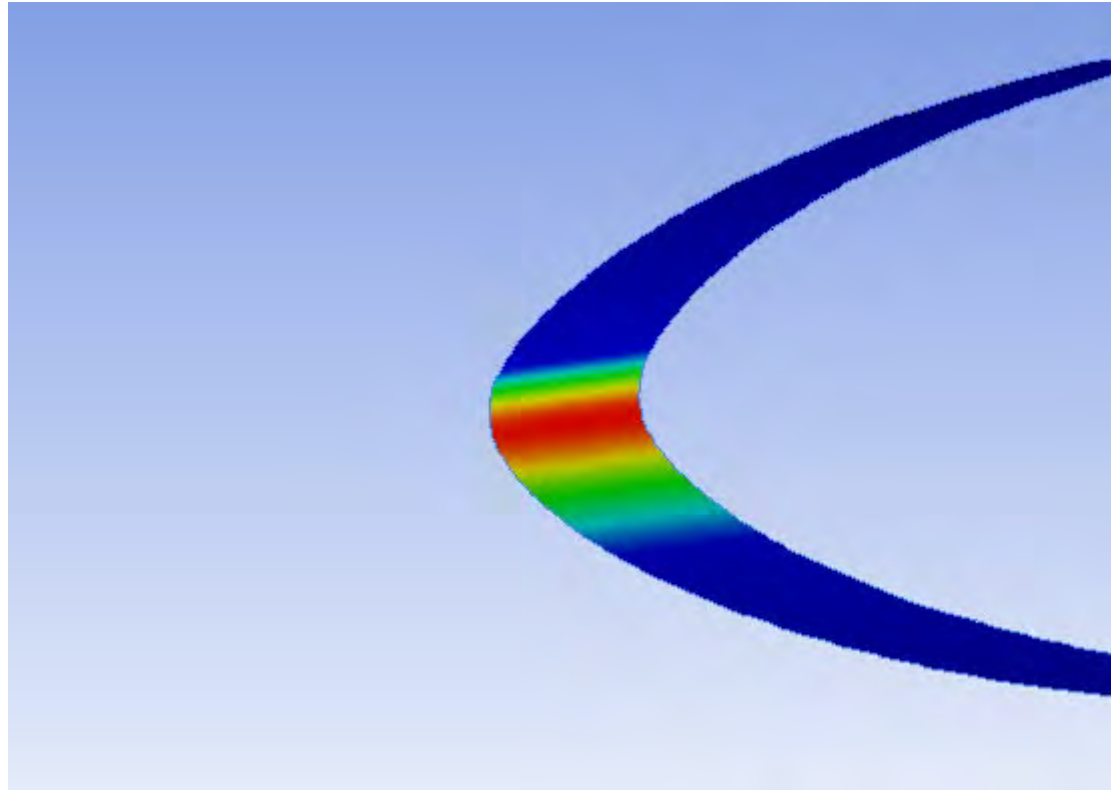
Flow solution



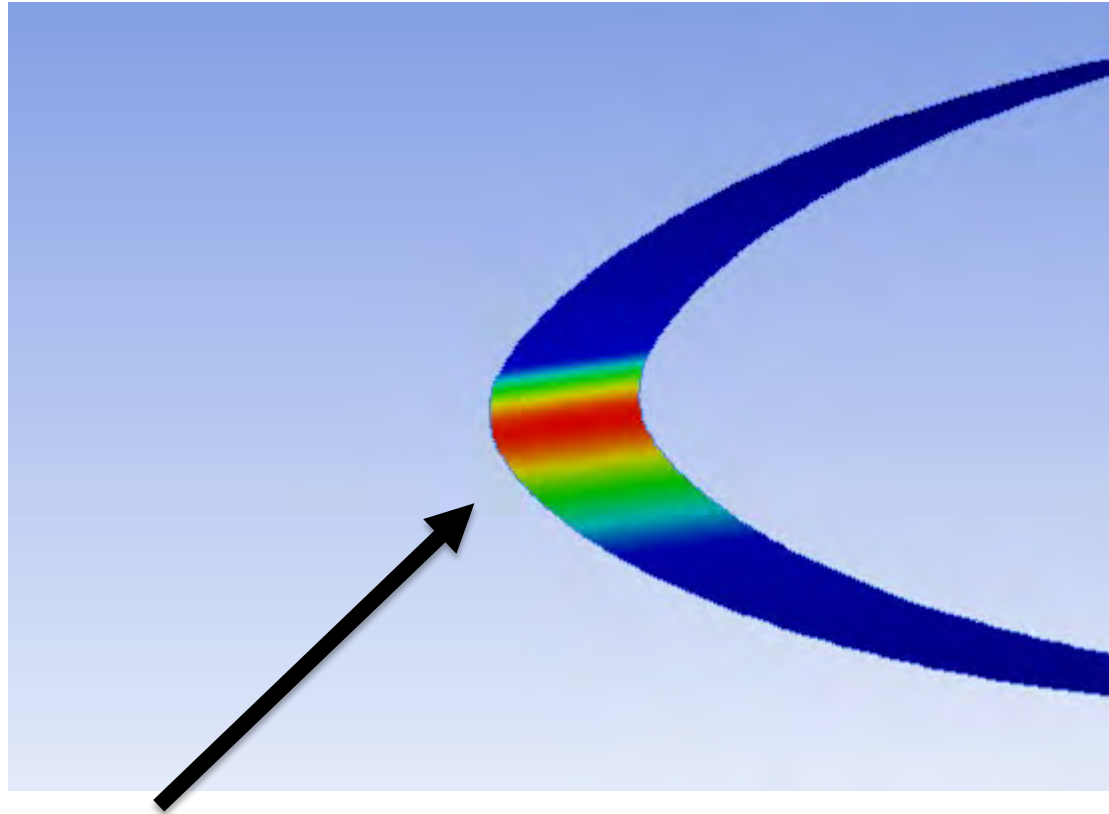
Droplet solution



Collection efficiency

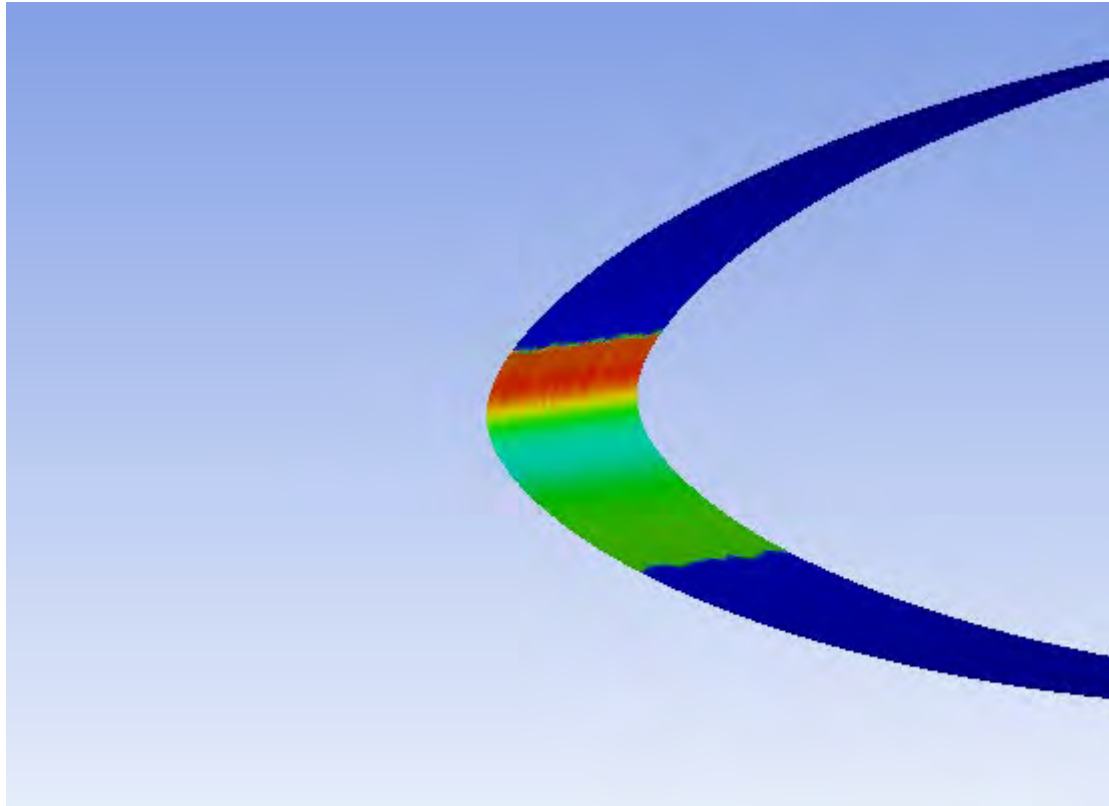


Collection efficiency

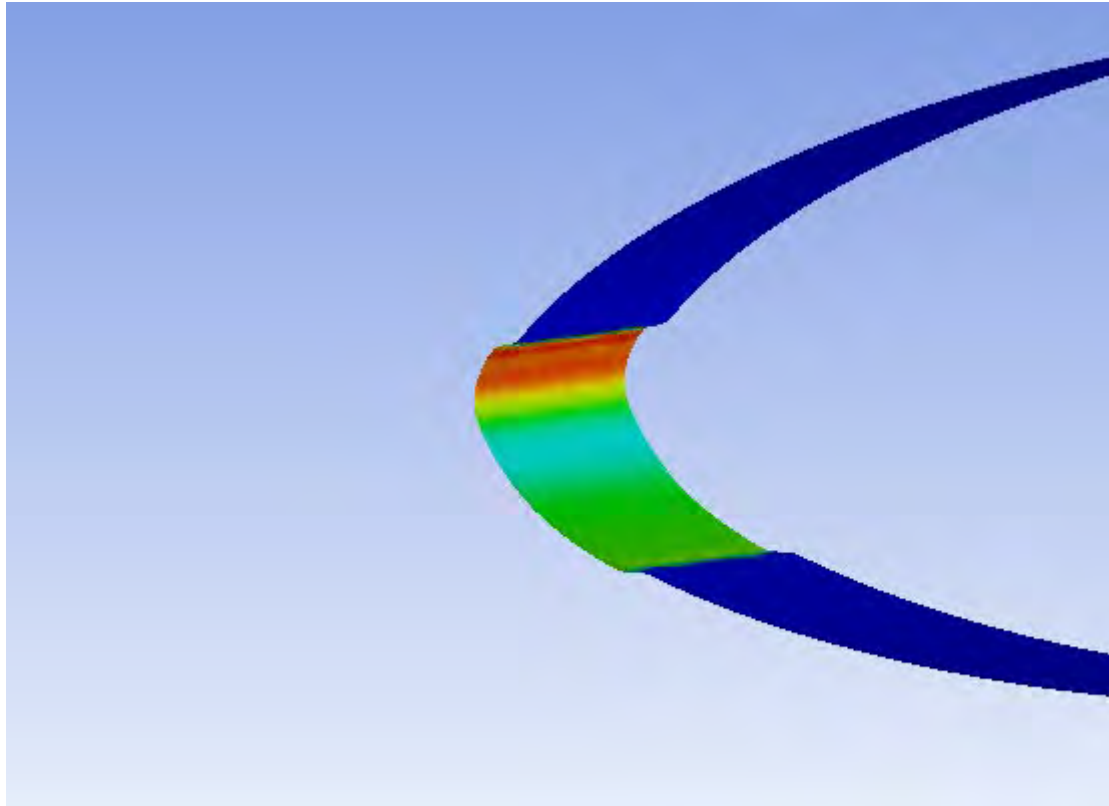


Energy & mass calculations
(Messinger model)

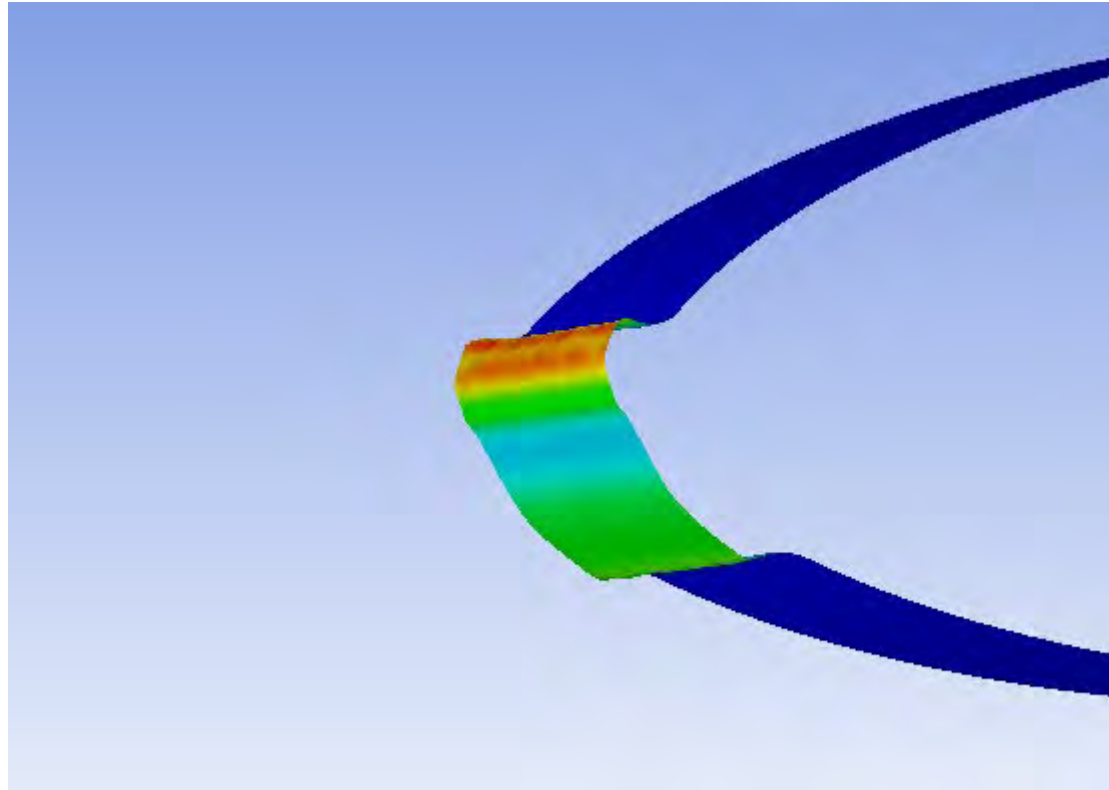
Ice growth (t=1)



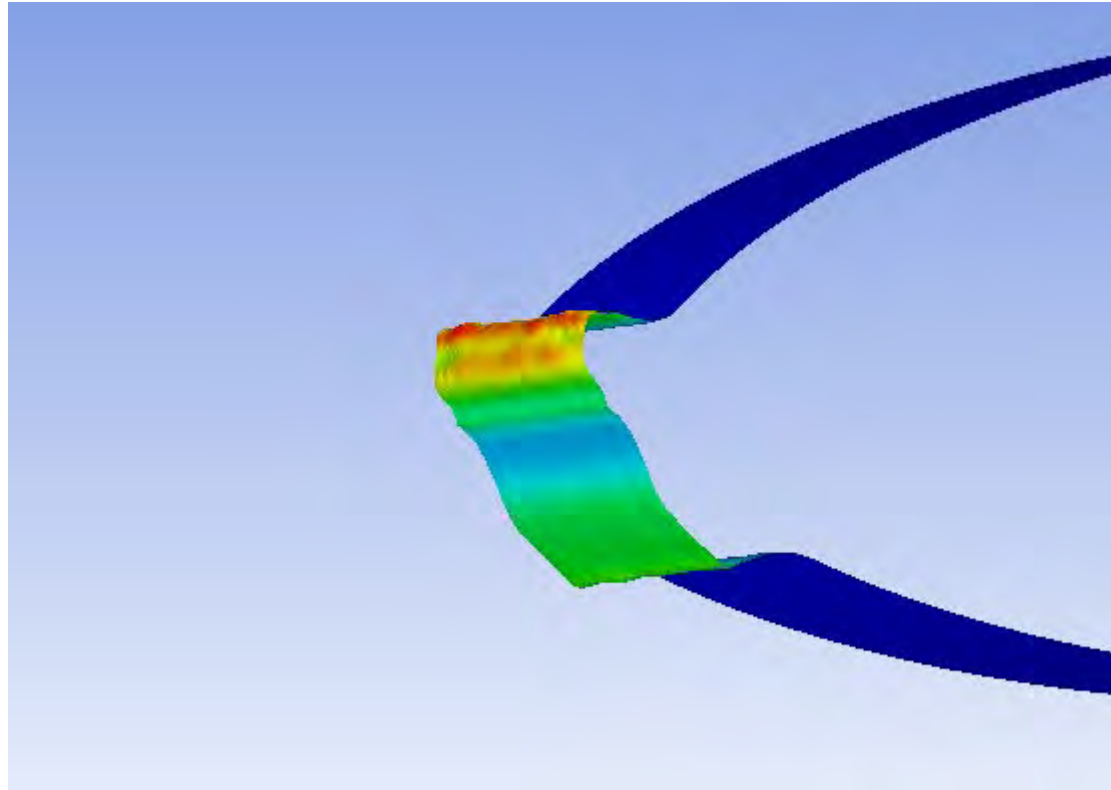
Ice growth (t=2)



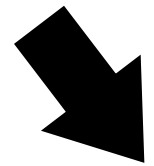
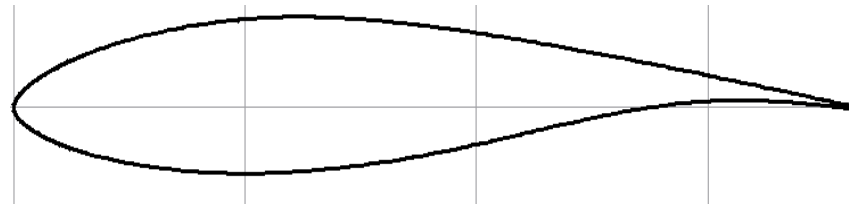
Ice growth (t=3)



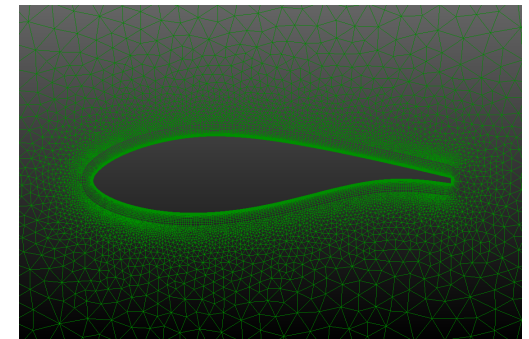
Ice growth (t=4)



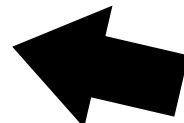
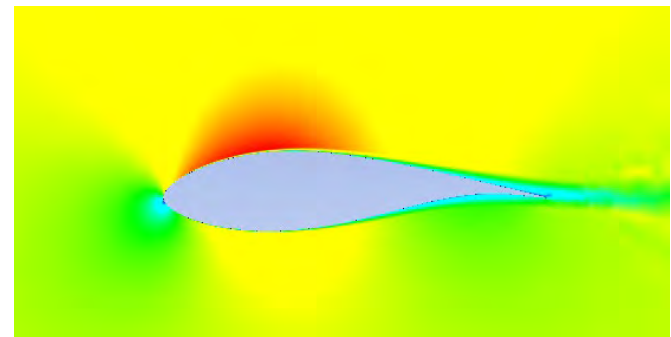
Airfoil geometry



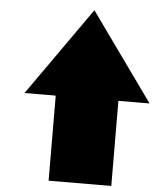
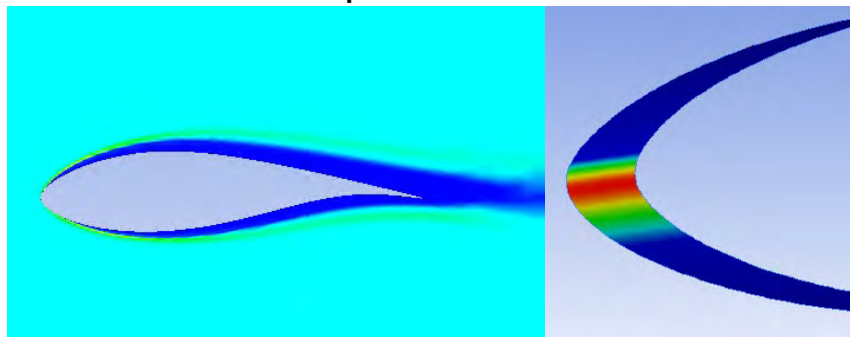
Mesh



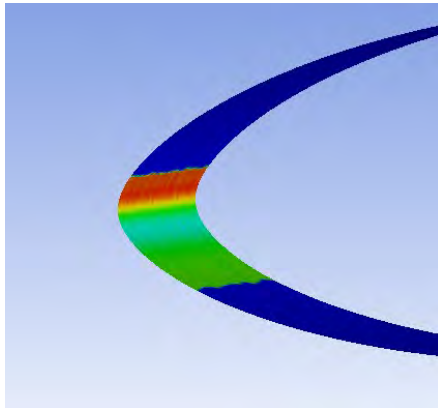
Flow solution

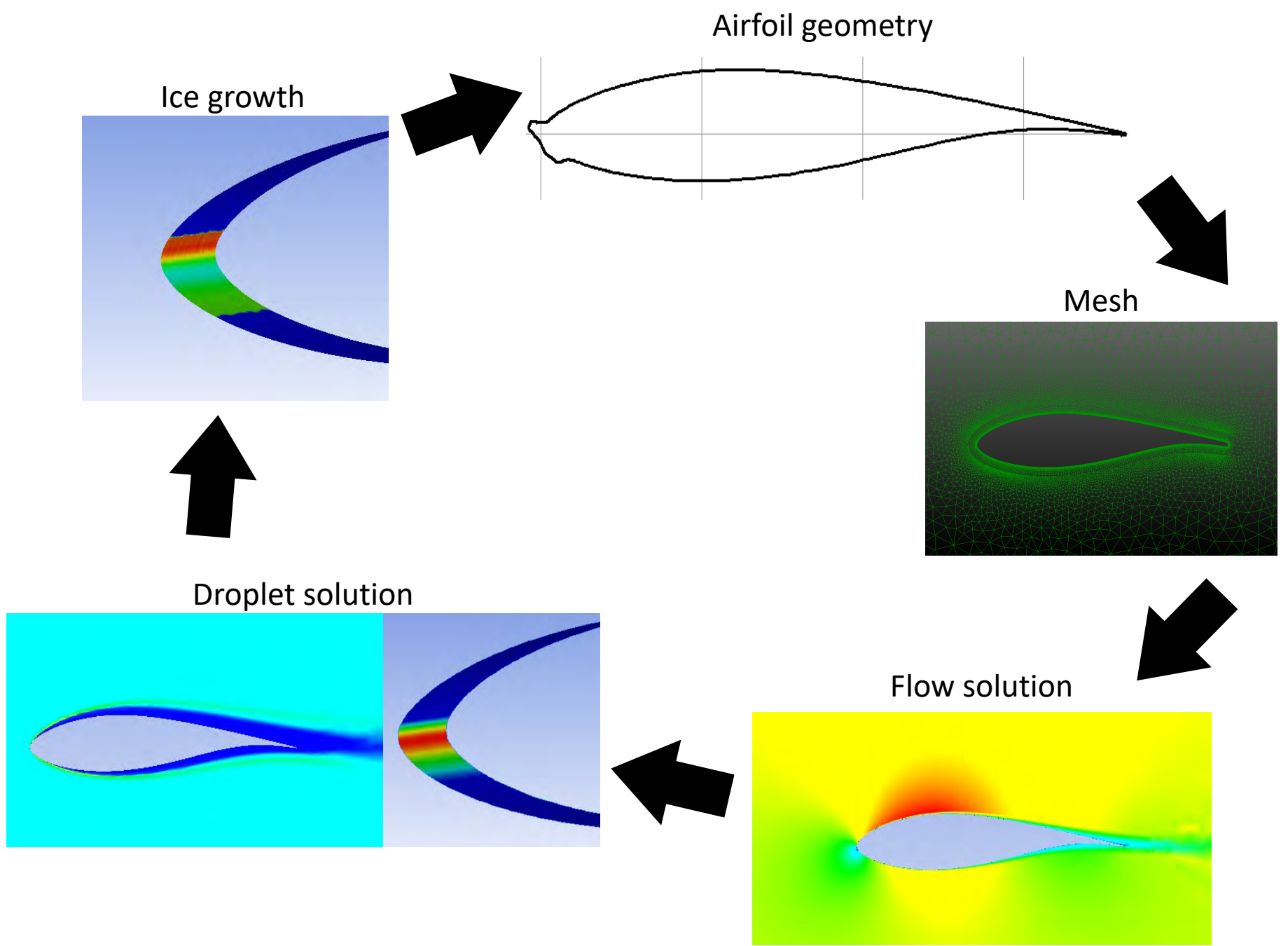


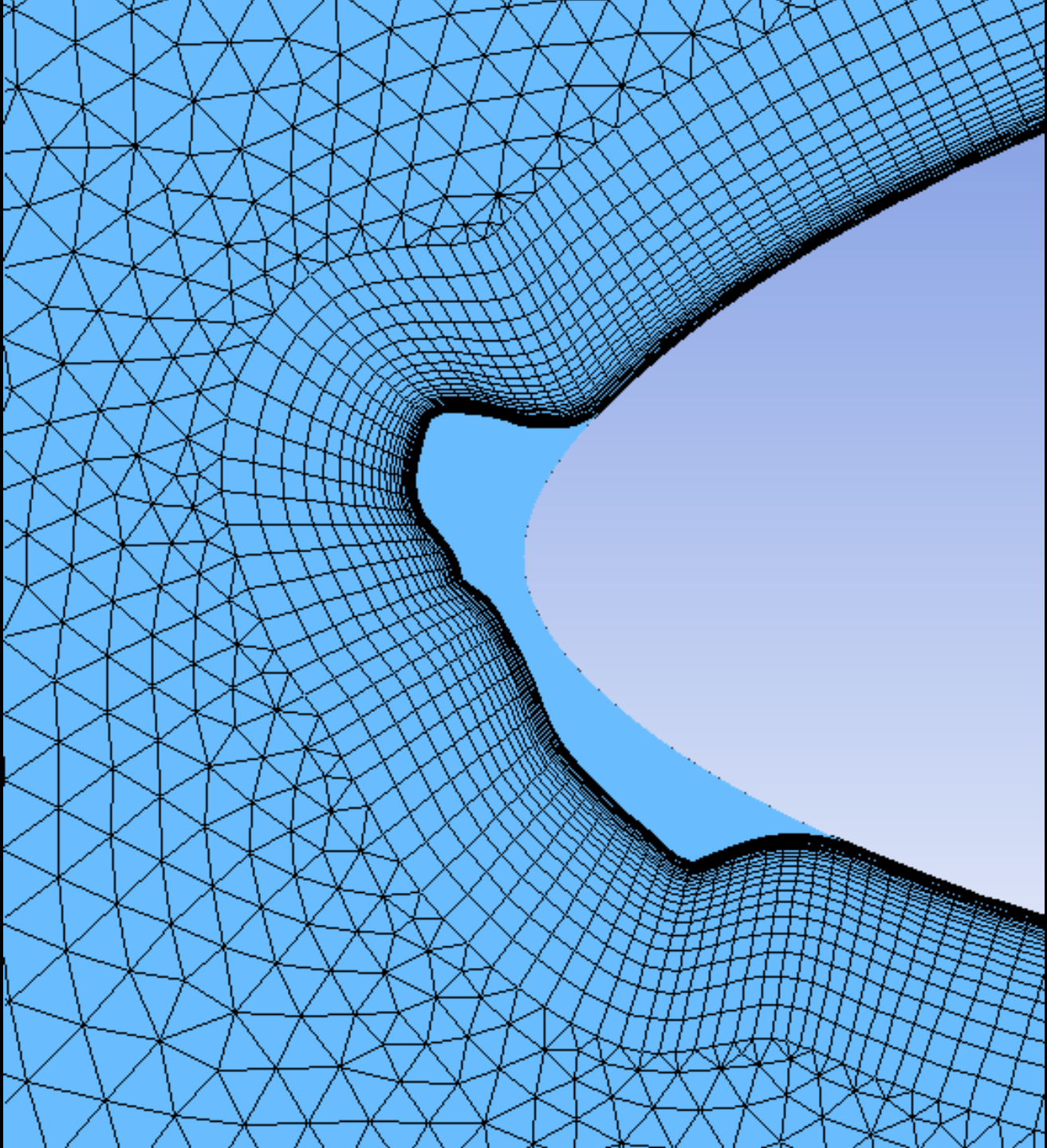
Droplet solution

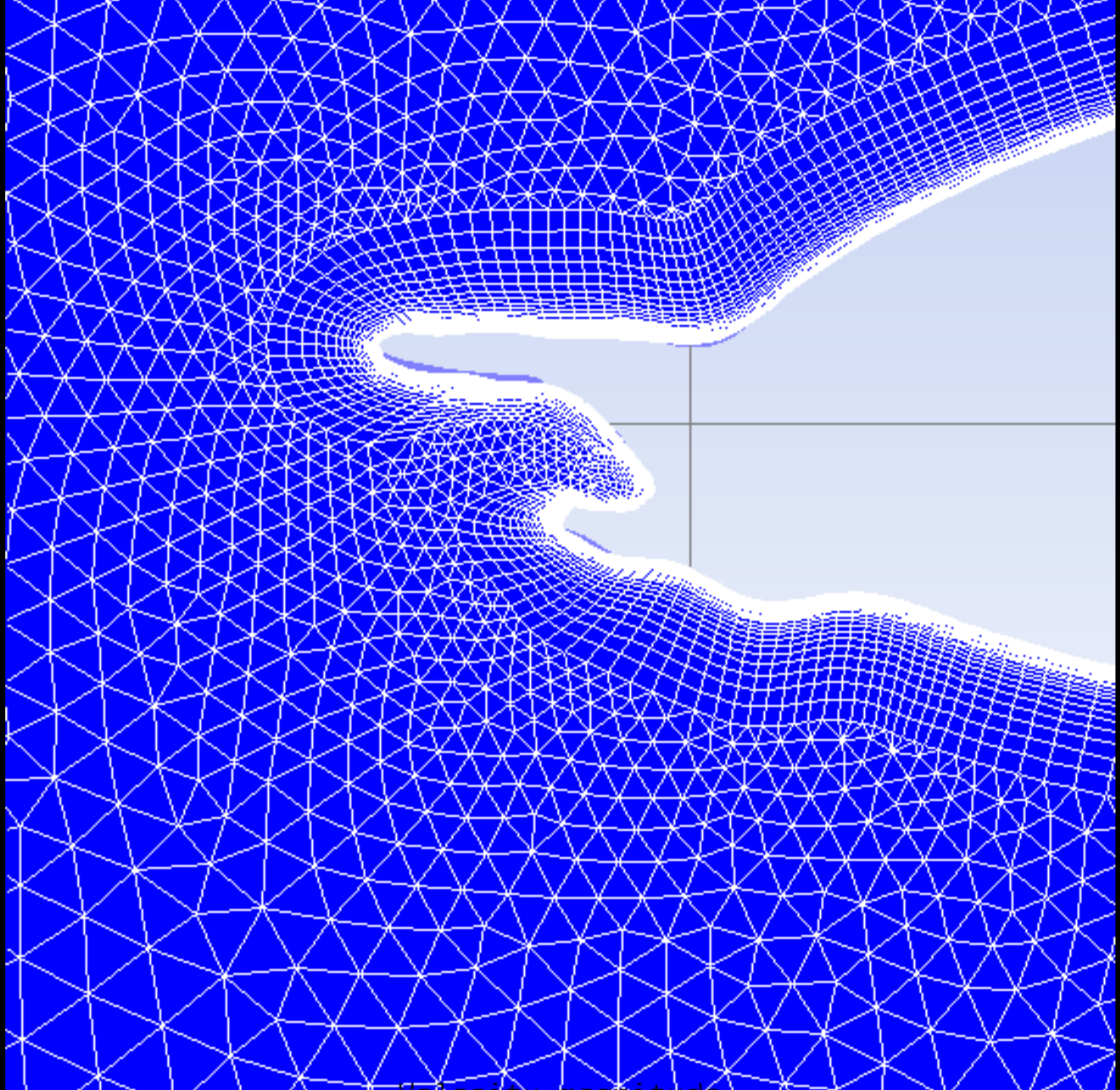


Ice growth

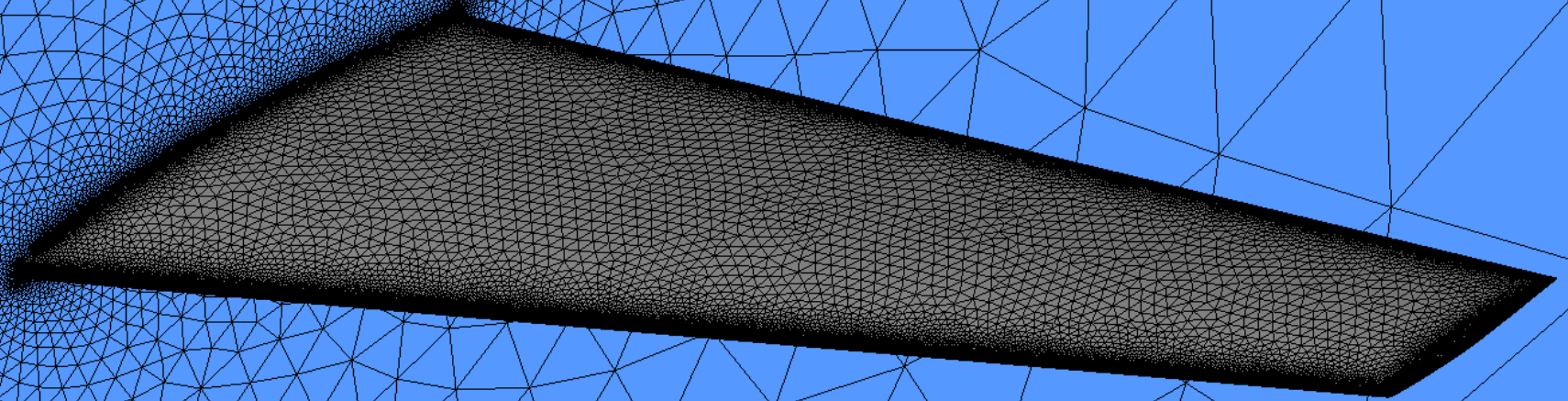






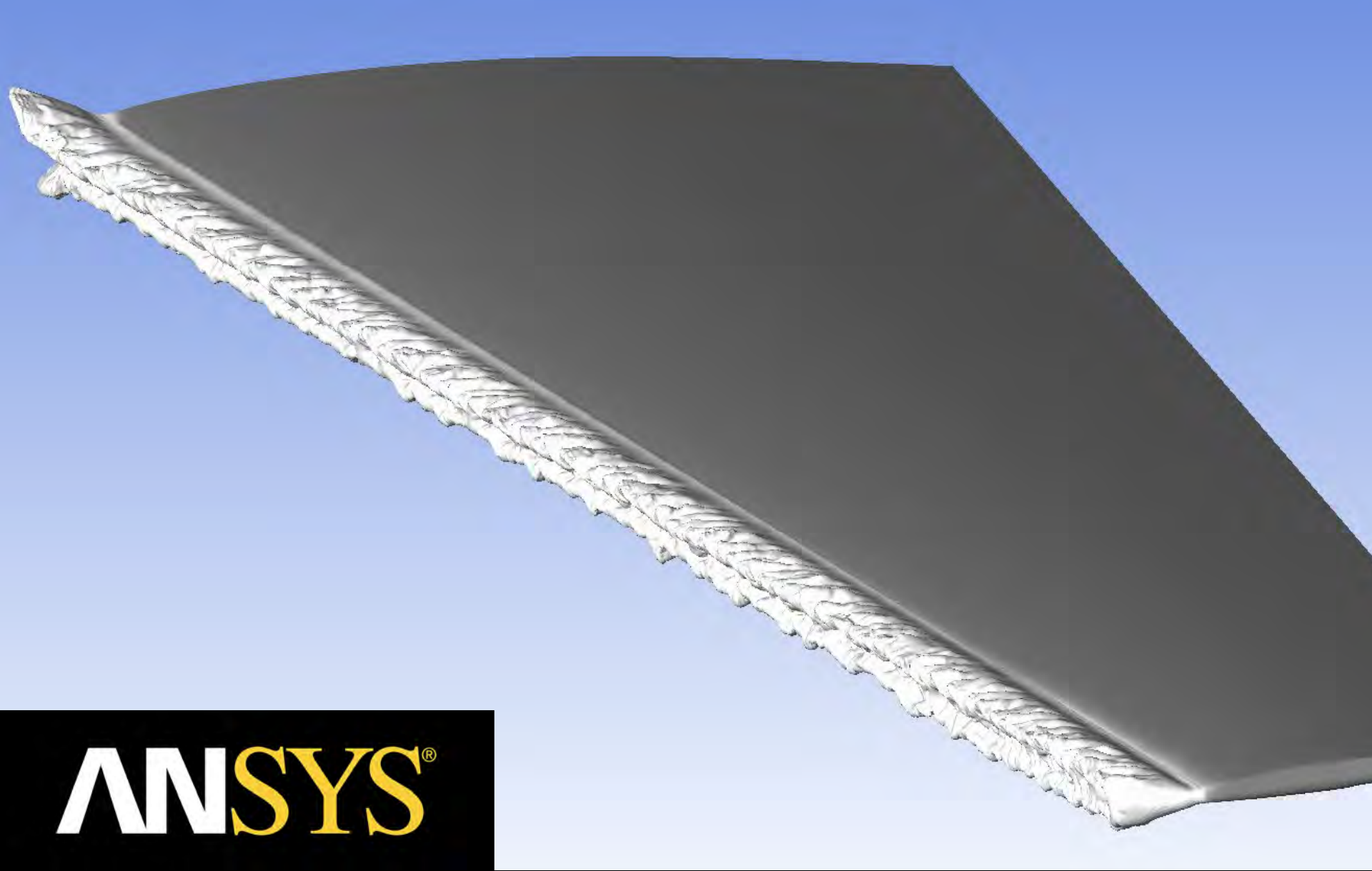


FENSAP-ICE: GLC305 Swept Wing, Glaze Icing



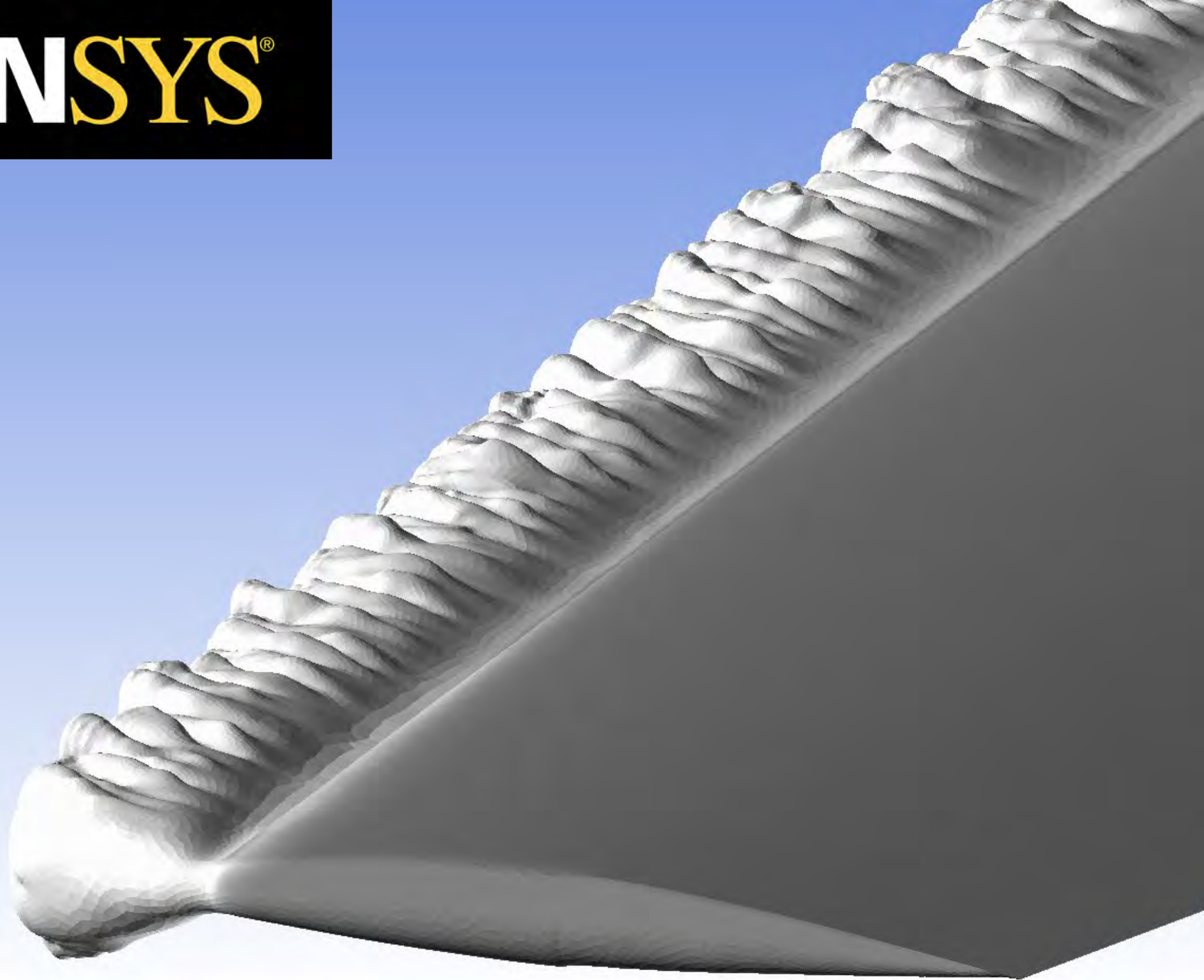
ANSYS[®]

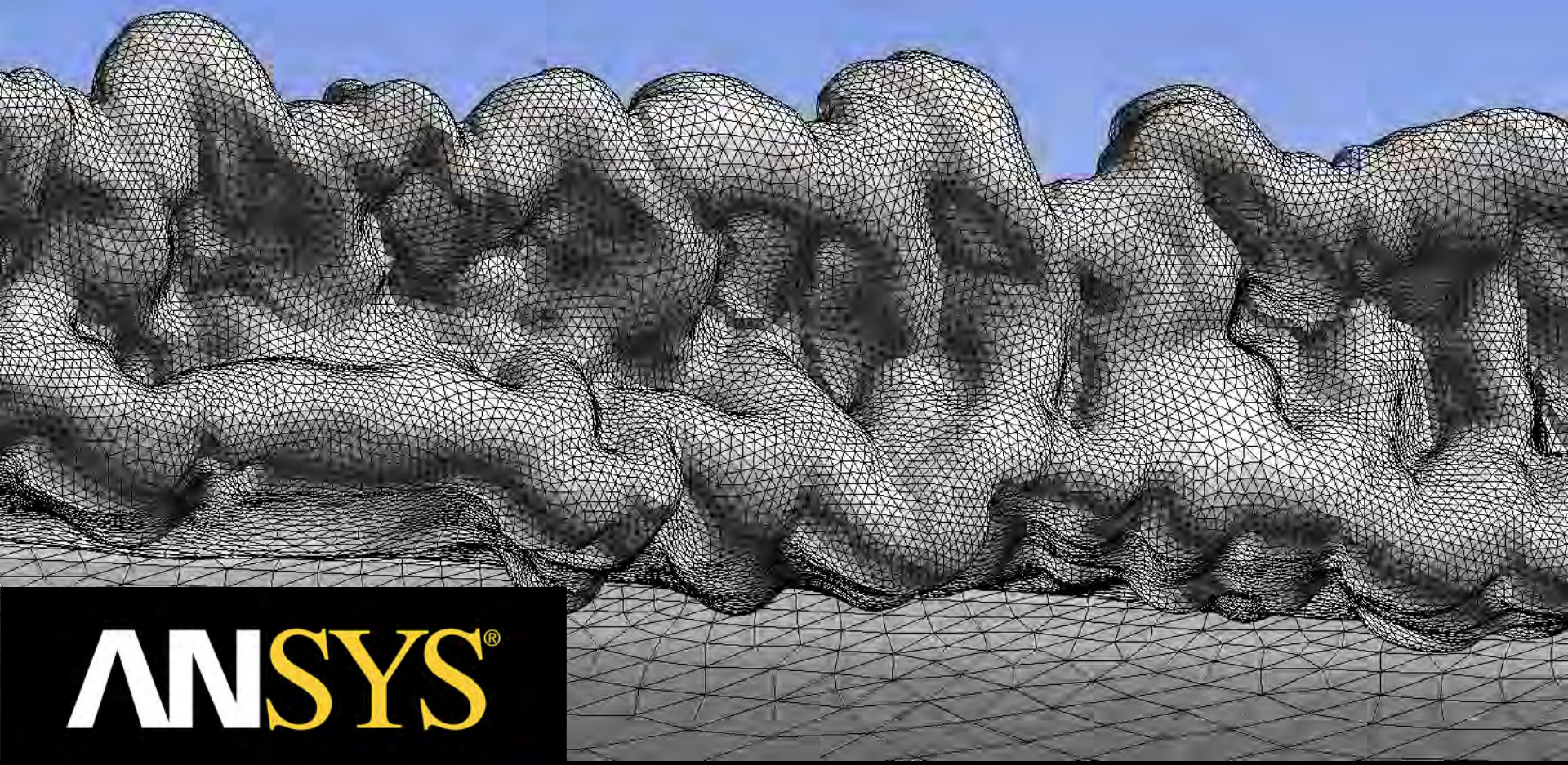




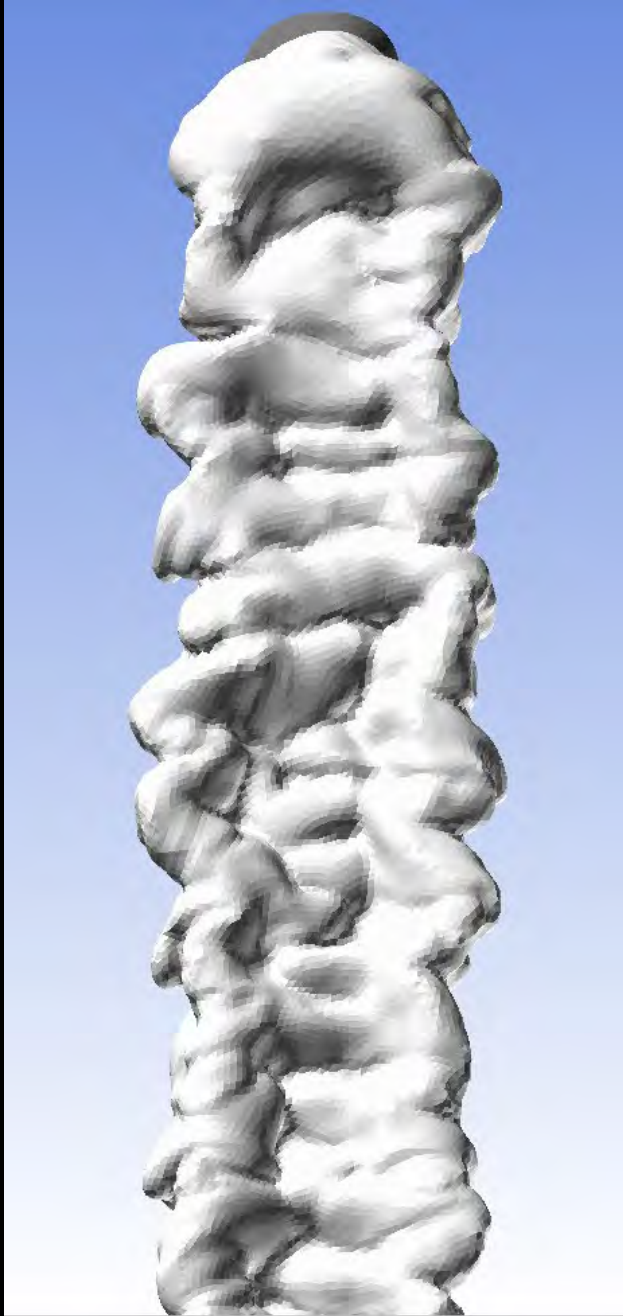
ANSYS[®]

ANSYS®



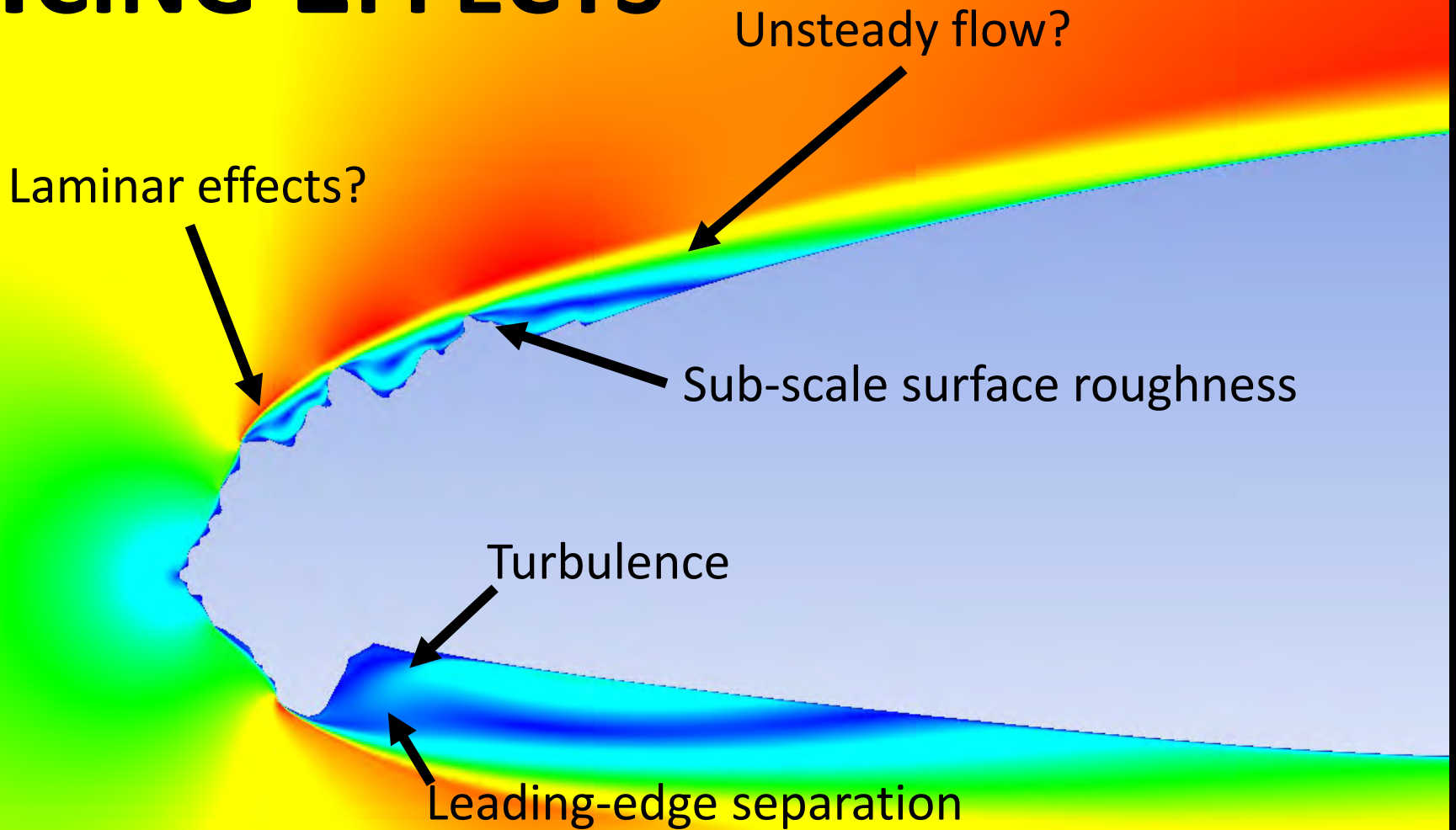


ANSYS[®]



IRT-
CS22

ICING EFFECTS

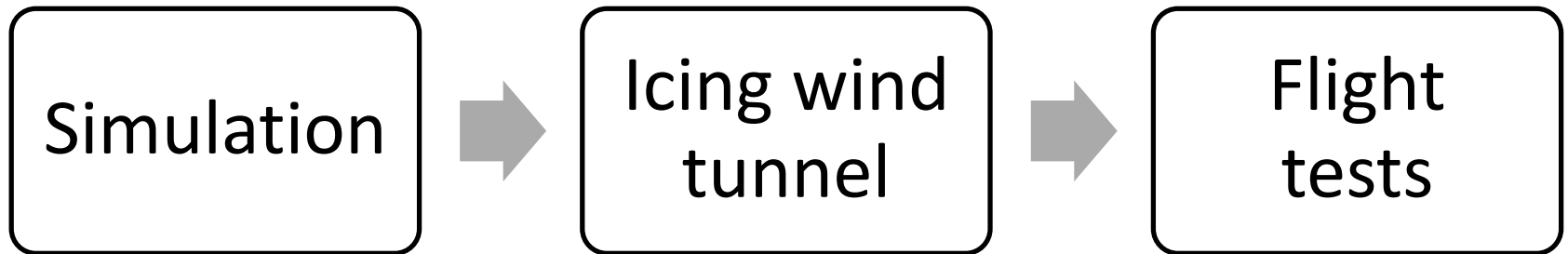


Velocity magnitude

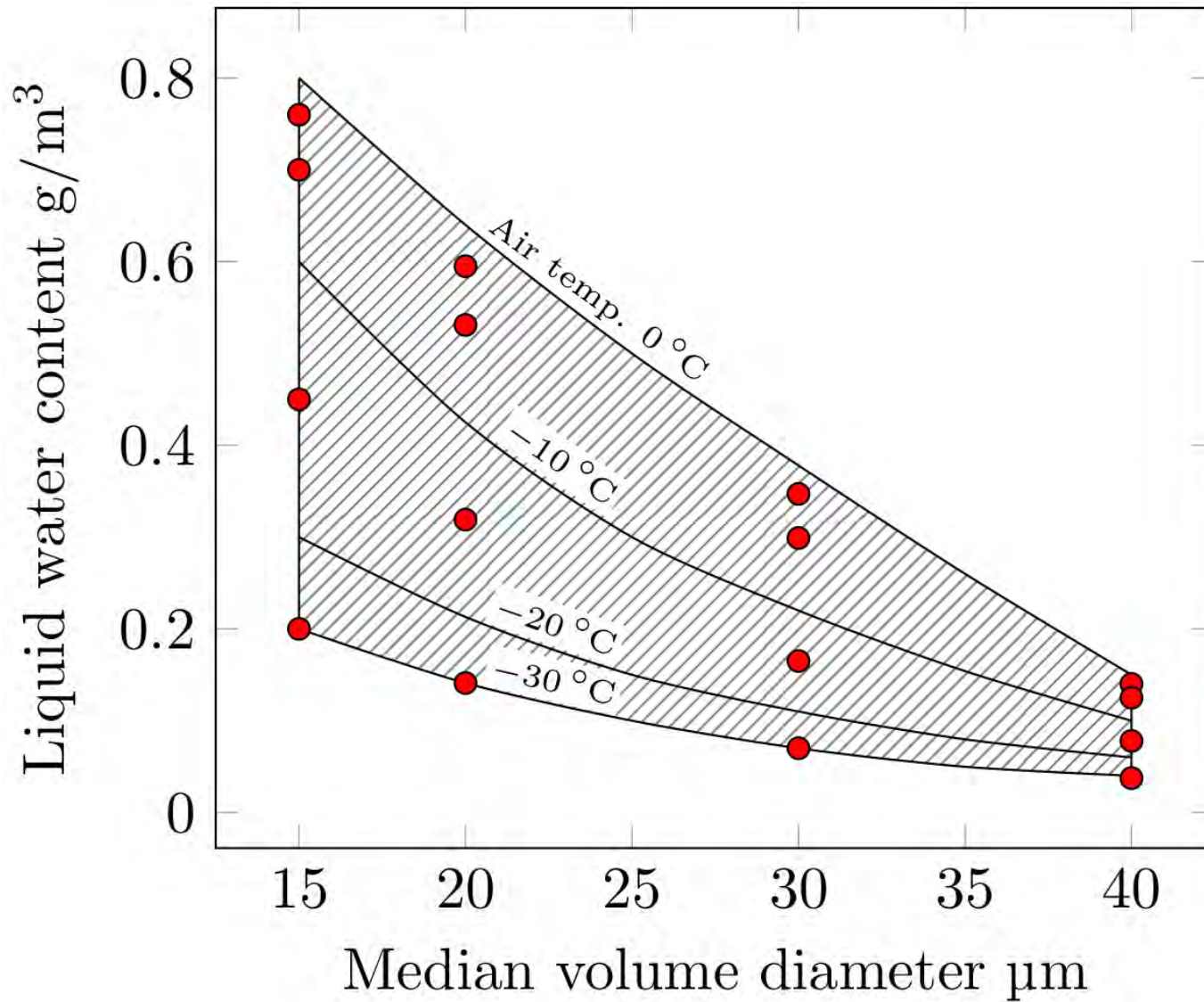


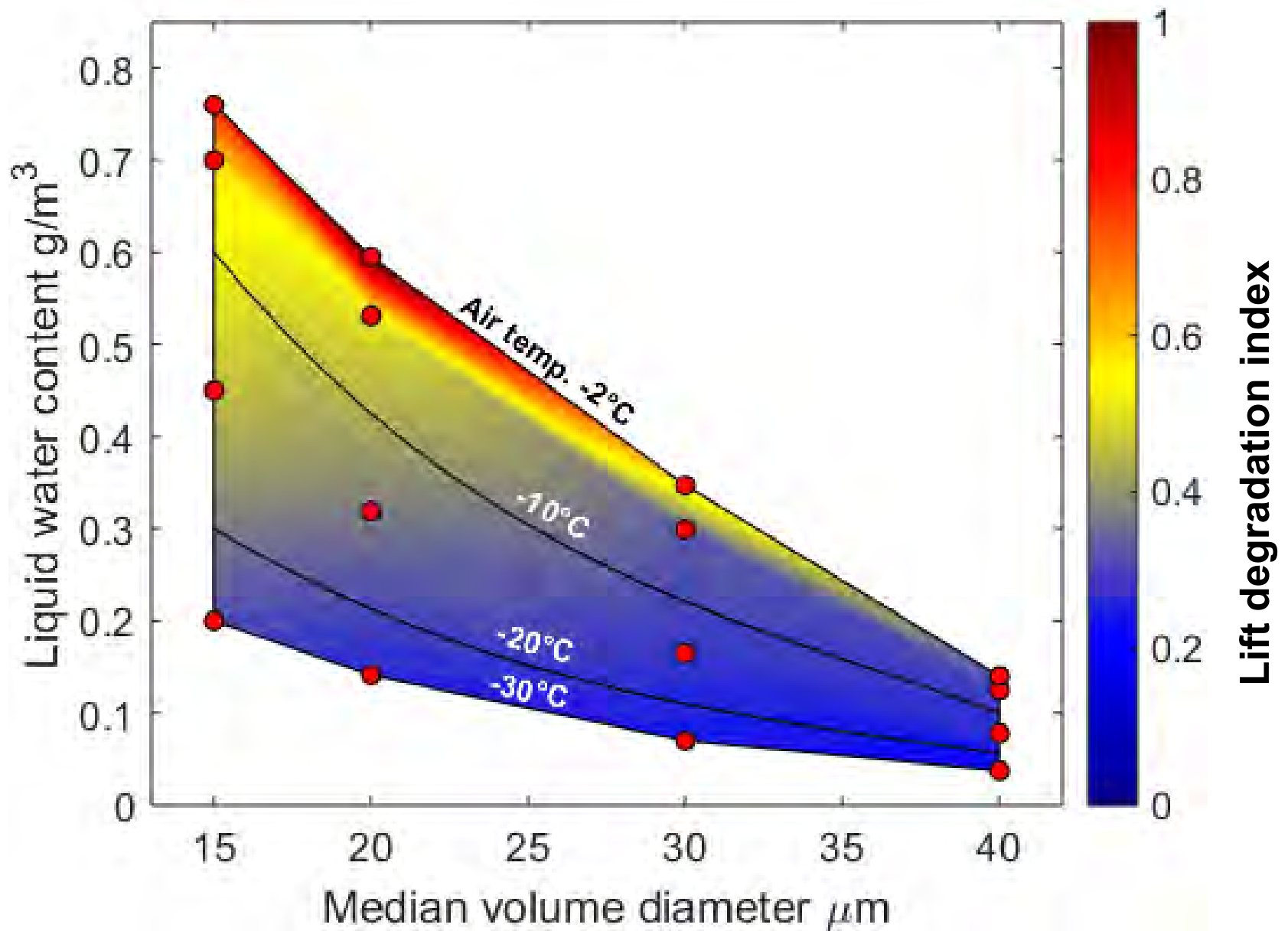
0.00000e+00

1.90000e+01



CFR 14, Part 25, Appendix C icing envelope





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

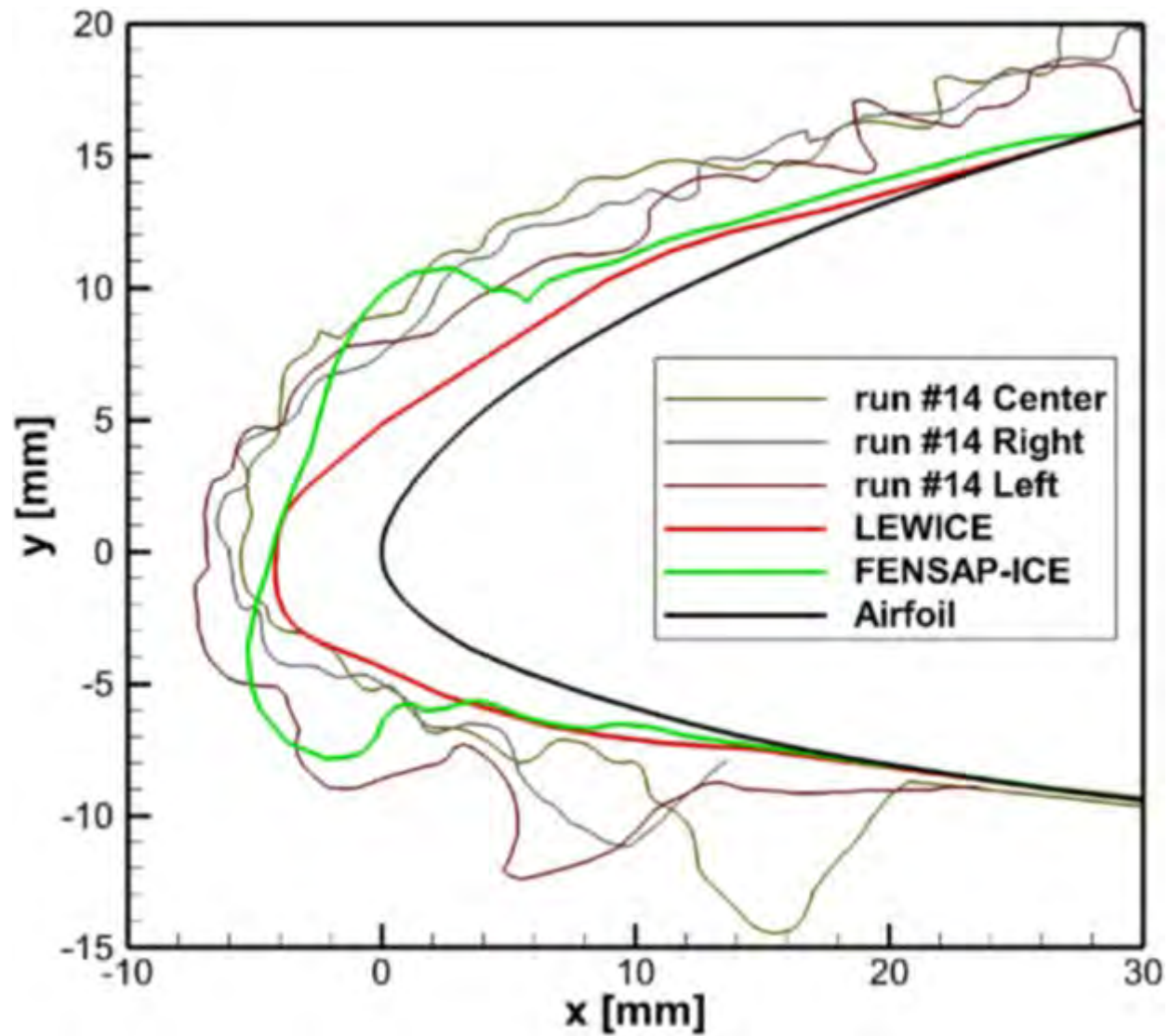
- German proverb



MISSING



LOW-REYNOLDS VALIDATION



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?

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