Rethinking ice protection for UAMs – Notional Vehicle Case Study

Alex Baty, VP Engineering

May 2022

OVERVIEW

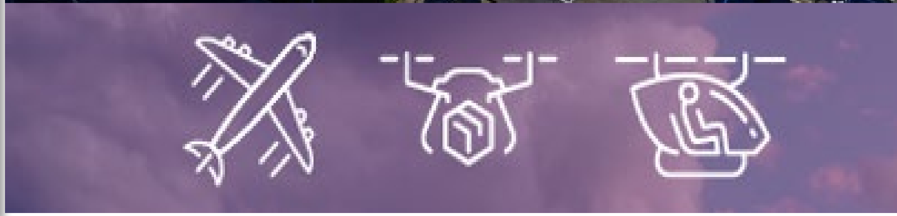
- **Introduction**
  - Alex Baty, VP Engineering
  - Expecting the unexpected: rethinking ice protection for UAMs
- **About CAV Systems**
- **IPS for eVTOL / UAM**
  - Direct System Weight & Endurance Requirements
  - In-Direct Impact of De-ice systems
- **Q&A**

electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

ABOUT CAV SYSTEMS

CAV is the global market leader in the design, production and aftermarket support of the globally unique and proprietary TKS® fluid based ice protection system and the only commercial manufacturer of laser micro-perforated structures for aviation drag reduction systems.

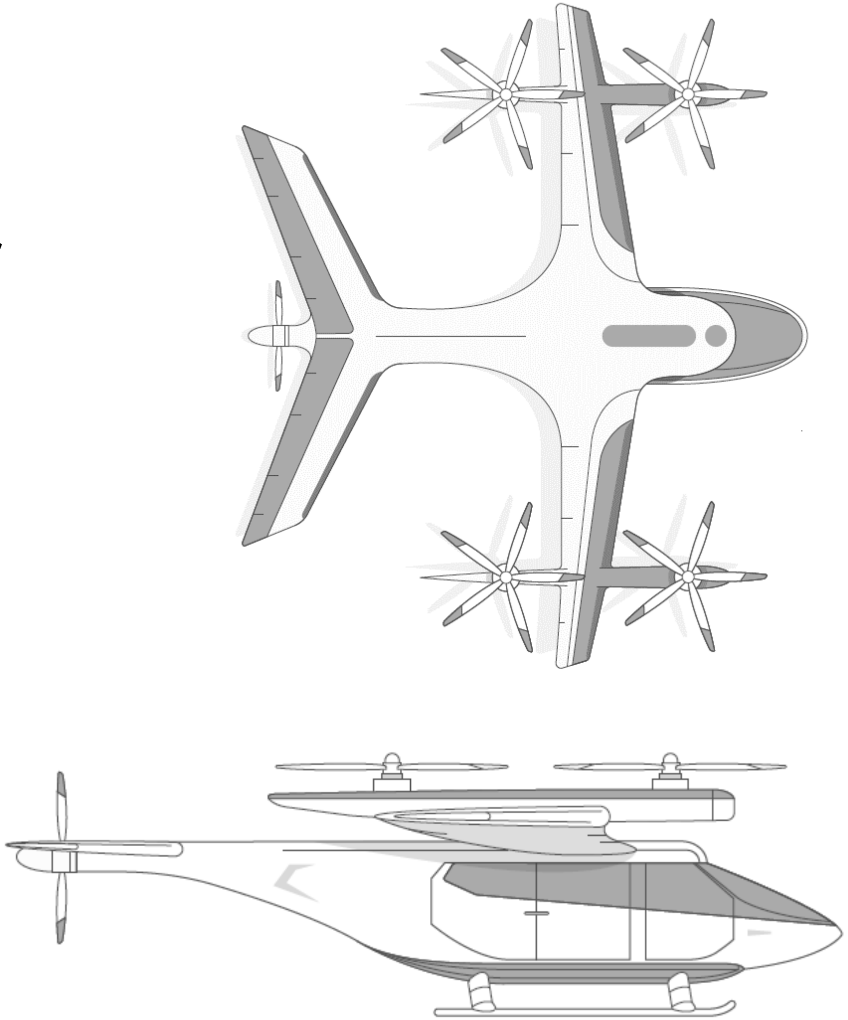
- We have operated as a critical technology and manufacturing partner to major commercial OEMs since 1942.
- Built upon strong foundations, we specialize in custom systems for general and commercial aviation, unmanned and urban air vehicles.
- Our in-house team of designers and engineers have extensive industry experience, which includes FIKI approval certification for a range IPS systems.
- Our ability to analyze aerodynamic data and unique laser drilling capabilities enables us to devise bespoke ice protection solutions for any aircraft.
- Recently applied for and awaiting CAA design organization approval.



electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

ICE PROTECTION FOR EVTOL AIRCRAFT

- In order to achieve widespread use and high utilization required to achieve commercial success UAM aircraft will need all weather capability.
- Selecting an Ice Protection System (IPS) may appear trivial to many, however the impact these systems can have on the performance of UAM aircraft can be significant.
- To illustrate, we have utilized our extensive knowledge, to size various IPS for a notional UAM aircraft.



electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

TYPES OF IPS CONSIDERED

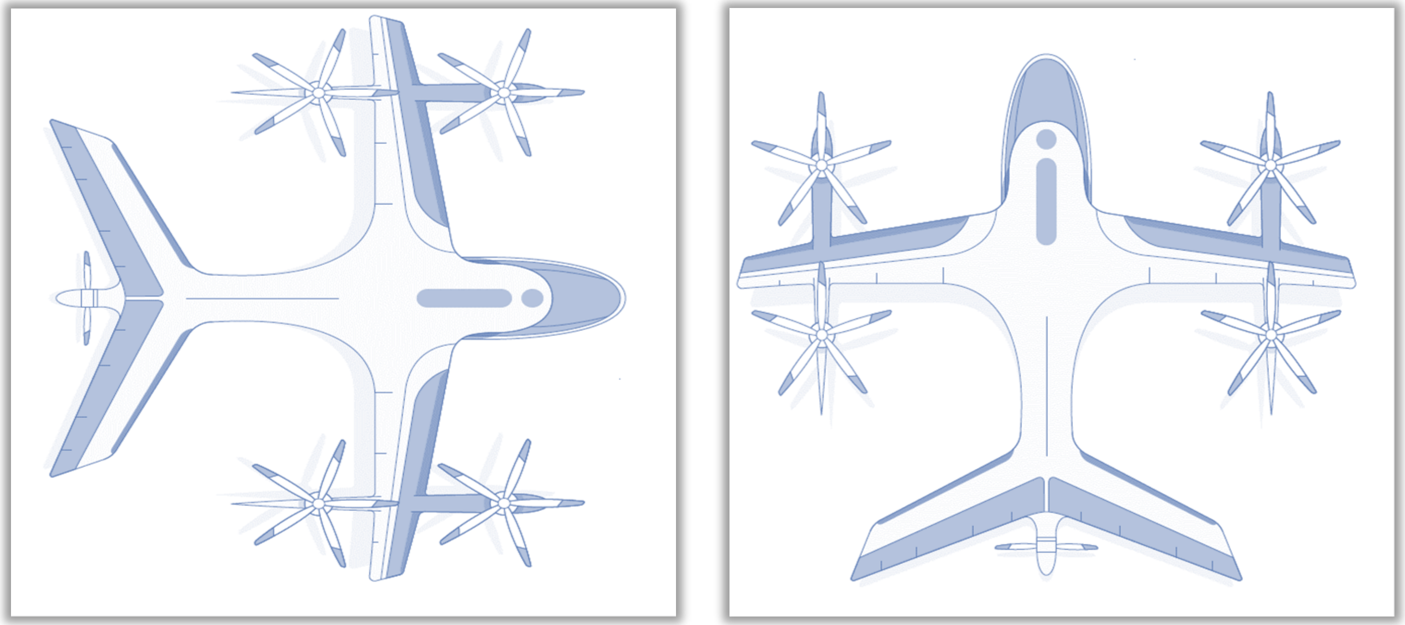
Electro-thermal	Expulsive	Boots	TKS
• De-ice system operating on a two-minute cycle to reduce energy consumption • Anti-ice energy consumption excessively high	• De-ice system operated by direct current pulse to conductors to eject the ice	• De-ice system operating on a two-minute cycle [industry standard]	• Fluid based system operating on the principle of freezing point depression • Provides anti-icing performance

electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

NOTIONAL AIRCRAFT

UAM aircraft come in many different shapes and sizes however, sizing an IPS is primarily dependent on the size of the protected areas and flight envelope of the aircraft – in this respect, our notional aircraft is reasonably representative of many UAM aircraft.

- Lift & Cruise Configuration
- Cruise speed ~135 KEAS



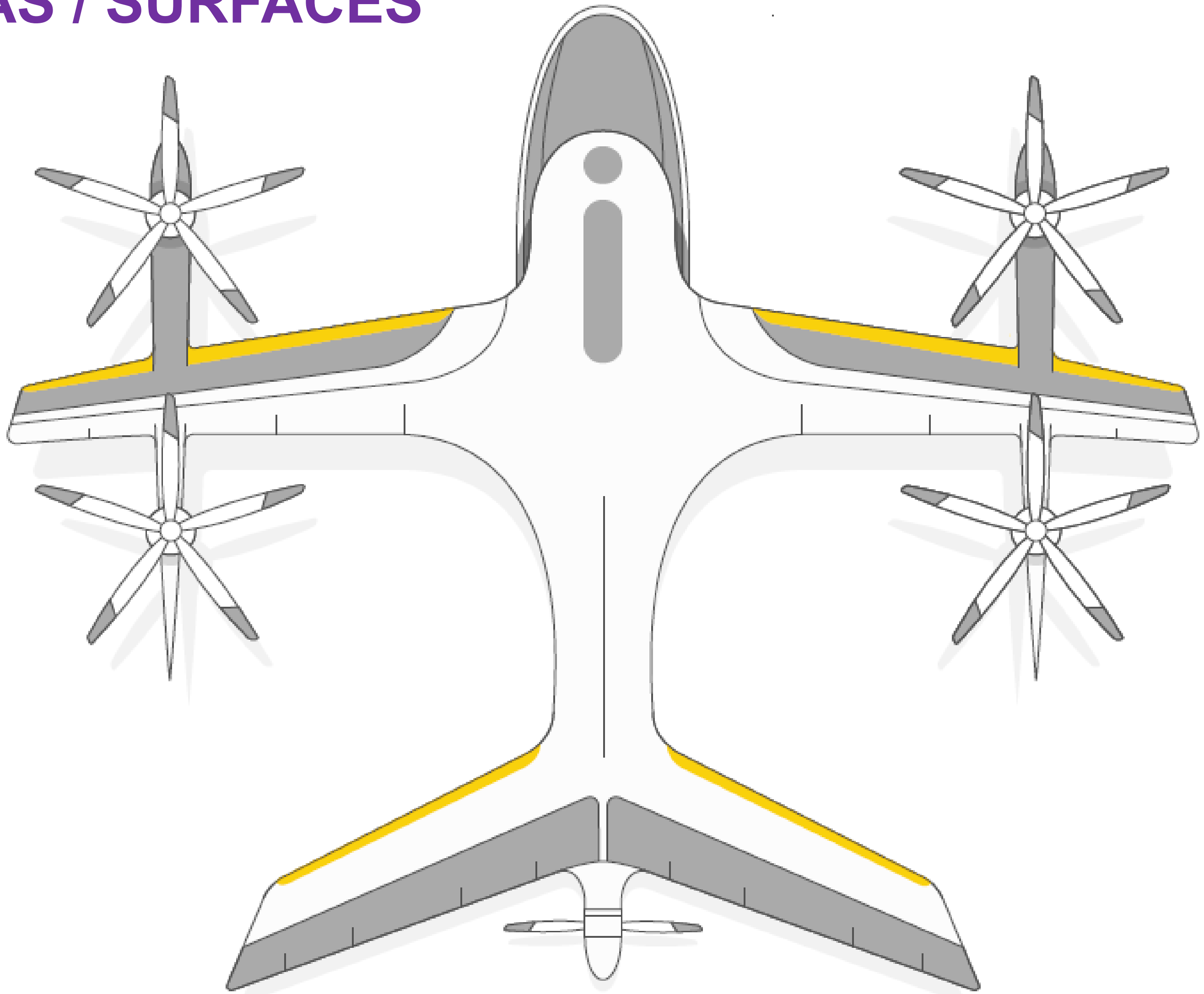
electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

DIRECT SYSTEM WEIGHT & ENDURANCE REQUIREMENTS

Ice Protection System → Reduced Range &/or Payload

electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

PROTECTED AREAS / SURFACES



- **Wing = 11.0m**
- **Horizontal Tail = 5.0m**

electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

REGULATORY REQUIREMENTS / ASSUMPTIONS

- Regulatory requirements around Ice Protection System endurance are currently being revised to address Electric Aircraft / UAM
- The requirement will be defined in *ASTM F3120* under the jurisdiction of the *ASTM Committee F44 on General Aviation Aircraft* - CAV engineers have played a pivotal role in the development of this standard
- Below is an excerpt of the latest draft

Aeroplane Type	*Minimum Endurance Capacity is the greater of:*
For aircraft with a maximum operating altitude below 10,000.	*150 minutes or 20 percent of the maximum endurance based on the energy required in typical continuous maximum icing conditions.* *For aircraft with less than 150 minutes of endurance the ice protection system shall be capable of being operated for an 80 nautical mile encounter at cruise speed.*

electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

SYSTEM WEIGHTS

	Electro-Thermal	Electro-Expulsive	Pneumatic Boots	TKS - Fluid System
Hardware*	15.0	10.1	12.5	5.7
Wiring / Plumbing	2.0	2.0	2.0	2.8
Leading Edges	3.8	11.3	11.3	9.4
Total	20.8	23.4	25.8	17.9

- *Hardware consists of control units, power switching units, energy storage units, pumps, valves etc. as required by the various systems
- Figures shown are for the system only – no account for energy required to operate the system
- All weights provided in Kg

electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

SYSTEM WEIGHTS - ENERGY

	Electro-Thermal	Electro-Expulsive	Pneumatic Boots	TKS- Fluid System
Electrical Energy [kWh]	26.2	2.6	0.5	0.1
Fluid [litres]	0.0	0.0	0.0	7.2
Weight	111.6	11.2	2.1	8.2

- Weight of Electrical Energy is based on a Battery Pack Energy Density of 235 Wh/Kg
- All weights provided in Kg

electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

TOTAL SYSTEM WEIGHT

	Electro-Thermal	Electro-Expulsive	Pneumatic Boots	TKS – Fluid System
Total Weight [with Dedicated Batteries]	132.4	34.5	27.9	26.1
Total Weight [with reduced range]	20.8	23.3	25.8	25.1
Range Reduction [nautical mile]	17.1	1.7	0.3	0.05
% range reduction	6.8%	0.7%	0.1%	0.02%

- Range Reduction based on loss of energy available for propulsion

electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

IN-DIRECT IMPACT OF DE-ICE SYSTEMS

electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

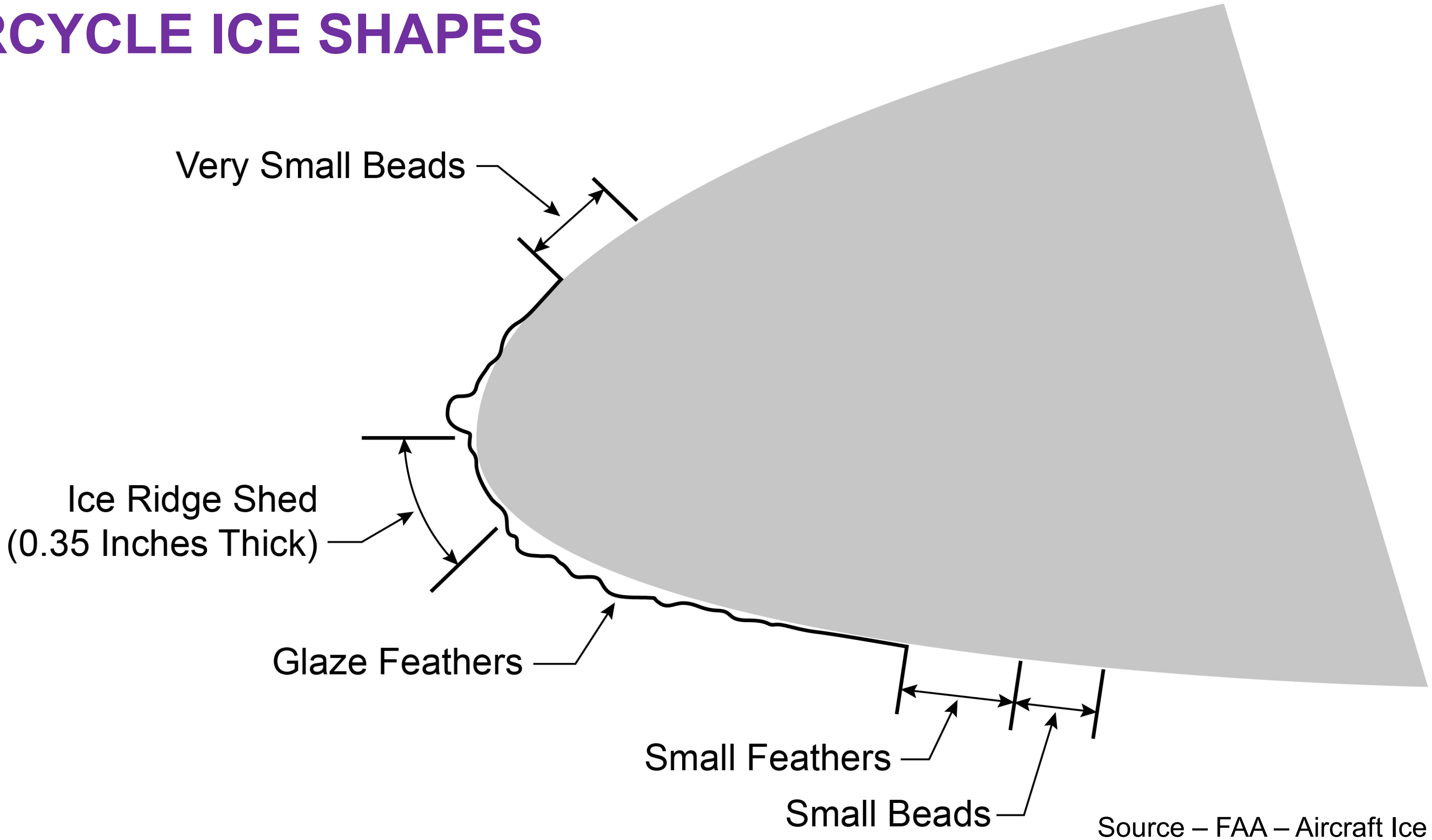
INTERCYCLE ICE SHAPES

Source – FAA – Aircraft Ice Protection - Advisory Circular

Figure 4-(b) Hybrid NACA 23012 2D (simulating a 72-inch chord airfoil) model intercycle ice before the sixth cycle of pneumatic deicing boot. One-minute boot cycle intervals were used. The test was performed in 14 CFR part 25, Appendix C Maximum Continuous Icing Conditions. (Static temperature = 14°F, LWC = 0.45 g/m^3, MVD = 20 micrometers, Spray time = 6:11 min., Tunnel airflow speed = 195 mph, Model AOA = 4°.)

electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

INTERCYCLE ICE SHAPES



Source – FAA – Aircraft Ice Protection - Advisory Circular
Figure 4-(b)

Hybrid NACA 23012 2D (simulating a 72-inch chord airfoil) model intercycle ice before the sixth cycle of pneumatic deicing boot. One-minute boot cycle intervals were used. The test was performed in 14 CFR part 25, Appendix C Maximum Continuous Icing Conditions. (Static temperature = 14°F, LWC = 0.45 g/m^3, MVD = 20 micrometers, Spray time = 6:11 min., Tunnel airflow speed = 195 mph, Model AOA = 4°.)

electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

INTERCYCLE ICE SHAPES
DRAG PENALTY – CURVE BASIC CALCULATIONS

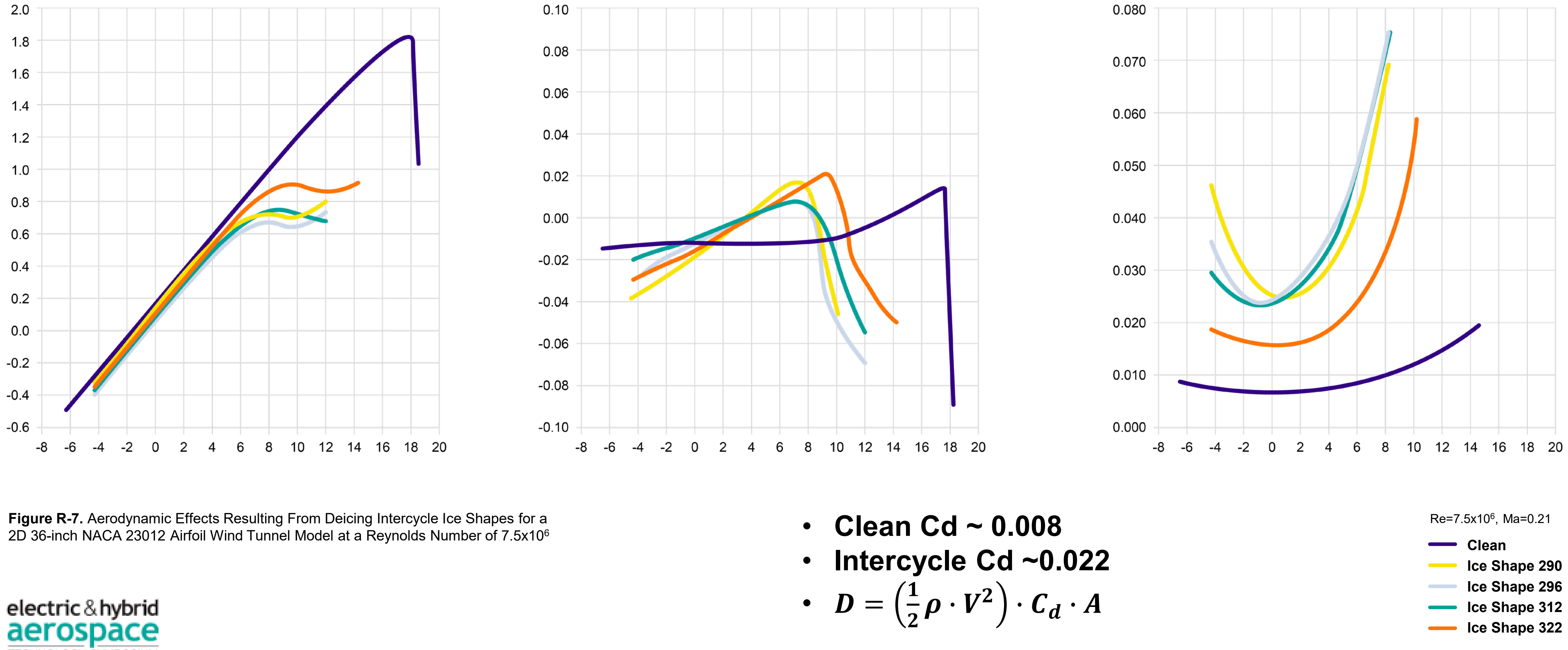
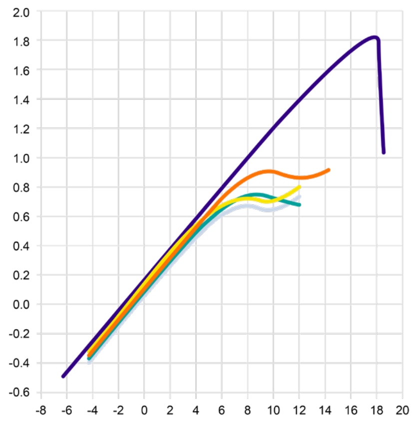


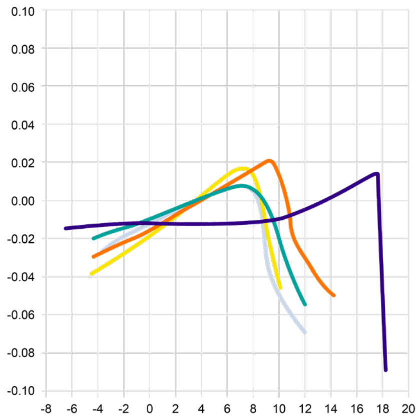
Figure R-7. Aerodynamic Effects Resulting From Deicing Intercycle Ice Shapes for a 2D 36-inch NACA 23012 Airfoil Wind Tunnel Model at a Reynolds Number of 7.5×10^6

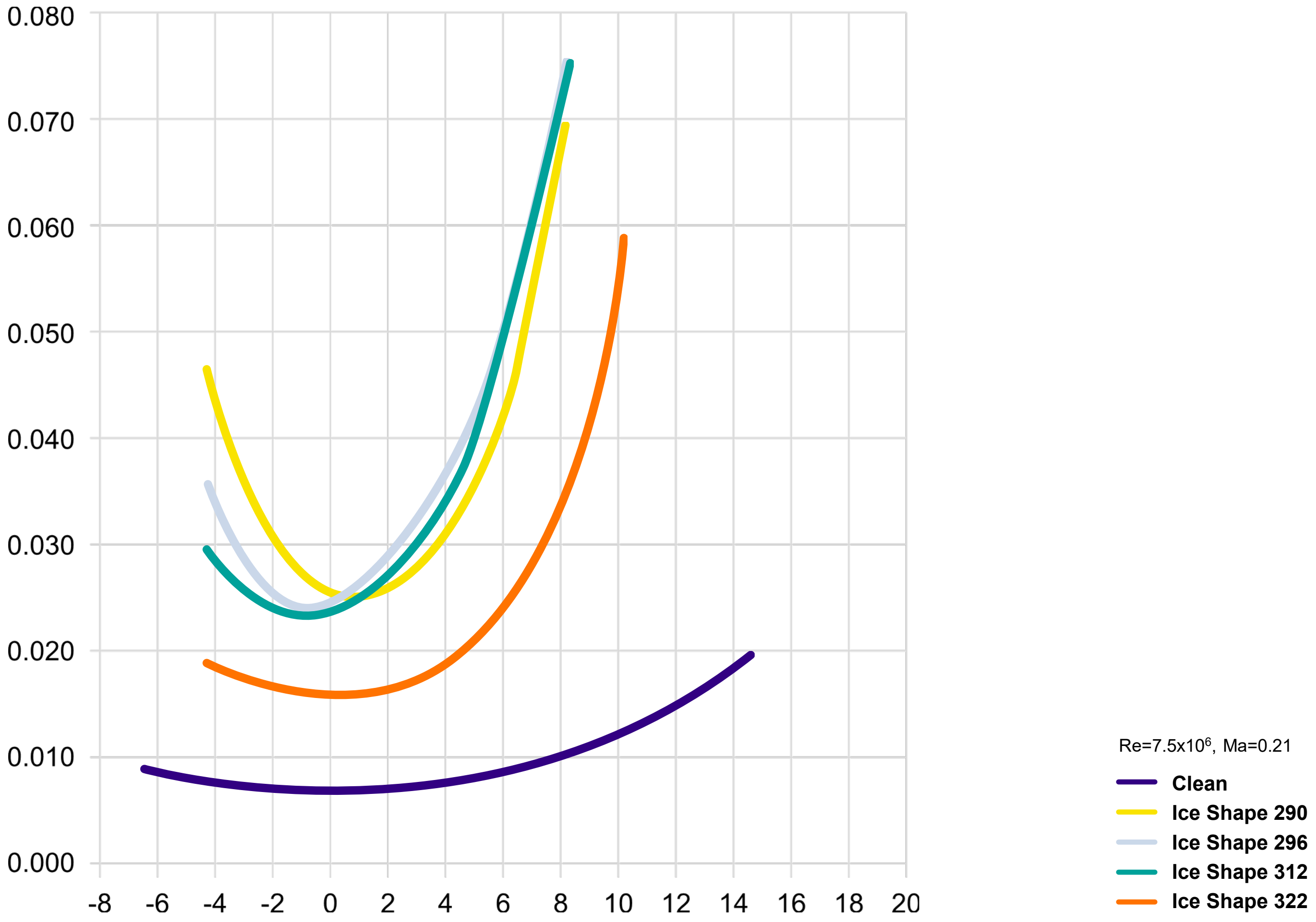
- **Clean Cd ~ 0.008**
- **Intercycle Cd ~0.022**
- $D = \left(\frac{1}{2}\rho \cdot V^2\right) \cdot C_d \cdot A$

electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

INTERCYCLE ICE SHAPES
DRAG PENALTY – CURVE BASIC CALCULATIONS







electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

IPS IMPACT ON AIRCRAFT DRAG

- Based on a single icing encounter halfway through a 250 nautical mile flight
- Intercycle and residual ice shapes associated with de-ice systems significantly increase aircraft drag resulting in further loss of range

	De-ice Systems [Boots, Electro-Thermal & Electro-Expulsive	Anti-Ice Systems [TKS]
Range Reduction [nautical mile]	29	0.0
% range reduction	11%	0.0%

electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

TOTAL IMPACT OF IPS ON THE AIRCRAFT

	Electro-Thermal	Electro-Expulsive	Pneumatic Boots	TKS - Fluid System
Total Weight [with reduced range]	20.8	23.3	25.8	25.1
Range Reduction [nautical mile]	40.3	24.9	23.5	0.05
% Range Reduction	16.1%	10.0%	9.4%	0.02%

- **Weight of the TKS fluid system includes fluid weight**
- **De-ice systems – assumed loss of range rather than dedicated batteries for IPS**
- **Range reduction is the result of**
  - Batteries primarily required for propulsion being used to power IPS
  - Intercycle and residual ice shapes associated with de-ice systems

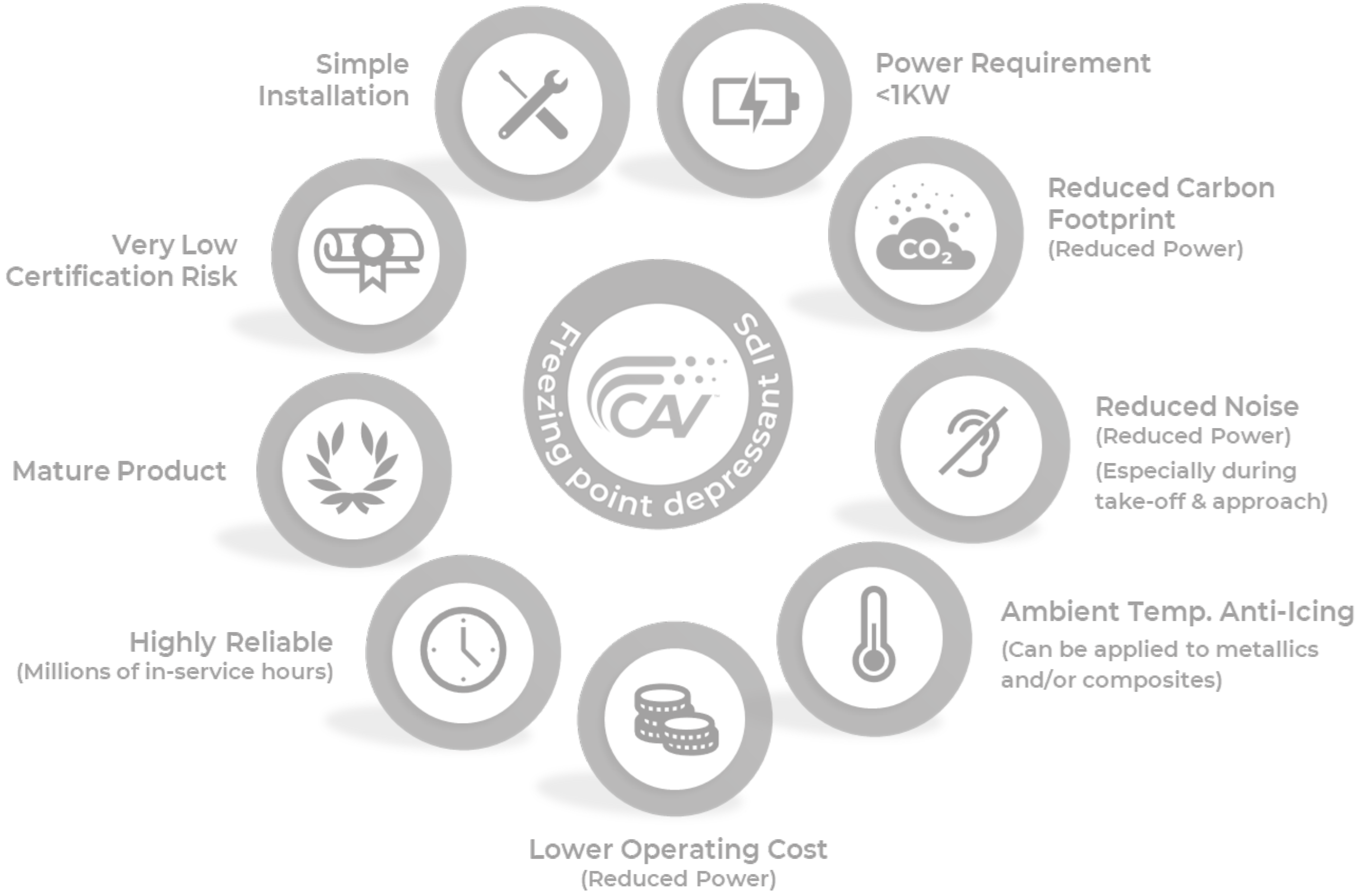
electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

SUMMARY

- Ice Protection is a key part of providing all weather capability & achieving high aircraft utilization
- Ice Protection Systems can have a considerable impact on aircraft performance and range
- De-ice systems although lower weight come with significant range penalties
- It is important to develop an Ice Protection Strategy early in the design and development.

electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

Q&A



electric & hybrid aerospace TECHNOLOGY SYMPOSIUM

Thank You

To find out more about partnering with CAVŪ for your new aircraft's TKS® ice protection system, please get in touch at the details below:

UK +44 (0) 1207 599 140
US +1 (913) 738 5390

TKS@cav-systems.com

Registered Offices:

– Number One Industrial Estate, Consett, United Kingdom, DH8 6SR
– 30 Leawood Drive, New Century, Kansas, 66301, USA

www.cav-systems.com