Flight Test Data Analysis

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Flight Test

Objective: To develop and evaluate the identification and characterization methods used in the smart icing system using flight data from clear air and in natural icing conditions.

Approach: In cooperation with NASA, acquire detailed flight dynamics data on the Twin Otter with and without ice. Use data to develop and test ID and characterization methods including the effects of dynamic input, sensor noise, repeatability, uncertainty, IPS detection, etc.

The Twin Otter

- DeHavilland DHC-6
- High-wing, twin-engine commuter class aircraft
- Max Gross Weight: 11,000 pounds
- Cruise Speed: 130 KIAS
- Range: approximately 300 nm

Twin Otter Instrumentation

Cloud Instrumentation:

FSSP-75: 3-47 micron particles

OAP-2d-Grey: 15-960 micron particles

King LWC (2)

Rosemount Ice Detector

Icing Documentation:

Wing stereo photography system

Video tape of right wing leading edge

Hand-held 35mm camera

Air Data:

Rosemount OAT probe

General Eastern Dew Point Hygrometer

Rosemount five-hole probe: pressure altitude, airspeed, angle of attack and sideslip.

Twin Otter Instrumentation

Aero-Performance Sensors:

Linear Accelerometers (3)

Angular Rate Gyros (3)

Vertical Gyro

Engine/Propeller Data

Data Acquisition System:

Science & Engineering Associates Lite 18

50 analog channels

Digitized at up to 100Hz and 16 bits

Test Matrix

Case	Icing Flight	Doublet Mag.	Test Information
1.1	Clear Air	0.25g	Baseline
1.2	Clear Air	0.10 to 0.50	Vary doublet magnitude
1.3	Clear Air	None	Standard maneuvers
1.4	Clear Air	None	Clear air turbulence
2.1	Icing	0.25g	Doublets during ice accretion
2.2	Icing	0.25g	Doublets with selective deicing
2.3	Icing	0.25g	Doublets with intercycle icing
2.4	Icing	None	Intercycle icing
2.5	Icing	None	Standard maneuvers

Flight Tests

- Phase I (February – March 2001)
  - Eleven iced and 22 clear air flights were flown
  - Standard doublets of varying magnitude used for lateral and longitudinal identification
- Phase II (February – March 2002)
  - Focused on collecting data in icing (12 flights) versus clear air conditions (3 flights)
  - Experimented with different types of doublets and excitations (phase change, chirp, 2-1-1)

Data Reduction

- Data cut into separate files containing doublet sets
- Filter used to remove nose boom oscillations
- Trim state extracted immediately before doublets using time average
- Doublet data passed to SIDPAC step-wise regression scheme to calculate S&C derivative values

Step-wise Regression Model

Lift:

$$C_L - C_{L1} = C_{La} \cdot (a - a_1) + C_{Lq} \cdot (q - q_1) + C_{Lde} \cdot (de - de_1)$$

Pitching Moment:

$$C_M - C_{M1} = C_{Ma} \cdot (a - a_1) + C_{Mq} \cdot (q - q_1) + C_{Mde} \cdot (de - de_1)$$

Rolling Moment:

$$C_l - C_{l1} = C_{lda} \cdot (da - da_1) + C_{lb} \cdot (b - b_1) + C_{lp} \cdot (p - p_1)$$

Yawing Moment:

$$C_N - C_{N1} = C_{Ndr} \cdot (dr - dr_1) + C_{Nb} \cdot (b - b_1) + C_{Nr} \cdot (r - r_1)$$

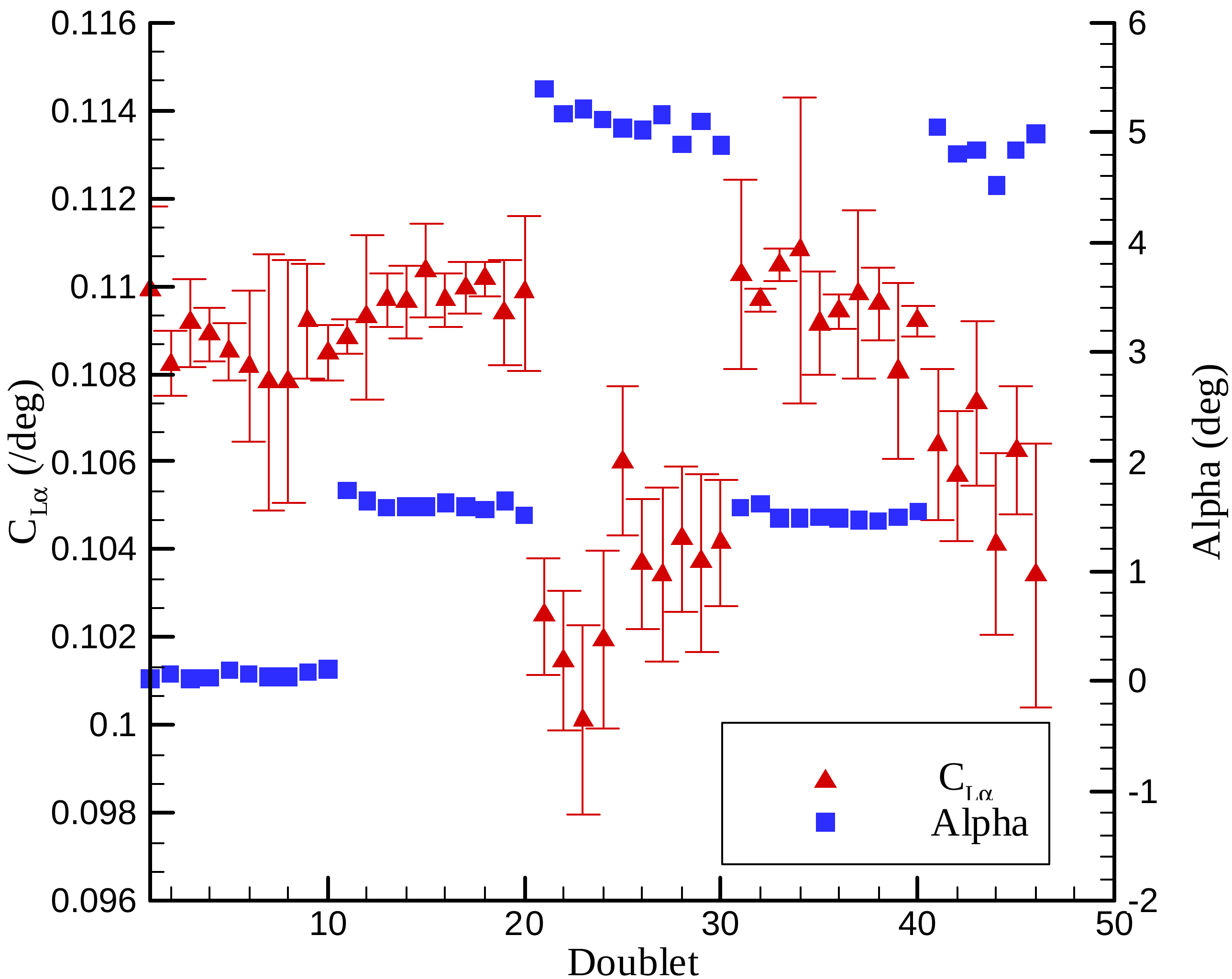
Uncertainty Analysis

- SIDPAC calculates Cramer-Rao bounds for the regression parameters accounting for the frequency content of the residuals
- 2σ error bars were used in the trim calculation to ensure 95% certainty
- Results exhibited good repeatability

Clean Aircraft Results

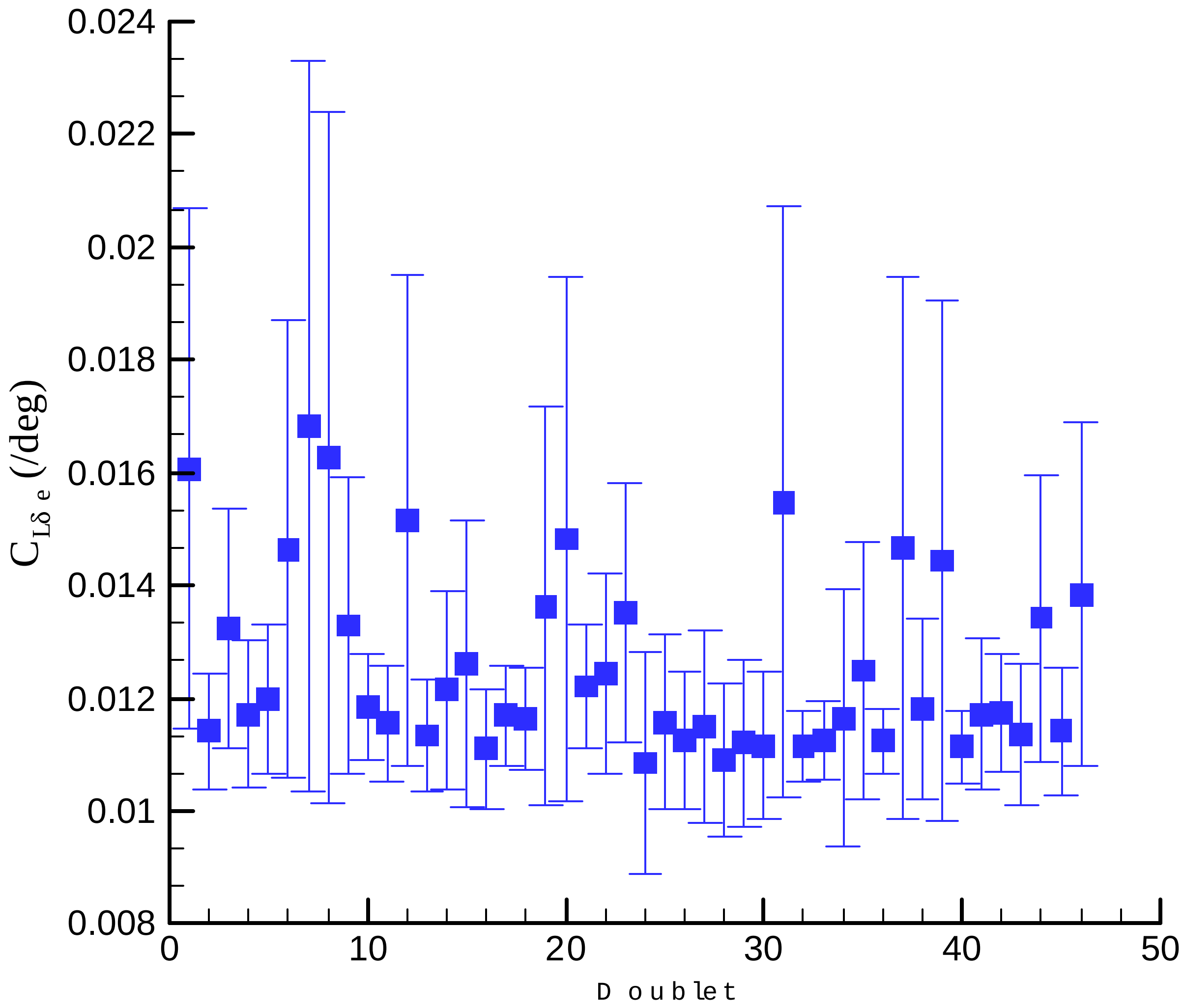
- Doublet sets consisted of a pair of elevator doublets, an aileron doublet and a rudder doublet
- Multiple doublets at the same trim condition were averaged to obtain clean values

$C_{L\alpha}$



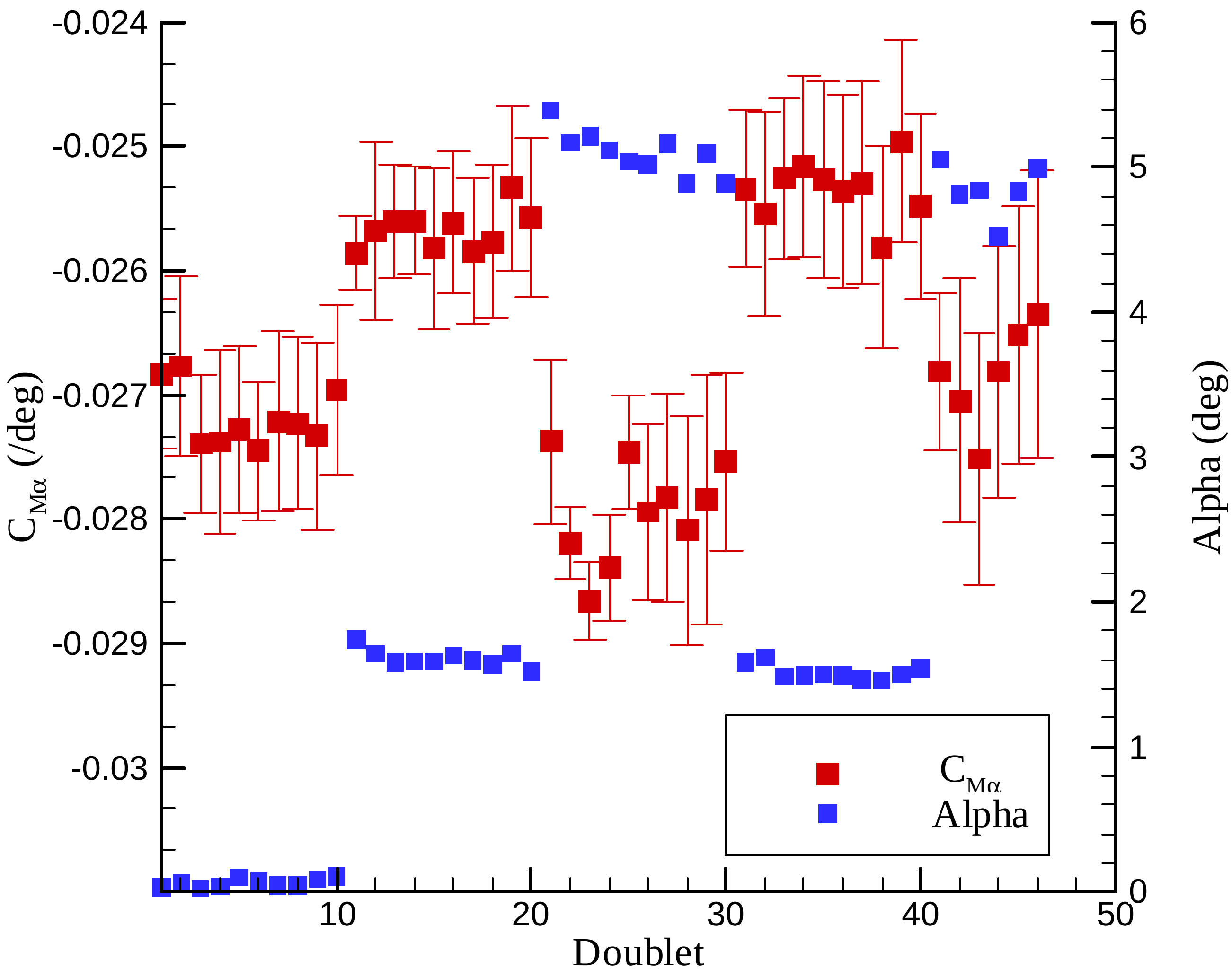
- Standard deviation for repeated doublets was, at worst, 2% of the mean.
- Reductions in $C_{L\alpha}$ due to change in α are visible
- Estimate agreed well with previous tests (0.1003 /deg)

$C_{L\delta e}$



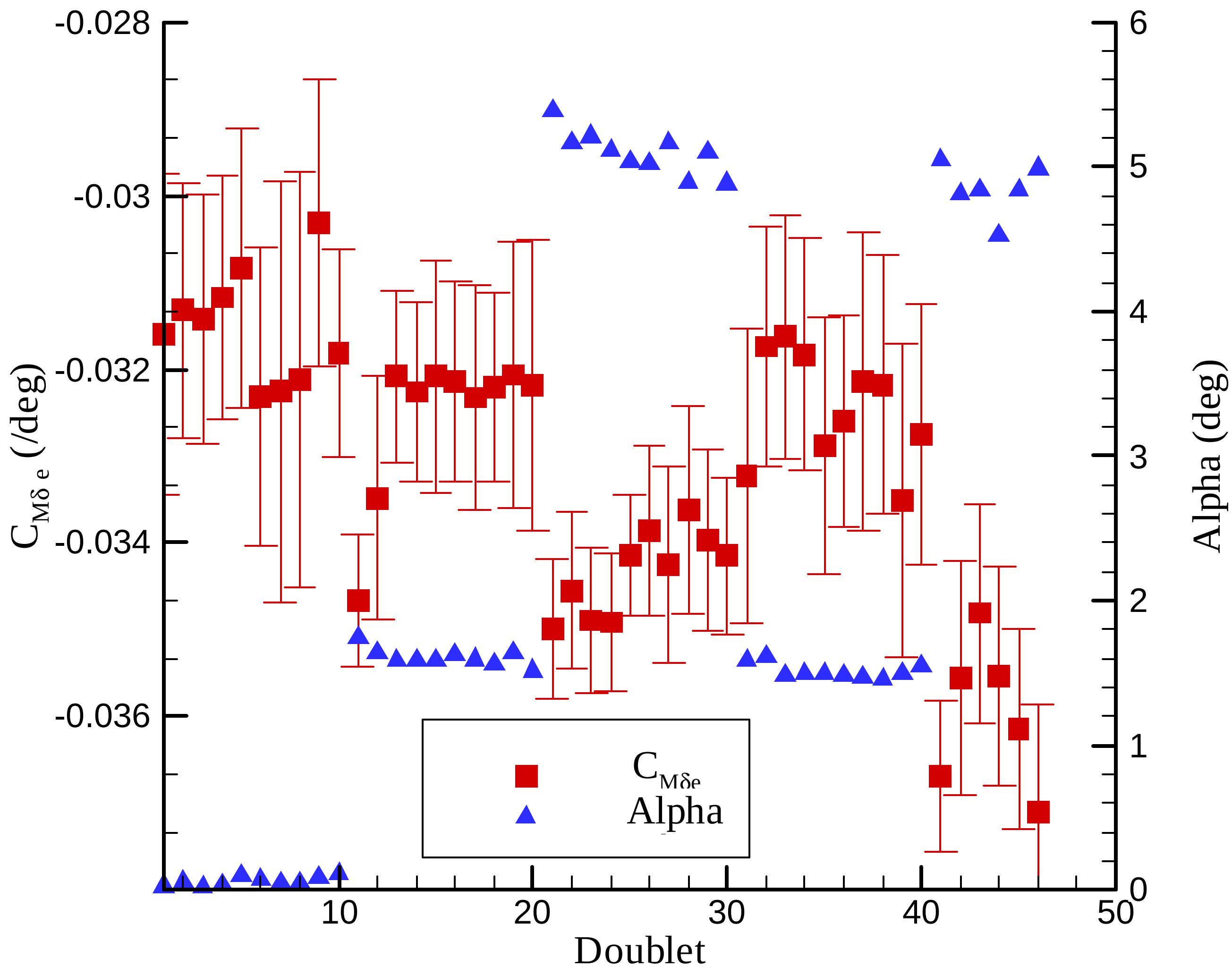
- Standard deviation was less than 15% of the mean over all the trim conditions
- Error bars reflected the accuracy of the estimate
- Estimate agreed well with previous tests (0.0118 /deg)

$C_{M\alpha}$



- Standard deviation was less than 1% of the mean
- Changes in $C_{M\alpha}$ with α were visible
- Agreed well with previous tests (-0.0229 and -0.0258 /deg)

$C_{M\delta e}$



- Standard deviation was less than 2% of the mean
- Variations in the estimate with α are visible, but within error bars
- Estimates agreed well with previous tests (-0.031 and –0.0305 /deg)

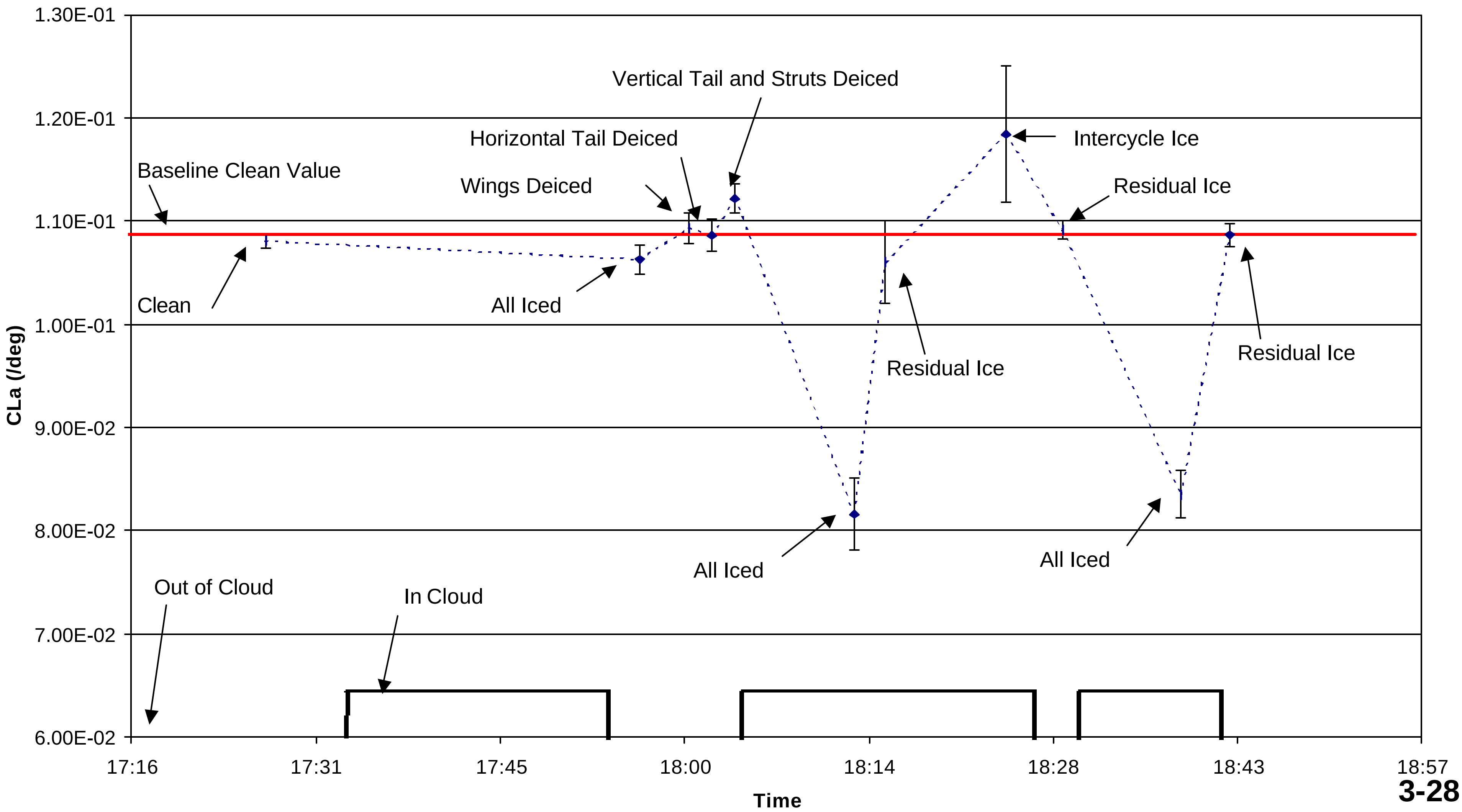
Summary of Results*

Derivative	TM 4099 (deg^{-1})	AIAA 93-0398 (deg^{-1})	Illinois (deg^{-1})
$C_{L\alpha}$	0.1003		0.1087
C_{Lq}	0.3498		0.3909
$C_{L\delta e}$	0.0118		0.0135
$C_{M\alpha}$	-0.0229	-0.0258	-0.027
$C_{M\delta e}$	-0.031	-0.0305	-0.0314
C_{Mq}	-0.611	-0.65	-0.6165
C_{nB}		0.00136	0.00169
C_{nr}		-0.0031	-0.0038
$C_{n\delta r}$		-0.00218	-0.00234

* Estimates are for α=0

Flight 010302f2

Smart Icing System Review, September 30 – October 1, 2002



Turbulence Effects

- Results of parameter identification in turbulence compare poorly with established parameters
- Icing is usually accompanied by turbulence
- There is a direct relationship between estimated measurement scaling factors/biases and poor parameter estimates
- The turbulence effect introduces a bias error to the parameter estimates
- Further investigation is required to achieve good identification in turbulence

$C_{L\alpha}$ Estimate in Turbulence

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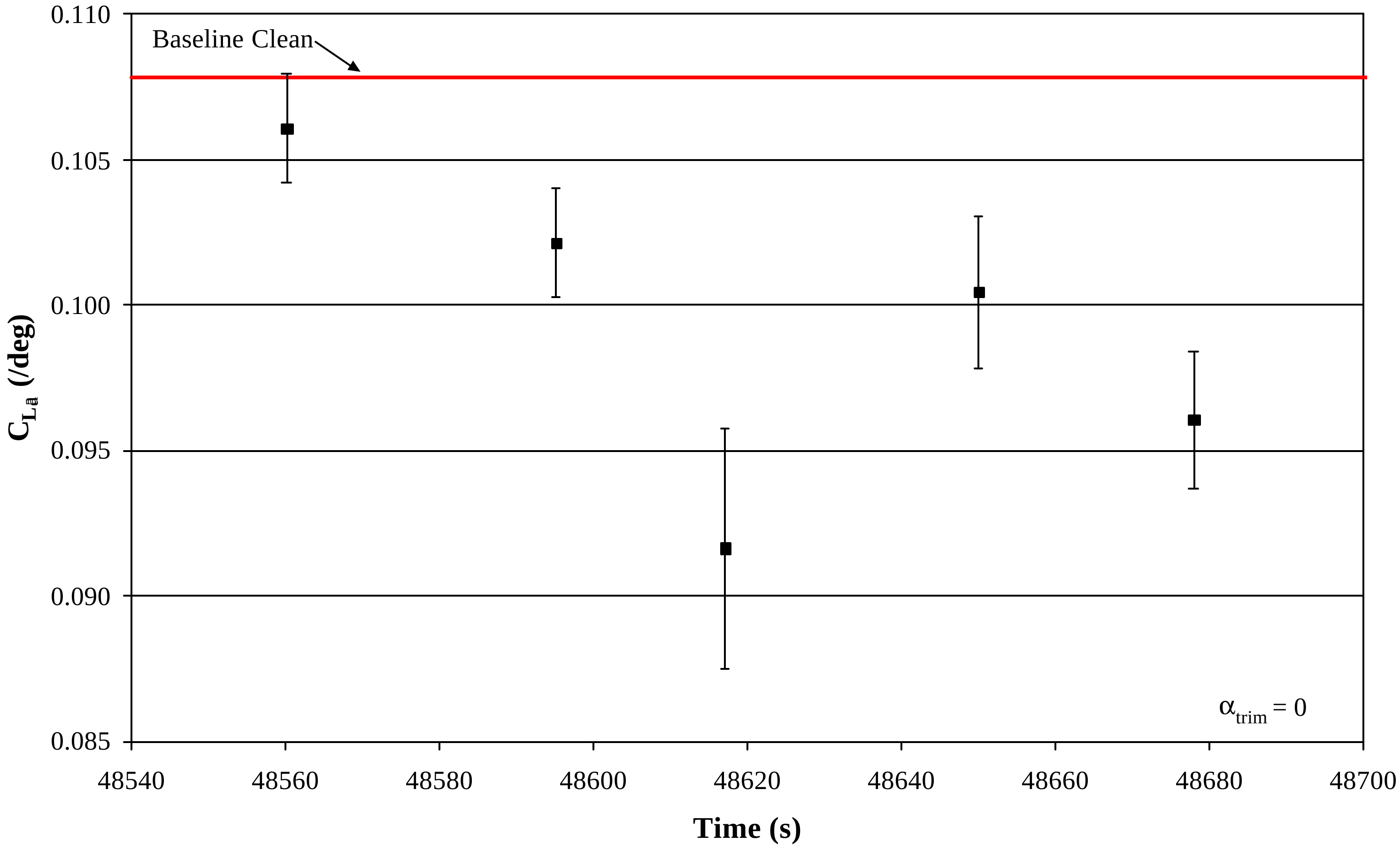

Estimated Scaling Factors/Biases

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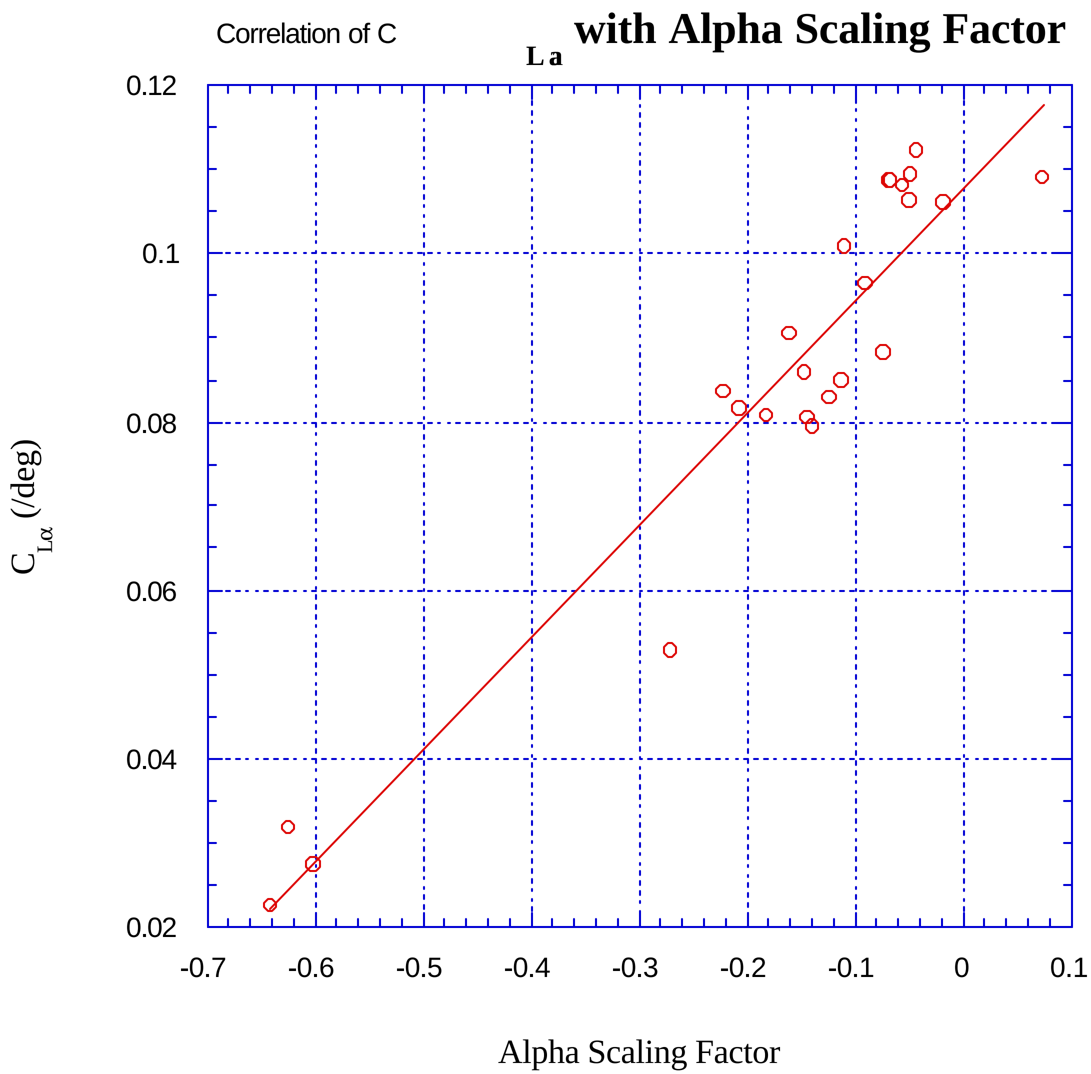

Summary

- A joint University of Illinois - NASA Glenn flight test program was conducted to assist in the development of the Smart Icing System
- The objective of this research was to develop and evaluate the identification and characterization methods used in the smart icing system using flight data
- The flight data were acquired in clear air and in icing conditions
- Stability and control derivatives were estimated through the use of SIDPAC
- The icing and deicing of the aircraft was observed through changes in aircraft trim and stability and control derivatives

Conclusions

- Stability and Control derivatives have been identified for the clean aircraft in smooth air with excellent results
- Turbulence significantly effects the parameter identification process
- Estimation results in icing conditions with atmospheric turbulence are, at this time, unreliable using SIDPAC methods

Work in Progress

- More extensive flight data analysis planned
  - Phase II flight test data analysis
  - Other stability and control derivatives
- Investigating changes in aircraft trim as an indicator of ice accretion