Aerodynamics and Flight Mechanics

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SMART ICING SYSTEMS
Research Organization

Core Technologies

- Aerodynamics and Propulsion
- Flight Mechanics
- Control and Sensor Integration
- Human Factors
- Aircraft Icing Technology

IMS Functions

- Characterize Icing Effects
- Operate and Monitor IPS
- Envelope Protection
- Adaptive Control

System Research/Integration

- Flight Simulation
- Flight Test

Aerodynamics and Flight Mechanics

Objective:

1) Develop linear and nonlinear iced aircraft models
2) Develop steady state icing characterization methods and identify aerodynamic sensors
3) Identify envelope protection needs and methods
4) Support neural network training, flight simulator development and flight test

Approach:

First use Twin Otter and tunnel data to develop a linear clean and iced model. Use the models to develop characterization and envelope protection. Flight Test Data will then be used to develop and validate the characterization,envelope protection and aircraft models.

Iced Aircraft Models

- Developed clean and iced aircraft model
  - Next generation aircraft based on NASA Twin Otter Flight Dynamics
  - Linear stability and control model based on published data
  - Used to develop characterization methods, flight simulator, etc.
- Nonlinear models:
  - CFD research
  - Neural net based method
  - Model based on B.A.R. tunnel data

Linear Aerodynamics Model Development

- Clean stability and control derivative model from published NASA Twin Otter data
- Iced model development:
  - Based on NASA Twin Otter data
  - Models for completely iced aircraft and tail-only iced aircraft developed from composite of various sources
  - Iced models originally for a single icing encounter
  - η_{ice} model developed to interpolate/extrapolate to other conditions

η_{ice} Model

- A linear icing effects model was developed that modified the different stability and control derivatives for various levels of icing

$$C_{(A)iced} = (1 + \eta_{ice} k'_{C_A}) C_{(A)}$$

- $C_{(A)}$ = arbitrary stability and control derivative
- η_{ice} = icing severity parameter
- k'_{C_A} = coefficient icing factor

h_{ice} Formulation

$$\eta_{ice} = \frac{\Delta C_d(\text{IRT airfoil data})}{\Delta C_{d_{ref}}(\text{IRT airfoil data, cont. max. conditions}, t = 10 \text{ min})}$$

- ΔC_d fit as a function of n and $A_c E$
  - ΔC_d data obtained from NASA TMs 83556 and 105374, and NACA TNs 4151 and 4155
  - n = freezing fraction
  - A_c = accumulation parameter
  - E = collection efficiency
- ΔC_{dref} calculated from ΔC_d equation using continuous maximum conditions

h Formulation

- To capture effects of aircraft geometry, the aircraft specific icing severity factor, η, was developed
- The aircraft specific icing severity factor incorporates the aircraft specific airfoil, chord, and angle of attack

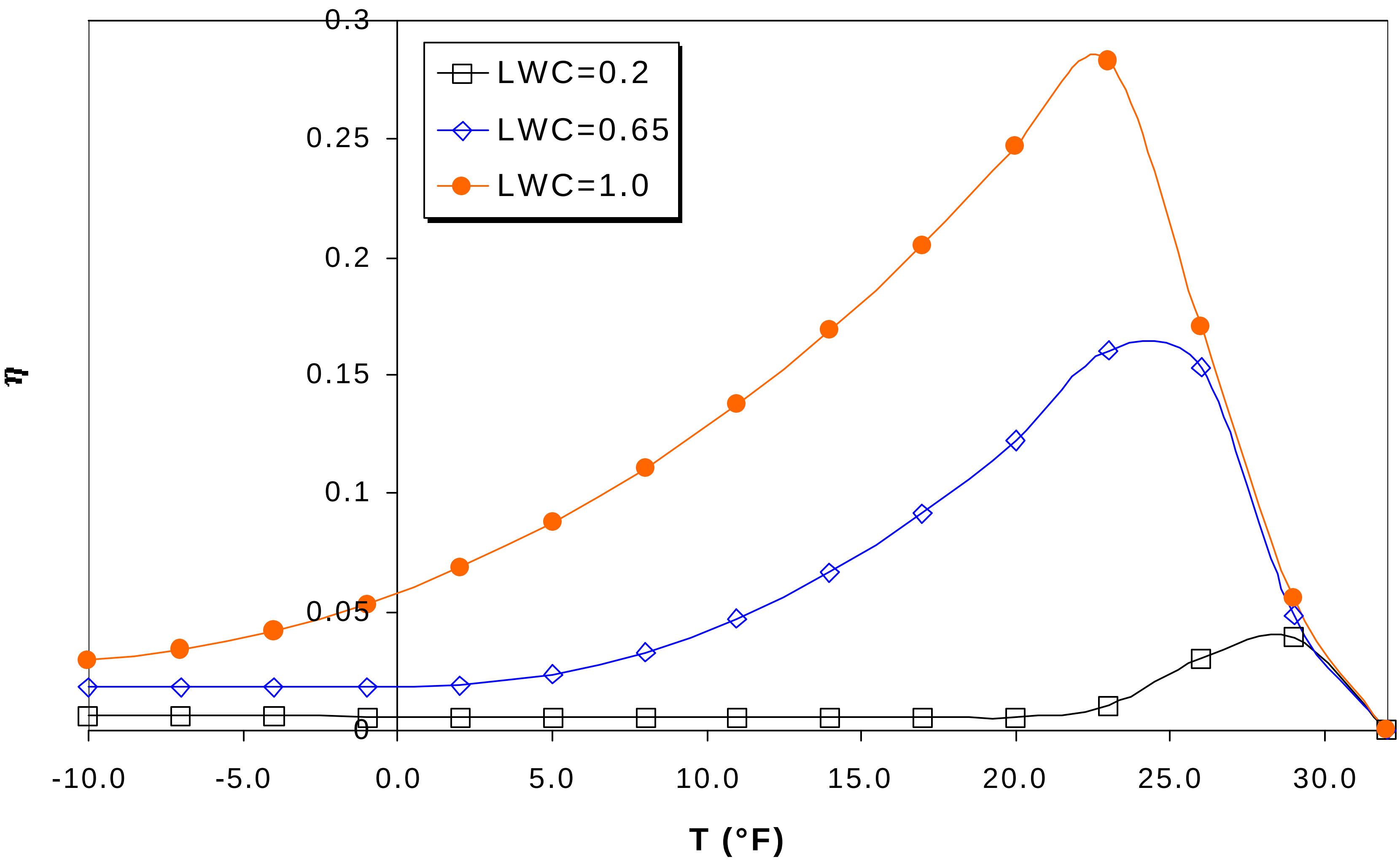
$$C_{(A)iced} = (1 + \eta_{ice}\, k'_{C_A})\, C_{(A)}$$

$$k'_{C_A} = \frac{\eta}{\eta_{ice}} k_{C_A}$$

Differences Between η and η_{ice}

	η_{ice}	η
Chord	3 ft.	Actual
Airfoil	NACA 0012	Actual
Velocity	175 knots	Actual
Angle of Attack	0°	Actual
MVD	Actual	Actual
LWC	Actual	Actual
T_∞	Actual	Actual
Time of encounter	Actual	Actual

Effect of T and LWC on h



Twin Otter

V≈130 kts

MVD=20 μm

h=9000 ft

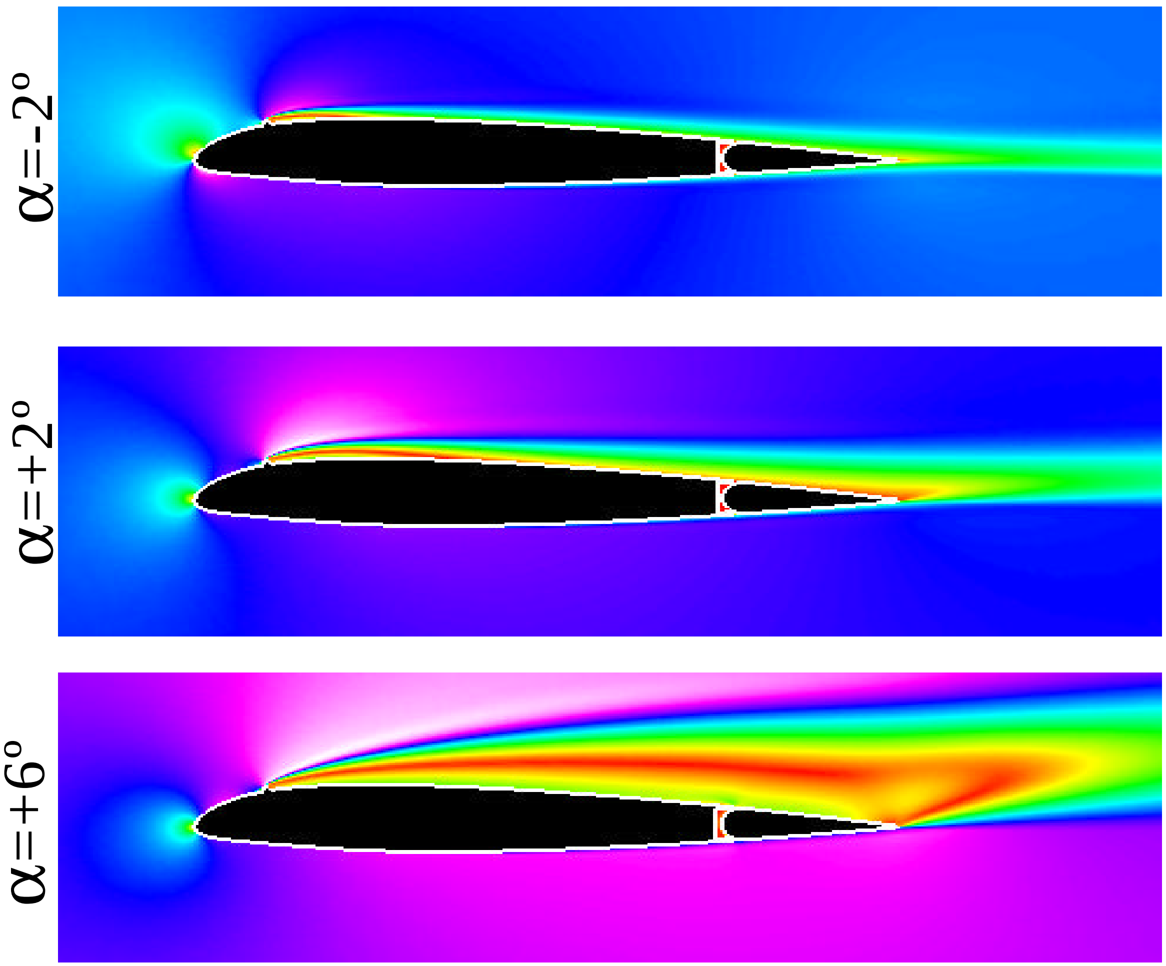
Time=600 s

CFD Efforts To Provide Aero Data

- NSU2D predictions with upper-surface ice shapes
- WIND predictions for leading-edge ice shapes
- Detached Eddy Simulation, DES, development with WIND to increase separated flow predictive performance for $C_{L,max}$
- After some exploratory research this method for building Aerodynamic aircraft models was abandoned. Research in icing CFD continues funded through other programs

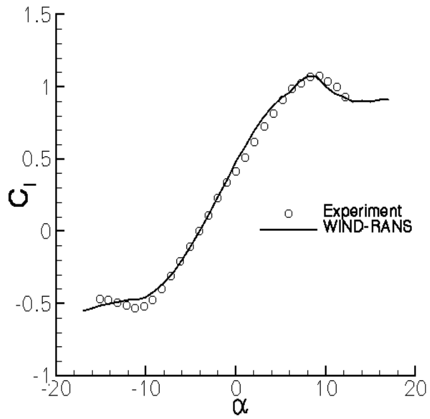
Velocity Contours

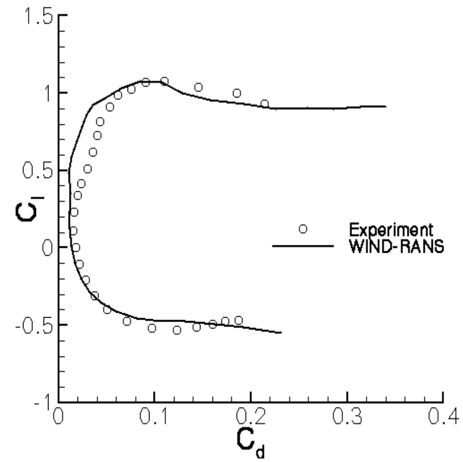
- NACA 23012m
- 0.15” Quarter Round at x/c=0.10
- B.L. tripped
- Re=1.8x10^6



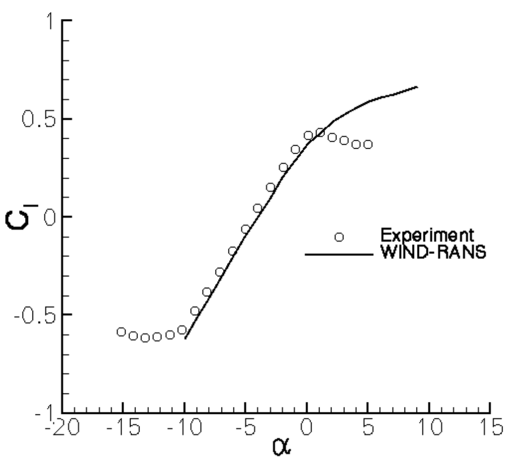
Iced NLF- 0414 Airfoil: Horn Ice

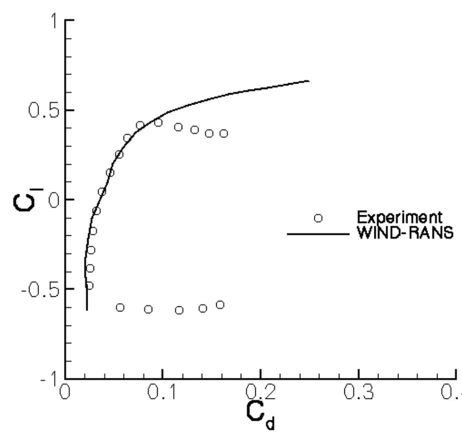
Re=1.8 x 10^6, Ma=0.185





s/c=0%
k/c=6.67%





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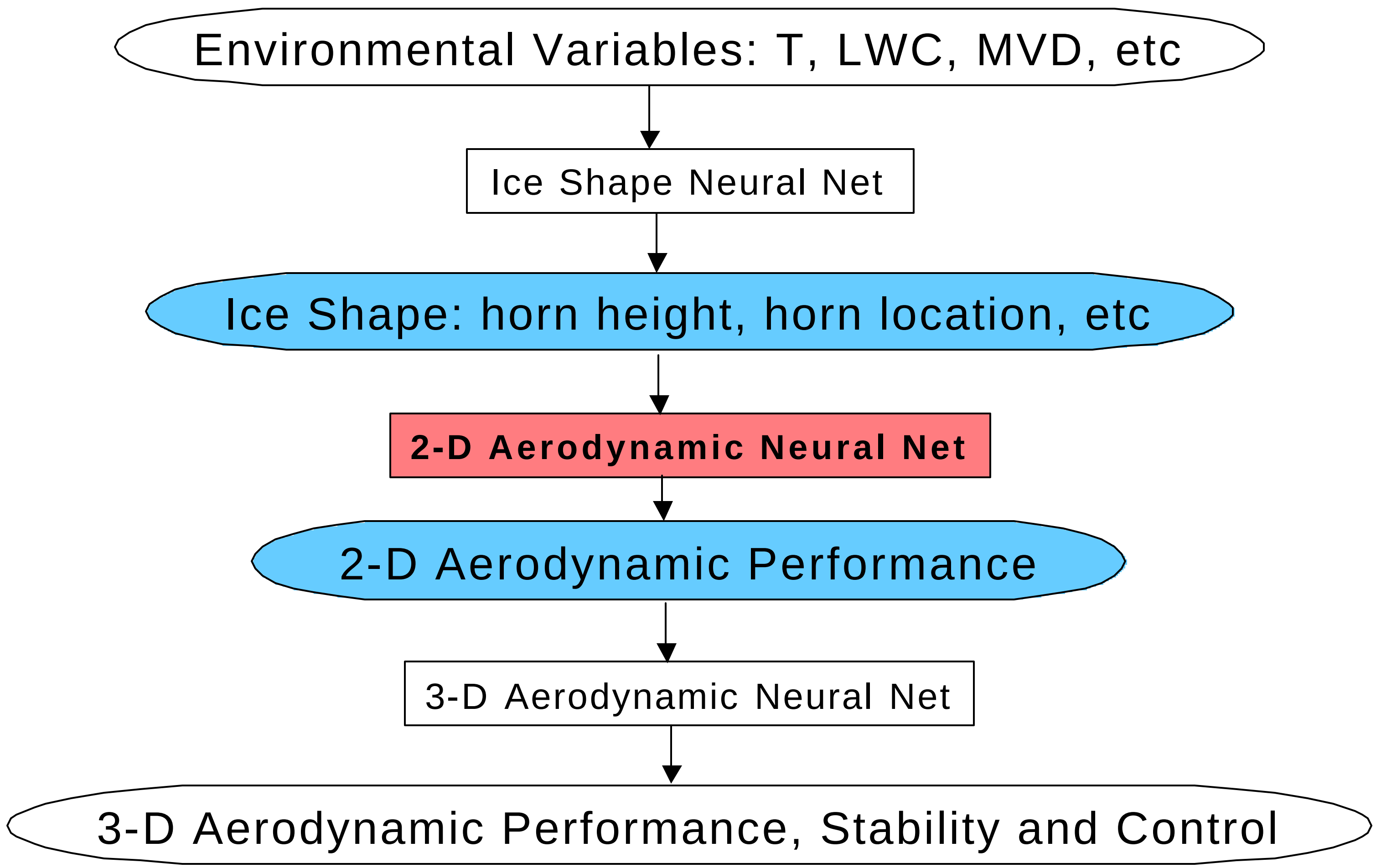
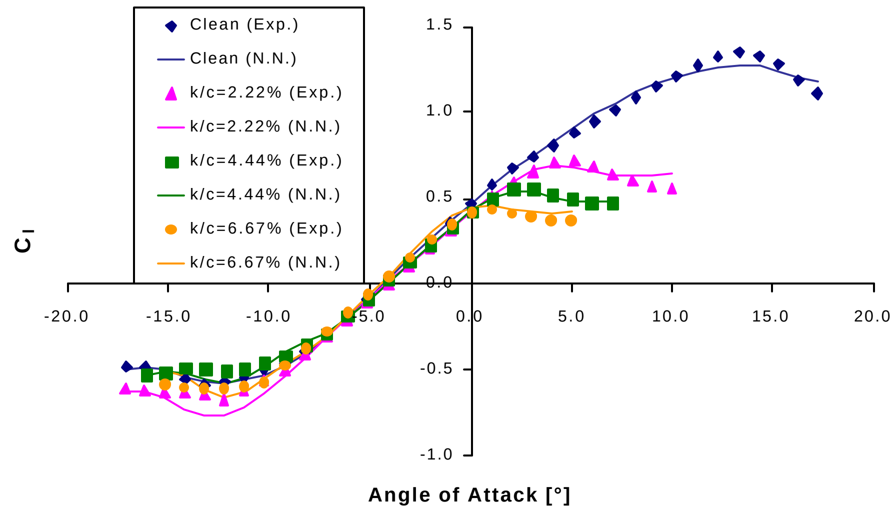
Neural Network Aero Model Approach

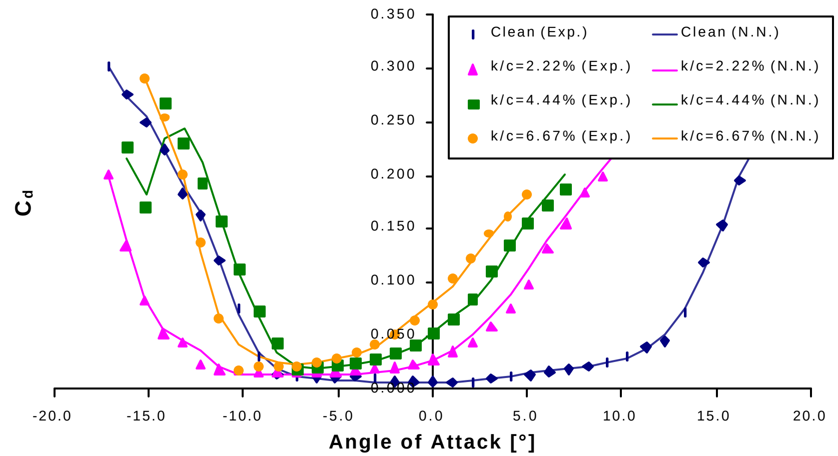
Proposed Neural Network approach to icing effects modeling:

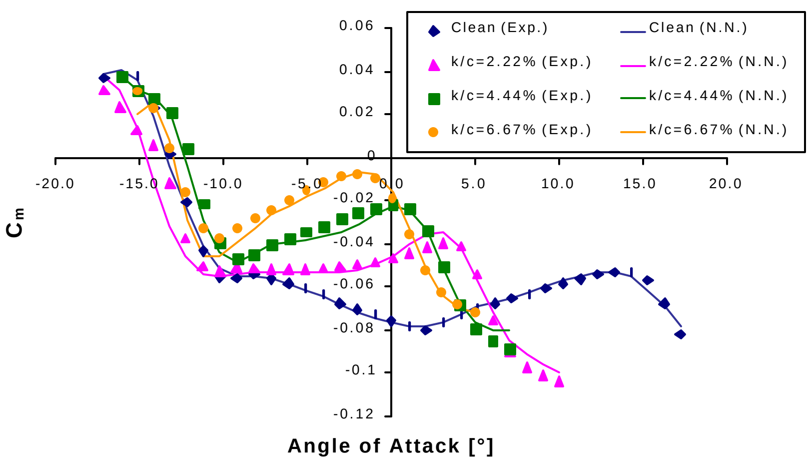


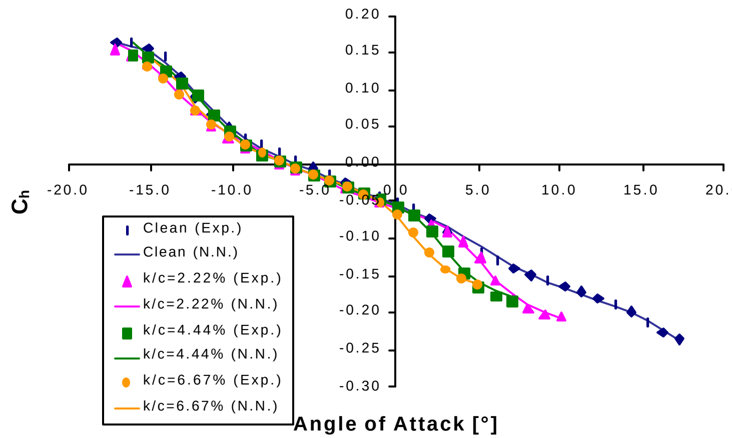
Neural Net Prediction of Airfoil Aero Coefficients

Smart Icing Systems Review, May 28, 2003









Non-linear Aerodynamics Model

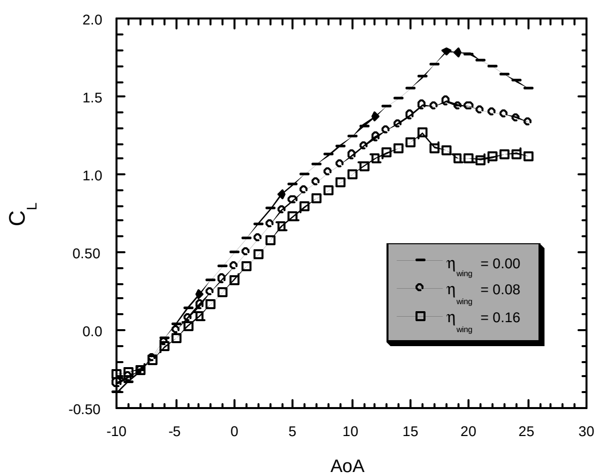
- Model based on B.A.R. rotary balance test results on the Twin Otter model
- Changes in the forces and moments were modeled as functions of icing

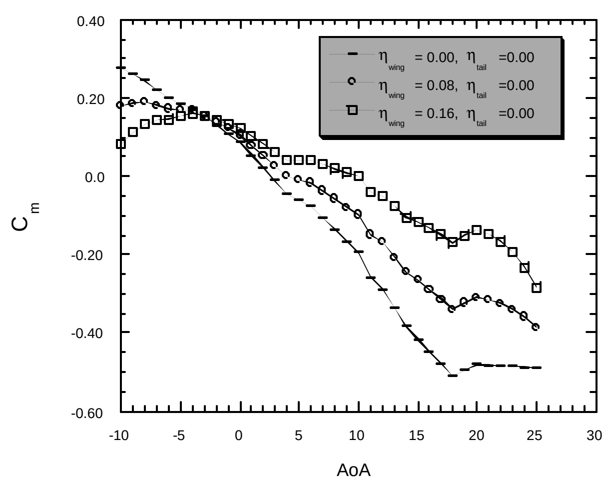
$$C_{(A)iced} = C_{(A)clean} + k_{C_{(A)},a} h_{wing} C_{(A)clean} + k_{C_{(A)},de} h_{tail} C_{(A)clean}$$

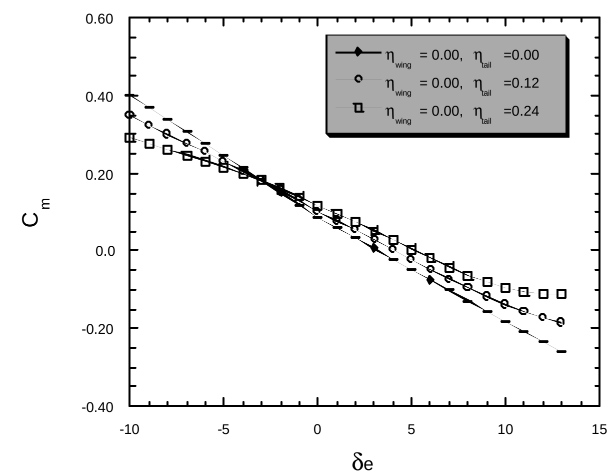
-C_A : Force or moment coefficient of interest

- η : Icing severity factor

-K_{CA}: Scaling factor for a particular force or moment coefficient







Flight Dynamics Code, FDC

- Flight Dynamics Code 1.3
  - FDC 1.3 is a free source code developed by Marc Rauw
  - Developed using Matlab and Simulink
  - 6 DoF equations, 12 nonlinear ODEs
  - Autopilot/open loop simulations
  - Atmospheric turbulence model (Dryden spectral model)
  - Code modifications
    - Nonlinear aerodynamic model capability
    - Changes in derivatives due to ice accretion simulated as a function of time
    - Incorporated sensor noise
    - Included hinge moment models
    - Simulated gravity waves and microbursts
    - Pitch rate due to wind gusts (q_g)
    - Envelope Protection

Flight Mechanics Analysis Example

- Aircraft Conditions
  - Altitude of 7550 ft
  - Velocity of 155 kts
  - $\eta(t = 0\ s) = 0.0$
  - $\eta(t = 600\ s) = 0.10$
  - Turbulence: z-acceleration RMS = 0.15 g
- Referenced From
  - Devesh Pokhariyal's Thesis
  - AIAA 2000-0360
  - AIAA 2001-0541

Flight Mechanics Analysis Example

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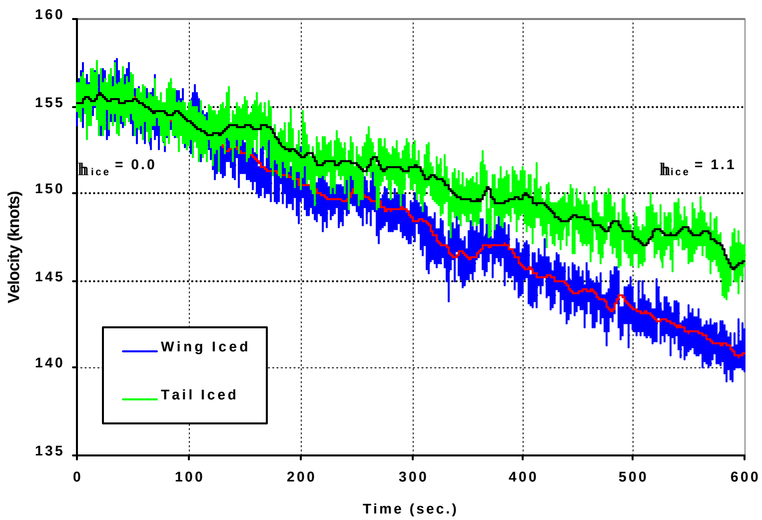

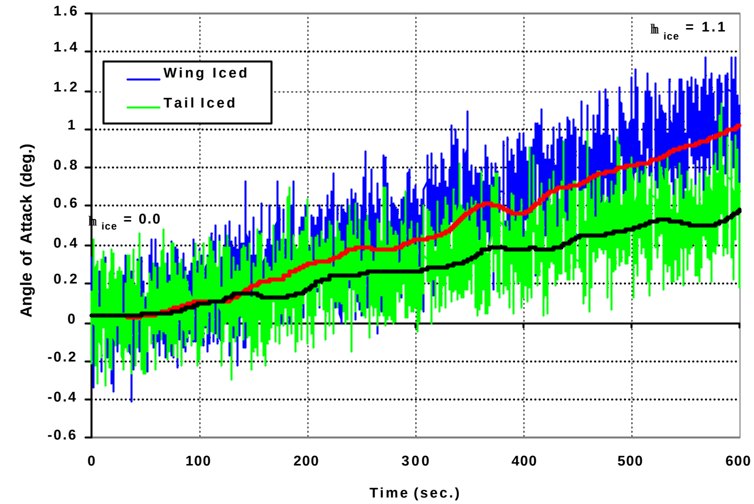

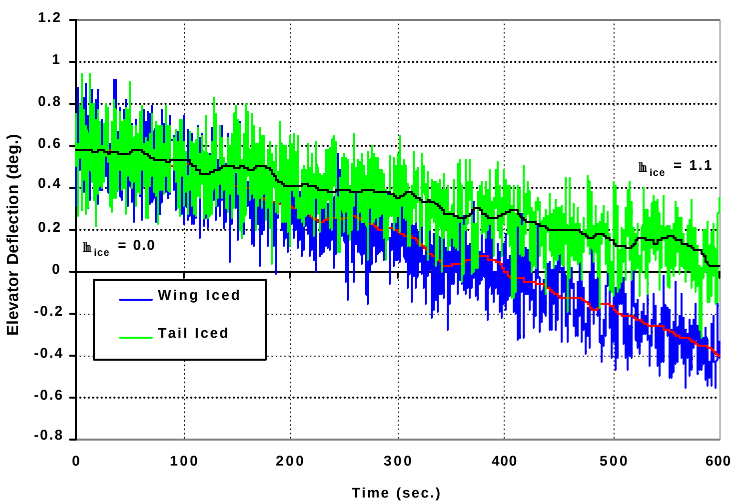

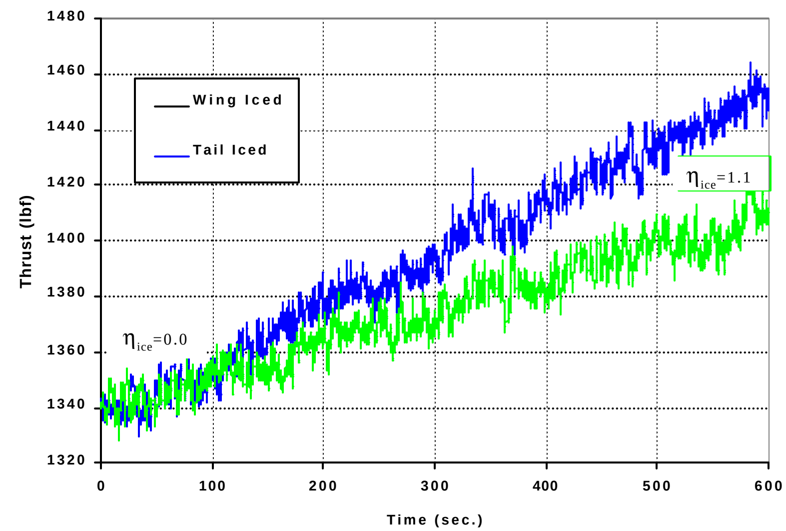

Hinge-Moment Models

- Models are used in simulations to study the potential use of hinge moment sensors as aerodynamic performance monitors
- C_h and C_{h_rms} capture the effects of icing on the flow field over the airfoil surface.
- C_{h_rms} is the RMS of the unsteady hinge moment, which is a measure of flow field separation due to ice accretion
- Models based on hinge moment measurements taken at UIUC on a NACA 23012 airfoil with quarter round ice-shapes (AIAA 99-3149)

Flight Mechanics Analysis Example

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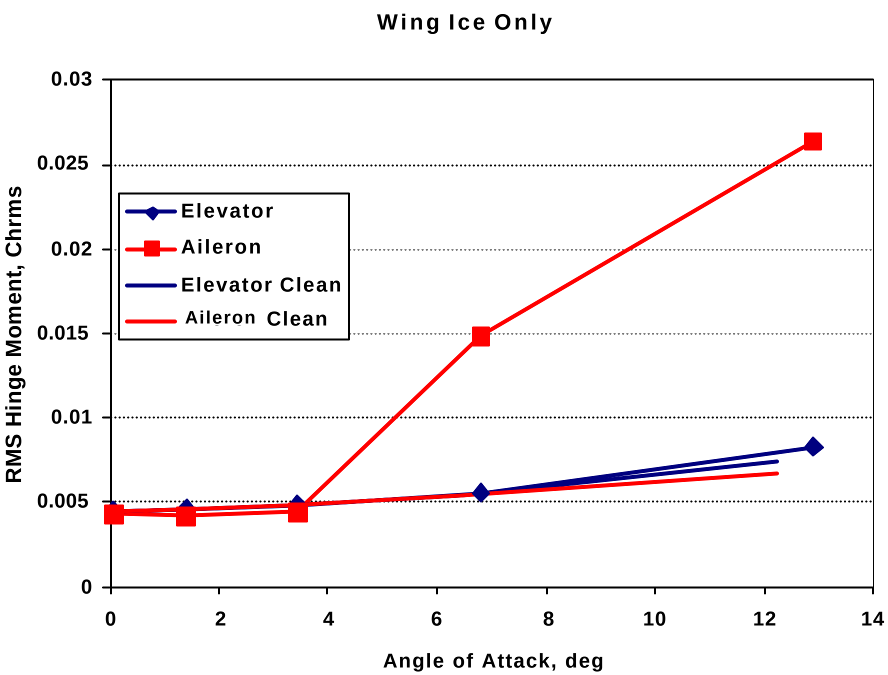
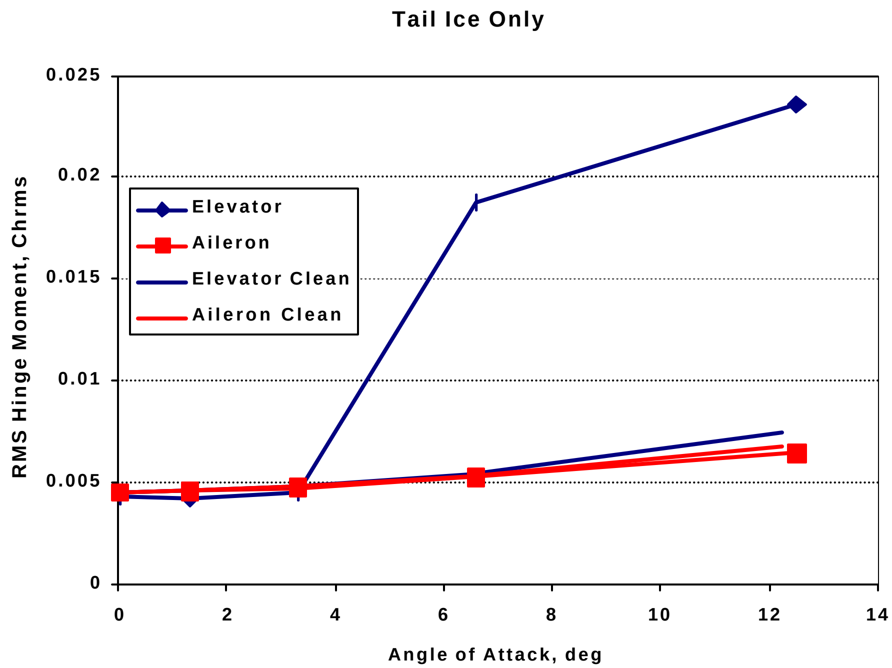




- Control surface hinge moment can help identify ice location

Atmospheric Effects on Characterization

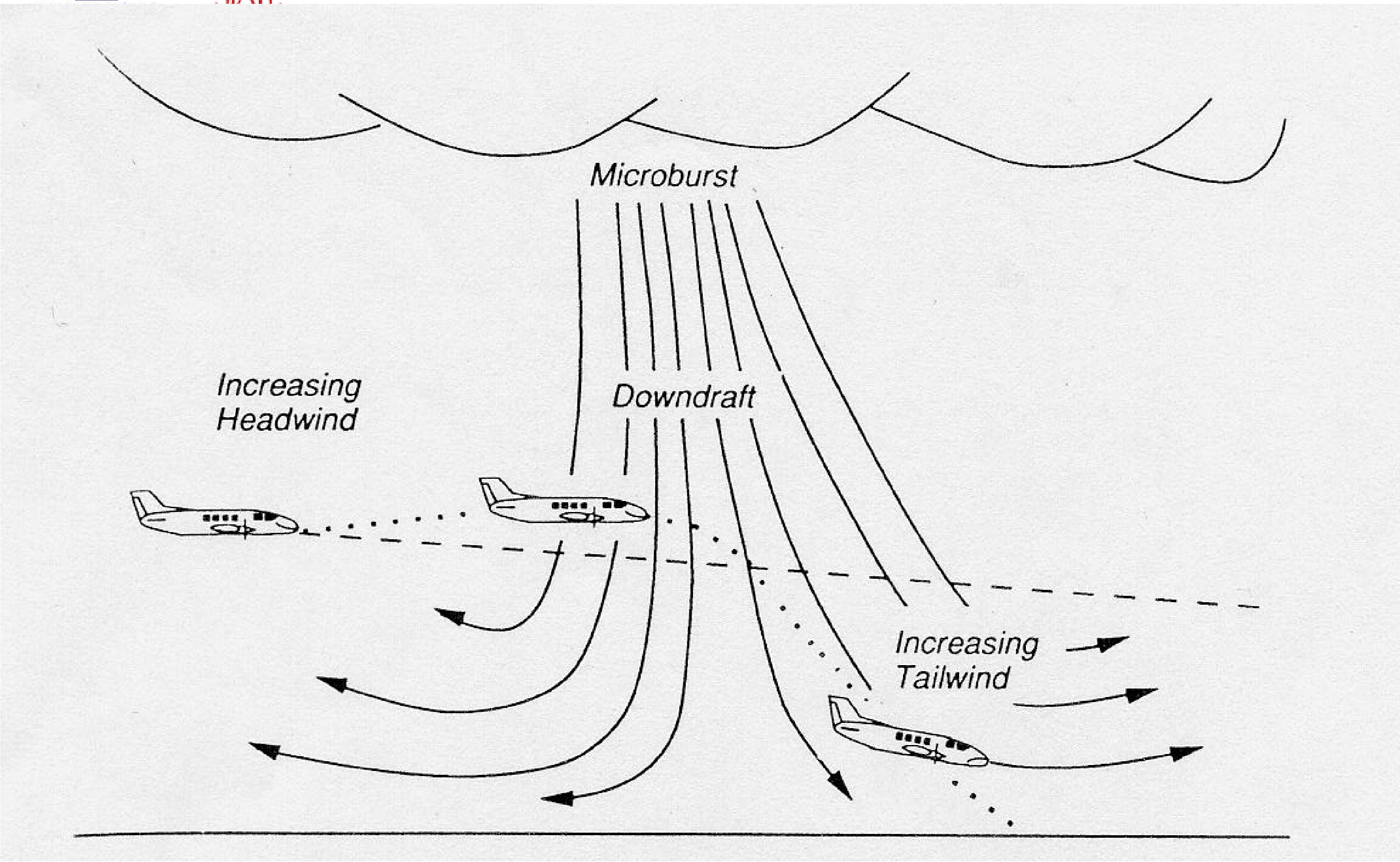
- Concerns about false alarms in the Smart Icing System were raised at Reno 2000
- Since the effects of windshear and other atmospheric disturbances may be similar to icing, false alarms in the Smart Icing System could possibly occur
- Study performed to analyze the effects of microbursts, windshear, and icing on aircraft
- For more information see:

  Jason Merret M.S. thesis,

  AIAA 2001 - 0541,

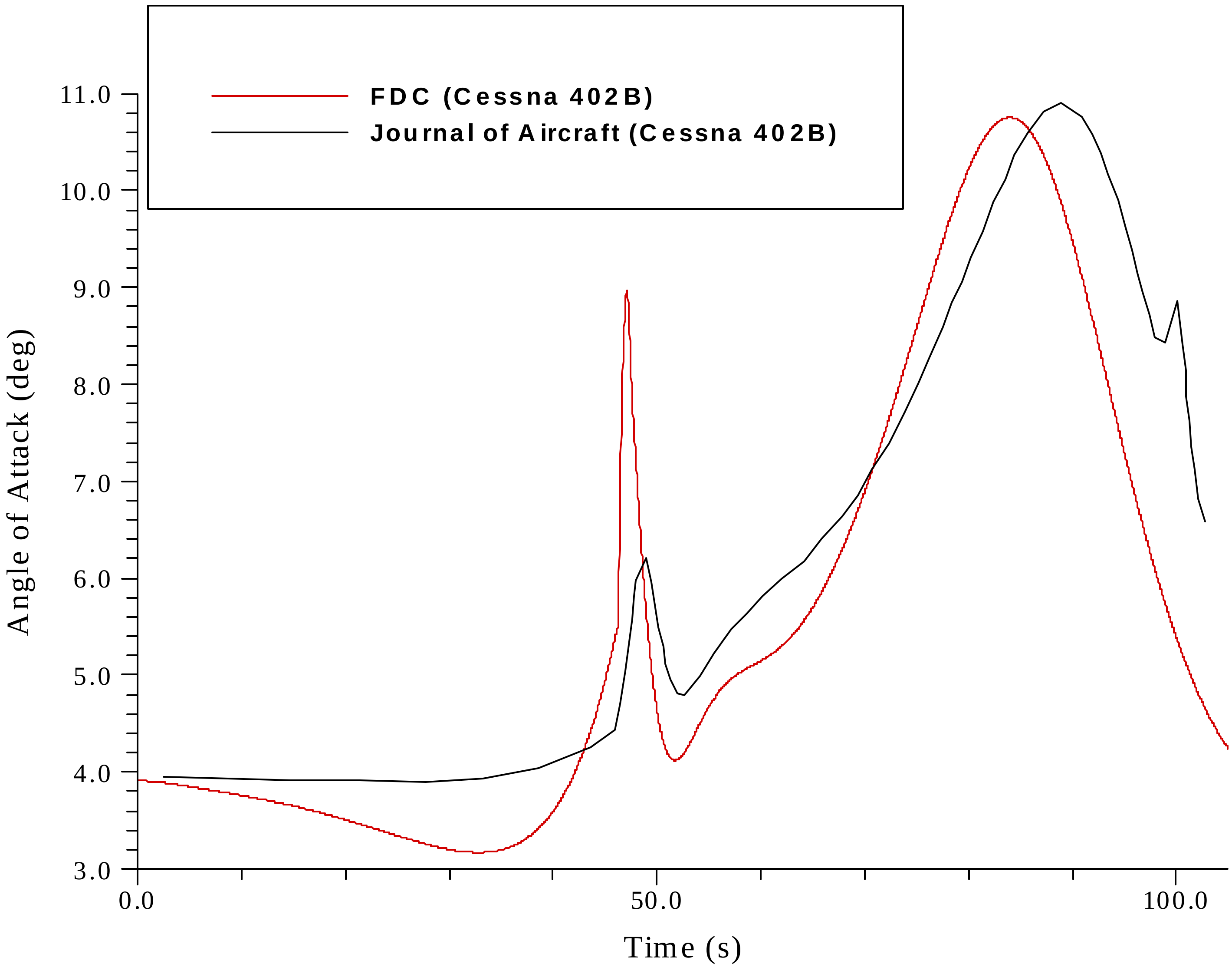
  AIAA 2002 - 0814

Microburst

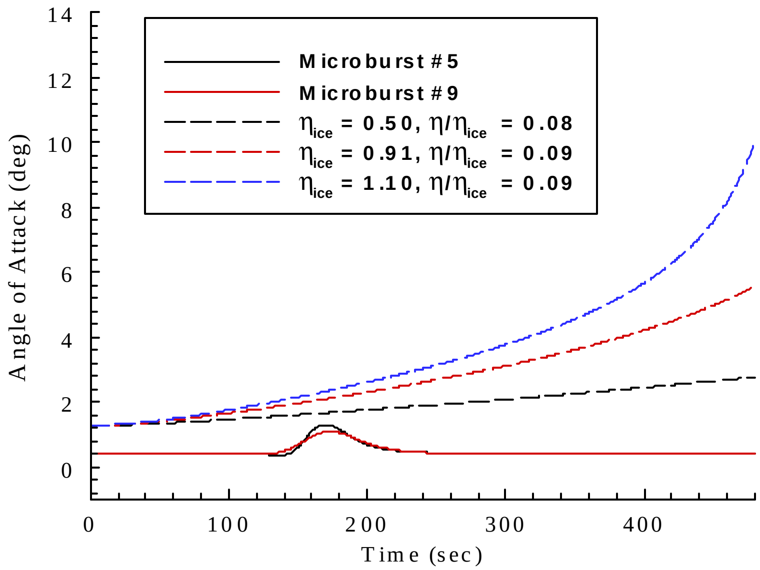


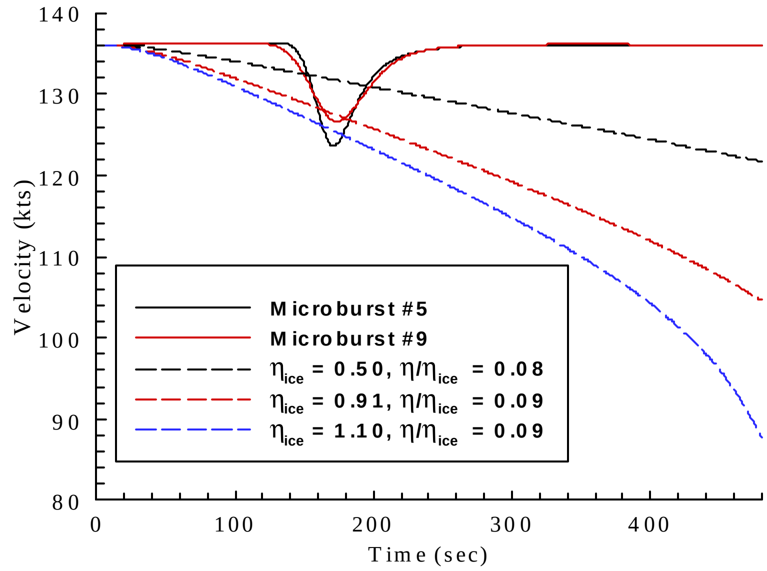
- Taken From Mulgund and Stengel, *Journal of Aircraft,* 1993
- Microburst model used from Oseguera and Bowles, NASA TM 100632

Wind Model Validation



Results for Microbursts and Icing

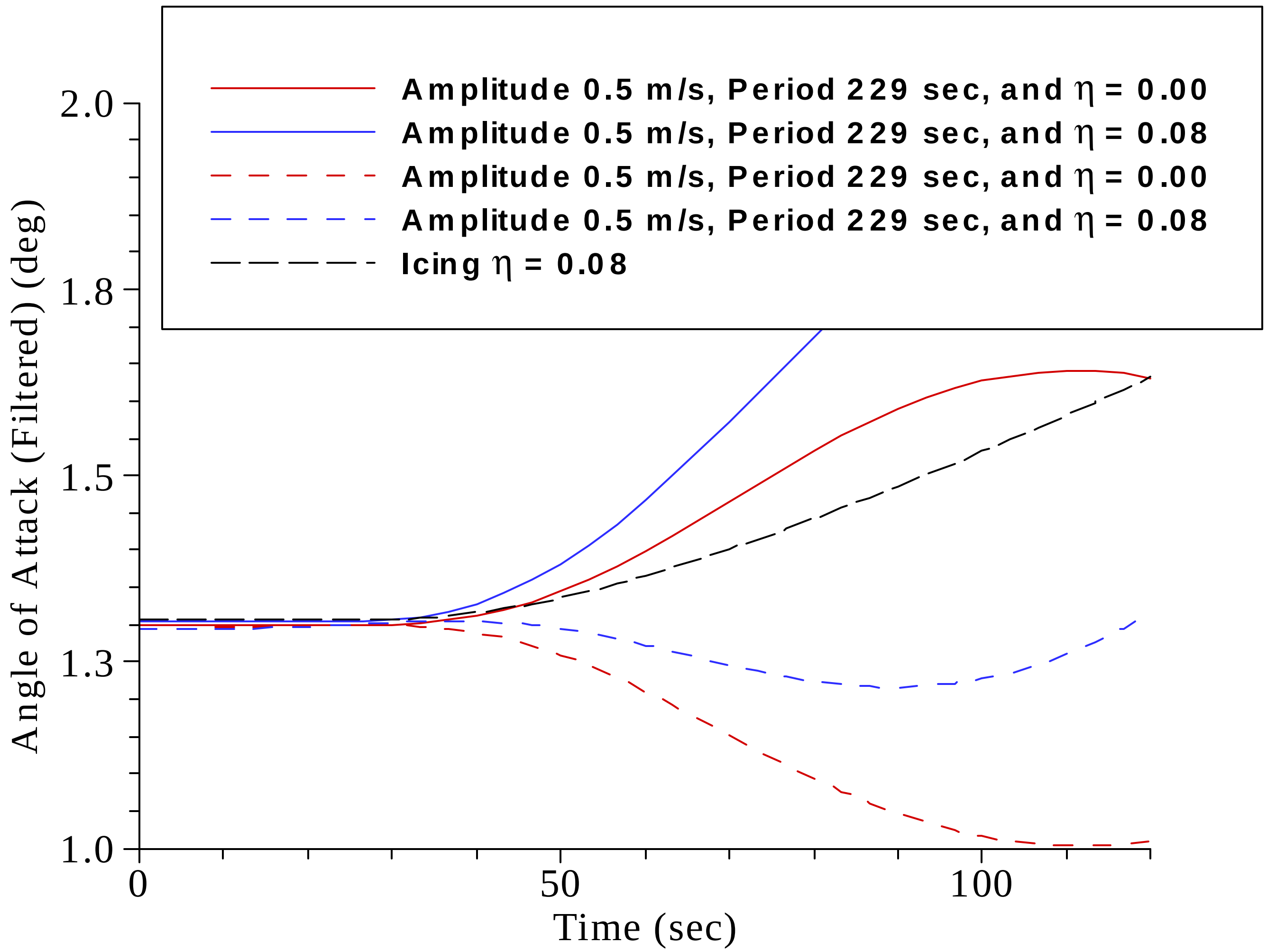




Gravity Waves

- Result of density variation with height
- Commonly caused by mountains
- Propagate vertically
- Horizontal wavelengths vary from 1 km to 100+ km
- Velocity amplitudes are small in the troposphere, but can be large in the mesosphere
- Gravity waves and icing are not exclusive events and frequently occur simultaneously

Icing and Gravity Wave Results



Conclusions

- Simulation capability developed through modified FDC code
- Linear and nonlinear aero models developed based on experimental data
- Microburst characteristics fundamentally different and should be distinguishable
- Atmospheric effects such as gravity waves may need to be considered in IMS design