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
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 \((\Gamma)\)
10) Cant angle \((\Gamma_{wl})\)
11) Sweep angle \((\Lambda)\)
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

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Sweep Angle (Λ)</th>
<th>Wing tip Span, in (b_w)</th>
<th>C.G. shift, in (aft of root ¼-chord)</th>
<th>Wing tip Yaw Control (% of rudder @ 10.0° deflection)</th>
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Baseline Values
Design Space Explored
Design Study Results, Configuration 2

<table>
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<tr>
<th>Wing tip Cant Angle</th>
<th>Pitch Trim</th>
<th>Stability Derivatives</th>
<th>Control Derivatives</th>
<th>Aileron Yaw Power Relative to Rudder</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$\delta_e$</td>
<td>$C_{m,\alpha}$</td>
<td>$C_{n,\beta}$</td>
<td>$C_{m,\delta_e}$</td>
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<td>0°</td>
<td>5.09° TEU</td>
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<td>5.77° TEU</td>
<td>-1.684 (S.M. = 31.8%)</td>
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</table>

All derivatives are per radian

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## Design Study Results, Configuration 8

### Pitch Trim
- **Wing tip Cant Angle**: 0°, 75°, -75°
- ** δ_e**: 5.12° TEU, 4.17° TEU, 4.48° TEU

### Stability Derivatives
- **C_m,α**: -1.564 (S.M. = 25.8%), -1.064 (S.M. = 20.5%), -1.122 (S.M. = 21.2%)
- **C_n,β**: 0.0569, 0.0607, 0.0896

### Control Derivatives
- **C_m,δ_e**: -1.521, -1.520, -1.520
- **C_n,δ_r**: -0.0552, -0.0543, -0.0545
- **C_n,δ_ao**: 0.0055, 0.0212, -0.0156

### Aileron Yaw Power Relative to Rudder
- 10%, -39%, 29%

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**Configuration chosen for PTERA-SAW**

*All derivatives are per radian*
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)

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Example of Equation-Error Matching (Wings Up)

![Graphs showing comparison of flight data and model predictions for different forces and moments over a range of frequencies.](image)
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
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.
• 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

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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

[Graph showing percentage change in $C_{n\beta}$ vs. wing deflection]
• 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?