A Fluid-Based Ice Protection System for sUAS Propellers

R. Brock Harden

CAV Systems, Ltd.

Introduction

- **Presentation Outline**
  - The "Why": Importance of Ice Protection for sUAS
  - System Overview: Pneumatic-Fluid Ice Protection System
  - Components Discussion: Key Parts and Functionality
  - Wind Tunnel Testing: Results and Insights
  - Flight Testing: Dry-Air Tests
  - Conclusions and Future Directions: Summary and Next Steps

Introduction

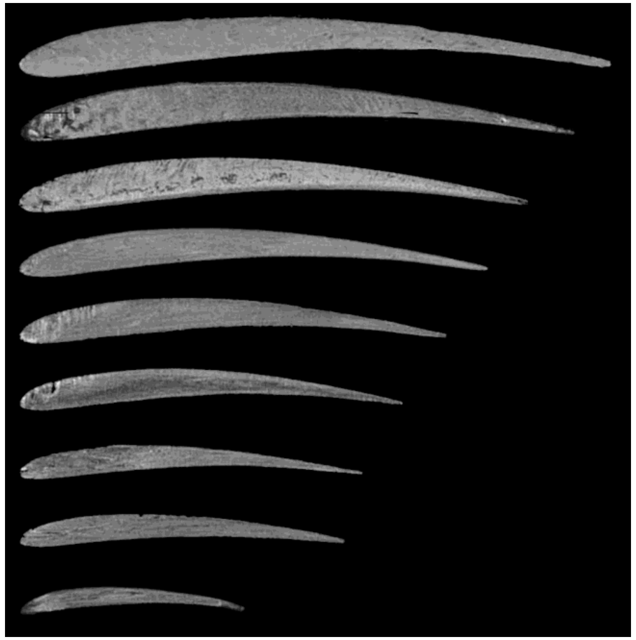
- **The sUAS industry is growing rapidly across many different use cases.**
  - Consumer goods delivery
  - Medical supplies
  - Emergency response
  - Research

- **In-flight protection from ice protects the aircraft, people, and property, and improves the efficiency of the systems that rely on sUAS.**

- **Tech presented in this presentation is subject of UK patent application No. GB 2218766.0**

The Small Propeller Icing Problem

- **sUAS propeller blades are sharp, small, and fast.**
- **Leads to...**
  - Very high water catch efficiency (~90%)
  - Large impingement limits (sometimes to the trailing edge!)
- **Testing shows extremely dangerous thrust loss within 2 to 3 minutes.**



The Small UAS Icing Problem

- **Energy and weight are paramount for sUAS.**
- **For a 16 kg all-up weight, every 0.5 kg increase in auxiliary system weight is nearly a 6% decrease in payload capacity.**
- **Electro-thermal IPS uses large amounts of power, forcing an increase in battery size.**
- **Other technologies are difficult to scale down.**
  - Bleed air, pneumatic boots
- **While others have not been shown to be effective and durable.**
  - Passive surface coatings
- **Fluid systems require that fluid is carried but are very low energy and can protect the propeller blades and the airframe.**

The Pneumatic-Fluid Ice Protection System Overview

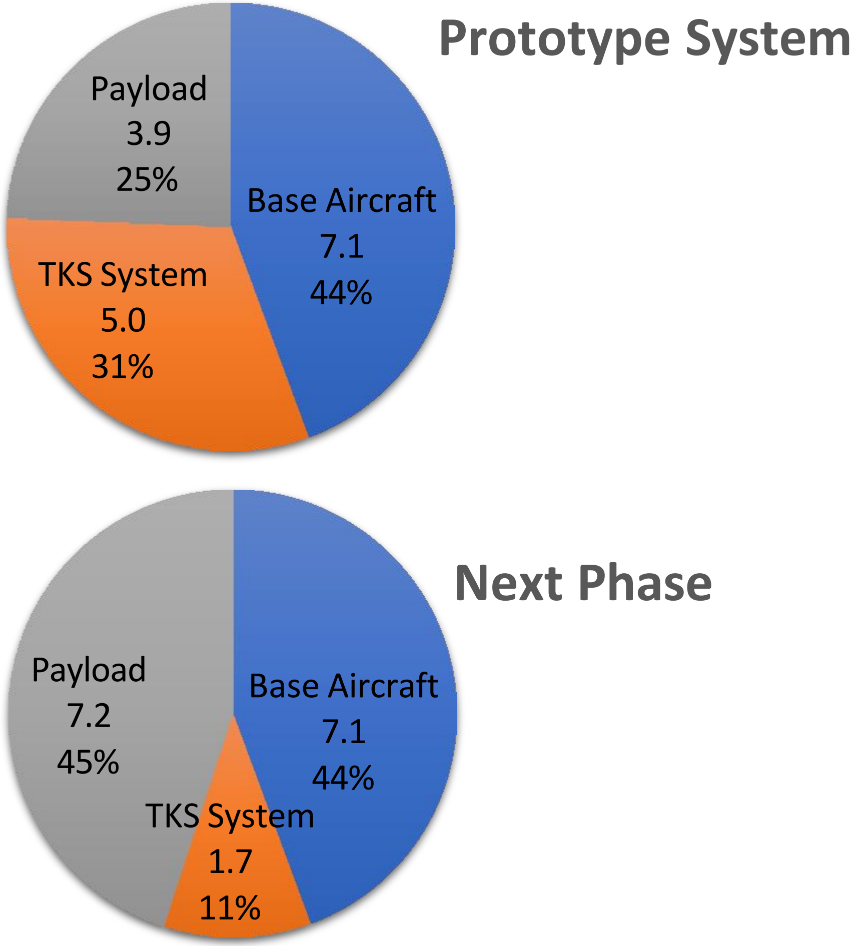
Prototype Weight

TKS Components

- TKS Tank
- Static Regulator
- Solenoid
- TKS Controller
- Propeller Protection

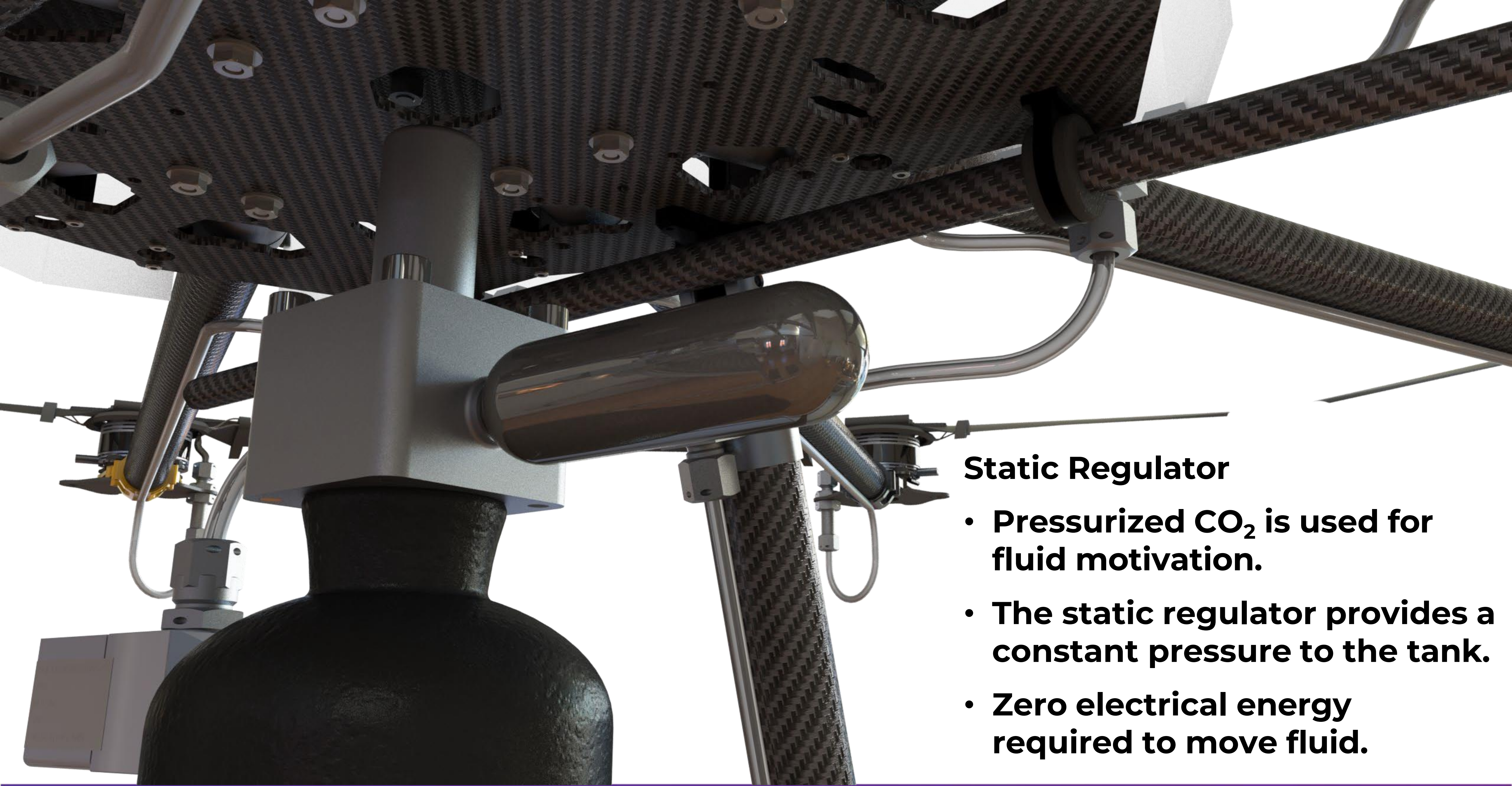
Prototype Weight

All-Up Weight: 16 kgf



Fluid Tank

- 1 liter of TKS = 30 minutes of icing endurance in freezing fog.
- Pressure vessel and fluid container in one.

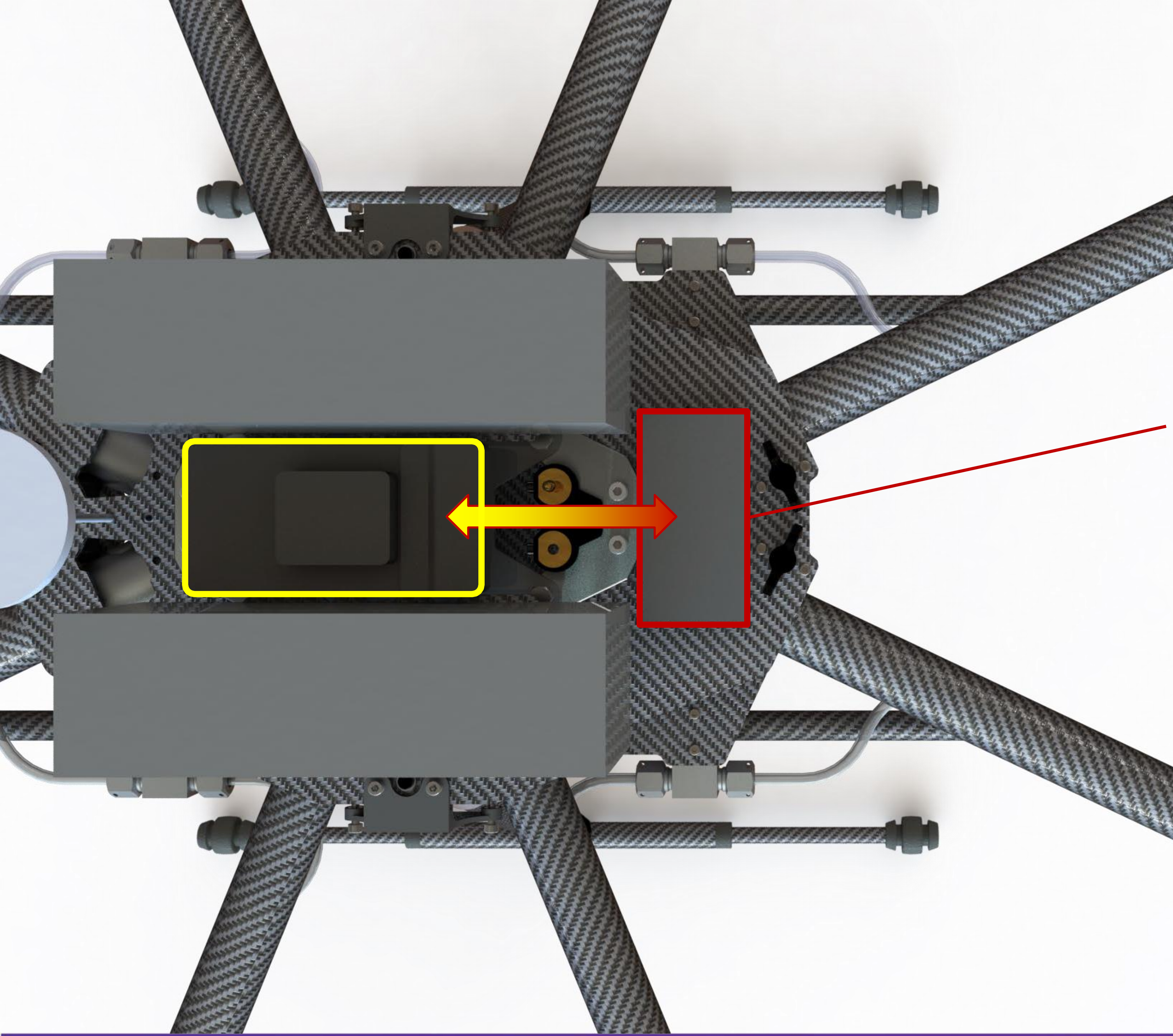


Static Regulator

- Pressurized CO_2 is used for fluid motivation.
- The static regulator provides a constant pressure to the tank.
- Zero electrical energy required to move fluid.

Solenoid

- A low-power solenoid turns off and on to modulate the flow to the arterial tubing.
- < 10 W power usage



TKS Controller

- **A small PWM circuit drives the solenoid to control flow rate.**
- **Can integrate with the flight controller to be manually controlled.**

Propeller Protection

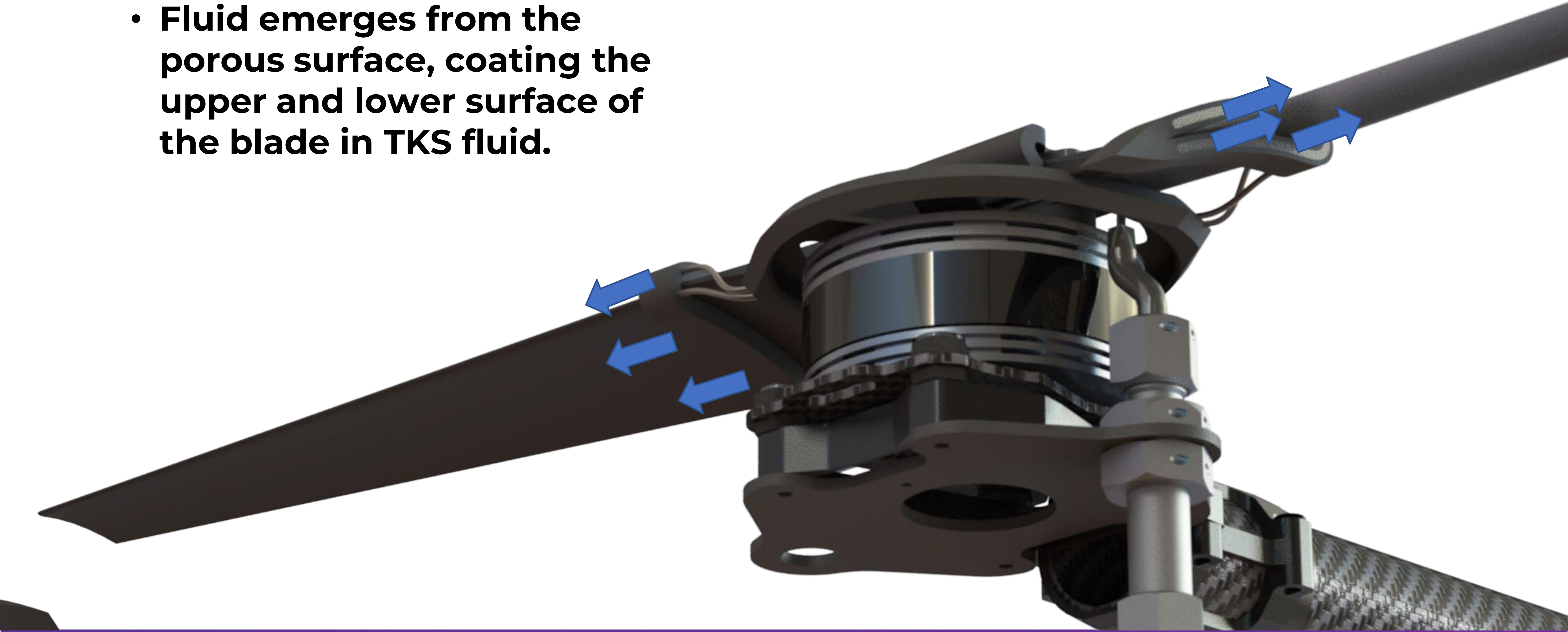
- **Fluid from the arterial system is fed into a nozzle, filling a channel in a slinger ring.**

Propeller Protection

- **Centrifugal force pushes the fluid through the feed tubes into porous cuffs at the root of the blade.**

Propeller Protection

- **Fluid emerges from the porous surface, coating the upper and lower surface of the blade in TKS fluid.**



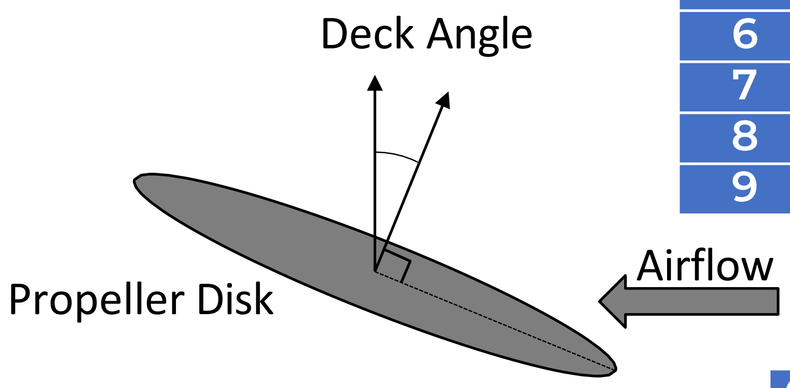
Wind Tunnel Testing

- **Icing wind tunnel tests performed at the LeClerc Icing Research Lab (Cox & Co.)**
- **Performed 40 runs on different cuffs at various freezing fog and flight conditions.**
- **Collected data using a DAQ thrust stand.**
  - Torque, thrust, vibration, electrical current

Test Conditions

Freezing Fog Conditions [1]

Case	Temperature	LWC	N	D
1	-4 °C	0.03 g m-3	50 cm-3	16 µm
2	-8 °C	0.03 g m-3	50 cm-3	16 µm
3	-12 °C	0.03 g m-3	50 cm-3	16 µm
4	-4 °C	0.3 g m-3	100 cm-3	26 µm
5	-8 °C	0.3 g m-3	100 cm-3	26 µm
6	-12 °C	0.3 g m-3	100 cm-3	26 µm
7	-4 °C	0.3 g m-3	300 cm-3	16 µm
8	-8 °C	0.3 g m-3	300 cm-3	16 µm
9	-12 °C	0.3 g m-3	300 cm-3	16 µm



Flight Conditions

Case	Flight Mode	Deck Angle	RPM
1	Hover	90°	60%
2	Cruise	18°	75%
3	Climb	90°	100%

[1] Developed in coordination with the University of North Dakota, Department of Atmospheric Sciences

Predictive Analysis

- **Flowrate per propeller (two blades)**
- **Assumes max beta across impingement range.**

Case	Temperature (°C)	LWC (g/m^3)	D (um)	Hover (ml/min)	Cruise (ml/min)	Vert Climb (ml/min)
1	-4	0.03	16	0.06	0.05	0.05
2	-8	0.03	16	0.19	0.19	0.20
3	-12	0.03	16	0.32	0.37	0.37
4	-4	0.3	26	0.72	0.58	0.58
5	-8	0.3	26	2.15	2.08	2.10
6	-12	0.3	26	3.50	3.96	3.98
7	-4	0.3	16	0.61	0.54	0.54
8	-8	0.3	16	1.94	1.94	1.96
9	-12	0.3	16	3.18	3.71	3.74

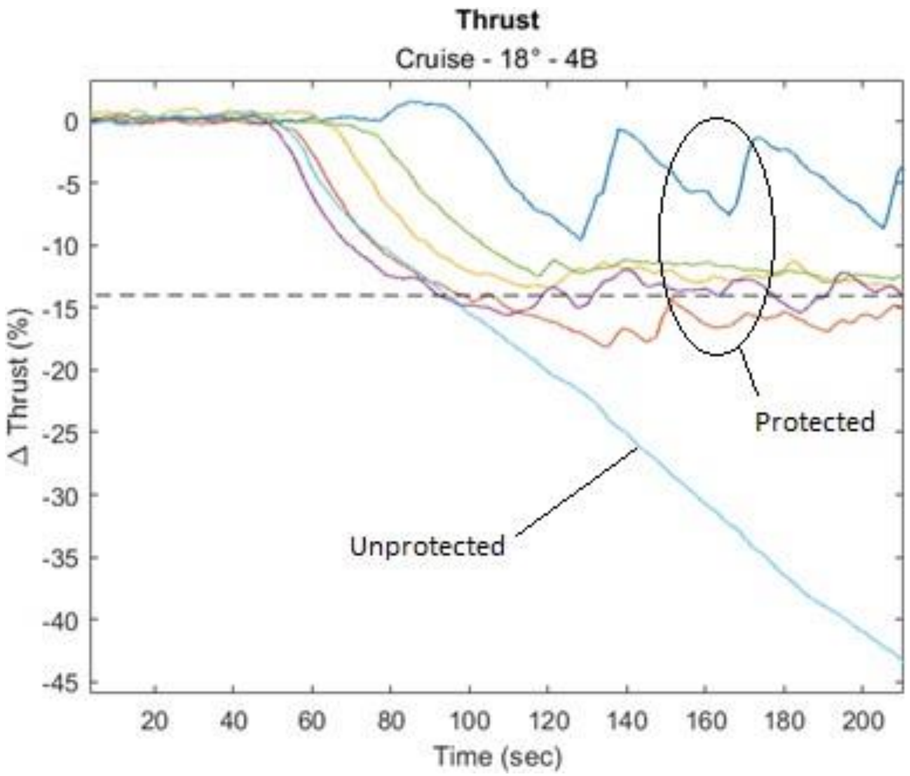
Predictive Analysis

				Maximum Beta			Normalized Beta		
Case	Temperature (°C)	LWC (g/m^3)	D (um)	Hover (ml/min)	Cruise (ml/min)	Vert Climb (ml/min)	Hover (ml/min)	Max Forward (ml/min)	Max Climb (ml/min)
1	-4	0.03	16	0.06	0.05	0.05	0.01	0.01	0.01
2	-8	0.03	16	0.19	0.19	0.20	0.04	0.03	0.03
3	-12	0.03	16	0.32	0.37	0.37	0.06	0.06	0.06
4	-4	0.3	26	0.72	0.58	0.58	0.12	0.09	0.09
5	-8	0.3	26	2.15	2.08	2.10	0.35	0.33	0.34
6	-12	0.3	26	3.50	3.96	3.98	0.57	0.63	0.64
7	-4	0.3	16	0.61	0.54	0.54	0.13	0.08	0.08
8	-8	0.3	16	1.94	1.94	1.96	0.36	0.29	0.29
9	-12	0.3	16	3.18	3.71	3.74	0.58	0.56	0.57

16%

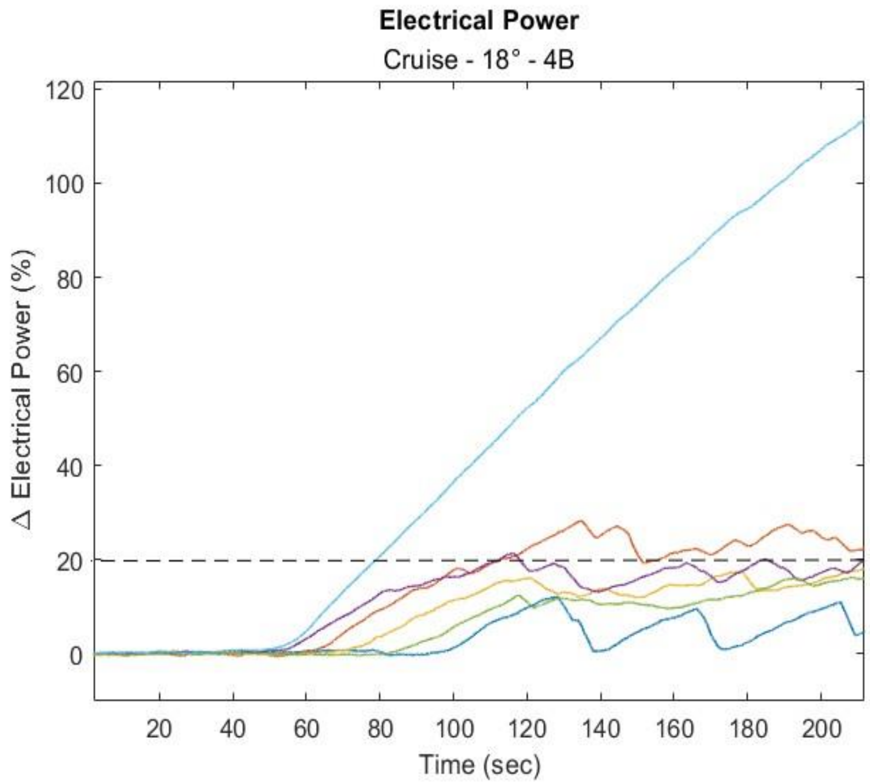
Thrust Loss

- **For an unprotected blade, thrust performance degrades linearly and rapidly.**
  - An analysis suggests that at this condition, an sUAS at 400 ft AGL would crash into the ground within 2.4 minutes.
- **The protected blades show a bounded 10-15% decrease in thrust. Enough to degrade performance but still capable of maintaining safe flight to exit icing.**

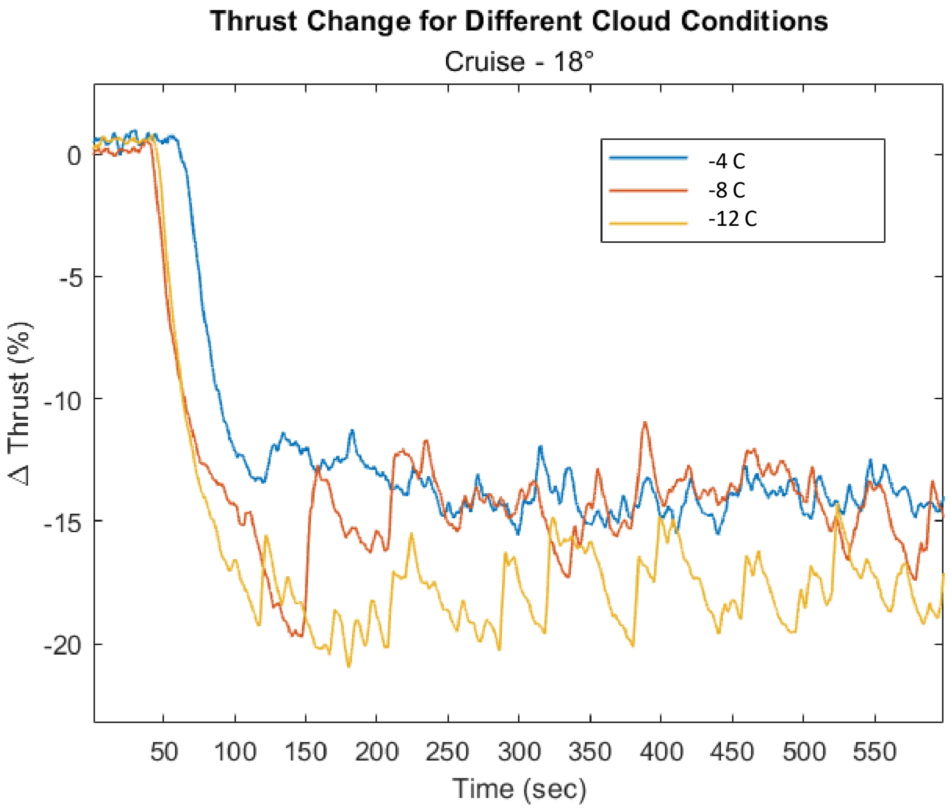


Power Draw

- **Similarly, a large increase in power is required due to increased drag.**
- **For this icing condition…**
  - Unprotected: ~ 115 % increase in power draw
  - Protected: ~ 20 % increase

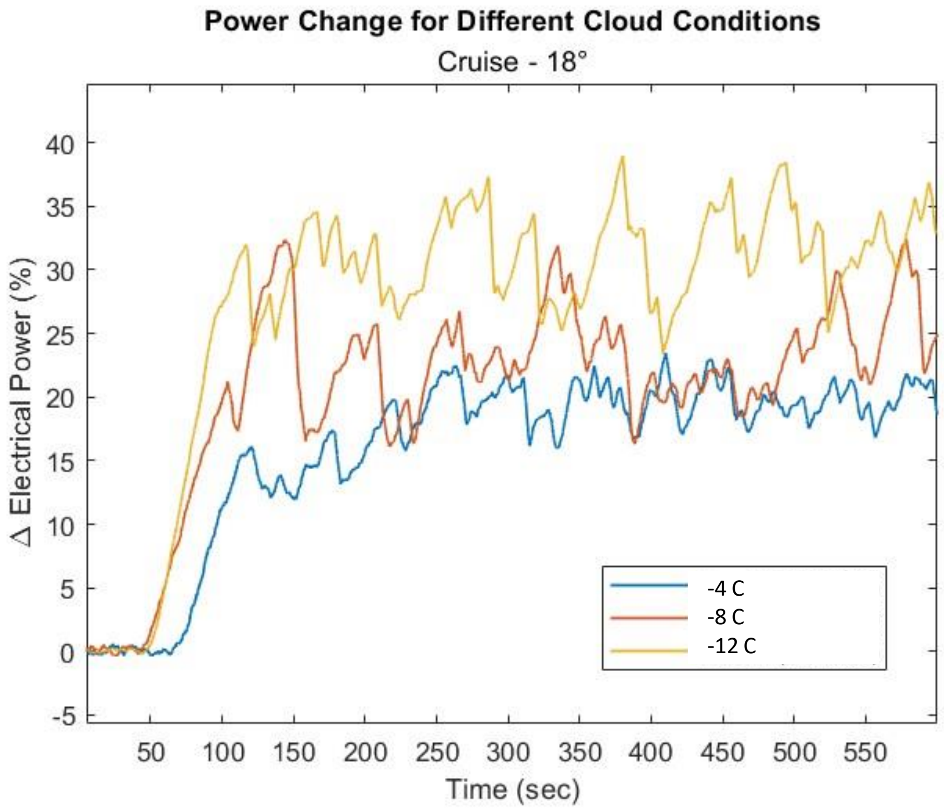


Temperature Effects



- **For a given LWC (0.3 g/m³) and droplet size (26 um), performance of the protected system decreased with temperature.**

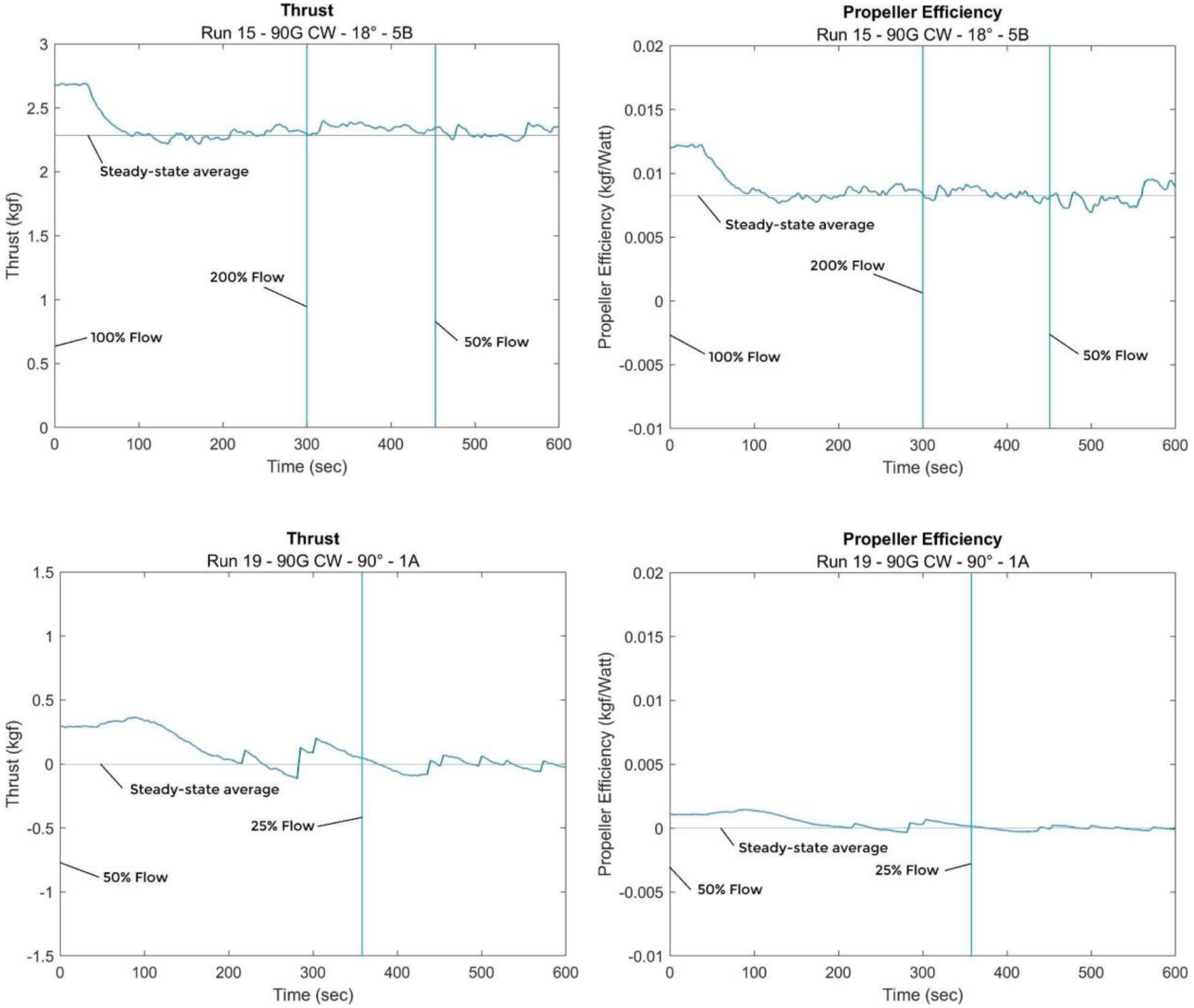
Temperature Effects



- **Similarly, at the same condition, power draw increased.**

Flow Rate Change

- **During testing, the flow rate was changed to monitor the effects for a few runs.**
- **Neither increased or decreased flow had a marked effect on performance.**
- **This suggests that the ability of TKS to prevent ice from adhering to the blade surface may be enhanced by the extreme environment of a propeller blade: high G-forces and vibration.**
- **Analysis and tests indicate a possibility to decrease fluid requirements, drastically decreasing system weight.**

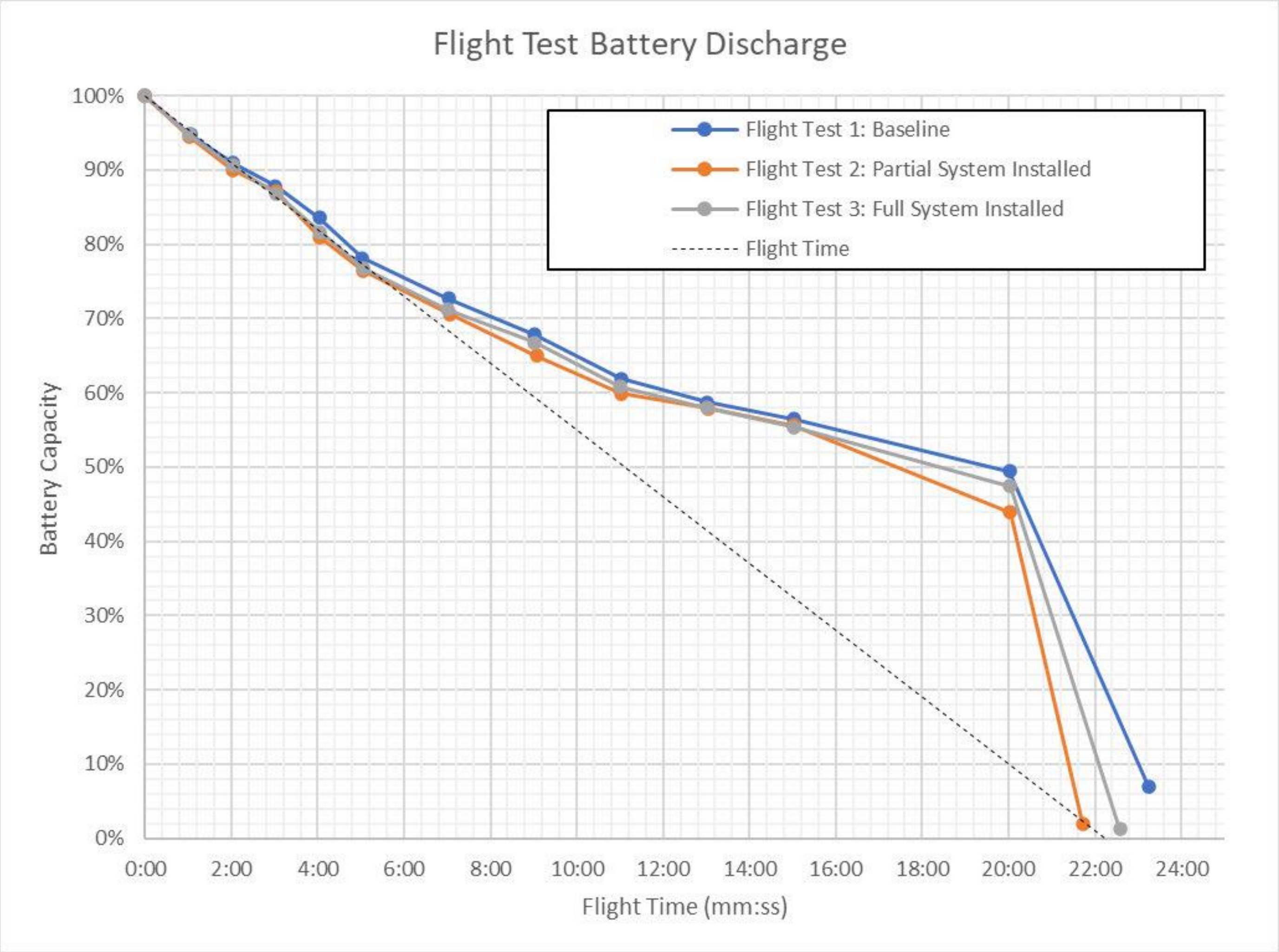


Comparisons

Comparisons

Ice Shape Models

Dry-Air Flight Testing



Conclusion And Future Directions

- A method of protecting sUAS blades with TKS was demonstrated in an icing wind tunnel for freezing fog conditions.
- Built on the blade protection methodology, a low-power pneumatic-fluid system was designed.
- Dry air flight tests showed negligible impacts to aircraft endurance with TKS hardware on and running.

- Natural icing flight tests are expected to take place next US winter season.
- Implement planned changes and optimizations to decrease system weight.
- Additional IWT testing to refine fluid consumption and verify system miniaturization.

- As discussed, this is a rapid-growth sector, and collaboration is key. CAV is interested and open to working with operators, manufacturers, regulators, et al!

- Reminder: Tech presented in this presentation is subject of UK patent application No. GB 2218766.0

Contact Information

R Brock Harden, Senior Engineer – Design
CAV Systems

Tel: +1 (913) 738 5398

Email: r.harden@cav-systems.com

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