A Preliminary Evaluation of Icing Scaling on AAM Propellers

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Outline

- Background
- Test Objective
- Test Description
- Preliminary Results
- Concluding Remarks
- Acknowledgments

Background

- Currently there are no accepted icing scaling methods for the AAM propeller and engine open rotor fan.
- Developing experimental icing simulation capabilities in the NASA Icing Research Tunnel (IRT) for propeller and engine fan icing studies.
- Acquiring ice shape and shedding data on non-proprietary propeller/rotor geometries to support
  - GlennICE code validation and development.
  - Ice shedding prediction capabilities.

NASA UAM - Tiltwing Concept Vehicle
(cruise configuration)

NASA AATT PT - Unducted Propulsor Research
(open-rotor engine architecture)

Background

- Current recommended scaling methods for icing
  - Unheated surfaces on fixed wings (i.e., straight & swept wings)
  - Super-cooled water droplets in App-C & SLD regimes
- Past studies on rotary wing ice accretion showed
  - Different ice shape with feather formation features observed on fixed wing and rotating blade surfaces, i.e., surface shear $\leftrightarrow$ surface shear + centrifugal force
  - The fundamental physics of ice accretion appears to be the same

Background

- Current proposed methods for size scaling (details in the full paper)
  - Choose scale model size & *LWC*
  - Match scale *J* (advance ratio) to reference
    - ➢ Determine scale propeller rotational speed RPM
  - Match scale K_0 (or β_0) to reference
    - ➢ Determine scale *MVD*
  - Match scale We_L to reference
    - ➢ Determine scale velocity V
  - Match scale n_0 to reference
    - ➢ Determine scale temperature T_∞
  - Match scale A_c to reference
    - ➢ Determine scale accretion time τ

Test Objective

- Begin preliminary evaluation of the proposed scaling methods for AAM propeller ice accretion
- Develop ice shape database in the IRT for three geometrically similar propellers of
  - ➢ 24”, 28”, and 36” in diameter
  - ➢ NACA 0012 airfoil profile w twist and chord distributions inspired by the NASA Computationally Optimized Proprotor (COPR)*

Diameter = Ø24”

Ø28”

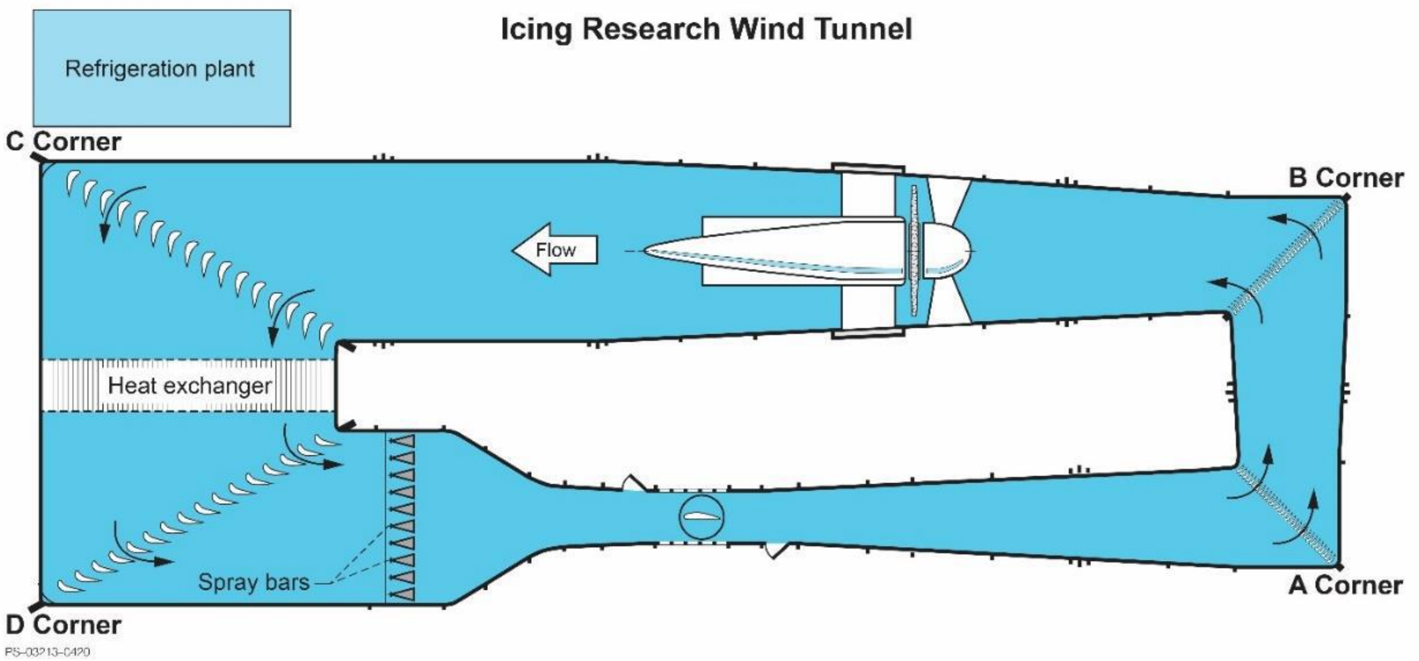
Ø36”

Note: Spinner not scaled with propeller size

*Zawodny et al., NASA TM 20220015637, NASA Langley Research Center, 2023

Test Description

- NASA Glenn IRT
- March 2023 - ARIES I
- January 2024 – ARIES II
- 24”, 28” and 36” diameter blades of NACA 0012 profile
- J = 2.3 – 2.7
- AoA $_{r/R=0.75}$ = 4.5°; 0°
- n_0 = 0.51 – 1.0
- *MVD’s* :15 - 80 μm
- *LWC’s* : 0.55 - 1.20 g/m^3
- Tunnel Speed : 87 - 130 kt

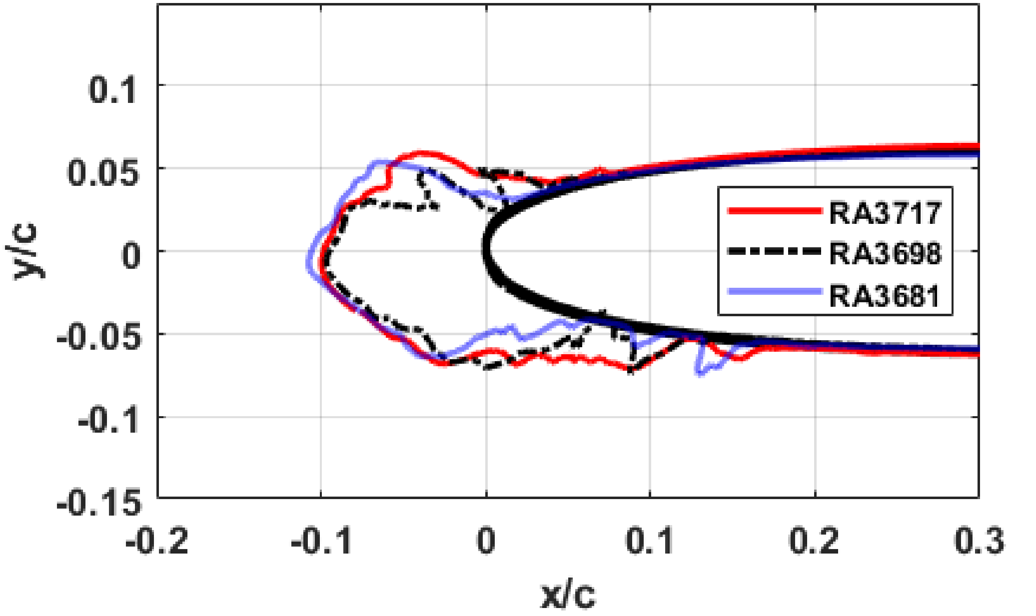


Model and Test Setup

- Propeller in axial flow configuration
- Constant RPM for duration of spray
- High speed imaging for shedding events
- Light strobing for ice growth monitoring
- Photographs of final ice shape
- 3D ice shape from laser scan
- Ice mass measurements
- 2D ice shape extraction at r/R = 0.75

Ice Shape Comparison (1)

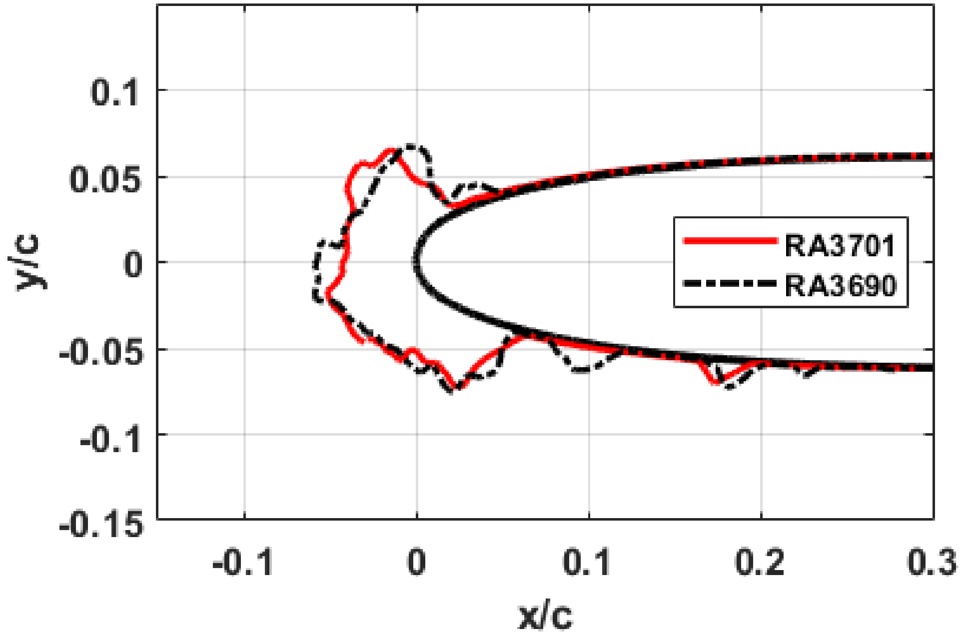
Model Size Scaling in ARIES I



	Target Operating and Cloud Conditions								Similarity Parameters (calculated at $r/R = 0.75$)			
Run	V_∞ knots	$t_{\infty,0}$ °C	δ μm	LWC g/m^3	τ min	RPM rev/min	D in	J	n_0	A_c	β_0	We_L 10^6
RA3717	95	-12.0	15	0.55	3.4	1928	24	2.49	1.0	3.76	0.90	0.15
RA3698	"	"	"	"	4.0	1657	28	2.49	1.0	3.78	0.89	0.18
RA3681	"	"	"	"	5.0	1300	36	2.47	1.0	3.67	0.86	0.23

Ice Shape Comparison (2)

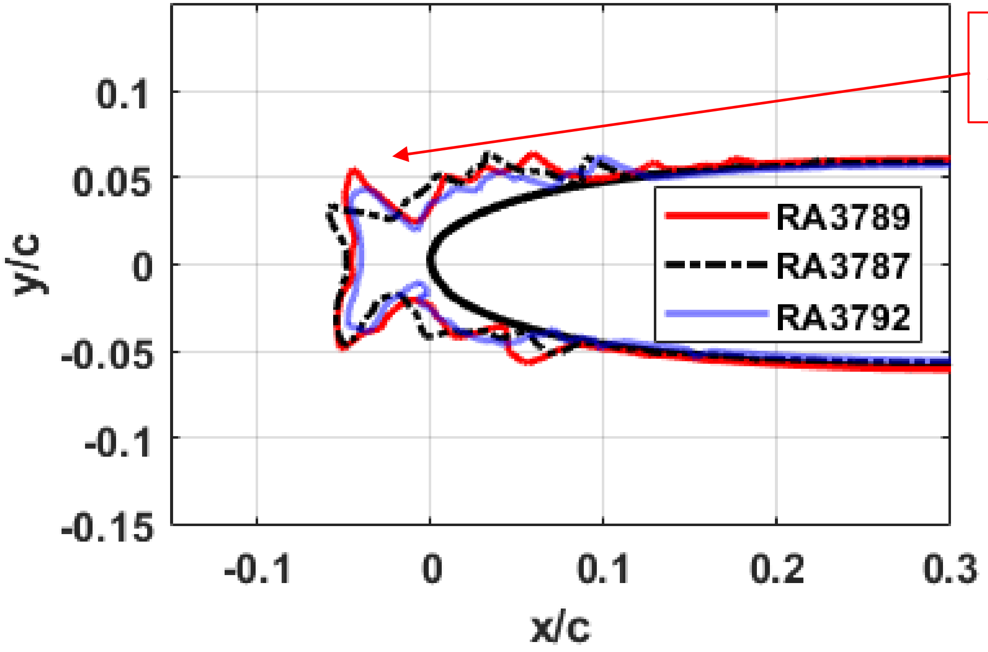
LWC Scaling in ARIES I



	Target Operating and Cloud Conditions								Similarity Parameters (calculated at $r/R = 0.75$)			
Run	V_∞ knots	$t_{\infty,0}$ °C	δ µm	LWC g/m^3	τ min	RPM rev/min	D in	J	n_0	A_c	β_0	We_L 10^6
RA3701	87	-3.0	15	0.55	3.0	1516	28	2.49	0.51	2.59	0.88	0.15
RA3690	"	-6.0	"	1.20	1.4	"	"	"	"	2.64	"	"

Ice Shape Comparison (3)

LWC Scaling in ARIES II



The n_0 values seemed to be over-estimated based on the resulting ice shapes obtained

	Target Operating and Cloud Conditions								Similarity Parameters (calculated at $r/R = 0.75$)			
Run	V_∞ knots	$t_{\infty,0}$ °C	δ µm	LWC g/m^3	τ min	RPM rev/min	D in	J	n_0	A_c	β_0	We_L 10^6
RA3789	110	-8.2	20	0.65	2.1	1330	36	2.79	0.94	1.99	0.91	0.28
RA3787	"	-10.0	"	0.80	1.7	"	"	"	"	"	"	"
RA3792	"	-13.3	"	1.1	1.2	"	"	"	0.93	1.93	"	"

Concluding Remarks

- Limited icing tests were performed in the IRT to evaluate the proposed scaling methods for propeller icing scaling.
- Preliminary results showed good agreement of both size and shape of main ice shapes and feather regions.
- More data is needed to assess the effectiveness of the proposed scaling methods, especially for freezing fractions less than unity.
- Further evaluation of the scaling methods over a wider range of propeller sizes and operating conditions is recommended to assess its applicability for the modern propeller and engine open rotor fan icing scaling analysis.

Acknowledgements

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