An Investigation of Pre-activation Ice and a Mechanical Deicer Intercycle Ice

FAA In-flight Icing / Ground De-icing International Conference

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Outline

- Background information
- Investigation objectives
- Test facilities and models
- Test Results

Deicing Ice Protection Systems Airworthiness Considerations 1/2

- Normal operation of deicing ice protection systems results in roughness on the protection surface.
  - » Pre-activation ice (prior to when the deicing system is fully effective).
  - » Residual ice (immediately after cycling of the deicing system).
  - » Intercycle ice (ice accumulation immediately prior to a subsequent deicer cycle).
  - » For deicing systems with sequentially activated elements, additional delayed activation time.

Deicing Ice Protection Systems Airworthiness Considerations 2/2

- Leading edge roughness on lifting surfaces, beyond that which is hydraulically smooth, can result in adverse aerodynamic effects. ("*Theory of Wing Sections*," Abbot, I.H. and von Doenhoff, A.E. *"Effects of ice accretions on aircraft aerodynamics,"* Lynch, F.T. and Khodadoust, A.)
- When demonstrating compliance with § .1419 of 14 CFR parts 23, 25, 27, and 29, consideration should be given to the adverse aerodynamic effects resulting from surface roughness of normally operating deicing systems.

Operational History of Airplane Equipped With Mechanical Deicing Ice Protection Systems 1/2

- The operational history of airplanes equipped with mechanical deicing ice protection systems contain accidents and incidents in which operation of the deicing system is cited as a contributing cause of the accident or incident.
- In several of these accidents and incidents, loss of control resulted from inadvertent loss in airspeed to stall entry, with and without operation of the deicing ice protection system.

Operational History of Airplane Equipped With Mechanical Deicing Ice Protection Systems 2/2

- The common practice of delaying activation of the deicing ice protection system until an accumulation of 1/4 to 1 1/2 inches of ice on the wing (to achieve more effective deicing boot ice shedding and to avoid ice bridging) may have contributed to these accidents and incidents. Increased airplane drag resulting from the delayed (pre-activation) ice roughness will cause airspeed bleed-off at constant engine thrust. Also, unknown to the pilot, maneuver margins to stall become less with increasing ice contamination.

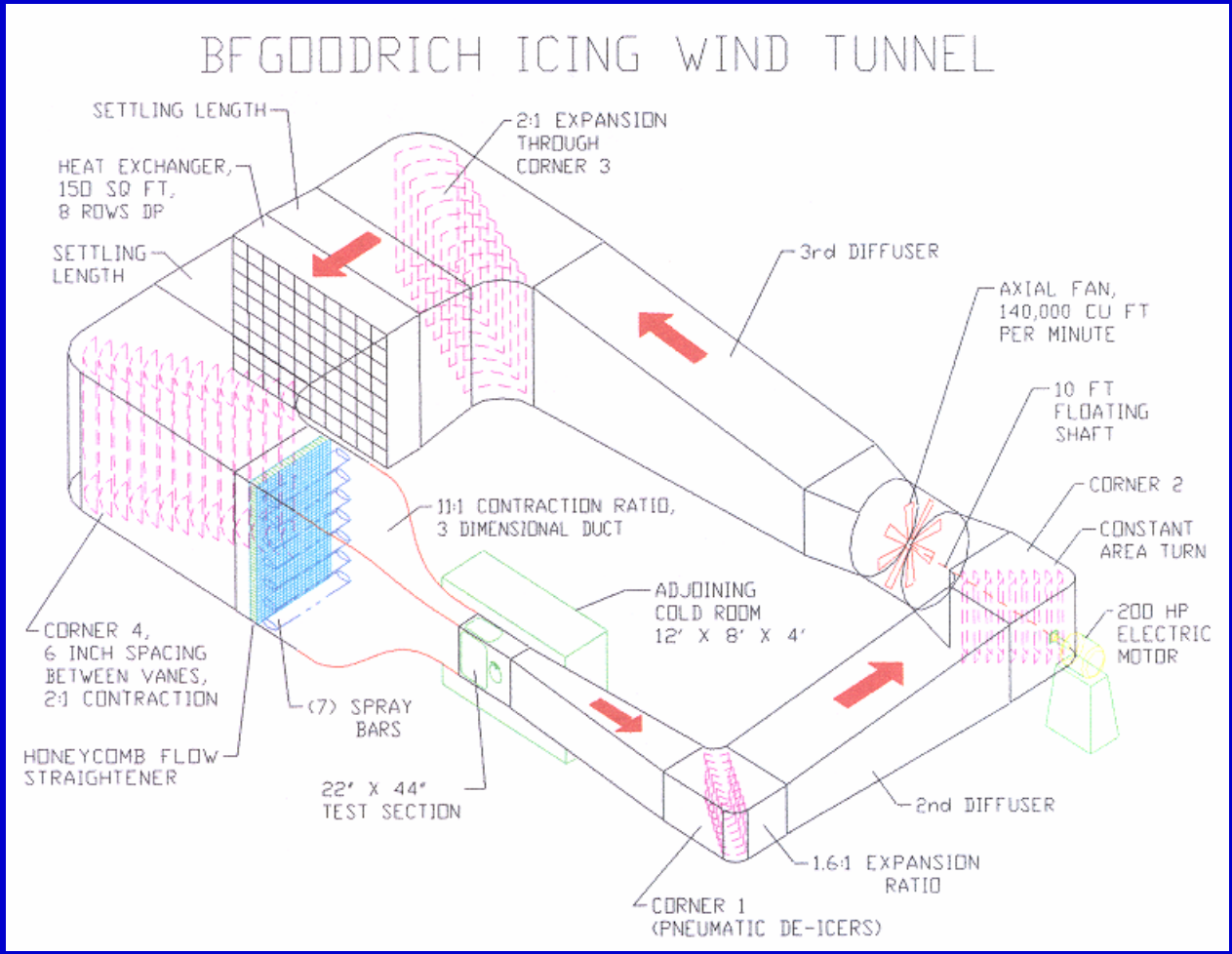
In-flight Icing Operational History of Airplane Model X

Event	Summary	Crew Awareness of Icing	Deicing Prior to event	Min. Airspeed - KIAS
June 1989	Speed dec., shaker, roll upset	Yes	Not available	Not avail.
Sept. 1991	Buffet, shaker, stall	Yes	No	Not avail.
Nov. 1991	Shaker, stall, roll upset	No	No	~150
April 1993	Shaker, pusher, stall, roll upset	No	No	~145
Oct. 1994	Shaker, pusher, stall, roll upset	Yes	No	~138
April 1995	Speed bleed-off, roll upset, shaker	Yes	No upset	~140
Jan. 1997	Speed bleed-off, roll upset	Yes	No	~145
Mar. 1998	Speed bleed-off, buffet, roll-off, shaker	Yes	Yes	~124
Mar. 2001	Speed bleed-off, roll-off, recovery following 7,000 feet altitude loss	Yes	Yes	~140

Investigation Objectives

- **In collaboration with Goodrich Aerospace, the NASA-GRC Icing Research Branch, the University of Illinois (Urbana-Chamjpaign), and two airframe manufacturers, investigate pre-activation ice and normal-operation intercycle ice of a typical wing pneumatic deicing boot ice ice protection system to provide guidance relative to:**
  - » **Characteristics of wing and stabilizer surface roughness that should be used during demonstrating compliance with §.1419 of 14 CFR parts 23 and 25 and the ARAC recommended revised icing certification requirements (§ 25.21(g), et al).**
  - » **Aerodynamic effects resulting from pre-activation ice and normal-operation intercycle ice of a typical pneumatic deicing boot ice protection system.**
  - » Deicing boot ice bridging.

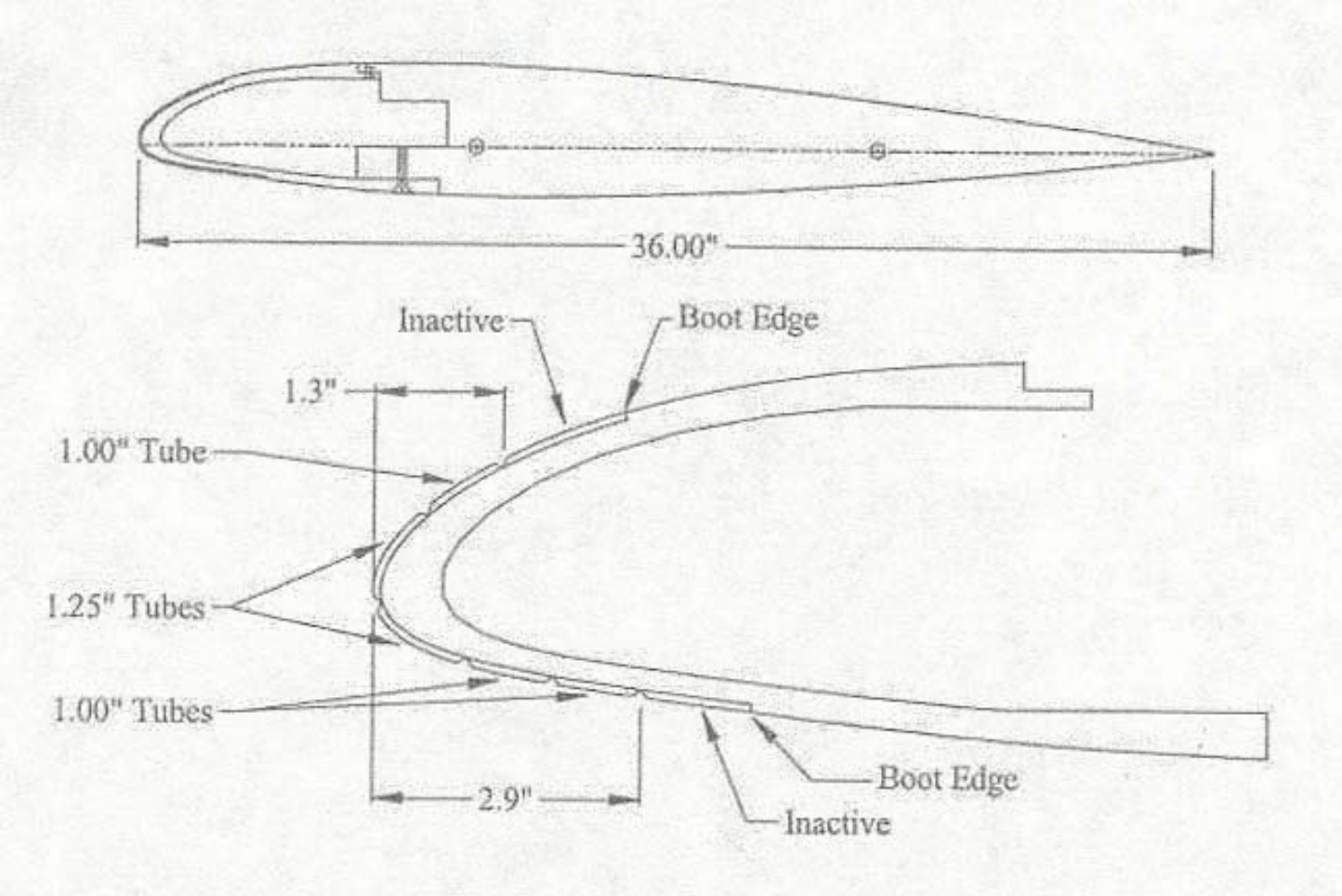
Test Facility - Goodrich Icing Wind Tunnel



Test Facility - NASA-LRC Low Turbulence Pressure Wind Tunnel

- The 36 inch NACA 23012 model, with uniformly distributed roughness and castings of ice shapes obtained in the NASA-GRC IRT, was tested in the NASA-LRC LTPT at a variety of Reynolds numbers and Mach numbers to obtain aerodynamic force and pressure data.

Models - 36 Inch Chord NACA 23012 Model Ice Protection System Design

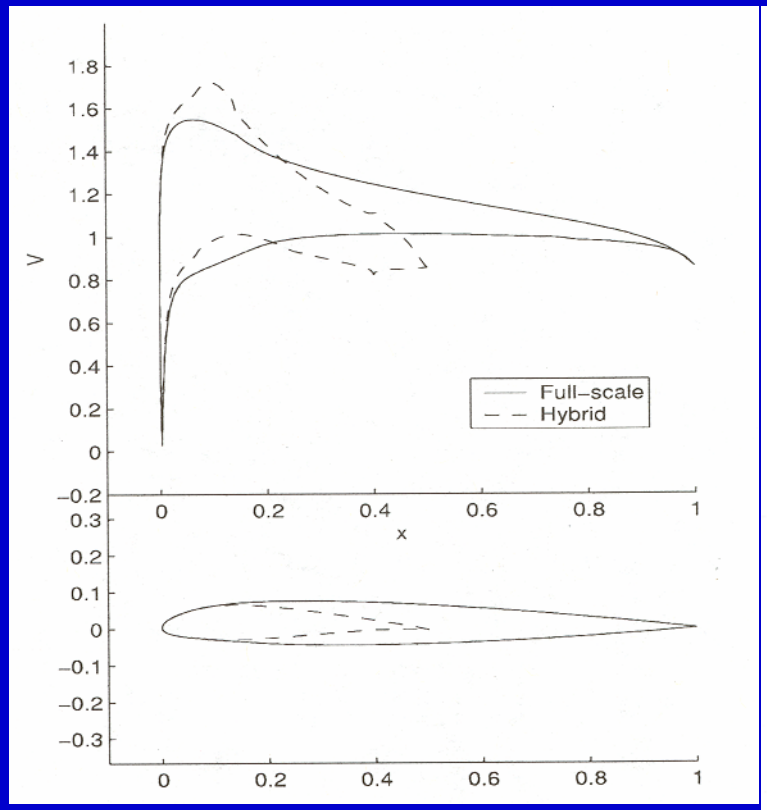


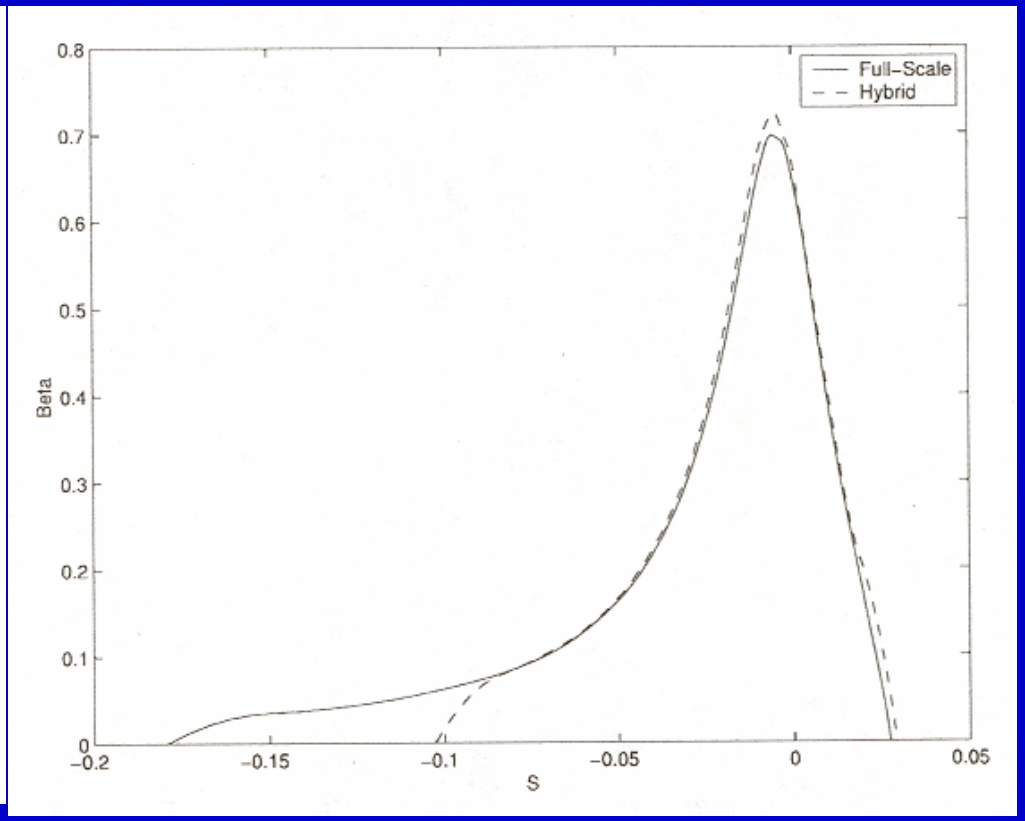
Models - 36 Inch Chord NACA 23012 Model Installed in The LTPT

Models - 36 Inch Chord Hybrid NACA 23012 Model Design

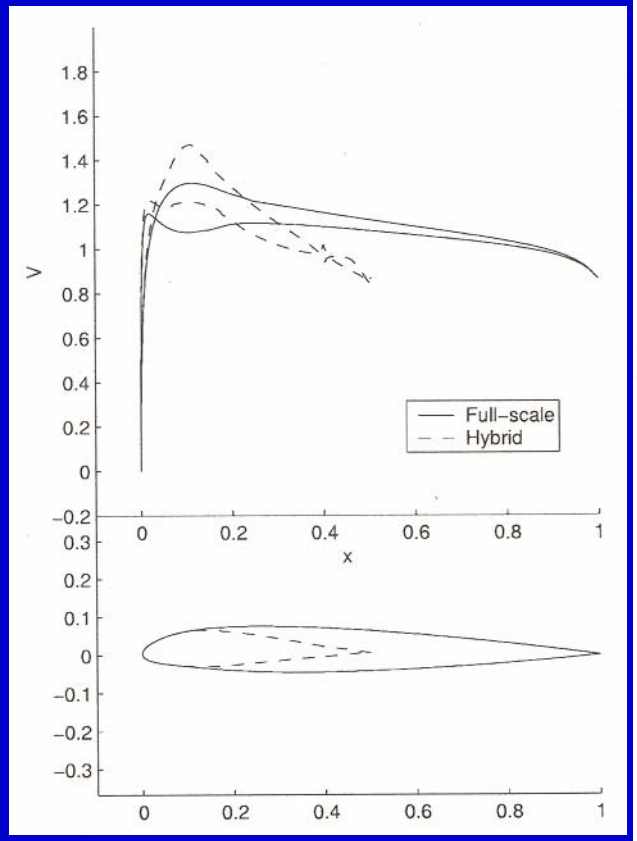
- To obtain pre-activation ice and normal-operation residual/intercycle ice of a typical full scale wing pneumatic deicing boot ice ice protection system, a hybrid NACA 23012 model was designed by the University of Illinois and tested in the Goodrich IWT.
- The design objective of the hybrid model was to closely match the water collection efficiency of a full scale (72 inch chord) airfoil, while being suitable for testing in the Goodrich IWT.

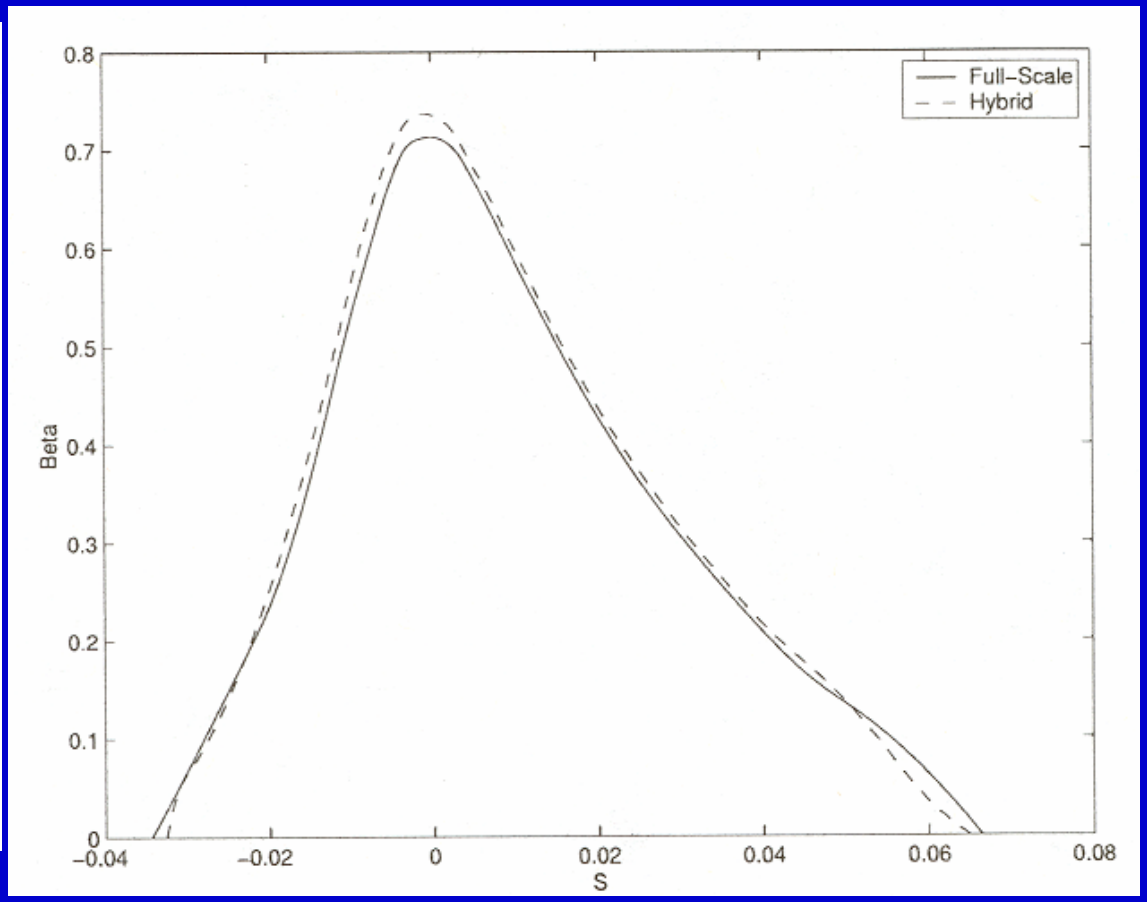
Comparison of the Full Scale and Hybrid Model Velocity Distribution and Water Collection Efficiency at 4° AOA



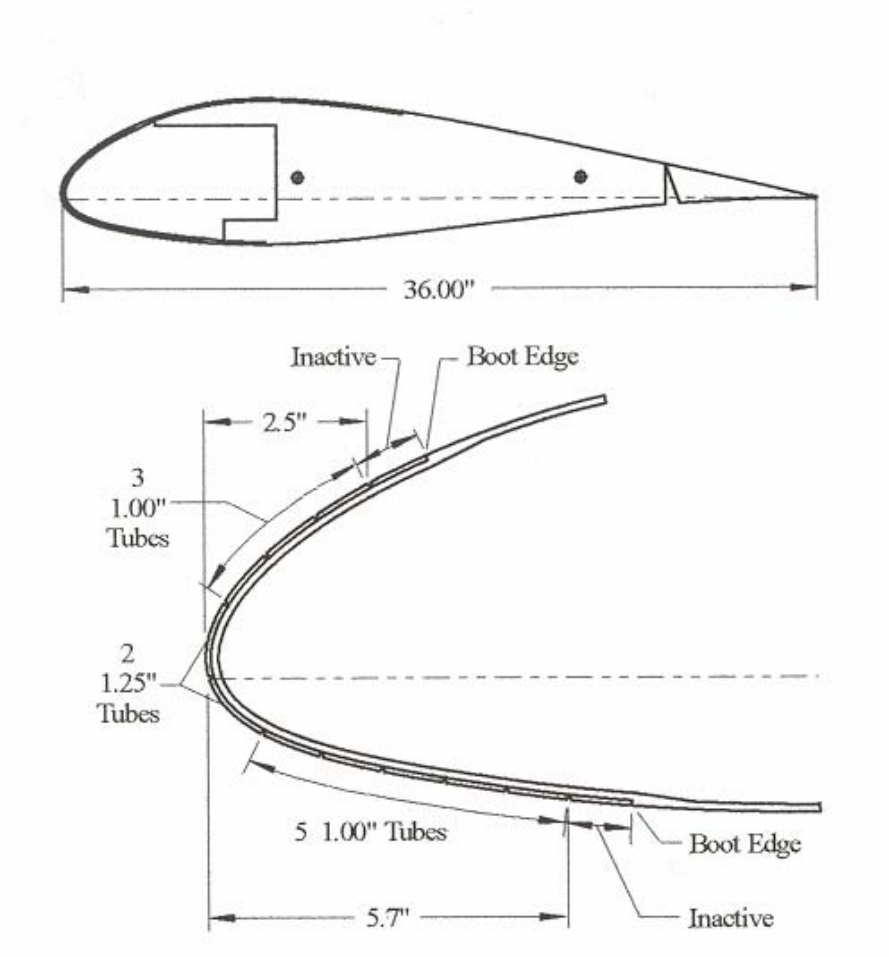


Comparison of the Full Scale and Hybrid Model Velocity Distribution and Water Collection Efficiency at 0° AOA

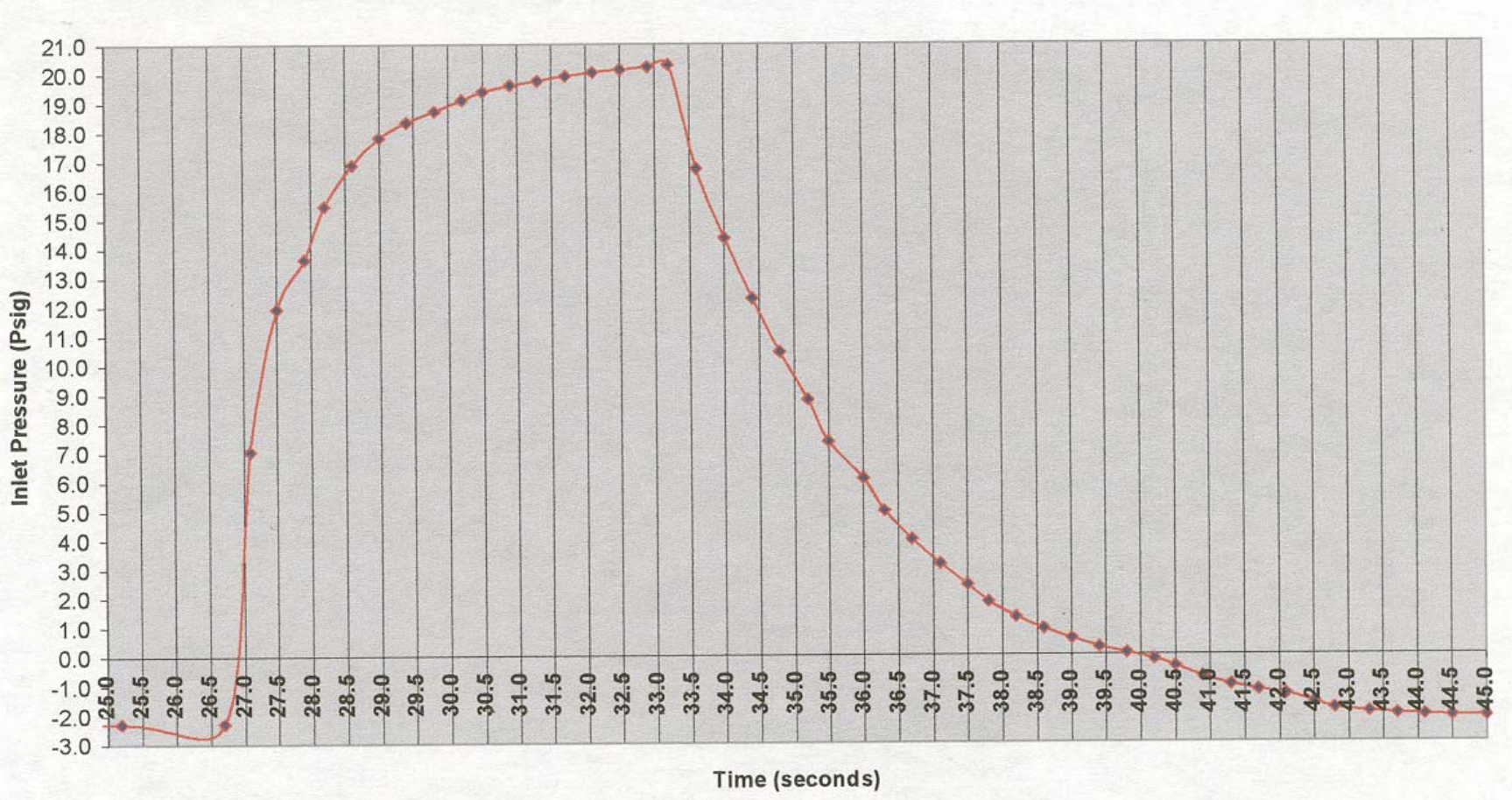




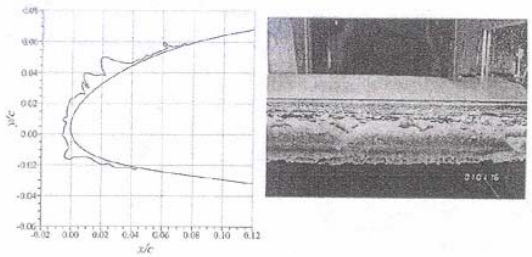
Models - 36 Inch Chord Hybrid NACA 23012 Model Ice Protection System Design



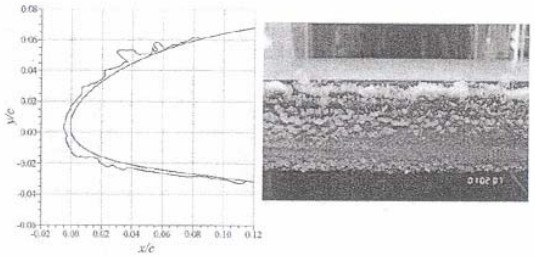
Models - Pneumatic Deicer System Operating Air Pressures



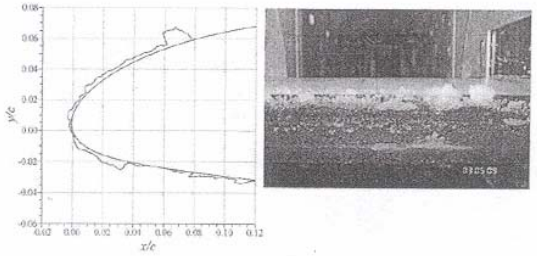
36 Inch Chord NACA 23012 Model Goodrich IWT Test Results



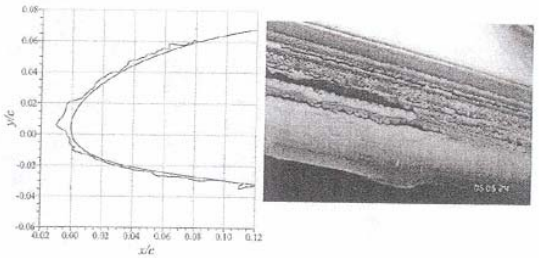
Ice shape 290



Ice shape 296



Ice shape 312



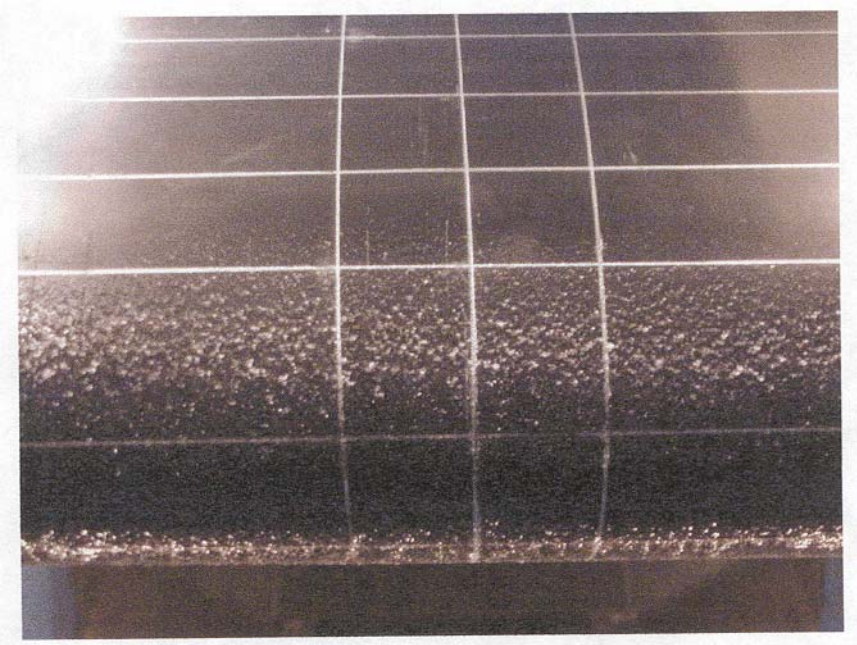
Ice Shape 322

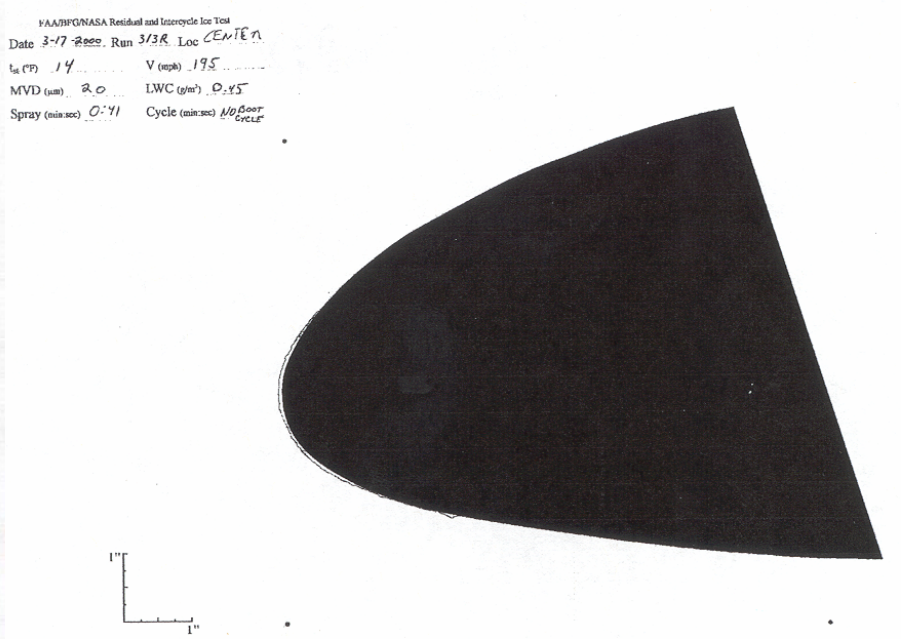
Ice Shape	Angel of Attack (deg.)	Droplet MVD (μm)	Static Temp. (deg. F)	LWC (g/m^3)	Spray Time (min.)	Boot Cycle Period (min.)
290	0	20	14	0.45	12	3
296	0	20	21	0.65	12	3
312	0	40	21	0.25	12	3
322	0	40	-4	0.40	3	1

36 Inch Chord Hybrid NACA 23012 Model Pre-activation Ice Accretion Investigation

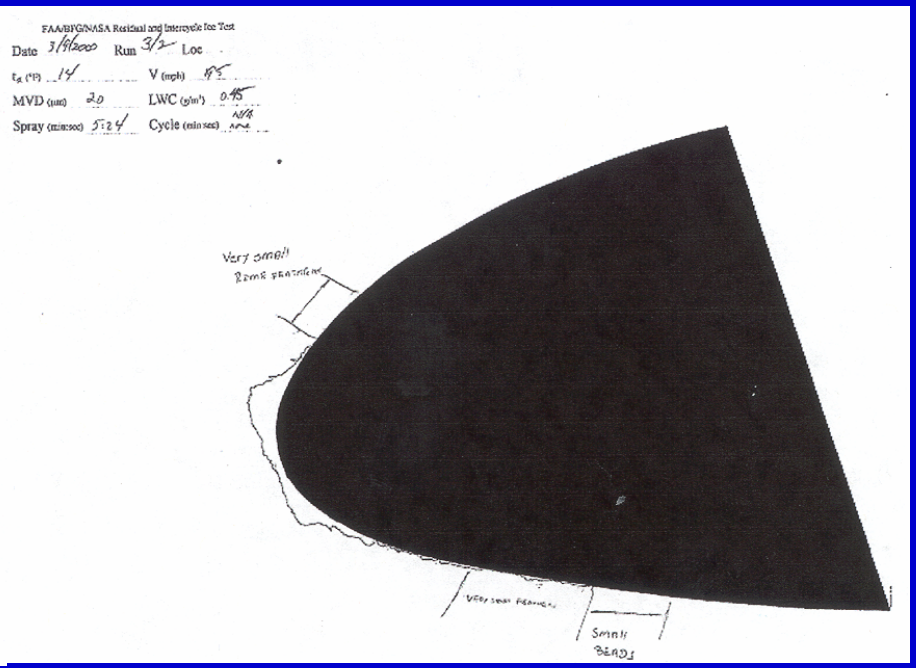
Scenario Prior to Ice Protection System Activation			Test Conditions						Run	Figure
			Angle of Attack – Deg.	Velocity – mph	Icing Conditions					
Ice Detection Response time - s	Pilot Reaction Time - s	Total - s			Type	T_S - °F	MVD - µm	LWC – g/m^3		
11 (Ice Detector)	30	41	4	195	CM	14	20	0.45	3/3R	21
3 (Ice Detector)	30	33	4	195	IM	14	20	1.95	6/3	23
30 (Visual)	30	60	4	195	CM	14	20	0.45	3/3	24
¼ inch (Measured)	-	180	4	195	CM	14	20	0.45	3/2	26
¼ inch (Visual)	30	107	4	195	IM	14	20	1.95	6/2	28

CM Pre-activation Ice With 11 s Detection and 30 s Reaction Times





CM Pre-activation Ice With Measured 1/4 inch Thickness (2:30 Min.) and 30 s Reaction Time Intervals



36 Inch Chord Hybrid NACA 23012 Model Pre-activation Ice Accretion Investigation Results and Conclusions

- For the test conditions and an ice protection system that includes an ice detector, the pre-activation ice accretion was characterized by a thin, distributed roughness with pebble-like, rounded particle texture.
- For the test conditions and delayed activation of the ice protection system, the resultant pre-activation ice accretion was characterized by a significant, rough ice shape. For the CM test conditions, the time required to accumulate 1/4 inches of ice approached the 3 minute rest period of some automatically cycled ice protection systems.
- Pre-activation of an ice protection system with sequentially operated elements was not investigated.

36 Inch Chord Hybrid NACA 23012 Model Intercycle Ice Accretion Investigation 1/2

Deicer Inter-cycle Ice Accretion Investigation

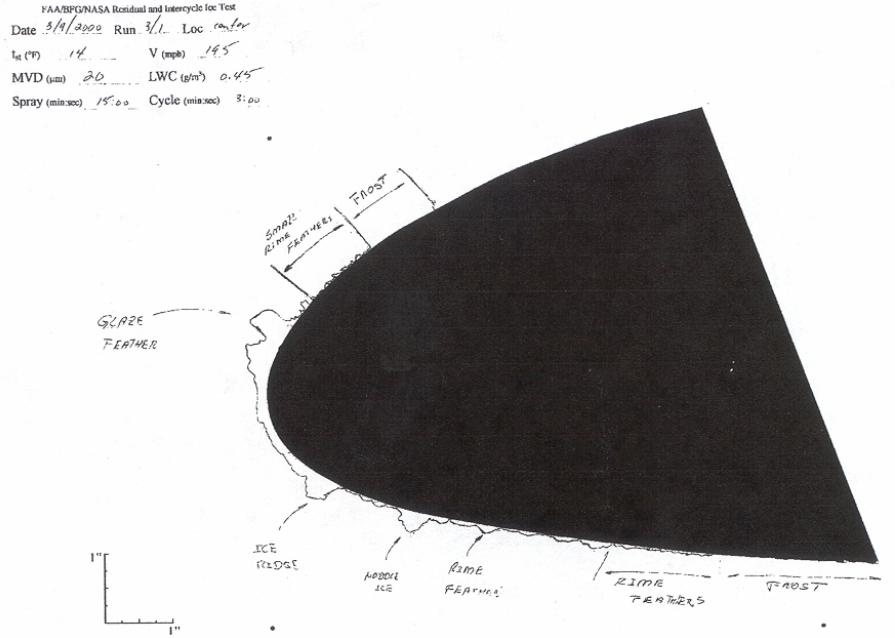
195 mph (2.82 Nmi /Min.) True Airspeed

Angle of Attack – Deg	Icing Conditions Description					Deicer Operation				Comments	Run	Figure
	Type Icing Cond.	Type Ice	T_S - °F	MVD – µm	LWC – g/m^3	Initial Activ. – s	Cycle Period – Min.	# Cycles	Icing Cloud Extent – Nmi.			
4	CM	Mix-ed	14	20	0.45	11	3	2	17.4	Appendix C LWC	2/1R	34
				"	"	"	"	4	Contin	"	2/1A	32
				"	"	"	1	5	17.4	"	2/2	36
				"	"	¼ in.	3	4	Contin	"	3/1	30
				40	0.25	19	"	"	Contin	App. C LWC = 0.1	3/6A	72
		Glaze	21	20	0.51	11	3	2	17.4	App. C LWC = 0.52	4/1	38
							"	4	Contin		4/1A	50
							1	5	17.4		4/1.5	40
		Rime	-22	20	0.15	34	3	4	Contin	App. C LWC = 0.14	5/1	66

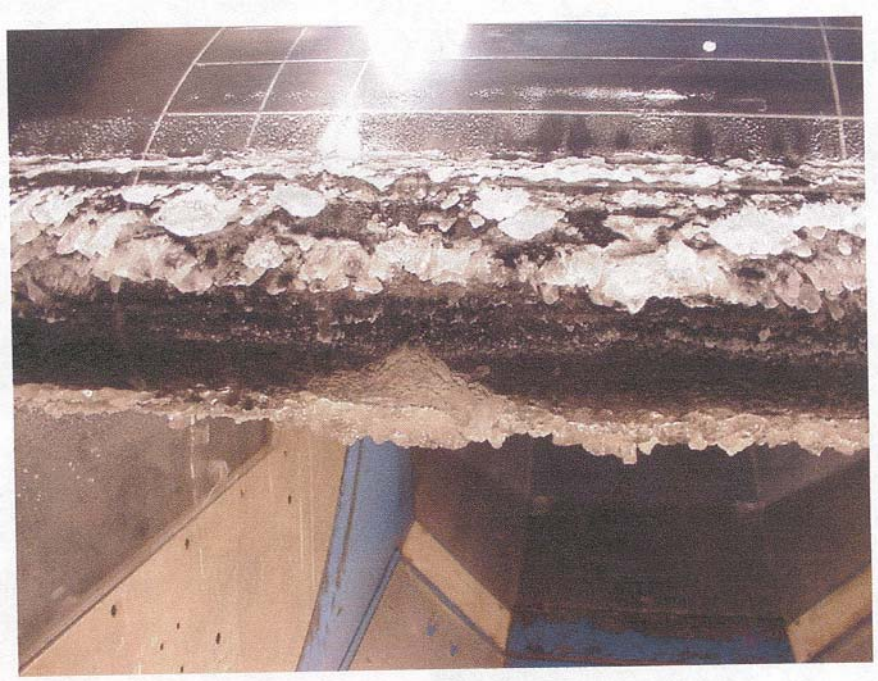
36 Inch Chord Hybrid NACA 23012 Model Intercycle Ice Accretion Investigation 2/2

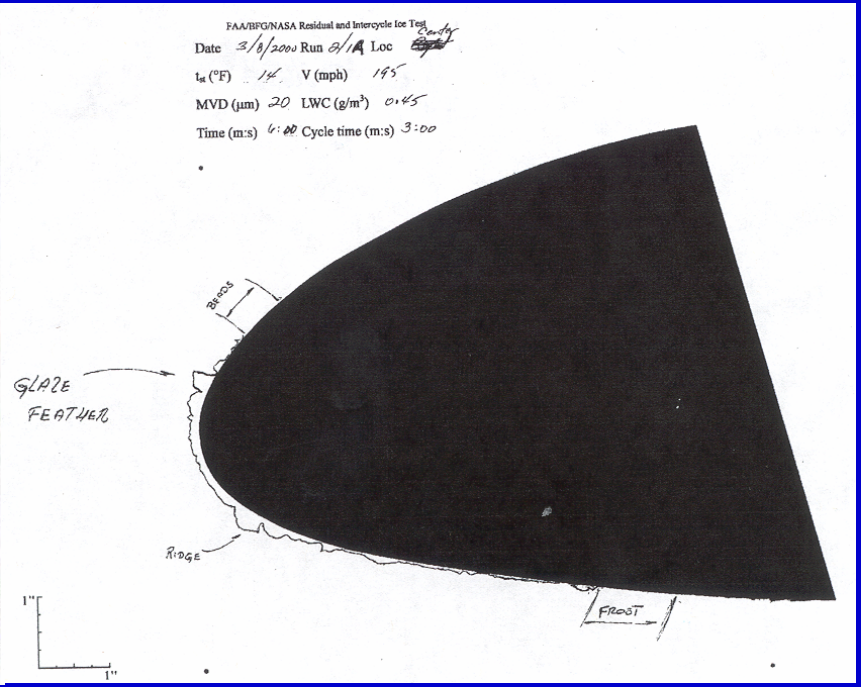
	IM	Mix-ed	14	20	1.87	3	3	4	Contin	App. C LWC = 2.21 but	6/1B	42
	IM			"	"	"	1	2	Contin	IWT max. LWC = 1.95	6/1	60
	IM			"	"	"	"	4	Contin		6/1A	44
	IM(s)			40	0.25	19	-	1	2.6(s)	2 min. to sim. 0.52 LWC	3/6	54
	IM			"	0.44	9	1	2	Contin	App. C LWC = 0.52	6/6	56
	IM			"	0.52	"	"	4	Contin	"	6/5	58
	IM(s)	Glaze	21	40	0.25	19	-	1	2.6(s)	2 min. to sim. 0.52 LWC	4/4	72
	IM(s)									3 min. to sim. 0.52 LWC	4/4.5	74
	IM	Rime	-22	20	0.85	6	1	2	Contin	App. C LWC = 0.99	5/5	68
0	CM	Mix-ed	14	20	0.45	11	3	2	14.7	Appendix C LWC	¾	52
							"	4	Contin		3/4A	46
							1	5	14.7		3/4.5	48
		Glaze	21	20	0.51	11	3	2	14.7	App. C LWC = 0.52	4/2	76
	IM	Mix-ed	14	20	1.87	3	1	2	Contin	App. C LWC = 2.21 but	6/4	62
	IM			"	"	3	"	4	Contin	IWT max. LWC = 1.95	6/4A	64
	IM(s)			40	0.25	19	-	1	2.6(s)	2 min. to sim. 0.52 LWC	3/5	78
	IM(s)			"	"	"	-	"	2.6(s)	3 min. to sim. 0.52 LWC	4/3	80

CM Intercycle Mixed Ice After Boot Activation W/ 1/4 Inch Ice (4 Cycles W/ 3-Min. Rest Periods)

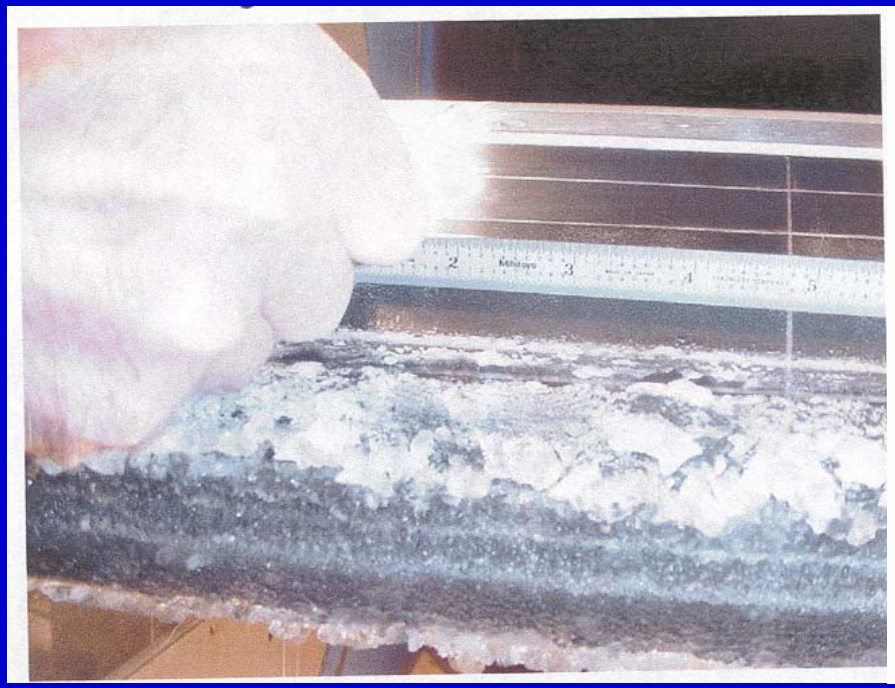


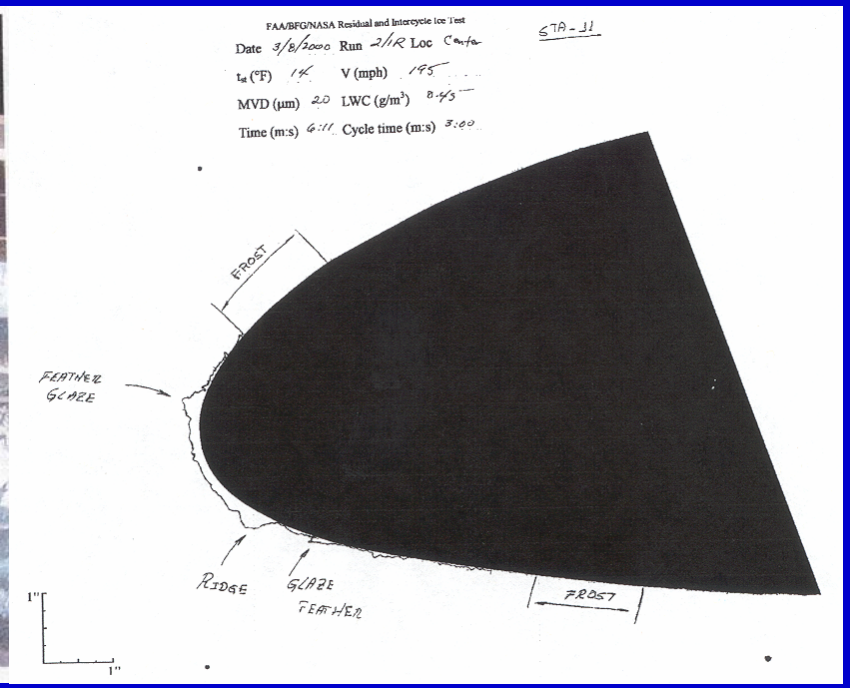
CM Intercycle Mixed Ice Following 11 s Detection Time and 4 Boot Cycles W/ 3-Min. Rest Periods



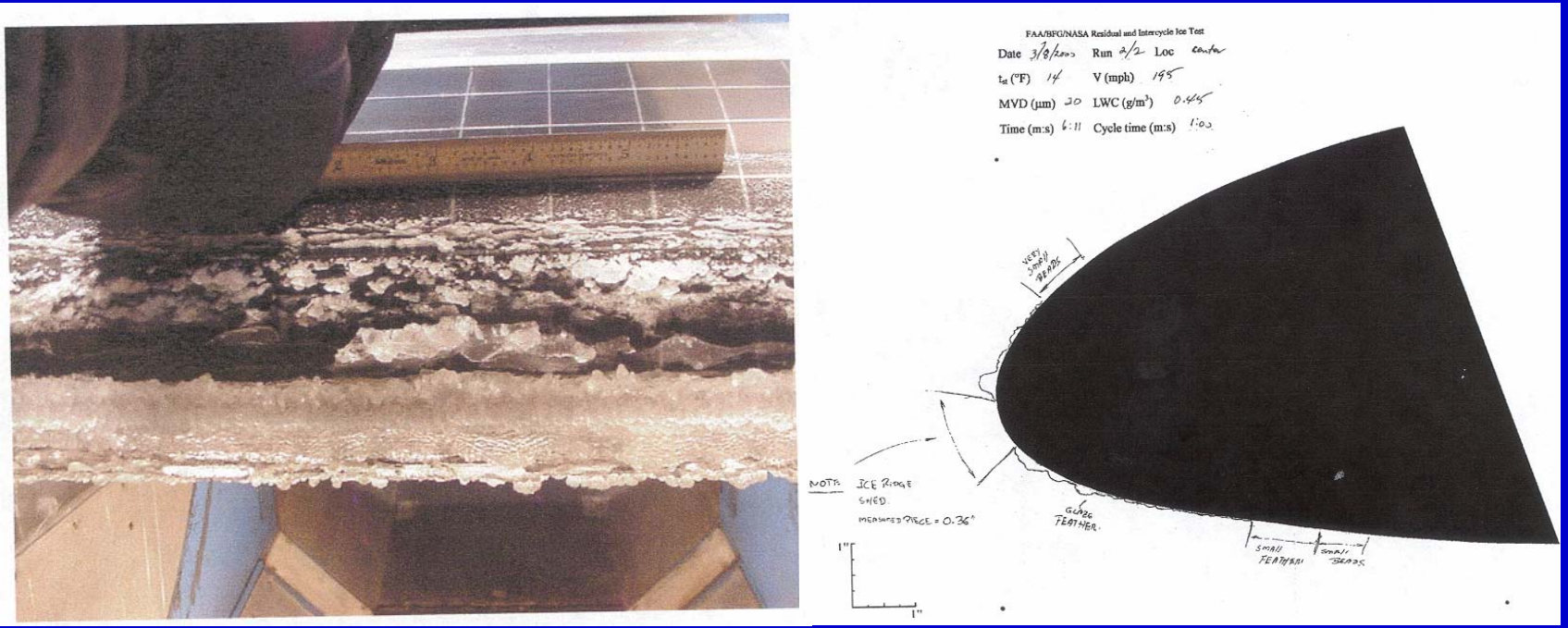


CM Intercycle Mixed Ice After 17.4 Nmi Icing Exposure (11 s Detection Time and 2 Boot Cycles W/ 3-Min. Rest Periods)

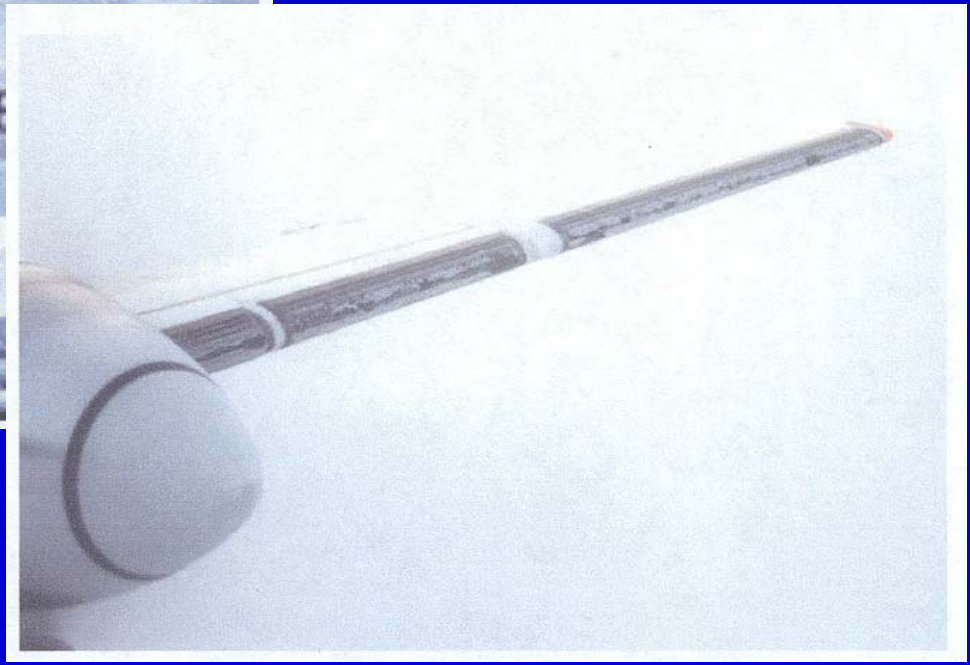




CM Intercycle Mixed Ice After 17.4 Nmi Icing Exposure (11 s Detection Time and 5 Boot Cycles W/ 1-Min. Rest Periods)



In-service Intercycle Ice



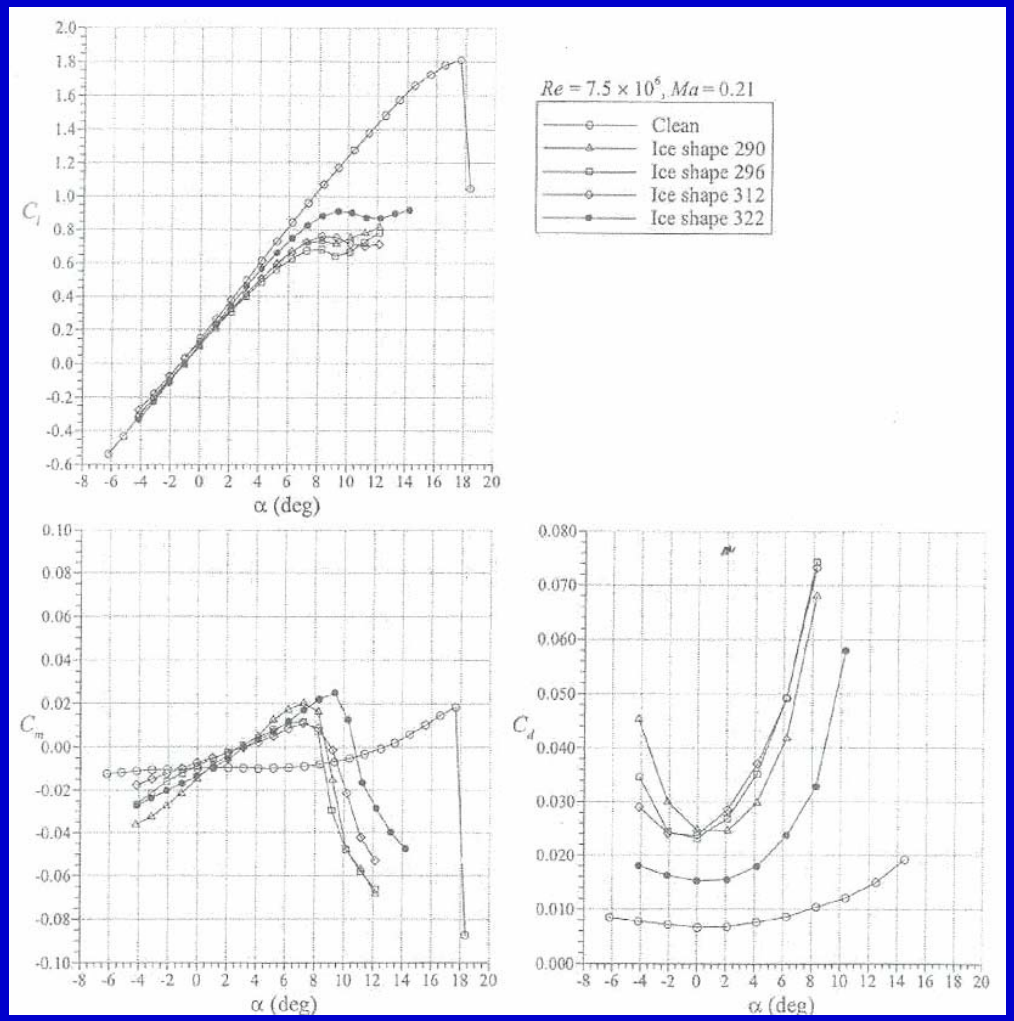
36 Inch Chord Hybrid NACA 23012 Model Intercycle Ice Accretion Investigation Results and Conclusions 1/2

- Intercycle ice tends to be highly three-dimensional and granular, yet defined by major coherent features. Accumulation of ice forward and along the deicer tube stitch lines dominated the major coherent features.
- Observation of the deicer ice shedding performance suggests that ice did not accrete on the forward portion of the inflated deicer tubes, perhaps because of the diversion of the small water droplets by the local airflow. However, ice did accumulate on the aft portion of the inflated tubes (perhaps because of entrainment of the water droplets by the turblent local air flow), forming residual ice which acted as a nuclei for ice growth when the tubes were deflated.

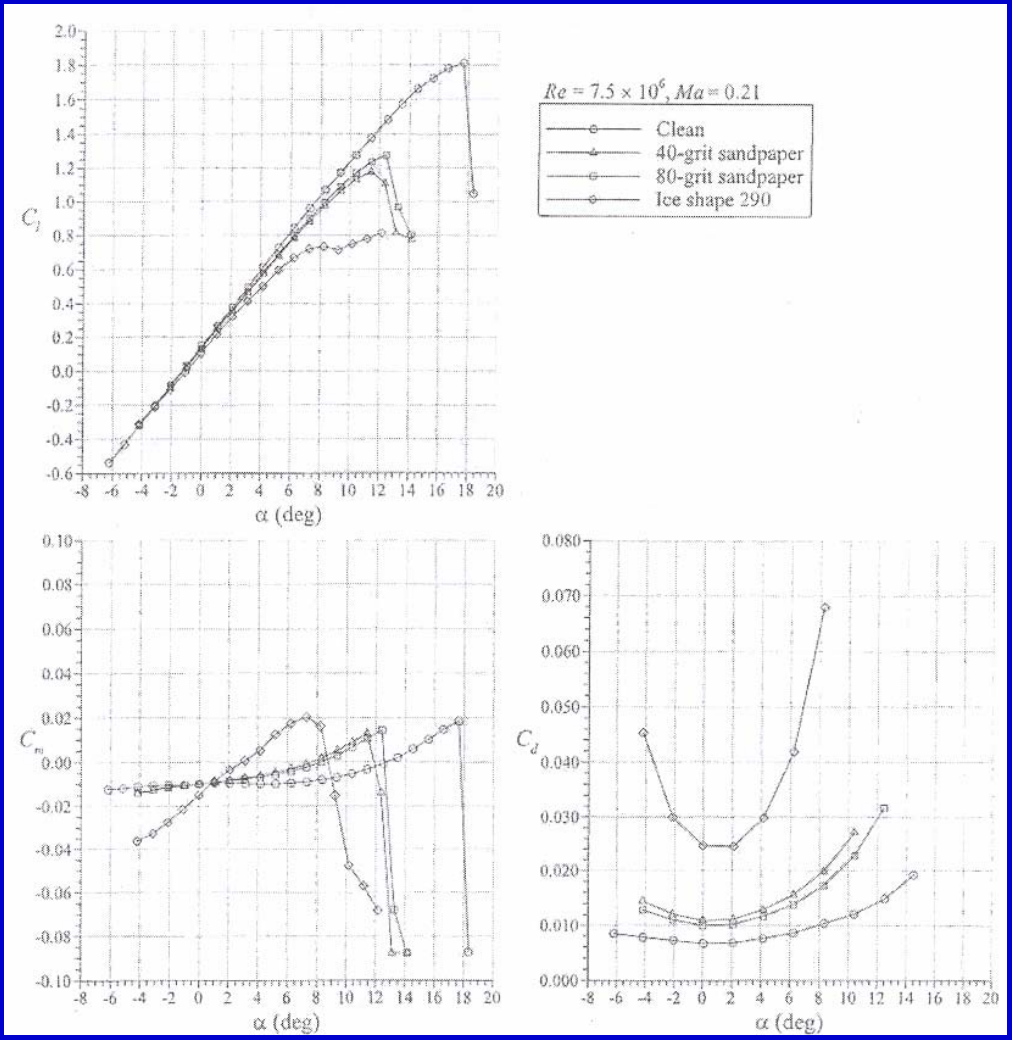
36 Inch Chord Hybrid NACA 23012 Model Intercycle Ice Accretion Investigation Results and Conclusions 2/2

- For the test conditions and using a 3-minute deicer rest interval, there were little differences in the intercycle ice between sequential cycling of the deicer after accumulation of approximately 1/4 inch of ice and the initial activation of the deicer at first detection of ice. Subsequent cycling of the deicer dominates the character of the intercycle ice, with intercycle ice from the initial deicer cycle being shed when sufficient ice thickness had been accumulated.
- Using of a 1-minute deicer rest interval resulted in less, smaller scale intercycle ice.
- Classic deicing boot ice bridging was not observed.

36 Inch Chord NACA 23012 Model NASA-LRC LTPT Intercycle Ice Test Results



36 Inch Chord NACA 23012 Model NASA-LRC LTPT Distributed Roughness Test Results



36 Inch Chord NACA 23012 Model NASA-LRC LTPT Intercycle Ice Test Results and Conclusions

- For the simulated ice shapes tested two-dimensionally at a Reynolds number of 7.5 E6, the intercycle ice shapes resulted in approximately:
  - » A 60 per cent loss in maximum lift.
  - » A 10º reduction of the maximum lift angle of attack.
  - » Upward toward a 270 percent increase in mimum parasitic drag.
- For the 40 and 80 grit distributed roughness tested two-dimensionally at a Reynolds number of 7.5 E6, the distributed roughness resulted in approximately;
  - » A 33 per cent loss in maximum lift.
  - » A 6º reduction of the maximum lift angle of attack.
  - » A 70 percent increase in mimum parasitic drag.

36 Inch Chord Hybrid NACA 23012 Model Intercycle Ice Aerodynamic Effects Investigation

- Simulated CM mixed intercycle ice shapes were flight tested on an EMB-120 during the summer of 2002. Test results may be presented at the January 2004 AIAA Aerospace Sciences Meeting and Exhibit in Reno, Nevada.

Questions?