Aerodynamics and Flight Mechanics

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SMART ICING SYSTEMS
Research Organization

Core Technologies

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

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IMS Functions

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

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Flight Simulation Demonstration

Safety and Economics Trade Study

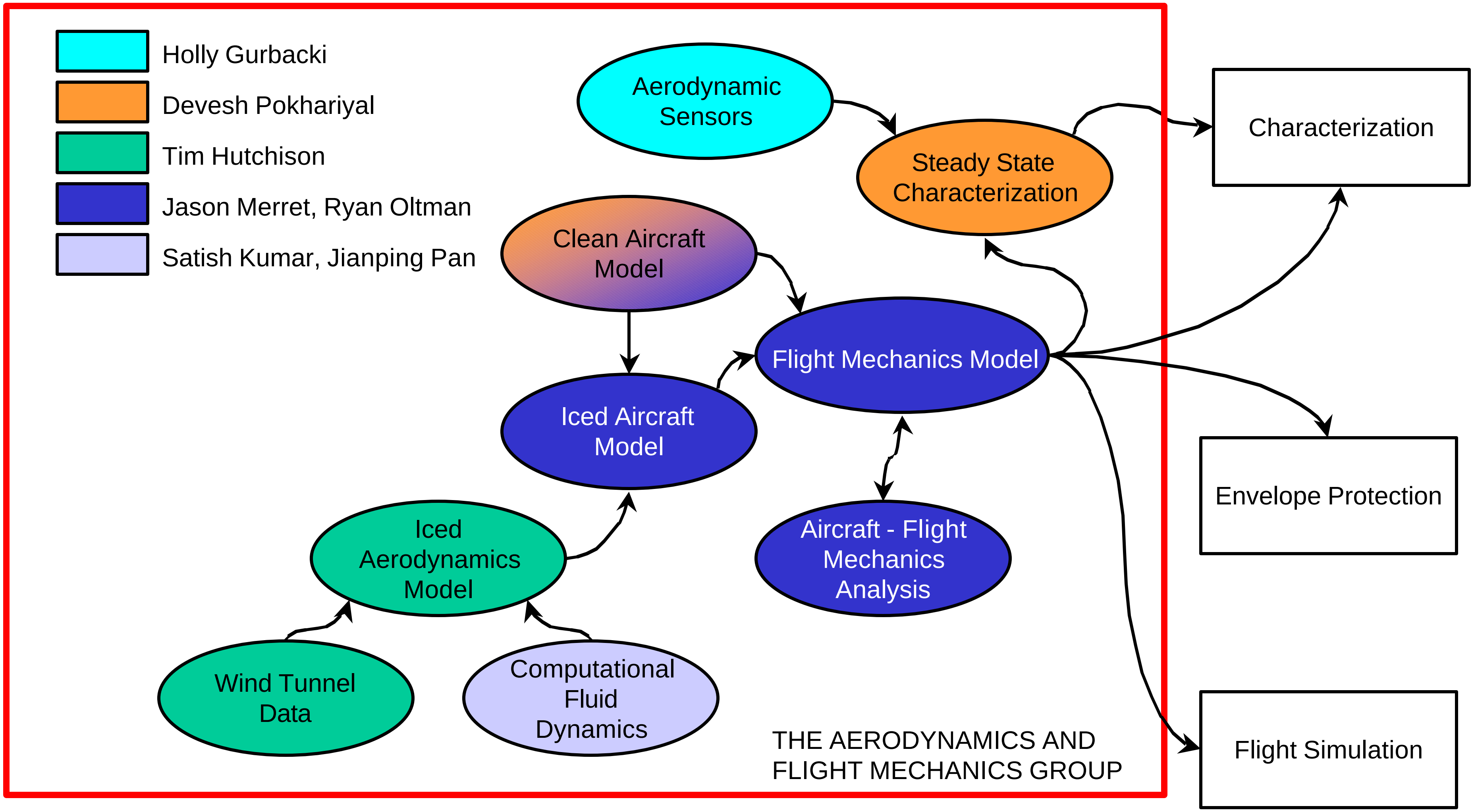
Aerodynamics and Flight Mechanics

Goal: Improve the safety of aircraft in icing conditions.

Objective:
1) Develop steady state icing characterization methods and identify aerodynamic sensors.
2) Develop linear and nonlinear iced aircraft models.
3) Identify envelope protection needs and methods.

Approach: First use Twin Otter and tunnel data to develop a linear clean and iced model. Then develop a nonlinear model with tunnel and CFD data. Use the models to develop characterization and envelope protection.

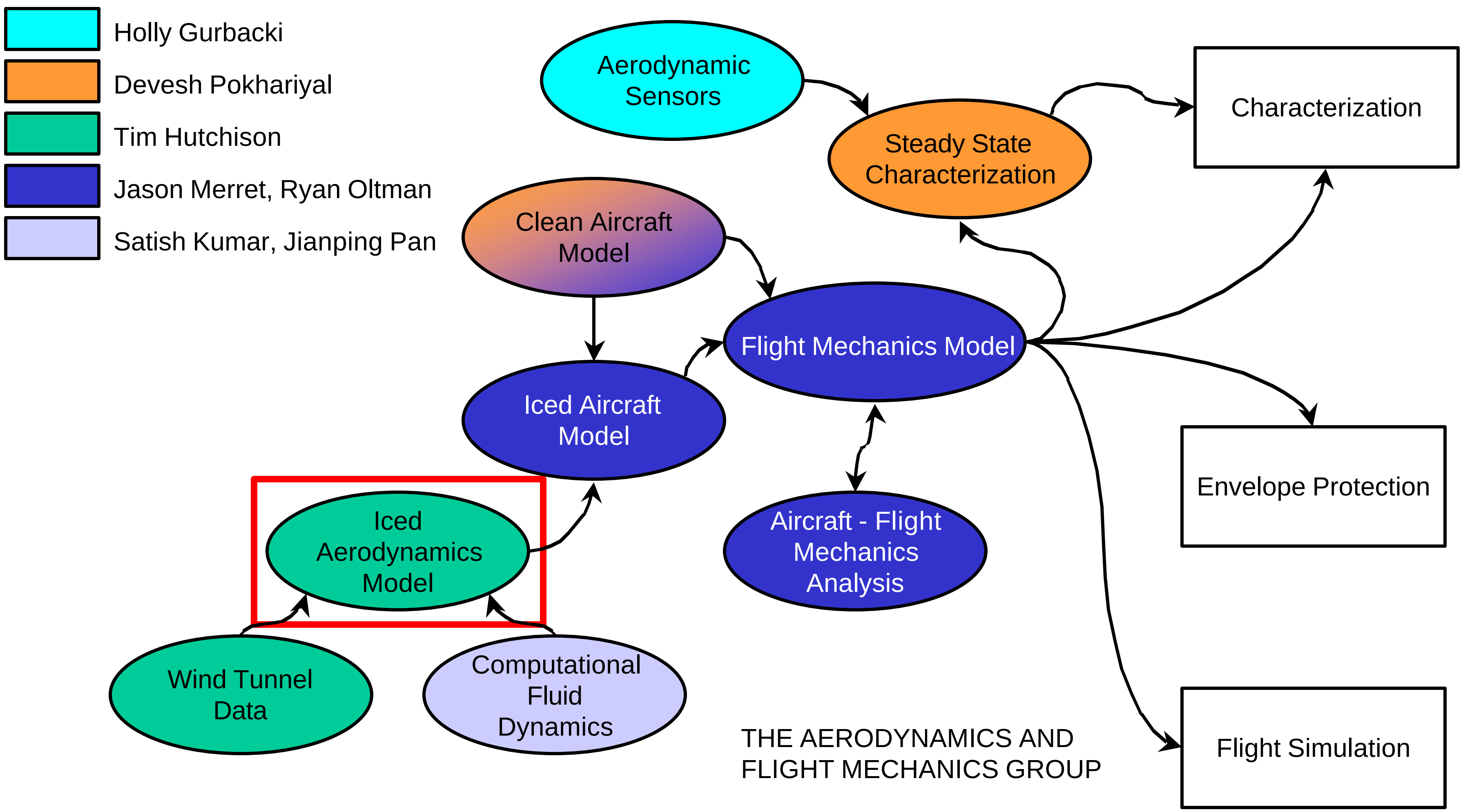
Smart Icing System Research



Outline

- Development of the Iced Aircraft Model
- Steady State Characterization
- Hinge-Moment Aerodynamic Sensor
- CFD Analysis
- Atmospheric Disturbances
- Conclusions and Future Plans

Smart Icing System Research



THE AERODYNAMICS AND FLIGHT MECHANICS GROUP

Outline

- Icing effects model
- η_{ice} and η formulations
- η variations with environmental variables
- Neural network approach
- Performance of neural network predictions
- Conclusions and future work

Icing Effects Model

Objective:

To devise a simple, but physically representative, model of the effect of ice on aircraft flight mechanics for use in the characterization and simulation required for the Smart Icing System development research.

Icing Effects Model

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

- $C_{(A)}$ = arbitrary stability and control derivative

  ($C_{L\alpha}$, $C_{m\delta e}$, etc.)

- η_{ice} = icing severity parameter
- k'_{C_A} = coefficient icing factor

$k'_{C_A} = f_{(A)}$(IPS, aircraft geometry and config., icing conditions)

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_{ice} Reference Value

- To nondimensionalize the ΔC_d equation, a reference condition was chosen based on FAA Appendix C Maximum Continuous conditions.
- NACA 0012 c = 3 ft.

  MVD = 20 μm V_∞ = 175 knots

  LWC = 0.65 g/m^3 t = 10 min

  T_0 = 25 °F
- These conditions yielded a $\Delta C_d = 0.0239$ at $\eta_{ice}=1$

h_{ice} Equation (v3.1)

For t ≤600s: $$\eta_{ice} = Z_1 \cdot (A_c E) \cdot g(n)$$

Z_1=183.339

g(n) is a function of n that varies between 0 and 1, and has its maximum at n=0.2

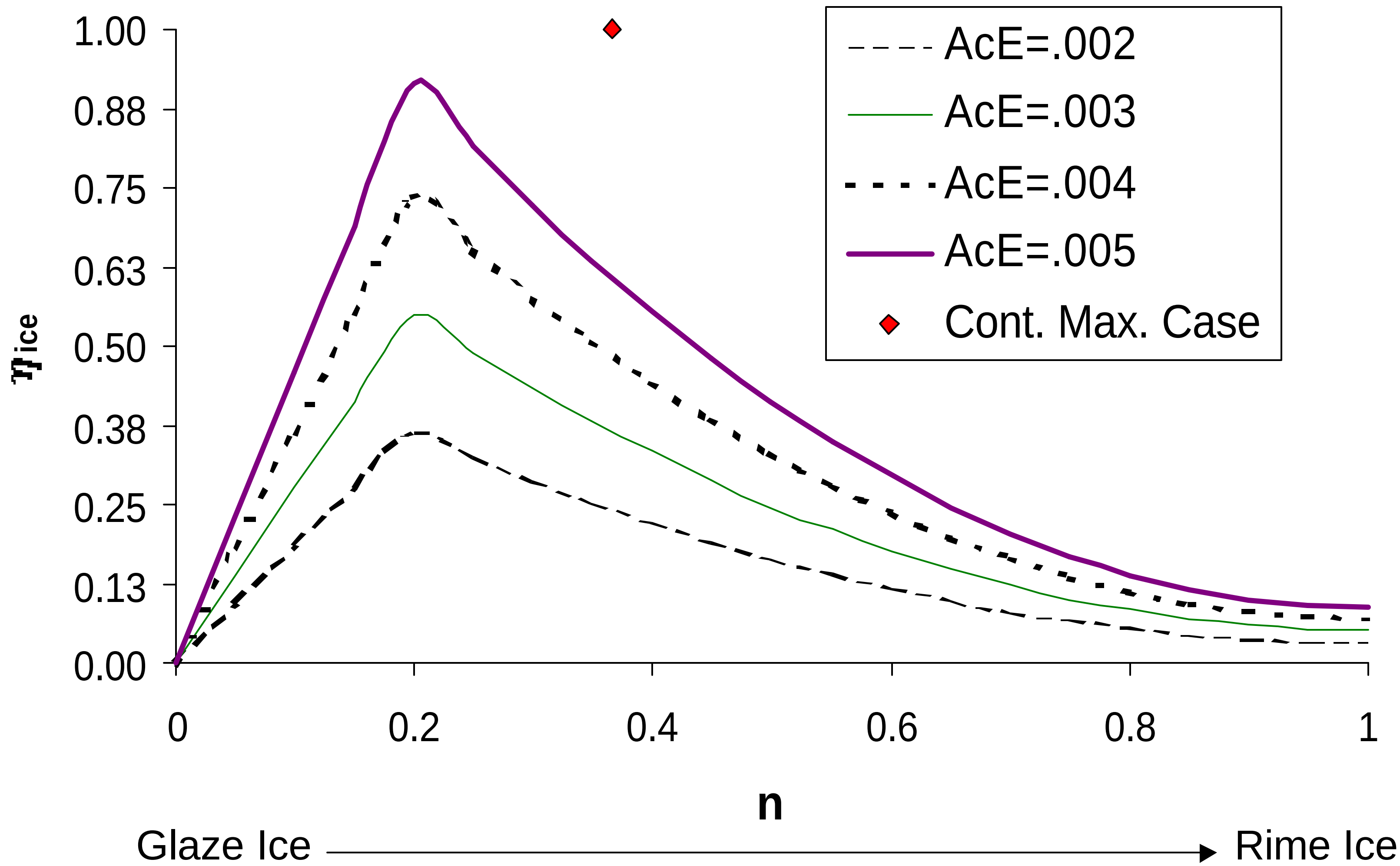
For t >600s: $$\eta_{ice} = Z_2 \cdot \left(1 - e^{Z_3 t}\right) + \eta_{ice}(600s)$$

Z_2 = f(maximum η_{ice}, η_{ice} at 600s)

Z_3 = f(Z_2, slope of η_{ice} at 600s)

η_{ice}(600s) = value of η_{ice} at 600s

Variation with n and A_cE



h_{ice} Variation with A_cE and n

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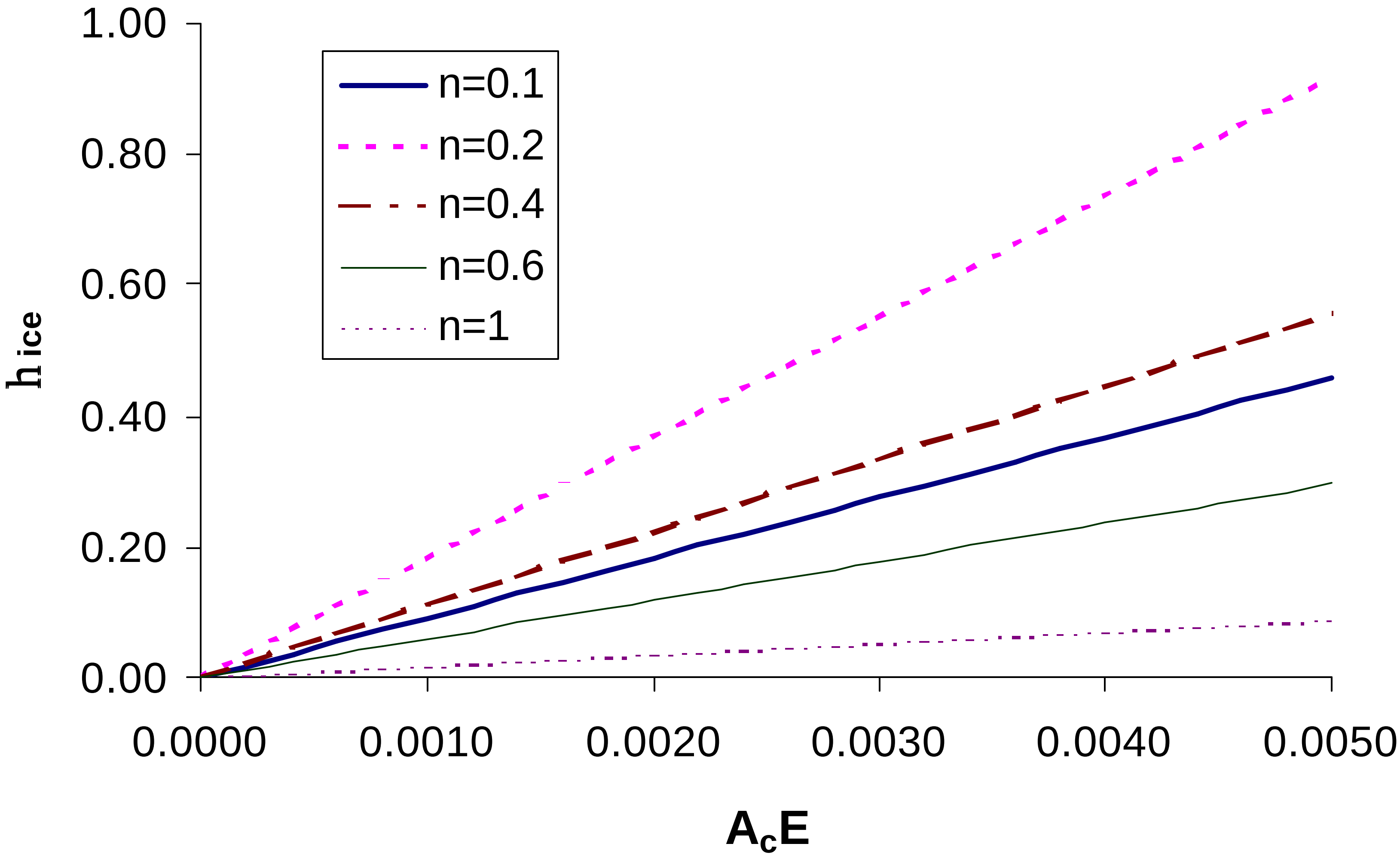


h Formulation

- 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

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

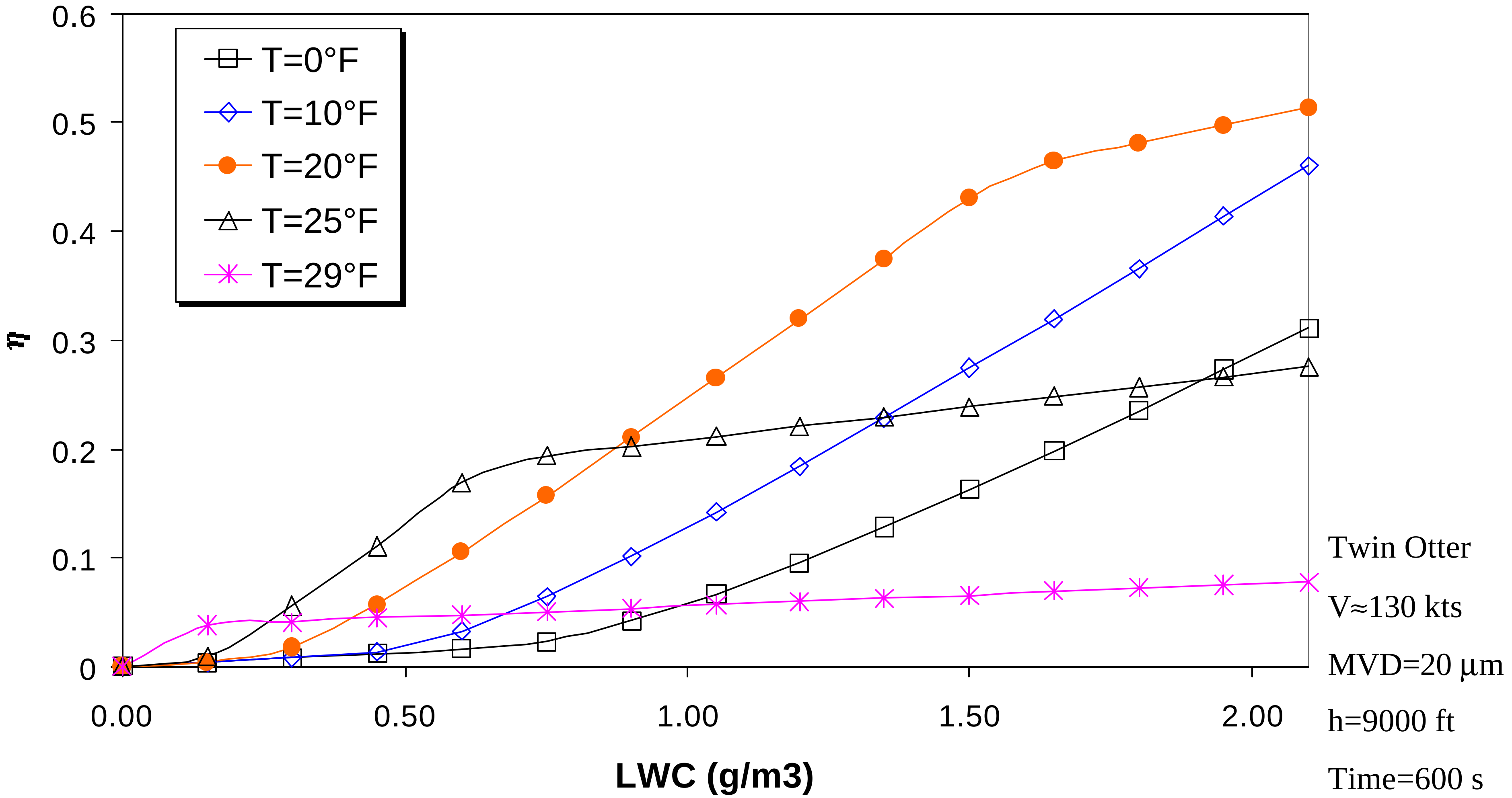
$$k'_{C_A} = \frac{\eta}{\eta_{ice}} k_{C_A}$$

Differences Between h and h_{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 LWC and T on h

Smart Icing Systems *NASA Review, June 13-14, 2000*



Effect of T and LWC on h

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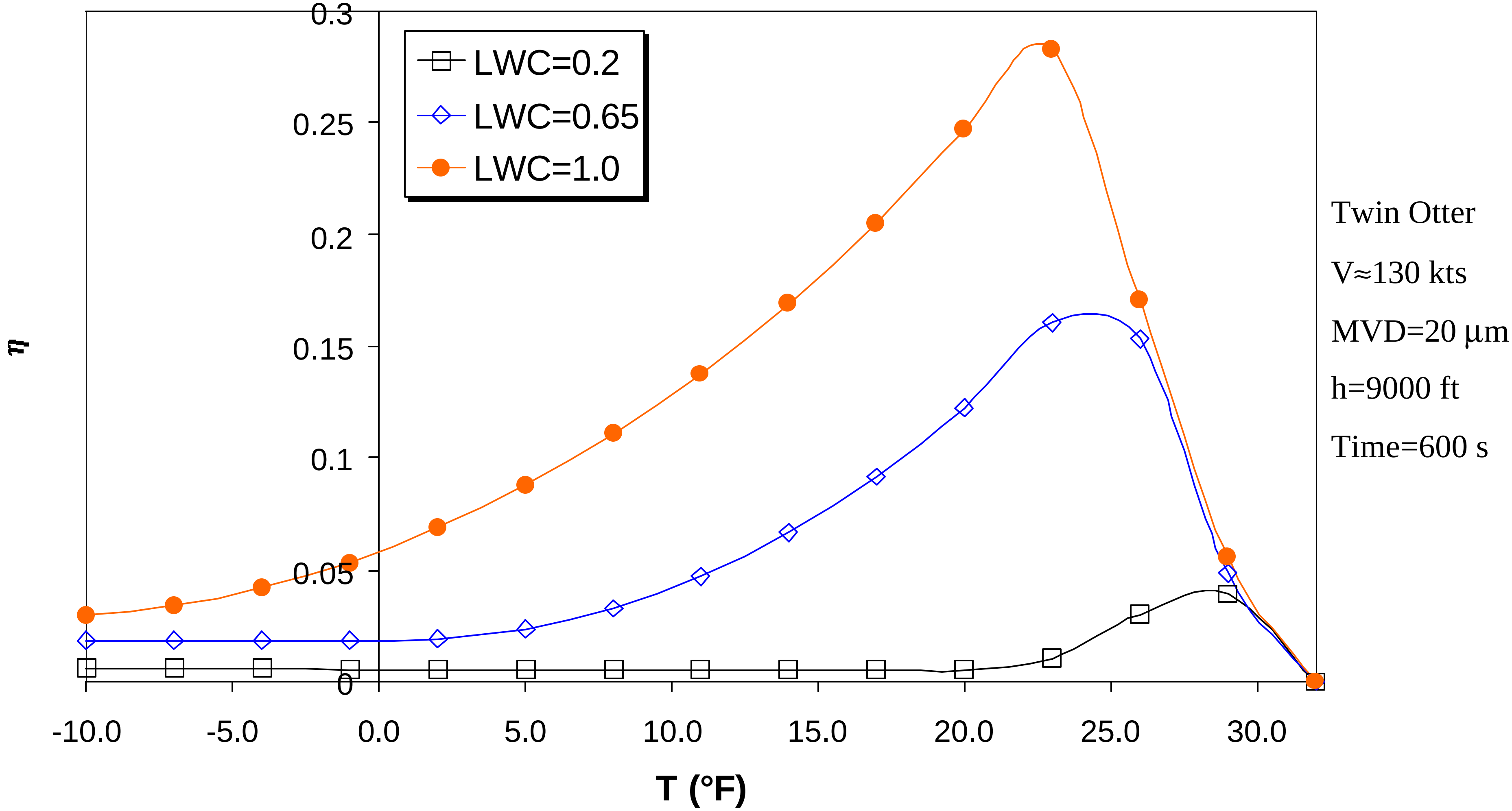

Effect of MVD and T on h

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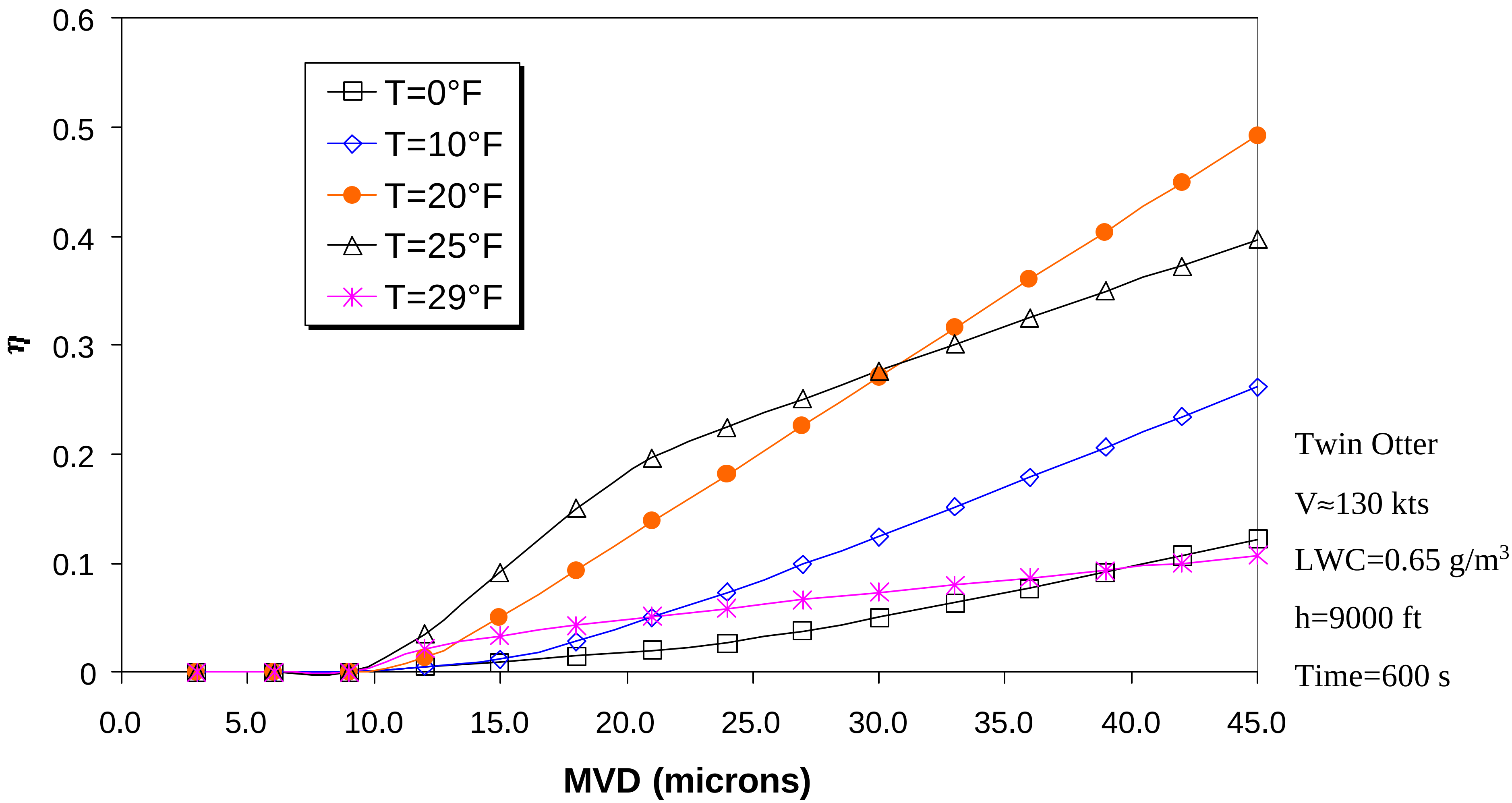
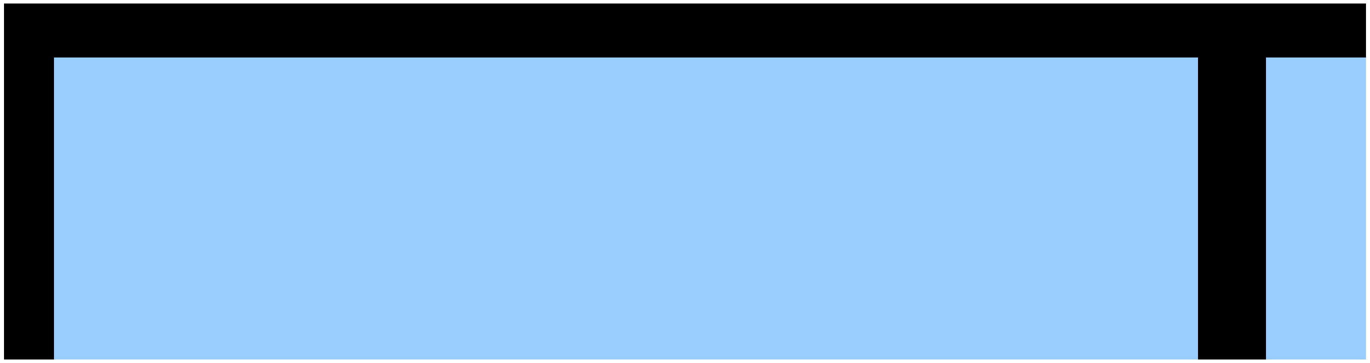
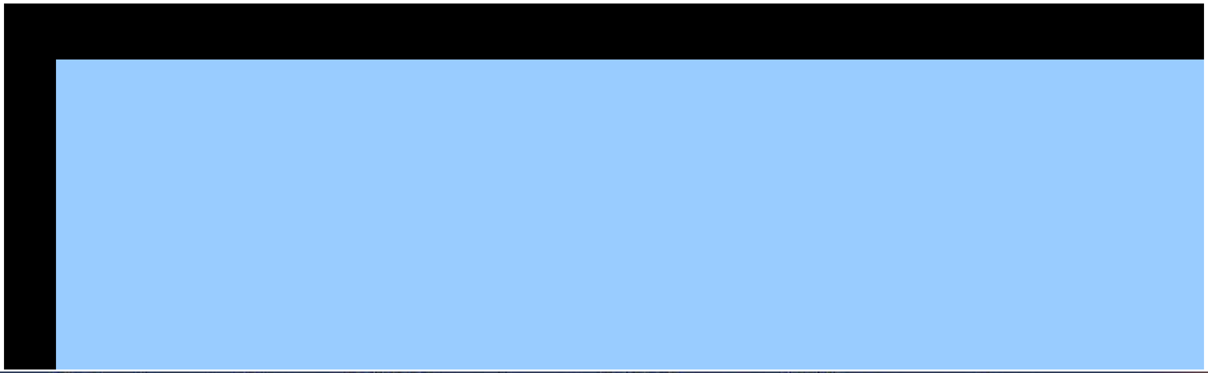


k_{CA} Definitions

- Equations: (using performance data from Twin Otter flight tests)

$$(C_A)_{ice} = (C_A)_{clean}(1 + k_{C_A}\eta_{ice}) \qquad k_{C_A}\eta_{ice} = \frac{(C_A)_{ice}}{(C_A)_{clean}} - 1 \qquad C_D = C_{D0} + KC_L^{\ 2}$$





Neural Network Approach

Proposed Neural Network approach to icing characterization:

Environmental Variables: T, LWC, MVD, etc

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Ice Shape Neural Net

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Ice Shape: horn height, horn location, etc

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2-D Aerodynamic Neural Net

↓

2-D Aerodynamic Performance

↓

3-D Aerodynamic Neural Net

↓

3-D Aerodynamic Performance, Stability and Control

Neural Networks

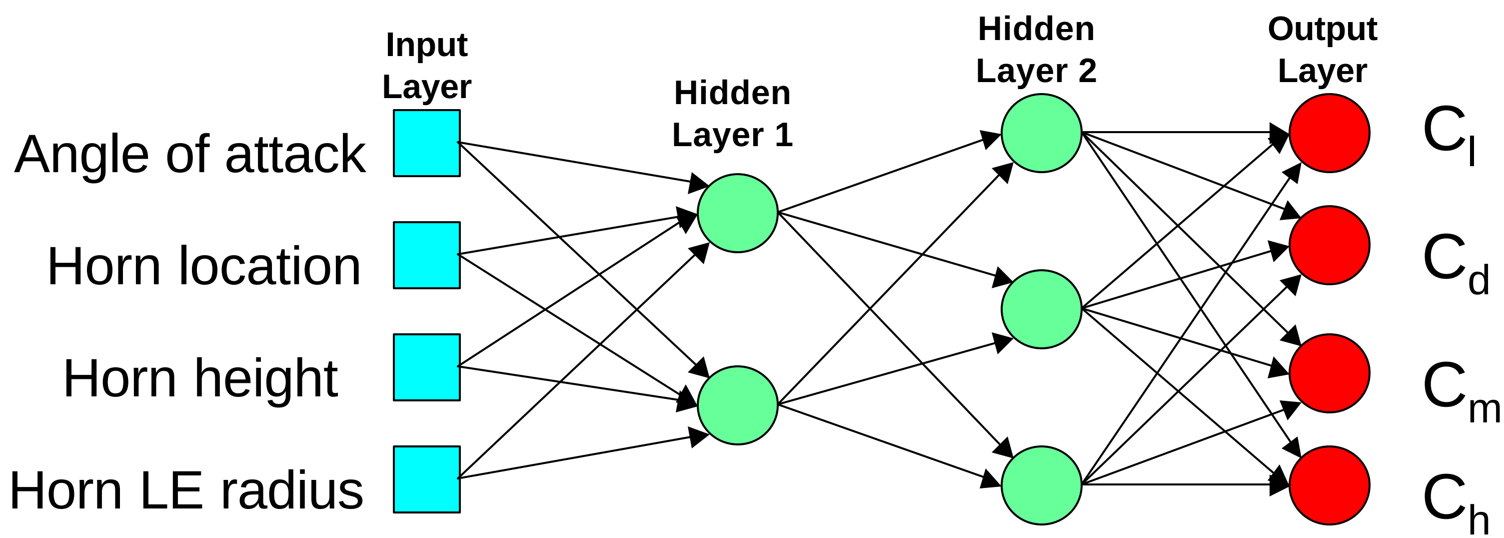
- Based on the structure of the human brain, with multiple neurons and synapses
- Each neuron multiplies its inputs by “synaptic weights” to achieve an output
- Very good at handling and fitting data that have complex, nonlinear correlations
- Must be trained with a set of known data
- For the SIS Project, the Matlab Neural Net Toolbox has been used

Neural Network Architecture

- Sample neuron: $Y = f(\Sigma\, W_i\, x_i)$ with x_i = inputs to neuron
- W_i are trained with known data (*f* refers to a sigmoidal function)
- Y = output of a neuron

<u>Simple neural net example</u>

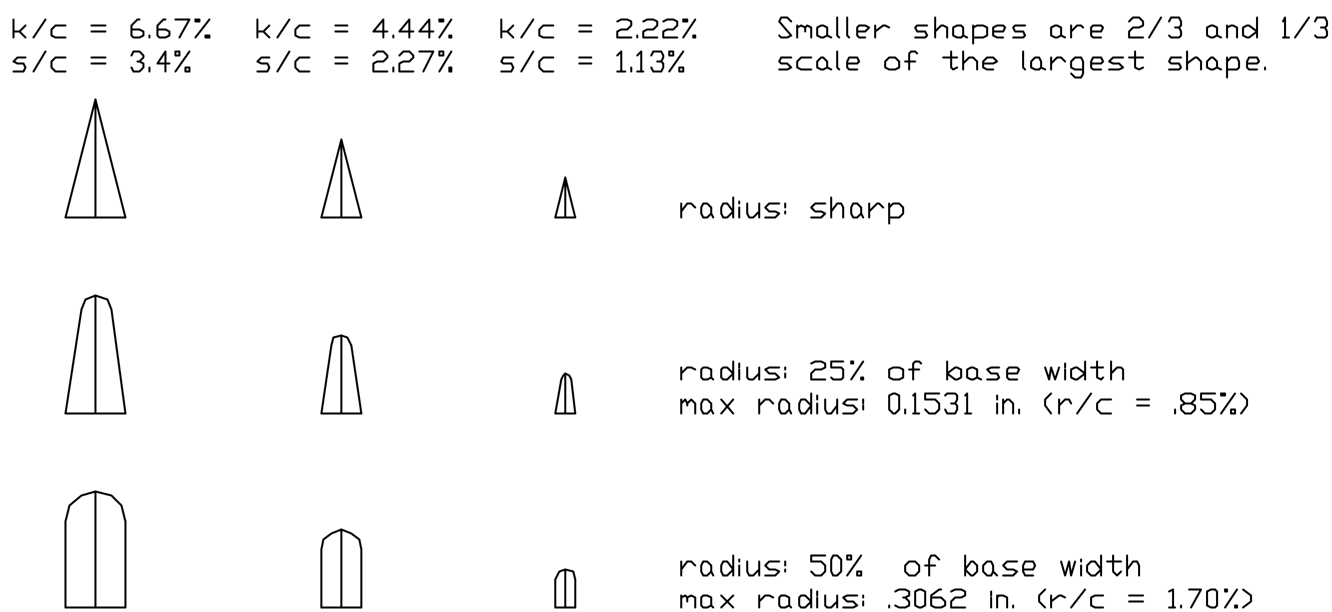
(actual neural net uses 5 layers of 8 nodes each)



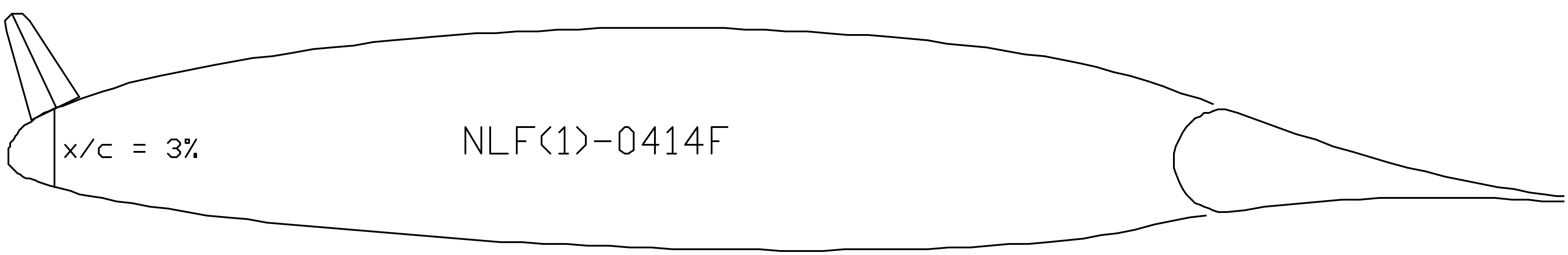
Training Data

- This neural net was trained using data collected by Kim and Bragg, which is presented in AIAA 99-3150
- This data examines three ice horn heights and three leading edge radii at six different locations
- The collected data includes C_l, C_d, C_m and C_h for the NLF(1)-0414 airfoil

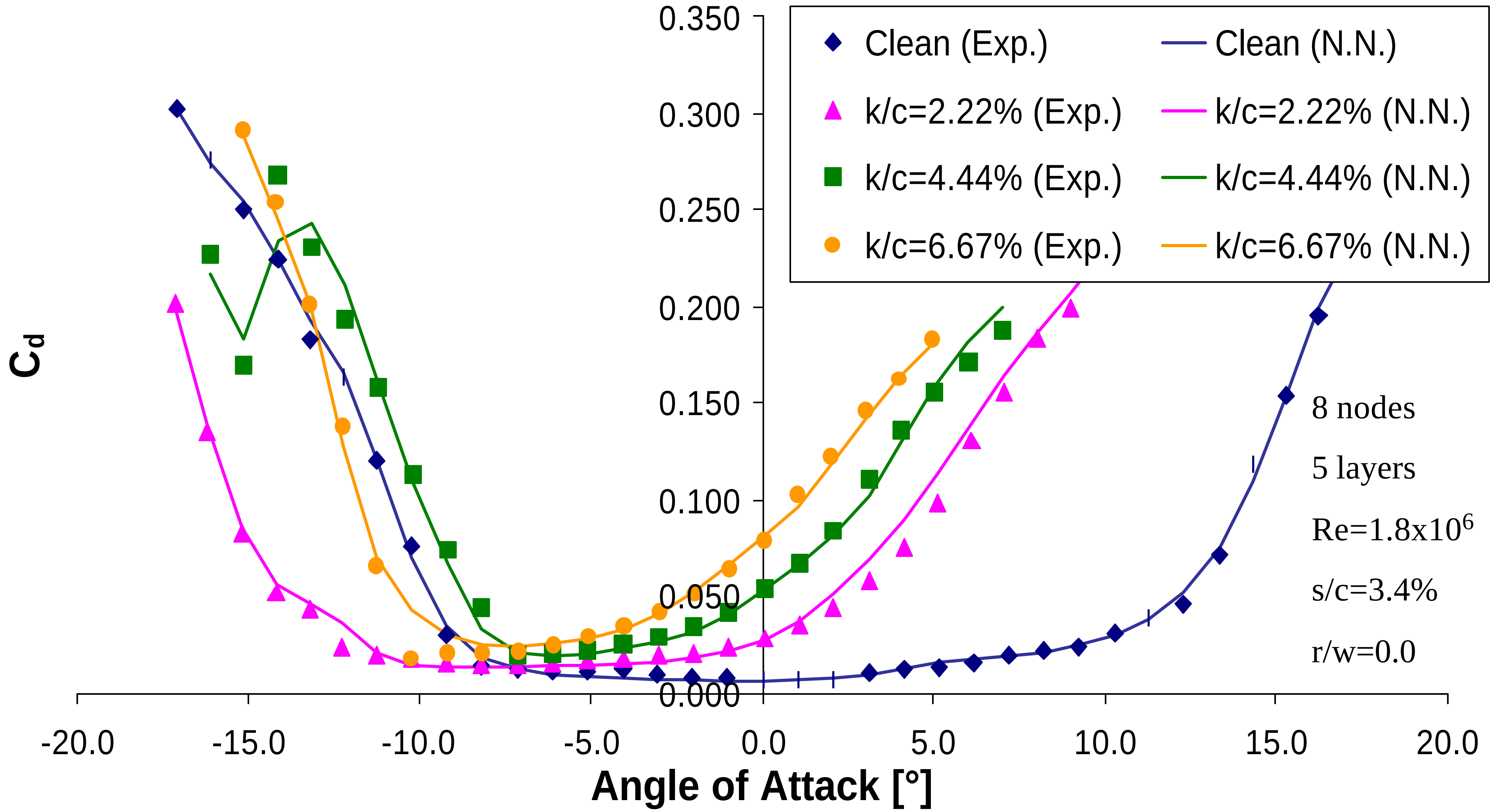
Training Data (cont.)



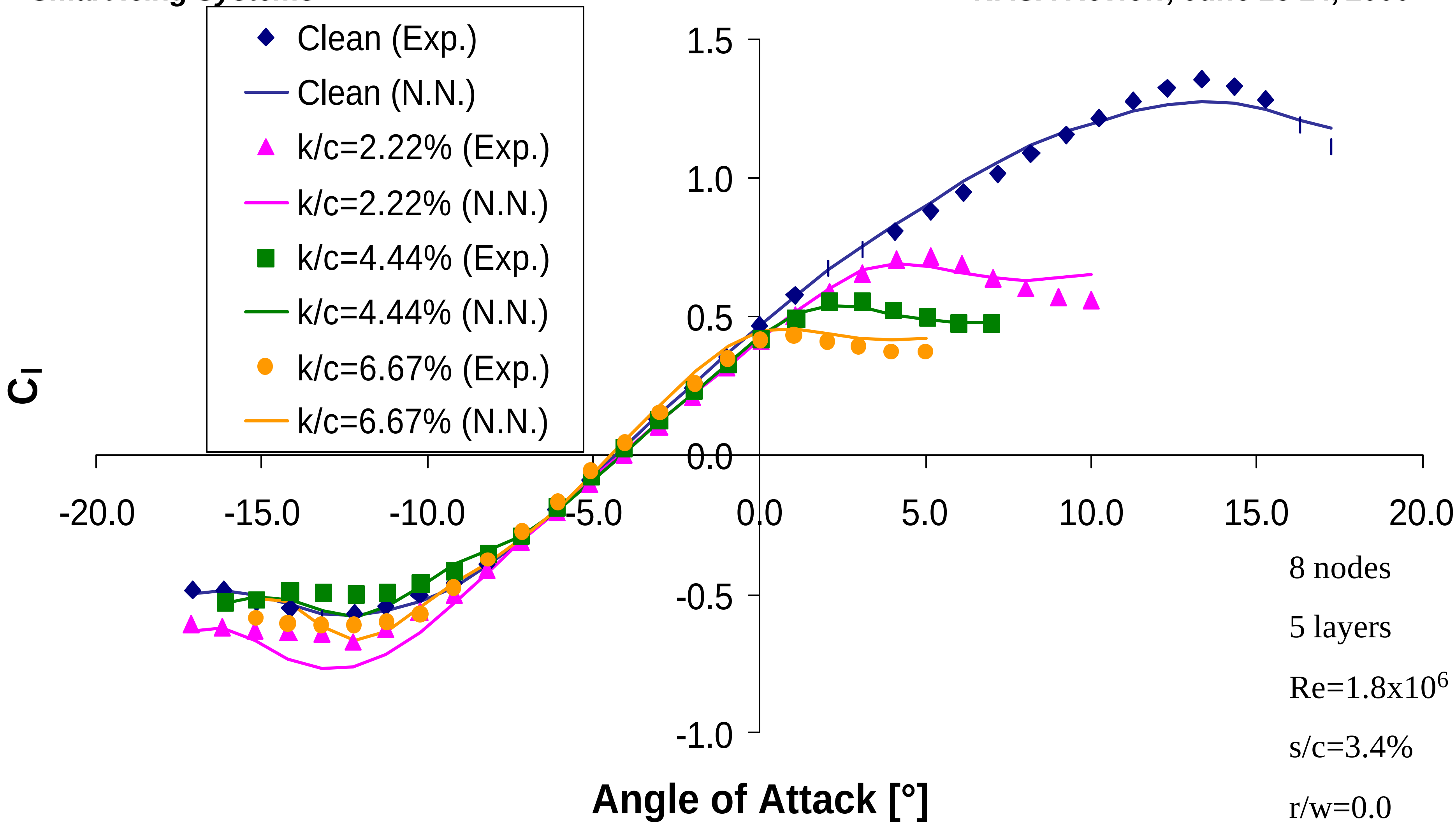
s/c locations
-1.5%
-0.75%
0.0%
0.85%
1.7%
3.4%



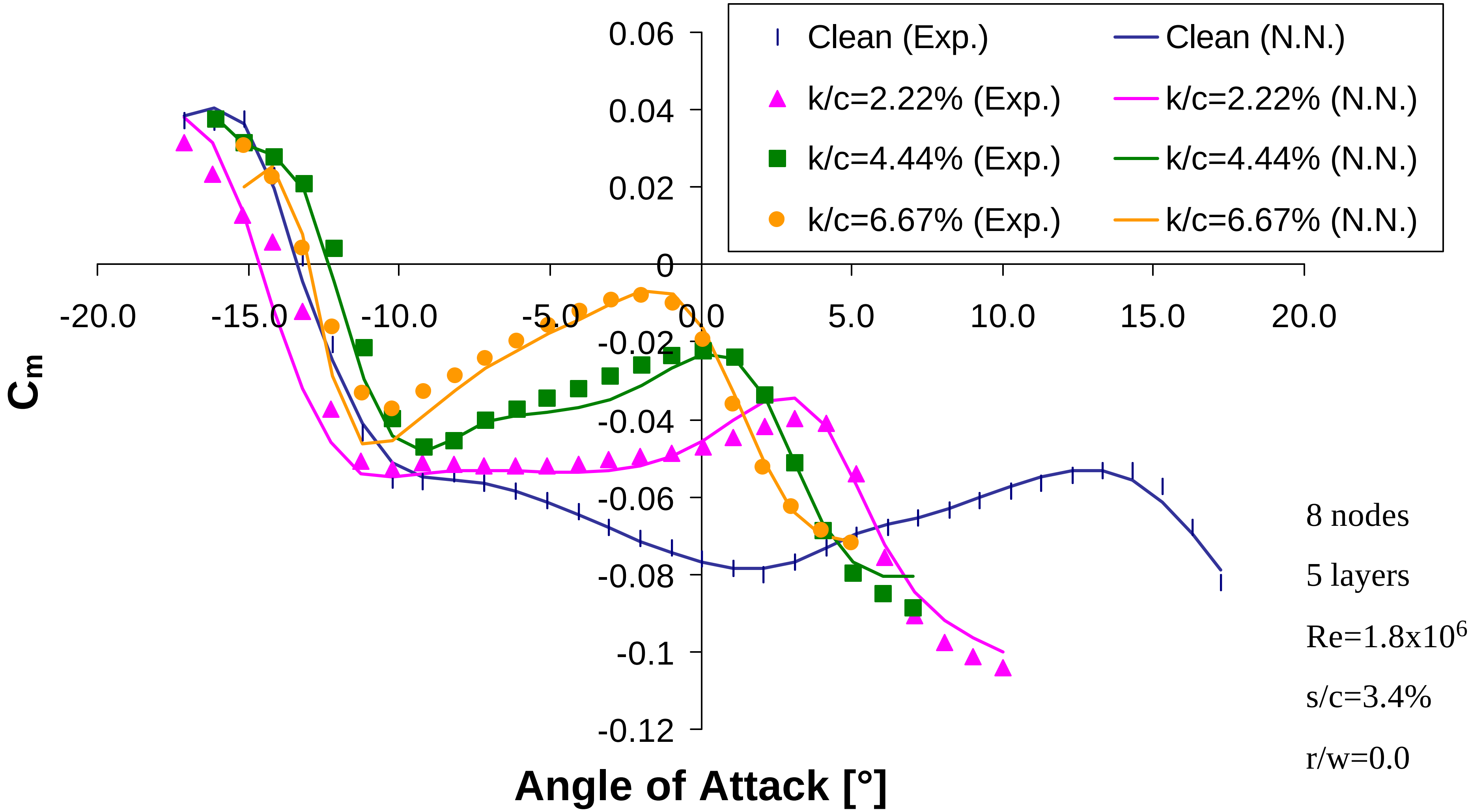
Prediction of C_d



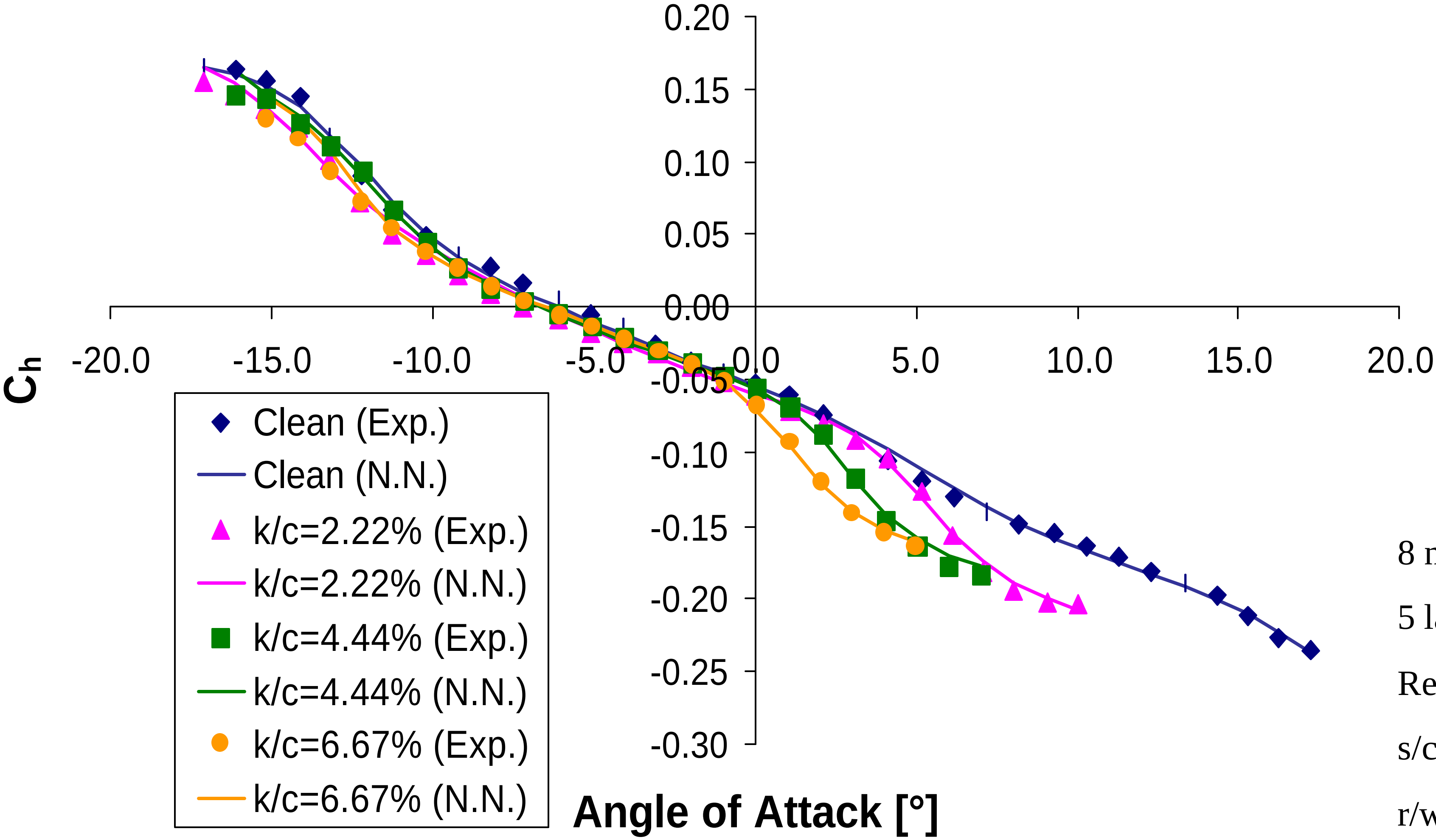
Prediction of C_l



Prediction of C_m



Prediction of C_h



8 nodes

5 layers

$Re=1.8x10^6$

s/c=3.4%

r/w=0.0

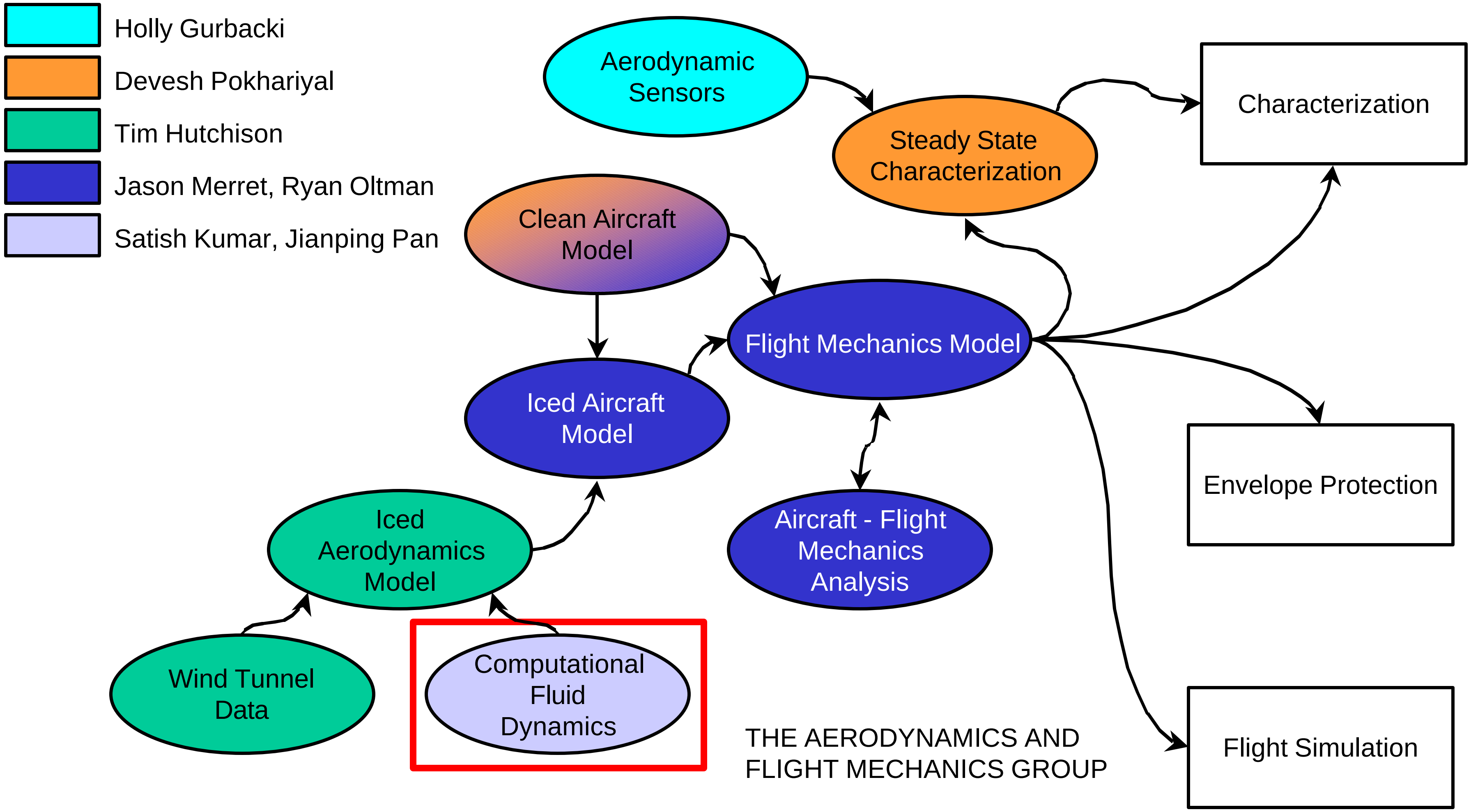
Conclusions

- Linear icing effects model, η_{ice}, is almost finalized
- Initial results from neural net analysis for prediction of 2-D flight performance parameters are promising

Future Research

- Develop neural nets for prediction of 2-D aerodynamic coefficients based on a larger data set
- Continue exploration of neural nets for prediction of ice shape characteristics
- Develop improved methods for converting 2-D to 3-D aircraft derivatives

Smart Icing System Research



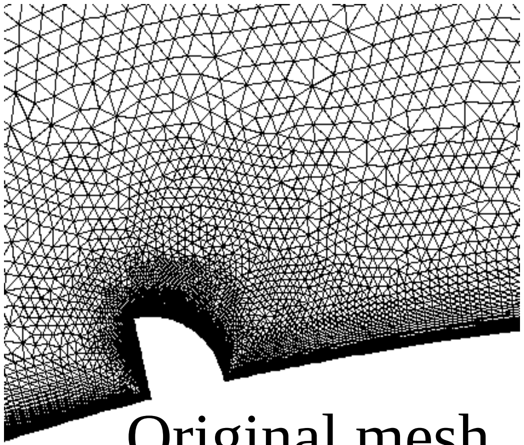
THE AERODYNAMICS AND FLIGHT MECHANICS GROUP

Outline

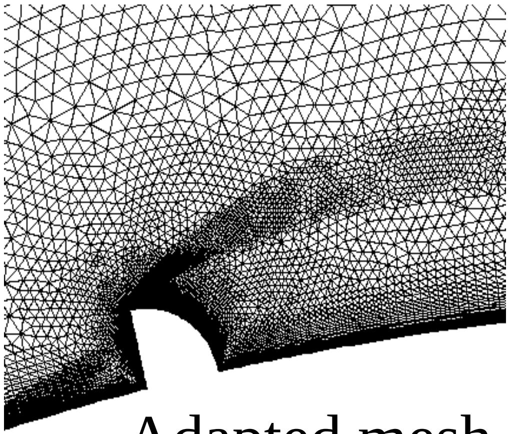
- NSU2D predictions with upper-surface ice - shapes (to establish the effects of location, size, flap deflection, Re, and airfoil shape)
- WIND predictions for leading-edge ice- shapes (for similar goals to allow 3-D effects)
- Detached Eddy Simulation development with WIND to increase separated flow predictive performance for $C_{L,max}$ and allow unsteady hinge moment prediction

NSU2D

- Mavriplis D. (ICASE Jan '91)
- Spalart-Allmaras 1-Eq. Turbulence Model with transition specification
- Unstructured Solution-Adaptive Triangular Element Grid
- Steady state convergence accelerated by employing local-time stepping, residual smoothing, and algebraic multigrid algorithm (AMG)



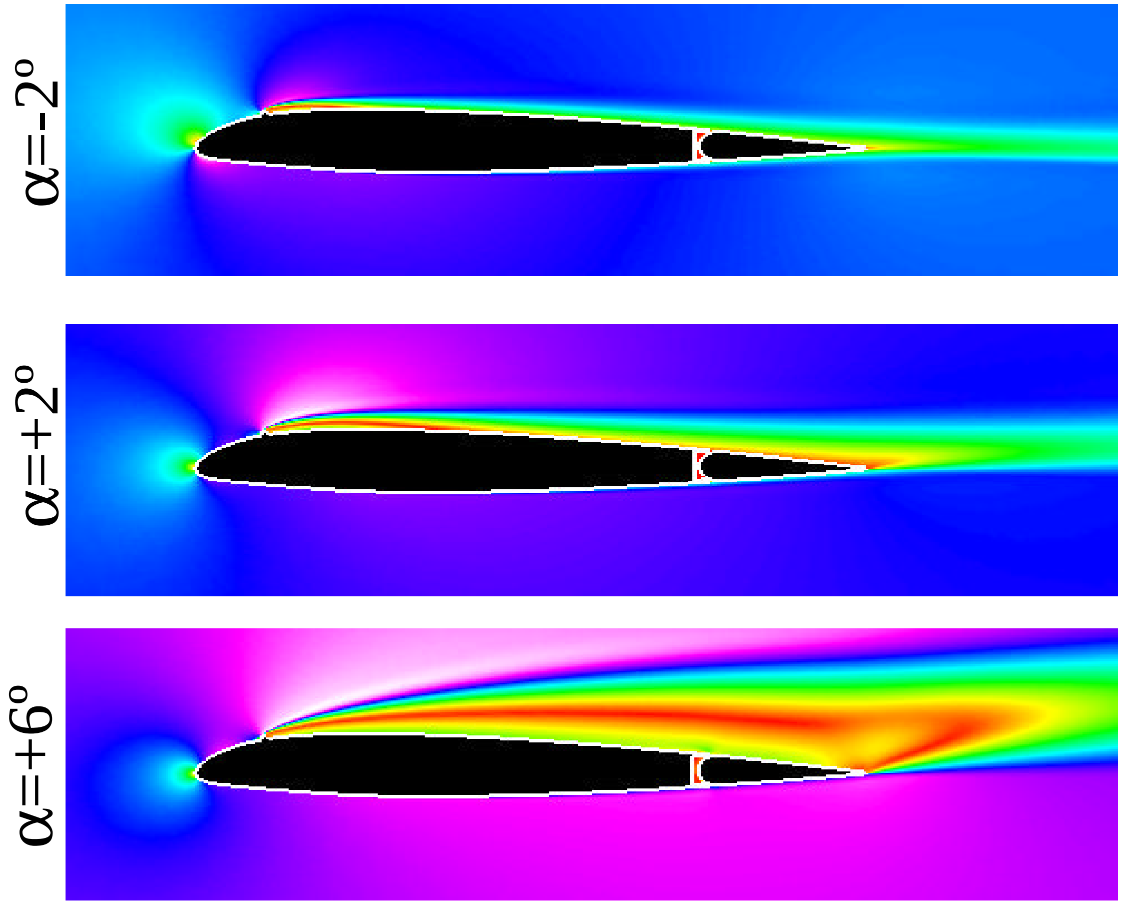
Original mesh



Adapted mesh

Velocity Contours

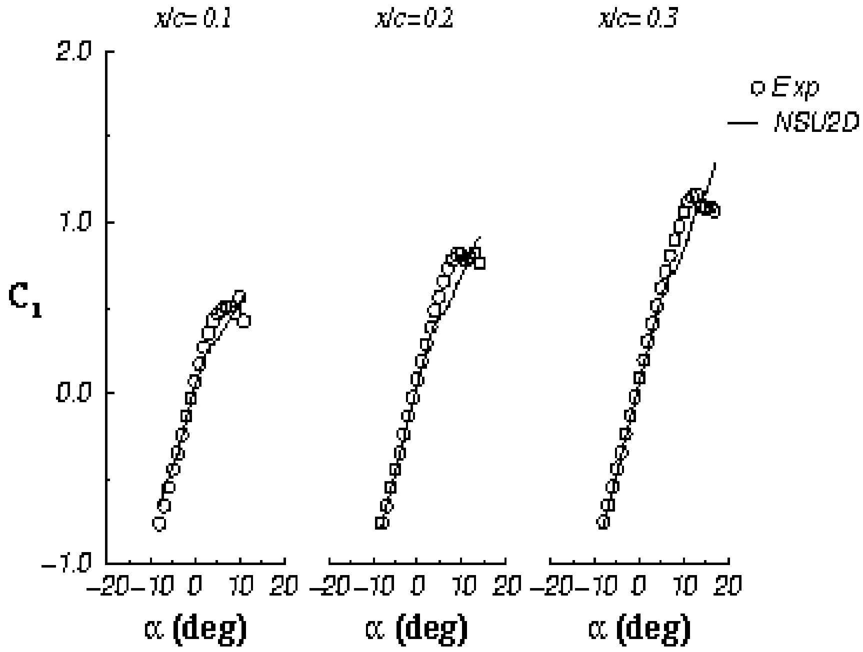
- NACA 23012m
- 0.15” Quarter Round at x/c=0.10
- B.L. tripped
- $Re=1.8x10^6$



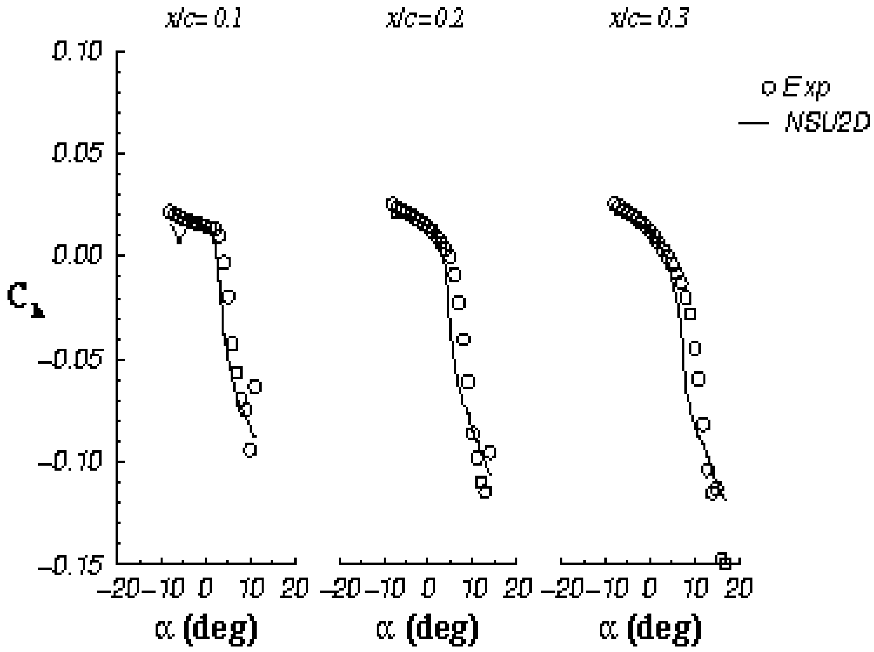
Effect of SLD Ice-Shape Location

NACA 23012m, Ice-shape size of k/c=0.0083,
B.L. Tripped, Re=$1.8x10^6$

LIFT

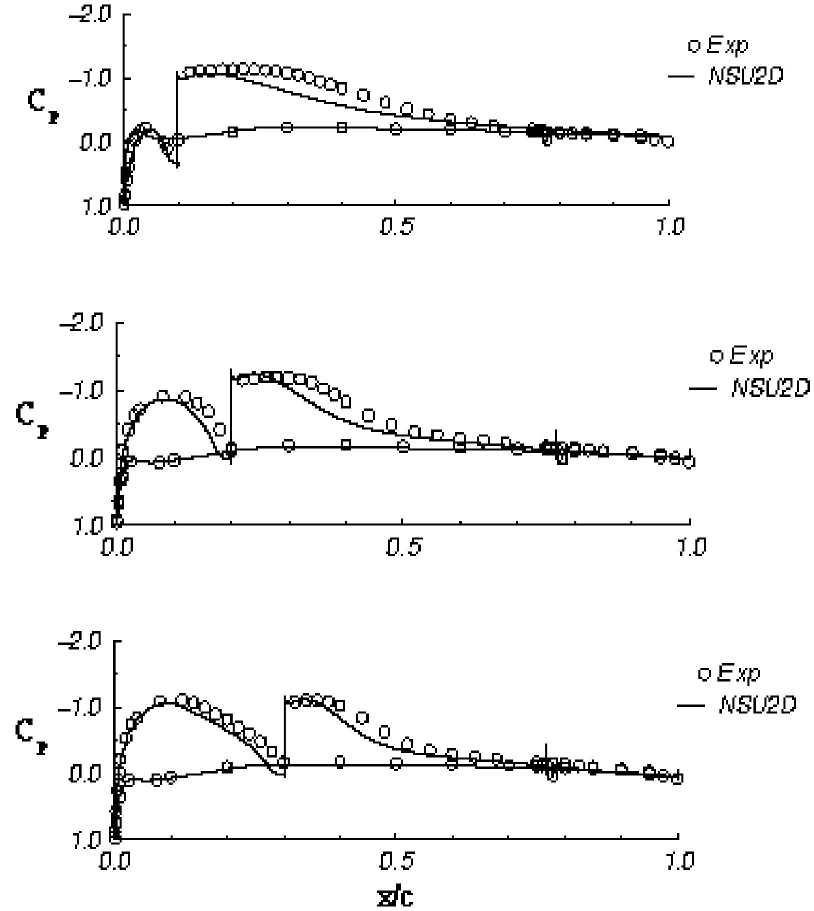


HINGE MOMENT



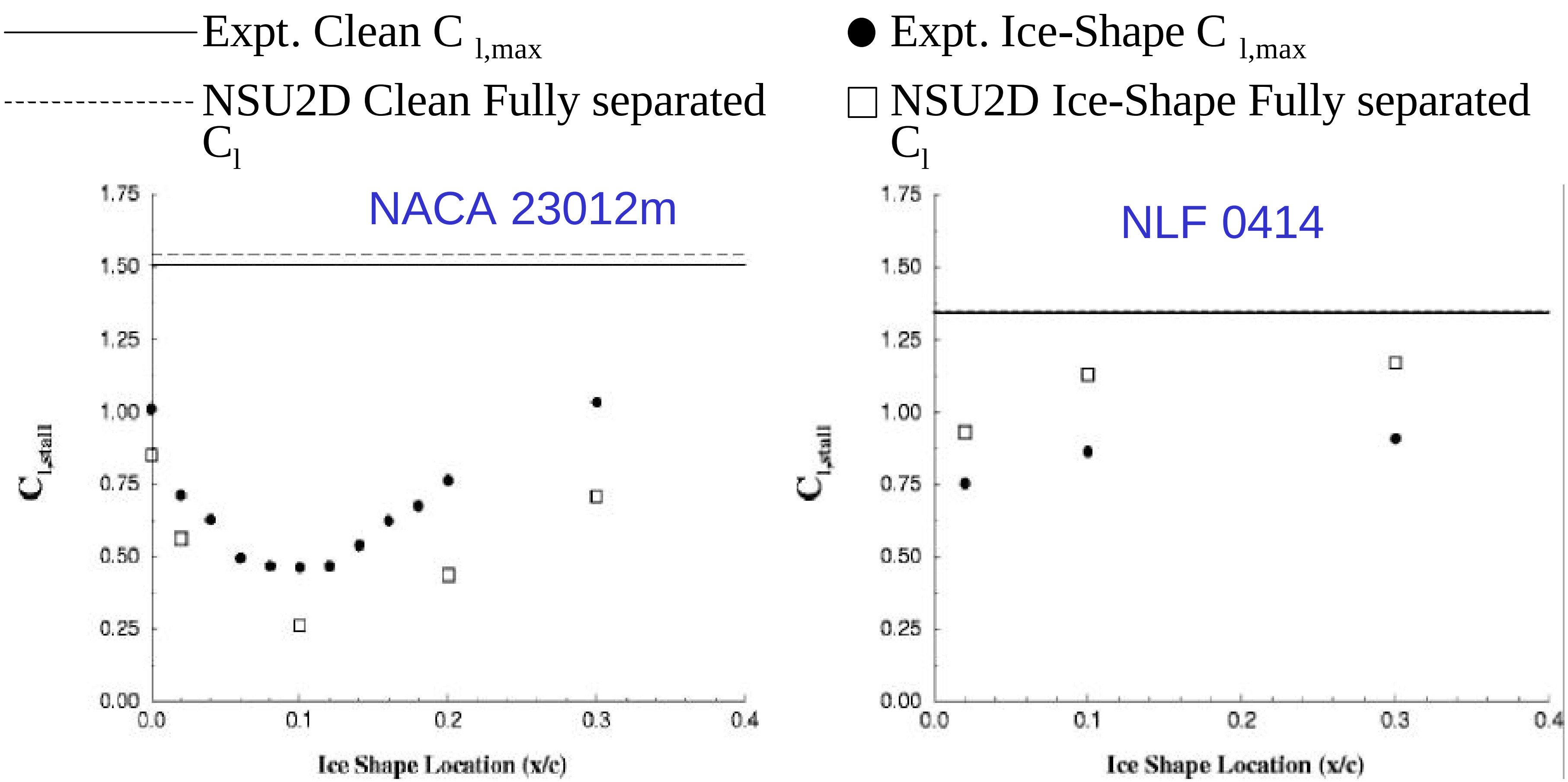
C_p

- NSU2D
- NACA 23012m
- Ice-shape size of k/c=0.0083
- α=3°
- B.L. Tripped
- Re=1.8×10^6



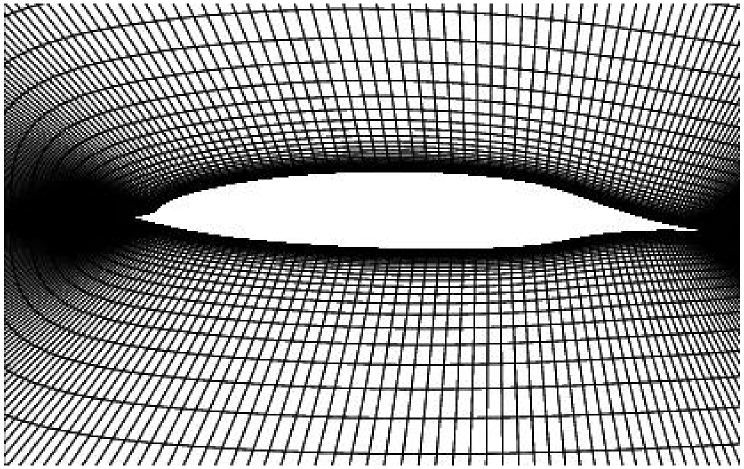
C_l for Fully Separated Flow

Ice-shape size of k/c=0.0083,B.L. Tripped; Re=1.8×10^6

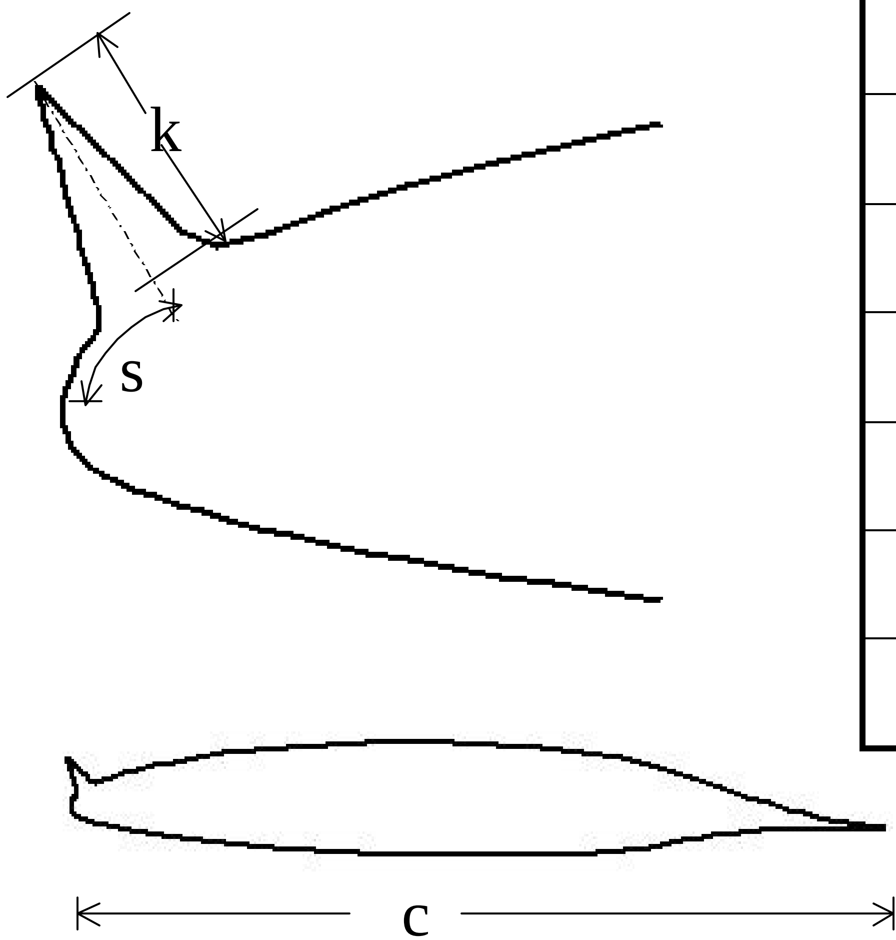


Leading Edge Ice Shapes

- WIND – RANS (Ver. 3.0)
  - NPARC Alliance (AIAA paper 98-0935)
  - Same turbulence model used as NSU2D
  - To be compatible with NASA GLENN
  - To Allow Efficient 3-D Simulations
  - To Allow DES
- GRIDGEN (Ver. 13.4)
  - Pointwise Inc.



Iced NLF-0414 Airfoil

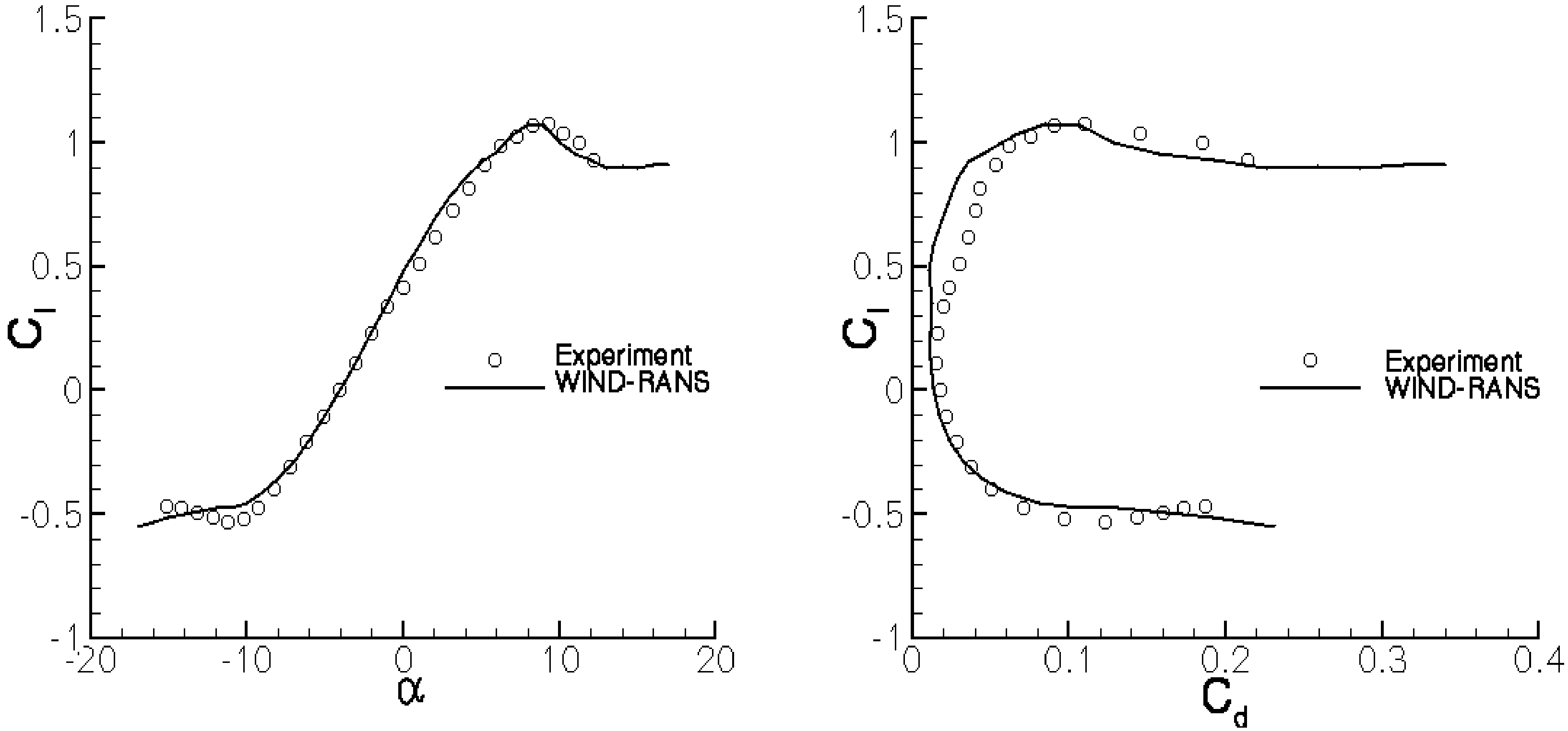


Case	s/c	k/c
1	0	6.67%
2	0	4.44%
3	0	2.22%
4	3.4%	6.67%
5	3.4%	4.44%
6	3.4%	2.22%

Iced NLF-0414 Airfoil : C_l, C_d

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

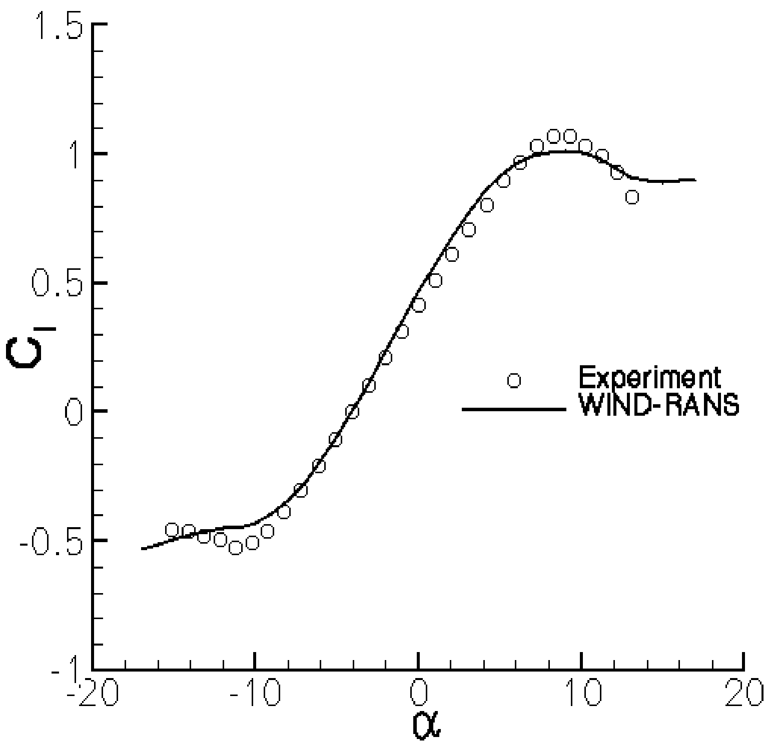
Re=1.8 X 10^6, Ma=0.185

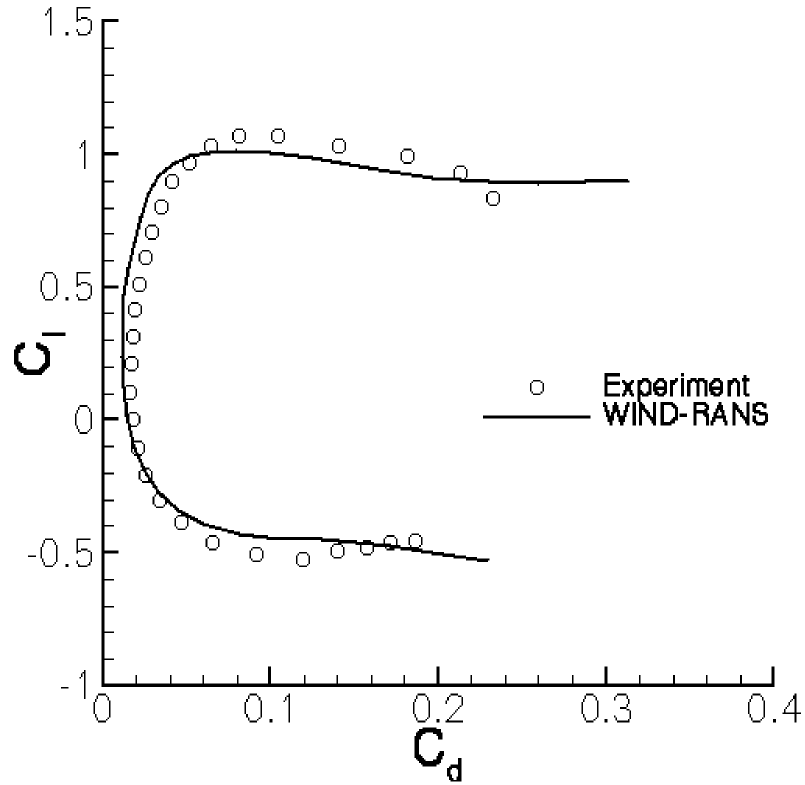


Iced NLF-0414 Airfoil : C_l, C_d

s/c=0%, k/c=4.44%

Re=1.8 X 10^6, Ma=0.185

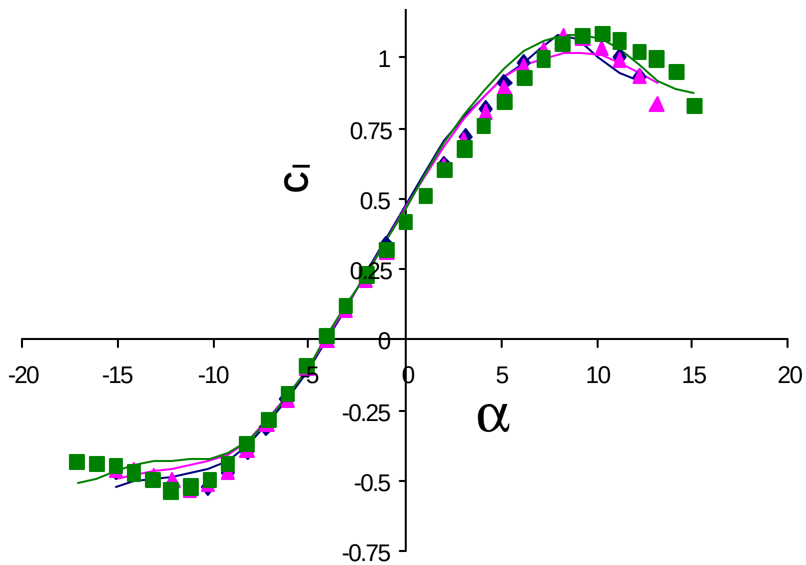


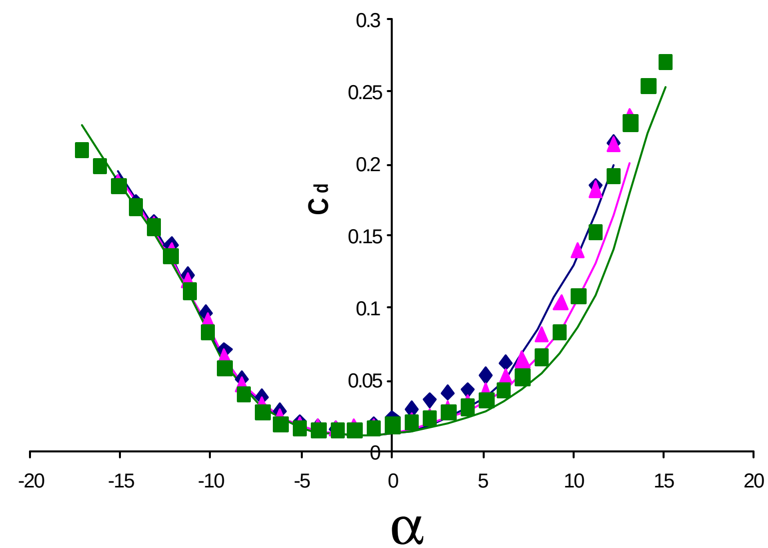


Neural Net Simulations

s/c=0%, Re=1.8 X 10^6, Ma=0.185

- k/c=6.67% (Exp.)
- k/c=4.44% (Exp.)
- k/c=2.22% (Exp.)
- k/c=6.67% (N.N. trained on CFD)
- k/c=4.44% (N.N. trained on CFD)
- k/c=2.22% (N.N. trained on CFD)

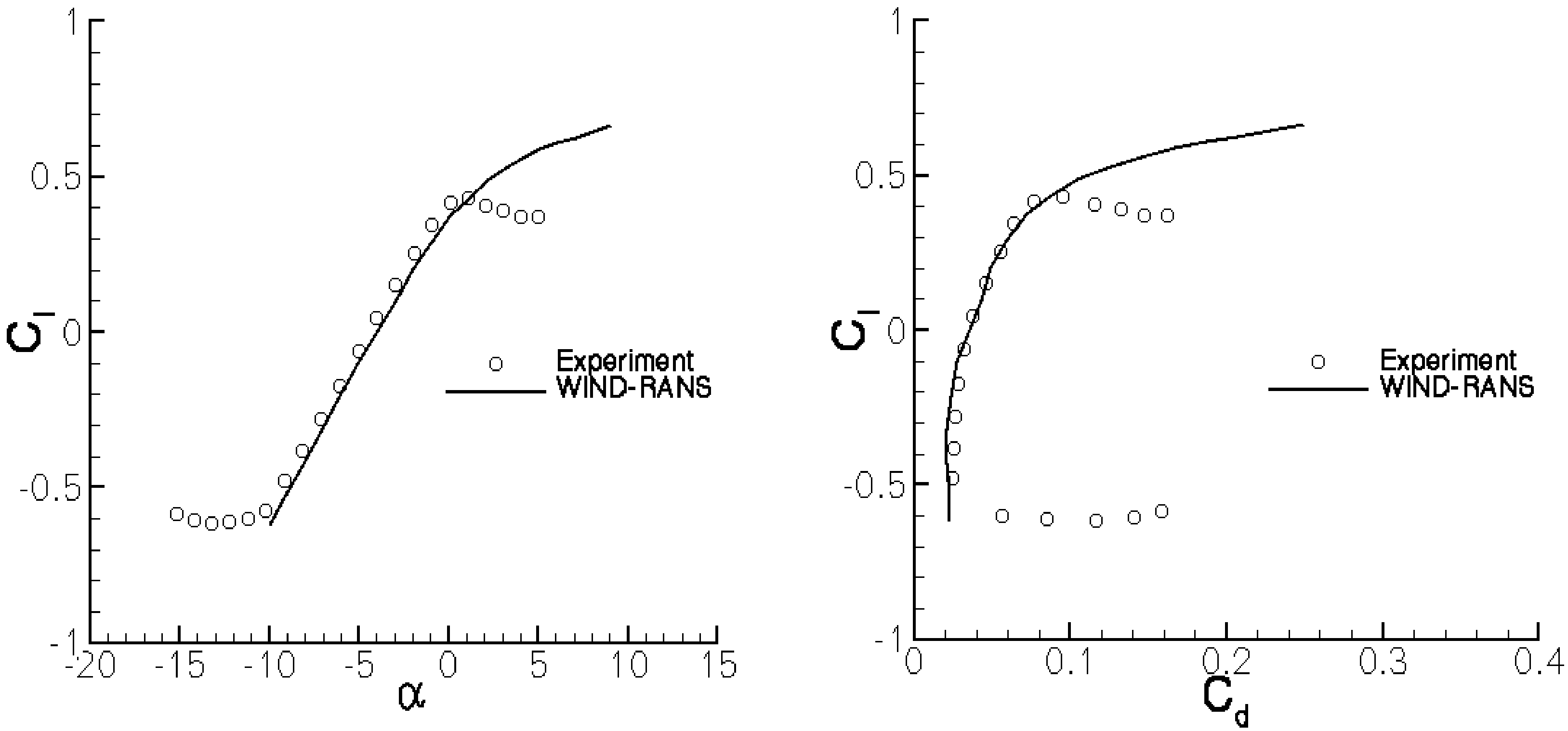




Iced NLF-0414 Airfoil : C_l, C_d

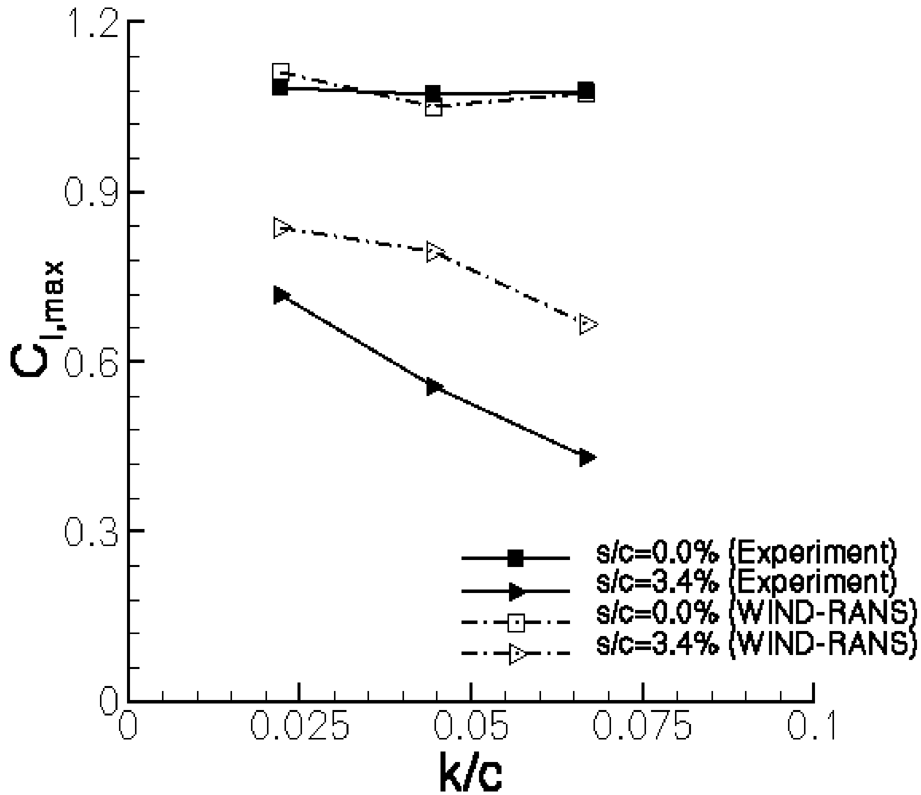
s/c=3.4%, k/c=6.67%

Re=1.8 X 10^6, Ma=0.185



Iced NLF-0414 airfoil : $C_{l,max}$

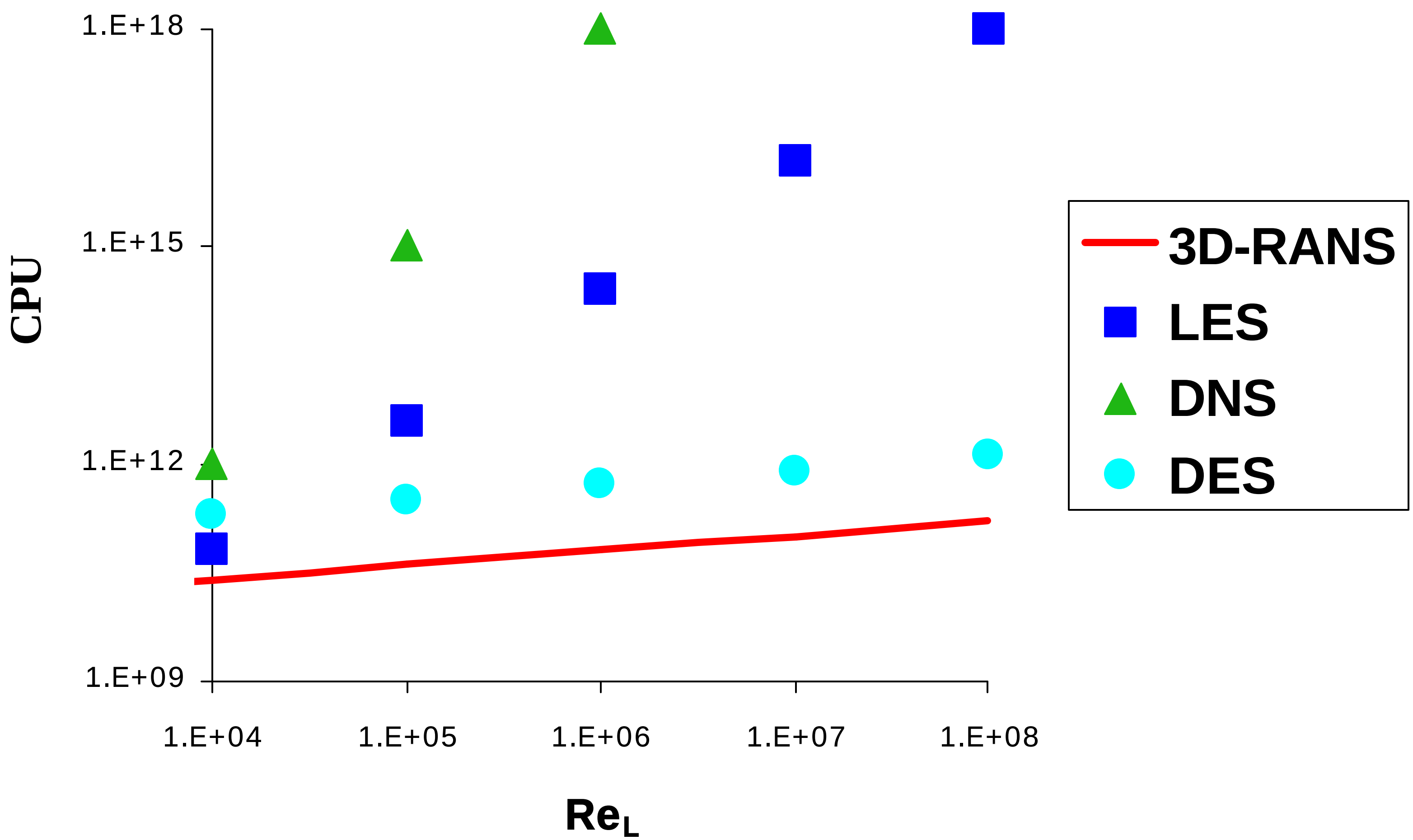
Re=1.8 X 10^6, Ma=0.185



Need for DES

- RANS does not give robust solution to massively separated flow and this may prevent accurate prediction of $C_{l,max}$ (especially for iced airfoils)
- Solution: Employ eddy-capturing scheme to handle large-separation regions
- Possible Choices:
  - LES (Large Eddy Simulation) uses subgrid filter to capture large scales
  - DNS (Direct Numerical Simulation) resolves all scales
  - DES (Detached Eddy Simulation) allows LES in free shear regions and RANS in attached flow

Approximate CPU time (cycles x N)



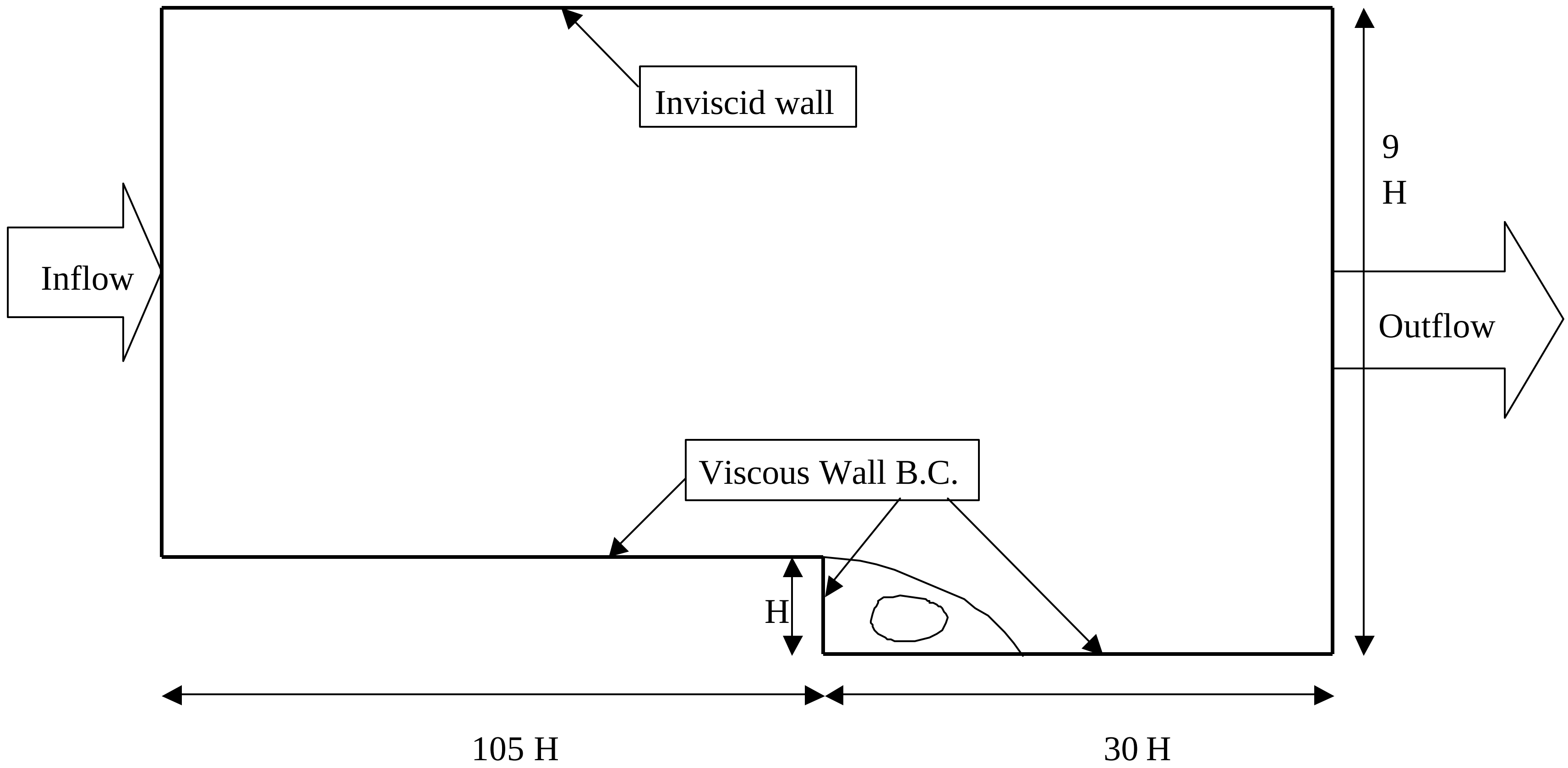
Detached Eddy Simulation

(Spalart *et. al.* 1999)

- Allows RANS description in the boundary layers and LES description for massively separated regions
- Can be formulated on S-A model with *d* (distance from the wall) replaced by $\tilde{d}$
- Has only one adjustable constant C_{DES}

$$\tilde{d} \equiv \min(d, C_{DES}\Delta)$$
$$\Delta \equiv \max(\Delta x, \Delta y, \Delta z)$$

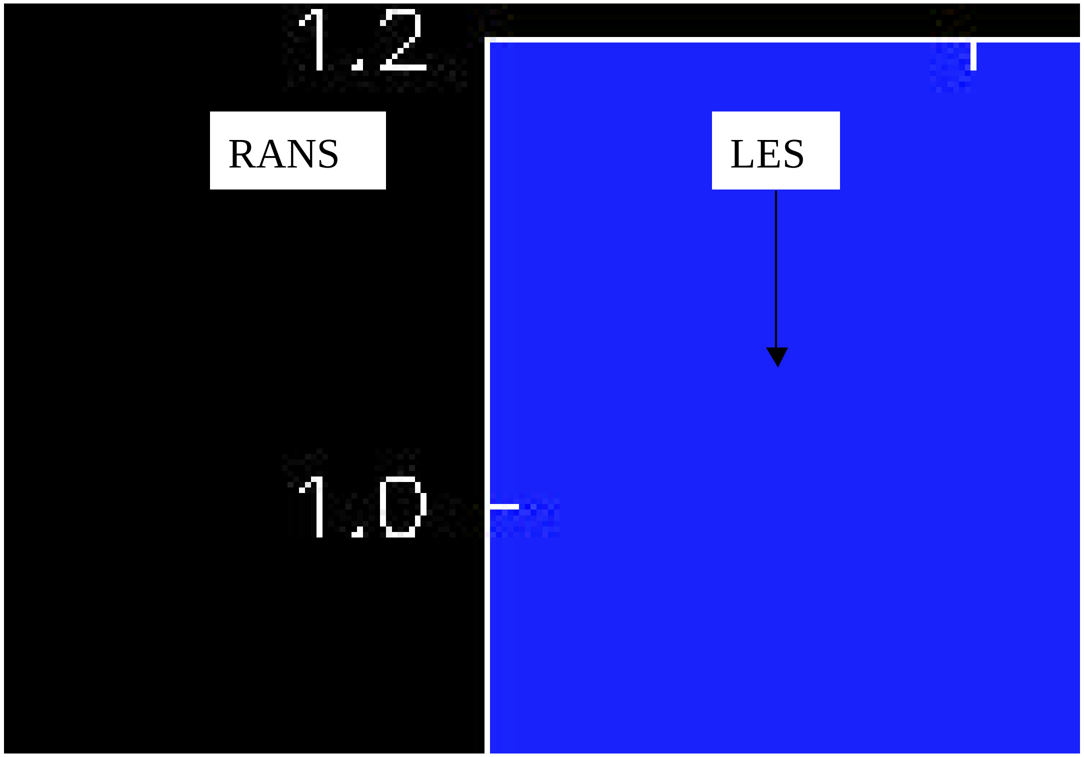
Geometry of the Grid for the Backstep



Backstep – Instantaneous Vorticity

WIND-DES

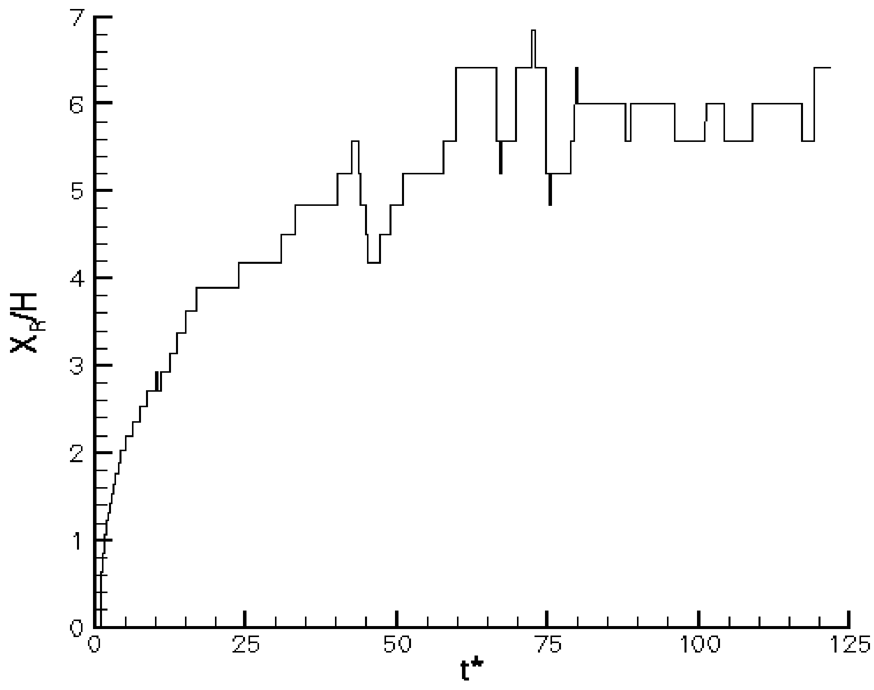
C_{DES}=1.0, Δt=0.00125 H/Uinf, After 8000 cycles



Grid Resolution Study: Sample plot

WIND-DES

$\Delta X_R/X_R$=0.07, $\Delta X_o/\delta$ = 0.05



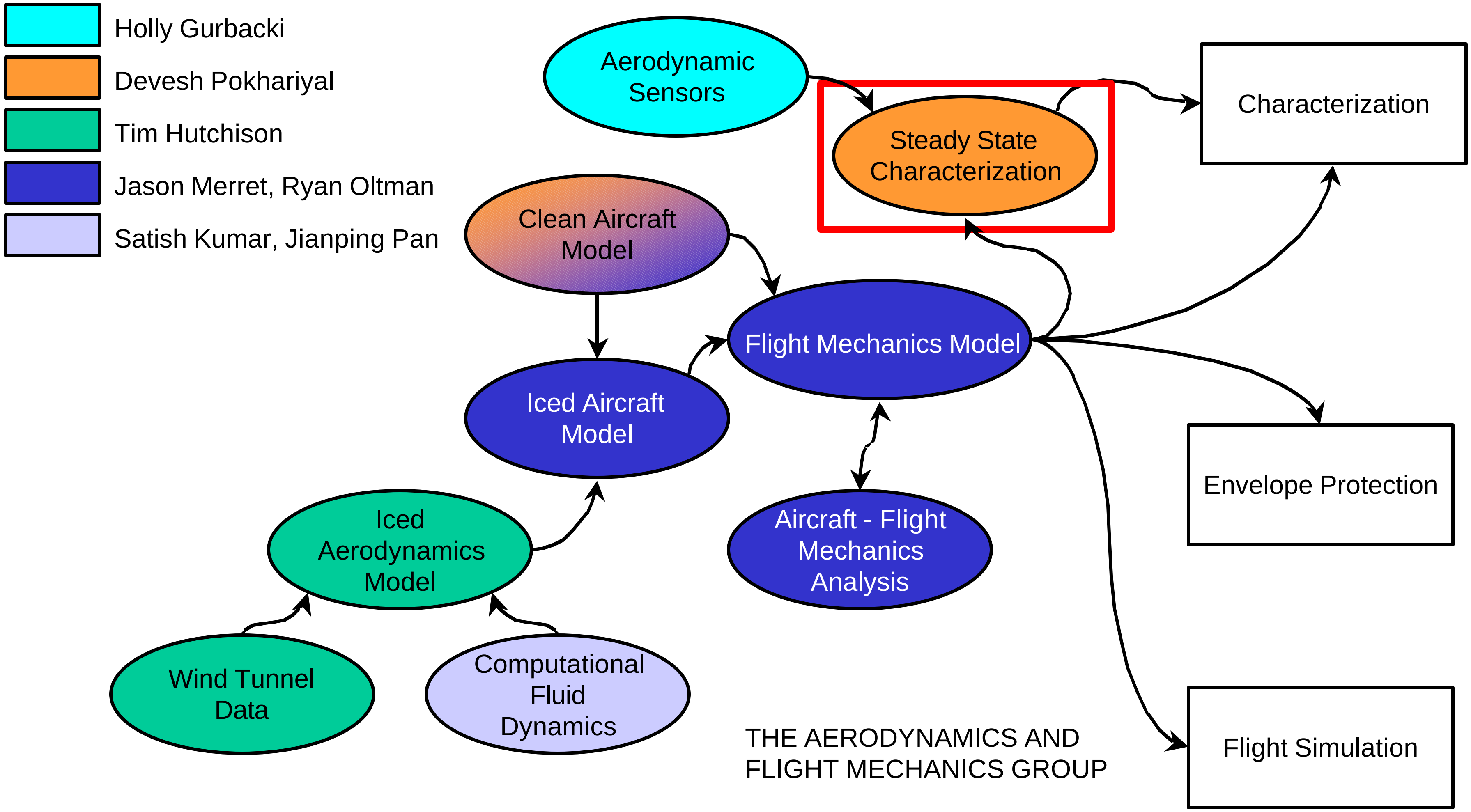
Conclusions

- NSU2D reasonably predicts the trends of all the aerodynamic forces and moments for upper surface icing on NACA 23012m and NLF 0414 (but $C_{l,max}$ not robust)
- WIND-RANS predictions agree reasonably well with experimental results for leading-edge icing for NLF 0414
- WIND-DES has been developed and captures the coherent structures in the free shear layer for backstep flow

Future Work

- Apply WIND-RANS to 2D ice-shapes on other airfoils (in particular the Twin Otter wing and tailplane) for the 2D aerodynamic net database
- Extend WIND-RANS to 3D iced wings for the 3D aerodynamic net database
- Apply WIND-DES to iced airfoils and wings to allow improved $C_{l,max}$ and predict unsteady hinge moments
- (Far term) Apply WIND-DES to simultaneously model wing and tail with unsteady ice accretion

Smart Icing System Research



Outline

- Introduction
- Flight Mechanics Models and Icing Effects
- FDC code and modifications to the code
- Effect of Ice on Aircraft Flight Mechanics
  – Cruise and hold in constant power flight
  – Turbulence, sensor noise and filters
  – Icing on selected aircraft components
- Neural Network training data
- Conclusions

Twin Otter Model

- Twin Otter Aircraft Characteristics

Parameter	Value	Units
Wing Area	39.02	m2
Wing Span	19.81	m
Aspect Ratio	10	
Mean Aerodynamic Chord	1.981	m
Mass	4150	kg
Moments of Inertia: Ixx, Iyy, Izz, Ixz	21279, 30000,44986, 1432	kg.m2
Flap Deflection	0	deg

Stability and Control Model

- Model is derived primarily from flight dynamics data in AIAA report 86-9758, AIAA report 89-0754 and AIAA 93-0754
- Icing scaled using η parameter (η = 0.0675, η/η_{ice} = 0.79)
- Non-dimensional derivatives:

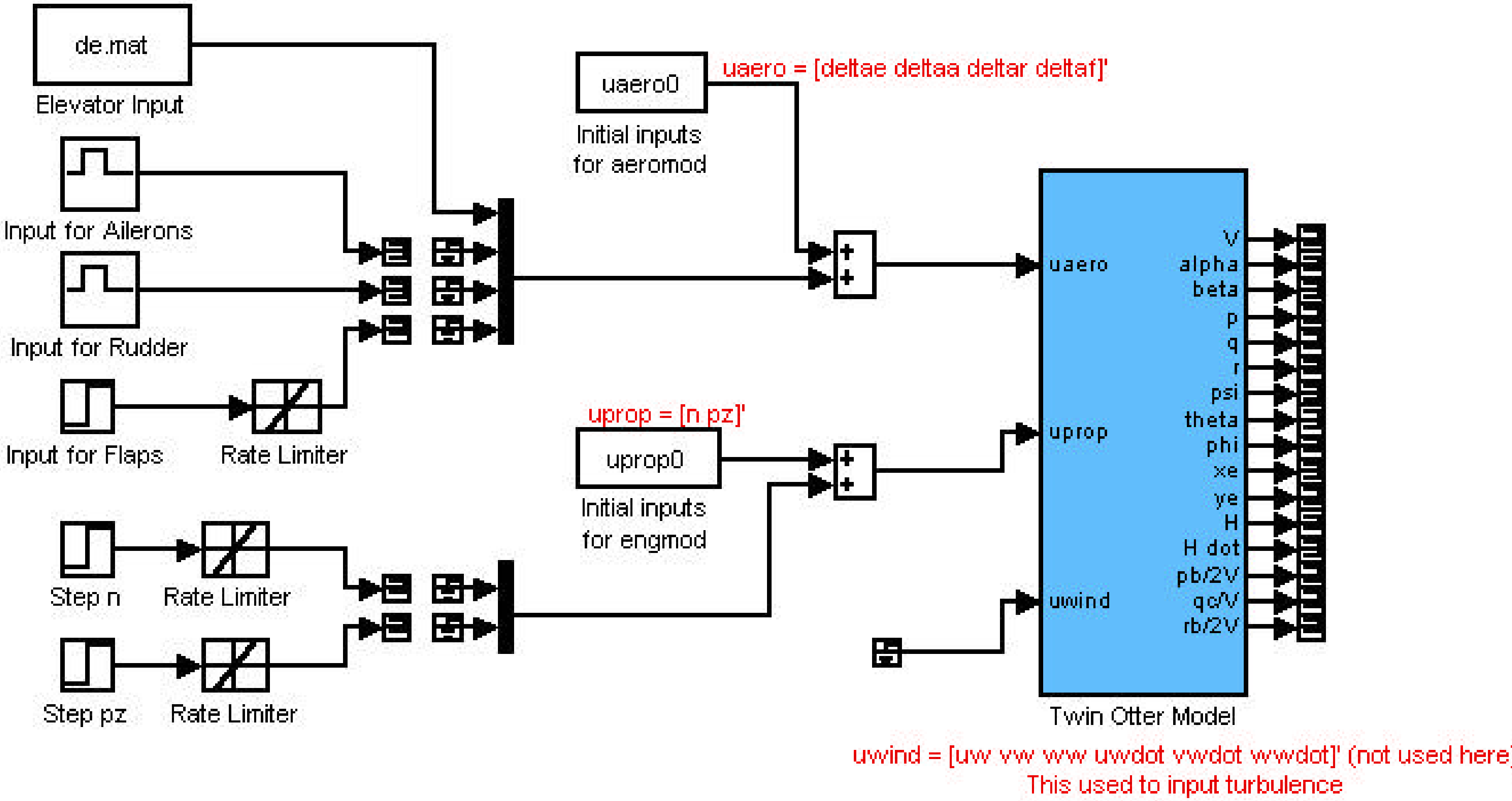
	C_{Z0}	$C_{Z\alpha}$	C_{Zq}	$C_{Z\delta e}$	C_{X0}	K	C_{m0}	$C_{m\alpha}$	C_{mq}	$C_{m\delta e}$
clean	0.360	-5.660	-19.970	-0.608	0.041	0.052	0.400	-1.310	-34.200	-1.740
wing_ice	0.360	-5.342	-19.700	-0.594	0.050	0.053	0.400	-1.285	-33.000	-1.709
tail_ice	0.360	-5.520	-19.700	-0.565	0.046	0.053	0.400	-1.263	-33.000	-1.593
all iced	0.360	-5.094	-19.700	-0.550	0.062	0.057	0.400	-1.180	-33.000	-1.566

	C_{Yb}	C_{Yp}	C_{Yr}	C_{Ydr}	C_{lb}	C_{lp}	C_{lr}	C_{lda}	C_{ldr}	C_{nb}	C_{np}	C_{nr}	C_{ndr}	C_{nda}
clean	-0.6	-0.2	0.4	0.15	-0.08	-0.5	0.06	-0.15	0.015	0.1	-0.06	-0.18	-0.12	-0.001
iced	-0.48	-0.2	0.4	0.138	-0.072	-0.45	0.06	-0.135	0.0138	0.08	-0.06	-0.169	-0.11	-0.001

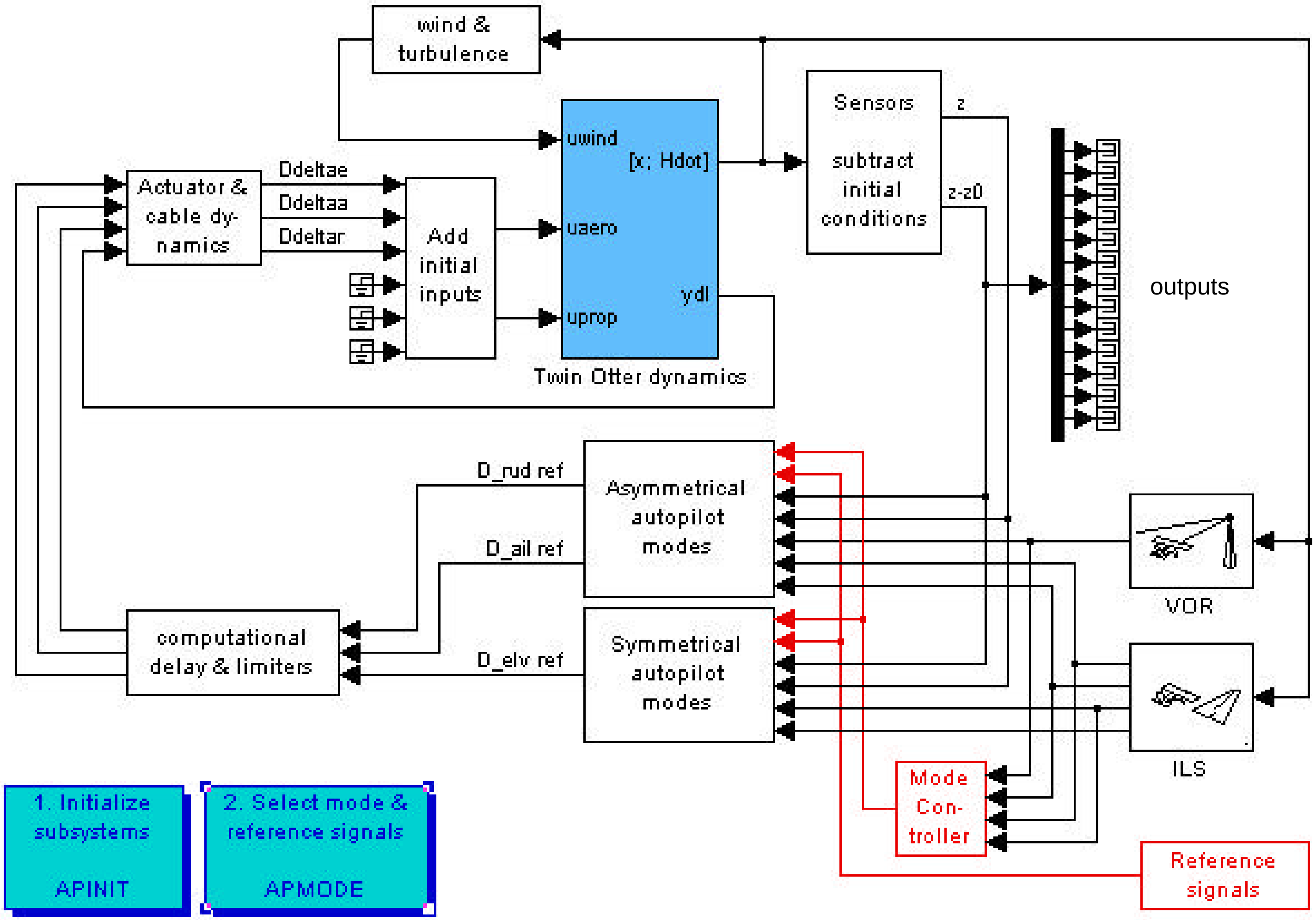
Flight Dynamics and Control Toolbox

- Flight Dynamics Code 1.3
  - FDC 1.3 is a free source code by Marc Rauw (based in the Netherlands: http://home-2.worldonline.nl/~rauw/)
  - Code developed using MATLAB and SIMULINK
  - 6 DoF equations, 12 nonlinear ODEs
  - Autopilot/open loop simulations
  - Atmospheric turbulence model
  - Code modifications:
    - Nonlinear derivatives represented using AOA "look-up tables"
    - Changes in derivatives due to ice accretion simulated as a function of time
    - Incorporated sensor noise
    - Included hinge moment models

Open Loop Analysis Tool for Nonlinear Twin Otter Model



Closed Loop Analysis Tool for Nonlinear Twin Otter Model

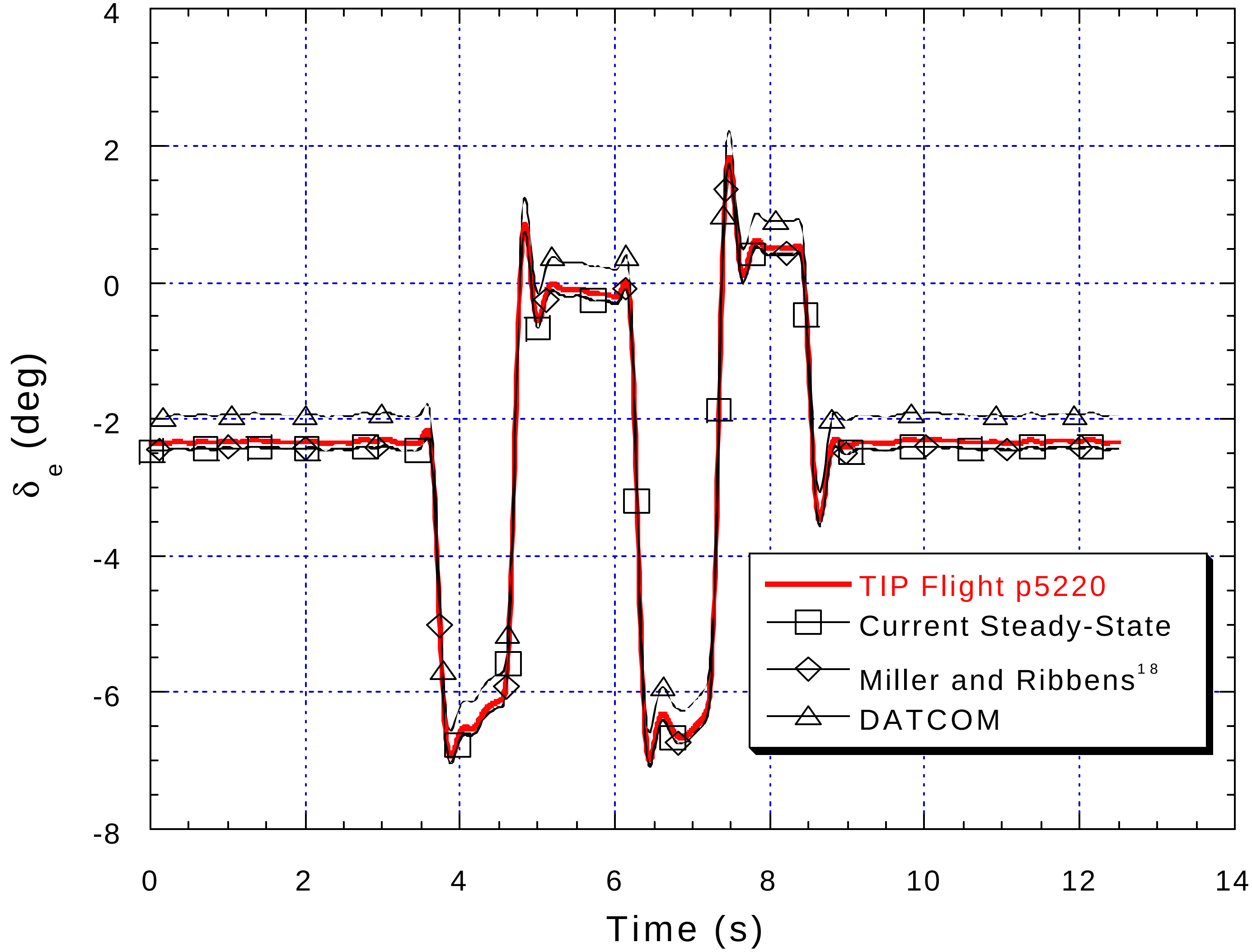


Note: Turbulence Removed!

FDC Validation

- The FDC Code is validated by comparing the response of a doublet to published NASA data (AIAA 99-0636) for the Twin Otter aircraft
- The validation results are published in AIAA 2000-0360
- The response of other Twin Otter models to the elevator doublet are also observed

Elevator Doublet Input

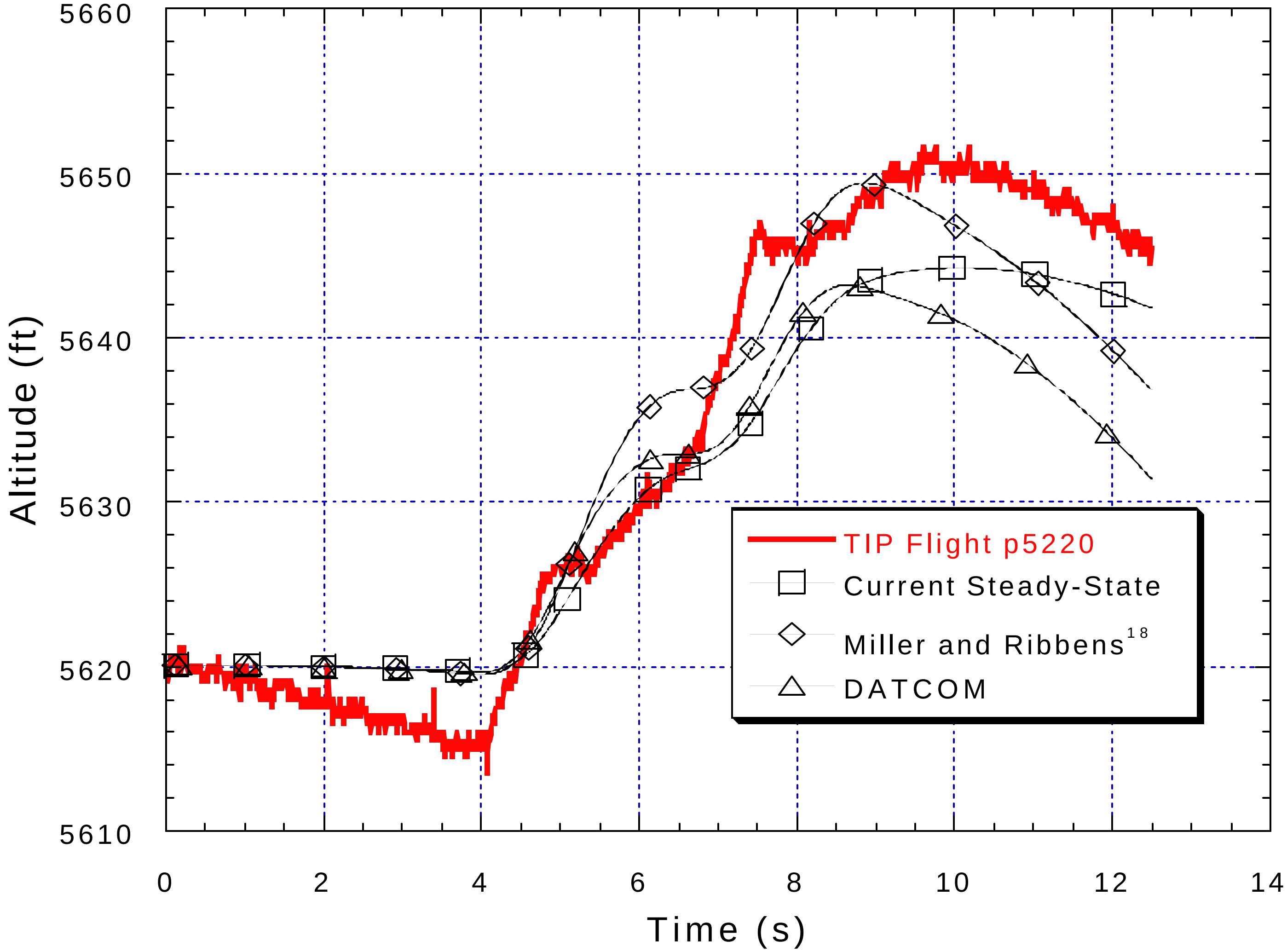


Twin Otter

V_0=111 kts

h=5620 ft

Twin Otter Response to Elevator Doublet



Twin Otter

V_0=111 kts

h=5620 ft

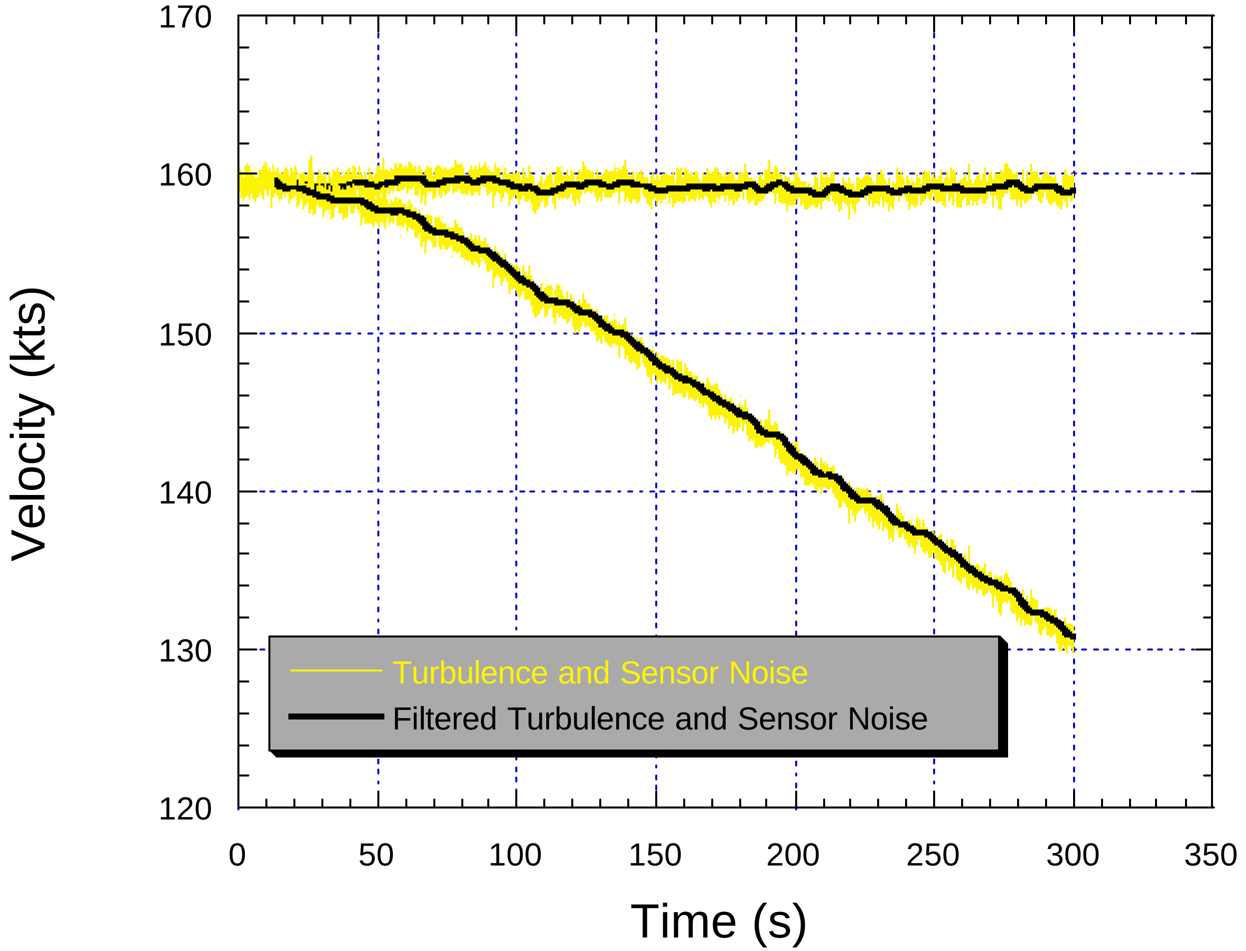
Atmospheric Turbulence and Noise

- The turbulence model used in the FDC 1.3 steady state analysis is based on the Dryden spectral density distribution
- Turbulence intensity can be varied and are characterized by the effect on the aircraft z-acceleration
- Sensor noise magnitudes are twice the uncertainty values given in AIAA 93-0398 and are modeled as band limited white Gaussian distributions
- The effects of turbulence provide an overlap between the quasi-steady characterization and the dynamic characterization

Effects of Filtering

- Filters are applied to data obtained from the constant power cruise flight conditions, in the clean and iced configurations. The initial trim values for the Twin Otter are:
  - V = 160 kts
  - h = 9000 ft
  - A/C RMS z-acceleration = 0.15g
- The data, sampled at variable time steps, is post-filtered using low-pass Butterworth filters

Effects of Filtering, V



Twin Otter

Const. Alt.

Const. Power

V_0= 160 kts

h=9000 ft

η_{ice}= 0 to 0.5

Filter:

2nd order low pass Butterworth

f_{cutoff}=0.17 Hz

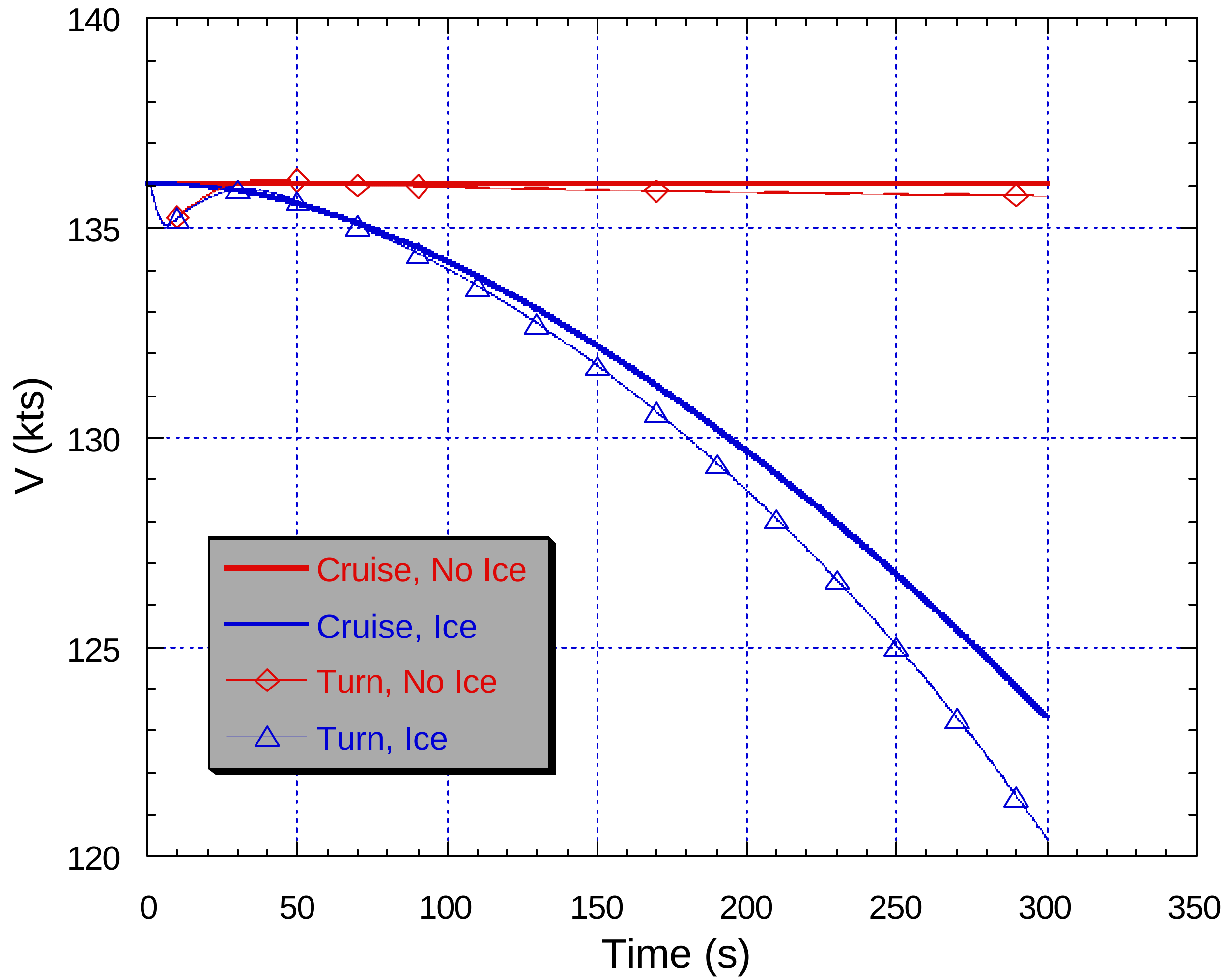
Performance in Holding Turn and Cruise

- A holding pattern is represented by a standard-rate turn and cruise flight at constant power.
- Initial trim conditions for the standard-rate turn and cruise case in clean and iced configuration:
    - V = 136 kts
    - h = 6560 ft
    - A/C RMS z-acceleration = 0.15g

    Standard 2 minute turn rate.

Performance in Holding Turn and Cruise, V

Smart Icing Systems *NASA Review, June 13-14, 2000*



Twin Otter

Const. Power

Const. Alt.

V_0=136 kts

h=6560 ft

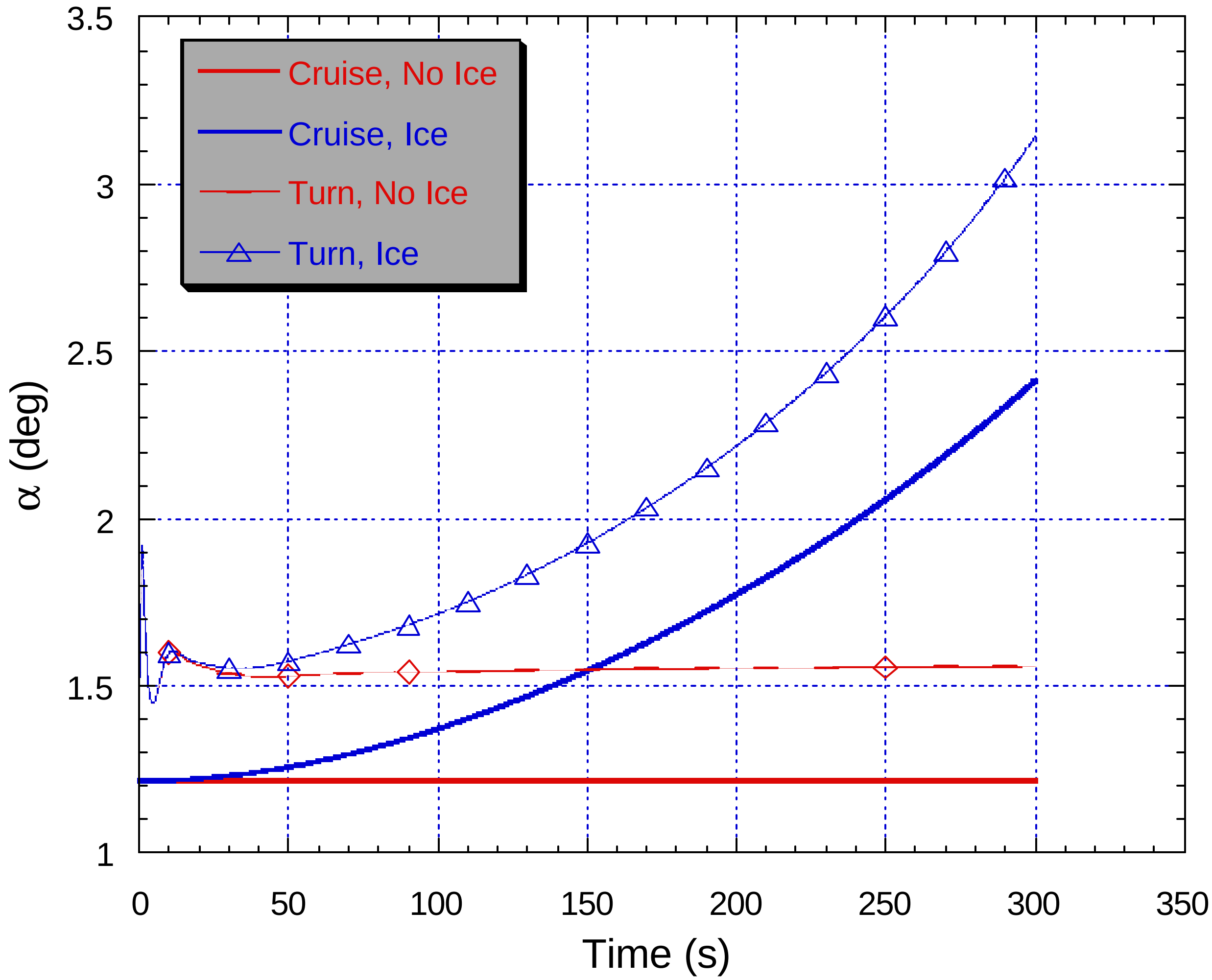
η = 0 to 0.5

Holding turn:

3°/s turn

Holding Turn and Cruise, α

Smart Icing Systems *NASA Review, June 13-14, 2000*



Twin Otter

Const. Power

Const. Alt.

V_0=136 kts

h=6560 ft

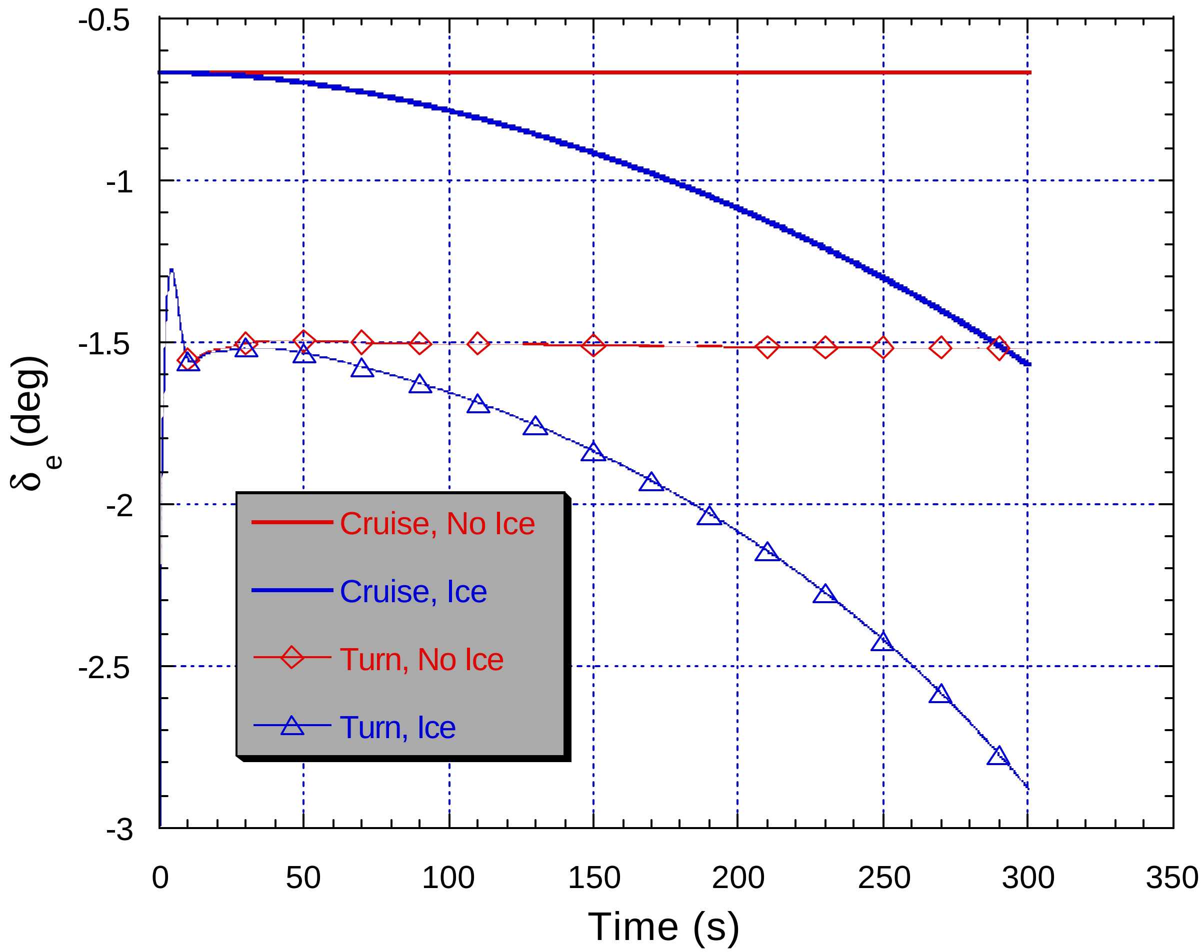
η = 0 to 0.5

Holding turn:

3°/s turn

Holding Turn and Cruise, δ_e

Smart Icing Systems *NASA Review, June 13-14, 2000*



Twin Otter

Const. Power

Const. Alt.

V_0=136 kts

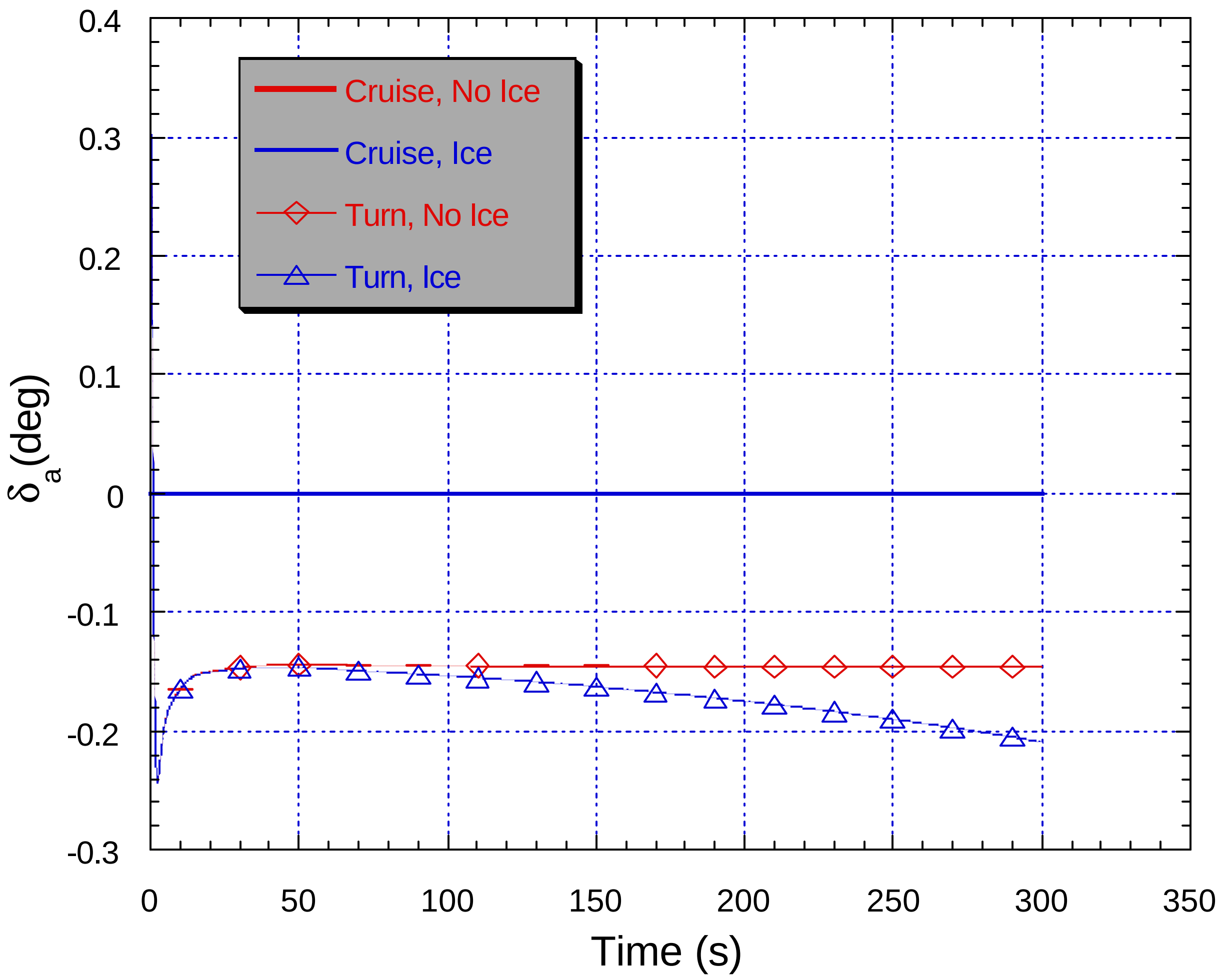
h=6560 ft

η = 0 to 0.5

Holding turn:

3°/s turn

Holding Turn and Cruise, δ_a



Twin Otter

Const. Power

Const. Alt.

V_0=136 kts

h=6560 ft

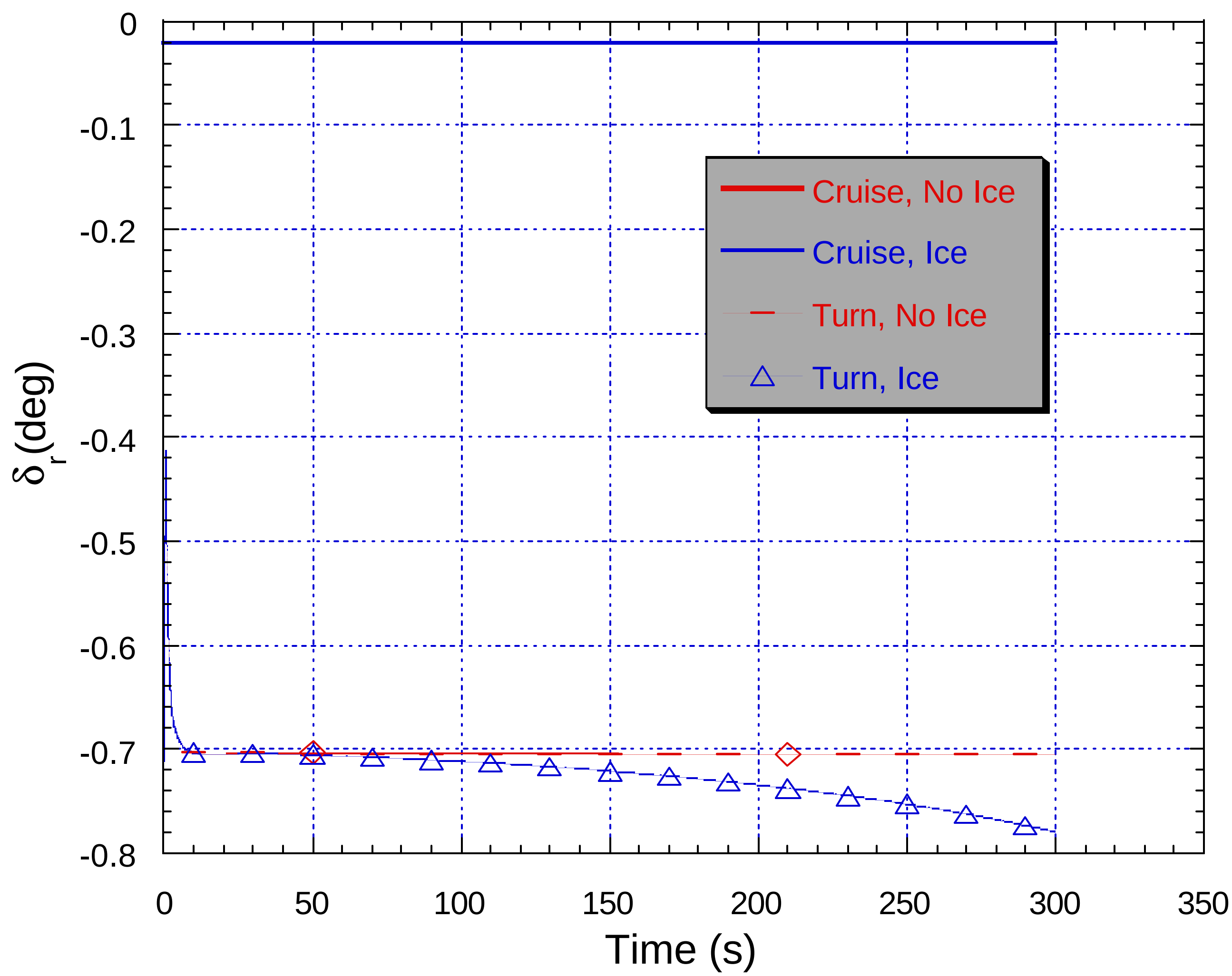
η = 0 to 0.5

Holding turn:

3°/s turn

Holding Turn and Cruise, δ_r

Smart Icing Systems — NASA Review, June 13-14, 2000



Twin Otter

Const. Power

Const. Alt.

V_0=136 kts

h=6560 ft

η = 0 to 0.5

Holding turn:

3°/s turn

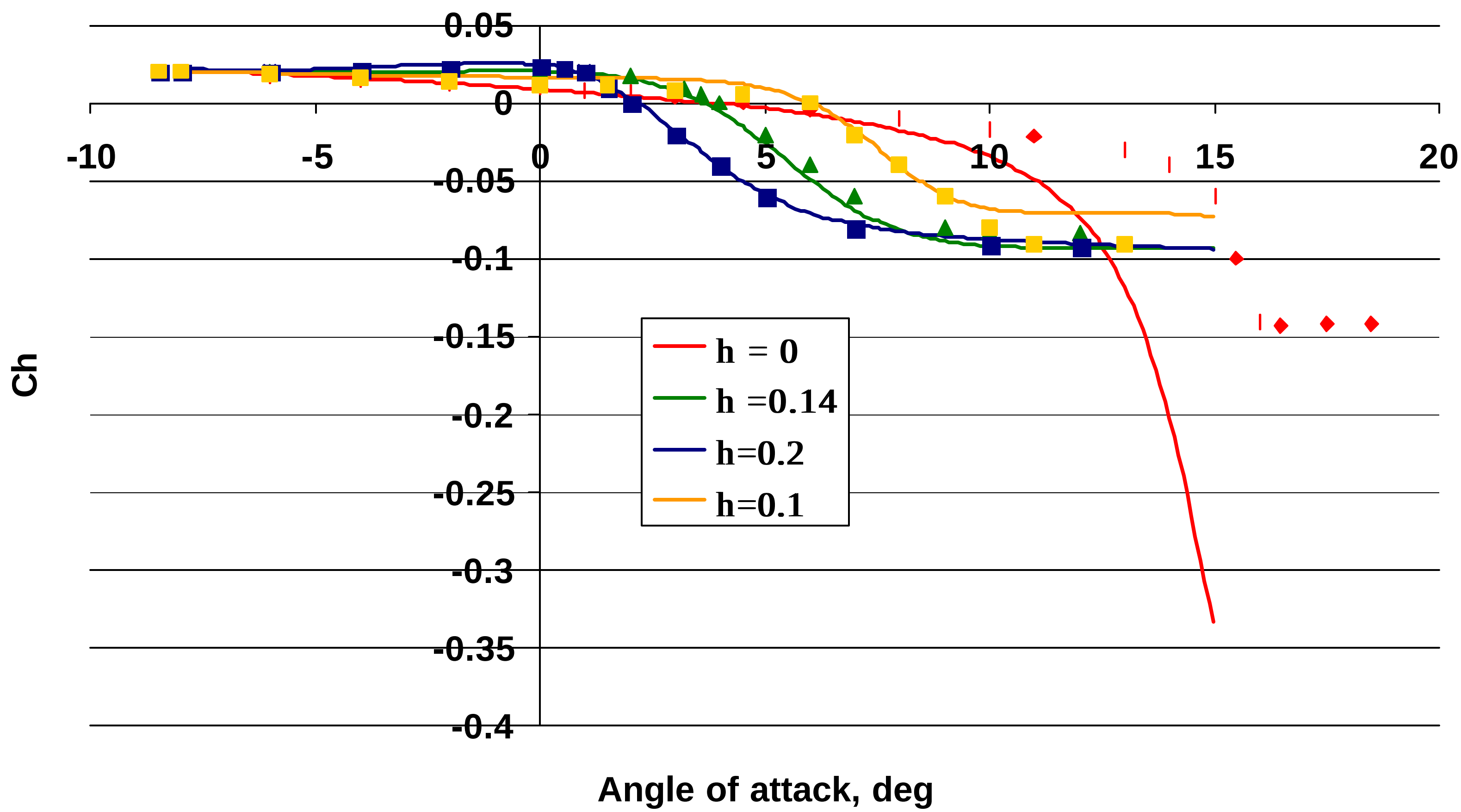
Hinge Moment Models

- 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)

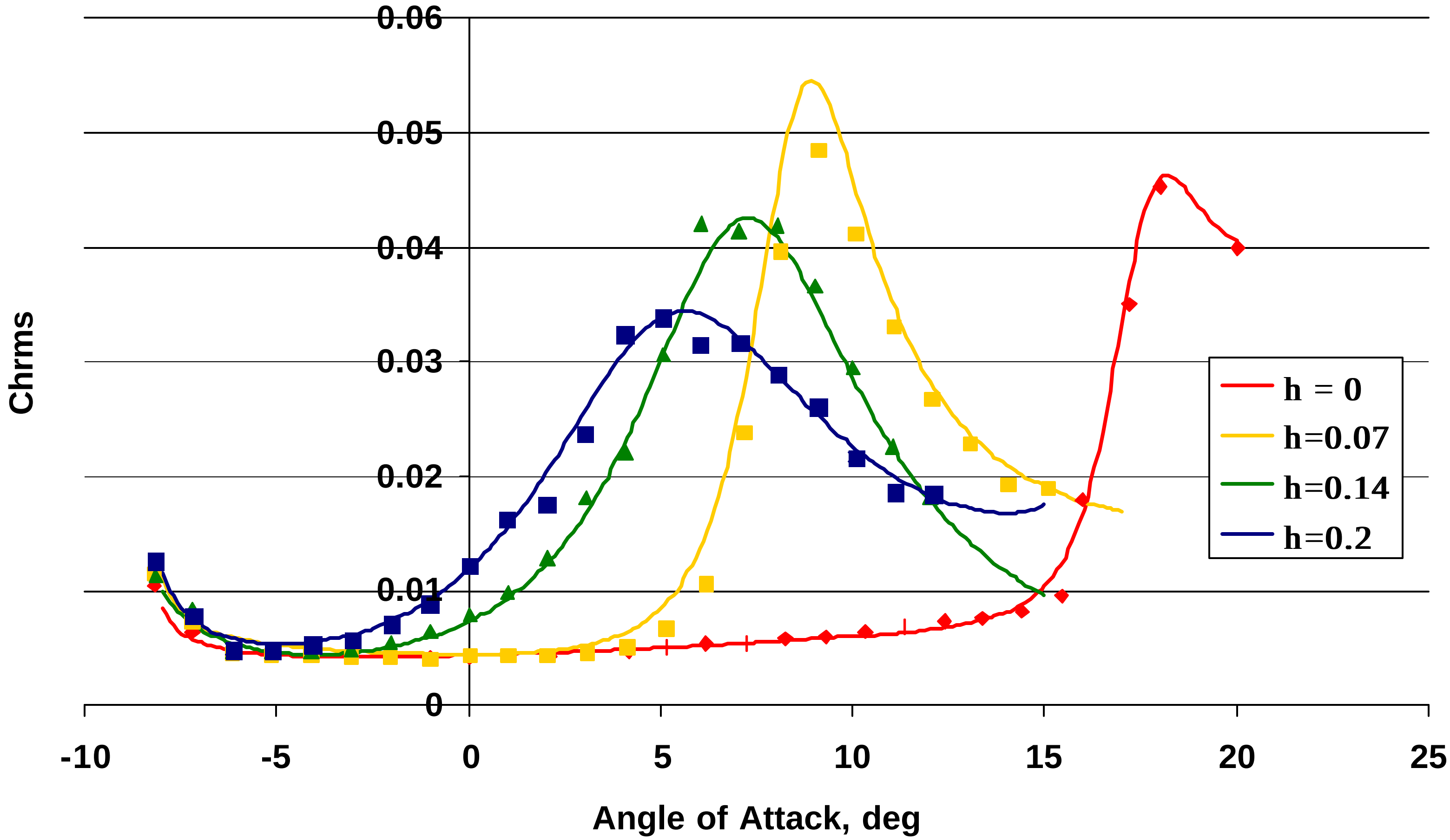
Hinge Moment Models

- Models are based on limited experimental hinge moment data.
- C_h and C_{h_rms} models are a functions of angle of attack, elevator deflection and icing parameter, η
- Hinge moment models do not include the effect of control surface mass.

C_h model


0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
-10
-5
0
5
10
15
20
Ch
Angle of attack, deg
h = 0
h =0.14
h=0.2
h=0.1

C_{h_rms} model

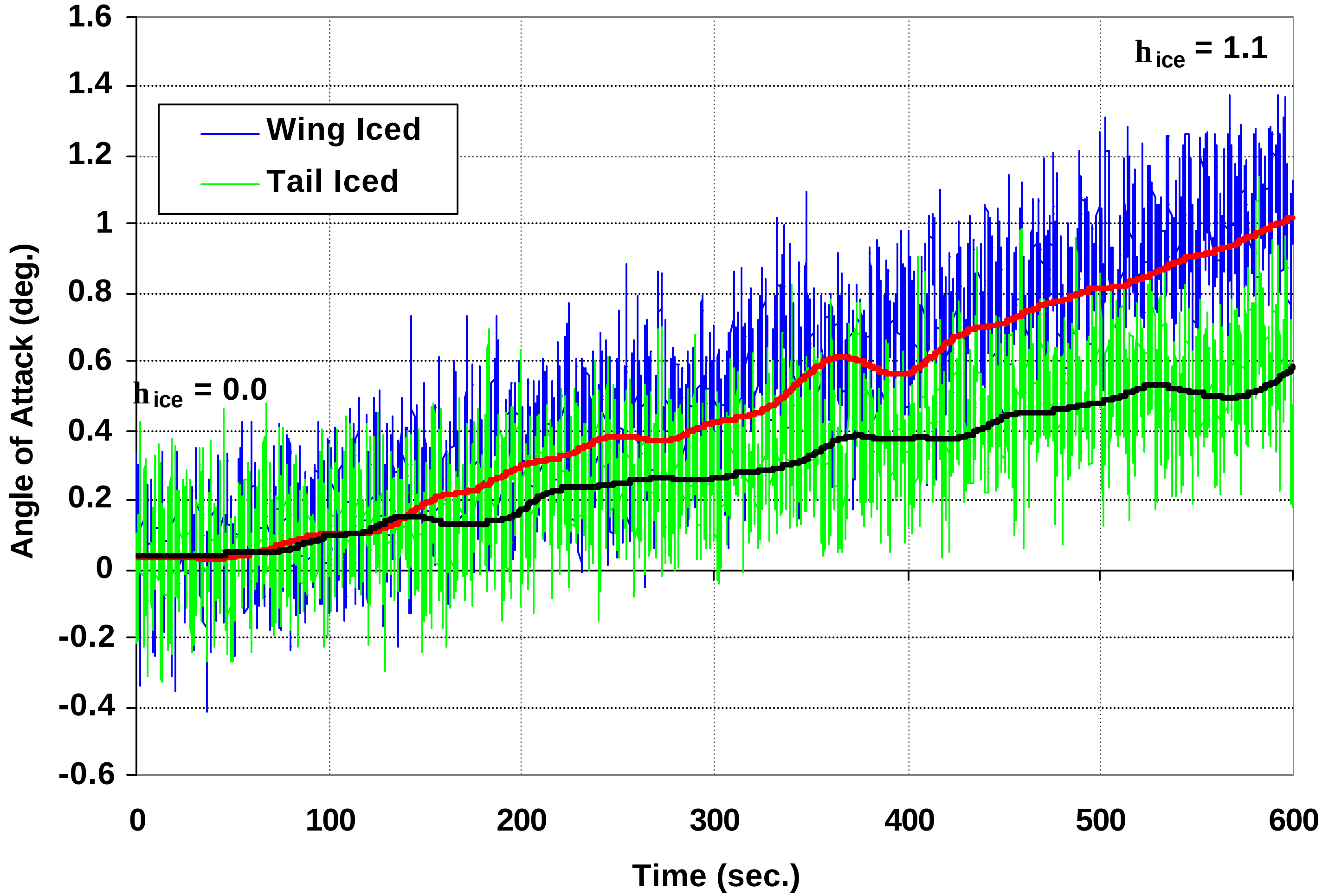

0.06
0.05
0.04
0.03
0.02
0.01
0
Chrms
-10
-5
0
5
10
15
20
25
Angle of Attack, deg
h = 0
h=0.07
h=0.14
h=0.2

Ice Location Effects

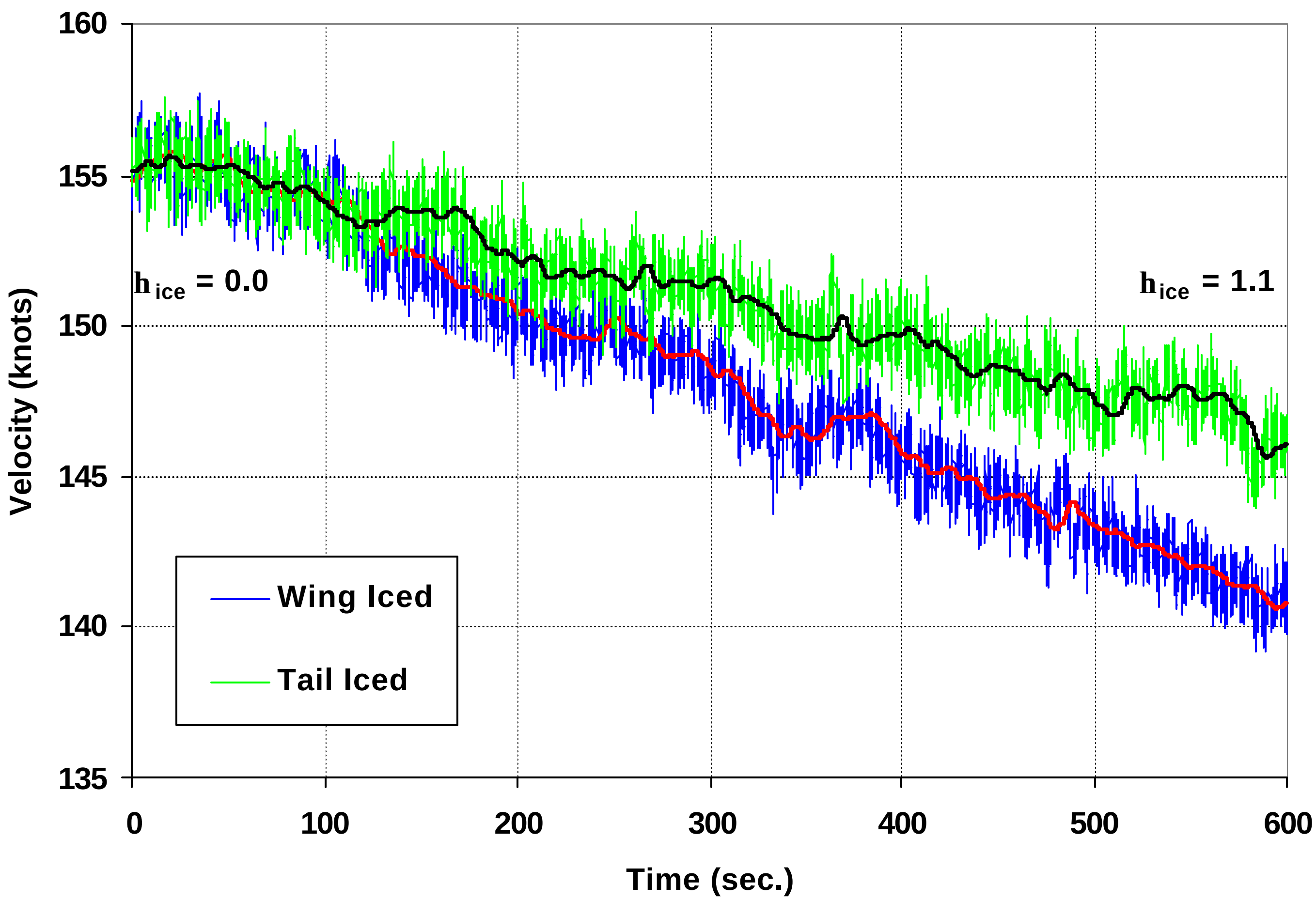
- Ice accretion on different aircraft locations was considered:
    - Tail ice
    - Wing ice
- A constant power, constant altitude scenario, maintained by the autopilot, was considered
    - V = 155 kts
    - h = 7550 ft
    - A/C RMS z-acceleration = 0.15g

Effect of Ice Location on a

Smart Icing Systems — *NASA Review, June 13-14, 2000*

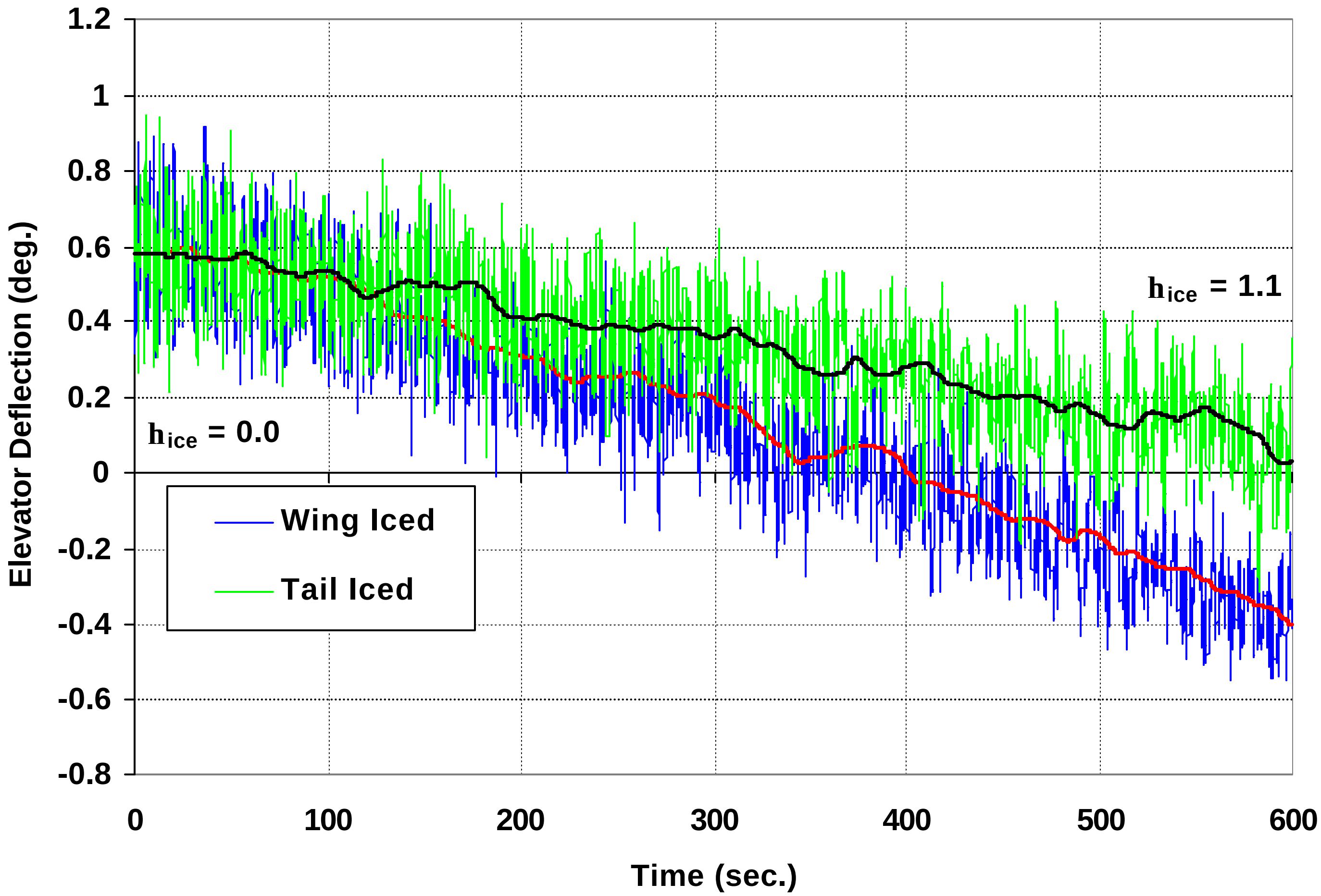


Effect of Ice Location on V

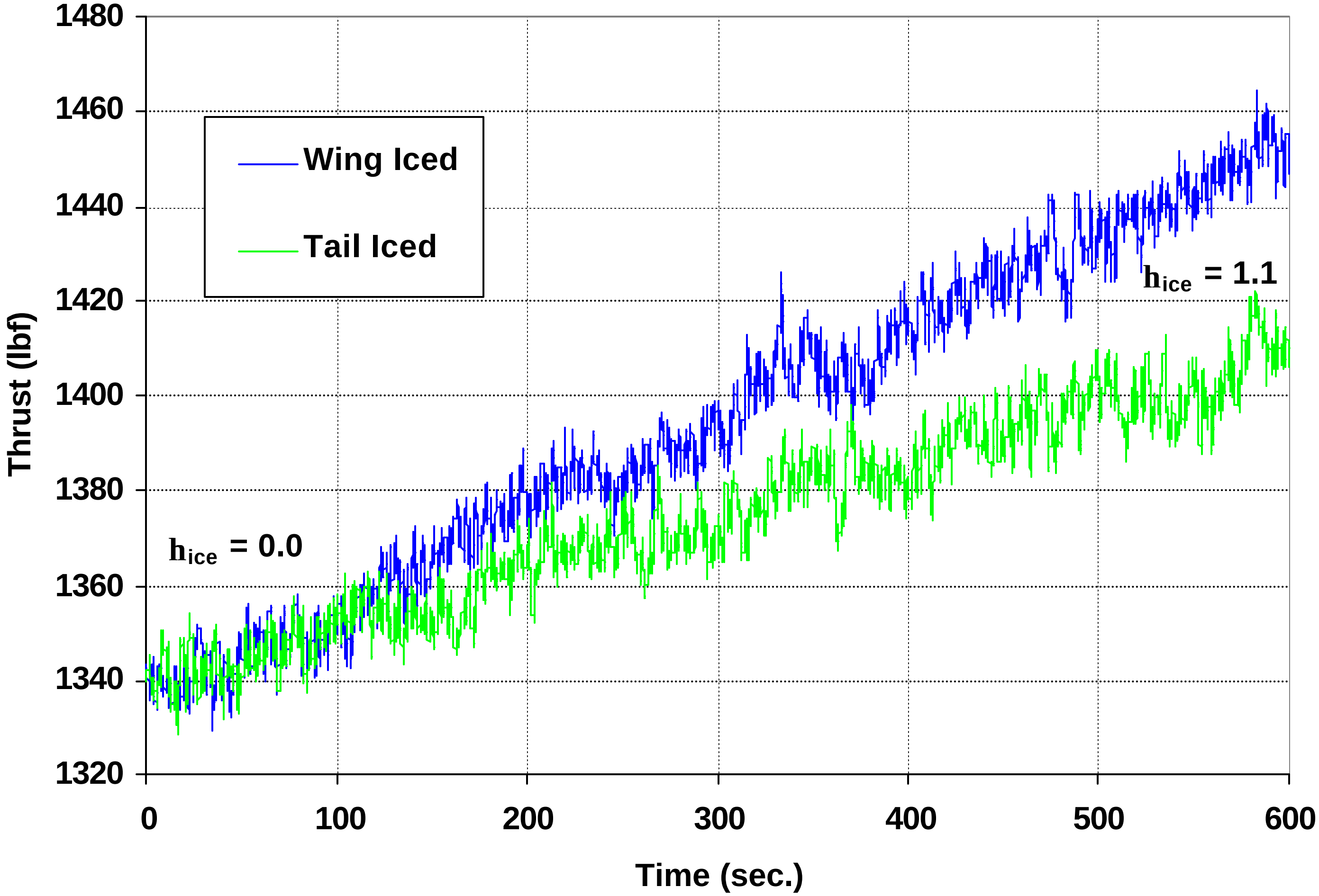


Effect of Ice Location on δ_E

Smart Icing Systems — *NASA Review, June 13-14, 2000*



Effect of Ice Location on Thrust



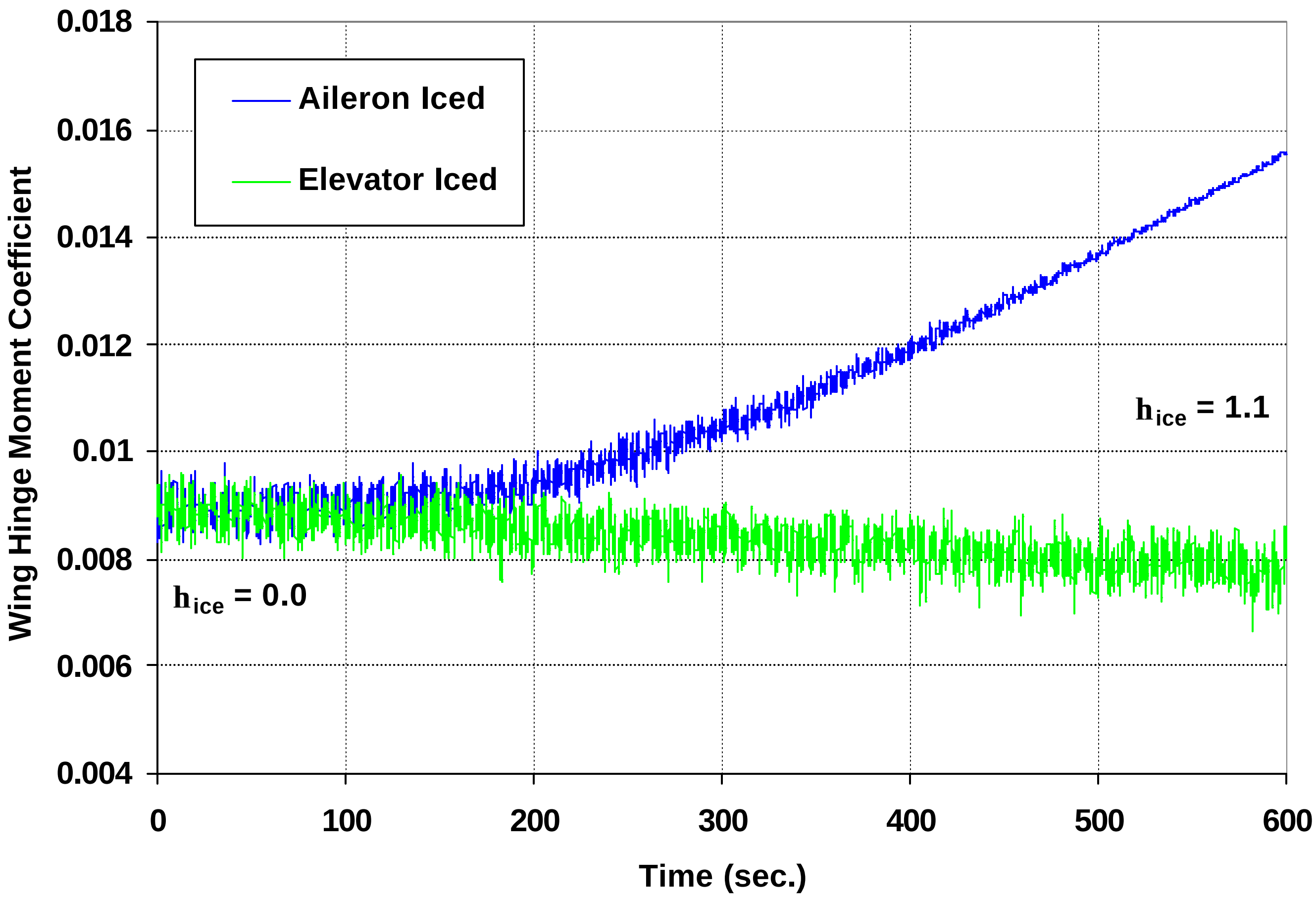
Determining Ice Location

- An analysis of the aerodynamic outputs shows the difficulty in determining the location of ice – the tail ice encounter resembles a less severe all aircraft icing encounter
- The increase in drag due to ice accretion dominate the aerodynamic outputs in both tail and all aircraft iced cases

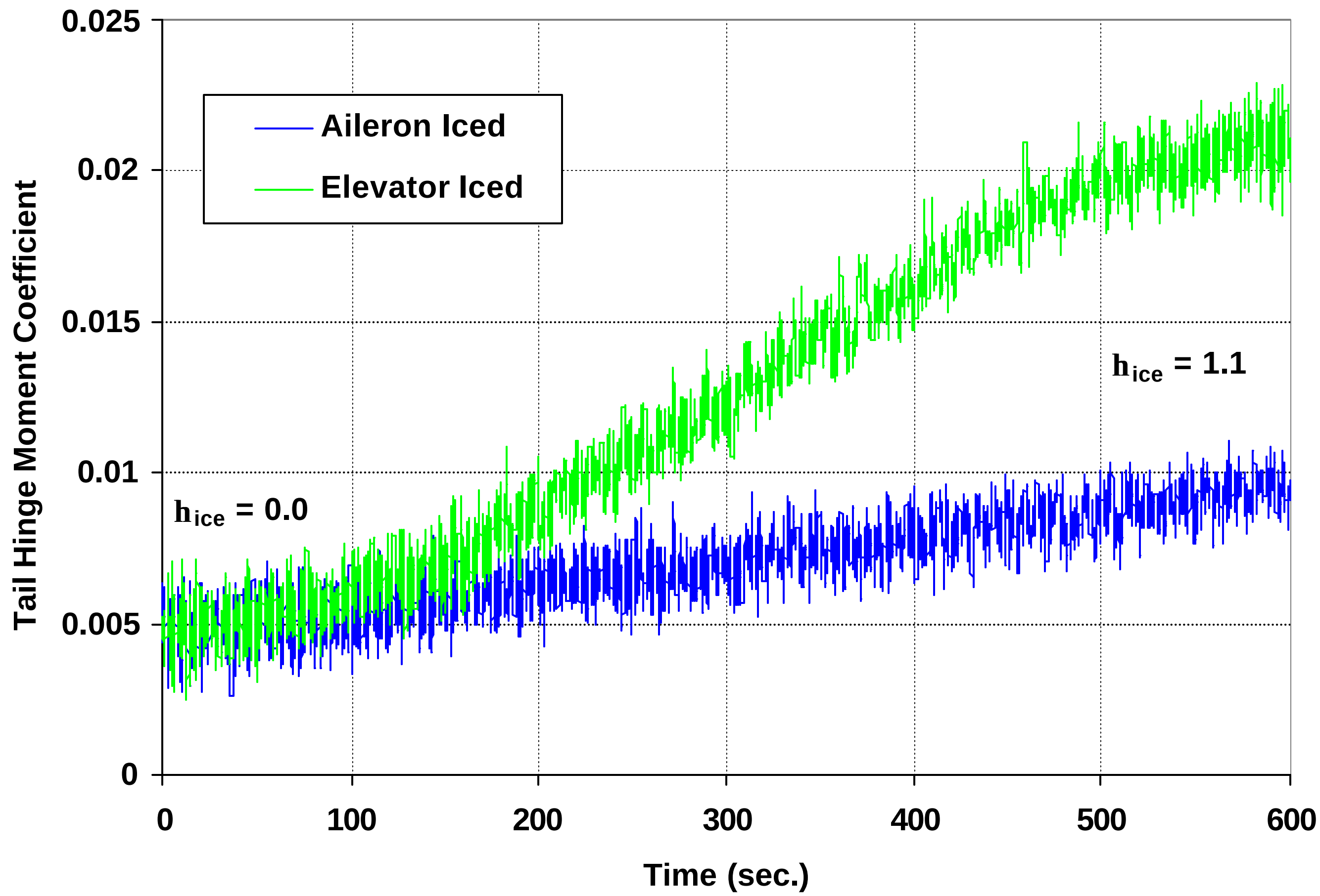
Hinge Moment Sensors

- The wing and tail hinge moments are calculated for the aileron and elevator deflections respectively
- The η values used for the tail is based on the Twin Otter horizontal tail chord length of 4.75 ft. A linearized relationship between the wing and tail icing severity parameter is used
- A constant power, constant altitude scenario, maintained by the autopilot, was considered
  - V = 155 kts
  - h = 7550 ft
  - A/C RMS z-acceleration = 0.15g

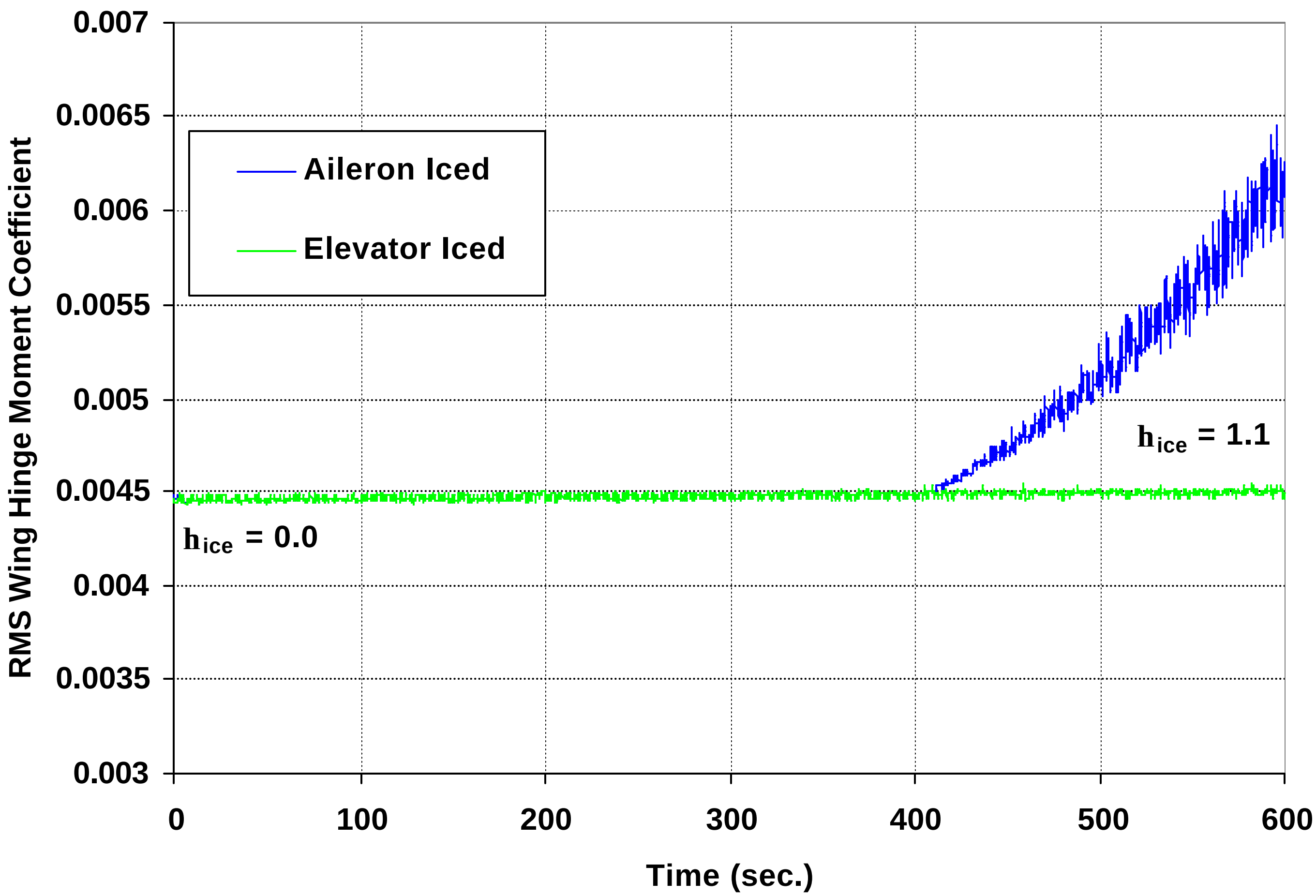
Effect of Ice Location on Wing C_h



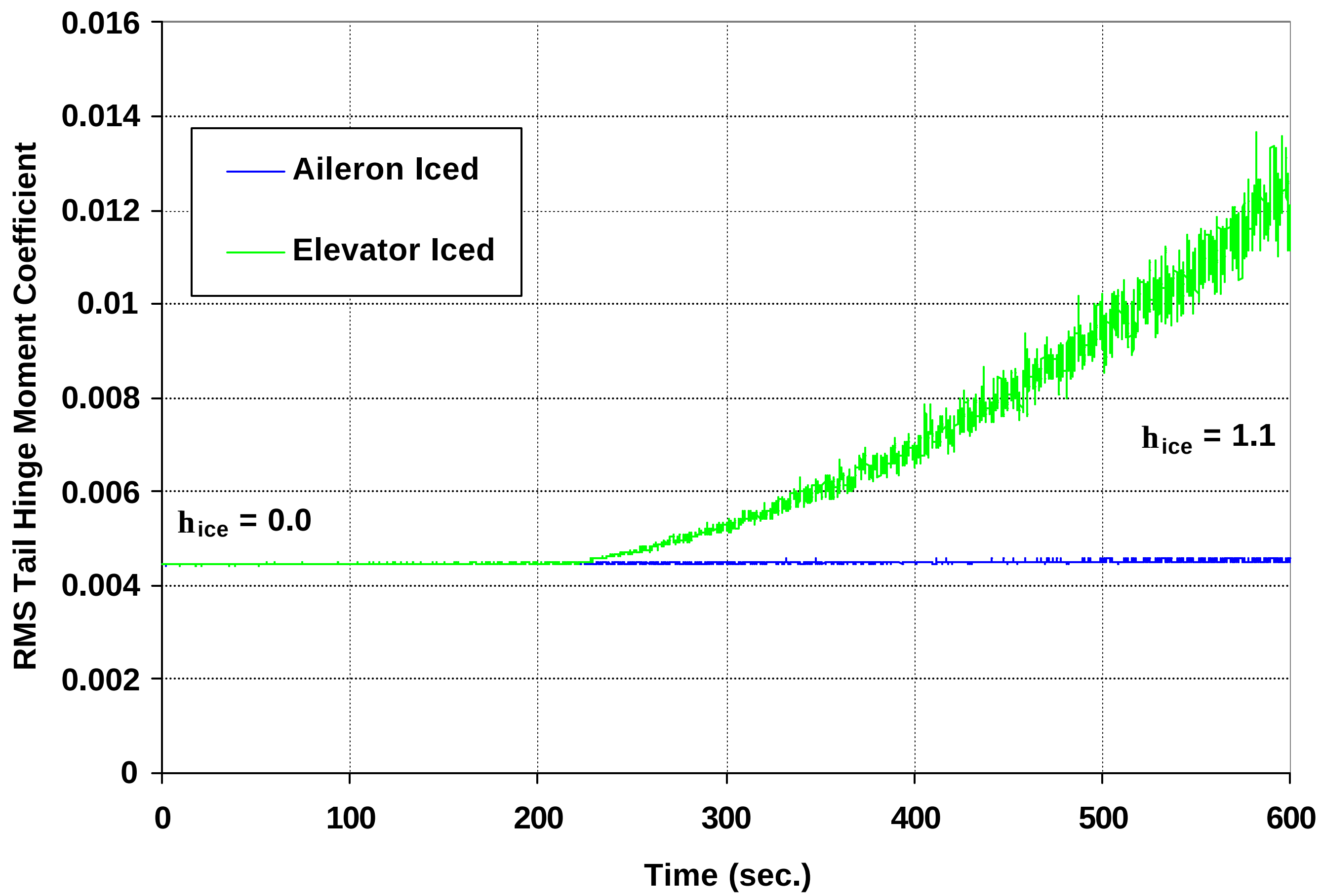
Effect of Ice Location on Tail C_h



Effect of Ice Location on Wing C_{h_rms}



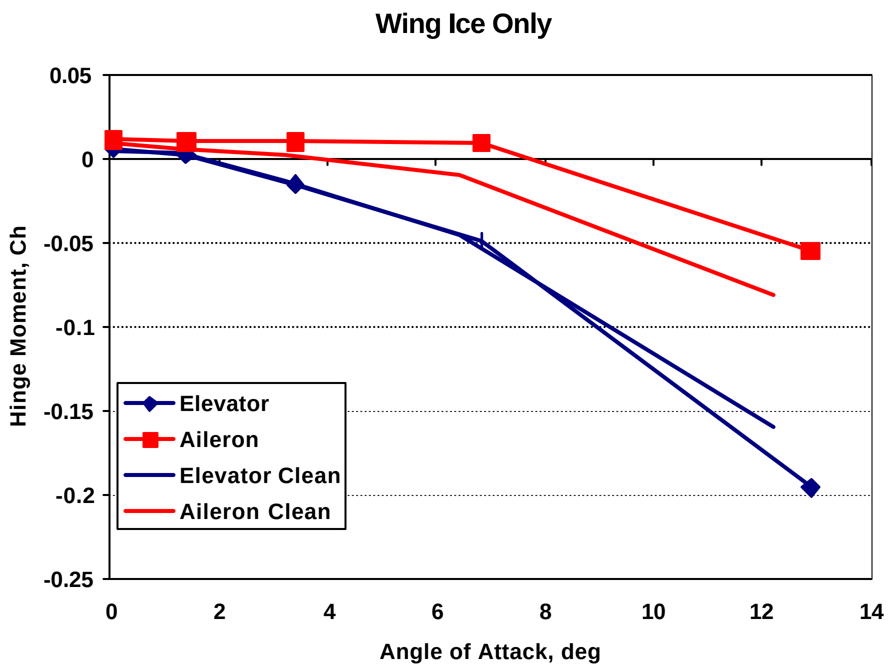
Effect of Ice Location on Tail C_{h_rms}

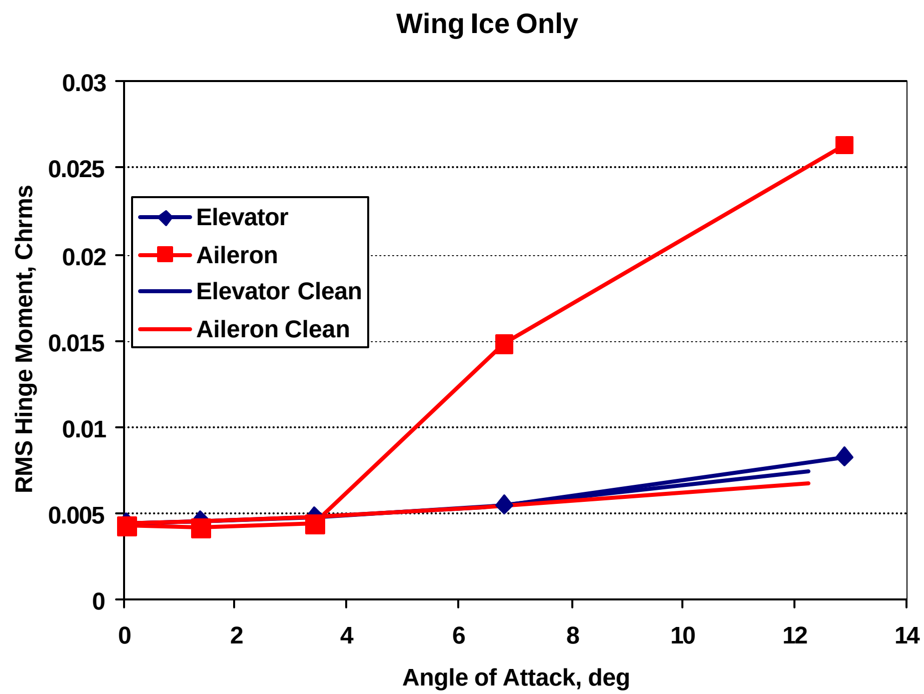


Hinge Moment for Varying Trimmed V

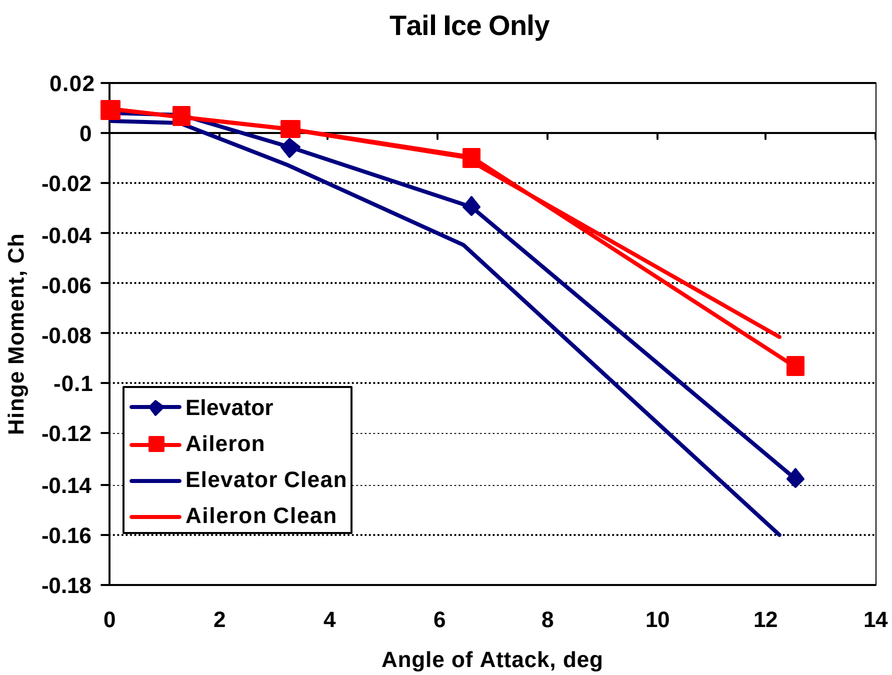
- C_h and C_{h_rms} are calculated for the following trim velocities:
  - V = 78 kts
  - V = 97 kts
  - V = 117 kts
  - V = 136 kts
  - V = 155 kts
- All other conditions are held constant:
  - H = 6560 ft
  - η_{ice}= 0.7112

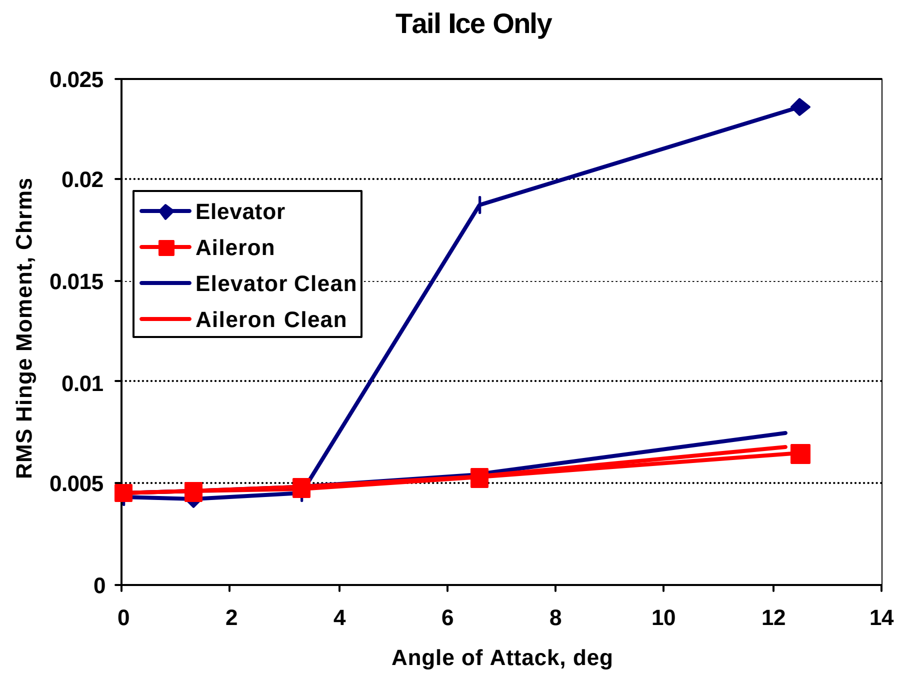
Wing Ice Cases



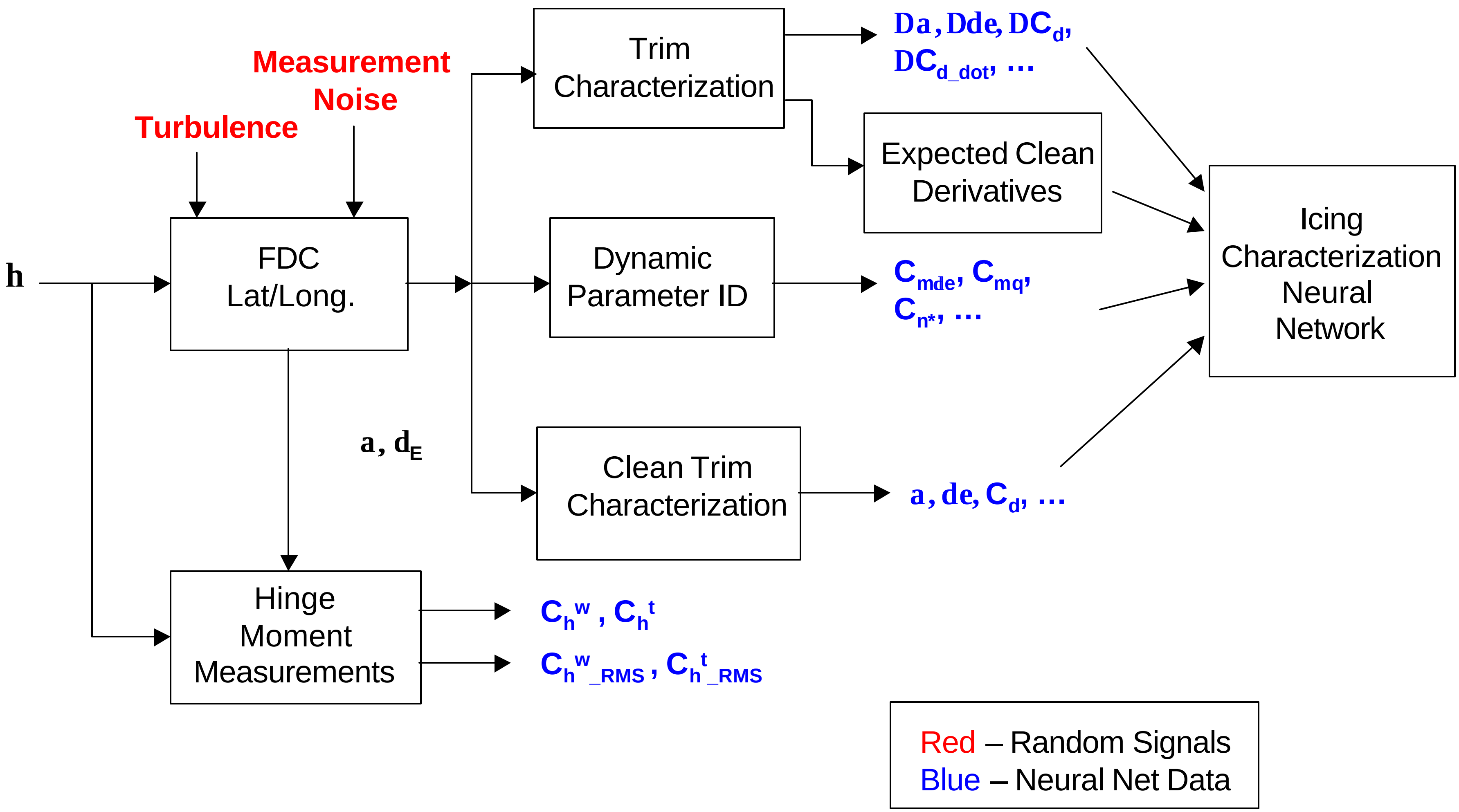


Tail Ice Cases





Icing Characteristic N-Net Input Data



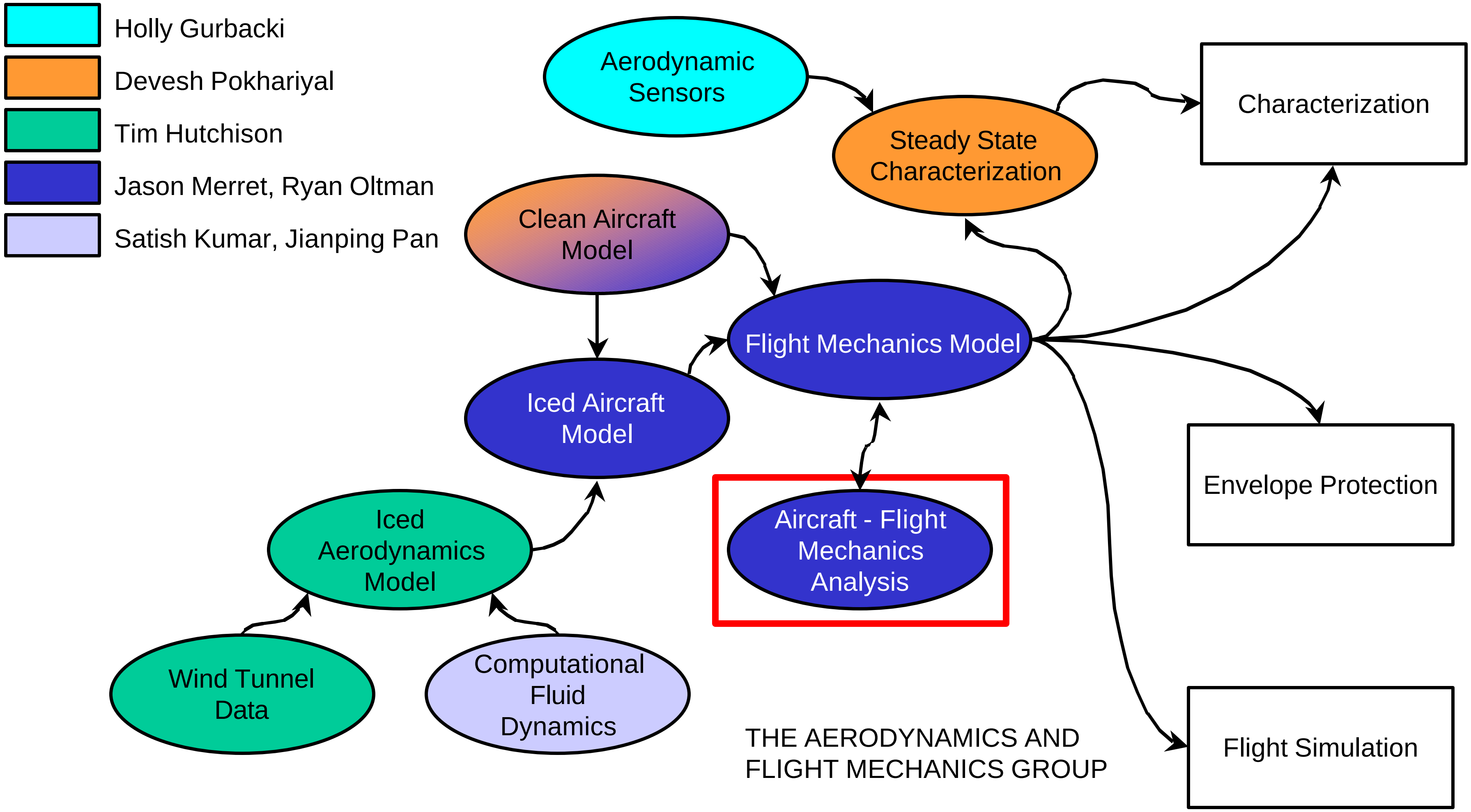
Conclusion

- Use of η_{ice} parameter provides a simple model to determine iced aircraft data
- Effect of ice on V, α, and δ_e for the constant power case are significant, and could be used to characterize the accretion
- Effects of turbulence and sensor noise can be filtered.
- Flight maneuvers increase the apparent effects of ice and improve the potential for ice detection
- The use of hinge-moment data to distinguish tail from wing ice is encouraging

Future Research

- Validate a fully nonlinear force and moment model
- Explore constant velocity and other scenarios using FDC
- Obtain hinge moment data for more airfoils and ice-shapes including the Twin Otter airfoil
- Examine envelope protection strategies

Smart Icing System Research



THE AERODYNAMICS AND FLIGHT MECHANICS GROUP

Introduction

- 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
- The SIS should be able to distinguish quickly between the icing and atmospheric disturbances so appropriate recovery maneuvers can be executed
- Preliminary analysis of the effects of microbursts will determine if further research is required

Objectives

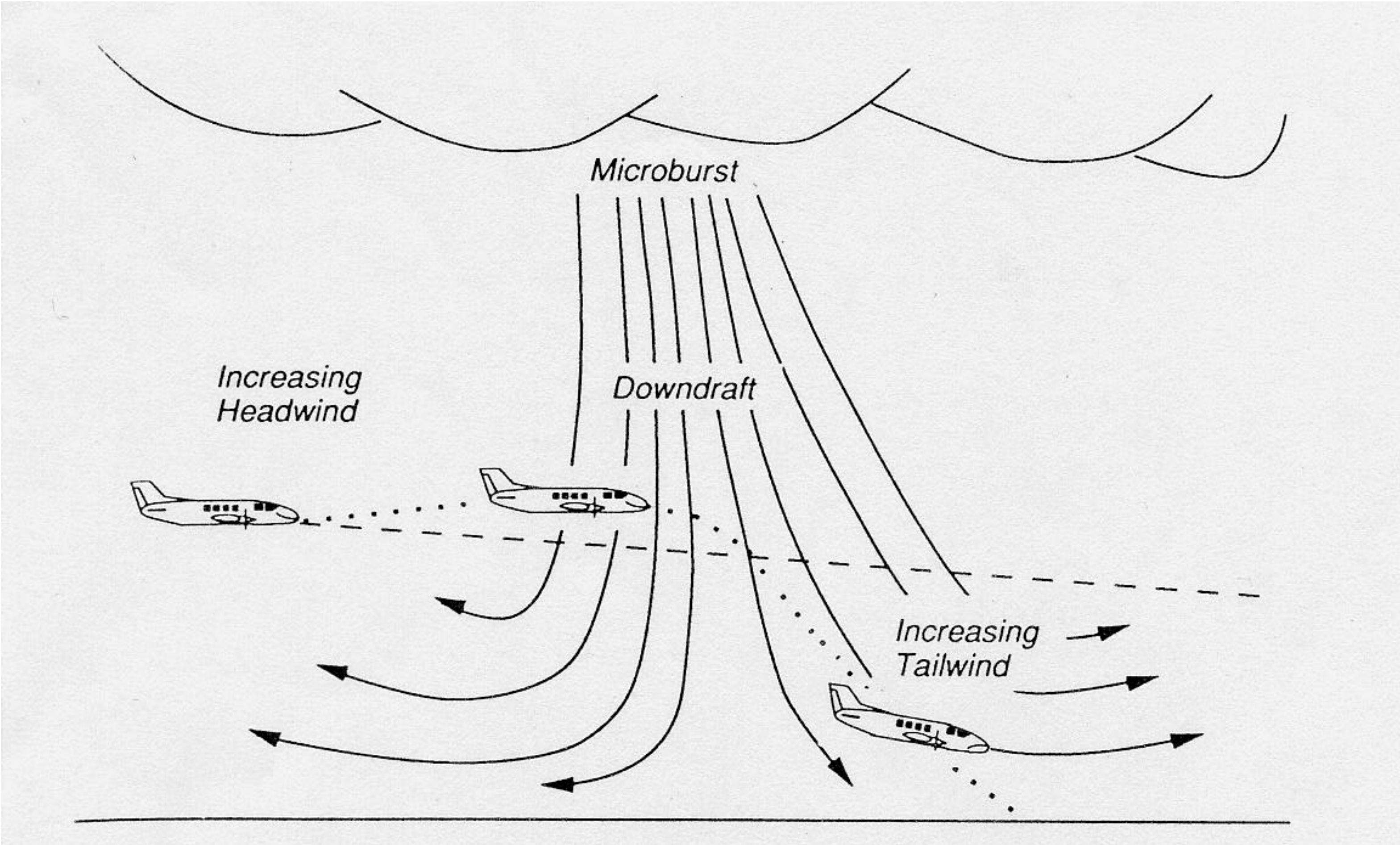
Objective:

To devise a simple, but physically representative, model of the effect of microbursts, gravity waves, and other atmospheric disturbances on aircraft flight mechanics. Then use this model to evaluate the effects on the SIS system.

Motivation:

To evaluate concerns of possible false alarms of the SIS due to atmospheric disturbances

Microburst

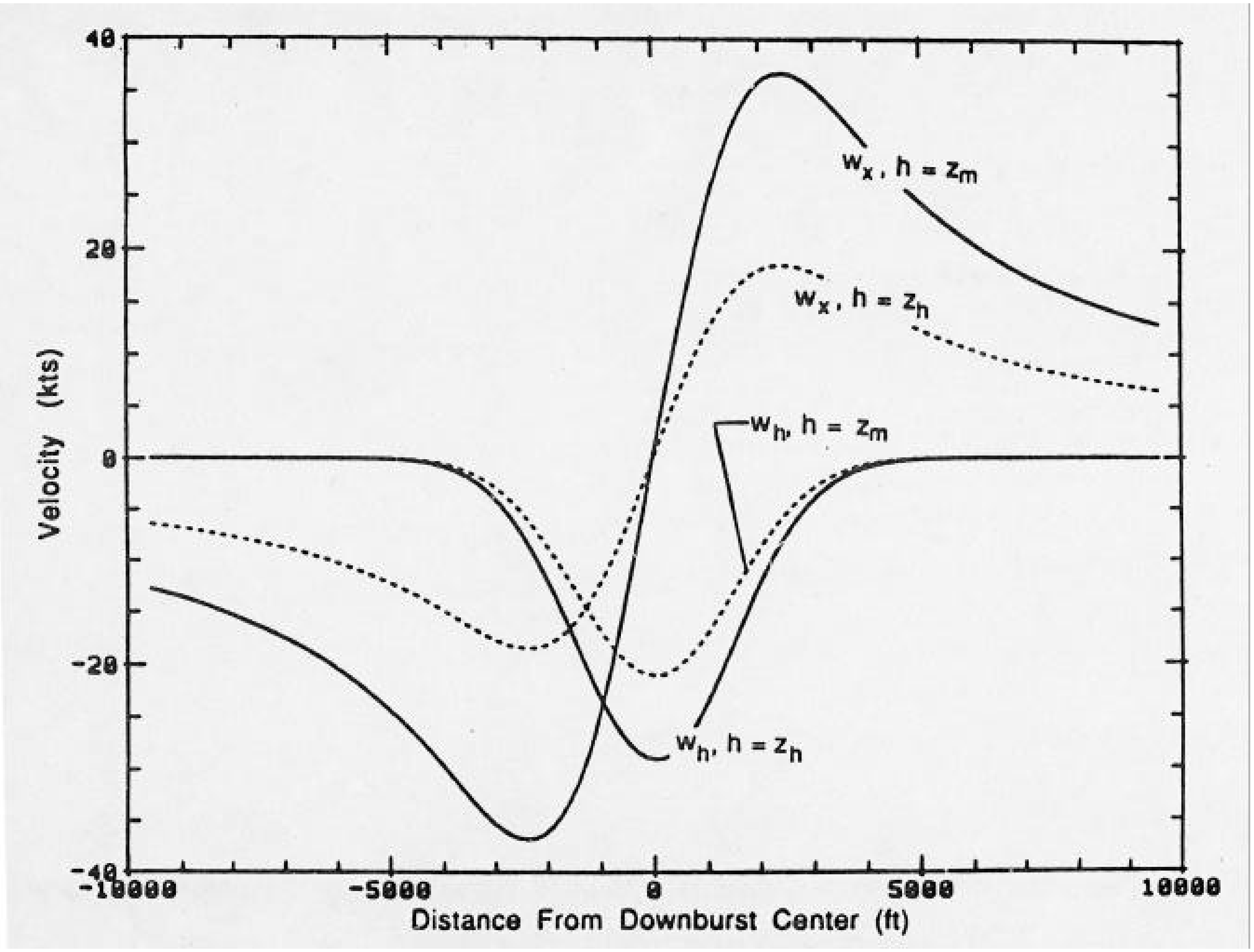


- Taken From Mulgund and Stengel, *Journal of Aircraft,* 1993

Microburst Model

- Microburst model is from Oseguera and Bowles, NASA TM 100632
- Microbust Parameters are
  - U_{max} : Maximum outflow (ft/s)
  - Z_{max} : Height of maximum outflow (ft)
  - R : Radius of the microburst (ft)

Microburst Model



- NASA TM 100632
- R = 2500 ft
- U_{max} = 63 ft/s
- Z_{max} = 119 ft

Implementation in FDC

$$F_x = X_{aerodynamic} + X_{propulsion} + X_{gravity} + X_{wind}$$
$$F_y = Y_{aerodynamic} + Y_{propulsion} + Y_{gravity} + Y_{wind}$$
$$F_z = Z_{aerodynamic} + Z_{propulsion} + Z_{gravity} + Z_{wind}$$

- Wind force components

$$X_x = -m(\dot{u}_w + qw_w - rv_w)$$
$$Y_w = -m(\dot{v}_w - pw_w + ru_w)$$
$$z_w = -m(\dot{w}_w + pv_w - pu_w)$$

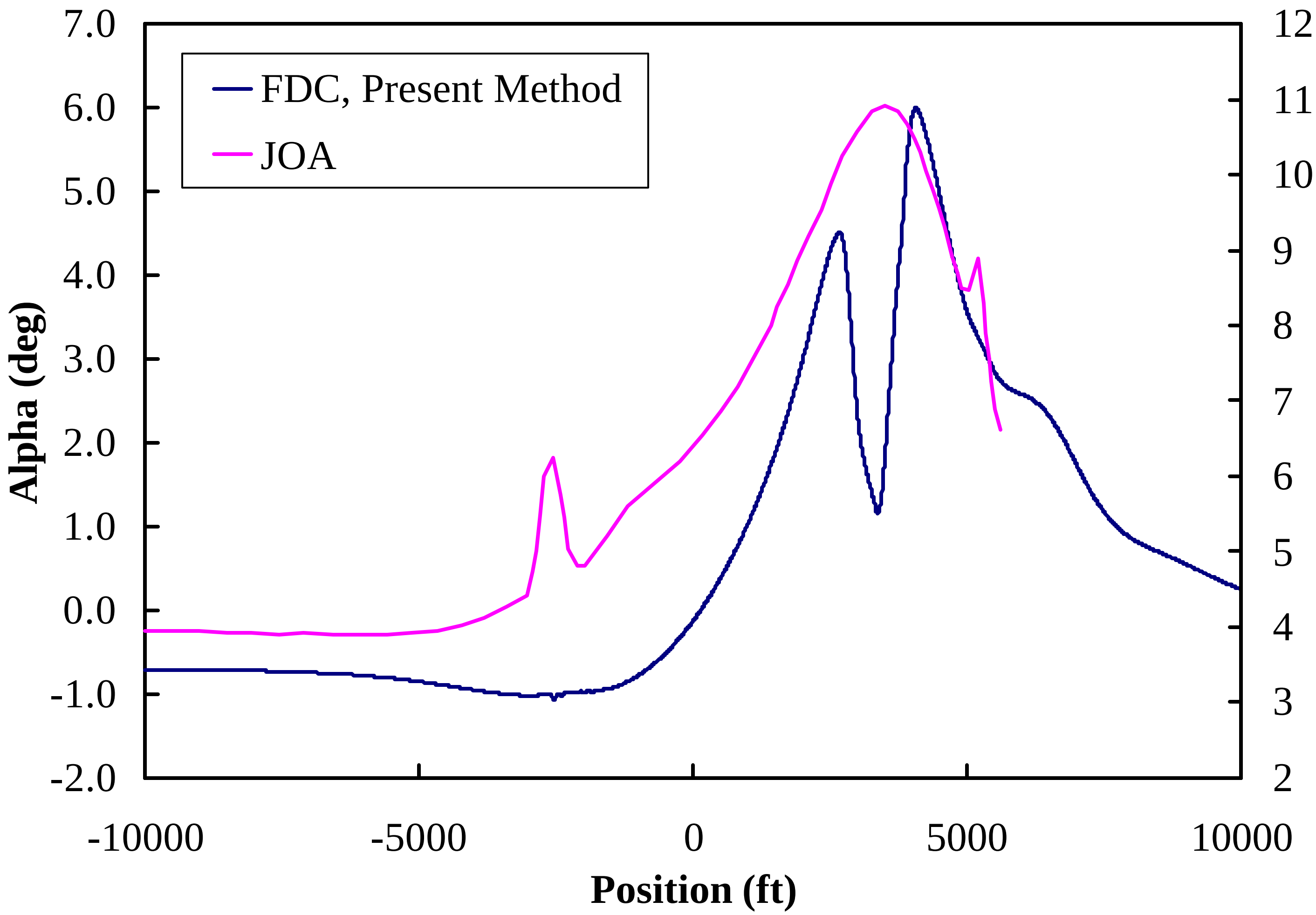
Comparision

- A FDC trajectory was compared to results from, *Target Pitch Angle for the Microburst Escape Maneuver* by S. Mulgund and R. Stengel, JoA, 1993
- Due to current limitations in the FDC the exact aircraft maneuver could not be simulated
- Both aircraft were light twin-turboprops
- Instead of a Target Pitch Angle (TPA) escape maneuver a maximum power maneuver was used

Comparison

- Simulated microburst parameters
  - $R = 3000$ ft
  - $U_{max} = 80$ ft/s ~ 47.4 kts
  - $Z_{max} = 150$ ft
- Initial conditions
  - Altitude = 1400 ft
  - Trim condition

Comparison


7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
12
11
10
9
8
7
6
5
4
3
2
FDC, Present Method
JOA
Alpha (deg)
-10000
-5000
0
5000
10000
Position (ft)

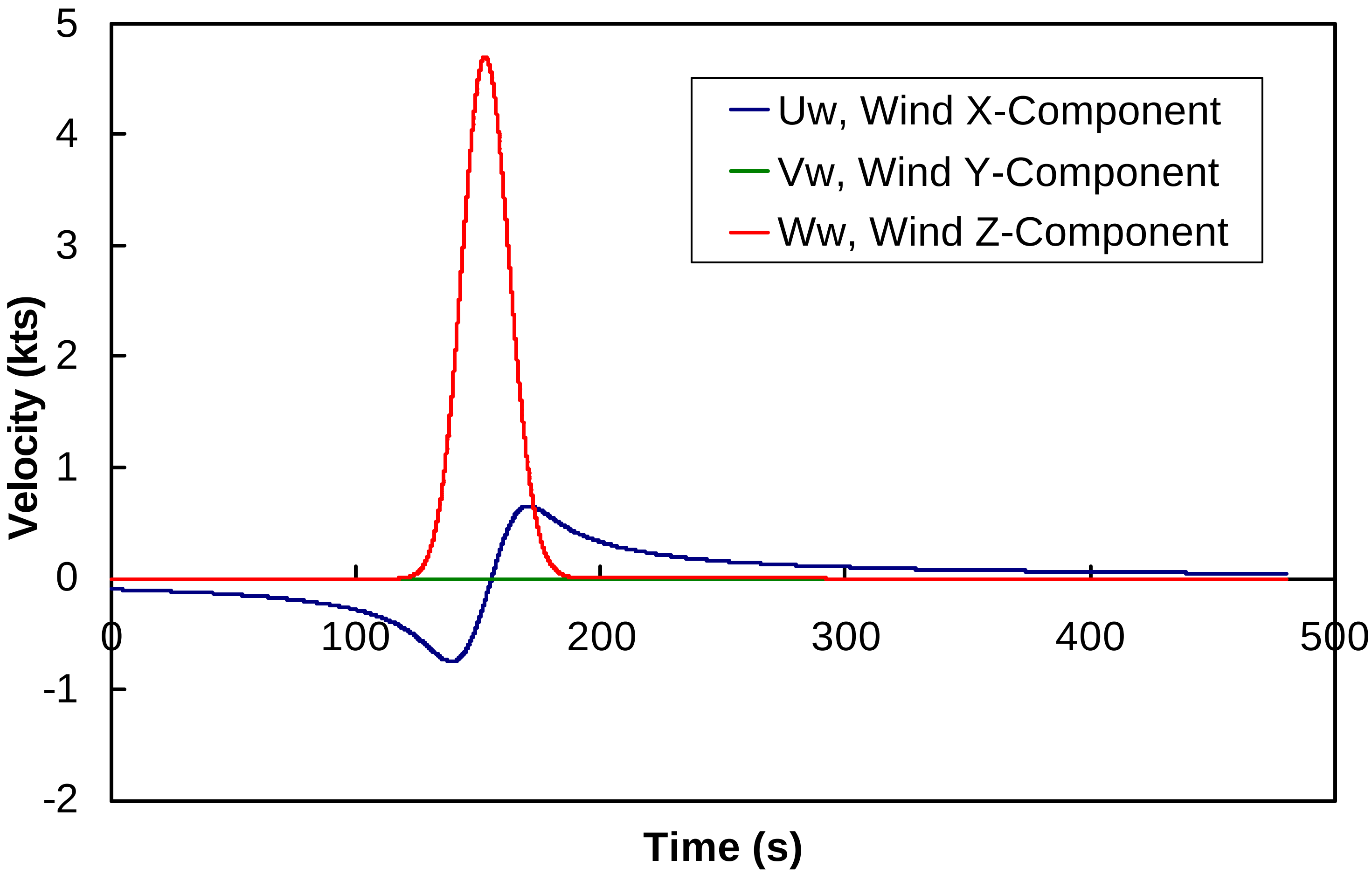
Microburst Analysis

- 11 different microbursts were simulated in FDC varying Radius, and U_{max}
- Simulation conditions
  - V = 136 kts
  - Initial altitude varied from 1312 ft to 2625 ft
  - Altitude hold autopilot setting
  - No recovery maneuver

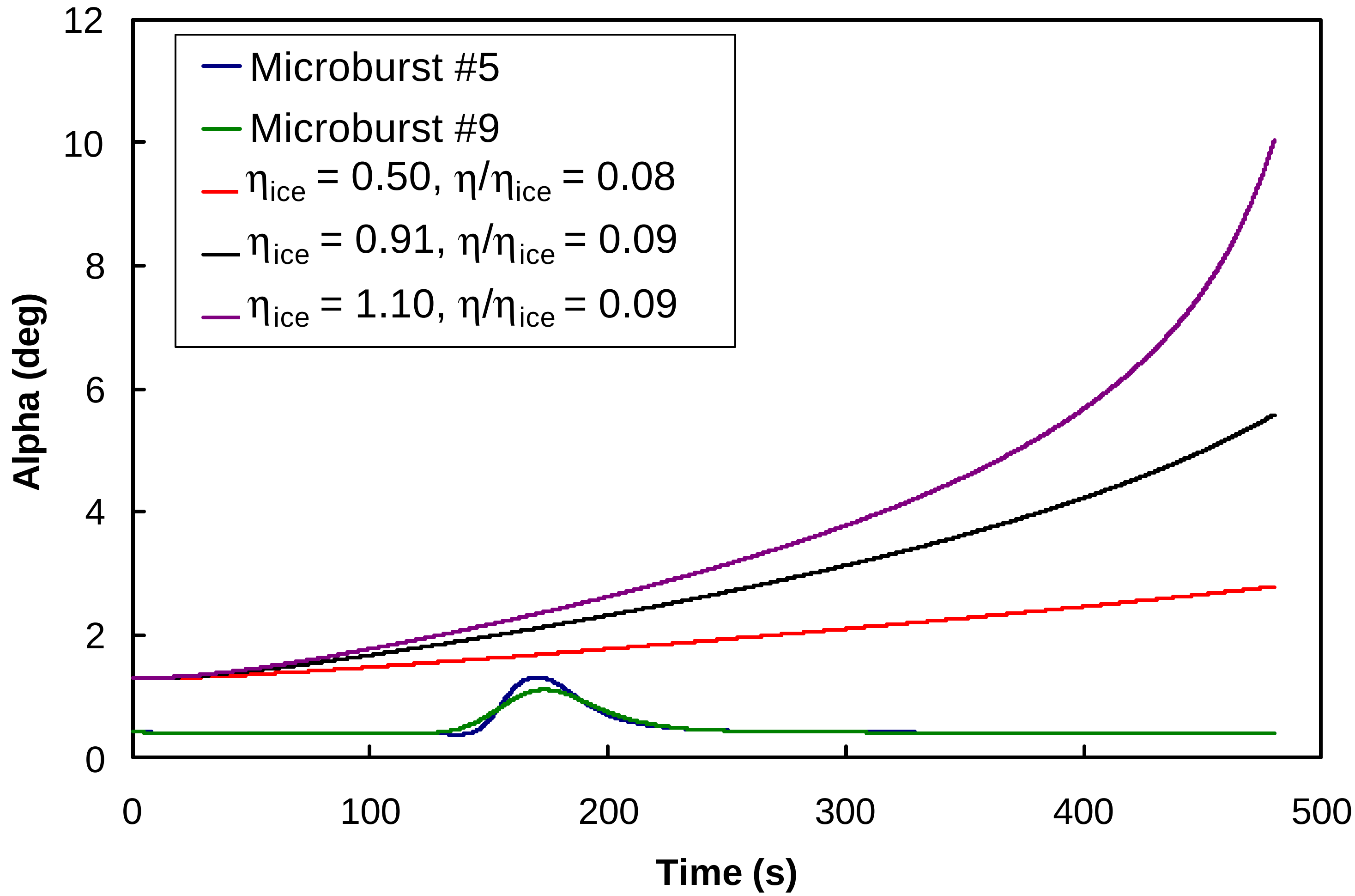
Microburst Analysis

Microburst Number	Microburst Paramaters			Severity
	R (ft)	Umax (ft/s)	Zmax (ft)	Umax/R (1/s)
1	1000	5	150	0.0050
2	1000	10	150	0.0100
3	1000	20	150	0.0200
4	3000	5	150	0.0017
5	3000	10	150	0.0033
6	3000	20	150	0.0067
7	3000	60	150	0.0200
8	3000	120	150	0.0400
9	5000	10	150	0.0020
10	5000	20	150	0.0040
11	5000	40	150	0.0080

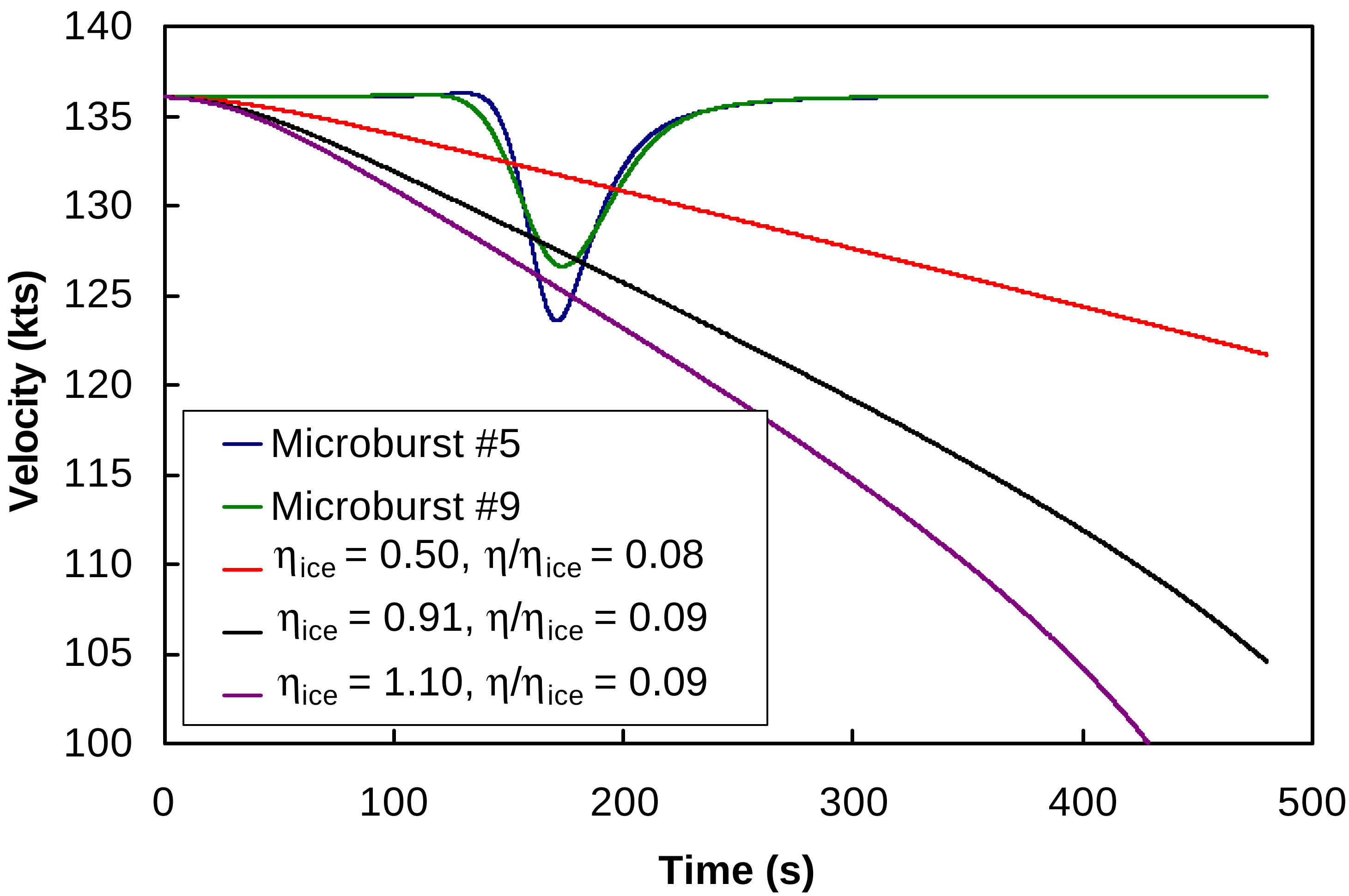
Wind Velocities for Microburst #5



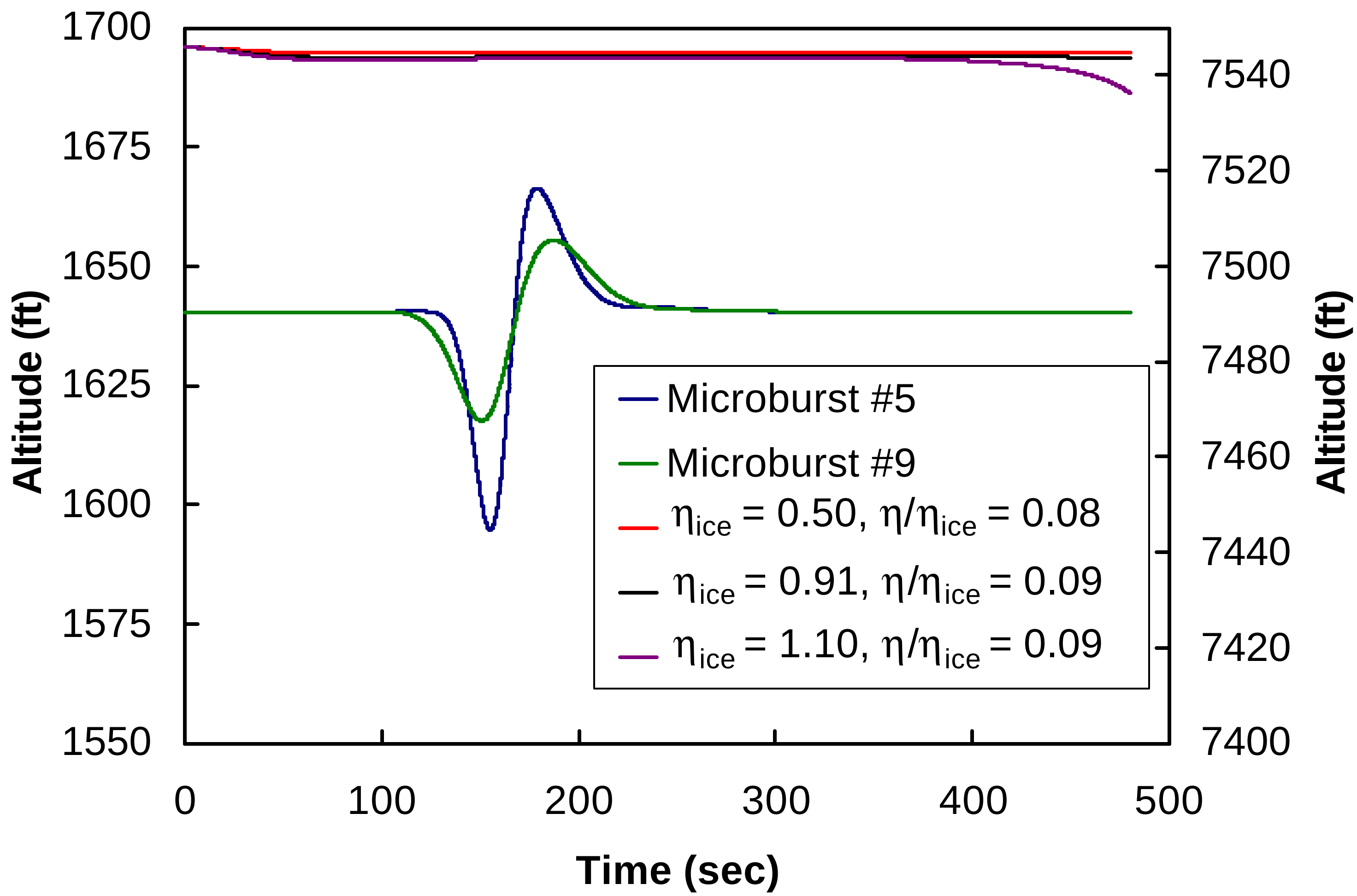
Results for Microbursts and Icing



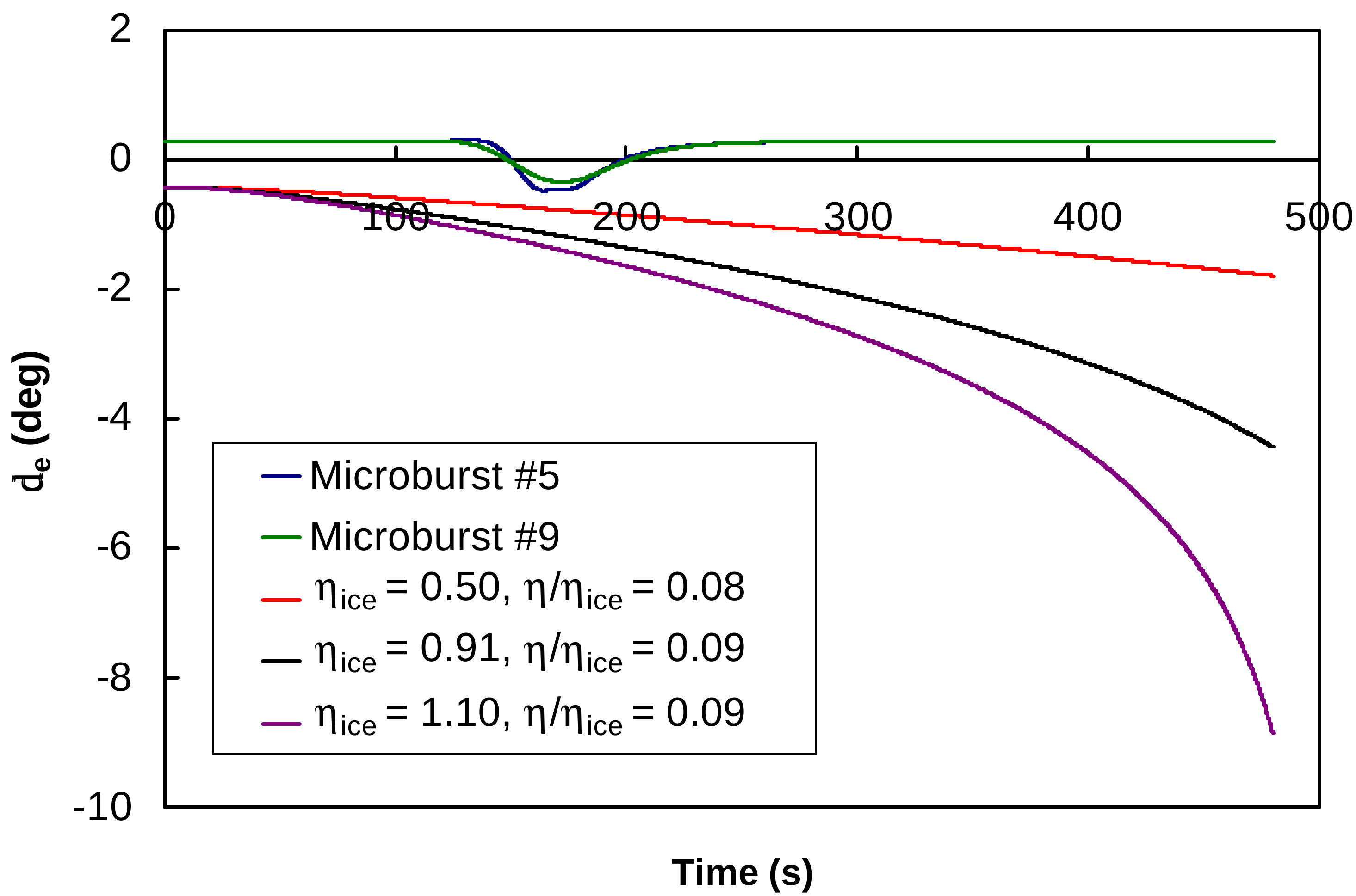
Results for Microbursts and Icing



Results for Microbursts and Icing



Results for Microbursts and Icing



Comparison to an Icing Case

- Compared the rates of change of alpha, velocity, and altitude

Case	$d\alpha/dt$ (deg/s)	dV/dt (kts/s)	dh/dt (ft/min)	$d\delta_e/dt$ (deg/s)
Microburst 1	0.1718	-0.4505	-466.6	-0.0343
Microburst 2	0.3830	-1.1468	-990.3	-0.0805
Microburst 4	0.0269	-0.2000	-150.0	-0.0143
Microburst 5	0.0472	-0.6000	-150.0	-0.0427
Microburst 6	0.1345	-1.5000	-266.7	-0.0851
Microburst 9	0.0229	-0.2917	-55.5	-0.0203
0.04	0.0040	-0.0323	0.0	0.0039
0.08	0.0204	-0.7951	0.0	-0.0196
0.1	0.1030	-0.2537	-5.0	-0.0943

Comparison to an Icing Case

- Microburst rates of change were larger than the worst icing case initially, but after a long icing encounter the rates were comparable
- These large differences sould make it straightforward to distinguish between icing and wind shear encounters
- Altitude is maintained for the icing case, but not in the microburst case
- In addition dynamic identification data would be available to help identify windshear as well

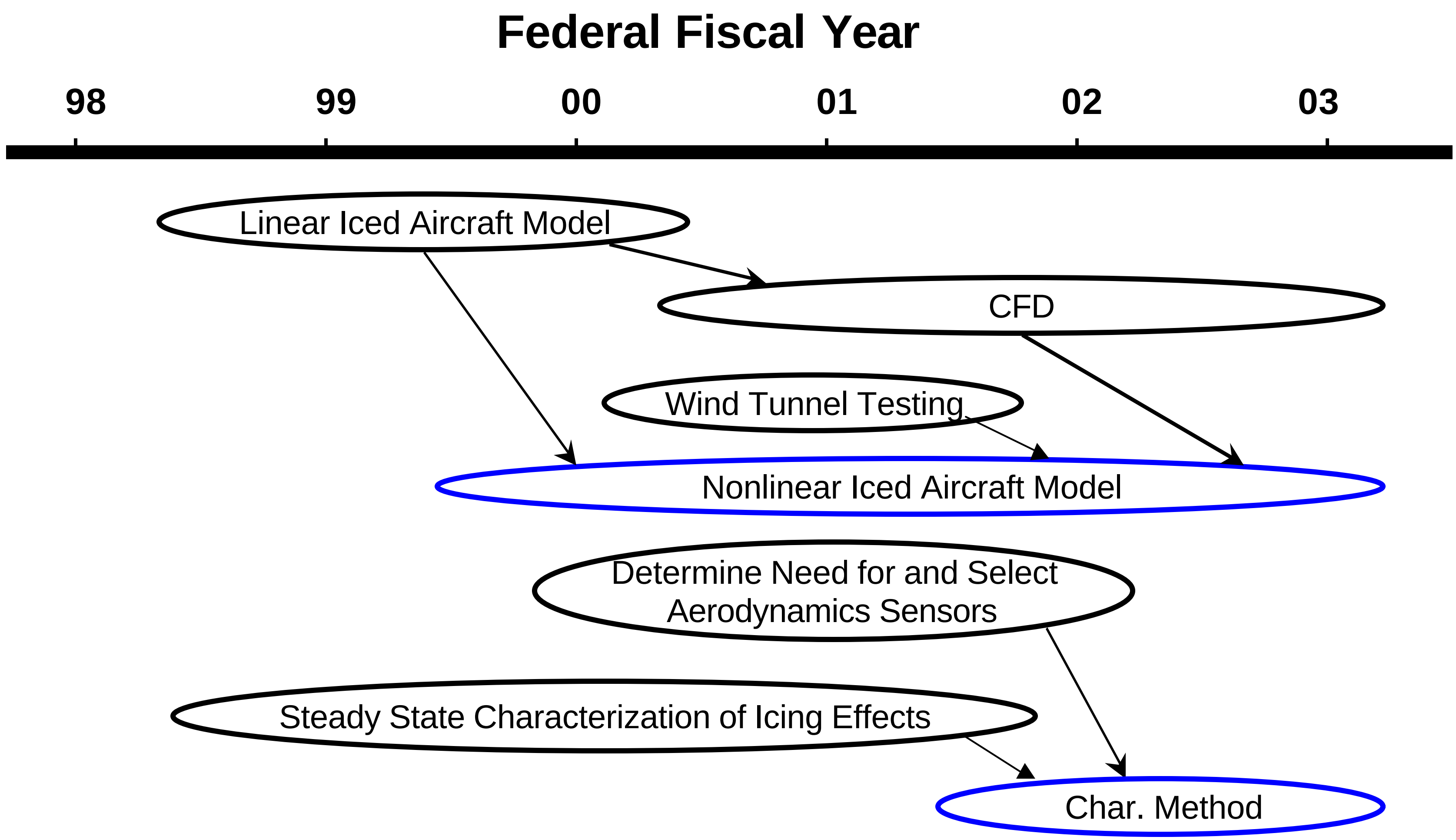
Conclusions

- Initial analysis of the microbursts demonstrated that the encounters would be distinguishable
- Effects are similar but of different magnitude or occur at different times (late in the encounter)
- Different strategies for recovery needed
  - Very important not to misinterpret the encounter
- Still need to address the gravity waves and other atmospheric disturbances

Future Work

- Validate the FDC windshear model
- Add icing to the windshear encounters
- Possibly develop a windshear neural network to detect windshear
- Analyze the effect other atmospheric encounters, gravity waves, etc
  - Need a simple model for gravity waves

Aerodynamics and Flight Mechanics Waterfall Chart



Conclusions

- Linear icing effects model, h_{ice}, is almost finalized
- Initial results from neural net analysis for prediction of 2-D flight performance parameters are promising
- Effect of ice on V, α, and δ_e for the constant power case are significant, and could be used to characterize the accretion.
- The use of hinge-moment data to distinguish tail from wing ice is encouraging.
- CFD reasonably predicts important trends. Moving to WIND-DES for better max lift prediction.
- Initial analysis of the microbursts demonstrated that the encounters would be distinguishable.

Future Research

- Continue exploration of neural nets for prediction of iced aircraft characteristics.
- Validate a fully nonlinear force and moment model.
- Improve the hinge moment models.
- Develop envelope protection strategies.
- Apply WINDS-DES to iced airfoils to improve maximum lift prediction.
- Analyze the effect other atmospheric encounters, gravity waves, etc.