HAIC – High Altitude Ice Crystals
FP7 Transport Info Day, 18th July 2011, Brussels

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HAIC – High Altitude Ice Crystals

Context

• Commercial aircraft have been experiencing jet-engine powerloss events while flying in the vicinity of deep convective cloud since at least the early 1990s.

• In 2004, an industry working group was established to look at the effects of supercooled large droplets and mixed phase icing conditions on engines. This working group established that this suspected engine icing phenomenon was present in both commuter and large transport category aircraft, and in all types/manufacturers of engine.

• The areas of aircraft that have shown sensibility to ice particles icing threat are heated probes and engines.

• Ice accretion will depend on surface temperature, Liquid Water Content, Ice Water Content, air speed, etc. but there is actually no model to simulate ice accretion due to ice particles icing.
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Context

- NPRM10-10 had been issued by FAA on June 2010 and NPA11/03 and NPA11/04 by EASA on March 2011 to propose a new regulation to cover, among other things, ice particles threat to Aircraft.

**FAR33 Appendix D (Ice Crystals & Mixed Phase):**

- This new envelope is for the moment dedicated to Engines, but should be applicable soon to other Aircraft equipments as Air Data Probes (Eurocae WG89 is working on an update of TSO C16a, SAE AC-9C is working on update of ARP).
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Context

The whole European aeronautical industry needs to anticipate the regulation change, and to develop acceptable means of compliance.

In coordination with airworthiness authorities, engine manufacturers, systems suppliers, airframers, Met offices, research institutes and universities, Airbus proposes to lead a L2 project proposal on High Altitude Ice Crystals.
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FP7 Workprogramme 2012

HAIC - High Altitude Ice Crystals

• Activity in Work Programme: ACTIVITY 7.1.3. ENSURING CUSTOMER SATISFACTION AND SAFETY
• Area in Work Programme: AREA 7.1.3.3. Aircraft safety
• Topic in Workprogramme : AAT.2012.3.5-1. Integrated approach to safe flights under icing conditions

• Content and scope: Research will target the development of measurement techniques and instrumentation for research purposes and for use on-board of commercial aircraft (detection and crew alert). Measurements of the physical characteristics of glaciated and mixed phase icing conditions will be performed in high altitude clouds. This knowledge will be used to improve the representativity of ground testing (wind tunnels) and modelling capacities. Selected icing tunnels should be modified to reproduce more faithfully conditions encountered in high altitude cloud and the computer based modelling will be refined to better include actual physical phenomena. An integrated cross-validation will be performed between in flight measurements, wind-tunnel measurements and model predictions. Results will be analysed in the light of the current regulatory framework and should lead to new recommendations.

• Expected impact: The work should aim at providing European aircraft manufacturers with enhanced understanding, measurement and modelling capacities of near icing or icing conditions at high altitude. The objective is to reduce the risk of incidents when an aircraft is flying in such weather conditions.

• Implementation and management: Cooperation with international working groups on this topic is encouraged as well as cooperation with North America.
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Objectives

Different technical aspects have to be studied to allow compliance with new rule (1/2):

- **Characterization of high altitude atmosphere**: Flight tests to measure Ice Water Content and Ice Mean Mass Diameters in high altitude clouds
  - Objective: Precise Appendix D diagrams that are based on adiabatic calculations and characterize the conditions to comply with.

- **Flight Test Instrumentation**: Need for instrumentation able to measure glaciated and mixed phase icing conditions during flight tests
  - Objective: Be able to justify the concordance of conditions encountered during flight tests with requirement of Appendix D.

- **Detection Means**: Development of glaciated and mixed phase icing conditions detectors (probes or radar) to be fitted on in-service Aircraft
  - Objective: Be able to alert crew of flight in this particular icing conditions.

- **Development of European Icing Wind Tunnels**: Development of icing wind tunnels to allow reproduction of glaciated and mixed phase icing conditions as defined per future regulations
  - Objective: Be able to perform qualification of equipments in European Facilities
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Objectives

Different technical aspects have to be studied to allow compliance with new rule (2/2):

• **Model of ice accretion phenomenon**: Understanding of macro-physic and micro-physic of phenomenon and writing of accretion equations
  • Objective: Be able to evaluate ice accretion pending on equipments thermal conditions and environmental conditions.

• **Model of ice particles trajectories**: Understanding of relative importance of different parameters in trajectories equations for modeling
  • Objective: Be able to predict ice particles trajectories and equipments exposure pending on their location on Aircraft.

• **Model Validation**: Tests in glaciated and mixed phase conditions to validate models
  • Objective: Validate models in order to be able to use them during certification loops.
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WBS & Responsibilities

- The work is split into 6 sub-projects:

- SP0 Management
- SP1 Instrumentation
- SP2 Flight Tests
- SP3 Meteo
- SP4 Detection & Awareness Technology
- SP5 Test capability
- SP6 Tools & Simulation

**AMC**
- F/T
- IWT/T
- Analysis

**Technology**
- Instrumentation
- Detection
HAIC – High Altitude Ice Crystals Roadmap

<table>
<thead>
<tr>
<th>Year</th>
<th>Activities</th>
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<tbody>
<tr>
<td>2011</td>
<td>SP1 - Instrumentation Development</td>
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<td>SP2 - Flight Tests</td>
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<td>SP3 - Meteo</td>
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<td>SP4 - Detection and Awareness Technology</td>
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<td></td>
<td>SP5 - Icing Wind Tunnels / Tests</td>
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<td>SP6 - Tools and Simulation</td>
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<tr>
<td>2012</td>
<td>Instrumentation Tests &amp; Development</td>
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<td>International Flight Tests</td>
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<td>Atmosphere characterization</td>
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<td></td>
<td>SP2 - Flight Tests</td>
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<td>SP3 - Meteo</td>
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<td>SP4 - Detection and Awareness Technology</td>
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<td></td>
<td>SP5 - Icing Wind Tunnels / Tests</td>
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<tr>
<td></td>
<td>SP6 - Tools and Simulation</td>
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<tr>
<td>2013</td>
<td>TRL3</td>
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International Activities
- NPRM10-10 Integration of Ind. Comments
- EUROCAE WG89 Activities / TSO update
- NPA Proposal
- NPA Integration of Ind. Comments
- SAE AC-9C Activities on update of ARPs

Regulation Activities
- European Icing Tunnel Tests Development
- European IWT Calibration
- Tests in IWT: Detection means & Models Validation (V&V)
- European Ice Particles and accretion Models & Tools development
- European Ice Particles and accretion Models & Tools validation in IWT

TLR3 Technology Concept
TLR2 Technology Analysis
TLR4 Technology Development and Laboratory Tests
TLR5 Technology Validation
TLR6 Technology Validation

Spaceborne retrievals of high IWC

European Flight Tests

NASA M&T activities

Instrumentation Validation

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Consortium

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<tr>
<th>Airframers</th>
<th>Airbus</th>
<th>Dassault</th>
<th>AleniaAerospace</th>
<th>Piaggio Aero</th>
<th>AR</th>
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<tr>
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<td>Safran</td>
<td>MTU Aero Engines</td>
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<tr>
<td>Management</td>
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HAIC – High Altitude Ice Crystals
International Cooperation

• Icing is a sensitive topic related to environmental aspects and certification

• European Commission is encouraging international cooperation on this subject especially with North America (US and Canada)

• Airbus and some partners of the HAIC consortium are already involved within International Working Groups which include international companies and organizations
  • EIWG : Engine Icing Working Group / ICC: Ice Crystals Consortium

• From an Airbus point of view, International cooperation is welcomed to address such a topic
  • No competitive issue,
  • Common aeronautical industry position in front of Airworthiness Authorities,
  • Joint development of AMC,
  • Joint specification of equipments (probes, detection and awareness technologies,...), etc...
International collaboration should be promoted and enhanced.

Such a collaboration should benefit the whole international aeronautical industry.

Areas for further collaboration

Darwin HIWC International Flight Test Campaign for atmosphere characterization - planned in Jan 2012 (trial campaign) and Jan-March 2013.

HAIC would bring the French Falcon 20 research aircraft to Darwin, Australia, equipped with the LATMOS 95 GHz multi-beam Doppler radar and a suite of state-of-the-art in-situ microphysical probes (2D-S, PIP, CIP, CPI, and bulk IWC measurements from the Robust and Nevzorov probes,...) deployed by LAMP and the French Falcon 20 operator (SAFIRE).
HAIC – High Altitude Ice Crystals
International Cooperation

• Any other collaboration item may be studied (physical phenomena understanding and modeling, test facilities enhancement, etc.)
  • Note: 1st CANNAPE Workshop held on June 23rd
HAIC – High Altitude Ice Crystals Status & Way Forward

- *Detailed HAIC synopsis distributed on June 9th*
- *1st HAIC Workshop on July 4th at Airbus, Toulouse*
- *FP7 Transport Info Days on July 18-19*
- *2nd HAIC Workshop to be planned in Oct 2011*
  - First Draft proposal available: Technical content, Budget,...
- *Final proposal submitted on 1st December 2011*
- *Evaluation by Q1 2012*
- *Start, if successful, expected in June-Sep 2012*
HAIC – High Altitude Ice Crystals
Technical Description - SP0: Management

**Objective:** Write and implement a project master plan giving the milestones & report timing, costing and monitor the timely performance of the project and perform administrative tasks with the EC. Dissemination. Interaction with other organizations, etc...
## HAIC – High Altitude Ice Crystals
### Technical Description – SP1: Instrumentation

### SP 1 - Instrumentation

**Objectives:**
- Develop adequate technology to measure ice particles in atmosphere,
- Provide technology and support to flight tests campaigns planned as part of the SP2,
- Provide technology and support to the development and calibration of icing facilities planned as part of the SP5,
- Provide support to SP6 for flight test results analysis

<table>
<thead>
<tr>
<th>WP 1.0 : WP Coordination</th>
<th>WP 1.1: Development of icing instrumentation</th>
<th>WP1.2: Support to Atmosphere measurement</th>
<th>WP1.3: Support to Icing Wind Tunnels Calibration</th>
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<tr>
<td>Gaps analysis,</td>
<td>Provide adequate technology for flight tests campaigns,</td>
<td>Provide adequate technology for flight tests campaigns,</td>
<td>Provide adequate technology for icing wind tunnels calibration campaigns,</td>
</tr>
<tr>
<td>Define specifications for instrumentation to measure icing conditions,</td>
<td>Provide installation definition for flight tests aircraft,</td>
<td>Calibrate new technologies,</td>
<td>Provide installation definition for icing wind tunnels calibration campaigns,</td>
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<tr>
<td>Support the development of icing probes,</td>
<td>Calibrate new technologies,</td>
<td>Support SP6 in flight tests results validation and analysis.</td>
<td>Calibrate new technologies,</td>
</tr>
<tr>
<td>Validate the new technologies via tests campaigns.</td>
<td></td>
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<td>Support SP5 in tunnel tests results validation and analysis.</td>
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</table>
## SP 2 – Flight Tests

### Objectives:
- Collaborate to international flight tests research campaigns on atmosphere characterization,
- Validate new technologies developed as part of the SP1 (Instrumentation) and SP4 (detection and awareness technologies),
- Provide data to define and then to validate simulation tools (interface with SP6).

<table>
<thead>
<tr>
<th>WP 1.0 : WP Coordination</th>
<th>WP 2.1: Flight tests for Atmosphere Characterization</th>
<th>WP2.2: Flight tests for validation of new technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ensure WP coordination and report to SP0</td>
<td>• Collect data and create database on icing conditions to evaluate the conditions that need to be furthermore investigated, • Collaborate and participate to HIWC flight test campaign, • Perform measurements of atmosphere for different icing conditions, • Provide flight tests results to SP3 (Meteo).</td>
<td>• Install new technologies provided by SP1 (instrumentation) and SP4 (detection and awareness technologies) on Flight test Aircraft, with adequate instrumentation to validate their functioning, • Install adequate instrumentation requested by SP6 to validate methods and tools, • Perform flight tests to validate the good functioning of new technologies in icing conditions and to validate new methods and tools (TRL6 demonstration), • Provide flight tests results to SP1 (Instrumentation), SP4 (Detection and awareness technologies) and SP6 (Tools &amp; Simulation).</td>
</tr>
</tbody>
</table>
HAIC – High Altitude Ice Crystals  
Technical Description – SP3: Meteo

**Objectives:**
- To characterize the microphysical properties of the HighIWC regions (total concentration NT, ice water content IWC, visible extinction $\alpha$, effective radius $R_e$, terminal fall speed $V_T$, ...) based on F/T performed as part of the SP2
- To improve and evaluate spaceborne retrieval of high IWC
- To test and evaluate nowcasting of IWC in weather forecast models

<table>
<thead>
<tr>
<th>WP 3.0: WP Coordination</th>
<th>WP 3.1: Microphysical properties of the high IWC regions using F/T observations</th>
<th>WP3.2: Spaceborne retrievals of high IWC</th>
</tr>
</thead>
</table>
| • Ensure WP coordination and report to SP0  
• Monitor progress against Milestone and Deliverable plans and plan corrective actions where required | • Characterize the microphysical properties of the High high IWC regions (total concentration, ice water content IWC, ...) based on F/T performed as part of the SP2  
• Update/validate representation of atmospheric icing conditions to support rulemaking activities and new standards establishment | • Combining in situ measurements and collocated satellite images, characterize the signature of IWC in spaceborne passive remote sensing systems.  
• Develop automated real time data processing of satellite passive remote sensing measurements to identify IWC and support assimilation in numerical weather forecast.  
• Evaluate the performance of IWC nowcasting techniques against in situ measurements |
### HAIC – High Altitude Ice Crystals
Technical Description – SP4: Detection & Awareness Technologies

#### SP 4 – Detection & Awareness Technologies

**Objectives:**
- Define requirements for new technologies (icing conditions, weight, cost, reliability, performance...),
- Develop adequate technology to be able to detect all icing conditions,
- Provide technology and support to SP2 (Flight tests) and SP5 (Test capability)

<table>
<thead>
<tr>
<th>WP 4.0 : WP Coordination</th>
<th>WP 4.1: Definition of new technologies specification</th>
<th>WP4.2: Development of icing conditions detectors</th>
<th>WP4.3: Development of icing conditions awareness systems</th>
</tr>
</thead>
</table>
| • Ensure WP coordination and report to SP0  
  • Monitor progress against Milestone and Deliverable plans and plan corrective actions where required | • Collect data and create database on existing detectors to evaluate the gaps between needs and existing solutions,  
  • Define specifications for new technologies needed | • Support the development of ice detectors,  
  • Validate the new technologies via tests campaigns. | • Support the development of awareness systems,  
  • Validate the new technologies via tests campaigns. |
# HAIC – High Altitude Ice Crystals
## Technical Description – SP5: Test Capability

### Objectives:
- Define the icing conditions that need to be reproduced in icing wind tunnel, based on analysis of gaps between needs and existing solutions,
- Develop technologies allowing the reproduction of icing conditions, Perform icing tunnel calibration,
- Validate SP1 (Instrumentation) and SP4 (Detection and awareness technologies) technologies,
- Support the development and the validation of methods and tools planned as part of the SP6

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<thead>
<tr>
<th>WP 5.0 : WP Coordination</th>
<th>WP 5.1: Analysis of the needs</th>
<th>WP5.2: Icing Wind Tunnel Development</th>
<th>WP5.3: Icing Wind Tunnel Calibration</th>
<th>WP5.4: Icing Tunnel Tests</th>
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</thead>
</table>
| • Ensure WP coordination and report to SP0  
  • Monitor progress against Milestone and Deliverable plans and plan corrective actions where required | • Needs and gaps analysis,  
• Define specifications for new technologies needed to reproduce the considered icing conditions,  
• Update specifications with SP2 flight tests results when available. | • Support the development of icing conditions production devices,  
• Validate the new technologies via tests campaigns with the support of SP1. | • Measure icing conditions in the wind tunnel test section thanks to existing instrumentation (SP1) and perform calibration of the IWT, | • Perform icing tests on technologies developed by SP1 and SP4 to validate good functioning of new devices : TRL4/5 demonstration,  
• Perform icing tests to validate methods and tools developed as part of the SP6. |
# HAIC – High Altitude Ice Crystals
## Technical Description – SP6: Tools & Simulation

### SP 6 – Tools & Simulation

<table>
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<th>Objectives:</th>
<th>WP 6.1: Develop Ice particles trajectory models</th>
<th>WP 6.2: Develop Ice particles accretion model</th>
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</table>
| • Develop validated models and tools to be used during both design and certification phases of new technologies | • Needs and gaps analysis,  
• Perform laboratory tests to understand and characterize physical phenomena and to support model development  
• Develop a European model for ice crystals trajectory,  
• Define flight tests plan and/or icing tunnel tests plan for model validation,  
• Validate model. | • Needs and gaps analysis,  
• Perform laboratory tests to understand and characterize physical phenomena and to support model development  
• Develop a European model for ice crystals accretion (ice shedding and coupling aspects for anti-icing or de-icing systems should be part of the proposed models),  
• Improve/adapt ice accretion tools  
• Define flight test plan and/or icing tunnel tests plan for model validation,  
• Validate model. |

- WP 6.0: WP Coordination
  - • Ensure WP coordination and report to SP0  
  - • Monitor progress against Milestone and Deliverable plans and plan corrective actions where required