Aviation Safety Program

Atmospheric Environment Safety Technologies (AEST) Project

Summary

<u>Engine Icing: Characterization and Simulation Capability</u>: Develop knowledge bases, analysis methods, and simulation tools needed to address the problem of engine icing; in particular, ice-crystal icing

<u>Airframe Icing Simulation and Engineering Tool Capability</u>: Develop and demonstrate 3-D capability to simulate and model airframe ice accretion and related aerodynamic performance degradation for current and future aircraft configurations in an expanded icing environment that includes freezing drizzle/rain

<u>Atmospheric Hazard Sensing and Mitigation Technology Capability</u>: Improve and expand remote sensing and mitigation of hazardous atmospheric environments and phenomena

Aviation Safety Program

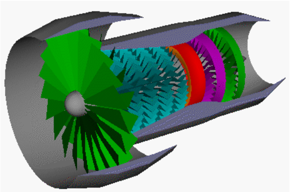
Atmospheric Environment Safety Technologies (AEST) Project

Dr. Ron Colantonio
AEST Project Manager

2011 Annual Technical Meeting
May 10–12, 2011
St. Louis, MO

AEST Project Objective

Objective: The Atmospheric Environment Safety Technologies (AEST) project will investigate sources of risk and provide technology needed to help **ensure safe flight in and around atmospheric hazards**.



Focus: In-flight icing, both engine and airframe. Research will also include investigations of other high priority atmospheric hazards and sensor technologies required for their detection.

Relevance to National Needs

1. Engine icing incidents are occurring on a frequent basis with the aviation community calling for action.
2. New aviation regulatory requirements necessitate the development new and enhanced icing simulation tools
3. Operations in the Next Generation Air Transportation System environment demand precise information about the atmosphere and awareness of weather hazards

Linkages to Program Goal

"By 2016, identify and develop tools, methods, and technologies for improving overall aircraft safety of new and legacy vehicles operating in the Next Generation Air Transportation System."

Summary of AEST Project Technical Challenges

<u>Engine Icing: Characterization and Simulation Capability</u>: Develop knowledge bases, analysis methods, and simulation tools needed to address the problem of engine icing; in particular, ice-crystal icing

<u>Airframe Icing Simulation and Engineering Tool Capability</u>: Develop and demonstrate 3-D capability to simulate and model airframe ice accretion and related aerodynamic performance degradation for current and future aircraft configurations in an expanded icing environment that includes freezing drizzle/rain

<u>Atmospheric Hazard Sensing and Mitigation Technology Capability</u>: Improve and expand remote sensing and mitigation of hazardous atmospheric environments and phenomena

Technical Challenge (Engine Icing)

<u>Engine Icing: Characterization and Simulation Capability</u>: Develop knowledge bases, analysis methods, and simulation tools needed to address the problem of engine icing; in particular, ice-crystal icing

Goal: *Eliminate turbofan engine interruptions, failures, and damage due to flight in high ice-crystal content clouds*

Benefit: *Verified basis for engine icing certification requirements; enable new engine icing protection systems and methods*

Benefit Domain: *All turbofan/turbojet powered aircraft; engine manufacturers, aviation system regulators, and pilots and operators*

<u>Elements</u>

- Ice-crystal icing environment characterization
- Validated engine ice-crystal icing test methods and techniques
- Validated and verified icing codes to determine potential engine core ice accretion sites and accretion rates
- Validated and verified engine simulation codes to predict ice-degraded engine and engine component performance
- Methods to mitigate ice-degraded engine performance

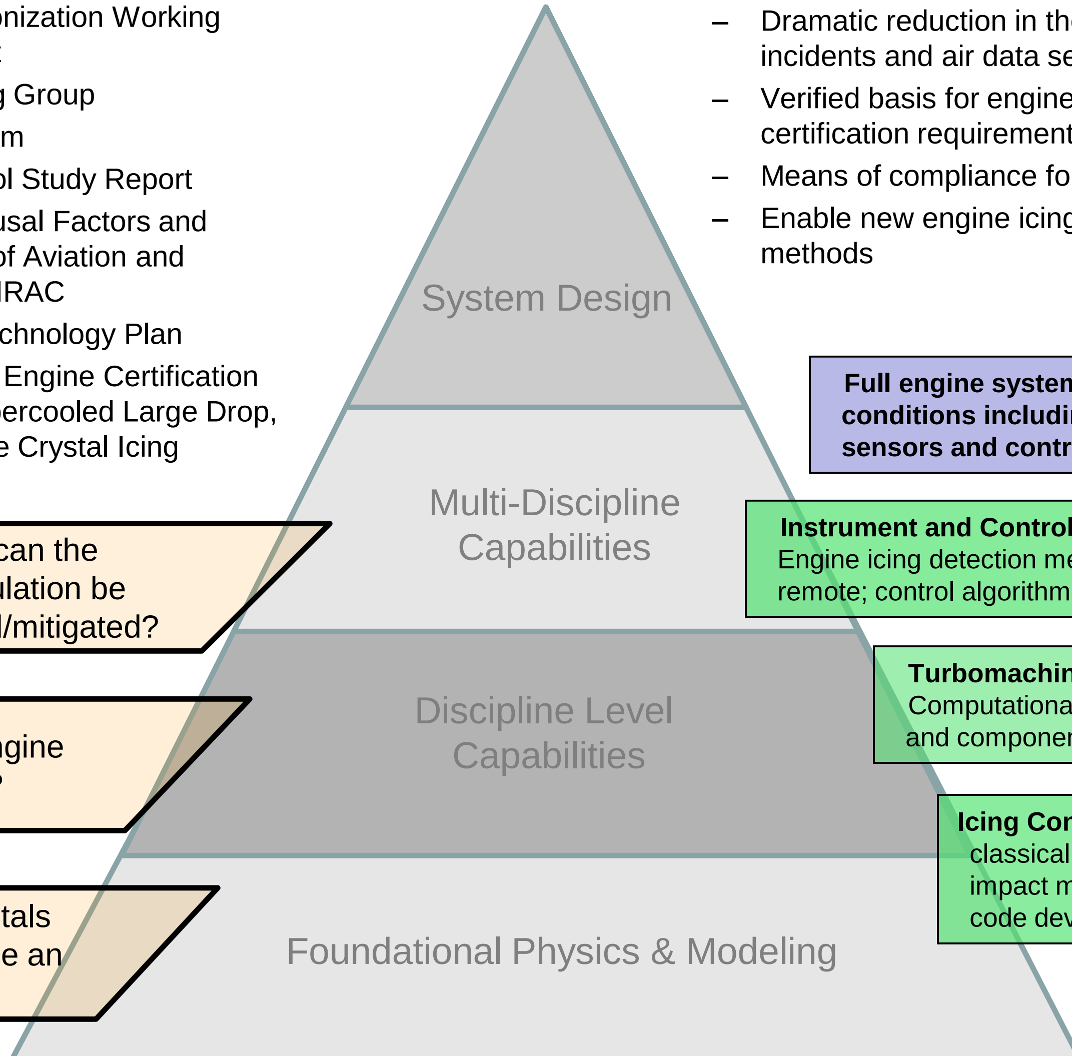
Engine Icing Approach

Technical Challenge Validated

- Ice Protection Harmonization Working Group Task 2 Report
- Engine Icing Working Group
- Ice Crystal Consortium
- NASA Loss of Control Study Report
- NASA Report on Causal Factors and Adverse Conditions of Aviation and Incidents Related to IRAC
- FAA Aircraft Icing Technology Plan
- NPRM: Airplane and Engine Certification Requirements in Supercooled Large Drop, Mixed Phase, and Ice Crystal Icing Conditions

Benefits of Successful Completion

- Dramatic reduction in the frequency of engine icing incidents and air data sensor malfunctions
- Verified basis for engine icing and air data sensor certification requirements
- Means of compliance for engine icing certification
- Enable new engine icing protection systems and methods



How can the accumulation be prevented/mitigated?

How is the engine affected?

Why do ice crystals accumulate inside an engine?

Full engine system test at altitude conditions including advanced sensors and control methods

Instrument and Control Contributions Engine icing detection methods: in-situ and remote; control algorithms

Turbomachinery Contributions Computational and classical engine system and component performance modeling

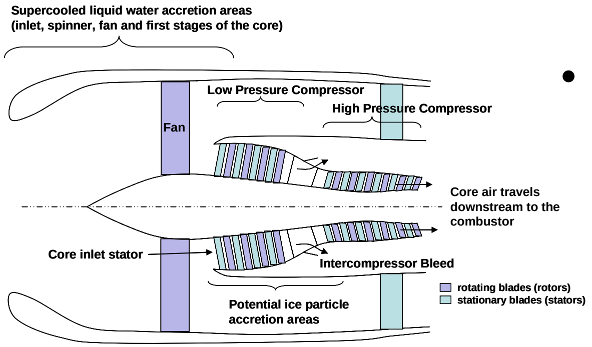
Icing Contributions Computational and classical ice crystal state, trajectory, and impact modeling; engine ice accretion code development

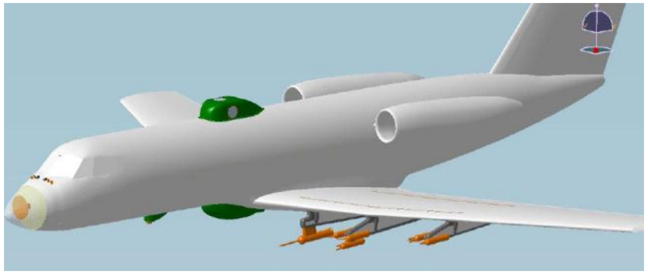
Fundamental Research Atmospheric environment characterization, engine environment analysis, ice-crystal aero-thermodynamics

Technical Challenge (Engine Icing)

<u>What are we trying to do?</u>

- Define the natural ice crystal icing environment through measurements in flight
- Develop methods to conduct ground-based ice-crystal icing tests
- Provide validated and verified computational simulation and analysis methods
- Enable engine icing prevention and mitigation





<u>Why?</u>

- Engine icing incidents are occurring on a frequent basis
- The aviation community, including airframers, airlines, pilots, and the flying public, is aware of the problem and is calling for it to be addressed
- NASA has a proven record and capability to address such aviation hazards (e.g., airframe icing)

Technical Challenge (Engine Icing)

How is it done today?

- Pilots are instructed to avoid areas of high radar-reflectivity (indicating heavy rain) at altitudes below their flight paths
- This approach has had no noticeable effect in reducing the frequency of engine and air data sensor malfunctions

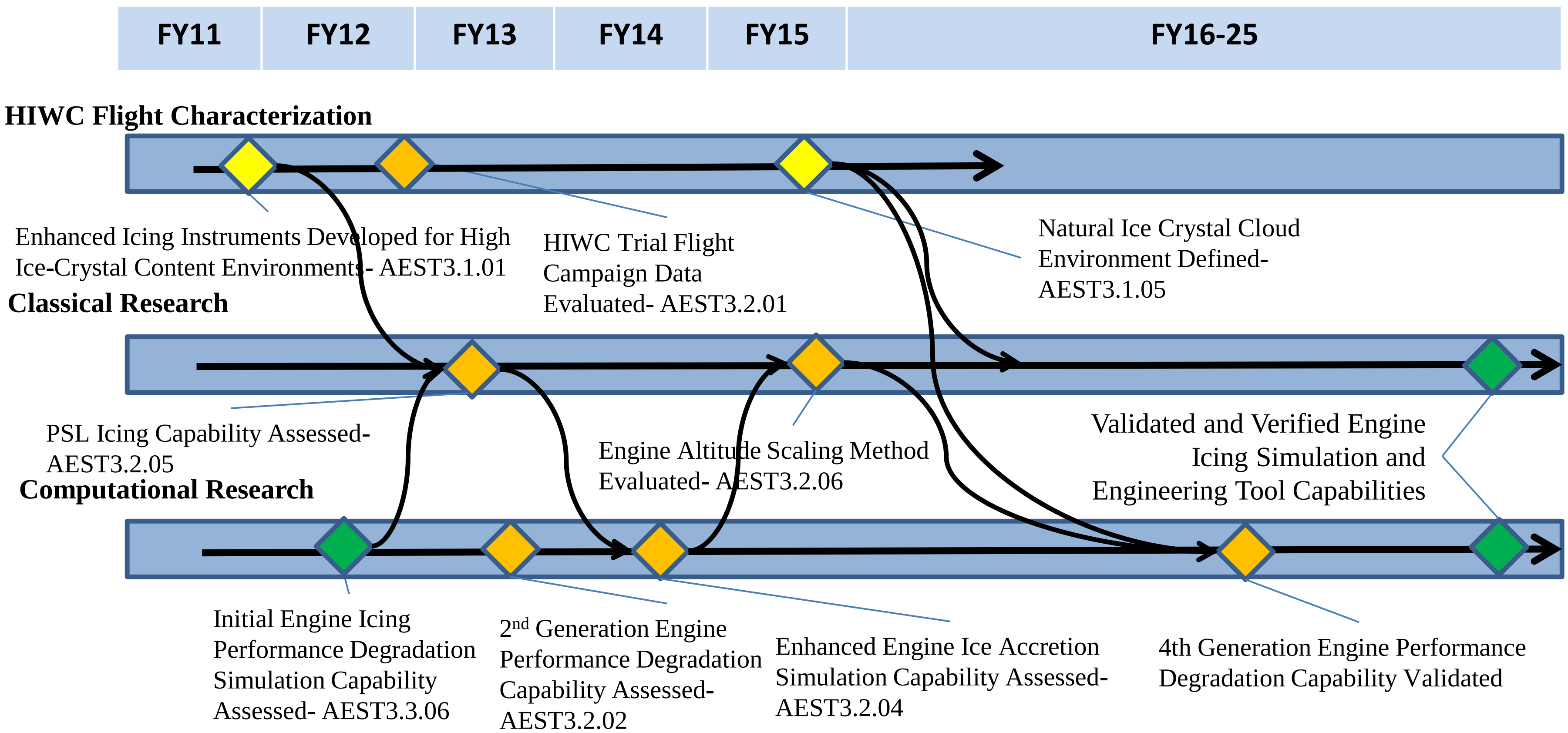
What's new?

- Problem has only recently been identified. The knowledge and technology developed in AEST will enable turbofan engine systems to be designed to operate in high ice-crystal clouds without interruption, failure, or damage
- Engine ice-crystal environment defined to guide simulation tool development.

What are the payoffs if successful?

- Dramatic reduction in incidents and accidents attributed to high ice water content (HIWC) icing
- Provide a means to ensure new engines are not susceptible to HIWC icing

Measuring Progress Toward Engine Icing



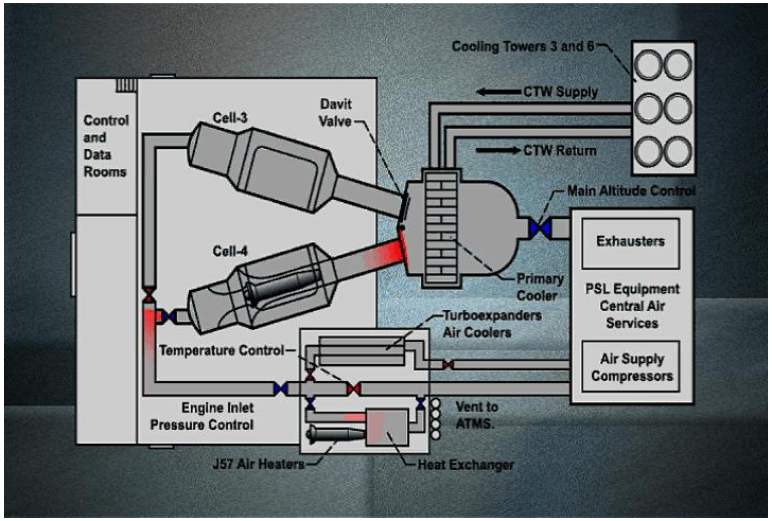
What are the intermediate and final exams to check for success?

- Validation of Propulsion Systems Laboratory (full scale engine test facility) Icing Simulation Capability
- Establishment of Ice-Crystal Icing Envelope for research, development, and certification
- Correlations of computations with data

FY11 Activity Details

Engine Icing

- Complete improvements of legacy icing instruments and characterization of new instruments for flight campaign. Awarded contract for High Ice Water Content research flight services. Complete critical design review for research aircraft instruments and data collection systems.



- Conduct computational engine icing performance studies in preparation for Propulsion System Laboratory (PSL)-Icing integration systems test, calibration, and validation test activities. Utilize collaborative approach to perform research in PSL-icing facility with an engine susceptible to ice-crystal icing.

Technical Challenge (Airframe Icing)

Airframe Icing Simulation and Engineering Tool Capability:

Develop and demonstrate capability to simulate and model airframe ice accretion and related aerodynamic performance degradation for current and future aircraft configurations in an expanded icing environment that includes freezing drizzle/rain

Goal: *Achieve acceptance of simulation tools for design and certification of swept wing configurations over an expanded range of icing conditions*

Benefit: *Enable aircraft manufacturers to perform reliable icing assessments and build in effective icing mitigation approaches for current and future aircraft; development of technology that enables safe flight operations in an super-cooled large droplet environment*

Benefit Domain: *Aircraft and aircraft sub-system manufacturers and aviation system regulators*

Elements:

- Computational Ice Accretion Simulation for Swept Wings
- Experimental Ice Accretion Simulation for Swept Wings
- Experimental Aerodynamic Simulation for Swept Wings
- Computational Aerodynamic Simulation for Swept Wings
- Computational Ice Accretion Simulation for Super-cooled Large Droplet (SLD) Icing Conditions
- Experimental Ice Accretion Simulation for SLD Icing Conditions
- Ice Protection System Modeling

Airframe Icing Approach

Technical Challenge Validated

- FAA In-flight Aircraft Icing Plan
- Ice Protection Harmonization Working Group Task 2 Final Report
- NTSB Most Wanted Transportation Safety Improvements
- NASA Loss of Control Study Report, NASA Report on Causal Factors and Adverse Conditions of Aviation and Incidents Related to IRAC
- NASA 2009 Airframe Icing Workshop; Aircraft Icing Research Alliance 3D Ice Accretion Code Workshop
- NPRM: Airplane and Engine Certification Requirements in Supercooled Large Drop, Mixed Phase, and Ice Crystal Icing Conditions

Benefits of Successful Completion

- Increase the safety of flight in icing conditions through introduction of validated and accepted icing simulation tools earlier in the design cycle.
- Reliable icing assessments and effective icing mitigation design approaches for current and future aircraft
- Development of technology that enables safe flight operations in a Super-cooled Large Droplet (SLD) environment

System Design

Experimental and Computational Capabilities Contributions
- Freezing rain/drizzle test methodologies and instrumentation
- 3-D ice scanning capability

Multi-Discipline Capabilities

What geometric features of swept wing ice accretion govern aerodynamics?

Aerodynamics Contributions
- Iced aerodynamics
- Stability, control and handling

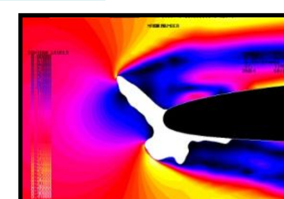
Discipline Level Capabilities

How can SLD icing conditions be simulated?

Icing Contributions
- Airframe ice accretion modeling
- Swept wing and SLD ice accretion database

Foundational Physics & Modeling

What physical phenomena in swept wing ice accretion are critical for accurate models?



Fundamental Research
CFD modeling; experimental techniques; icing physics, scaling

Technical Challenge (Airframe Icing)

What are we trying to do?

- Investigate the physics of ice accretion on swept wing surfaces
- Investigate the physics of ice accretion under freezing drizzle and freezing rain conditions
- Develop methods to conduct ground-based freezing drizzle and freezing rain icing tests
- Determine the level of ice accretion simulation fidelity required for assessment of aerodynamic performance degradation during an icing encounter
- Provide validated and verified computational simulation and analysis methods for both swept wing icing encounters and SLD icing conditions

Why?

- Icing simulation methods for swept wing configurations are not sufficiently mature and require further development and validation for acceptance at the level of current 2D methods
- Current simulation tools do not cover the entire range of SLD icing conditions proposed in new regulatory requirements, therefore there is a technology gap between the requirements and the means of compliance

Technical Challenge (Airframe Icing)

How is it done today, and what are the limits of current practice?

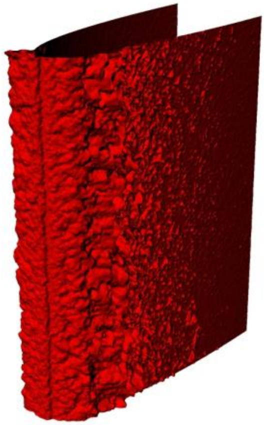
- Upcoming regulations will require manufacturers to rely on expensive flight testing
- Computational simulation capability for SLD is limited because little validation data exist and the models cannot be validated and verified over the full range of SLD conditions
- Swept wing ice accretion computational simulation is at a lower level of technological maturity than its 2D counterpart
- Current industry practice for icing aero performance evaluation is based upon simplified 3D ice shape geometries with unknown fidelity

What is new in our approach?

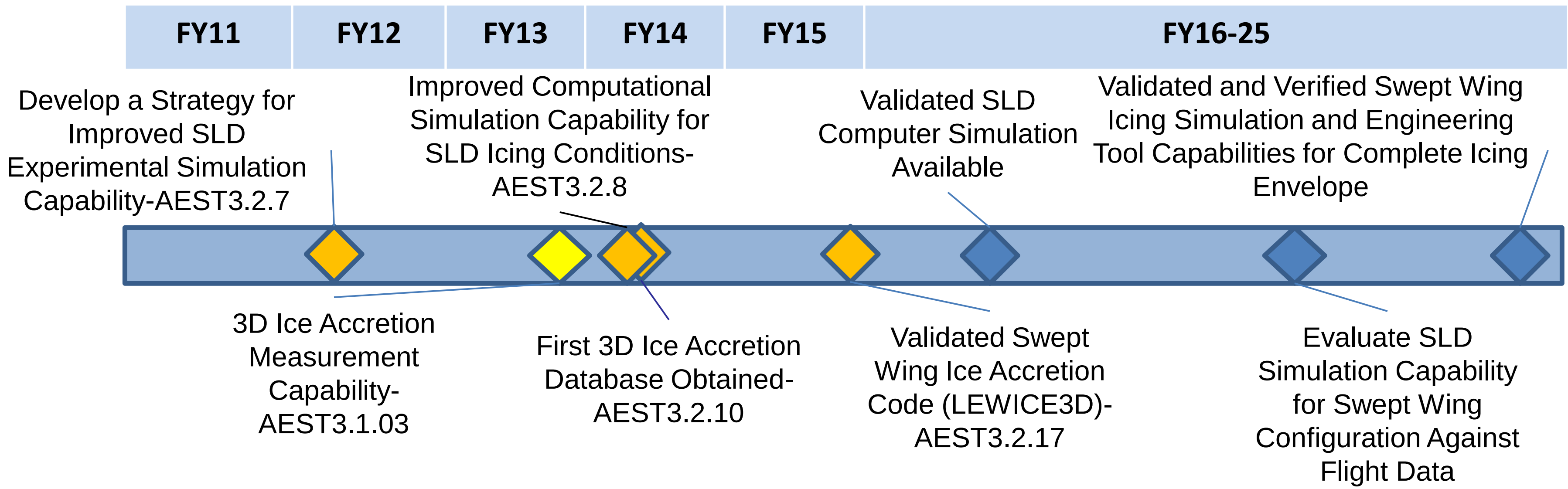
- NASA will investigate alternate means for simulation of freezing drizzle and freezing rain; methods for SLD condition simulation will be recommended
- Development of a modeling capability for scalloped ice shapes will increase the range of capabilities for existing 3D ice accretion methods
- Data will be used to validate and verify computational icing simulation capabilities as well as to develop methods for use of CFD tools for evaluation of swept wing performance changes

What are the payoffs if successful?

- Allow for design and certification of aircraft, including swept wing configurations and aircraft subsystems, that are substantially safer for flight in SLD
- Enhance the ability of airlines to operate under even the most severe weather conditions



Measuring Progress Toward Airframe Icing



<u>What are the intermediate and final exams to check for success?</u>

- Identification of approach for SLD testing capability
- Validation of SLD icing simulation capability
- Correlations of computations with data
- Development of swept wing ice accretion testing methods

FY11 Activity Details

Airframe Icing

- Formalize ONERA-FAA-NASA cooperative agreement on Swept-Wing Ice Accretion Characterization and Aerodynamics

- Evaluation and adaptation of commercial 3-D measurement capability for documentation of ice shapes in NASA Glenn Icing Research Tunnel

- Preparation of existing facilities for fundamental ice accretion studies

- Conduct review of 3D computational ice accretion and aerodynamic capabilities, determine requirements for accurate simulation of swept wing configurations over the full range of icing conditions including SLD, identify gaps in capabilities, and recommend further development efforts

- Assess current state-of-the-art in experimental SLD simulation capabilities throughout the aviation community. Identify gaps in the capability and recommend an investment strategy for addressing the deficiencies

Technical Challenge (Atmospheric Hazard Sensing and Mitigation)

Atmospheric Hazard Sensing & Mitigation Technology Capability: Improve and expand remote sensing and mitigation of hazardous atmospheric environments and phenomena

Goal: *Mature technologies for sensing and measurement of icing, turbulence, and wake vortex hazards for real-time information to the pilot and operators in the NAS and to address low visibility conditions for safer runway operations; develop technologies for a lightning immune composite aircraft*

Benefit: *Greater ability for aircraft to avoid hazards; hazard information available for sharing with other aircraft and ground-based systems; reduced vulnerability to lightning and other hazards*

Benefit Domain: *All aircraft flying in the NAS; pilots, operators, and controllers*

Elements:

- Icing Weather Systems Development
- Advanced Radar
- Lidar and Electro-Optical Sensor Development
- Smart Visual Awareness Sensor Systems
- Lightning and Electromagnetic Effects- Sensing and Mitigation

Atmospheric Hazard Sensing and Mitigation Approach

Technical Challenge Validated

– FAA NextGen commitment to Reduce Weather Impact (RWI) to facilitate safe NextGen operations

– NRC Review: “Review of NASA's Aerospace Technology Enterprise: An Assessment of NASA's Aeronautics Technology Programs”

– Decadal Survey of Civil Aeronautics

– “FAA should continue to encourage and fund research to further investigate the electromagnetic characteristics of lightning.” David Walen, Chief Scientific and Technical Advisor – Electromagnetic Interference and Lightning, FAA Aviation Safety

Benefits of Successful Completion

– Expanded remote sensing capabilities to include clear air turbulence and wake vortices and more accurate convective weather diagnosis

– Greater ability for aircraft to avoid hazards including icing conditions, kinetic air hazards, and convective weather

– Atmospheric, weather, and hazard information available for sharing with other aircraft and ground-based systems

– Reduced vulnerability to lightning, low visibility and other hazards

– Safety improvement as capacity increases

System Design

Multi-Discipline Capabilities

Discipline Level Capabilities

Foundational Physics & Modeling

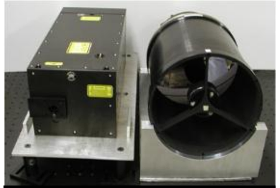
How can most atmospheric hazards be remotely detected?

How can safe operations in reduced visibility be enabled?

What are the innovative mitigation strategies for composite aircraft?

Lightning Contributions

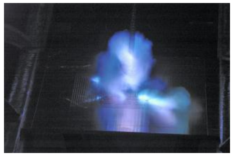
- Multifunctional, passive and active sensing or mitigation technologies



Active Imaging (Lidar)

Sensor Contributions

- Airworthy Lidar and electro optic sensors
- Advanced weather radar capability
- Automated imagery processing for runway and object detection in low visibility conditions
- Weather characterization and databases

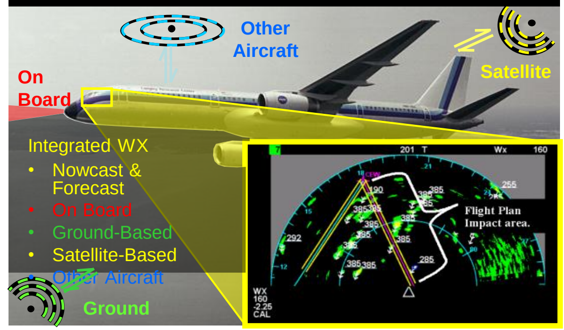


Technical Challenge (Atmospheric Hazard Sensing and Mitigation)

What are we trying to do?

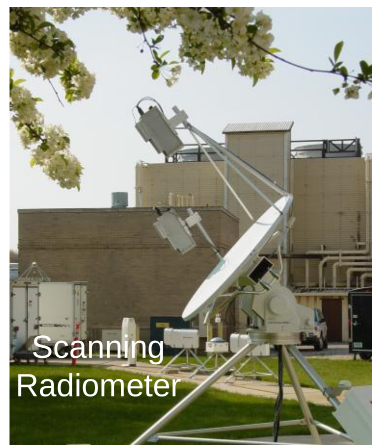
- Improve safety by increasing the availability of real-time atmospheric hazard information in the cockpit and throughout the NAS
- Develop sensor technologies to provide the capability to detect and quantify atmospheric hazards and enable safe operations in and around hazardous environments
- Make new sensor technology economical
  - Expand utility – Develop and expand sensor detection and discrimination capabilities
  - Identify and remove technical or other barriers to sensor deployment
- Provide improved imagery in reduced visibility
- Develop technologies for lightning-immune composite aircraft

More & Improved Information through Integration



New Technologies

Multispectral Imaging System



Scanning Radiometer

Lightning Mitigation System

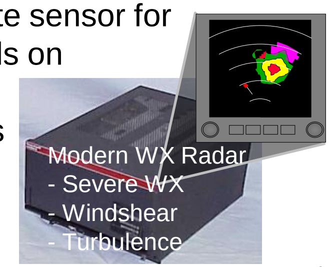
Why?

- Atmospheric hazards are a primary cause and contributor to aviation accidents
- NextGen operational environments will require a **greater awareness of hazards** and the ability to avoid them
- Safety benefits can only be realized if new capabilities are deployed
- Composite aircraft need protection from structural and avionic lightning damage

Technical Challenge (Atmospheric Hazard Sensing and Mitigation)

How is it done today, and what are the limits of current practice?

- Weather radar is currently the only common remote sensor for atmospheric hazards on commercial aircraft. Sensing capabilities are limited by old designs and apps, not the technology



- Off-board hazard information, when it is available, is provided to the aircraft by voice or text; This information is often sparse, inaccurate, or non-specific
- Known and potential hazards are avoided with large, conservative margins for safety, due to high uncertainty
- Lightning protection is achieved through the use of metal shielding
- Lightning damage identification is conducted post-flight through ground visual inspections and tap tests

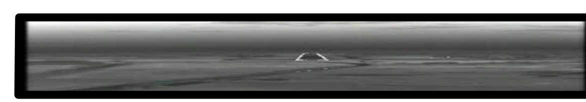
What is new in our approach?

- AvSP will enable the deployment of new and enhanced sensor technologies by increasing their utility with enhanced detection and discrimination capabilities, and reducing their deployment costs by removing technical barriers
- AvSP will enable safe operations in reduced visibility by employing multispectral techniques to remove the effect of obscurants, and by advanced image processing techniques
- AvSP will develop innovative lightning mitigation strategies for composite aircraft for improved flight safety and reduced weight, cost and maintenance by exploring multifunctional, passive and active technologies

What are the payoffs if successful?

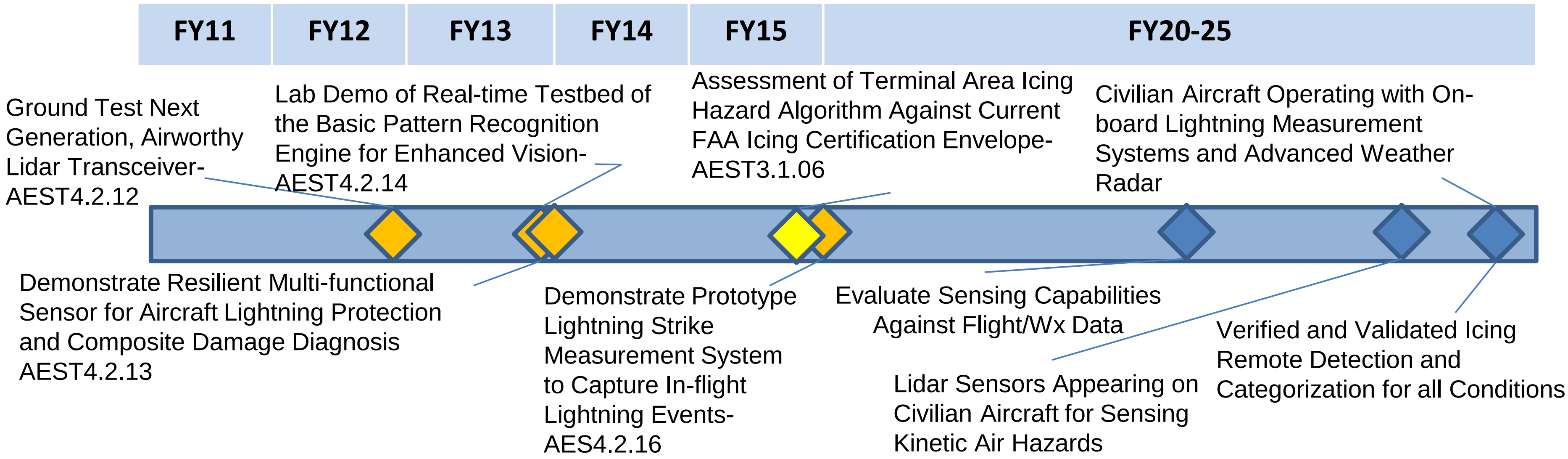
- User community has confidence to equip or buy aircraft with additional remote sensors and upgraded technologies
- NAS users will enjoy safer and less expensive flights as atmospheric hazards are dealt with more effectively and efficiently
- Composite aircraft will be safer and more robust in a lightning environment, and in the event of damage, it can be assessed in flight

FLIR Technologies and SVA Processes



Provides Vision in IMC

Measuring Progress Toward Atmospheric Hazard Sensing and Mitigation



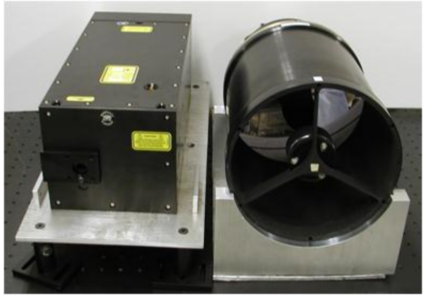
What are the intermediate and final exams to check for success?

- Demonstration of advanced radar capabilities for airborne weather radar (enhancements may include electronic scanning, polarimetric sensing, and multi-frequency radar)
- Assessment of terminal area icing algorithm and sensor systems (for Appendix C and SLD)
- Development of new, affordable and effective remote sensor capability (e.g. Lidar, multi-spectral sensors) for kinetic air hazards (e.g. wake vortices, turbulence)
- Improved and new remote sensing capabilities installed on transport aircraft, and procedures and operations modified to capitalize on improved safety capabilities (i.e. safety improvements absorbed into NAS)
- Demonstration of lightning strike damage mitigation and assessment for composite aircraft structures

FY11 Activity Details

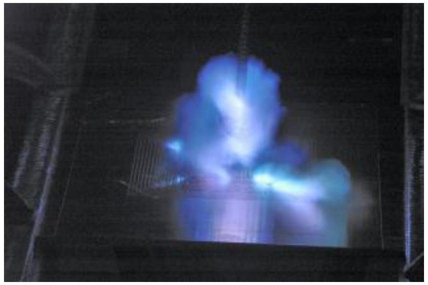
Atmospheric Hazard Sensing and Mitigation

– Laser Imaging Through Obscurants (LITO) system functionality validated in lab and field



– Interferometric imaging capability of real time observation of wake vortex hazard determined, predicted performance based on modeling tested

– Completion of initial near-real-time Neural-Net processing software for Liquid Water Content (LWC) and Cloud Droplet Size output using Multi-Frequency Radar (MFR) X-, Ka-, and W-band data



– Develop computational electro-magnetic tools to predict shielding effectiveness characteristics of lightning SansEC sensors and the experimental test methods for validation; Conduct direct effect lightning test investigations on Lightning SansEC Sensors to characterize lightning resilience and to evaluate differential resistance sensor designs

Q&A