AERODYNAMIC ANALYSES IN SUPPORT OF THE SPANWISE ADAPTIVE WING PROJECT

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Outline

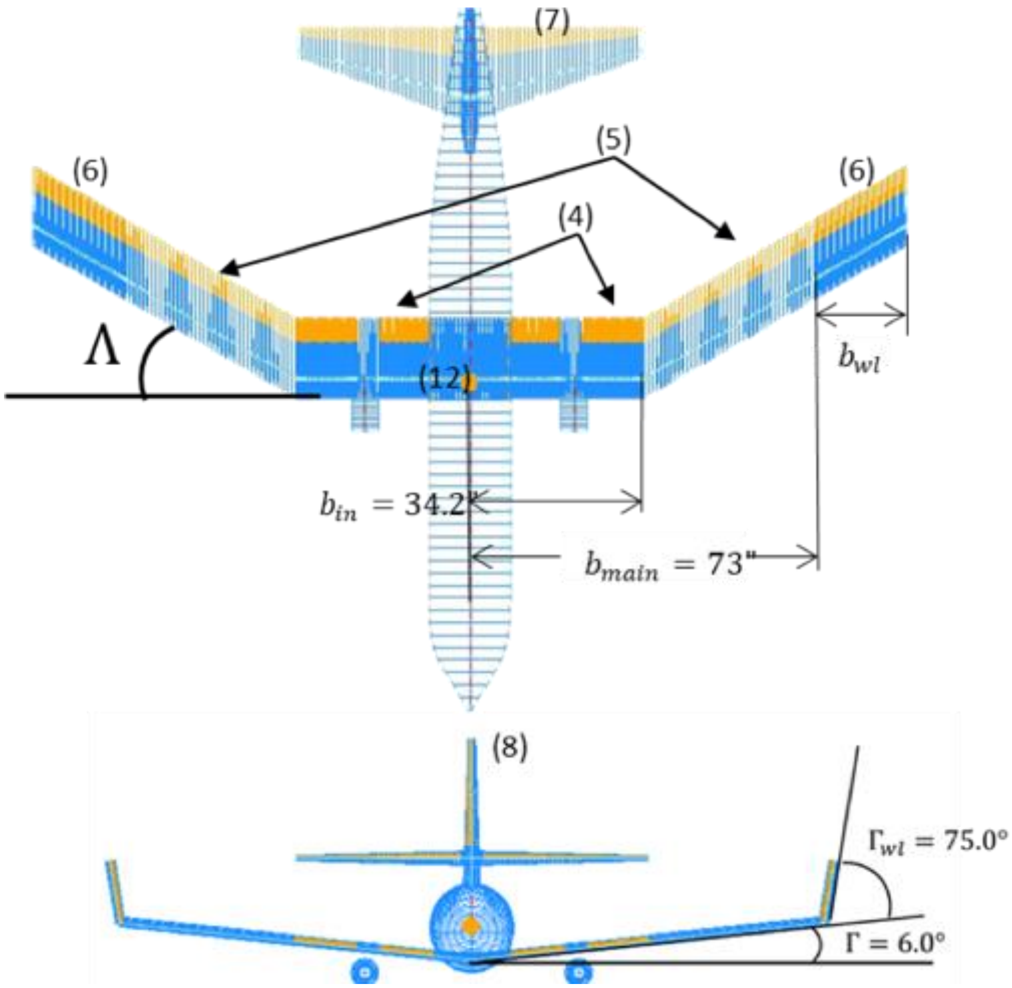
- PTERA-SAW design efforts
- PTERA-SAW flight test parameter estimation work
- Feasibility studies for potential supersonic testing

PTERA-SAW Design Approach

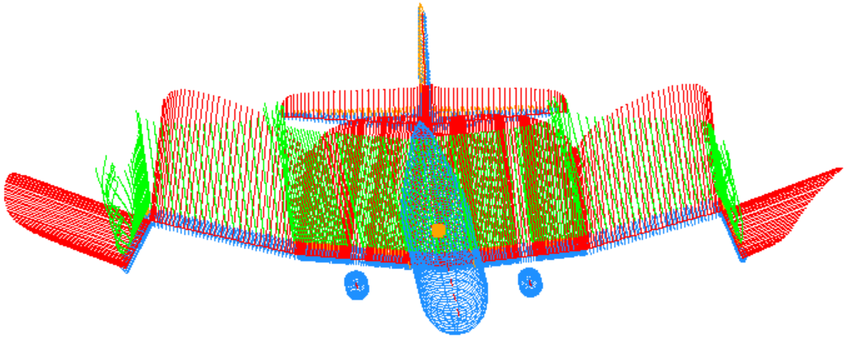
- During the preliminary design of PTERA-SAW, Area-I explored the effects of the wing tip control surfaces on PTERA's stability and control, particularly with respect to pitch trim and yaw
- Approach:
  - Adapt baseline PTERA aircraft:
    - Minimize subsystem redesign (e.g. propulsion system, landing gear, etc.)
    - Aft stabilizers remain the same
    - Keep main span constant
  - Vary wing sweep, to increase the wing tip's yaw moment arm; allow wing area to change with sweep
  - Vary wing tip span, to increase control surface size
  - Move center of gravity slightly aft to offset aerodynamic center movement caused by sweep, to regain elevator trim authority

PTERA-SAW Layout

1) Wing tip span (b_{wl})
2) Inner wing span (b_{in})
3) Main wing span (b_{main})
4) Flaps
5) Inboard ailerons
6) Outboard ailerons
7) Elevator
8) Rudder
9) Wing dihedral (Γ)
10) Cant angle (Γ_{wl})
11) Sweep angle (Λ)
12) Center of gravity ($c.g.$)



Design Analysis Toolset



- Area-I's *WingsX*
  - Lift, drag, moments
  - Elevator-trimmed drag polar
  - Aerodynamic derivatives
  - Static and dynamic stability and control
  - Development of aircraft control laws
  - Flow field analysis
  - Prediction of interactions between multiple aircraft
- Accuracy validated through numerous flight test programs, including PTERA baseline configuration (which was documented in AIAA 2014-2577)

Design Trade Space

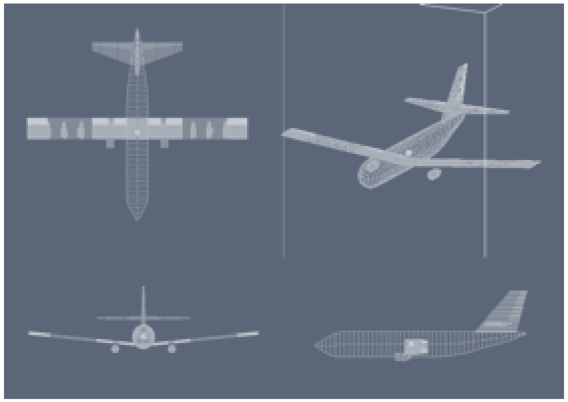
Flight condition: 90 KIAS at 10,000 ft MSL
Gross weight: 200 lbs
Constants: Main wing span and dihedral, wing chord, inboard control surfaces
Variables: Wing tip span, sweep, and cant angles

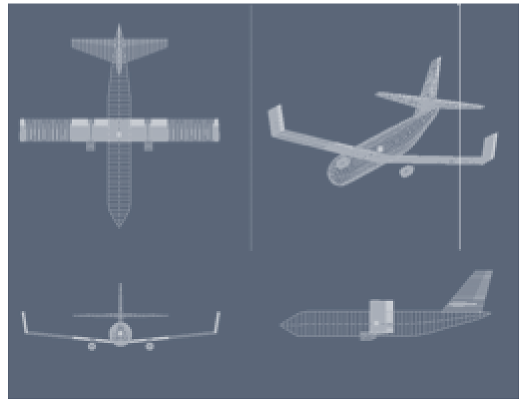
Configuration	Sweep Angle (Λ)	Wing tip Span, in (b_{wl})	C.G. shift, in (aft of root ¼-chord)	Wing tip Yaw Control (% of rudder @ 10.0° deflection)		
				75.0°	-75.0°	0.0°
1	0°	12	1.0	10	9	6
2	0°	15	1.0	12	11	9
3	0°	18	1.0	14	13	12
4	10°	12	3.0	20	12	11
5	10°	15	3.0	26	16	13
6	10°	18	3.0	32	21	16
7	20°	12	5.4	30	15	13
8	20°	15	5.4	39	22	17
9	20°	18	5.4	48	29	20
10	30°	12	8.0	38	17	16
11	30°	15	8.0	51	27	20
12	30°	18	8.0	64	38	24

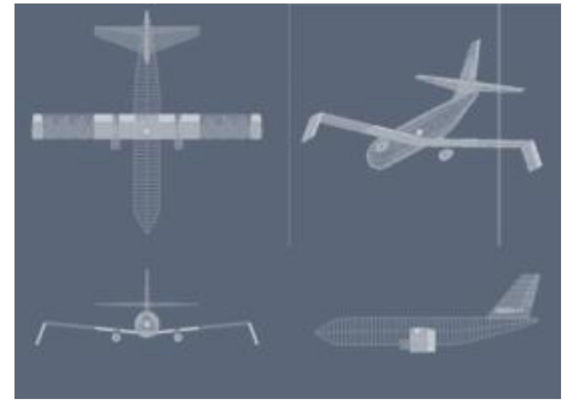
Baseline Values (configurations 1–3)

Design Space Explored (configurations 4–12)

Design Study Results, Configuration 2



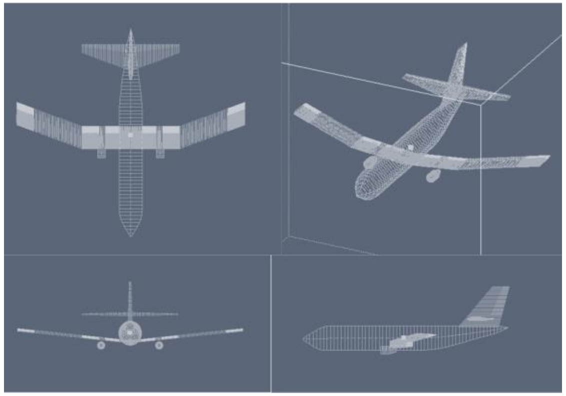


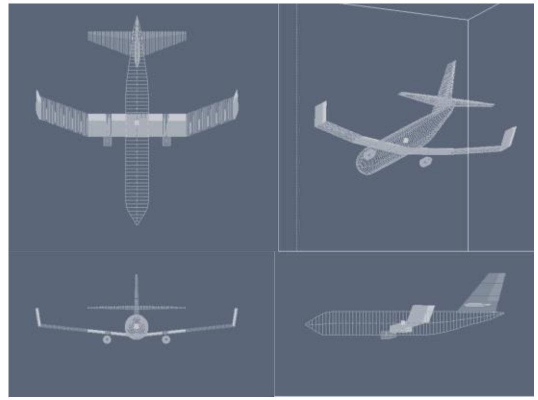


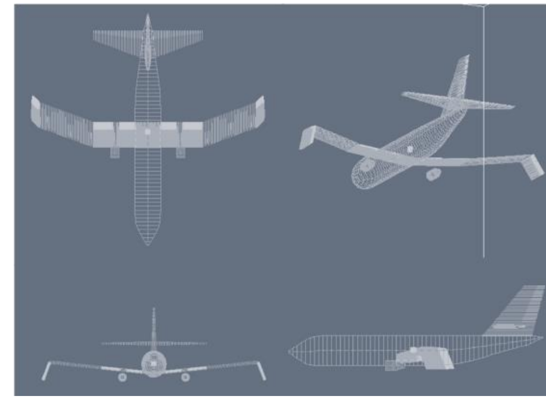
	Pitch Trim	Stability Derivatives		Control Derivatives			Aileron Yaw Power Relative to Rudder
Wing tip Cant Angle	δ_e	$C_{m,\alpha}$	$C_{n,\beta}$	C_{m,δ_e}	$C_{n,\delta r}$	$C_{n,\delta ao}$	
0°	5.09° TEU	-1.744 (S.M. = 25.6%)	0.0757	-1.645	-0.0591	-0.0011	2%
75°	5.71° TEU	-1.687 (S.M. = 31.6%)	0.0502	-1.646	-0.0580	0.0037	-6%
-75°	5.77° TEU	-1.684 (S.M. = 31.8%)	0.0903	-1.647	-0.0581	-0.0101	17%

All derivatives are per radian

Design Study Results, Configuration 8







	Pitch Trim	Stability Derivatives		Control Derivatives			Aileron Yaw Power Relative to Rudder
Wing tip Cant Angle	δ_e	$C_{m,\alpha}$	$C_{n,\beta}$	C_{m,δ_e}	$C_{n,\delta r}$	$C_{n,\delta ao}$	
0°	5.12° TEU	-1.564 (S.M. = 25.8%)	0.0569	-1.521	-0.0552	0.0055	-10%
75°	4.17° TEU	-1.064 (S.M. = 20.5%)	0.0607	-1.520	-0.0543	0.0212	-39%
-75°	4.48° TEU	-1.122 (S.M. = 21.2%)	0.0896	-1.520	-0.0545	-0.0156	29%

All derivatives are per radian

Configuration chosen for PTERA-SAW

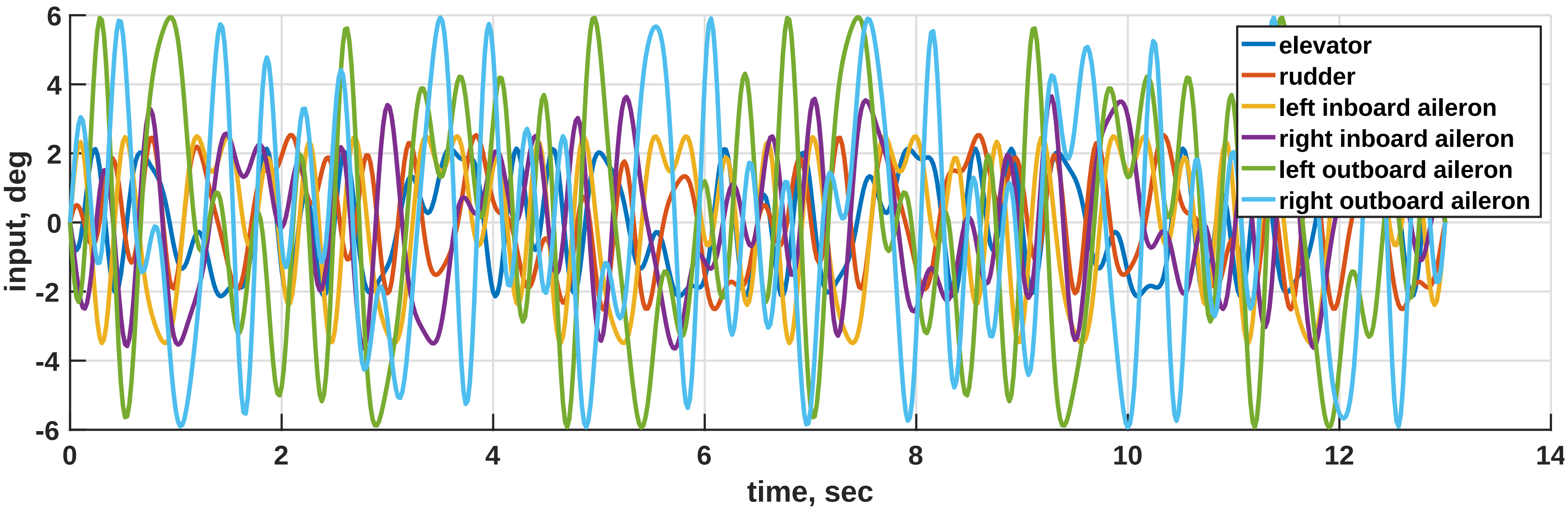
Aerodynamic Modeling

- After choosing the configuration for PTERA-SAW, Area-I generated an aerodynamic model using *WingsX* data

- Additional aerodynamic predictions were generated at AFRC before and after the flights
  - Prior to the flights, Athena Vortex Lattice (AVL) was used to create an aerodynamic model overlay for simulating asymmetric wing tip deflections
  - Additional VSPAERO (using its vortex lattice method) and AVL work was performed after the flights

PTERA-SAW Flight Test: Parameter Estimation Maneuver Design

- Orthogonal multisines
  - All axes simultaneously (6 independent surfaces)
  - 13 sec
  - Frequency range of 0.15 to 3 Hz
  - Sized in an attempt to produce similar response levels from all surfaces, based on predicted aerodynamics
  - Additional scale factors based on airspeed



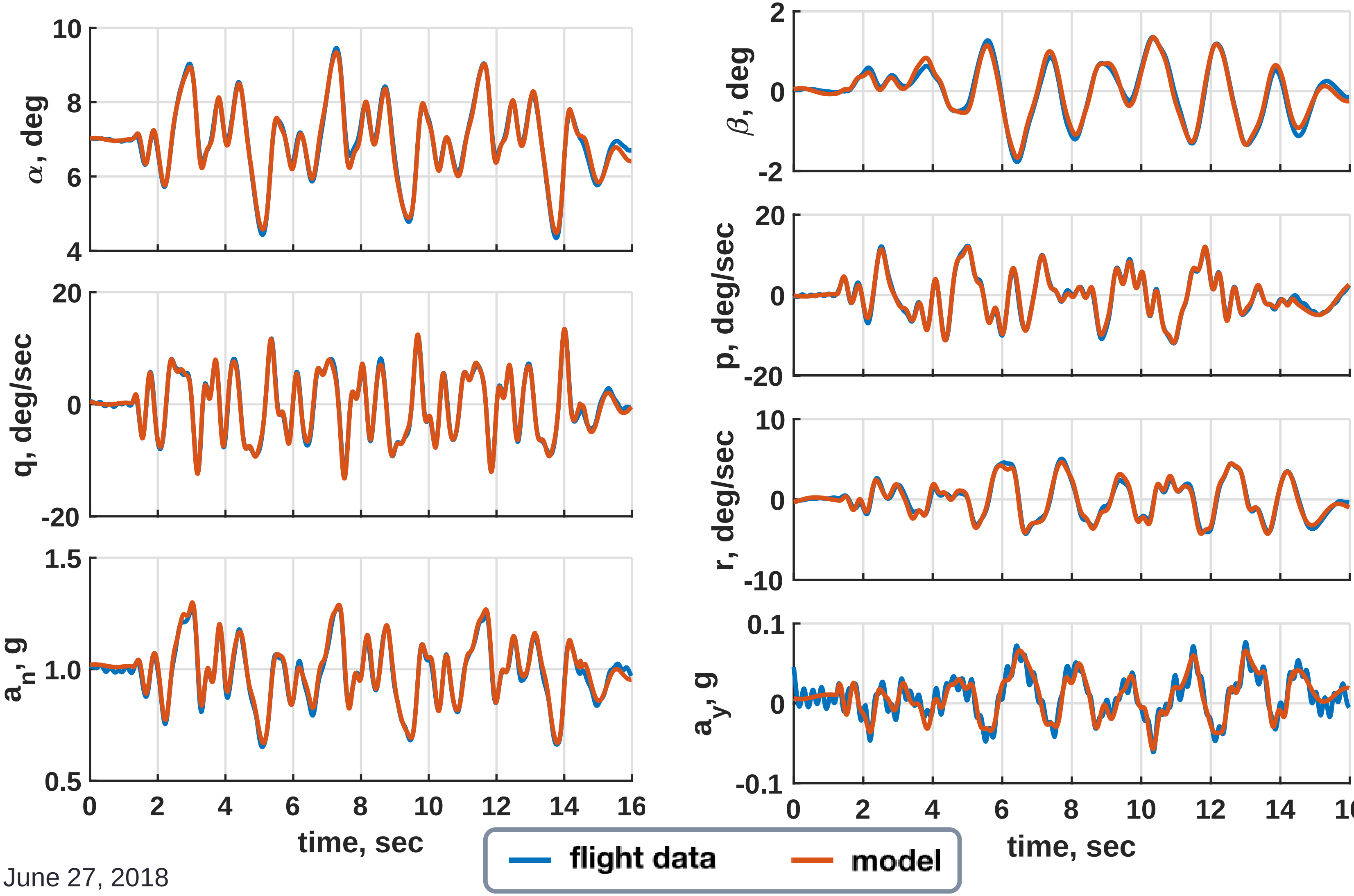
Flight Data Analysis

- Available maneuvers:
  - A total of 11 multisines were performed
  - No multisines were done for baseline configuration, but some windows of data were usable for identifying some derivatives

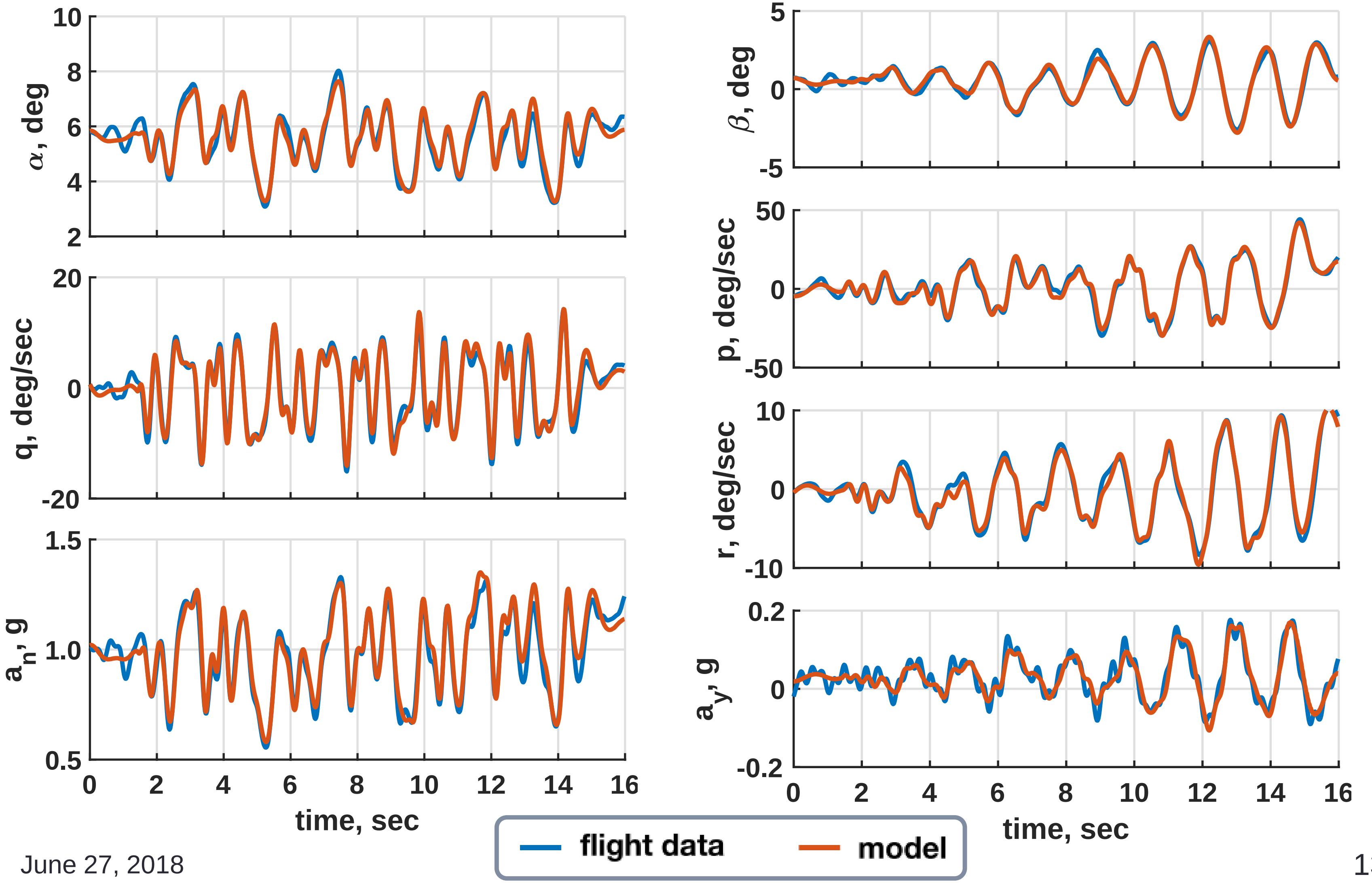
- Several parameter estimation techniques were used: output error in time domain and equation error in both time and frequency domains

- Parameter estimation results shown in subsequent plots are from output error and frequency domain equation error techniques, with 2-sigma error bars based on estimated standard errors

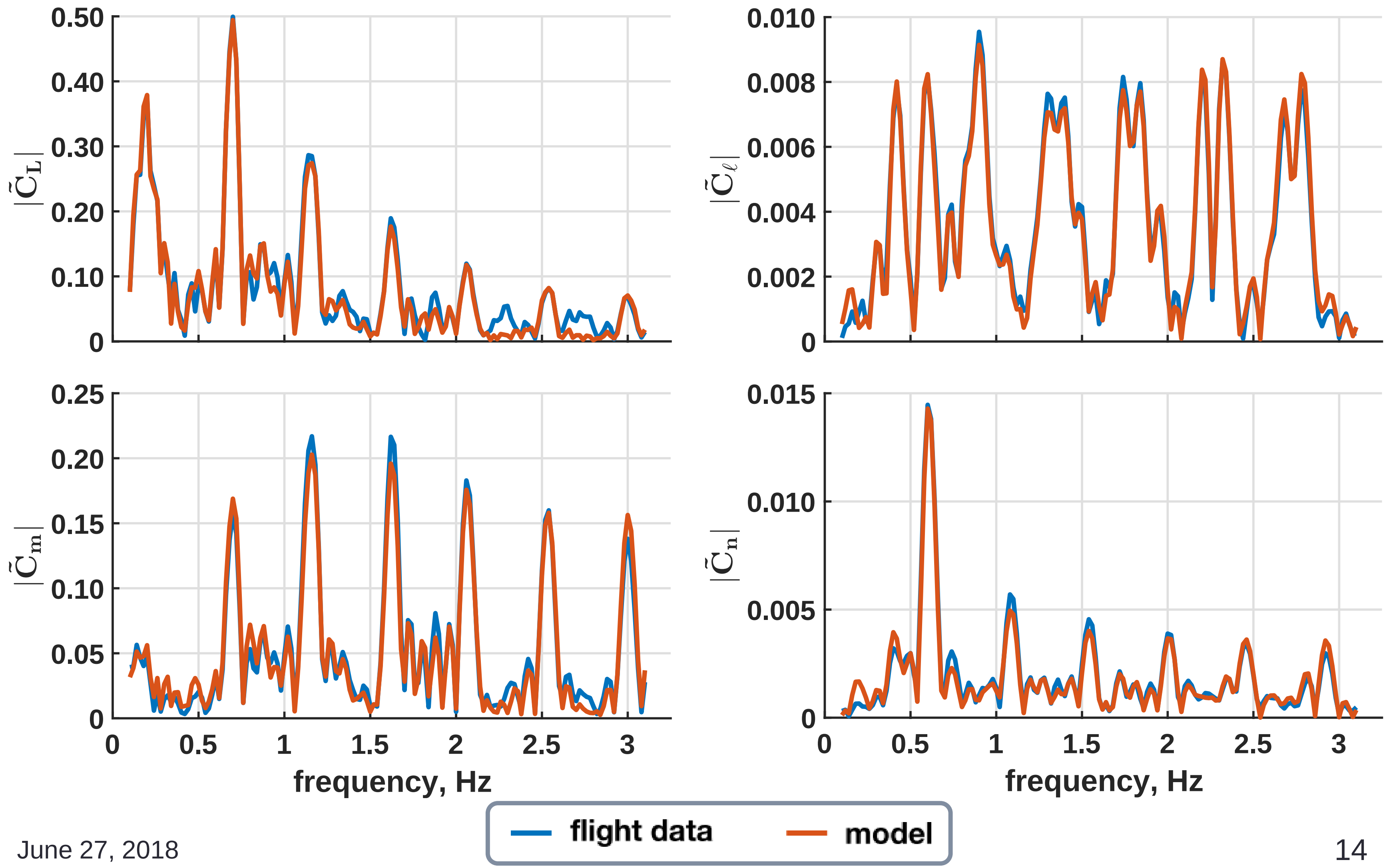
Example of Output-Error Response Matching (Wings Down)



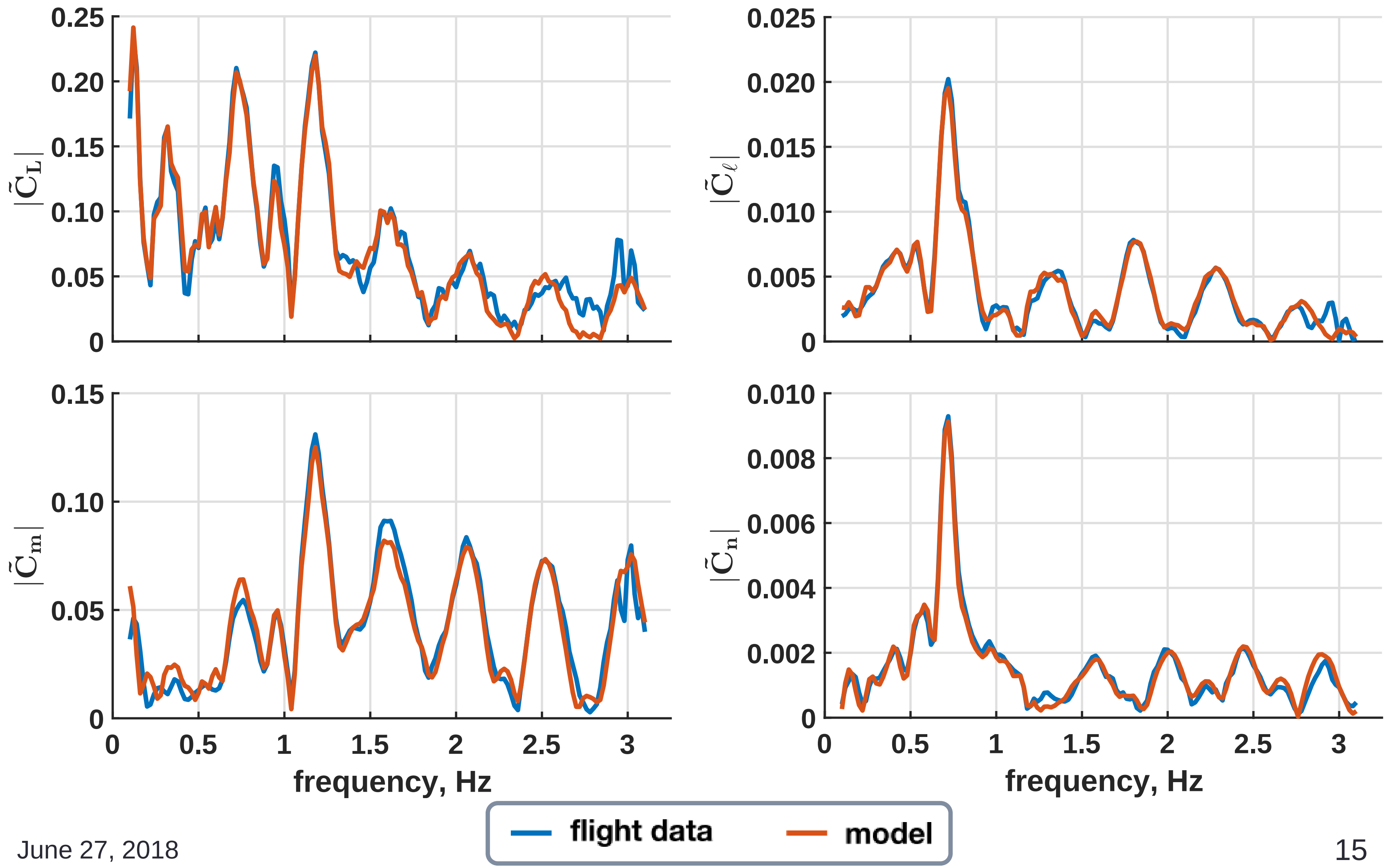
Example of Output-Error Response Matching (Wings Up)



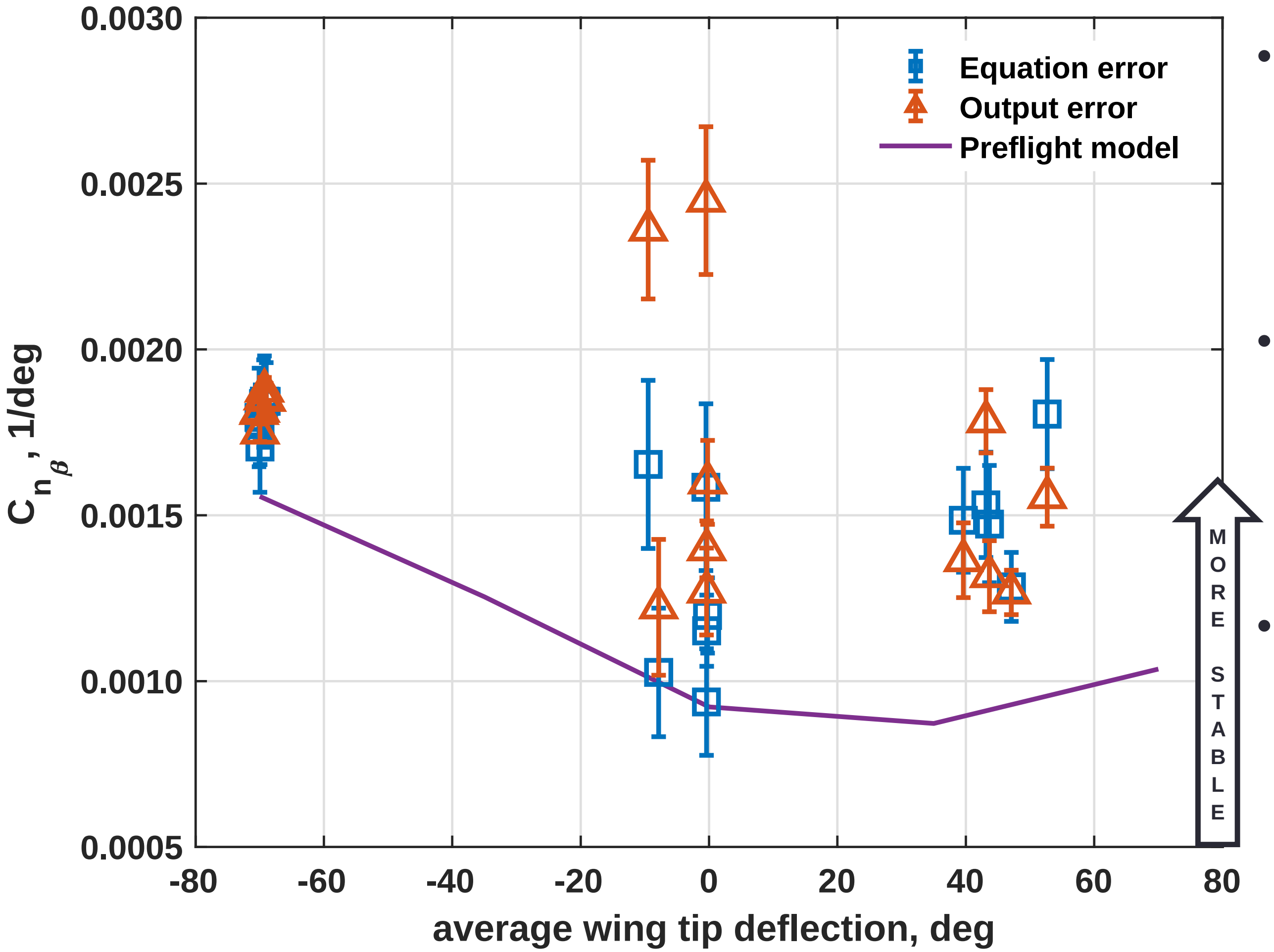
Example of Equation-Error Matching (Wings Down)



Example of Equation-Error Matching (Wings Up)

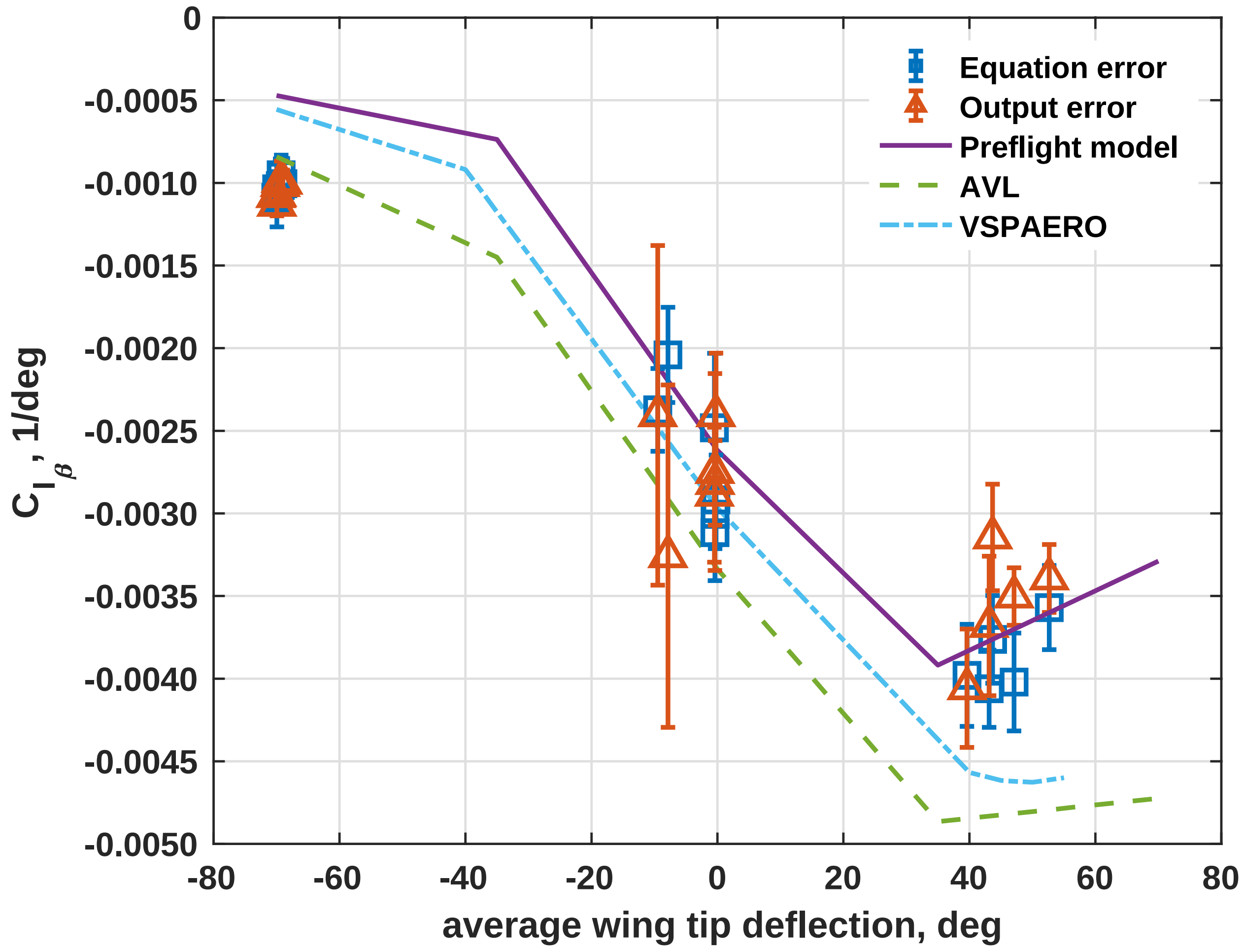


Yawing Moment due to Sideslip



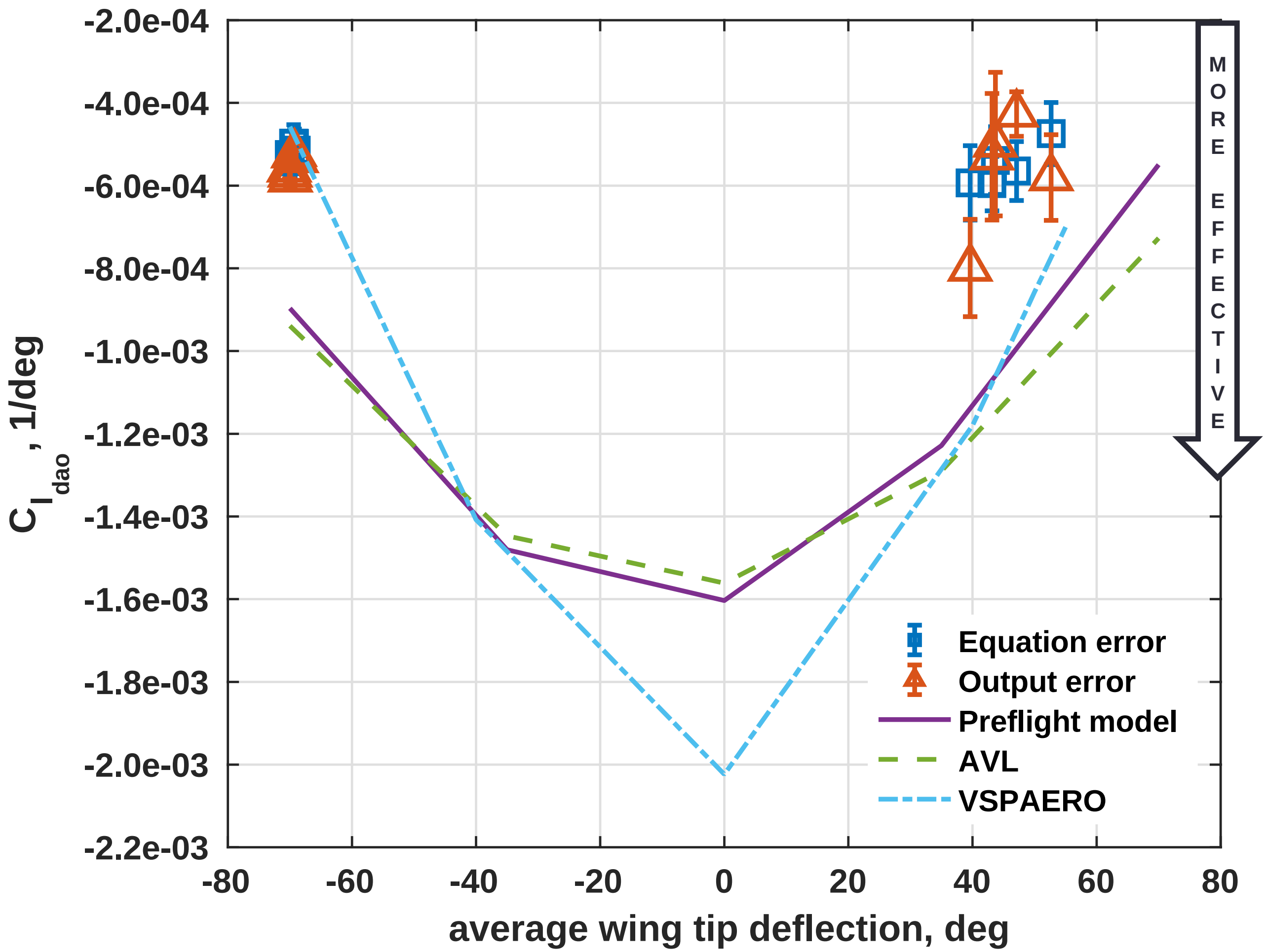
- Recall that no maneuvers were done with non-deflected wing tips
- Deflecting the wing tips down appears to slightly improve directional stability
- Effects of deflecting the wing tips upward are harder to discern due to scatter

Rolling Moment due to Sideslip



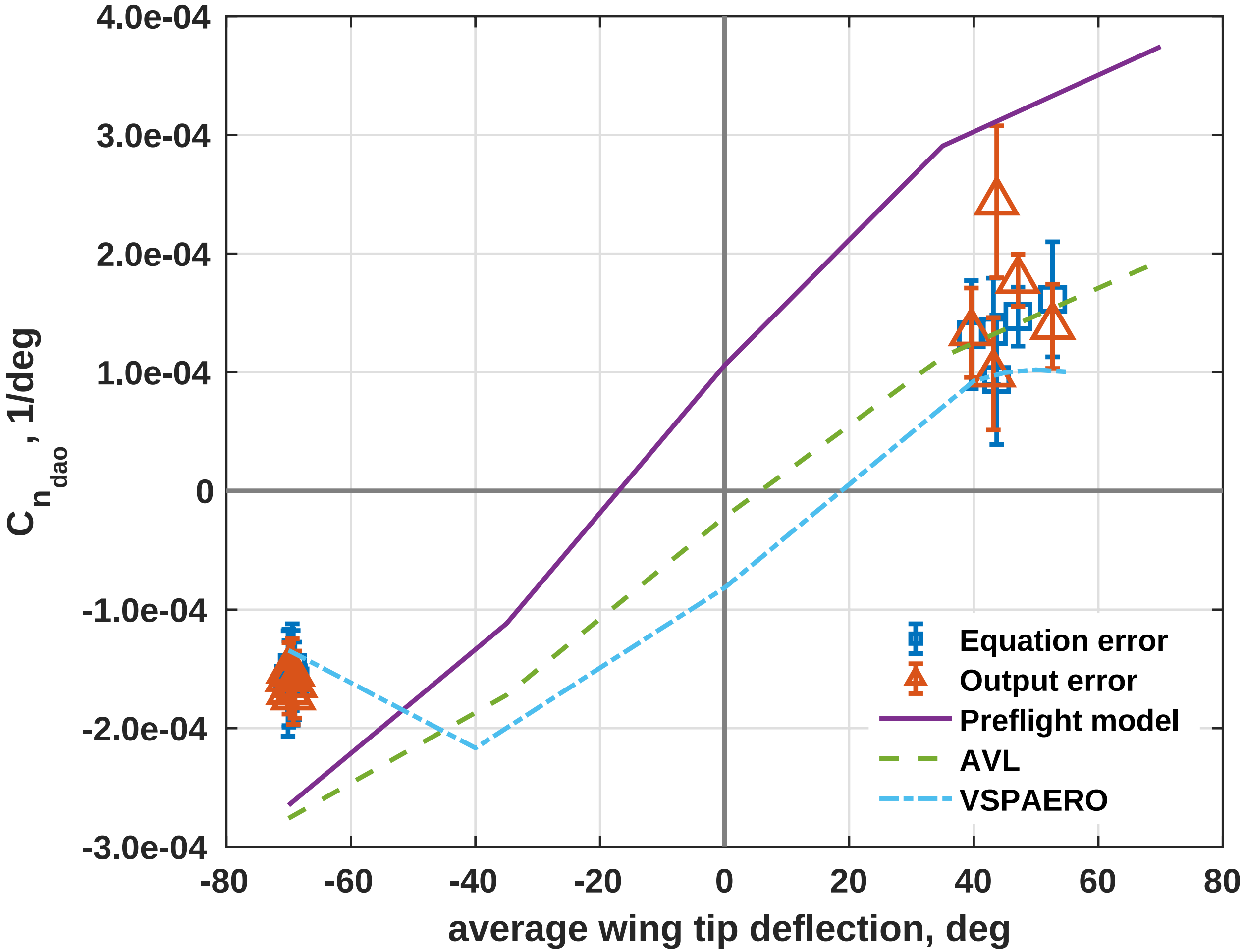
- As predicted, deflecting the wing tips downward reduced the amount of roll due to sideslip
- Deflecting the wing tips upward increased the amount of roll due to sideslip, contributing to poor flying qualities

Rolling Moment due to Outboard Ailerons



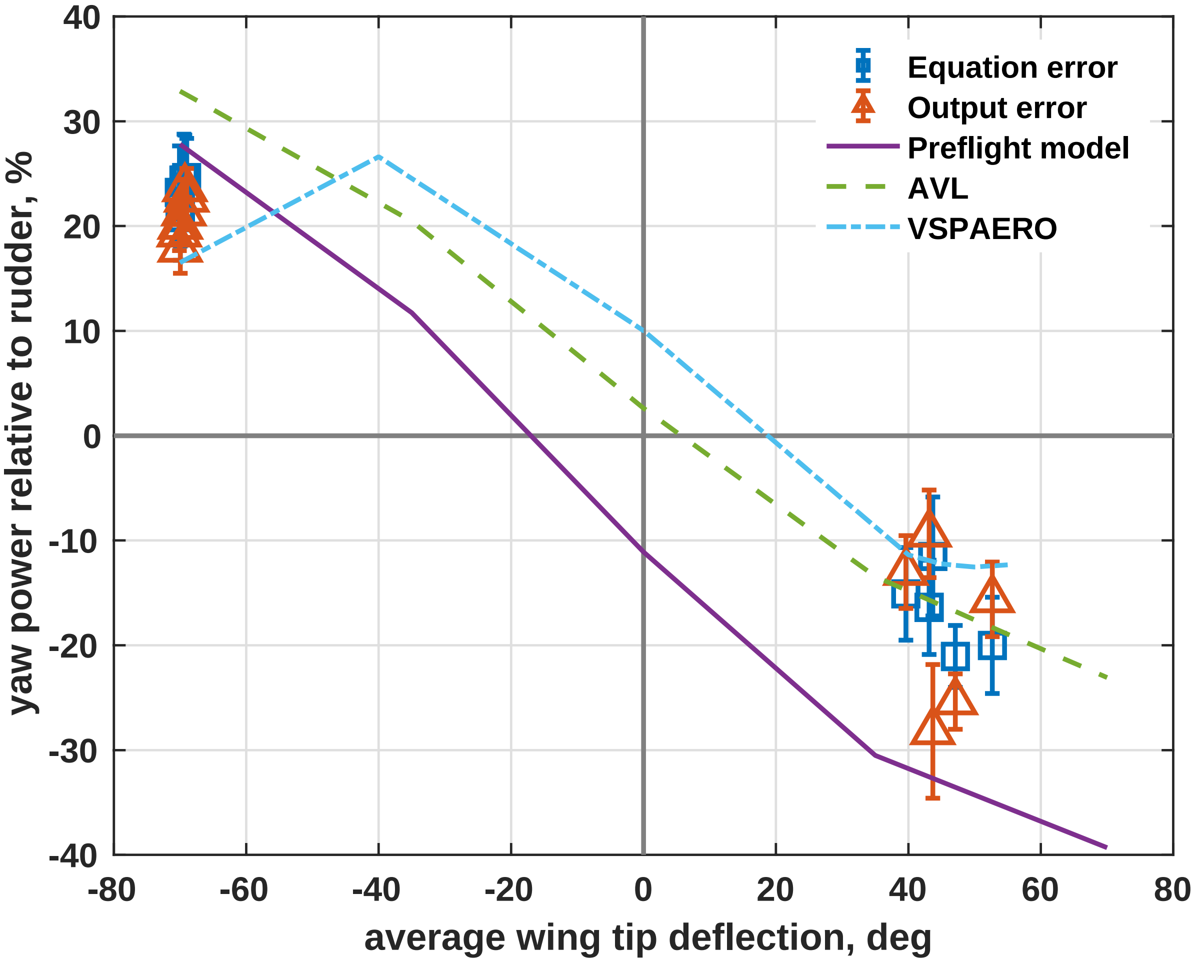
- Outboard aileron roll power was less than predicted, regardless of wing deflection direction
- Outboard ailerons are not used by the control system, so no data were available for non-deflected wing conditions

Yawing Moment due to Outboard Ailerons



- Outboard aileron yaw power was less than predicted before the flights, regardless of wing deflection direction
- Post-flight AVL matched wings-up cases
- Post-flight VSPAERO matched wings-down cases

Outboard Aileron Yaw Power Relative to Rudder



- Rudder was slightly less effective than predicted
- Outboard aileron yaw power was close to preflight predictions for wings-down cases and lower than preflight predictions for wings-up cases

Additional Comments About Parameter Estimation Results

- Output error and frequency domain equation error techniques agreed well with each other
  - Both techniques showed little scatter for wings-down cases
  - Both techniques had more scatter for wings-up cases; the output-error results had a lot more scatter, possibly due to the poor flying qualities of the wings-up PTERA-SAW configuration

- Deflecting the wing tips caused a slight reduction in roll damping, regardless of deflection direction

- Deflecting the wing tips did not cause appreciable changes to yaw damping

- Longitudinal parameters did not change much with wing tip deflection

Analysis for Potential Supersonic Follow-On Project (SAW 2.0)

- F-18
  - Quick study into effects of deflecting outer wing panels in flight (lift, stability, aileron control power)

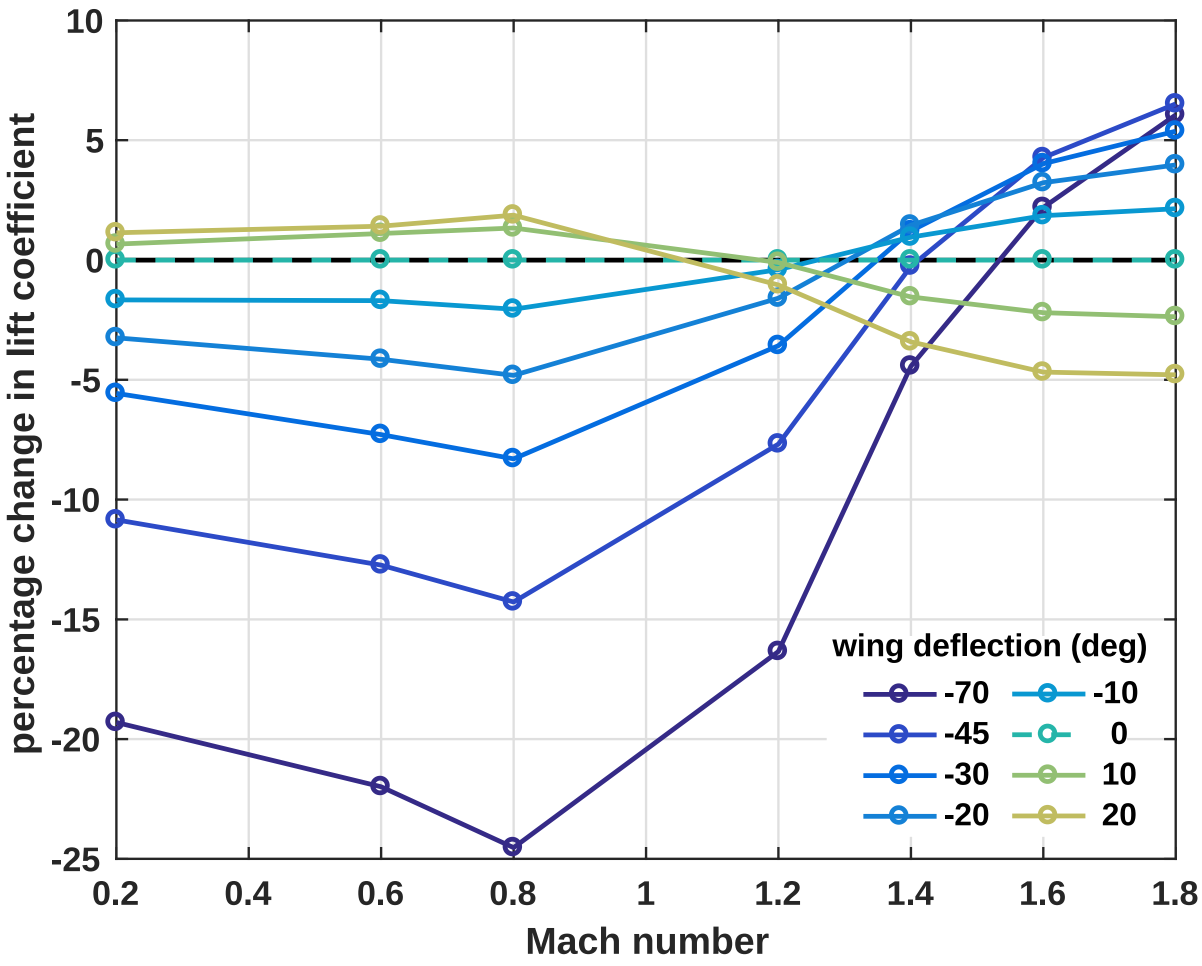
- Subscale vehicle
  - A feasibility study is in progress at AFRC for aircraft configurations picked specifically for SAW
  - No results to present at this time

SAW 2.0 F-18 Analysis

- Predictions were made of the aerodynamic effects of deflecting the outer wing panels on an F-18
- Analysis was performed using CFD (Cart3D), with additional data from vortex lattice codes at low speeds

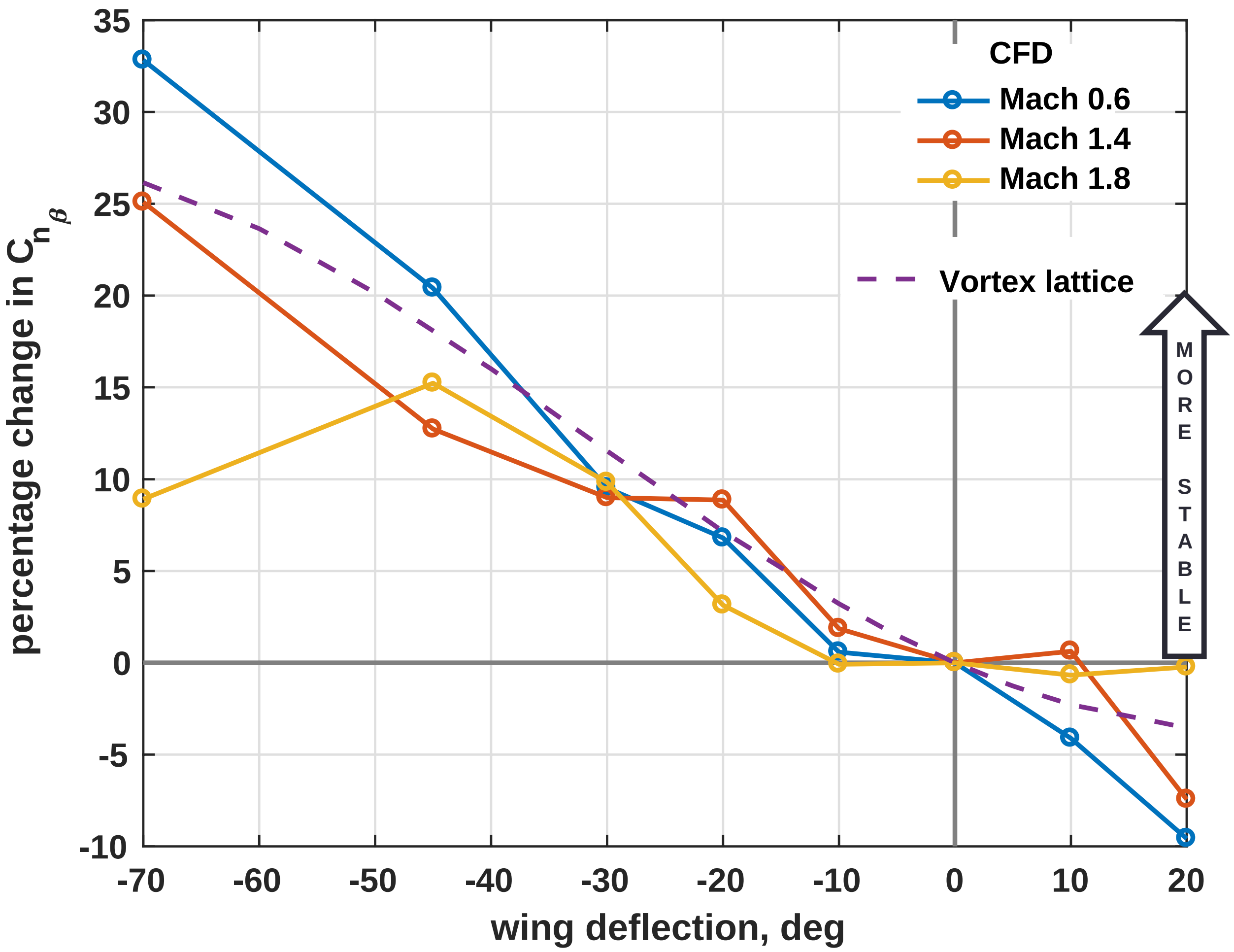
Shown: wing tip deflection of -70 deg

Predicted F-18 Lift vs. Mach



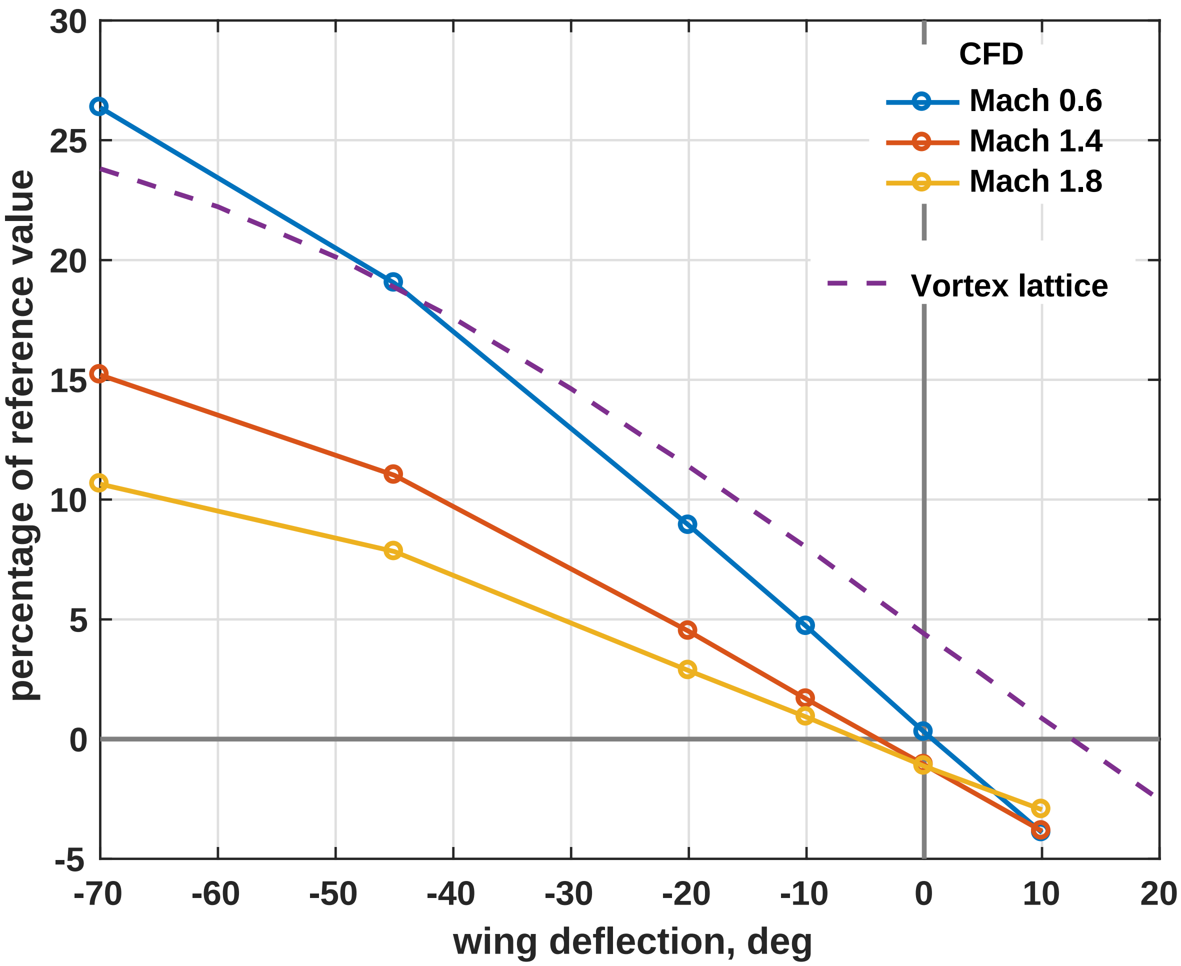
- Results shown are for an angle of attack of 2 deg
- CFD predicts a slight increase in lift coefficient at high Mach numbers

Predicted F-18 Yaw due to Sideslip



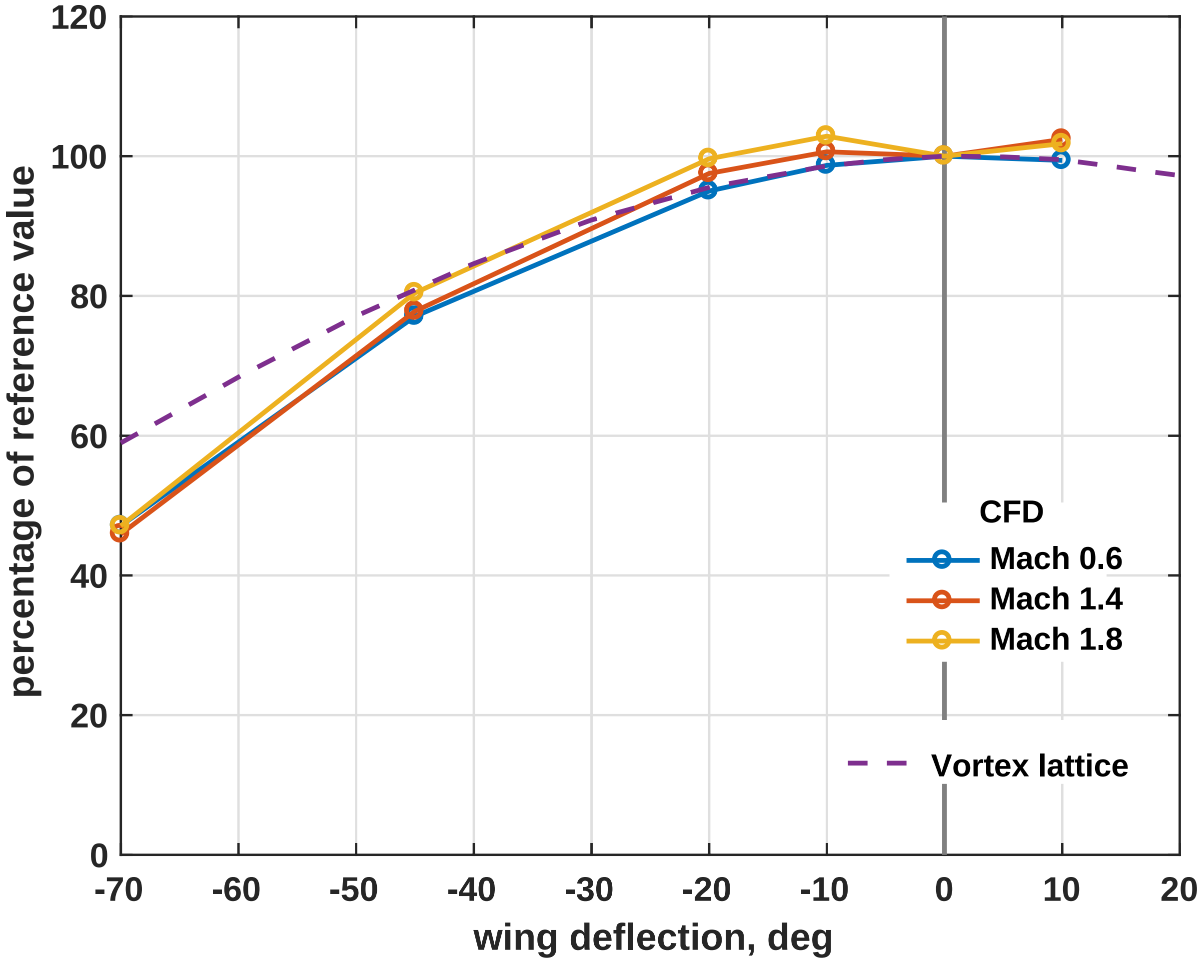
- CFD and vortex lattice predict substantial increases in static directional stability with negative wing tip deflections
- Given the nature of the tools used, the effects could be over-predicted

Predicted F-18 Aileron Yaw Power Relative to Rudders



- Tools predict that the ailerons would not produce a large percentage of the yaw produced by the F-18's rudders
- Shown is the total for the left and right ailerons

Predicted F-18 Aileron Roll Power Relative to Baseline



- Tools predict substantial losses in aileron roll power relative to the baseline aileron control power
- Shown is the total for the left and right ailerons

Concluding Remarks

- PTERA-SAW configuration was chosen from an aerodynamic trade study that utilized Area-I in-house tools
- PTERA-SAW flight test parameter estimation results were good
  - Multisine maneuvers worked well
  - Trends were similar to predictions
  - Outboard ailerons produced less yaw than was predicted
- Aerodynamic analyses for a supersonic follow-on project are ongoing

QUESTIONS?