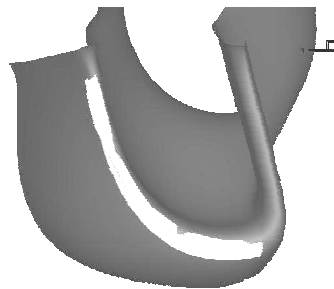


3D ICE ACCRETION WORKSHOP
AIAA Atmospheric and Space Environments Conference
Toronto, Ontario, Canada



3D ICE ACCRETION WORKSHOP
AIAA Atmospheric and Space Environments Conference
Toronto, Ontario, Canada

Contents

- ✓ **Current means of 3-D validations**
- ✓ **3-D databases that are publicly available**
- ✓ **Issues and concerns for supporting validation data and inter-code comparisons studies**
- ✓ **Interest in supporting future AIRA working groups to continue developing the principles of this workshop**



3D ICE ACCRETION WORKSHOP
AIAA Atmospheric and Space Environments Conference
Toronto, Ontario, Canada

Current means of 3-D validations

- **Data from public literature**
- **CIRA own IWT, but usually test results are client 'property' and cannot be used for validation issues**
- **For 3D shapes difficulties in defining 'quantitative criteria'**



3D ICE ACCRETION WORKSHOP
AIAA Atmospheric and Space Environments Conference
Toronto, Ontario, Canada

3-D databases that are publicly available

- **In the following is reported a list of reports that have been used by CIRA for 3D validation purposes**



3D ICE ACCRETION WORKSHOP
AIAA Atmospheric and Space Environments Conference
Toronto, Ontario, Canada

Papadakis, M., Hung, K. E., Vu, G. T., Wei Yeong, H., Bidwell, C., Breer, M., Bencic, T. J., Experimental Investigation of Water Droplet Impingement on Airfoils, Finite Wings, and an S-Duct Engine Inlet, NASA/TM2002-211700, 2002.

Very good amount of impingement data:

**NACA 64A008 Swept Tail
25%-Scale Business Jet Empennage (BJE)
Full-Scale Business Jet Horizontal Tail
S-duct Engine Inlet**

All geometries are available, only S duct geometry is not available



3D ICE ACCRETION WORKSHOP
AIAA Atmospheric and Space Environments Conference
Toronto, Ontario, Canada

Bidwell, C., and Papadakis, M., Collection Efficiency and Ice Accretion Characteristics of Two Full Scale and One 1/4 Scale Business Jet Horizontal Tails, NASA/TM2005-213653, 2005.

swept NACA 64A008, swept finite wing with a GLC-305 : ice shapes, impingement coefficient. Geometries not provided have to be collected from other sources

“Experimental Investigation of Ice Accretion Effects on a Swept Wing “ DOT/FAA/AR-05/39

Geometries, ice shapes and impingement quantitative data not provided, paper mainly addressed to icing performance degradation



3D ICE ACCRETION WORKSHOP
AIAA Atmospheric and Space Environments Conference
Toronto, Ontario, Canada

Bidwell, C., and Mohler, S. R. , Collection Efficiency and Ice Accretion Calculations for a Sphere, a Swept MS(1)-317 Wing, a Swept NACA-0012 Wing Tip, an Axisymmetric Inlet, and a Boeing 737-300 Inlet, NASA Technical Memorandum 106831, AIAA-95-075, 1995.

Collection Efficiency and Ice Accretion for a Sphere, a Swept MS(1)-317 Wing, a Swept NACA-0012 Wing Tip, an Axisymmetric Inlet, and a Boeing 737-300 Inlet

All geometries available, only Boeing 737-300 geometry not available



3D ICE ACCRETION WORKSHOP
AIAA Atmospheric and Space Environments Conference
Toronto, Ontario, Canada

Papadakis, M., Elangonan, R., Freund, G.A., Breer, M., Zumwalt, G.W., and Whitmer, L. "An Experimental Method for Measuring Water Droplet Impingement Efficiency on Two- and Three-Dimensional Bodies", NASA Contractor Report 4257-DOT/FAA/CT87/22, 1989.

Geometries and impingement data for several test article (wing and air inlet) available

Colin S. Bidwell "Collection Efficiency and Ice Accretion Calculations for a Boeing 737-300 Inlet", NASA Technical Memorandum 107347

3D axisymmetric air intake: impingement data and geometry available (different angle of attack and flow rate). 737-300 air intake: impingement data available, geometry not available

3D ICE ACCRETION WORKSHOP

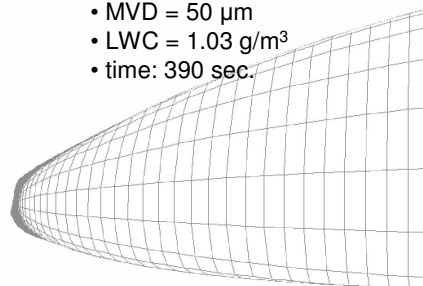
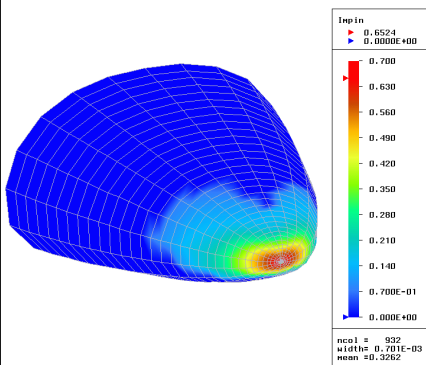
AIAA Atmospheric and Space Environments Conference
Toronto, Ontario, Canada

Issues and concerns for supporting validation data and inter-code comparisons studies

- Main concern is related to data availability. Present interest on swept wing and air-intakes, but also rotorcraft and fuselages
- CIRA interested in inter-code comparison, but reference experimental data (even from public literature as to be identified)
- Missing data on full 3D geometries such as air-intakes and fuselages

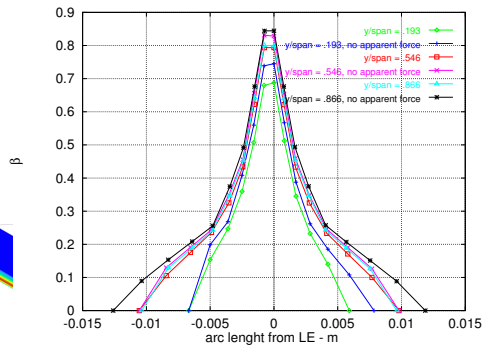
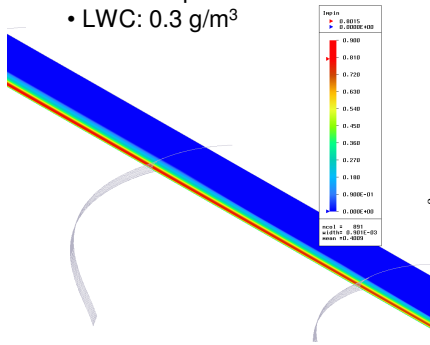
Example of past 3D ice accretion analysis from CIRA: Impingement and ice accretion on Helicopter nose: no available experimental data

- nose length: 1 m
- $M_\infty = 0.23$
- $T_\infty = 255 \text{ K}$
- $\text{AoA} = 0^\circ$
- $\text{MVD} = 50 \mu\text{m}$
- $\text{LWC} = 1.03 \text{ g/m}^3$
- time: 390 sec.



Additional complicated cases: ice accretion on helicopter blade in hover

- Span: 1.045 m
- chord: .0762 m
- AoA: 0°
- M_{tip} : 0.8
- MVD: 20 μm
- LWC: 0.3 g/m^3



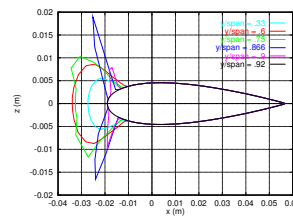
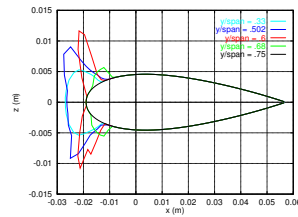
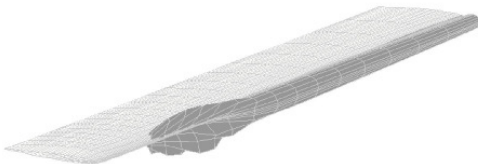
Use or disclosure of the information contained herein is subject to specific written CIRA approval

Additional complicated cases: ice accretion on helicopter blade in hover

T = 265 K



T = 255 K



Use or disclosure of the information contained herein is subject to specific written CIRA approval

UH-1H helicopter rotor blade with a NACA 0012 airfoil

- ✓ Test in hover condition in 1982-83 by NASA Lewis Research Center and US army
- ✓ Test performed by using NRC spray rig in Ottawa

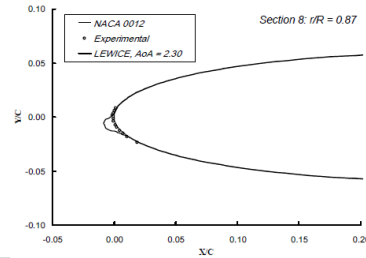
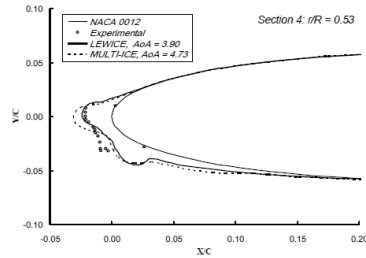
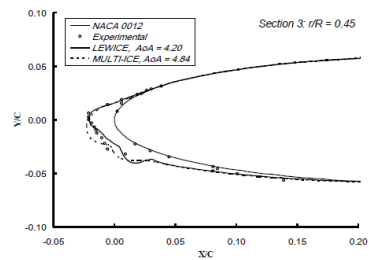
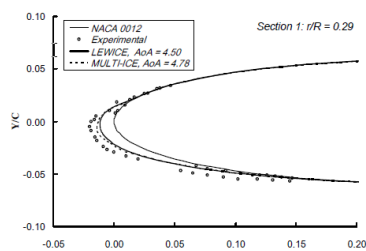


| Fit Number | Wind Speed (m/s) | Gusts | LWC (gm/m ³) | T Ambient °C | Time (min) | Ice Extent (r/R) |
|------------|------------------|--------|--------------------------|--------------|------------|------------------|
| A | 3.6 | Medium | 0.4 | -12.0 | 4.5 | 0.75 |
| B | 5.1 | Medium | 0.4 | -9.5 | 4.25 | 0.65 |
| C | 3.0 | Medium | 0.4 | -17.5 | 4.0 | |
| D | 2.1 | Low | 0.4 | -21.5 | 6.0 | |
| E | 4.6 | Low | 0.7 | -19.0 | 3.0 | 0.92 |

Numerical analysis Work performed within a Boeing-Philadelphia and CIRA cooperation: SAE paper 2007-01-3309 "Ice accretion Prediction on Helicopter Rotor Blade in Hover Flight" G. Zanazzi, G. Mingione, A. Pagano, A. Visingardi (CIRA), R. Narducci (the Boeing company)

Use or disclosure of the information contained herein is subject to specific written CIRA approval

UH-1H helicopter rotor blade with a NACA 0012 airfoil

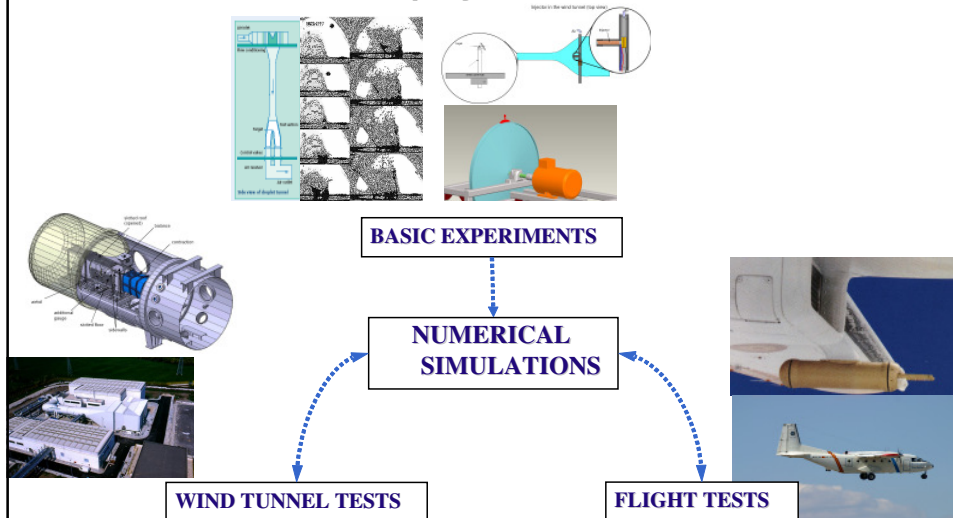


Use or disclosure of the information contained herein is subject to specific written CIRA approval

The EXTICE project: EXTrime ICing Environment

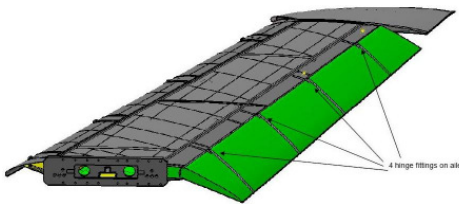
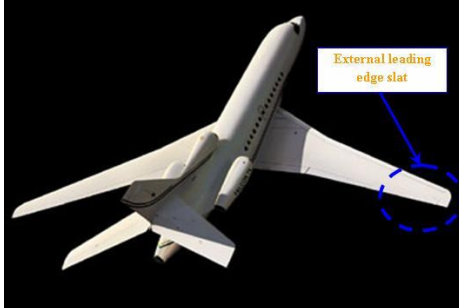
1. Industrial partners
 - ✓ Alenia, Piaggio, Dassault, Airbus, Eurocopter, ATR
2. Basic SLD droplets physics studies
 - ✓ Un. of Cranfield, Un. of Dortmund, ONERA
3. Inclusion of basic physics result in industrial ice accretion model
 - ✓ CIRA, INTA, ONERA, Un. of Napoli, Un. of Twente
4. Industrial validation test
 - ✓ CIRA, CepR, INTA

EXTICE project rationale





EXTICE Test Article IWT test



- External leading edge wing section
- Full scale
- length 3.17 m
- span 2.67 m
- sweep angle 32.65 deg
- chord at the root of the model 1.81 m
- chord at the tip 1.22 m
- Slat: tests in both clean (0 deg angle deflection) and extended configuration (35 deg angle deflection)
- Flap: pressure distribution over the model surface adjustment

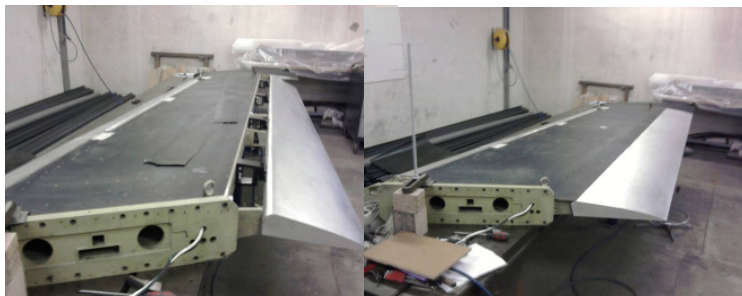
Use or disclosure of the information contained herein is subject to specific written CIRA approval

17



EXTICE 3D tests

EXTICE Test article



Use or disclosure of the information contained herein is subject to specific written CIRA approval

18



Test matrix

| Run n. | Test article | LWC g/m3 | MVD micron | T C° | Alpha deg | V m/s | Time sec | Time sec |
|--------|----------------|----------|------------|------|-----------|-------|----------|---------------------|
| 1 | Slat closed | LWC1 | D1 | -25 | 0 | 60 | 300 | * Water imp. |
| 2 | Slat closed | LWC1/2 | D1 | -25 | 0 | 60 | 600 | * Water imp. |
| 3 | Slat closed | LWC1 | D2 | -25 | 0 | 60 | 300 | * Water imp. |
| 4 | Slat closed | LWC1 | SLD1 | -25 | 0 | 60 | 300 | * Water imp. |
| 5 | Slat closed | LWC1 | SLD2 | -25 | 0 | 60 | 300 | * Water imp. |
| 6 | Slat closed | LWC1 | SLD3 | -25 | 0 | 60 | 300 | * Water imp. |
| 7 | Slat closed | LWC1 | SLD4 | -25 | 0 | 60 | 300 | * Water imp. |
| 8 | Slat deflected | LWC1 | D1 | -25 | 0 | 60 | 300 | * Water imp. |
| 9 | Slat deflected | LWC1 | D2 | -25 | 0 | 60 | 300 | * Water imp. |
| 10 | Slat deflected | LWC1 | SLD1 | -25 | 0 | 60 | 300 | * Water imp. |
| 11 | Slat deflected | LWC1 | SLD2 | -25 | 0 | 60 | 300 | * Water imp. |
| 12 | Slat deflected | LWC1 | SLD3 | -25 | 0 | 60 | 300 | * Water imp. |
| 13 | Slat deflected | LWC1 | SLD4 | -25 | 0 | 60 | 300 | * Water imp. |
| 14 | Slat deflected | LWC1 | SLD3 | -5 | 0 | 60 | 300 | * Temperature sweep |
| 15 | Slat deflected | LWC1 | SLD3 | -10 | 0 | 60 | 300 | * Temperature sweep |
| 16 | Slat deflected | LWC1 | SLD3 | -15 | 0 | 60 | 300 | * Temperature sweep |
| 17 | Slat deflected | LWC2 | SLD3 | -10 | 0 | 60 | 300 | * LWC sweep |
| 18 | Slat deflected | LWC3 | SLD3 | -10 | 0 | 60 | 300 | * LWC sweep |
| 19 | Slat deflected | LWC1 | SLD3 | -10 | 4 | 60 | 300 | * alpha-sweep |
| 20 | Slat deflected | LWC1 | SLD3 | -10 | 8 | 60 | 300 | * alpha-sweep |
| 21 | Slat deflected | LWC1 | SLD3 | -10 | 10 | 60 | 300 | * alpha-sweep |
| 22 | Slat deflected | LWC1 | SLD3 | -10 | 12 | 60 | 300 | * alpha-sweep |

Use or disclosure of the information contained herein is subject to specific written CIRA approval

19



EXTICE Flight tests

Flight tests under icing conditions will be performed by INTA (C212 research aircraft).

The objective of the flight tests will be to collect ice shapes under SLD conditions and to use this ice shape for numerical code validation.

INTA will perform two flight test programs, the duration of each being 10 hours.

Original plan to measure icing on wing or empennage not feasible, ice accretion on an 'ad-hoc' probe

Use or disclosure of the information contained herein is subject to specific written CIRA approval

20

Instrumentation

Basic meteorological instrumentation:
Static pressure sensor, Rosemount temperature, Humidity EGG

Cloud microphysical instrumentation:
FSSP-100 ER (5-95 μm)
OAP-2D2-C (25-800 μm)
King probe
Data Acquisition system
Video Camera

Performance instrumentation:
Accelerometers, turn rates,
pitch, roll, yaw, TAS, GPS, etc

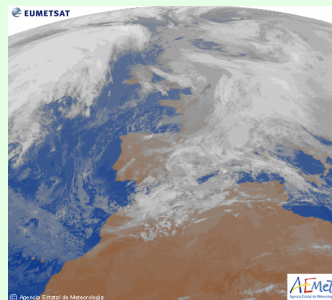


INTA C-212 research aircraft

Planning

Preliminary calibration test performed

Flight test planned next winter





3D ICE ACCRETION WORKSHOP
AIAA Atmospheric and Space Environments Conference
Toronto, Ontario, Canada

Interest in supporting future AIRA working groups to continue developing the principles of this workshop

- **CIRA has a strong interest in supporting AIRA**
- **Due to travel cost it is proposed to limit number of meeting and use TELECON or alternative systems.**
- **Piaggio aerindustries, Dassault and Alenia also showed interest in the topic and could be involved**