

Supercooled Large Droplet Ice Formations from Flight Research

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Icing Branch

SLD Engineering Tools Development Workshop
Wichita, Kansas
October 21, 2004

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at Lewis Field



SLD Icing Flight Research Program

- 3 year collaborative activity between NASA, FAA, and NCAR (National Center for Atmospheric Research)
- Utilized NASA's Twin Otter Icing Research Aircraft based in Cleveland, Ohio
- NCAR provided weather forecast support & in-flight guidance to locate regions of SLD
- 70 flights (113 flight hours) conducted in the Great Lakes Region
- SLD Cloud Characterization data analyzed and delivered to FAA in 2000
- This flight work supported the development of NCAR's Integrated Icing Diagnostic Algorithm (IIDA) the basis for the Current Icing Potential (CIP) and Forecast Icing Potential (FIP)

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Other NASA Icing Flight Research Programs

- **Icing conditions & ice shape documentation continued in other research activities**
 - MWISP (1999)
 - AIRS (2000)
 - Smart Icing Systems (2001-2002)
 - Natural Ice Shape Database (2003-2004)
 - AIRS2 (2004)
- **SLD conditions were occasionally encountered and included in this data set**



NASA Twin Otter *Icing Research Aircraft* Instrumentation

- **Meteorological**
 - Droplet Sizing
 - FSSP
 - OAP-200X 1-DC
 - OAP-260X 1-DC
 - OAP-2DC-Grey
 - Liquid Water Content
 - CSIRO-King
 - Nevzorov LWC/TWC
 - Rosemount Ice Detector
 - Temperature
 - Total, static, dew point
- **Imaging**
 - Wing Stereo Camera System
 - Tail Video
 - Over Wing Video
 - 35 mm stills
 - Hi-8 video
- **A/C Aerodynamics**
 - V , α , β , Altitude
 - Accels, rates, attitude
 - Control surface positions
 - Pilot force / hinge moment
 - Prop RPM, Torque
 - Fuel flow (mass)
 - GPS position



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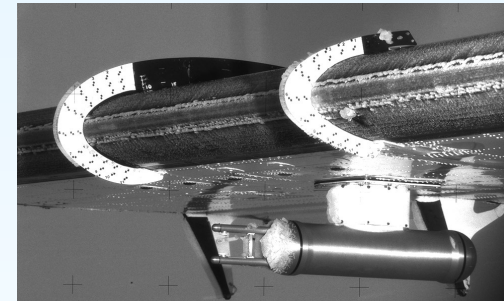
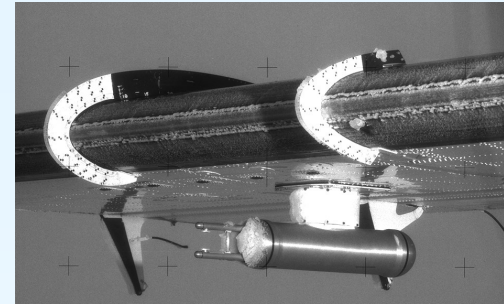
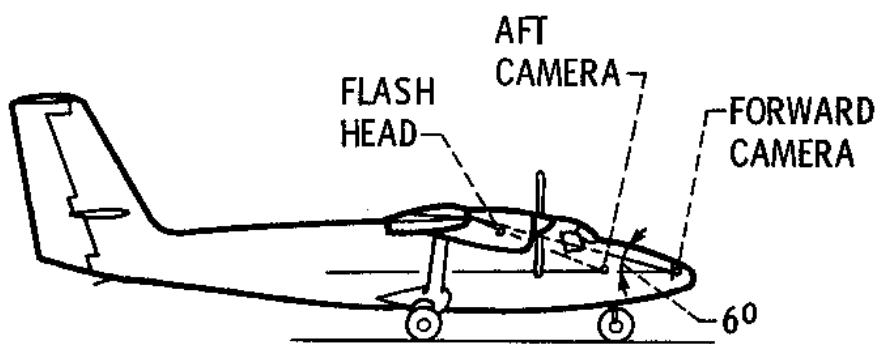
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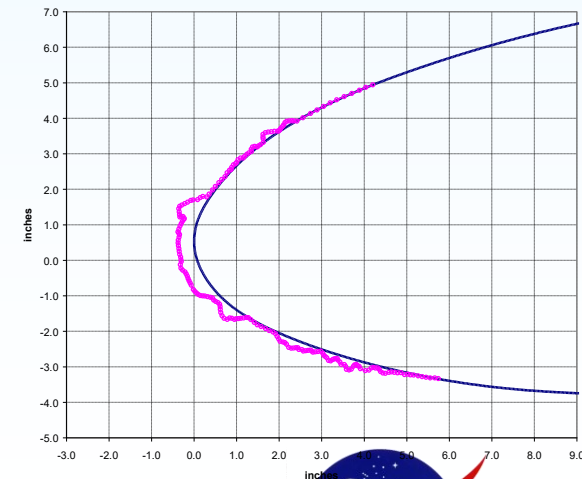
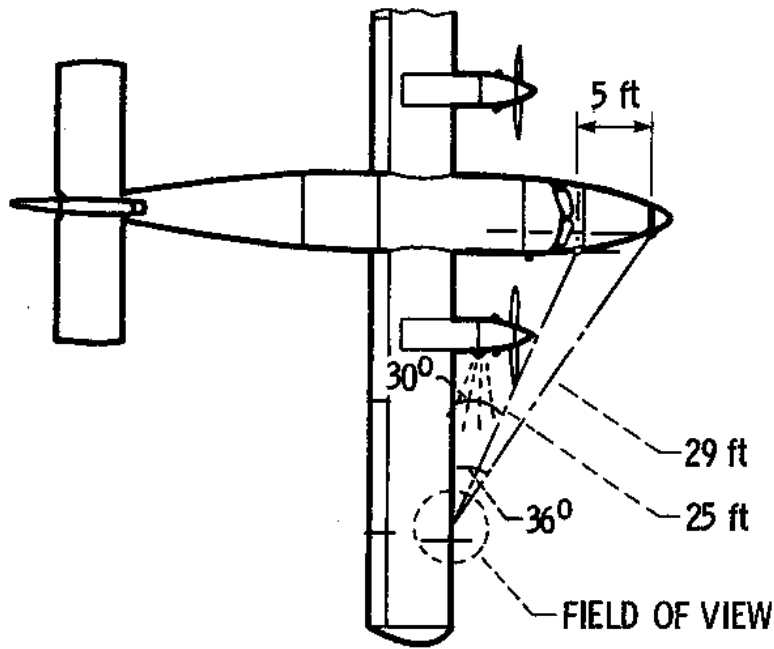
at Lewis Field



Wing Stereo System Process



Flight No.9768 ; Flight Date: 12/11/97; Time: 15:05:51; Span= 18

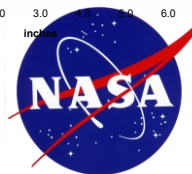


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Wing Stereo Image Statistics

	97	98	99	00	01	02	03	04	Totals
Wing Stereo Image Pairs	42	44	12	13	23	20	16	18	188
Pairs Analyzed	19	17	7	5	11	6	9	6	80
Cases with SLD	8	5	0	2	1	1	2	5	24

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Collection of SLD Ice Formations on NASA Twin Otter Wing

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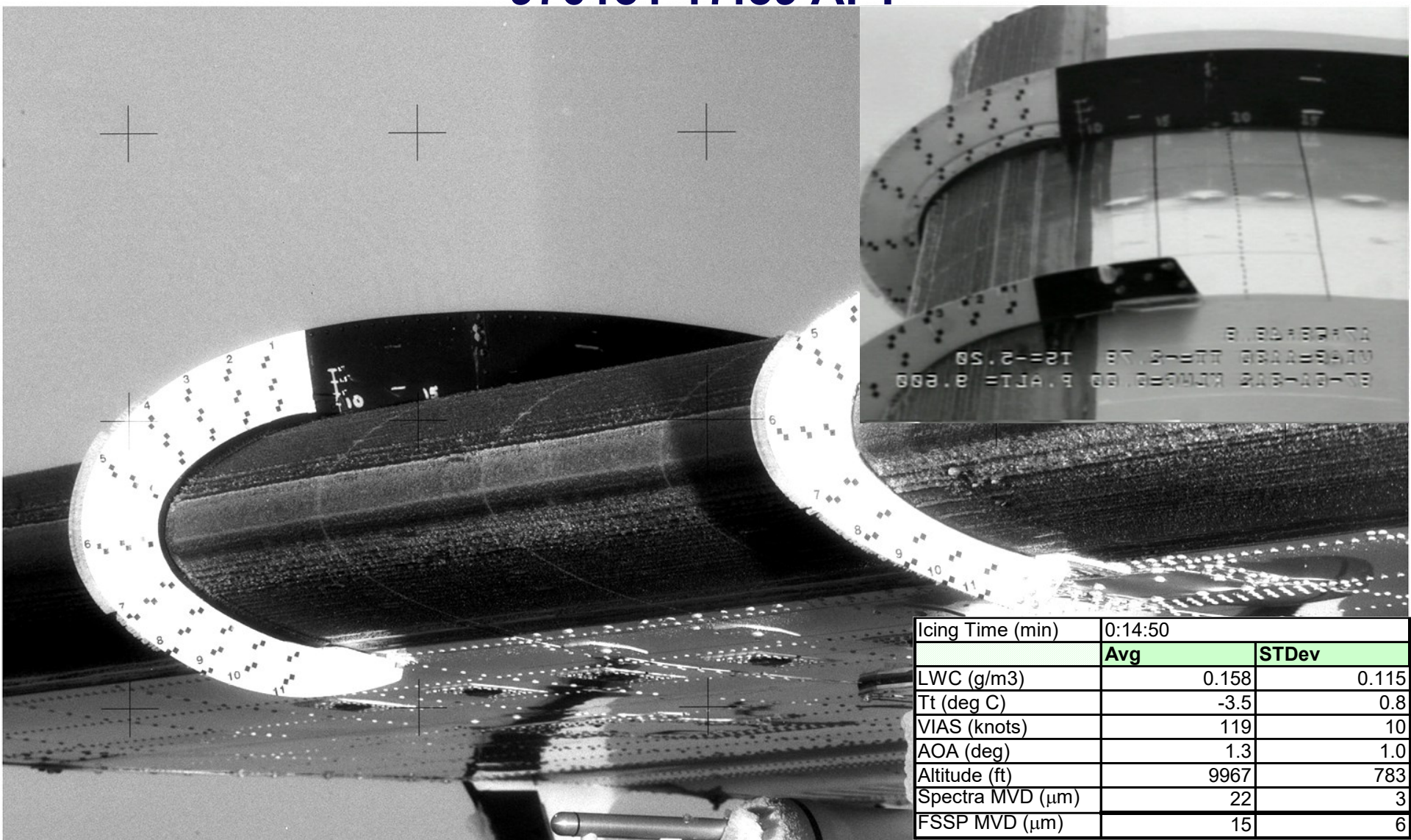




AFT 13
DATE: 970131

FLT 97-13A
TIME: 17:59:30

970131 17:59 AFT



Icing Time (min)	0:14:50	
	Avg	STDev
LWC (g/m3)	0.158	0.115
Tt (deg C)	-3.5	0.8
VIAS (knots)	119	10
AOA (deg)	1.3	1.0
Altitude (ft)	9967	783
Spectra MVD (μm)	22	3
FSSP MVD (μm)	15	6

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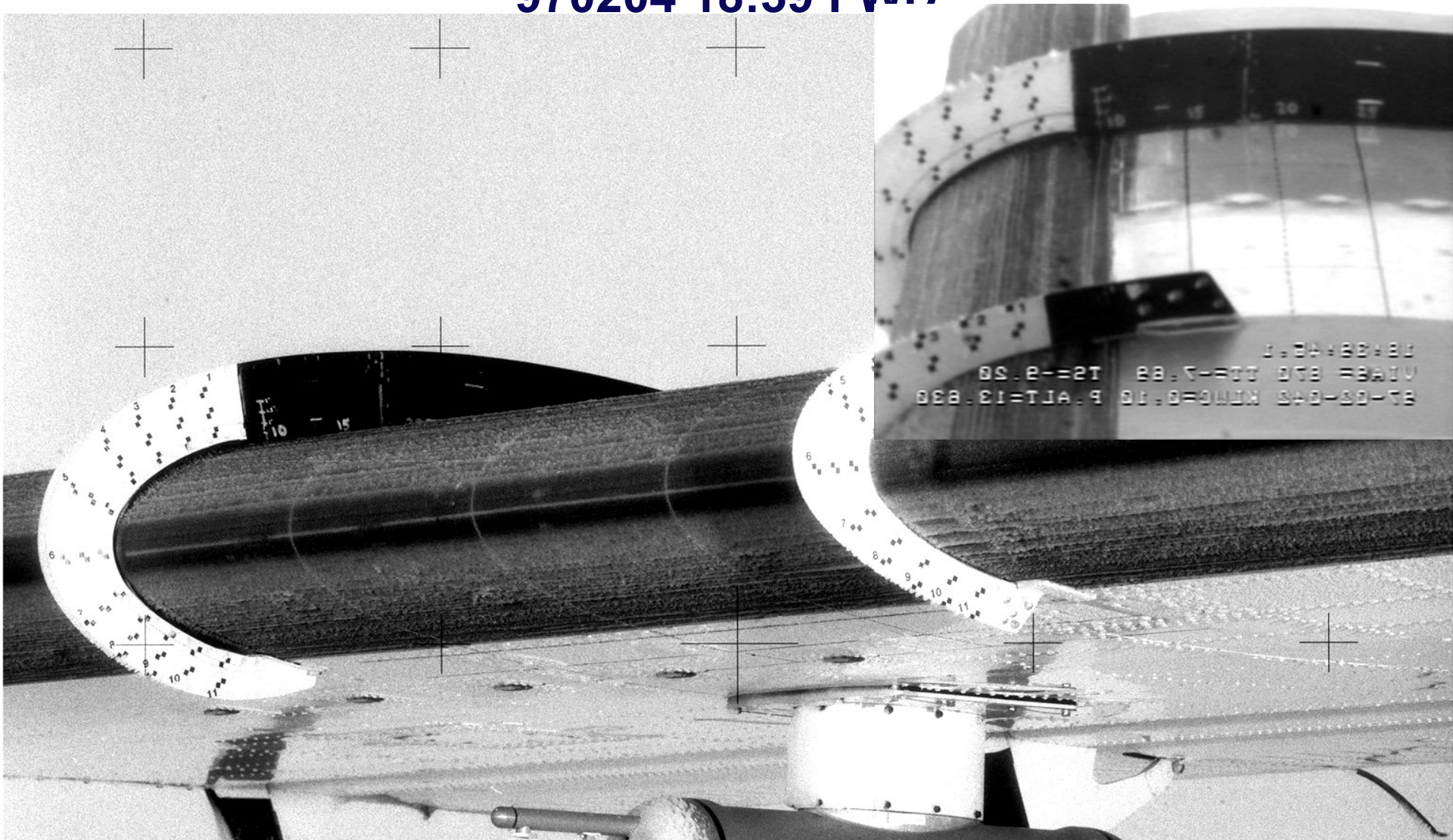




FWD 20
DATE: 970204

FLT 97-14B
TIME:18:39:38

970204 18:39 FWD



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at Lewis Field

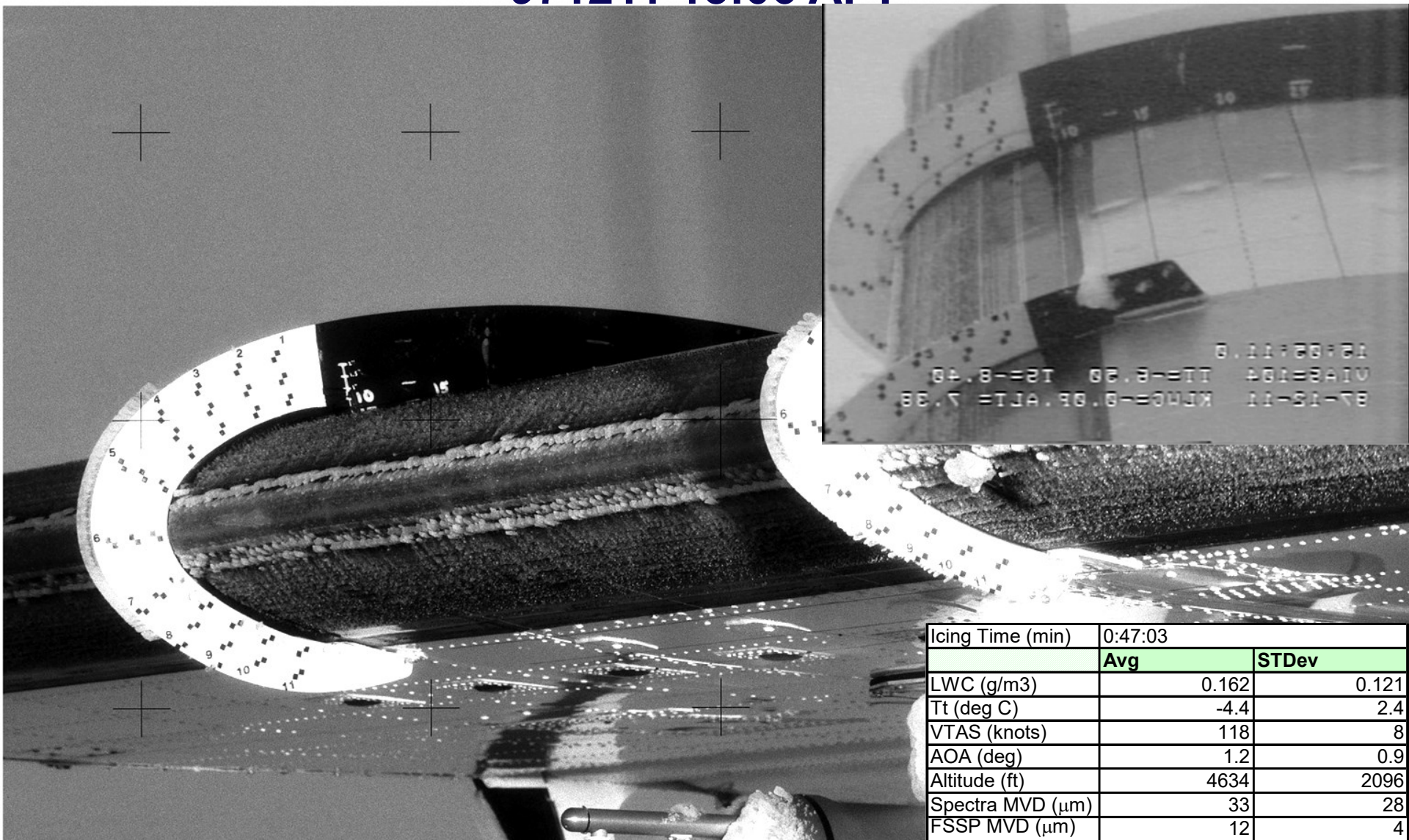




AFT 23
DATE: 971211

FLT 97-68
TIME:15:06:18

971211 15:06 AFT



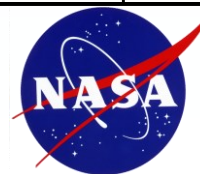
Icing Time (min)	0:47:03	
	Avg	STDev
LWC (g/m3)	0.162	0.121
Tt (deg C)	-4.4	2.4
VTAS (knots)	118	8
AOA (deg)	1.2	0.9
Altitude (ft)	4634	2096
Spectra MVD (μm)	33	28
FSSP MVD (μm)	12	4

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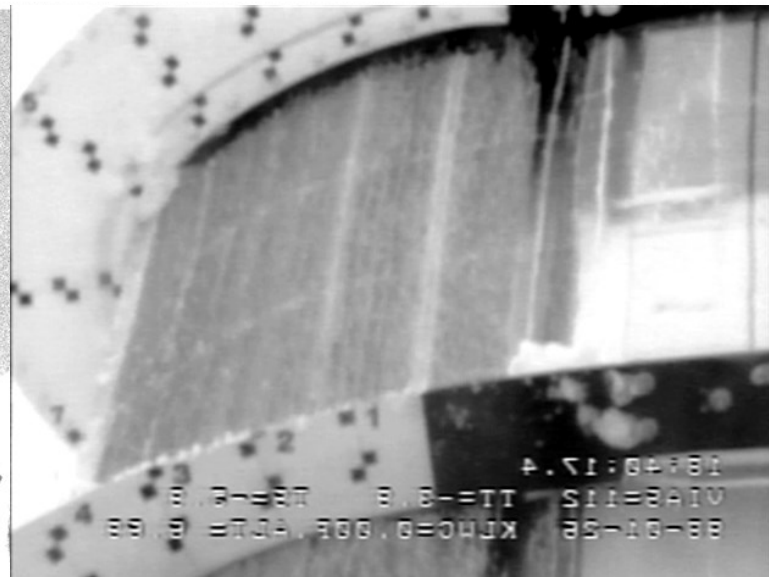
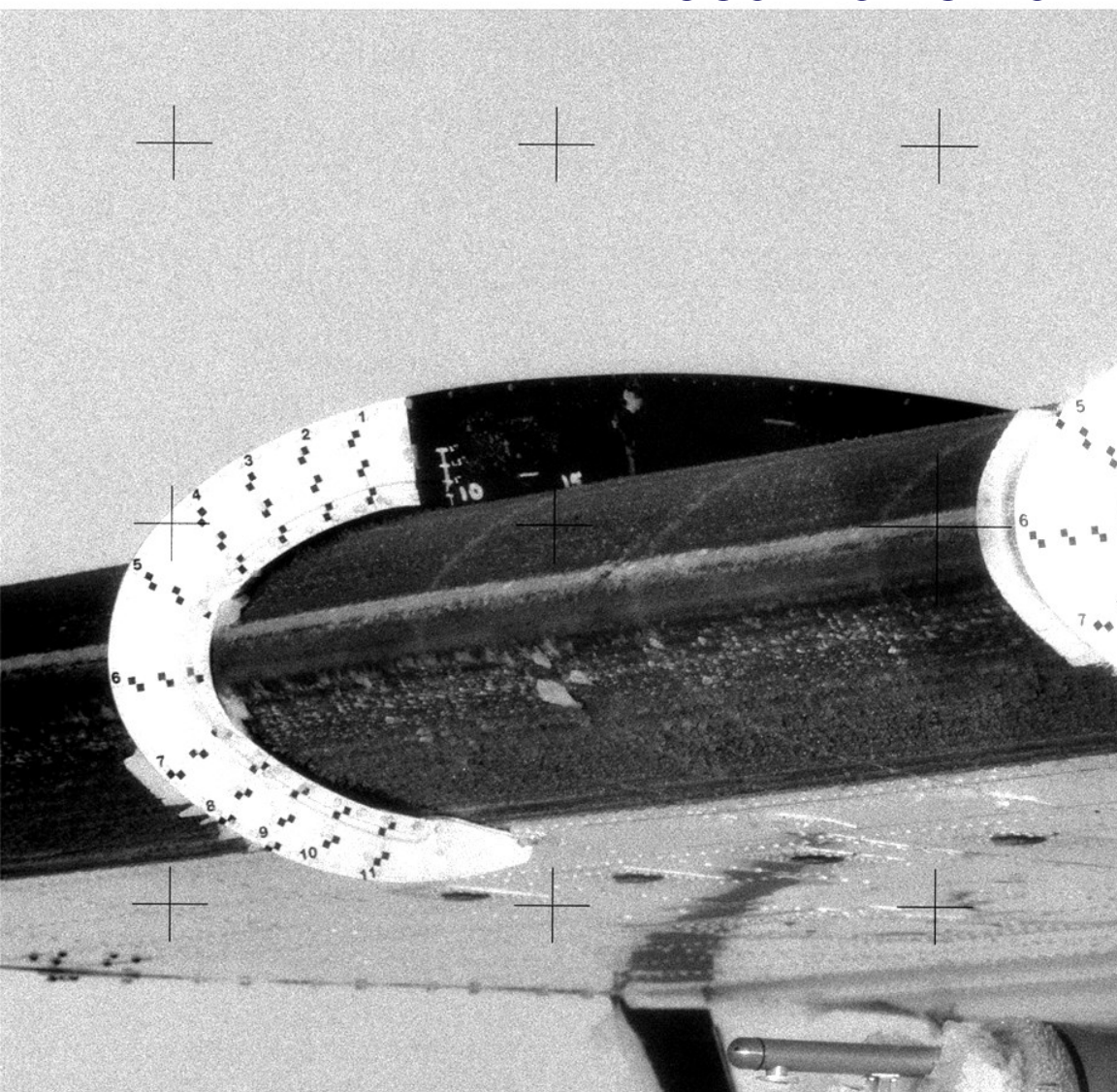




AFT 26
DATE: 980126

FLT 98-05
TIME:18:40:54

980126 18:40 AFT



Icing Time (min)	0:50:31	
	Avg	STDev
LWC (g/m3)	0.180	0.120
Tt (deg C)	-2.5	1.1
VIAS (knots)	119	9
AOA (deg)	1.1	0.9
Altitude (ft)	3354	1196
Spectra MVD (μm)	18	14

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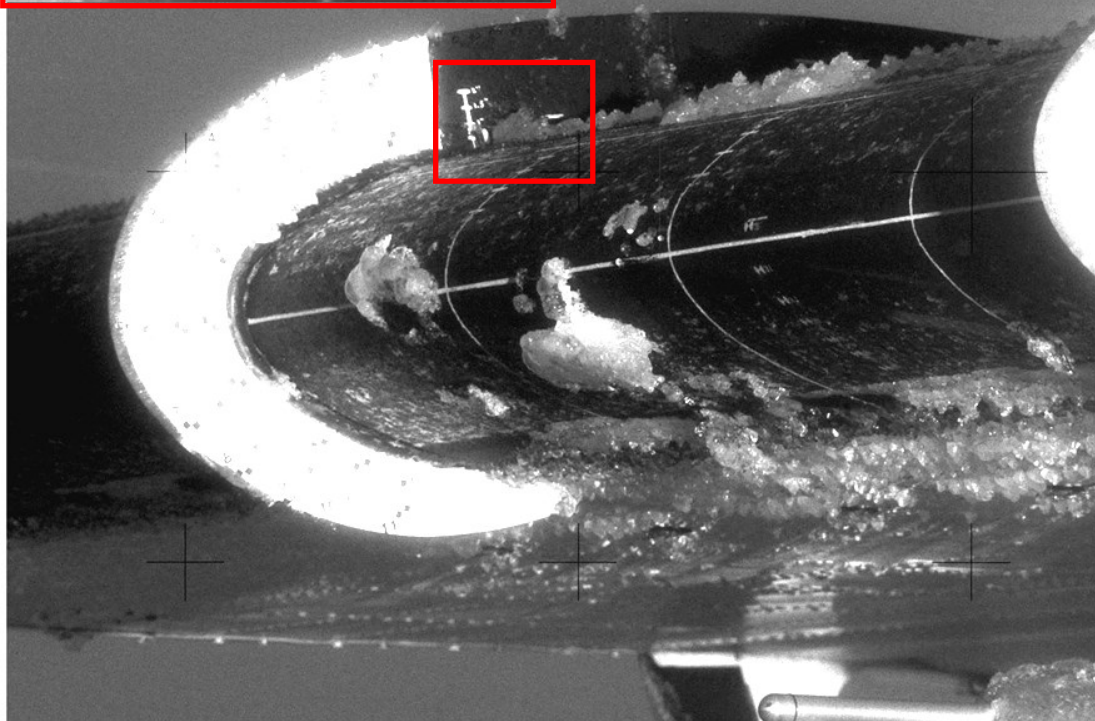




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DATE: 980204

FLT 98-09B
TIME: 20:04:29

980204 20:08 AFT



7.31:08:02		
8.2-08T 8.1-08T 00-0810		
.1-0811.911.8-0811 18-28-00		
Icing Time (min)	1:35:00	
	Avg	STDev
LWC (g/m3)	0.252	0.131
Tt (deg C)	-0.6	0.4
VIAS (knots)	103	4
AOA (deg)	3.3	0.9
Altitude (ft)	3176	287
Spectra MVD (μm)	789	352

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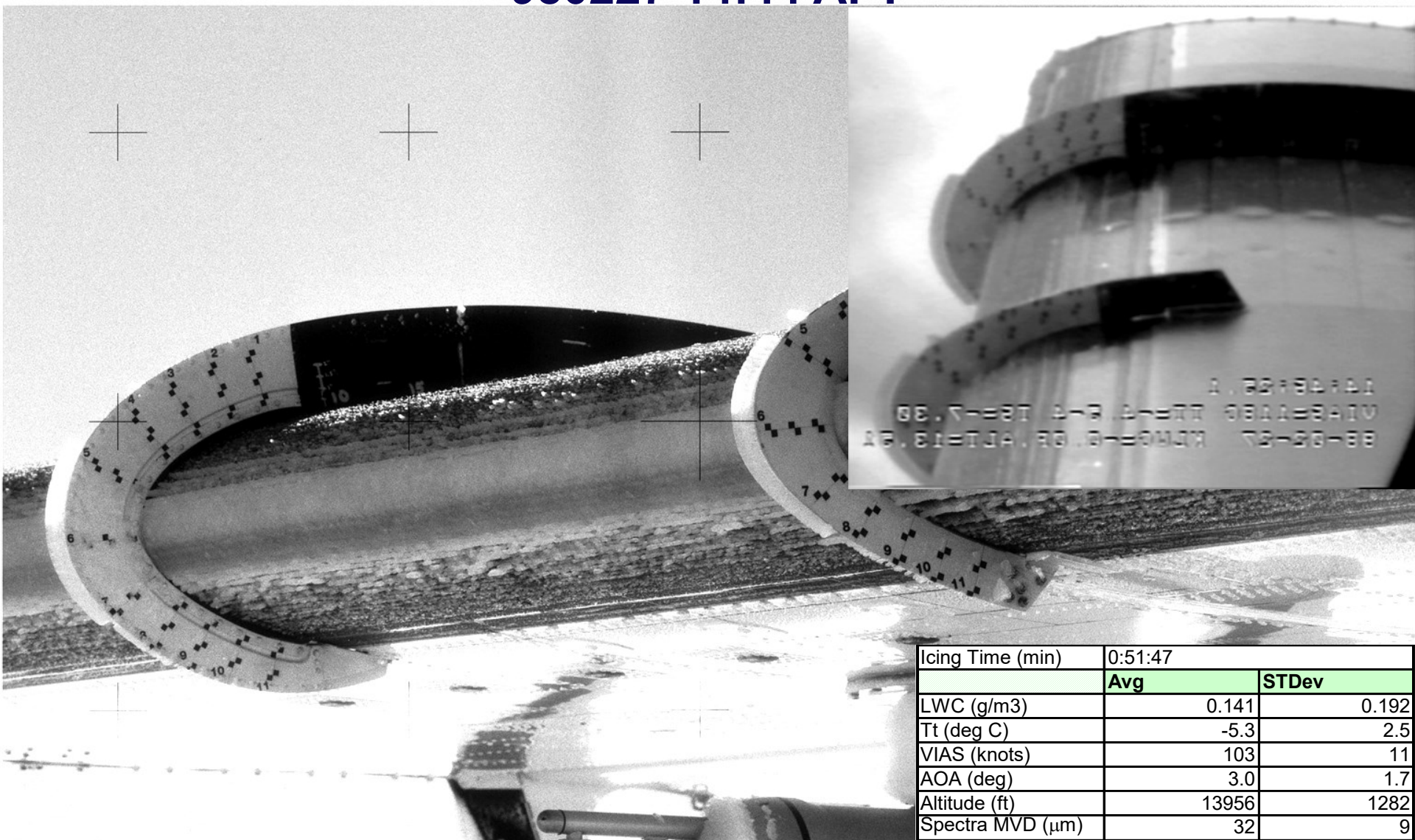




AFT 03
DATE: 980227

FLT 98-16A
TIME: 14:44:59

980227 14:44 AFT



Icing Time (min)	0:51:47	
	Avg	STDev
LWC (g/m3)	0.141	0.192
Tt (deg C)	-5.3	2.5
VIAS (knots)	103	11
AOA (deg)	3.0	1.7
Altitude (ft)	13956	1282
Spectra MVD (μm)	32	9

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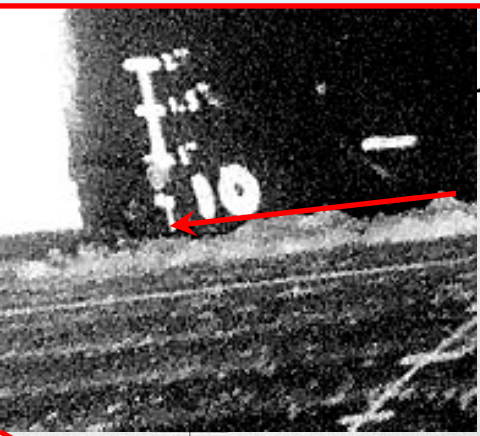
Icing Branch

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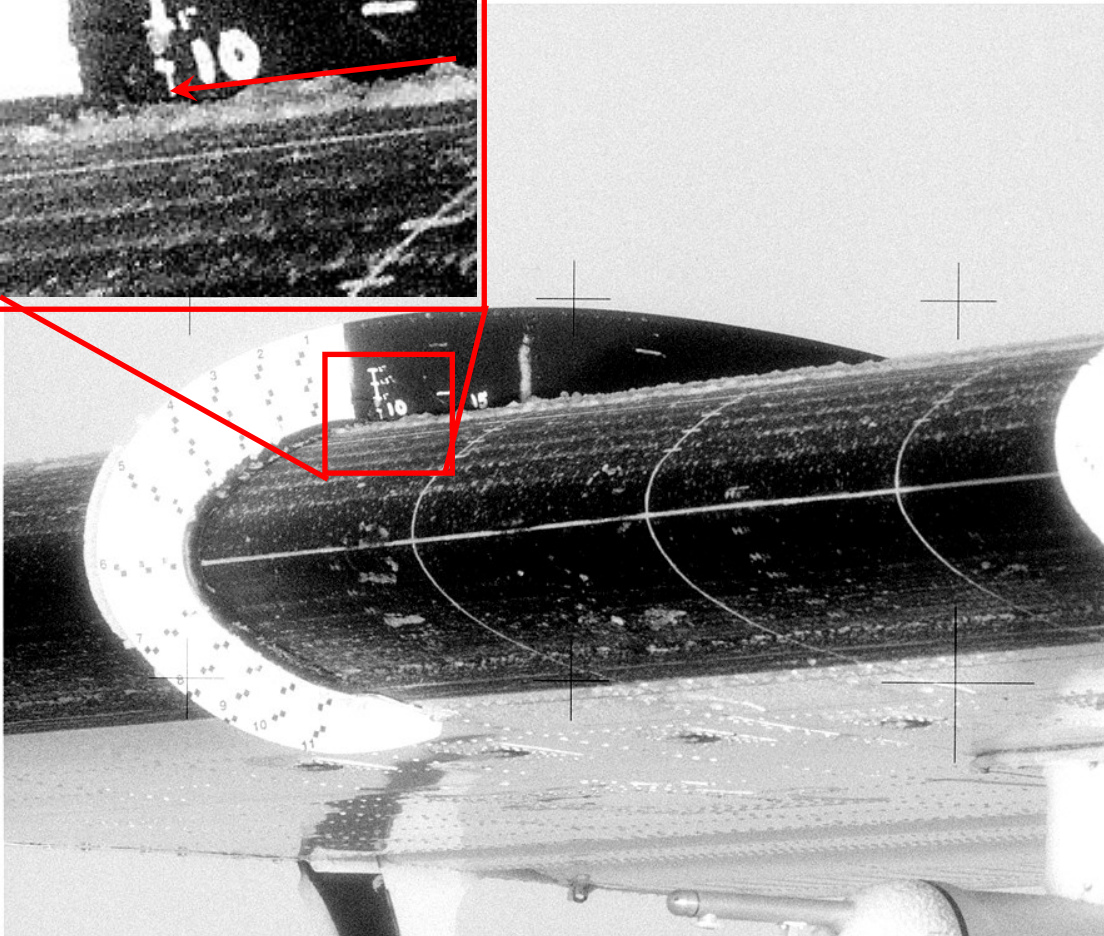
at Lewis Field



980320 20:14 FWD



4:14



Icing Time (min)	0:23:54	
	Avg	STDev
LWC (g/m3)	0.198	0.063
Tt (deg C)	-3.2	0.3
VIAS (knots)	125	6
AOA (deg)	0.9	0.6
Altitude (ft)	2988	55
FSSP MVD (μm)	9	1

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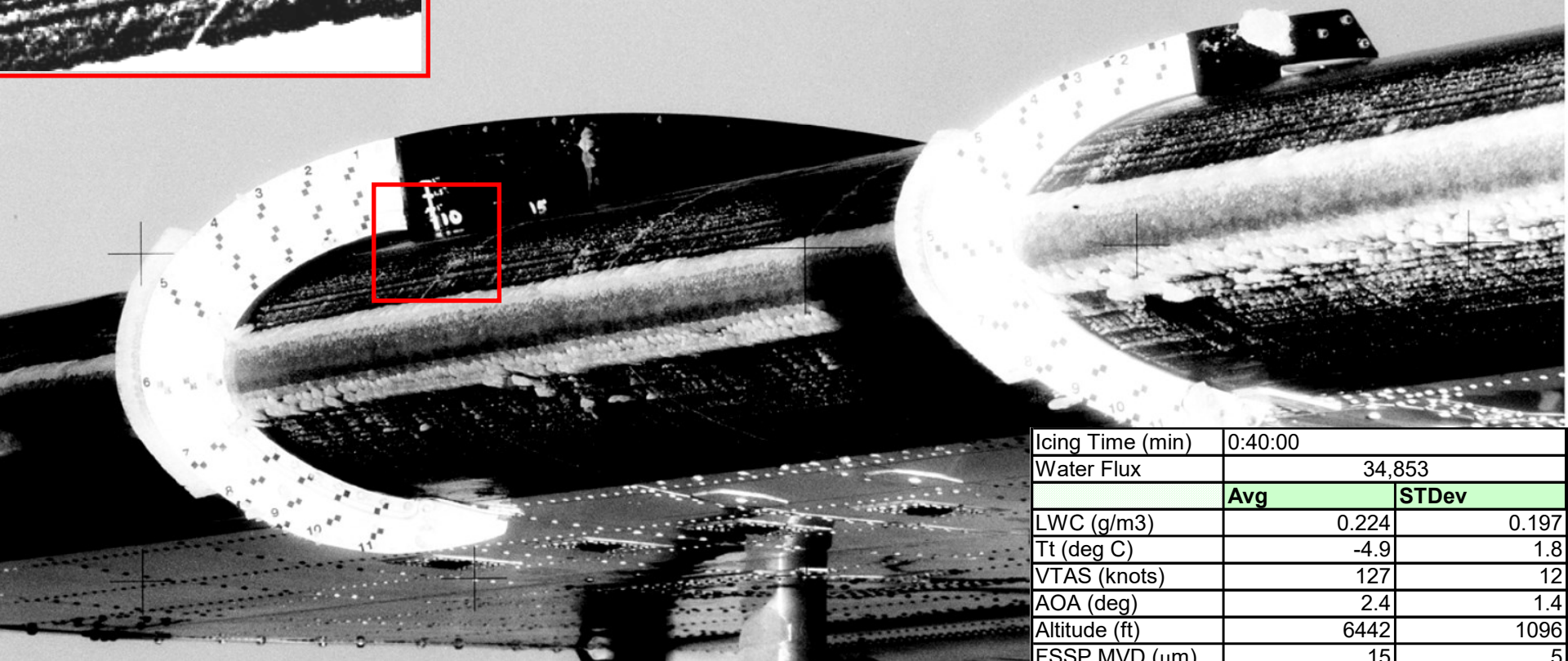
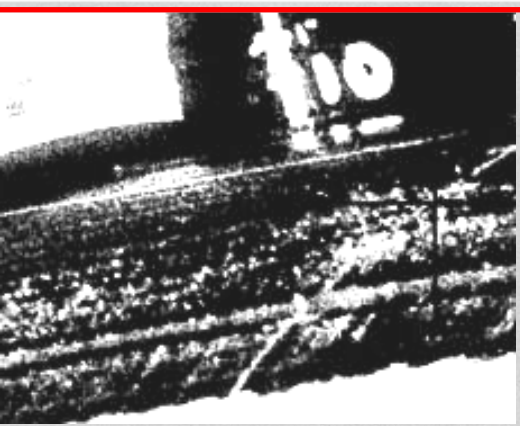




AFT 31 FLT 02-18

Date: 21FEB02 Time: 20:53:05

020221 20:53 AFT



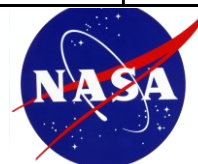
Icing Time (min)	0:40:00	
Water Flux	34,853	
	Avg	STDev
LWC (g/m3)	0.224	0.197
Tt (deg C)	-4.9	1.8
VTAS (knots)	127	12
AOA (deg)	2.4	1.4
Altitude (ft)	6442	1096
FSSP MVD (μm)	15	5

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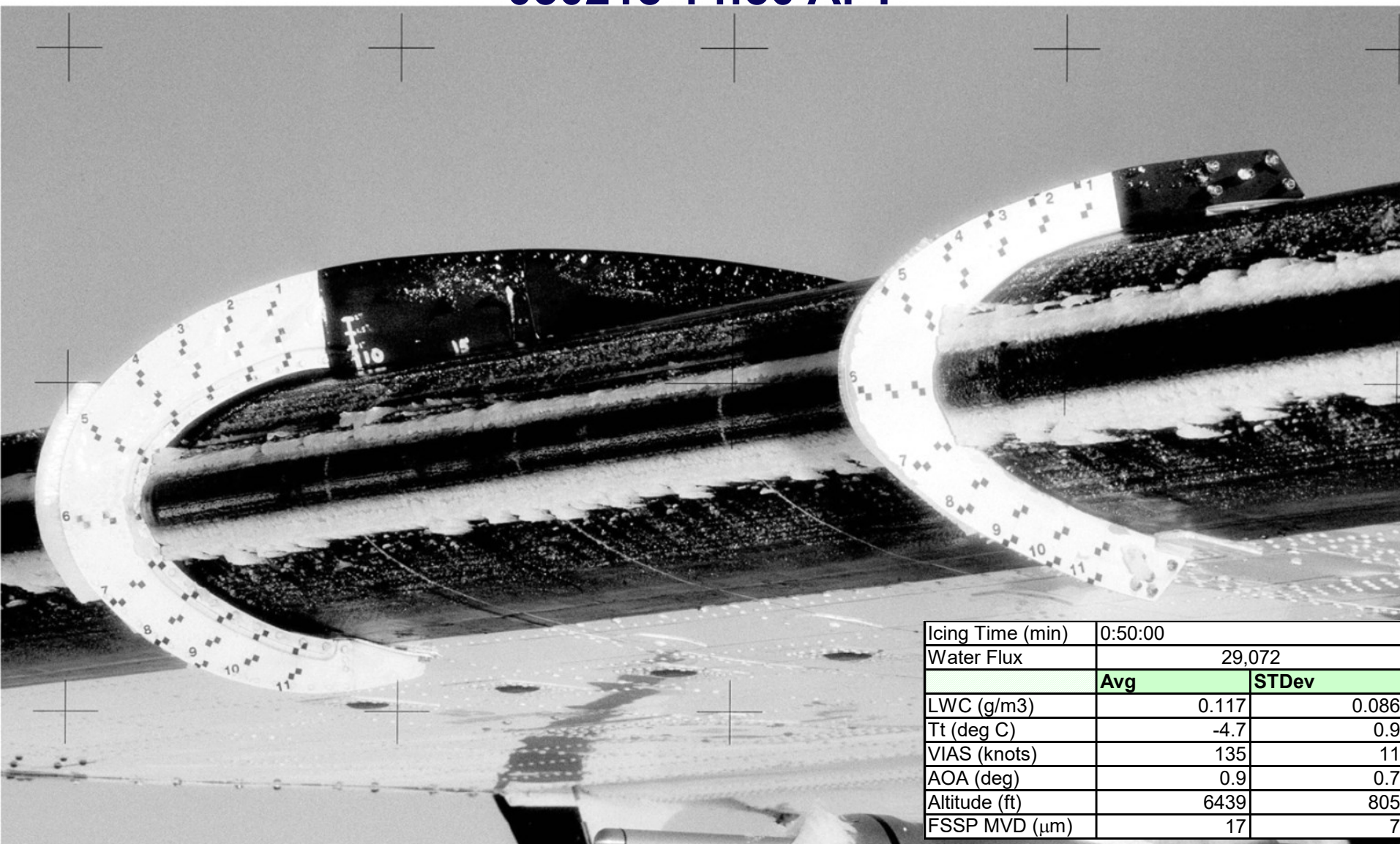




AFT 41
DATE: 030218

FLT 2003-10
TIME: 14:50:24

030218 14:50 AFT



Icing Time (min)	0:50:00	
Water Flux	29,072	
	Avg	STDev
LWC (g/m3)	0.117	0.086
Tt (deg C)	-4.7	0.9
VIAS (knots)	135	11
AOA (deg)	0.9	0.7
Altitude (ft)	6439	805
FSSP MVD (μm)	17	7

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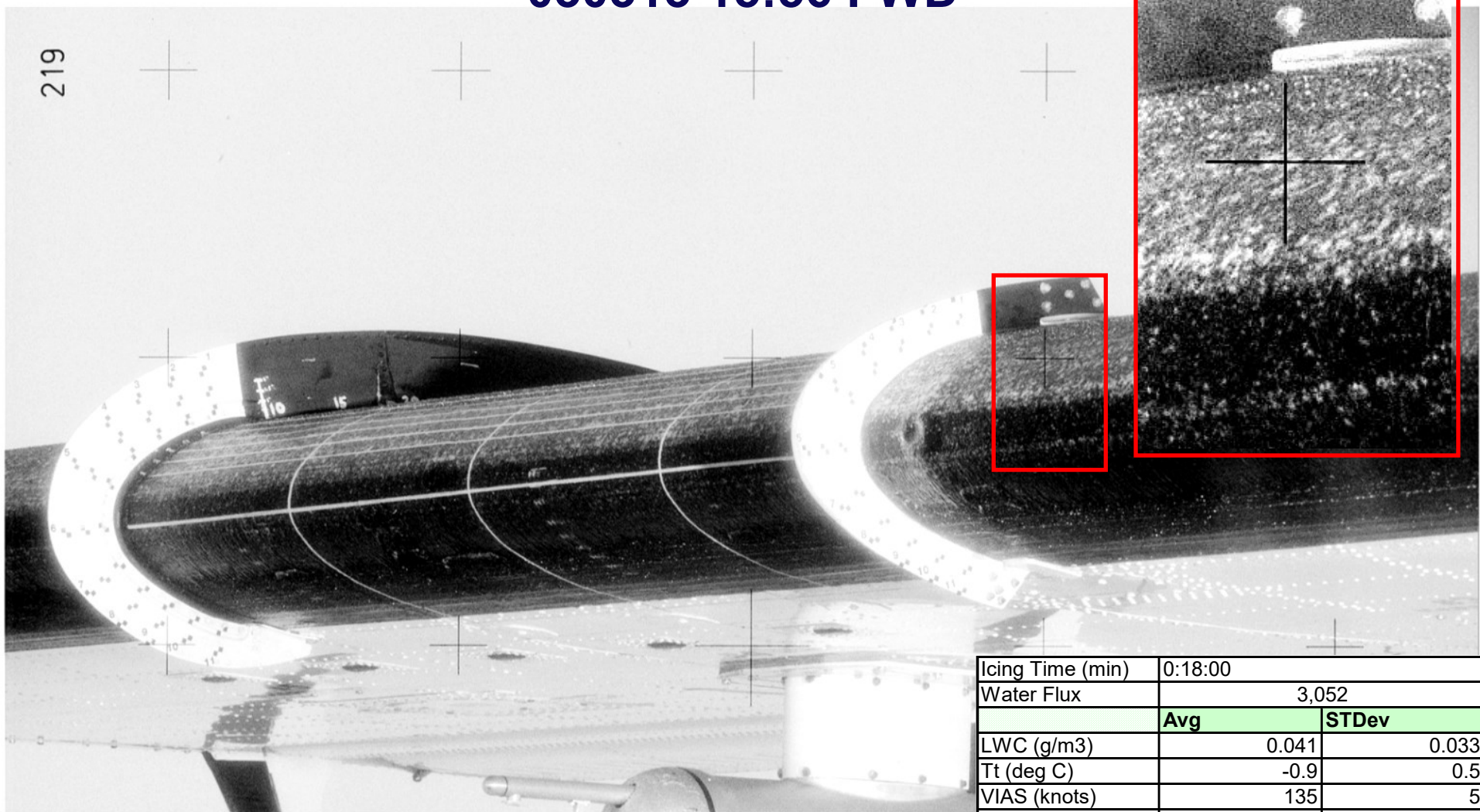
at Lewis Field





030313 15:56 FWD

219



Icing Time (min)	0:18:00	
Water Flux	3,052	
	Avg	STDev
LWC (g/m3)	0.041	0.033
Tt (deg C)	-0.9	0.5
VIAS (knots)	135	5
AOA (deg)	0.3	0.3
Altitude (ft)	2330	56
FSSP MVD (μm)	9	2

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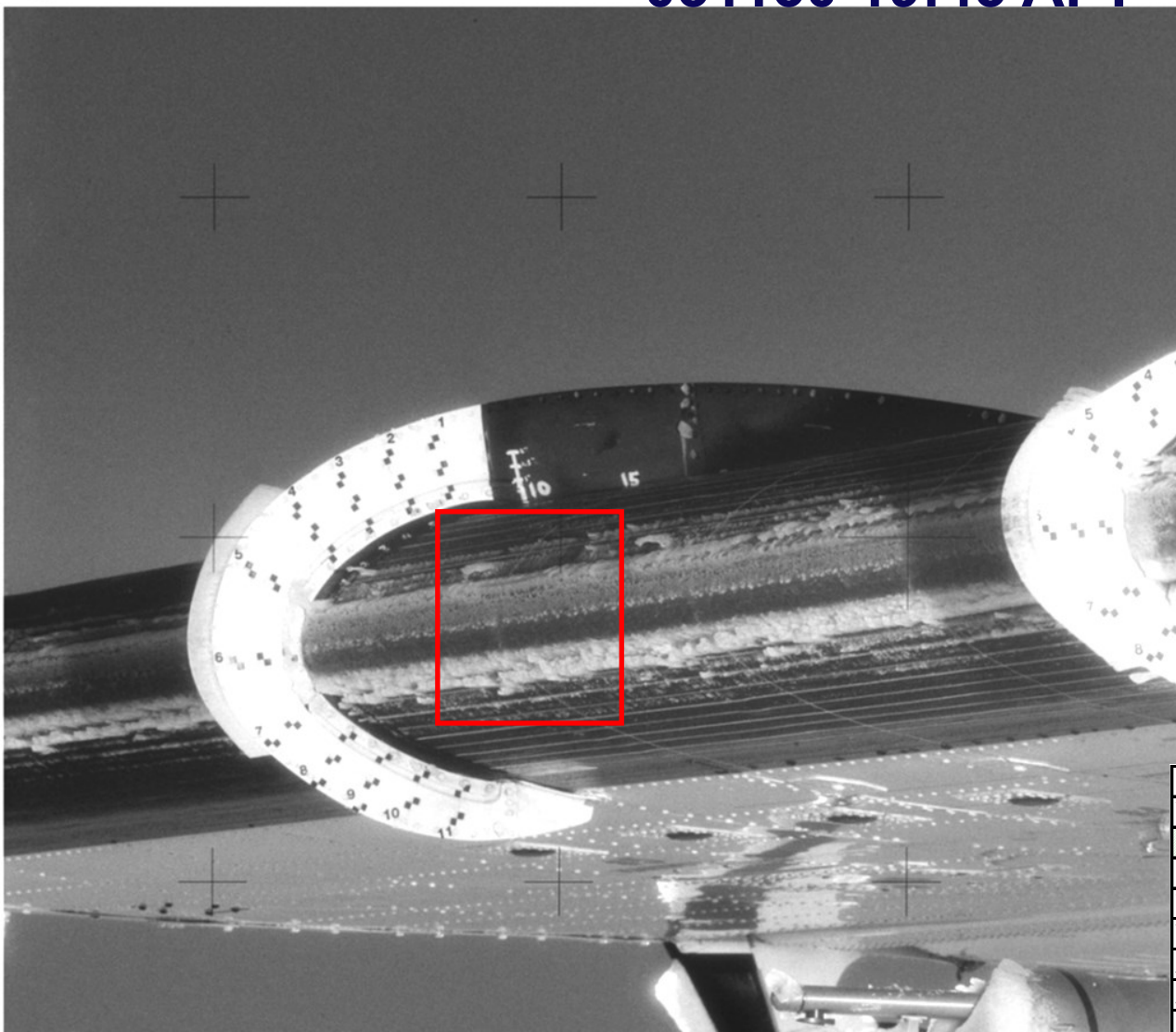




AFT 032V
DATE: 031130

FLT 2003-61
TIME: 19:43:00

031130 19:43 AFT



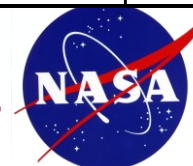
Icing Time (min)	0:17:00	
Water Flux	27,844	
	Avg	STDev
LWC (g/m3)	0.424	0.104
Tt (deg C)	-8.1	0.9
VTAS (knots)	125	11
AOA (deg)	1.3	1.1
Altitude (ft)	6992	308
FSSP MVD (μm)	19	2
Spectra MVD (μm)	21	2

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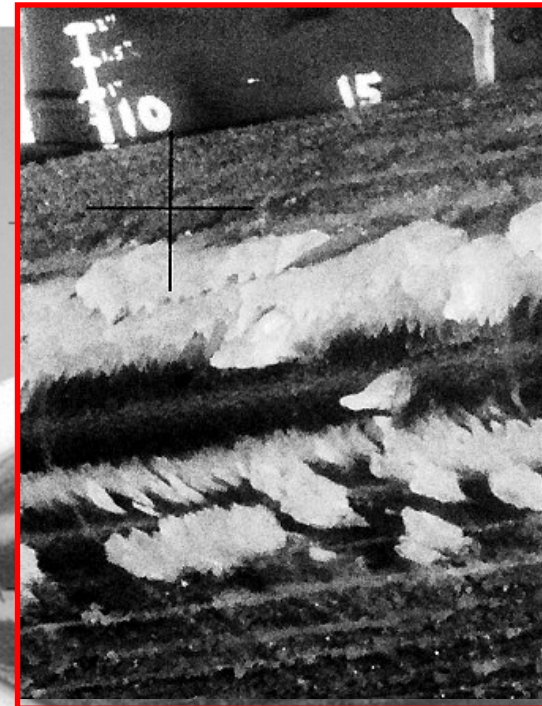
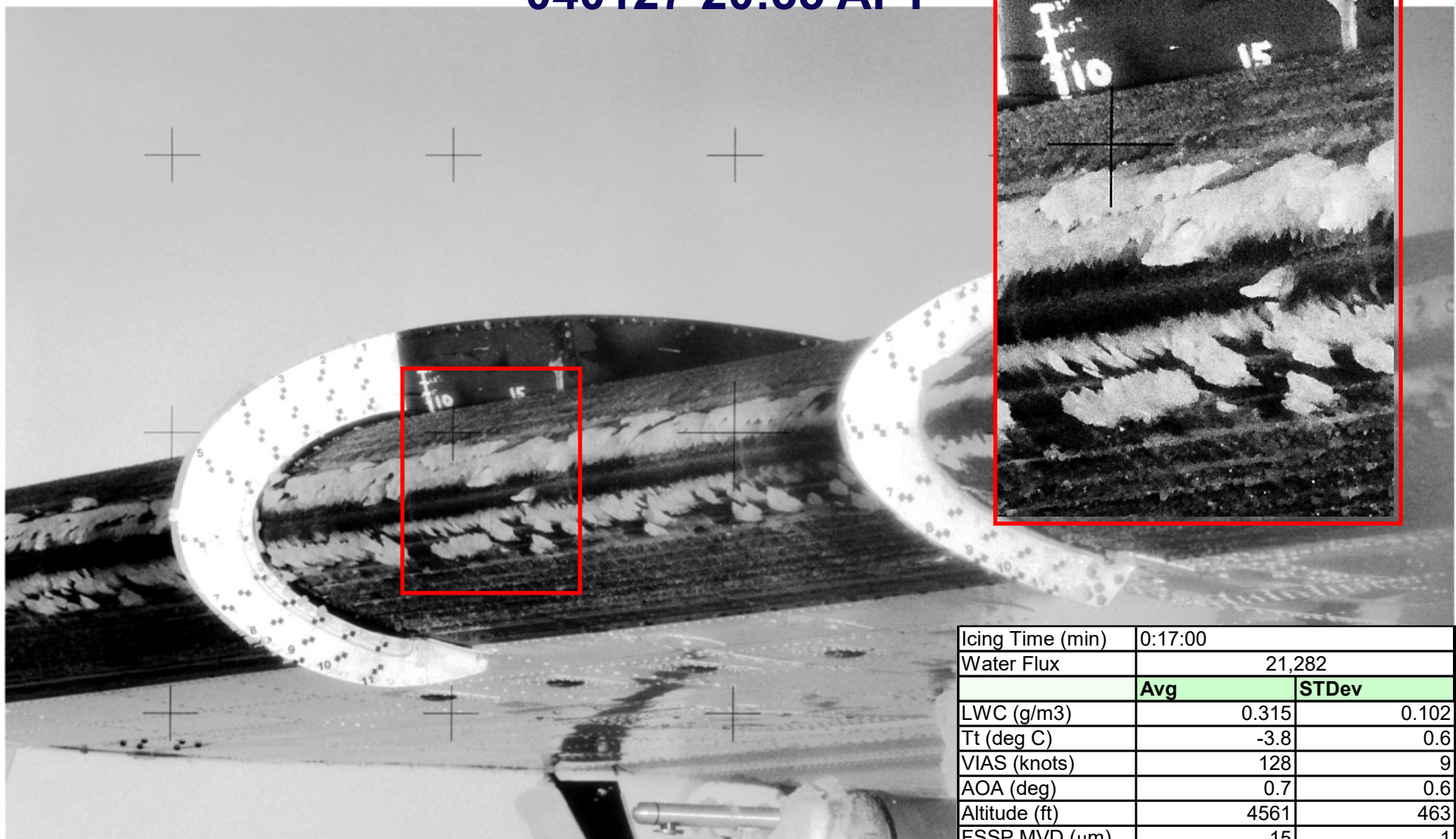
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040127 20:35 AFT



Icing Time (min)	0:17:00	
Water Flux	21,282	
	Avg	STDev
LWC (g/m3)	0.315	0.102
Tt (deg C)	-3.8	0.6
VIAS (knots)	128	9
AOA (deg)	0.7	0.6
Altitude (ft)	4561	463
FSSP MVD (µm)	15	1
Spectra MVD (µm)	17	1

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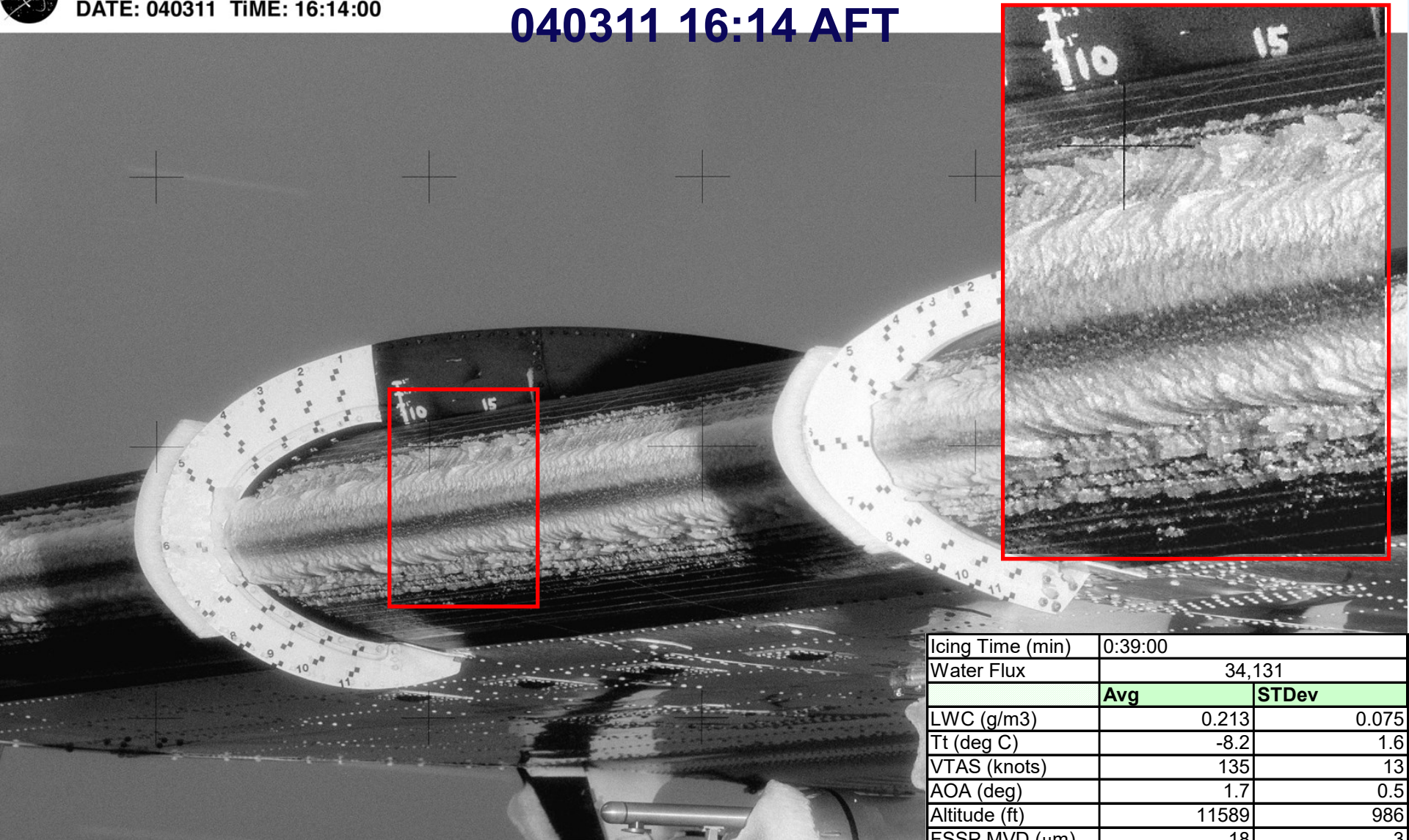
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040311 16:14 AFT



Icing Time (min)	0:39:00	
Water Flux	34,131	
	Avg	STDev
LWC (g/m3)	0.213	0.075
Tt (deg C)	-8.2	1.6
VTAS (knots)	135	13
AOA (deg)	1.7	0.5
Altitude (ft)	11589	986
FSSP MVD (µm)	18	3
Spectra MVD (µm)	21	2

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SLD Ice Formation Analysis Process

- **Select stereo image pairs for photogrammetric analysis where SLD conditions were encountered**
- **Examine icing conditions and deicing boot cycles that preceded ice shape development**
- **Develop summary tables to indicate icing time, time out of cloud, and average & standard deviations of icing conditions**
 - Possible conditions for icing simulations (IRT, LEWICE, etc.)
- **Additional analysis of the time variations in icing conditions including drop spectra are needed for IRT simulation**
 - Segment spray conditions for varying LWC (freezing fraction)
 - Sequence spray conditions for cases where drop spectra do not match



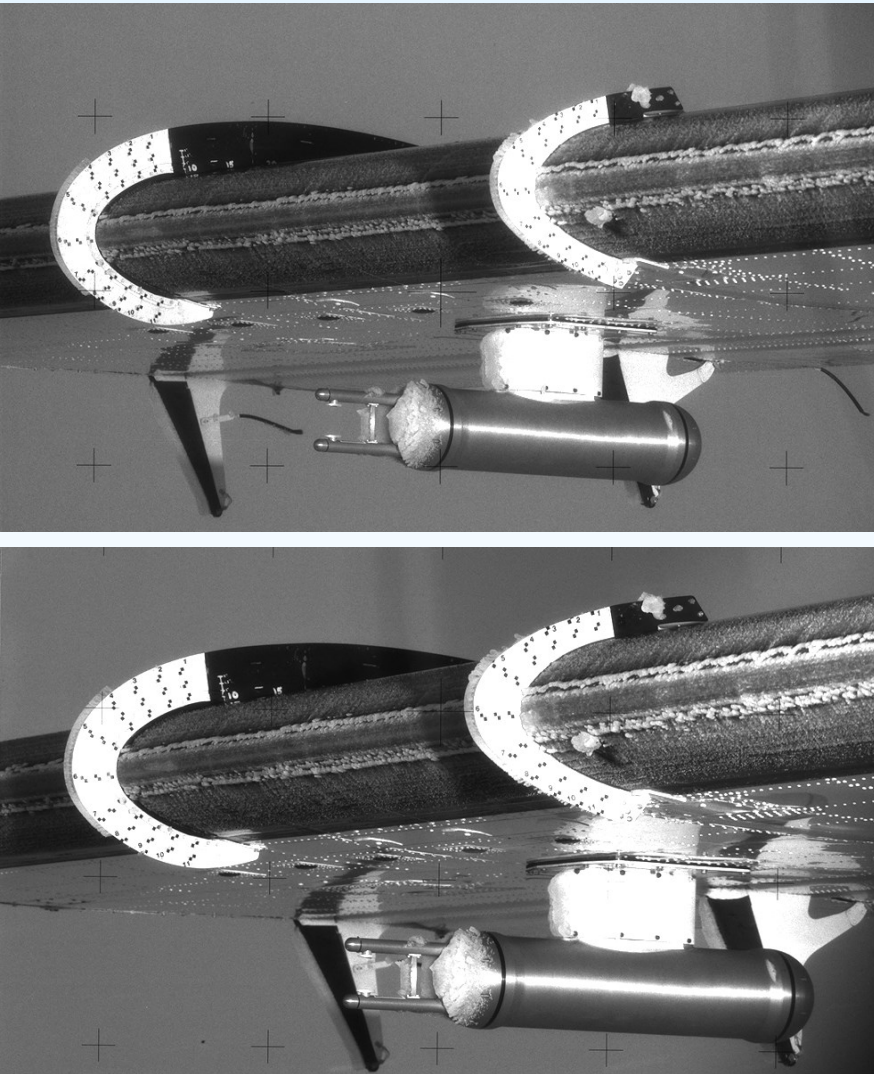
SLD Ice Formation Analysis Process

Natural Ice Shape Issues:

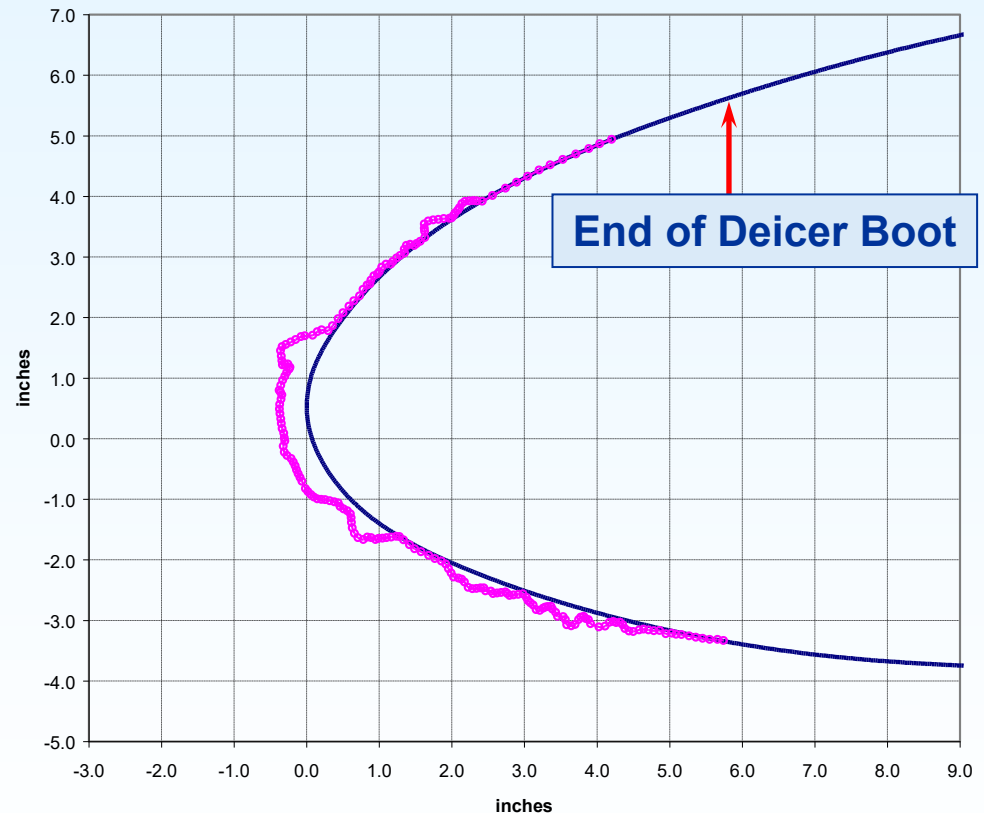
- **The resulting ice formations are an integration of ALL the icing conditions encountered during the icing time**
 - Variations in LWC, temp (freezing fraction)
 - Contributions of small and large droplets
- **If deice boots were cycled prior to encounter, residual ice may affect final ice formation**



Example Case 971211: Stereo Photogrammetric Analysis



Flight No.9768 ; Flight Date: 12/11/97; Time: 15:05:51; Span= 18



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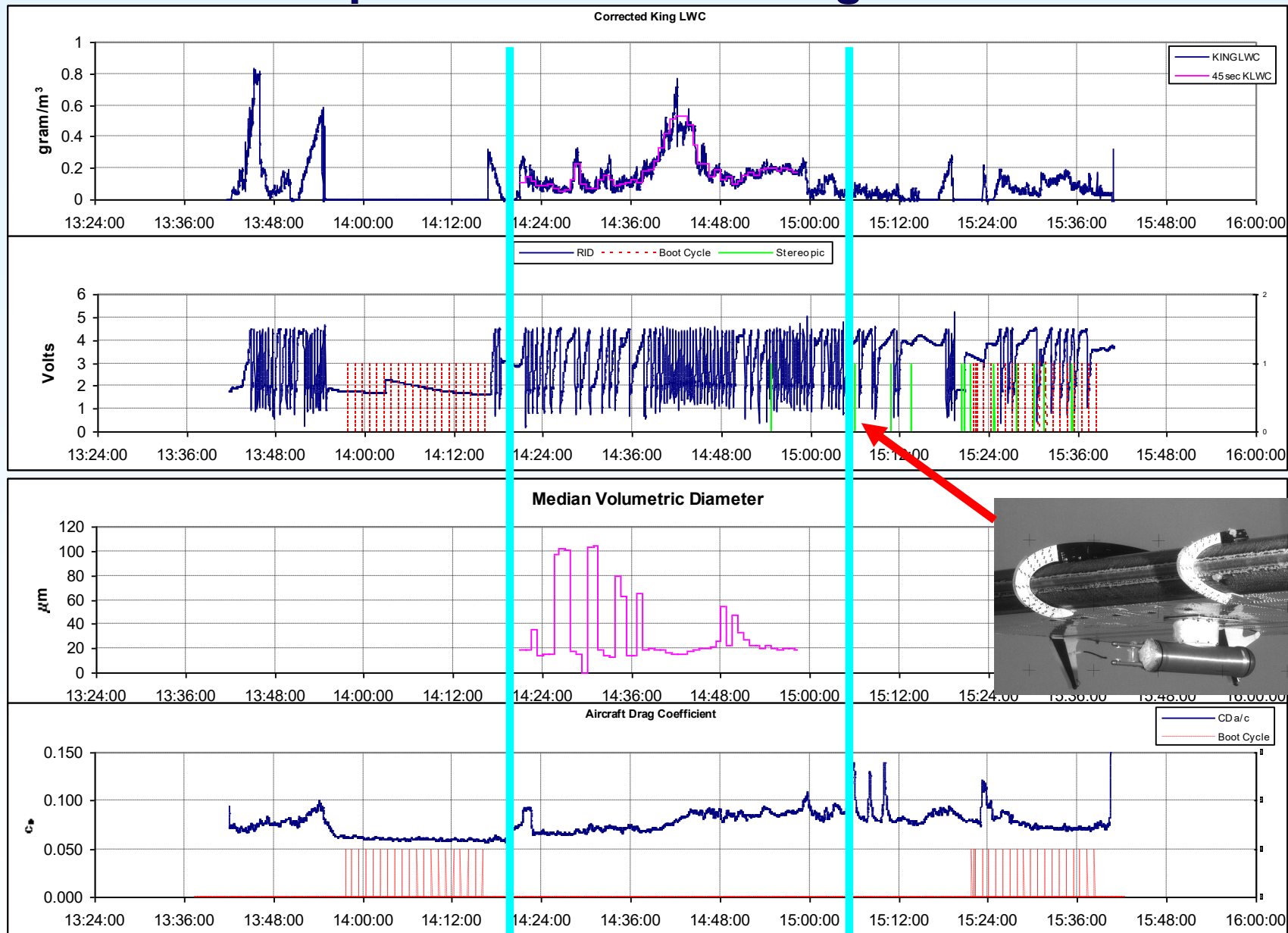
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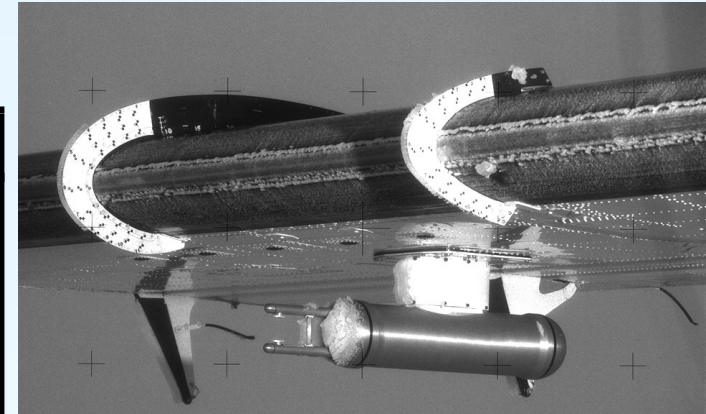


Example Case 971211: Icing Conditions

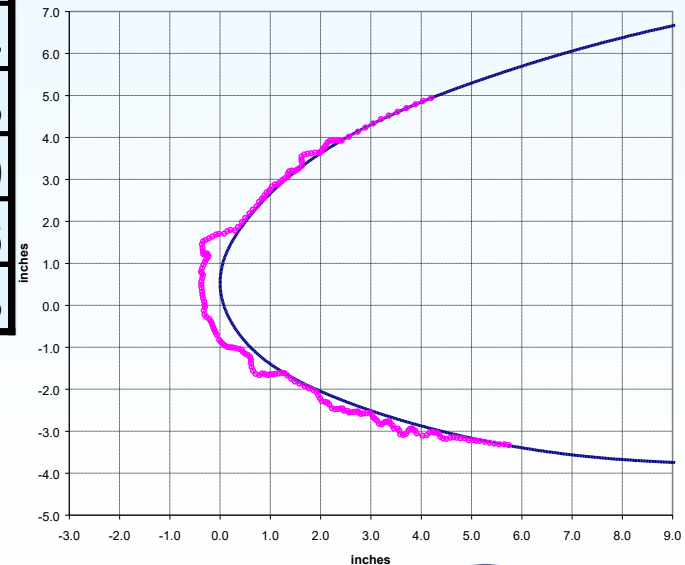


Example Case 971211: Summary Table

Ice Accretion Summary Data		
	Start	End
Time	14:16:48	15:05:51
Icing Time (min)	0:49:03	
	Avg	STDev
LWC (g/m3)	0.162	0.121
Tt (deg C)	-4.4	2.4
VIAS (knots)	118	8
AOA (deg)	1.2	0.9
Altitude (ft)	4634	2096
MVD (μ m)	33	28



Flight No.9768 ; Flight Date: 12/11/97; Time: 15:05:51; Span= 18



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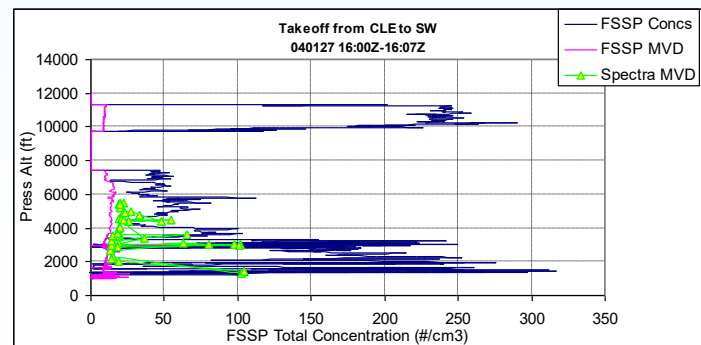
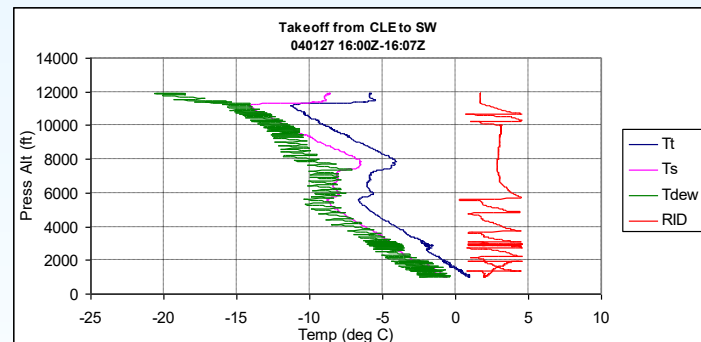
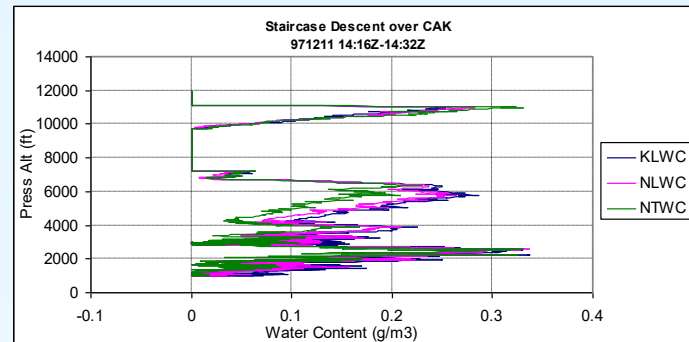
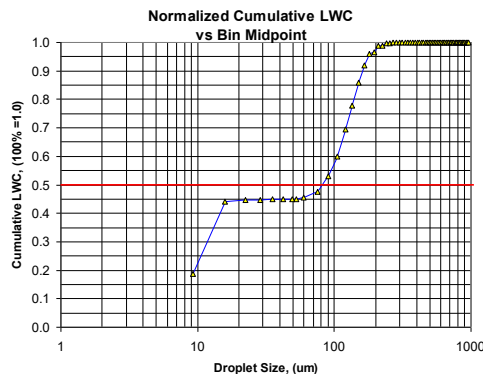
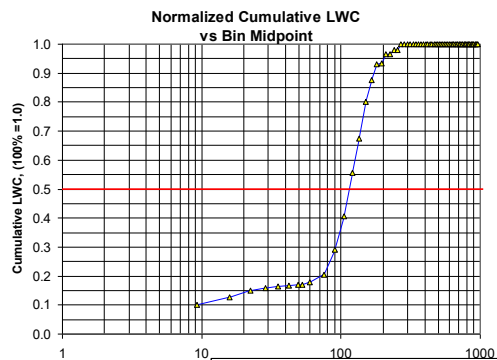
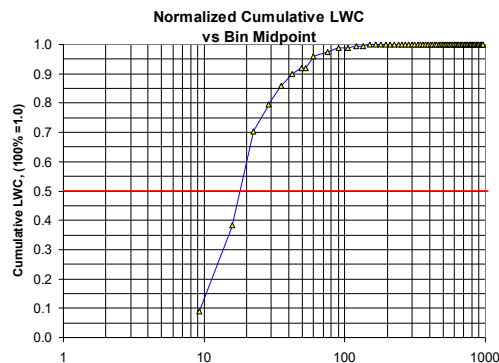
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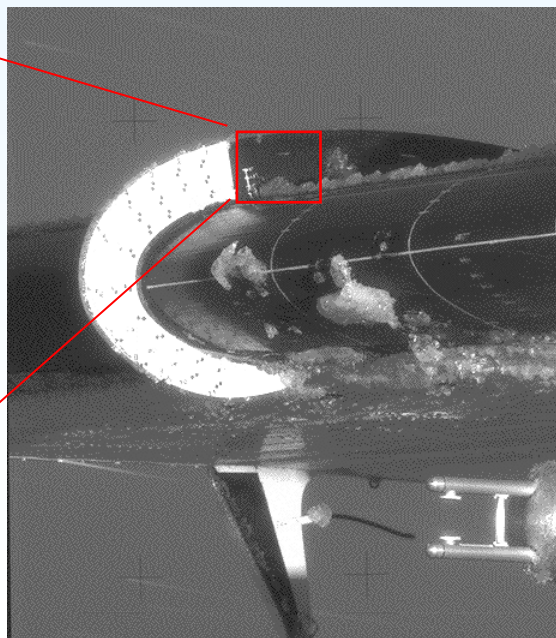


Example Case 971211: Additional Analysis



Observations on SLD Ice Formations

- **SLD ice aerodynamic studies have focused on ridge ice shapes**
 - Ridge ice shapes represent operational scenarios with deicing systems active
 - Leading edge ice removed, but ice aft of IPS remains
 - Step change in airfoil acts as accretion site for small drops as well as large drops

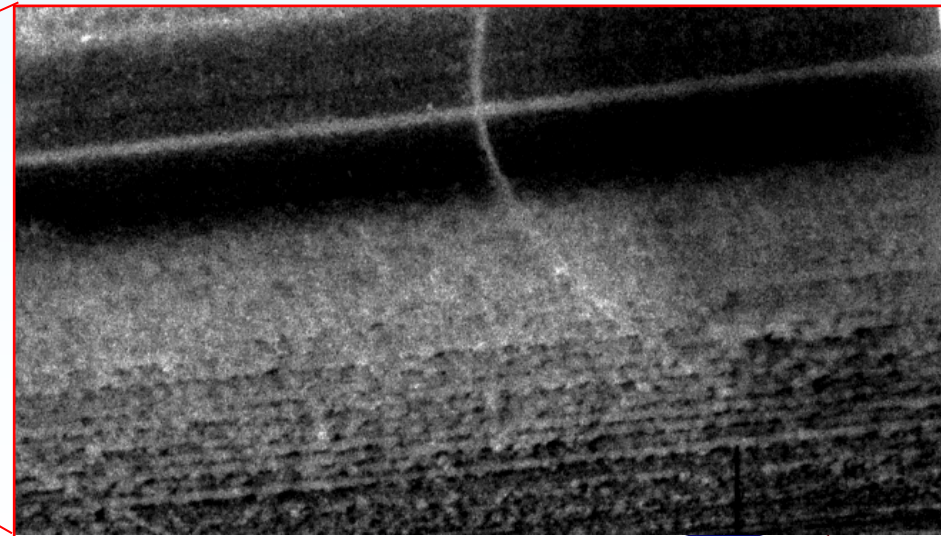
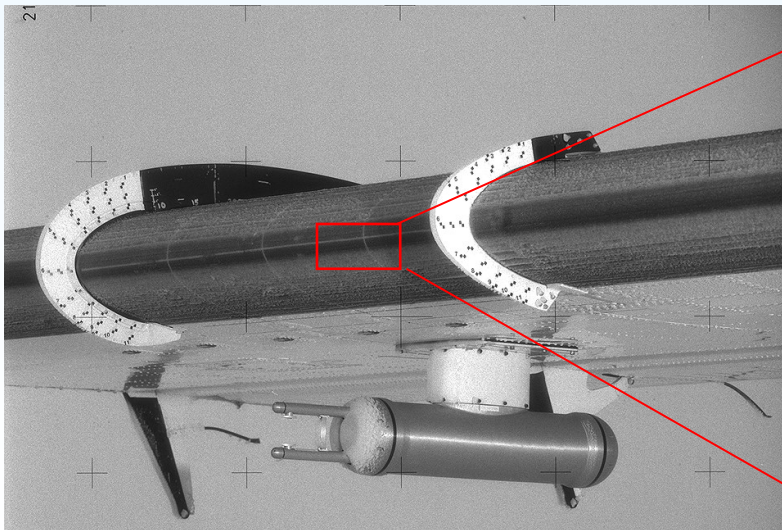


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Observations on SLD Ice Formations

- Pre-IPS activation ice formations represent operational scenarios with deicing systems inoperative or prior to detection / activation
- NASA's observation of features from this class of accretions
 - Most ice concentrated on leading edge
 - No ridges at boot/wing juncture
 - Thin ice accretion aft of leading edge extends to 10-15% chord
 - Thin spanwise feather banding (approximate frequency every 0.2")



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Findings & Plans

- **SLD ice formations from flight useful for simulation verification are limited (~8)**
 - Primary flight objective of SLD flights was for characterization, which by nature of the flight path, caused significant deviations in icing conditions
- **IRT tests with Twin Otter wing are being conducted in FY05 & FY06 based on flight data & ice shapes**
- **NASA plans to continue collecting more flight data in SLD icing conditions in FY05**
 - Focus on getting into steady icing conditions for ice shape development

