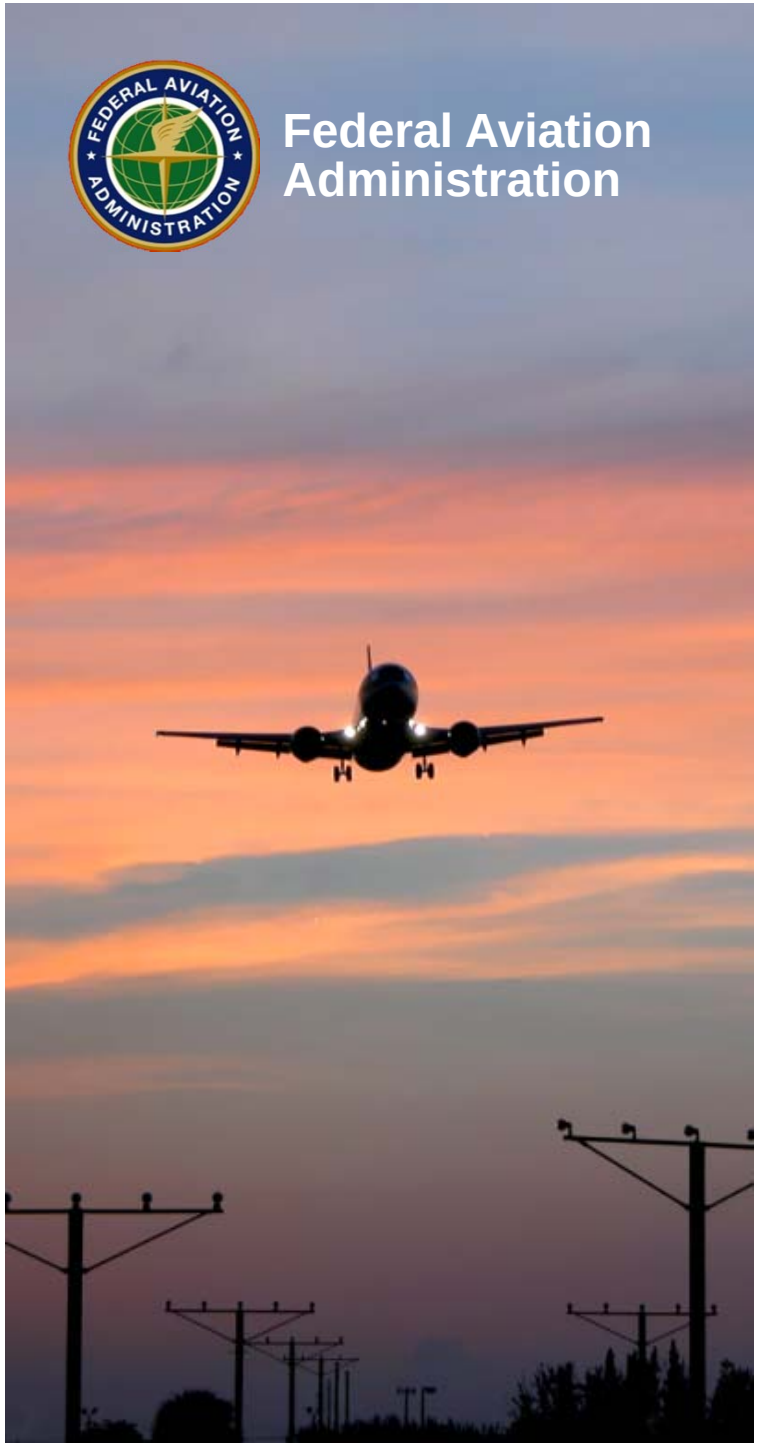
FAA's Aircraft Icing R&D Activities

Aircraft Icing and Weather TCRG R&D

Presented To: REDAC Subcommittee on Aviation Safety

Prepared By: Tom Bond – Icing CSTA
Jim Riley – Manager, Aircraft Icing Research Program

Date: March 24, 2016



Presentation Outline

- FAA Icing Program Overview
- FAA R&D Icing Themes
- Icing TCRG R&D Budget Line Items
- Icing TCRG Requirements
  - Support Certifications and Operational Threats
- Rqmts – Objectives and Outcomes
- Rqmts – Current Status

Aircraft Icing Program Overview

What is this program?

Purpose

- Improve aviation safety related to aircraft icing by developing a better understanding of the effects of environmental icing, the development of data in support of new regulations and guidance materials, the support for improvements to engineering tools for certification and operations, and (in collaboration with FAA Aviation Weather Research Program) improved icing weather information for decision-making in terminal areas and for in-flight avoidance of high ice water content ice crystal conditions
- Integration of current icing operations into NextGen

Benefits

Support for new regulations, policy, and guidance material, improvements in mean of compliance and continued operational safety

FAA Icing R&D – Themes

- We currently have two main icing R&D themes
  1. Operational threats – icing weather; aloft and ground. The R&D supports:
     - Automated icing weather (type and rate) reporting
     - New icing regulations - ice crystal icing (ICI) mitigation and terminal area icing information management
     - NextGen "*Reduce Weather Threat*"
  2. Certification & Continued Operational Safety (COS)
     - New icing regulations – ICI and SLD means of compliance
     - Ground icing – new/changing technologies and operations
     - Swept wing icing: test methods, database, and CFD validation

FAA Icing R&D – Budget Line Items

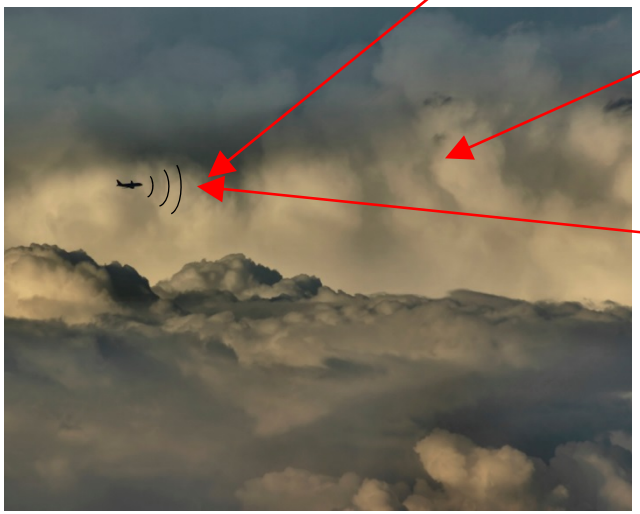
- Aircraft Icing TCRG A11.D
  - AI.01 Turbine engine ingestion of ice crystal icing
    - Means of compliance
  - AI.02 Safe operations for ground icing & takeoff
  - AI.03 Swept wing icing
  - AI.05 Supercooled large drop icing
    - Means of compliance
- Weather TCRG A11.K
  - WX.02 Terminal area icing weather information
  - WX.03 Convective weather ice crystal icing
    - Atmospheric characterization
    - Threat mitigation

Aircraft Icing & Weather TCRG – Requirements

A11K.WX.3 – Ice crystal Atmospheric Threat

A11K.WX.3 – Ice Crystal On-board Weather Radar

A11D.AI.1 – Engine Ice Crystal Ingestion



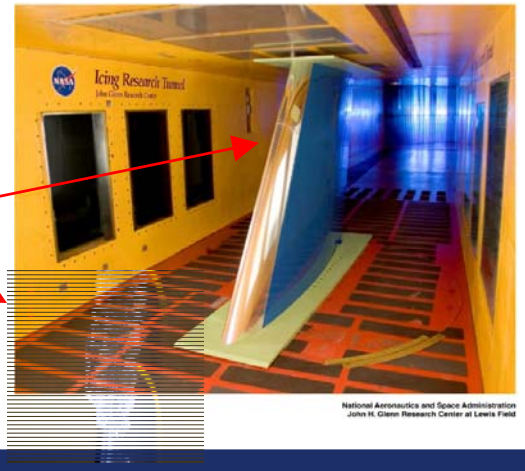
A11.AI.5 – Supercooled Large Drop (SLD)

A11K.WX.10 – Advanced Radar Validation*

A11.AI.3 – App. C Cert

A11D.AI.2 – Safe Ground Icing Ops

A11K.WX.2 – Terminal Area Icing



* A11K.WX.10 is for validation of advanced airborne weather radar hazards detection – a portion of this requirement supports ICI weather radar development and evaluation

Aircraft Icing – R&D to Support Certification (1/2)

***A11D.AI.1* –**

Engine Ice Crystal Ingestion

Ice Crystal Icing (ICI) Means of Compliance

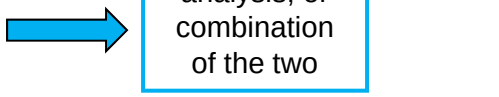
- Currently, use rudimentary design methods to support new regs – use comparative analysis (CA). Described in AC 20-147A
  - Review previous designs for susceptibility to ICI
  - Identify design features
  - Show new design does not have similar features or mitigations for previous designs are in place
- Improved validation is needed – similar methodology to what is used for Appendix C icing
  - Test and analysis: engine tests for ICI conditions, test methods, and analysis for both standardized & CPA test points

ICI MOC Roadmap – Supports Capabilities for § 33.68

New Regs – Amdt. 33-34

From 33.68, Section (e)

Demonstrate by test, analysis, or combination of the two, acceptable operation for turbojet, turbofan, and turboprop engines in mixed phase and ice crystal icing conditions throughout Appendix D of this part, icing envelope throughout its flight power range, including minimum descent idling speed.



Test | Analysis | Combination

Flight*
Ground*
Altitude (Full Engine)
Altitude (Rotating Rig)
Component

** CA information is discussed in AC 20-147A. Robust guidance to support MOC needs to be developed and then updated in FAA advisory circular documents*

Aircraft Icing – R&D to Support Certification (2/2)

***A11.AI.5* – Supercooled Large Drop (SLD)**

SLD Means of Compliance

- Existing engineering tools used for Appendix C icing certification have limited functionality in SLD icing conditions
  - We have some MOC available adapted from Appendix C experience and recent R&D on large drop dynamics, scaling, and CFD
- Need more robust capabilities to support certification to Appendix O
  - Improvements in experimental and analytical methods, ice accretion physics, instrumentation, and ground test facilities.
    - New physical models that represent the trajectory, droplet dynamics for impact, splash and mass loss, and accretion of ice formations for SLD
    - Improvements to ground test facilities for FZDZ and FZRA
    - Instrumentation that can accurately measure large drop liquid water content and drop size distributions

SLD MOC Needed – Supports Capabilities for § 25.1420

New Regs – Amdt. 25-140

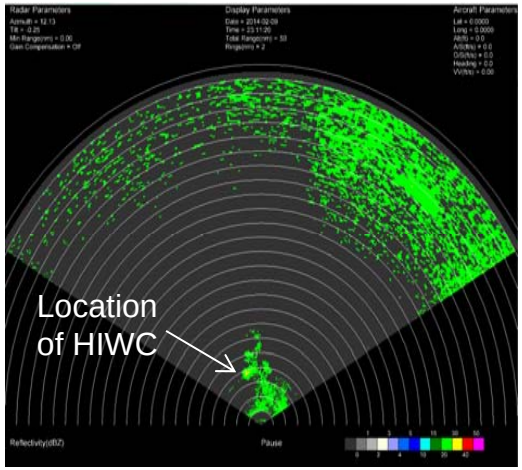
From 25.1420, Section (b)

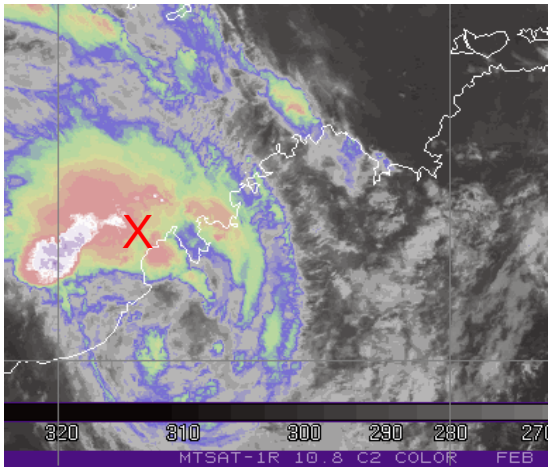
To verify the analysis – *that the ice protection for the various components of the airplane is adequate* – one, or more as found necessary, of the following methods must be used:

1) Laboratory dry air or simulated icing tests, or a combination of both
   - of the components or models of the components
   - of models of the airplane.
2) Flight tests of the airplane or its components in simulated icing conditions, measured as necessary to support the analysis
3) Flight tests of the airplane with simulated ice shapes.
4) Flight tests of the airplane in natural icing conditions, measured as necessary to support the analysis.

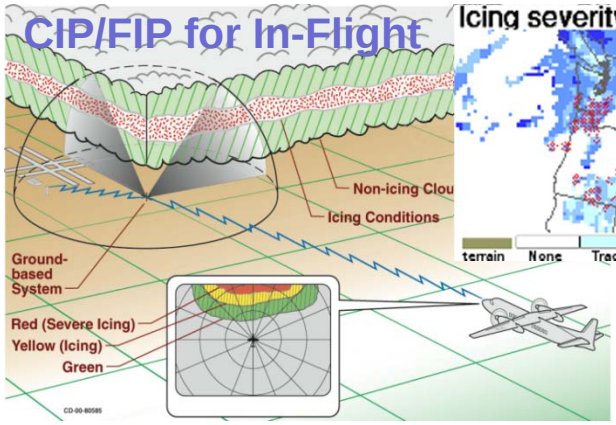
Aircraft Icing – Operational Threats

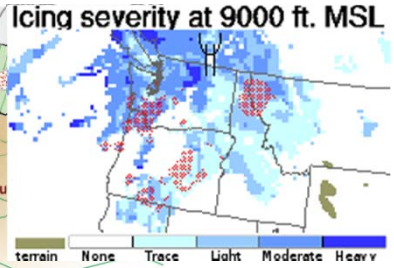
Convective weather → **Airborne weather radar identifies ICI threat** → **Re-route to avoid**





Icing Weather Forecast & Diagnostics Tools





Courtesy of CNRS, NCAR, & NASA

Aircraft Icing TCRG – Objectives & Outcomes

A11D.AI.01 Develop new MOC to support analysis of turbine engine ice crystal ingestion – the results will provide new guidance materials to support ICI engine certification

A11D.AI.02 Improvements to managing ground icing conditions and winter weather operations – supports safe ground and take-off icing operations

A11D.AI.03 Improve MOC for 3-D swept wing ice accretions by developing public database, test methods, and CFD validation for modern swept wing airfoils – the results will provide new guidance materials to support Appendix C icing certification

A11D.AI.05 Develop/update SLD MOC for large drop icing conditions - the results will provide new guidance materials to support airframe and engine inlet certification

Weather TCRG (icing tasks) – Objectives & Outcomes

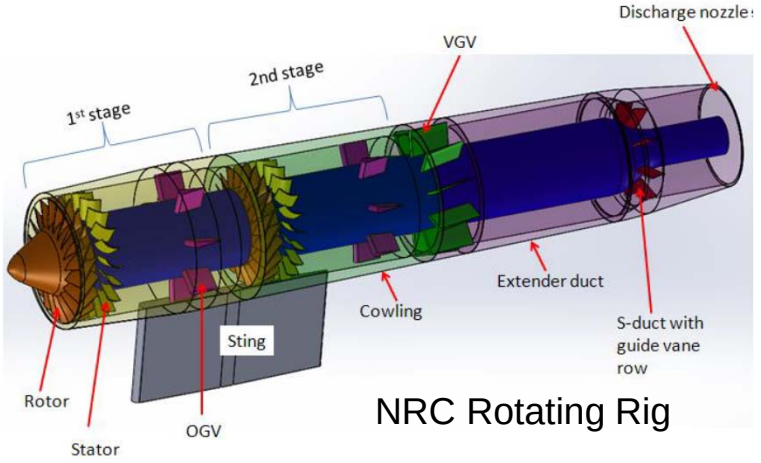
A11K.WX.02 Support NextGen winter weather operations and new icing regulations (§ 25.1420) where certain revenue service aircraft will be required to identify their certification basis and determine if both ground and aloft icing conditions in the terminal area are acceptable for aircraft take-off, landing, and alternate airport planning. The result will be new capabilities to report icing weather type and rate in the terminal area.

A11K.WX.03 Characterize ice crystal properties for assessing their threat to aviation safety, and to develop mitigation strategies. The result will be an understanding of the ICI atmospheric properties to support review of Appendix D engineering standard, identify simulation requirements for ground testing, and develop awareness technologies to avoid these conditions.

Aircraft Icing R&D – Current Status; A11D.AI.01

Turbine Engine Ice Crystal Ingestion

- FAA working with NRC
  - NRC static model tests completed
    - Developed altitude test capabilities
    - Identified parameters of interest for ice crystal impact and sticking efficiency
  - Design & fabrication of scale model rotating rig starting in FY 2016. Test planned in FY 2017
    - Evaluate rotational, gooseneck, and blade configuration effects in altitude chamber
  - Collaborate with NRC and NASA, review with EIWG



NRC Rotating Rig

NASA Funded

- *NASA improving recently developed capabilities for altitude engine test cell simulations with ice crystal icing*
- *NASA conducting research on instrumentation, ice crystal ingestions physics, and computational modeling*

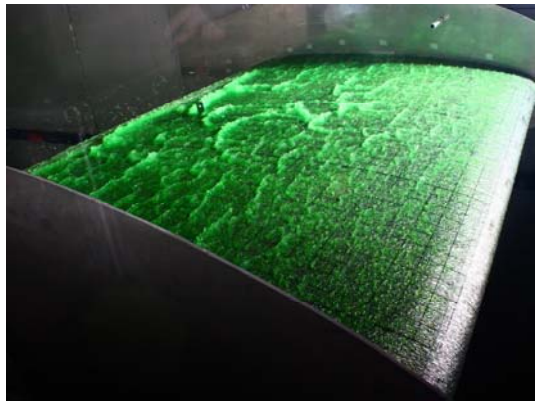
Aircraft Icing R&D – Current Status; A11D.AI.02

Safe Ground & Takeoff Operations

Images courtesy of APS Aviation

Other on-going ground icing research tasks:

- Evaluate mixed precip, ice pellet, and heavy snow conditions

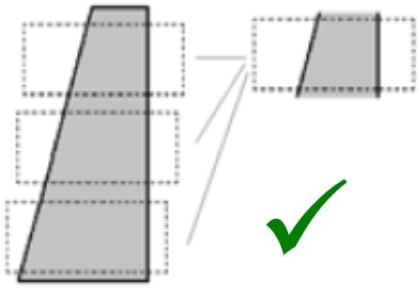


- CSFF – develop public database for cold-soaked fuel frost

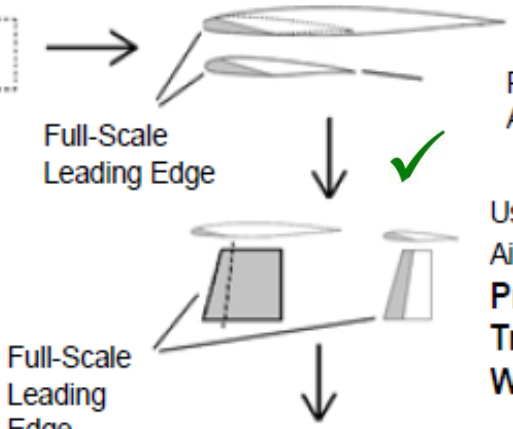
Aircraft Icing R&D – Current Status; A11D.AI.03

Swept Wing Icing Project

Select Sections of Wing to Simulate in IRT



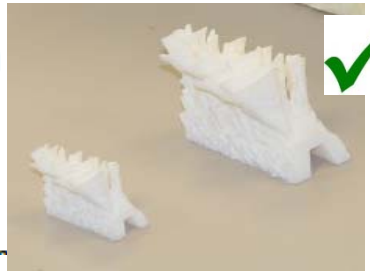
Design Truncated Airfoils



Redesign
Aft Sectio

3-D ice shapes developed in IRT using imaging scanning and mold techniques

Use Truncated Airfoils to **Design Preliminary Truncated Wings**



Fabricate small scale 3-D model & ice shapes – test in 7x10 WSU dry-air tunnel

Images courtesy of NASA

Fabricate large scale 3-D model

Ongoing

Install 3-D model with ice shapes in ONERA pressure tunnel

Install & test in FY 2017

Aircraft Icing R&D – Current Status; A11D.AI.05

SLD MOC

- FAA working with NASA
  - Improve SLD engineering tools based on areas identified in ARAC IPHWG Phase IV study. Conducting research on:
    - Large droplet ice accretion physics: droplet impact, bounce, and re-entrainment, water film movement, & heat transfer
    - Ice shape feature studies
    - CFD modeling and validation databases
    - Icing test facilities improvements in large droplet icing conditions
    - Icing wind tunnel and icing tanker test methods, including scaling
- FAA & NASA are evaluating potential partnerships with EU researchers

Open question on how to develop FZRA test capabilities

Aircraft Icing R&D – Current Status; A11D.AI.05

SLD MOC

Challenge is to turn: Yellow/red(s) to green

		Unprotected Areas				Protected Areas					Detection Methods			Air Data Sensors	
		Wing	Tail	Radome	Non-lifting Surfaces (antenna, inlets, external modifications)	Thermal (protected area)	Thermal (Aft of protected area)	Mechanical (protected area)	Mechanical (aft of protected area)	Fluid Freezing Point Depressant	Visual Cues (Reference Surface)	Instrument (position or installation effects)	Instrument (performance)	Instrument (position or installation effects)	Instrument (performance)
FZDZ MVD < 40µm	Icing Tunnels			*								*		*	
	Codes				**							**			
	Tankers														
FZDZ MVD > 40µm	Icing Tunnels			*								*		*	
	Codes				**							**			
	Tankers														
FZRA MVD < 40µm	Icing Tunnels			*											
	Codes			**	**										
	Tankers														
FZRA MVD > 40µm	Icing Tunnels			*											
	Codes			**	**										
	Tankers														

LEGEND Updated FEB 2009

- The capability exists today and is suitable to be an element of a means of compliance, or is readily achievable based on current experience
- The capability is possible, but has not been demonstrated, or there is limited or no validation.
- The capability is unknown, or does not currently exist
- * It may be possible to test small scale installation effects, but large scale installations are not currently feasible
- ** Current 2D capabilities exist with large droplet effects, but limitations exist in the use of 3D codes for simulation of Appendix X effects

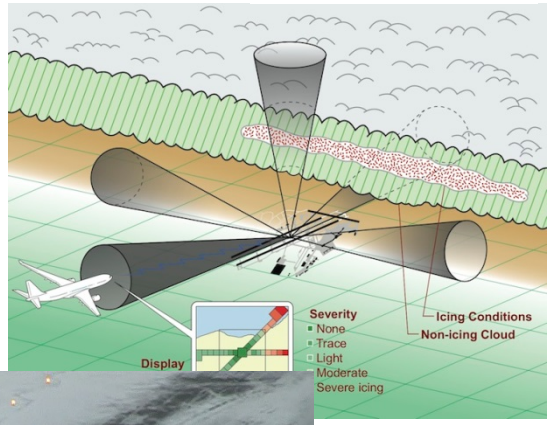
Aircraft Icing R&D – Current Status; A11K.WX.02

Terminal Area Icing Weather Information for NextGen

Courtesy of NASA

- FAA working with NCAR and NOAA
  - Develop/evaluate real-time representative rate measurement and identification of type for all ground-level precipitation
    - Use of dual polar radar for determination of precipitation type
    - Determination of liquid water equivalent (LWE) at ground for freezing precipitation types, and aloft (possibly with microwave radiometry)
  - Develop highly resolved, micro-physical models & observations that provide timely diagnoses/forecasts for terminal area icing
  - Evaluate on-aircraft sensing equipment that can report icing conditions information and provide automated updating

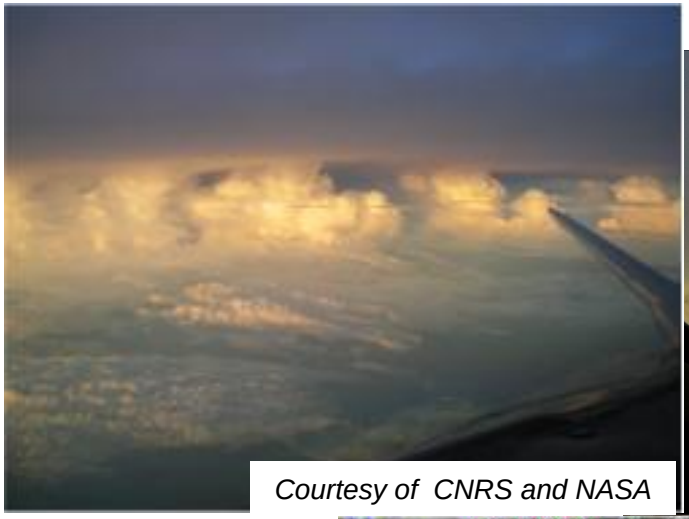
Approach & landing decisions



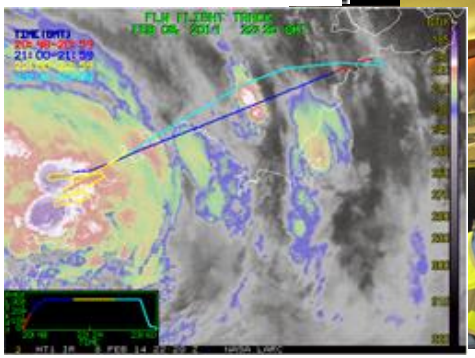
Take-off decisions

Aircraft Icing R&D – Current Status; A11K.WX.03

Ice Crystal Icing – Characterization ✓



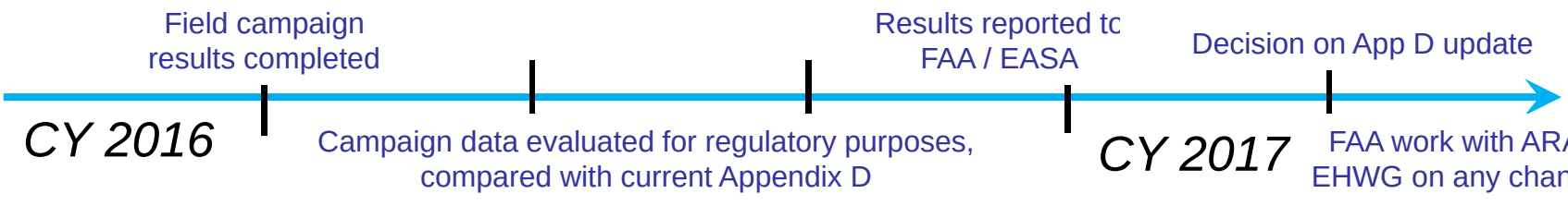
Courtesy of CNRS and NASA



FS140018 - 3.4 F/H – Flight in system located North/West of Broome. 6 legs performed at FL310 / -30°C with sustained IWC at 1.0g/m3 and peaks from 1.5g/m3 to 2.5g/m3 (1 peak).

2014 Darwin and 2015 Cayenne field campaigns completed

- Ice crystal cloud properties data being analyzed
- Projected completion is March 2016; HAIC-HIWC science meeting in May 2016 to resolve any open issues



Aircraft Icing R&D – Current Status; A11K.WX.03

Ice Crystal Icing – Mitigation

NASA DC-8 Airborne Science Laboratory

RDR-4000 Radar

- 2015 FC radar data analyses in-process
- *Started planning* for FY 2017 NASA-FAA Field Campaign

✓ 2015 FL Field Campaign (NASA principle, FAA support)

- Develop airborne means to identify HIWC conditions – use for tactical avoidance decision-making
- Acquire pilot weather radar data in mesoscale convective systems along with the corresponding in-situ ice crystal cloud physics data (water content, particle spectra, temp)
- Characterize the response of the radar and develop and test HIWC identification algorithms

Aircraft Icing Program Partnerships

Partnerships

- U.S.
  - NASA – Glenn and Langley
  - Recent past – DOD (O-HISS & McKinley Climatic Hangar)
- International
  - Australian Bureau of Meteorology
  - CNRS (French national research group) - aircraft and science lead of European Union High Altitude Ice Crystal (HAIC) project
  - Environment Canada
  - National Research Council of Canada
  - ONERA (French Aerospace agency)
  - Transport Canada
  - Trafi – Finland Department of Transportation