

AIRCRAFT DEICING RESEARCH IN SIMULATED MIXED CONDITIONS WITH ICE PELLETS

By

Marco Ruggi



**Transportation Development Centre
Transport Canada**

and the

Federal Aviation Administration



PRESENTATION OUTLINE

- BACKGROUND
- PREVIOUS RESEARCH (2005-06)
- OVERVIEW OF 2006-07 RESEARCH
- WIND TUNNEL TESTING
- FALCON 20 TESTING
- ALLOWANCE TIMES
 - ZR-/IP-
 - IP-
 - IP (moderate)
 - IP/SN
- CONCLUSIONS AND RECOMMENDATIONS

BACKGROUND

- ➔ Recent industry need to provide aircraft operators with holdover times for ice pellet conditions
- ➔ During the winter of 2006, FAA provided a 25-minute allowance as a preliminary guideline
- ➔ Allowance based on the previous research conducted during the winter of 2005-06, primarily as a result of Falcon 20 aerodynamic research (SAE Lisbon 2006)
- ➔ Allowance was followed by a list of conditions restricting operations
 - ➔ i.e. Ice pellets alone, no mixed conditions

BACKGROUND

- ➔ Due to the high occurrence of ice pellets combined with rain, freezing rain, or snow, industry requested additional guidance material for operations in mixed ice pellet conditions
- ➔ Additional endurance time testing and aerodynamic research was conducted in simulated ice pellet conditions during the Winter of 2006-07
- ➔ Testing was directed by TC and FAA

PRESENTATION OUTLINE

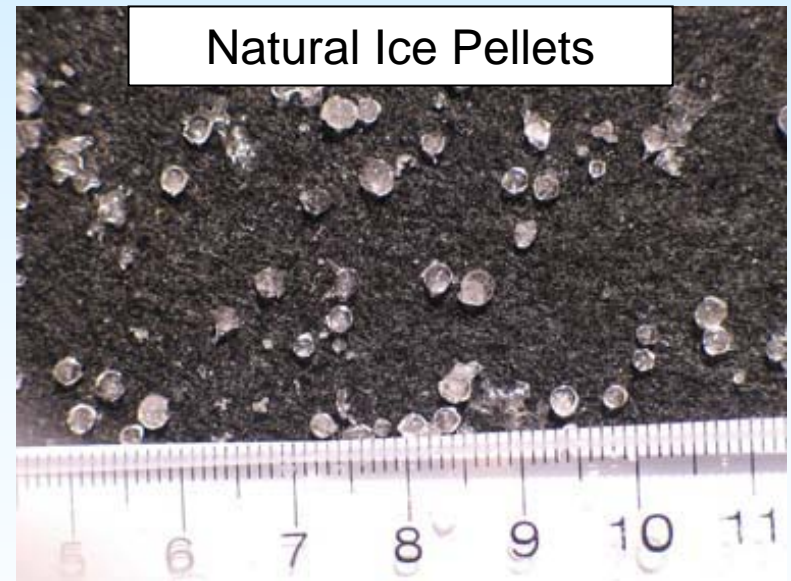
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APS SIMULATED ICE PELLETS

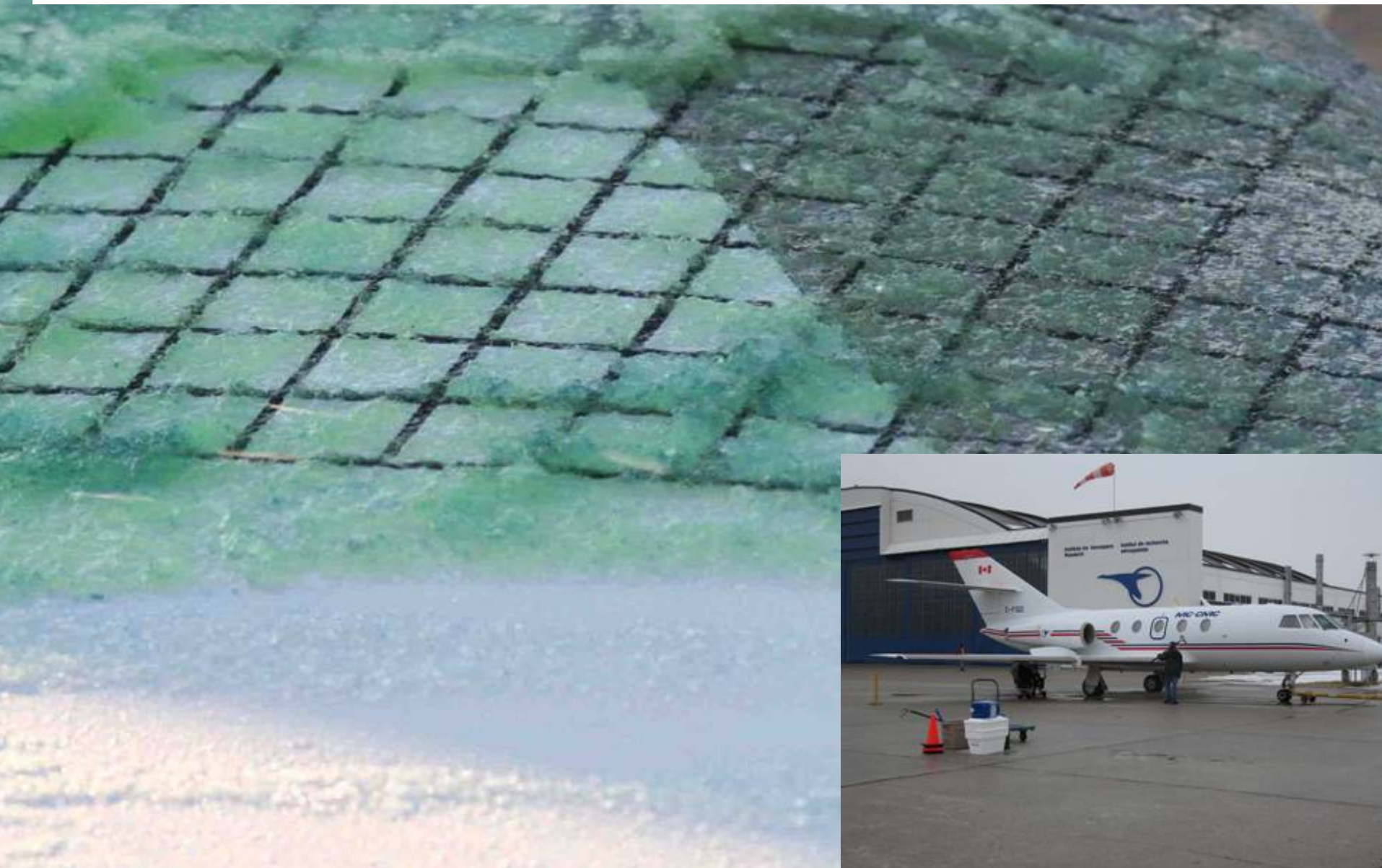
APS Manufactured Ice Pellets



Natural Ice Pellets



2005-06 FALCON 20 FULL-SCALE RESEARCH



2005-06 NATURAL ICE PELLET ENDURANCE TIME RESEARCH



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OVERVIEW OF WINTER 2006-07 GENERAL OBJECTIVES

- Conduct research to substantiate and possibly expand current 25-minute ice pellet only allowance time
- Flat plate testing was conducted to investigate fluid adherence in mixed ice pellet conditions
- Aerodynamic research was conducted to investigate fluid flow-off of contaminated fluid following simulated ice pellet and mixed conditions
 - NRC open circuit wind tunnel
 - NRC Falcon 20 aircraft

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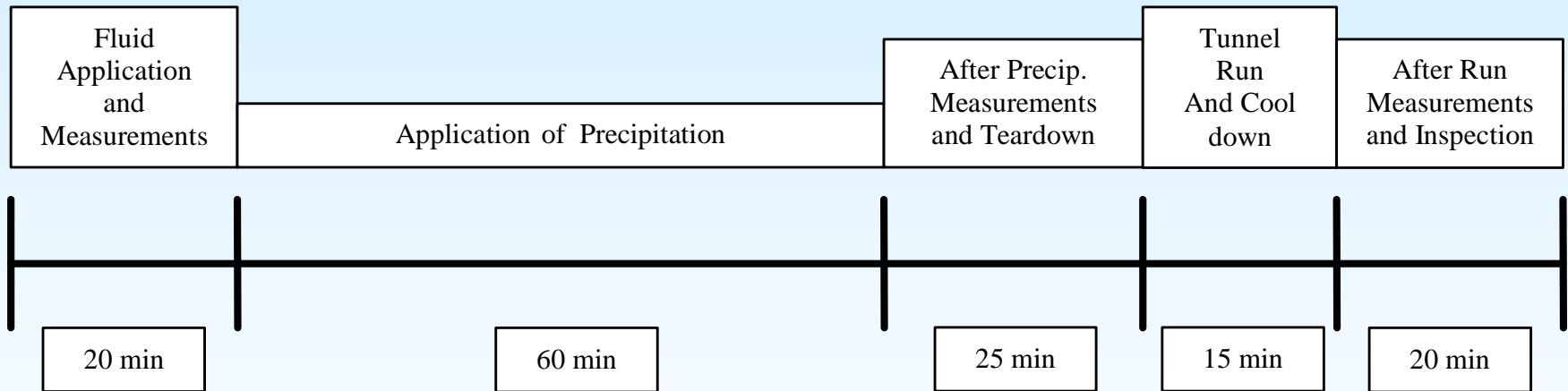
Wind Tunnel Testing

- Objective: To determine the level of contamination of anti-icing fluid at which the aerodynamic shear forces during take-off ground roll, rotation and lift off fails to remove the resultant slush.
- 22 tests conducted over a period of 2 weeks
- A NACA 23012 wing section was used for testing
- OAT varied during testing – open circuit tunnel

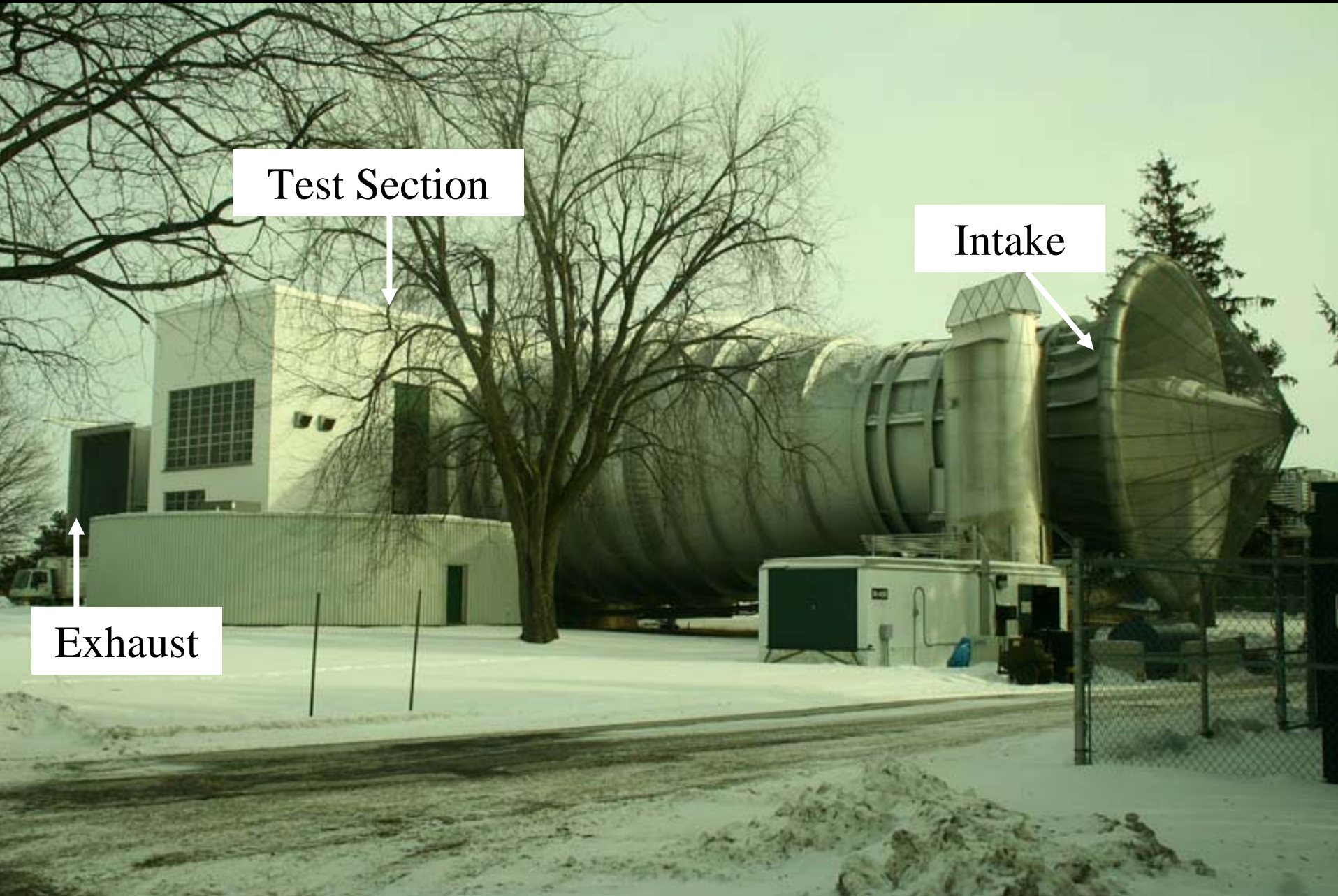
Wind Tunnel Testing

- Fluid was applied to wing section approximately 20 minutes prior to the start of precipitation
- The wind tunnel was started approximately 20-25 minutes following the end of precipitation
- Wind tunnel test profile:
 - Initial angle of attack 0°
 - 0-100 Knots in 30-35 seconds
 - At 100 Knots, Pitch wing to 8° in 3 sec
 - Pitch wing back to 4° in 16 sec
 - Hold wing at 4° for 1 minute and stop test

Sample Run Timeline



Wind Tunnel Testing

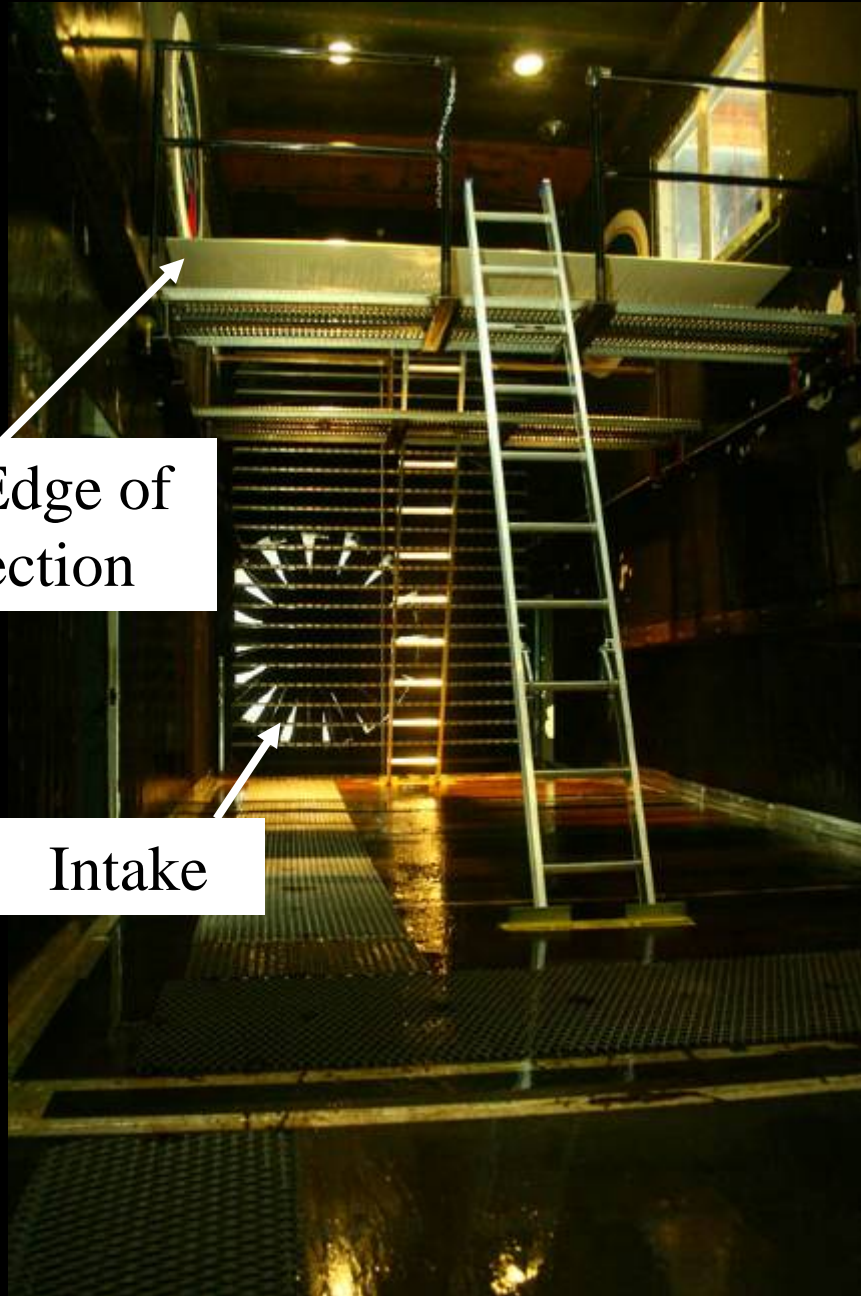


Test Section

Intake

Exhaust

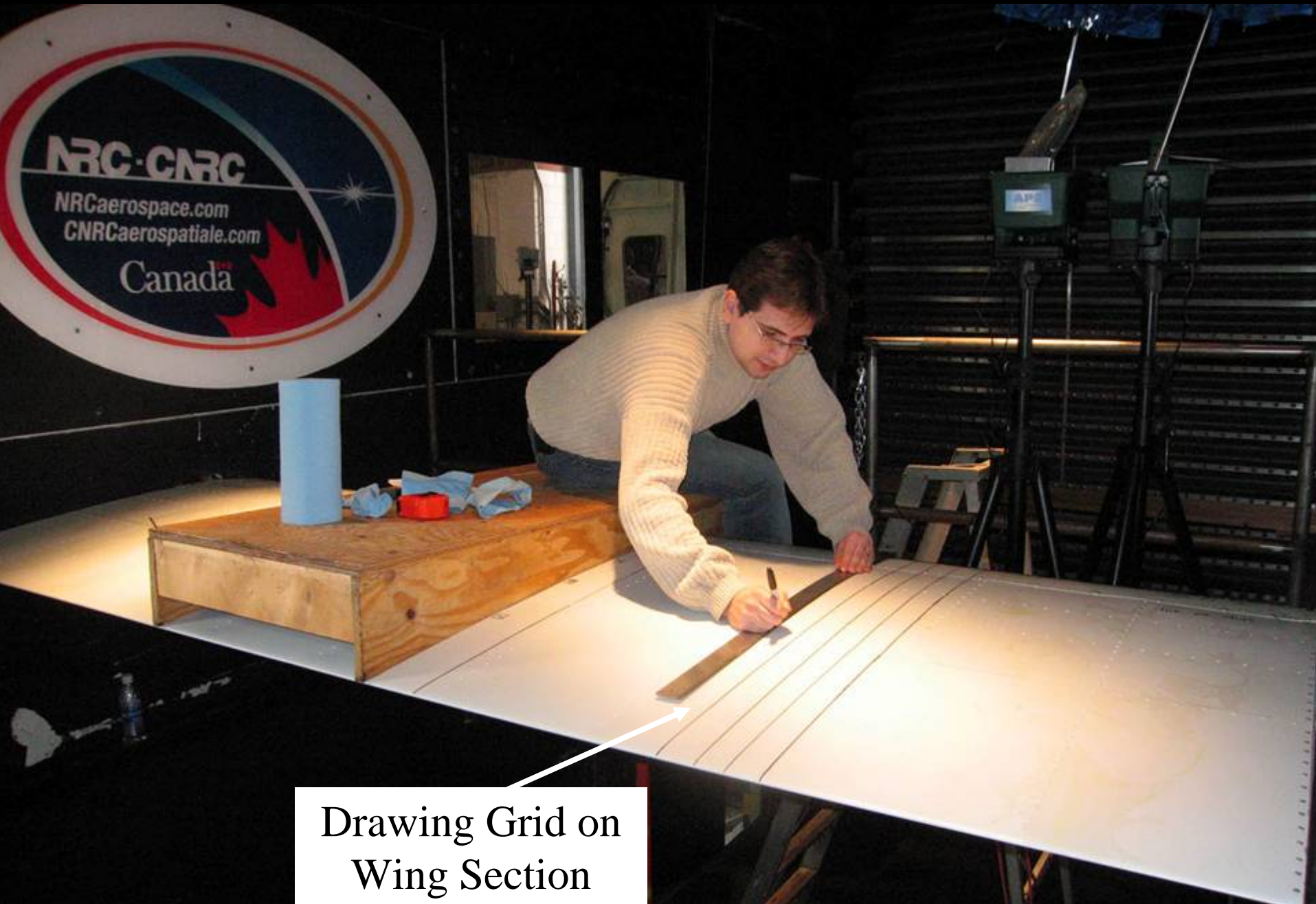
Wind Tunnel Testing



Trailing Edge of
Wing Section

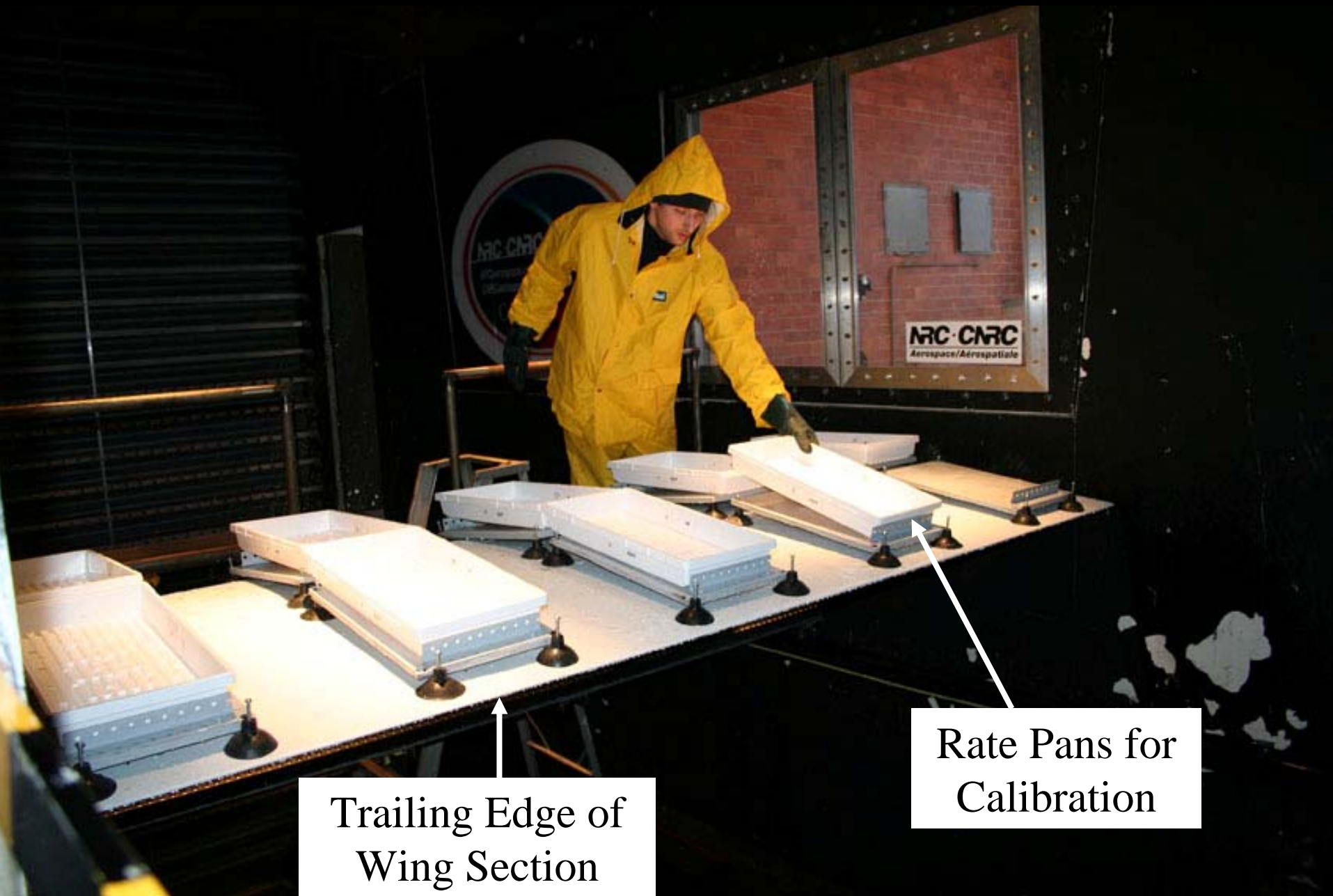
Intake

Wind Tunnel Testing



Drawing Grid on
Wing Section

Wind Tunnel Testing



Trailing Edge of
Wing Section

Rate Pans for
Calibration

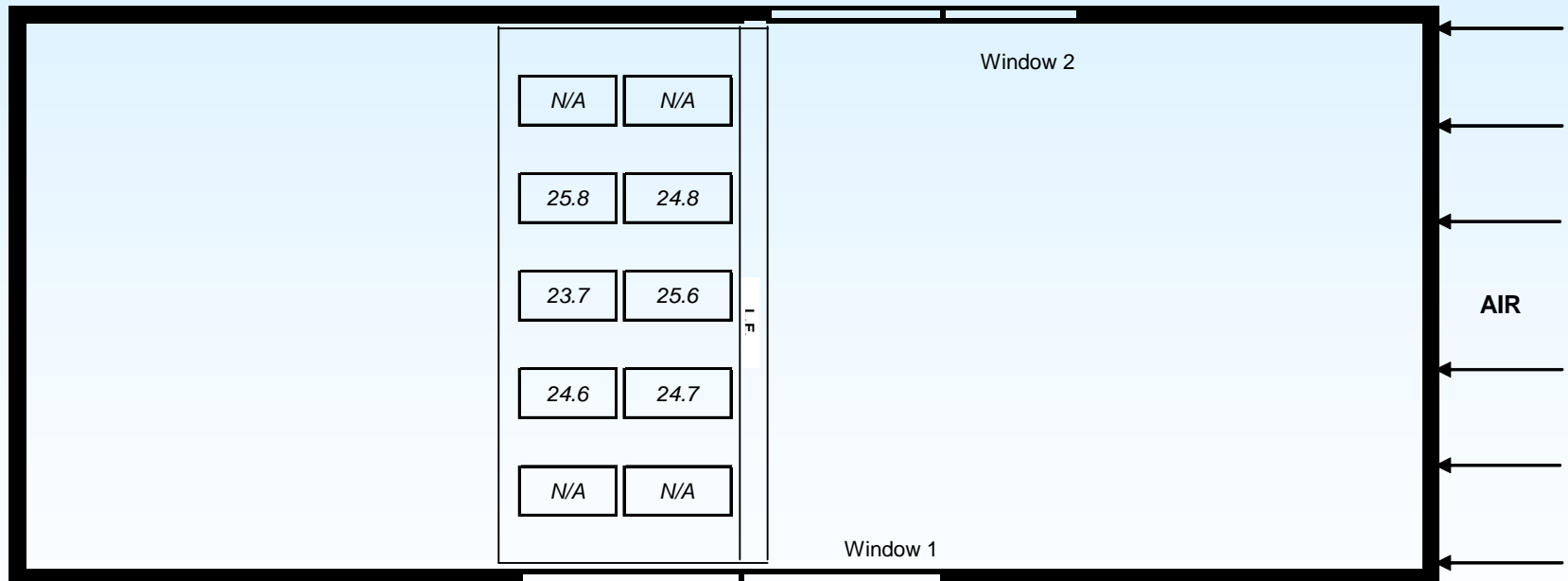
Example of Rate Distribution

Precipitation Rate Summary for Test No. 6

Date: 15-Feb-07

Precipitation Type ZR&IP

Average Combined Precipitation Rate: 25

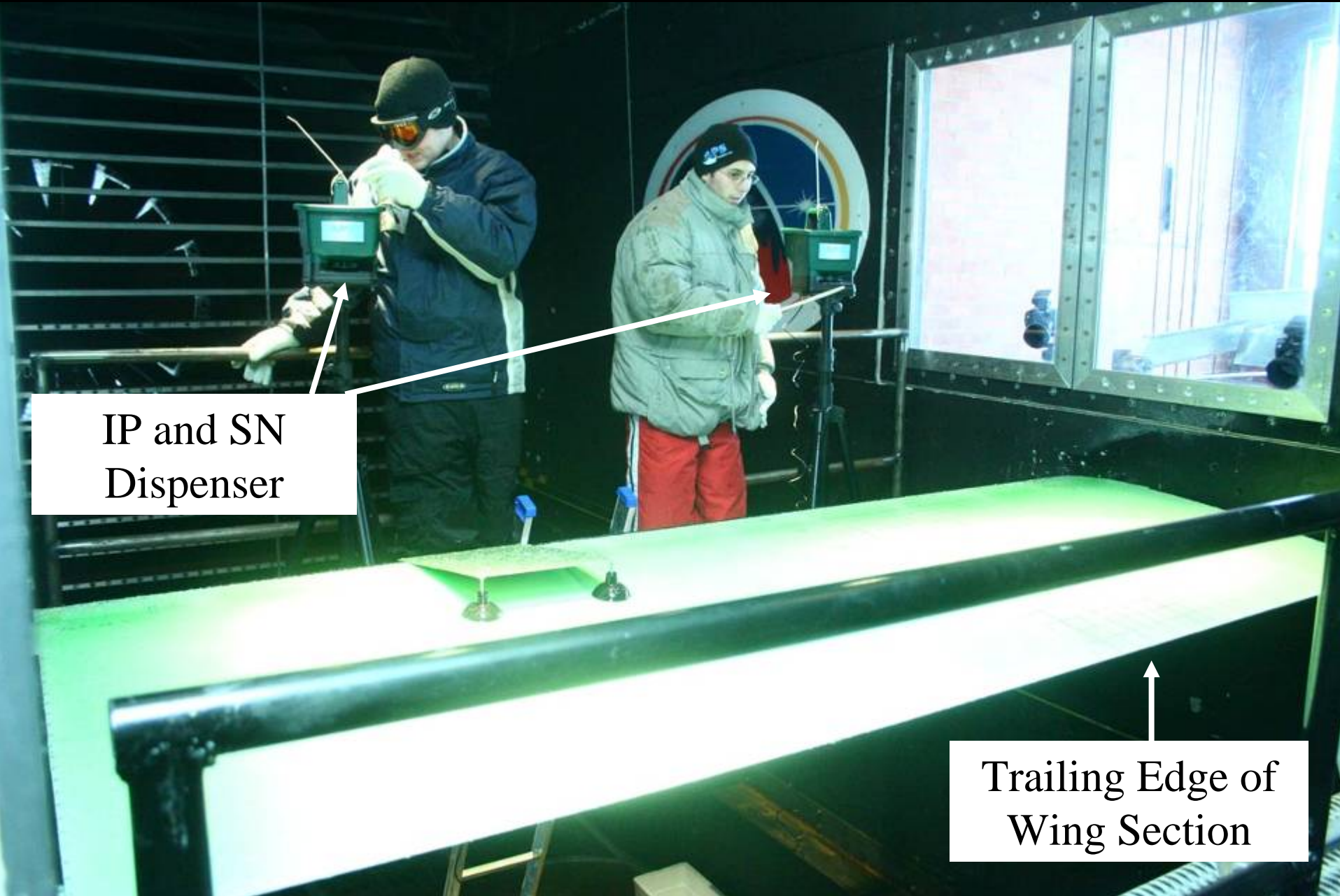


Wind Tunnel Testing

Fluid Application



Wind Tunnel Testing



IP and SN
Dispenser

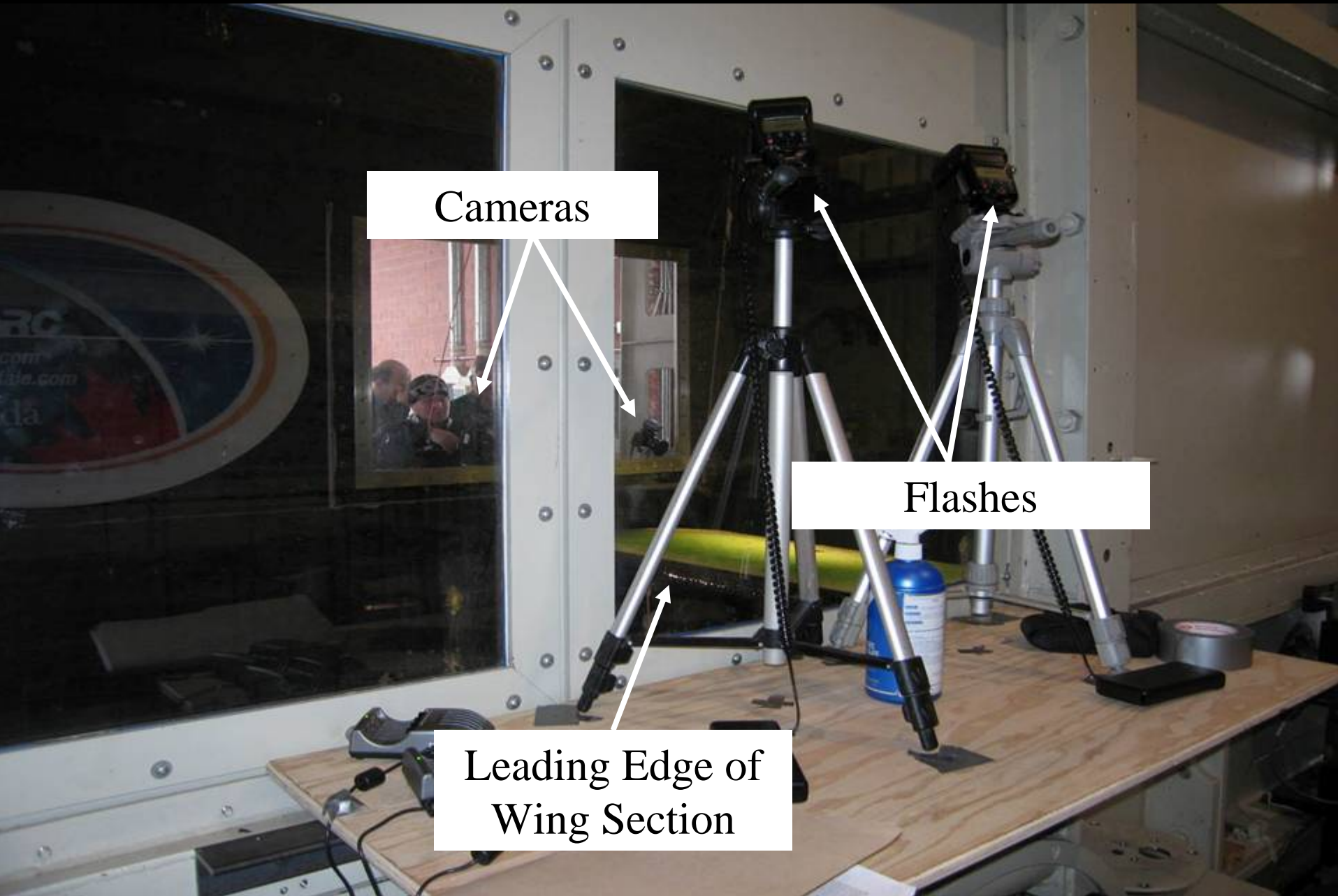
Trailing Edge of
Wing Section

Wind Tunnel Testing



ZR sprayer

Wind Tunnel Testing



Cameras

Flashes

Leading Edge of
Wing Section

Wind Tunnel Testing



Wind Tunnel Testing

- Conditions Tested:
 - Mixed ZR and IP (5 tests)
 - Mixed SN and IP (4 tests)
 - IP only (4 tests)
 - Fluid only and dry tests (5 tests)
- Also investigated:
 - ZR only (1 test)
 - Simulated stall runs (3 tests)

Wind Tunnel Summary Test Log

Wind Tunnel Tests										
Test #	Feb day	Type IV Fluid	Condition	ZR Rate g/dm ² /h	IP Rate g/dm ² /h	SN Rate g/dm ² /h	Precp. Time (min)	Tunnel OAT (°C)	Wing Avg Temp (°C)	Visual Severity Rating (1-5)
1	14	Dry	Dry	0	0	0	-	-1.7	-2	-
1A	16	Dry	Dry	0	0	0	-	-7	N/A	-
2	14	PG	Baseline	0	0	0	-	-10	-9	-
3	14	EG	Baseline	0	0	0	-	-11	-8	-
4	14	PG	ZR	28	0	0	60	-2	-1	1
5	15	PG	IP	0	25	0	60	-16.8	-13	4.5
6	15	PG	ZR/IP	20	5	0	40	-8	-7	5
6A	15	PG	ZR/IP	20	5	0	20	-8	-7	1
7	22	PG	IP	0	25	0	60	1	-5.5	1
8	22	EG	IP	0	25	0	60	1	-9	1
9	22	PG	IP (mod)	0	75	0	30	3.2	-7	2.5
10	23	PG	IP/ZR	7	20	0	40	-7.2	-7	3
11	23	PG	ZR/IP	20	5	0	40	-1.9	-4	2
12	23	EG	ZR/IP	20	5	0	40	-5.9	-4	1
13	23	PG	Baseline	0	0	0	-	-5.7	-5	-
SP1	20	PG	IP/SN	0	20	5	40	-2	-7	2
SP2	20	PG	SN/IP	0	5	20	40	-3	-6	1
SP3	20	EG	IP/SN	0	20	5	40	1.2	-8	1
SP4	23	PG	IP/SN	0	25	25	30	3.2	-7	2
A1	21	PG	Stall Run	0	0	0	-	3.7	1	-
A2	21	EG	Stall Run	0	0	0	-	4.6	0.5	-
A3	21	Dry	Stall Run	0	0	0	-	2.3	N/A	-

Visual Severity Rating (1-5)

1 = best

5 = worst

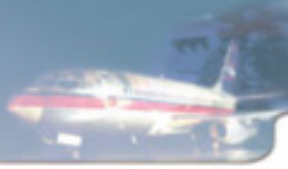
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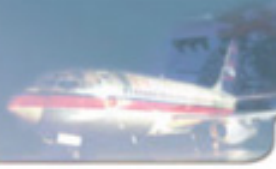
Falcon 20 Testing

- ➔ Objective: To determine the level of contamination of anti-icing fluid at which the aerodynamic shear forces during take-off ground roll and rotation fails to remove the resultant slush.
- ➔ 6 tests conducted over a period of 4 days
- ➔ Tests conducted at YOW



Falcon 20 Testing

- Wing test surface area was approximately 3m²
3m²
- Two wings were tested per run
 - Baseline wing (fluid only)
 - Test wing (contamination)



Falcon 20 Testing

- Fluid was applied approximately 20 minutes prior to the start of precipitation
- Break release approximately 20-25 minutes following the end of precipitation
- Aircraft take-off run profile:
 - 0-120 knots in approx. 20-25 sec
 - Engines Cut-off at 120 knots
 - Rotate to approx. 8°
 - Keep nose up until 3000ft of runway left
 - Rotate down to 0°
 - Apply brakes (no spoilers®)

Falcon 20 Testing

NRC Hangar

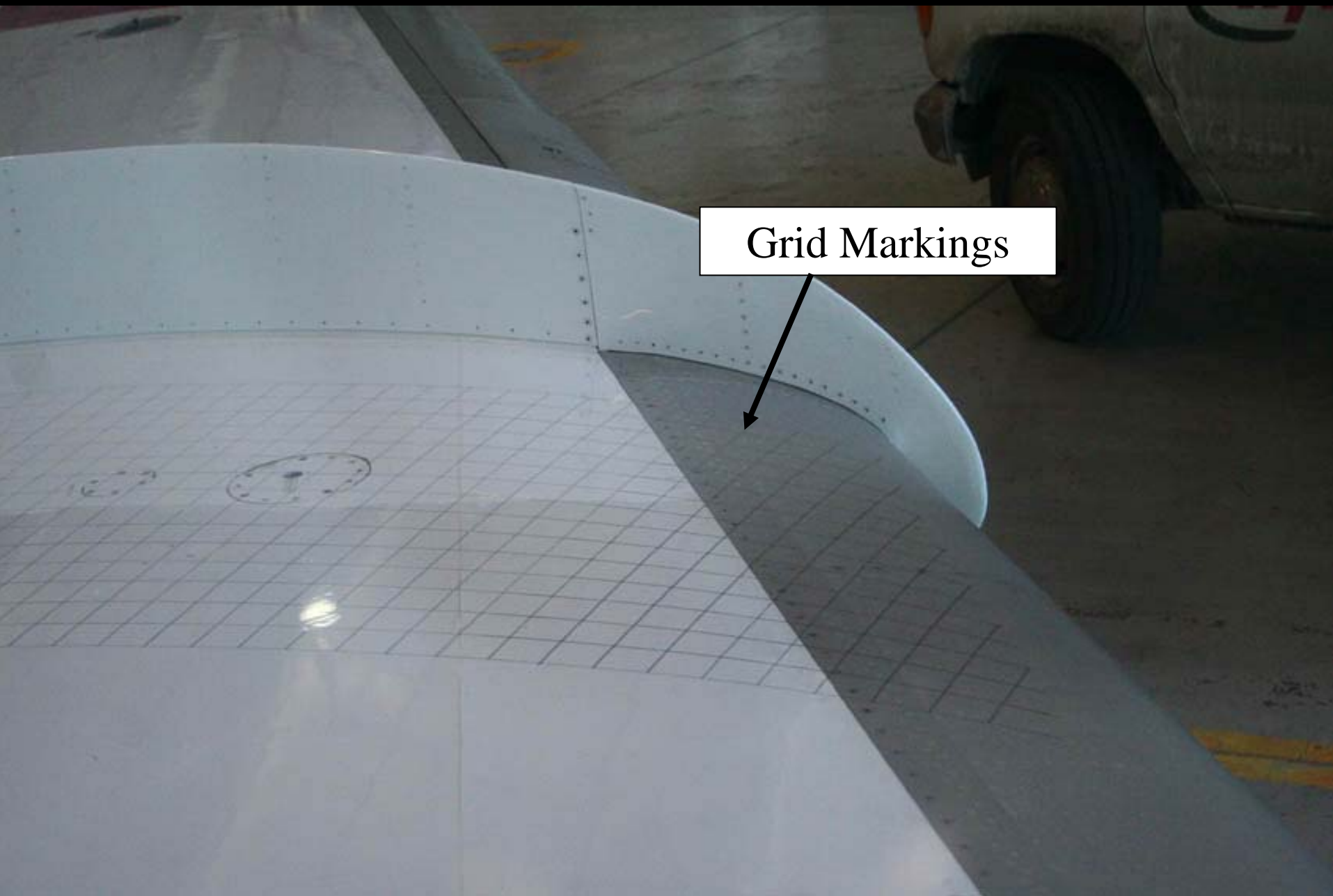


Falcon 20 Testing

Falcon 20 Aircraft

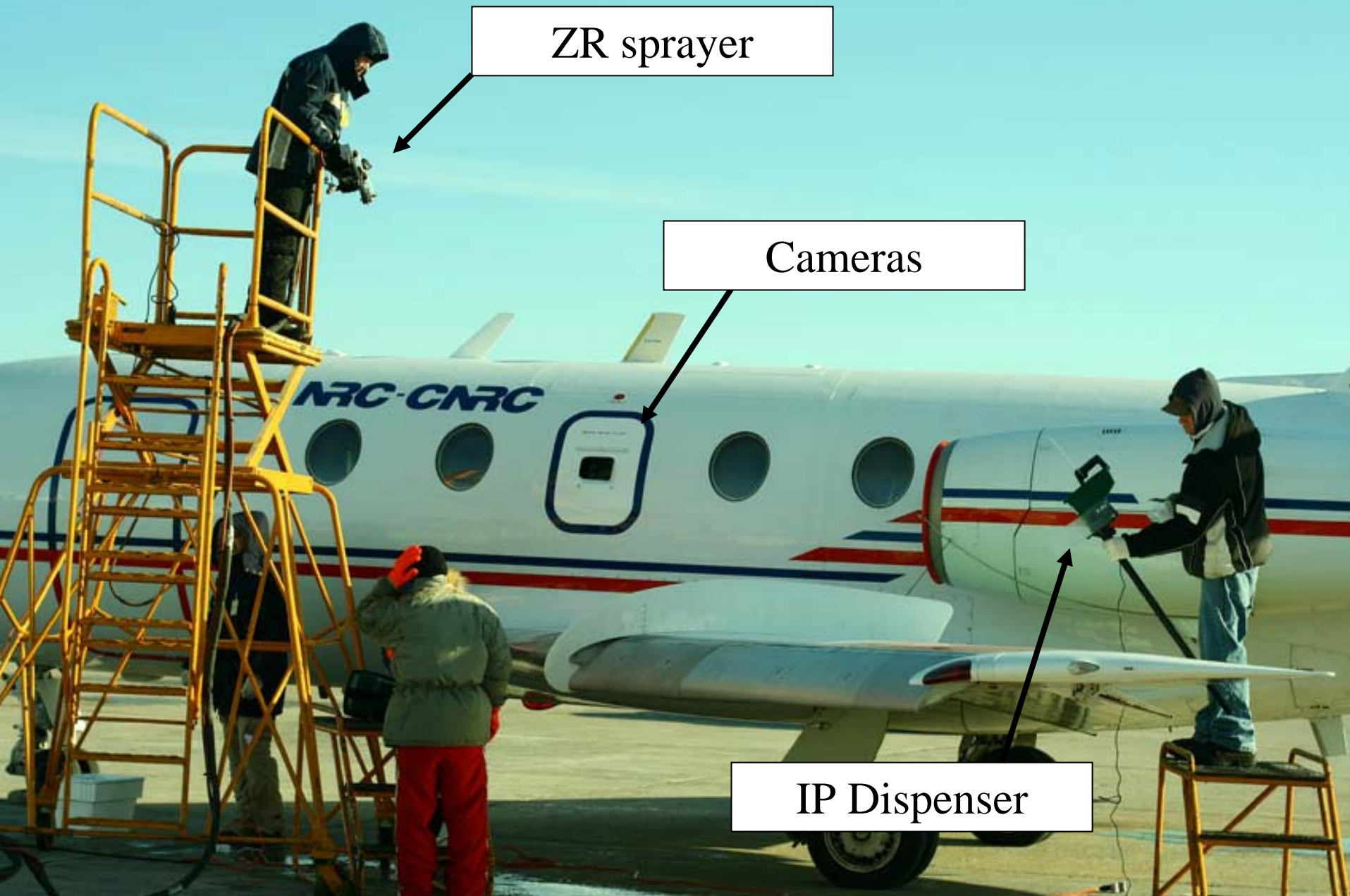


Falcon 20 Testing



Grid Markings

Falcon 20 Testing



ZR sprayer

Cameras

IP Dispenser

Falcon 20 Testing

Freezing Rain
Sprayer Equipment



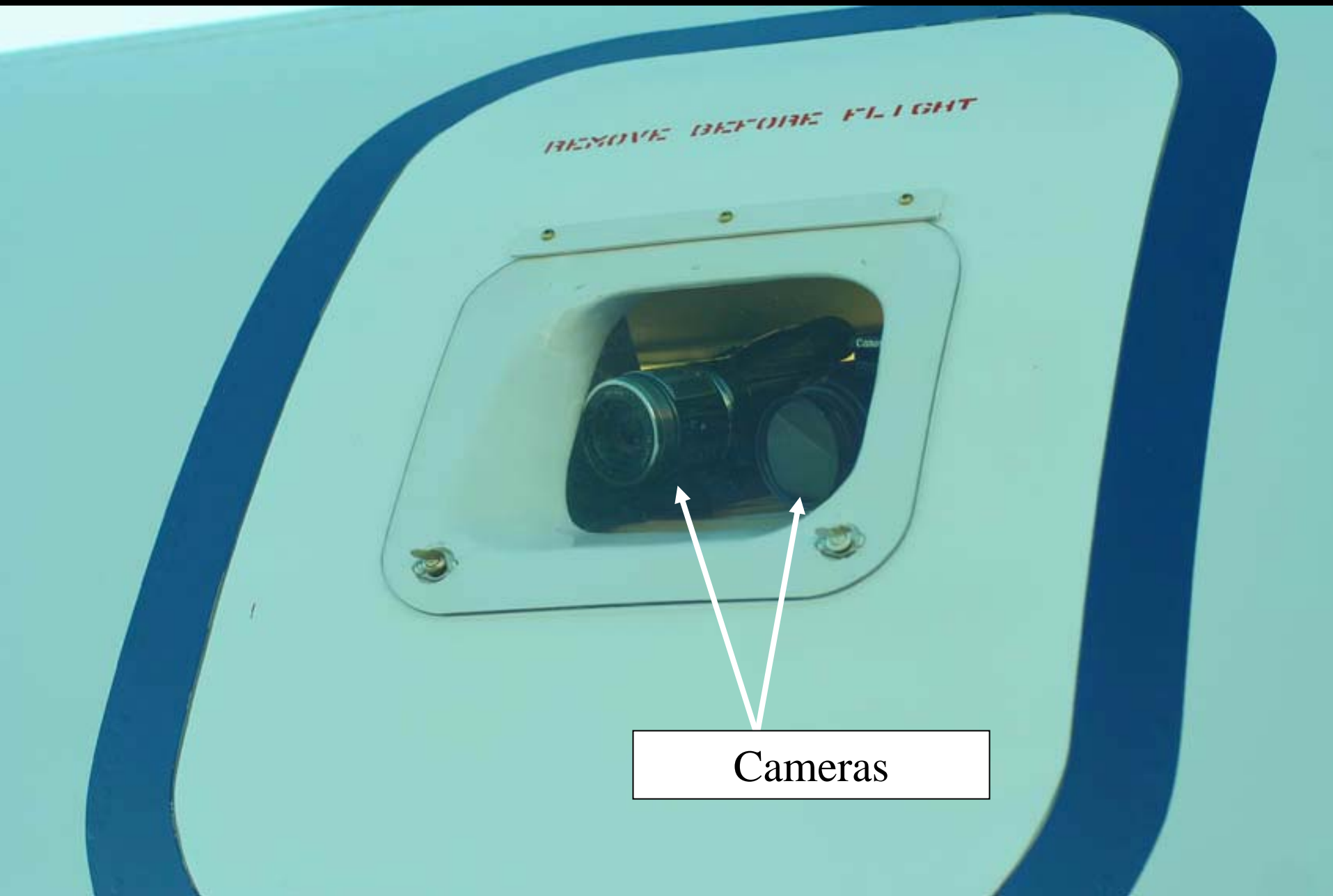
Falcon 20 Testing



Freezing Rain
Sprayer

Nozzles

Falcon 20 Testing



REMOVE BEFORE FLIGHT



Cameras

Falcon 20 Testing

- Conditions Tested:
 - Mixed ZR and IP
 - Mixed SN and IP

Falcon 20 Summary Test Log

Falcon 20 Tests									
Test #	Date	Type IV Fluid	Condition	ZR Rate g/dm ² /h	IP Rate g/dm ² /h	SN Rate g/dm ² /h	Precp. Time (min)	OAT (°C)	Wing Avg Temp (°C)
3S	Feb-28	PG	IP/SN	-	25	25	30	-8	-11
3P	Feb-28	PG	Baseline	-	-	-	-	-8	-10.5
4S	Feb-28	PG	Baseline	-	-	-	-	-10	-6
4P	Feb-28	PG	ZR/IP	20	5	-	40	-10	-6
5S	Mar-01	EG	Baseline	-	-	-	-	-11	-14
5P	Mar-01	PG	IP/SN	-	20	20	30	-11	-13

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Allowance Times for Ice Pellet and Mixed Conditions

- A working group meeting was held April 11-13th, 2007
- Attendees
 - Federal Aviation Administration
 - Transport Canada
 - APS
- Objective: Review current data and recommend allowance times for ice pellet and mixed ice pellet precipitation conditions

Allowance Times for Ice Pellet and Mixed Conditions

→ ANALYSIS METHODOLOGY

- Contaminated fluid tests were compared to baseline fluid baseline fluid only tests and dry wing tests
- Visual severity was determined based on observations observations during the test and review of photography photography
- Lift coefficient data was acquired at the end of the testing the testing and used to investigate the effects of contamination

Mixed ZR- and IP- Conditions

- 5 Wind Tunnel Tests Conducted
- 2 Falcon 20 tests Conducted

Wind Tunnel Tests										
Test #	Feb day	Type IV Fluid	Condition	ZR Rate g/dm ² /h	IP Rate g/dm ² /h	SN Rate g/dm ² /h	Precp. Time (min)	Tunnel OAT (°C)	Wing Avg Temp (°C)	Visual Severity Rating (1-5)
6	15	PG	ZR/IP	20	5	0	40	-8	-7	5
6A	15	PG	ZR/IP	20	5	0	20	-8	-7	1
10	23	PG	IP/ZR	7	20	0	40	-7.2	-7	3
11	23	PG	ZR/IP	20	5	0	40	-1.9	-4	2
12	23	EG	ZR/IP	20	5	0	40	-5.9	-4	1

Falcon 20 Tests									
Test #	Date	Type IV Fluid	Condition	ZR Rate g/dm ² /h	IP Rate g/dm ² /h	SN Rate g/dm ² /h	Precp. Time (min)	OAT (°C)	Wing Avg Temp (°C)
4P	Feb-28	PG	ZR/IP	20	5	-	40	-10	-6
6P	Mar-01	EG	ZR/IP	20	5	-	30	-11	-4

Test #11

Type IV PG, ZR-&IP- 20+5 g/dm²/h, 40 min,
OAT-2°C, Wing -4°C

Photos

Test #2

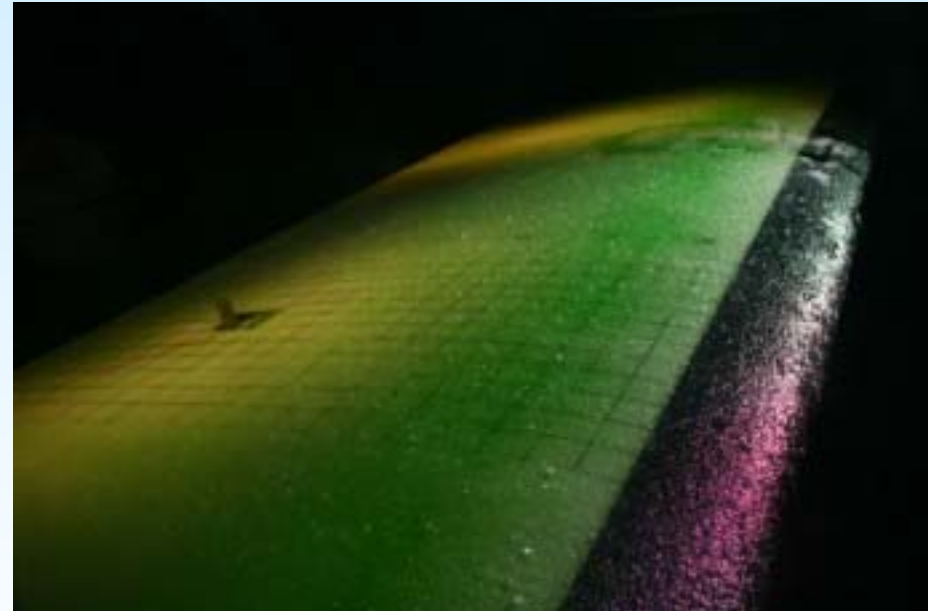
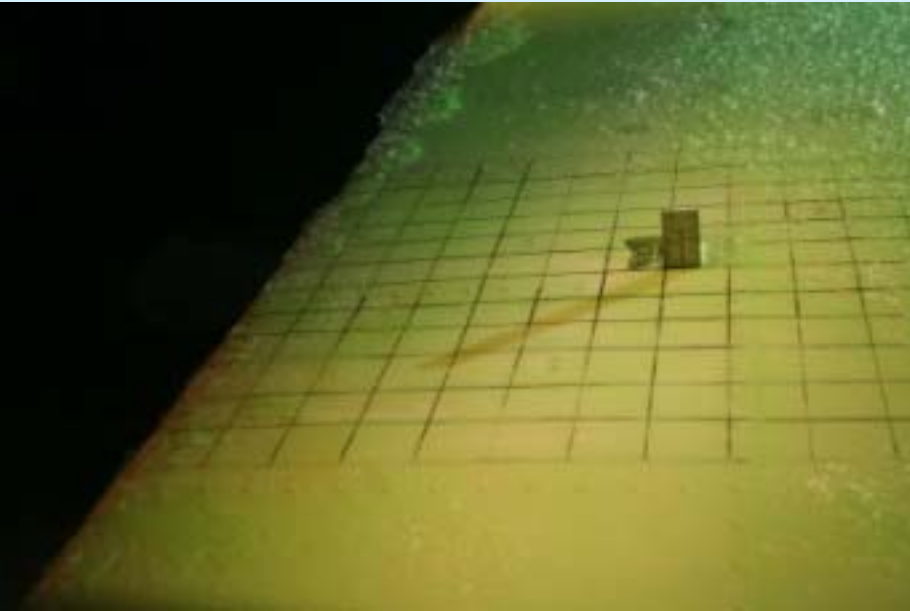
Type IV PG, No Contamination
OAT-10°C, Wing -9°C

Photos

Test #6

Type IV PG, ZR-&IP- 20+5 g/dm²/h, 40 min,
OAT-8°C, Wing -7°C

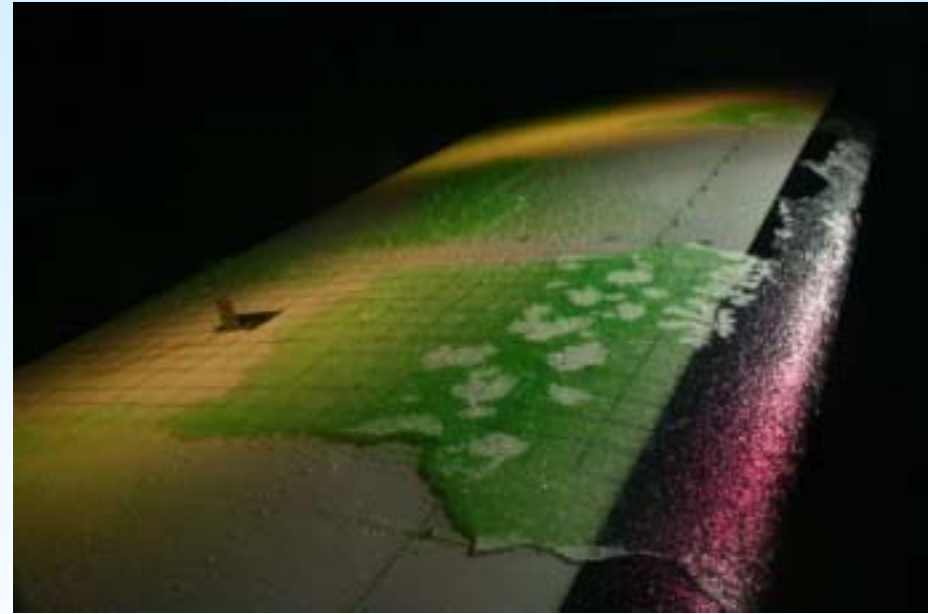
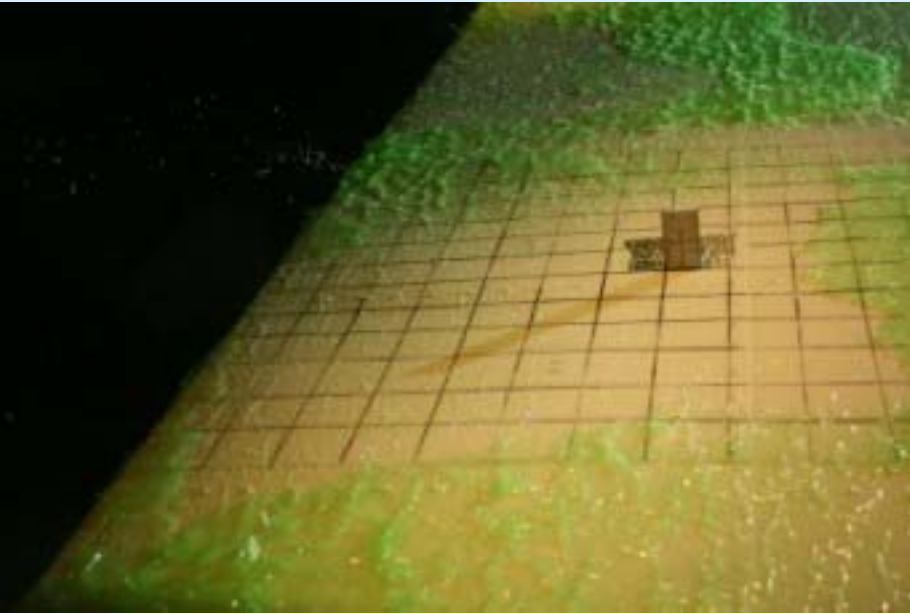
Start of Test



Test #6

Type IV PG, ZR-&IP- 20+5 g/dm²/h, 40 min,
OAT-8°C, Wing -7°C

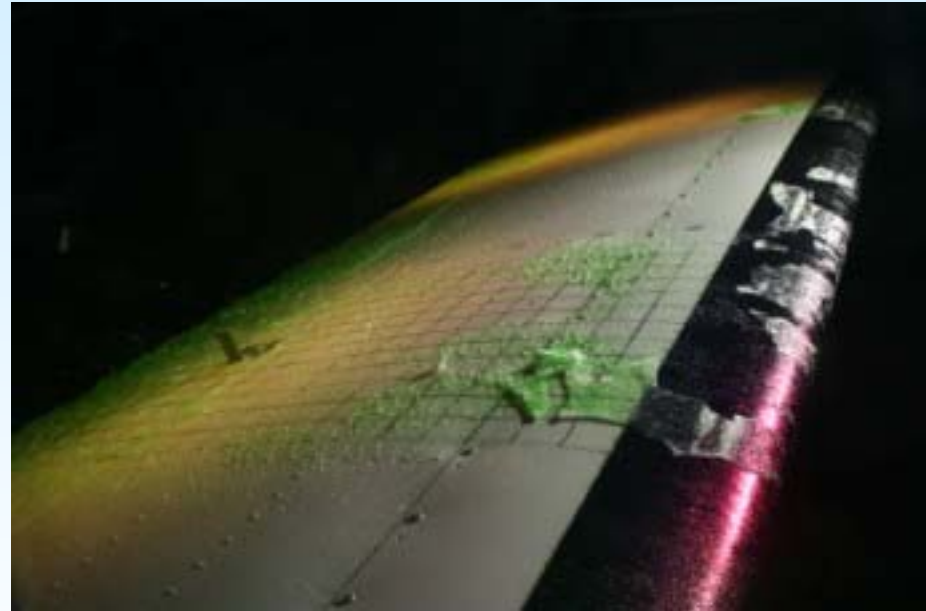
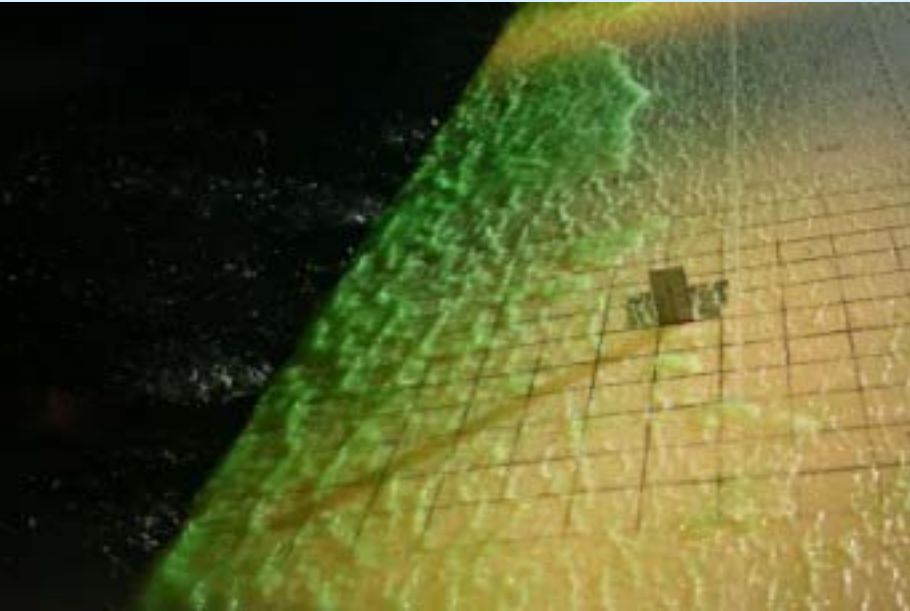
Before Rotation



Test #6

Type IV PG, ZR-&IP- 20+5 g/dm²/h, 40 min,
OAT-8°C, Wing -7°C

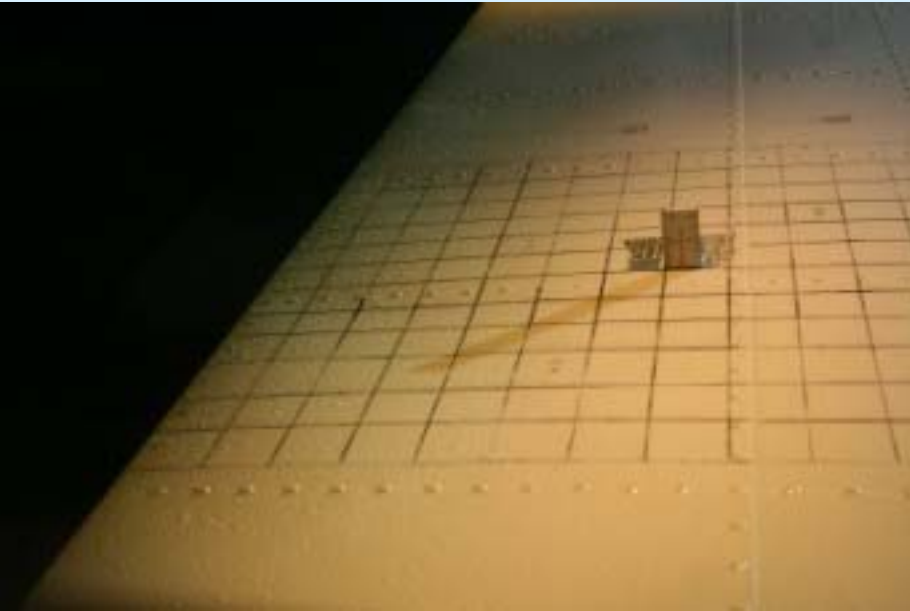
10 sec After Rotation



Test #6

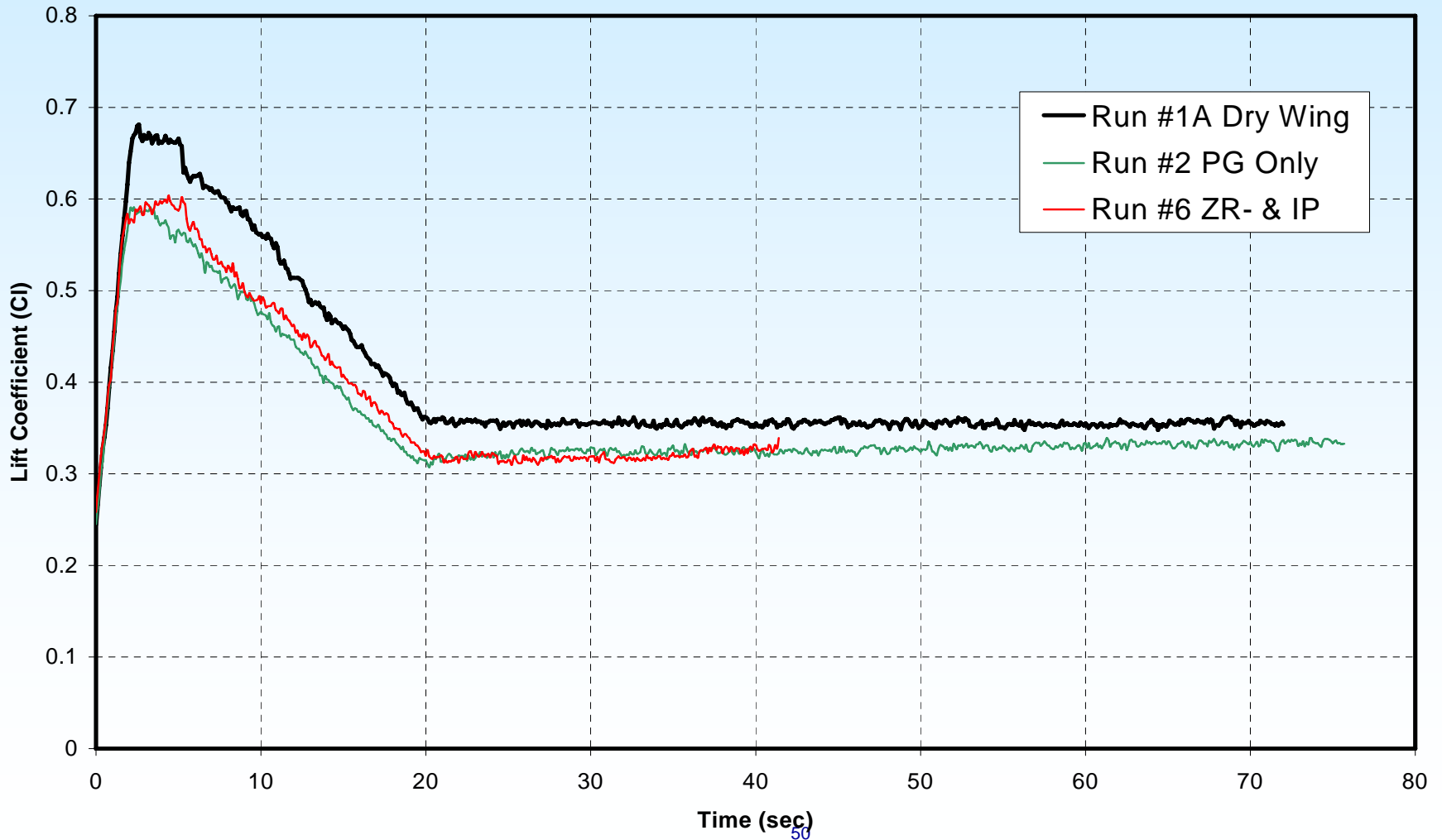
Type IV PG, ZR-&IP- 20+5 g/dm²/h, 40 min,
OAT-8°C, Wing -7°C

End of Test



Lift Coefficient Comparison

**Lift Coefficient Comparison
Dry vs. Fluid Only vs. Contaminated Fluid**



Mixed ZR- and IP- Conditions

→ Observations and Recommendations

- ZR is the primary concern due to adherence and increased increased roughness with presence of IP
- Generic lower ZR HOT referenced and modified
- Use temperature -5°C (instead of -3°C) to allow for increased increased latitude to operators
- Allow operations down to -10°C

Mixed ZR- and IP- Conditions

→ Recommended Allowance Times

	OAT -5°C and above	OAT Less than -5°C to -10°C	OAT Less than -10°C
Light Ice Pellets Mixed with Light Freezing Rain	25 Minutes	10 Minutes	Caution: No Allowance times currently exist

Mixed ZR- and IP- Conditions

- Allowance times were presented in May 2007 at the SAE SAE meeting in San Diego
- Industry requested additional guidance material
 - Mixed Freezing Drizzle and Ice pellets
 - Mixed Rain and Ice Pellets
- Additional flat plate testing and analysis was conducted conducted
- ZR/IP Allowance times were referenced and modified modified

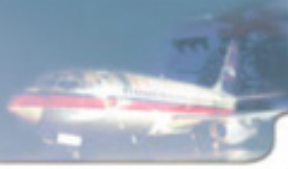
Mixed ZR- and IP- Conditions

→ Recommended Allowance Times

	OAT -5°C and above	OAT Less than -5°C to -10°C	OAT Less than -10°C
Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle	25 Minutes	10 Minutes	Caution: No Allowance times currently exist
Light Ice Pellets Mixed with Light Rain	25 Minutes		

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IP- Only Conditions

- ➔ 3 Wind Tunnel Tests Conducted
- ➔ IP only tests were NOT conducted with the Falcon Falcon 20 this year
- ➔ 2005-06 Falcon 20 tests were referenced

Wind Tunnel Tests										
Test #	Feb day	Type IV Fluid	Condition	ZR Rate g/dm ² /h	IP Rate g/dm ² /h	SN Rate g/dm ² /h	Precp. Time (min)	Tunnel OAT (°C)	Wing Avg Temp (°C)	Visual Severity Rating (1-5)
5	15	PG	IP	0	25	0	60	-16.8	-13	4.5
7	22	PG	IP	0	25	0	60	1	-5.5	1
8	22	EG	IP	0	25	0	60	1	-9	1

IP- Only Conditions

- Observations and Recommendations
 - Wind Tunnel 60min exposure tests at warmer temperatures demonstrated positive results
 - Test #5 for 60 min at colder temperature showed residual contamination
 - -5°C temperature cut-off suggested to be consistent with consistent with ZR/IP Allowance Times

IP- Only Conditions

→ Recommended Allowance Times

	OAT -5°C and above	OAT Less than -5°C to -10°C	OAT Less than -10°C
Light Ice Pellets	50 Minutes	30 Minutes	30 Minutes

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Moderate IP Only Conditions

- 1 Wind Tunnel Test Conducted
- Moderate IP tests were NOT conducted with Falcon 20 this year
- 2005-06 Falcon 20 tests were referenced

Wind Tunnel Tests										
Test #	Feb day	Type IV Fluid	Condition	ZR Rate g/dm ² /h	IP Rate g/dm ² /h	SN Rate g/dm ² /h	Precp. Time (min)	Tunnel OAT (°C)	Wing Avg Temp (°C)	Visual Severity Rating (1-5)
9	22	PG	IP (mod)	0	75	0	30	3.2	-7	2.5

Moderate IP Only Conditions

- Observations and Recommendations
 - Wind Tunnel test demonstrated positive results (I.e. lift (I.e. lift loss and minimal visual contamination following following run)
 - IP- Allowance times were referenced and modified modified

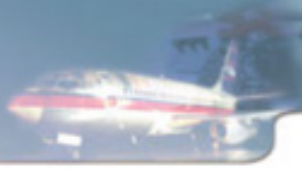
Moderate IP Only Conditions

→ Recommended Allowance Times

	OAT -5°C and above	OAT Less than -5°C to -10°C	OAT Less than -10°C
Moderate Ice Pellets	25 Minutes	10 Minutes	10 Minutes

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IP-/SN Conditions

- 4 Wind Tunnel Tests Conducted
- 2 Falcon 20 tests Conducted

Wind Tunnel Tests										
Test #	Feb day	Type IV Fluid	Condition	ZR Rate g/dm ² /h	IP Rate g/dm ² /h	SN Rate g/dm ² /h	Precp. Time (min)	Tunnel OAT (°C)	Wing Avg Temp (°C)	Visual Severity Rating (1-5)
SP1	20	PG	IP/SN	0	20	5	40	-2	-7	2
SP2	20	PG	SN/IP	0	5	20	40	-3	-6	1
SP3	20	EG	IP/SN	0	20	5	40	1.2	-8	1
SP4	23	PG	IP/SN	0	25	25	30	3.2	-7	2

Falcon 20 Tests									
Test #	Date	Type IV Fluid	Condition	ZR Rate g/dm ² /h	IP Rate g/dm ² /h	SN Rate g/dm ² /h	Precp. Time (min)	OAT (°C)	Wing Avg Temp (°C)
3S	Feb-28	PG	IP/SN	-	25	25	30	-8	-11
5P	Mar-01	PG	IP/SN	-	20	20	30	-11	-13

IP-/SN Conditions

- Observations and Recommendations
 - Wind tunnel tests demonstrated minimal lift loss and minimal visual contamination following run at warmer temperatures
 - Testing at colder temperatures showed contamination at end of run
 - No allowance for temperatures below -5°C due to lack of data collected

IP-/SN Conditions

→ Recommended Allowance Times

	OAT -5°C and above	OAT Less than -5°C to -10°C	OAT Less than -10°C
Light Ice Pellets Mixed with Light or Moderate Snow	25 Minutes	Caution: No Allowance times currently exist	

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Summary of Ice Pellet Allowance Times

	OAT -5° C and above	OAT Less than -5°C to -10°C	OAT Less than -10° C	
Light Ice Pellets	50 Minutes	30 Minutes	30 Minutes	
Moderate Ice Pellets	25 Minutes	10 Minutes	10 Minutes	
Light Ice Pellets Mixed with Light or Moderate Snow	25 Minutes	Caution: No Allowance times currently exist		
Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle	25 Minutes			10 Minutes
Light Ice Pellets Mixed with Light Freezing Rain	25 Minutes			10 Minutes
Light Ice Pellets Mixed with Light Rain	25 Minutes			

Recommendations

- Future Wind Tunnel Work
 - Additional testing to refine allowance times
 - Conduct testing with different wings (maybe super critical.) critical.)
 - Verify results at lower speeds
 - Conduct testing at lower temperatures
 - Conduct testing with bare wing contamination (no fluid) fluid)
 - Conduct aerodynamic tests in mixed Rain and Ice pellet pellet conditions
 - Conduct aerodynamic tests in mixed Freezing Drizzle and Drizzle and Ice pellet conditions



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