AEPW2 SIMULATIONS WITH THE EZNSS CODE

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## TEST CASES

<table>
<thead>
<tr>
<th>Mach</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Optional Case 3</th>
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<tr>
<th>AoA</th>
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<table>
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<tr>
<th>Data Type</th>
<th>Case 1</th>
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<tr>
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<td>PAPA</td>
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<td>R-134a</td>
<td>R-12</td>
<td>R-134a</td>
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<tr>
<td>Flutter</td>
<td>Unforced Unsteady</td>
<td>Separated flow</td>
<td>Repeat of AePW-1 OTT</td>
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<td>• PAPA</td>
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<td>• R-134</td>
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</table>
• Elastic Zonal Navier-Stokes Solver (EZNSS)
• Finite difference method
• Several implicit algorithms
• Second-order in space and time
• In this study:
  – Implicit ADI time-marching
  – Flux splitting - AUSM+-up
COARSE AND MEDIUM MESHES

- Coarse Mesh: 71x253x99 (1.8 Mil)
- Medium Mesh: 126x361x184 (8.4 Mil)
CASE 1 (M 0.7, AOA 3°, R-134A) - STATIC ANALYSIS

- Two linear eddy viscosity models: k-ω-SST, SA
- Coarse Mesh
- CL=0.425 (0.410), CD=0.026 (0.026), CM=-0.075 (-0.072)

Convergence

Pressure Map
CASE 1 (M 0.7, AOA 3°, R-134A) - STATIC ANALYSIS

Cp at 0.6 span

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**Graph Description:**

- **X-axis:** x/c
- **Y-axis:** Cp
- **Data Points:**
  - SST
  - SSGLRR
  - SA
  - Exp. lo
  - Exp. up

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CASE 1 (M 0.7, AOA 3°, R-134A) - STATIC ANALYSIS

Cp at 0.6 span

![Diagram showing Cp at 0.6 span with various lines and data points representing different models and experimental data.](attachment:chart.png)
CASE 1 (M 0.7, AOA 3\(^\circ\), R-134A) - STATIC ANALYSIS

Cp at 0.6 span

![Graph showing Cp at 0.6 span]
CASE 1 (M 0.7, AOA 3°, R-134A) - FORCED EXCITATION, 10HZ

- SA turbulence model
- \( dt=2\times10^{-4} \) sec -> 500 time steps in a cycle
- Snapshots every 10 time steps -> 50 snapshots in a cycle
- Reduced frequency:
  \[ k = \frac{2\pi fb}{V} = 0.1 \]
- 2% difference between simulated CL and CL based on Theodorsen (and the steady CL)
CASE 1 (M 0.7, AOA 3°, R-134A) - FORCED EXCITATION, 10HZ

Upper Surface $C_p/\theta$ Transfer Function

Lower Surface $C_p/\theta$ Transfer Function
CASE 1 (M 0.7, AOA 3°, R-134A) - FORCED EXCITATION, 10HZ

Upper Surface -Cp during a cycle
TF Magnitude, and phase shift region

AoA, and -Cp at various chord locations
CASE 2 (FLUTTER, M 0.74, AOA 0°, R-12) - STATIC ANALYSIS

- Three linear eddy viscosity models: k-ω-SST, k-ω-TNT, SA
CASE 2 (FLUTTER, M 0.74, AOA 0°, R-12) - STATIC ANALYSIS

- Three linear eddy viscosity models: k-ω-SST, k-ω-TNT, SA
CASE 2 (FLUTTER, M 0.74, AOA 0°, R-12) - 
STATIC ANALYSIS

- SA
- Two meshes: Coarse 253x71x99, Medium 361x126x184
CASE 2 (FLUTTER, M 0.74, AOA 0°, R-12) - STATIC ANALYSIS

- SA
- Two meshes: Coarse 253x71x99, Medium 361x126x184
STRUCTURAL MODEL

Heave - 3.33 Hz

Pitch - 5.20 Hz
CASE 2 (FLUTTER, M 0.74, AOA 0°, R-12)

LINEAR FLUTTER ANALYSIS

- Linear flutter analysis in ZAERO:
  - Flutter dynamic pressure 157 psf (169 psf in the WT)
  - Flutter frequency 4.3 Hz (4.3 in the WT)
CASE 2 (FLUTTER, M 0.74, AOA 0°, R-12) AEROELASTIC SIMULATION

- Analysis dynamic pressure 169 psf (as in WT)
- Nominal computational parameters:
  - Coarse mesh
  - SA model
  - dt=2e-4 s
  - Sub-iteration convergence criterion: 5 OOM residual drop
CASE 2 - FLUTTER, M 0.74, AOA 0°, R-12

- Flutter frequency: Computed 4.2 Hz, WT 4.3 Hz
- Tip displacement and wing twist during flutter:
CASE 2 (FLUTTER, M 0.74, AOA 0°, R-12)
AEROELASTIC SIMULATION

- Temporal convergence - effect of time-step

Heave

Pitch
CASE 2 (FLUTTER, M 0.74, AOA 0°, R-12)
AEREOELASTIC SIMULATION

- Temporal convergence - effect of convergence in sub-iterations

Heave

Pitch
CASE 2 - FLUTTER, M 0.74, AOA 0°, R-12

- Turbulence model:
CASE 2 - FLUTTER, M 0.74, AOA 0°, R-12

- Mesh (SA):
CASE 3 (M 0.85, AOA 5°, R-134A) - STATIC ANALYSIS

- Turbulence models: SST, SA
- Coarse Mesh
- CL=0.465, CD=0.065, CM=-0.075 (SST)

\[ L_2 \text{Norm} = \sqrt{\sum_{\xi=1}^{\xi_{max}} \sum_{\eta=1}^{\eta_{max}} \sum_{\zeta=1}^{\zeta_{max}} \sum_{m=1}^{5} \hat{R}_k^m dt} \]
CASE 3 (M 0.85, AOA 5°, R-134A) - STATIC ANALYSIS

Cp at 0.6 span

- SST
- SA
- Exp. lo
- Exp. up

Cp vs. x/c
CASE 3 (M 0.85, AOA 5°, R-134A) - STATIC ANALYSIS

Cp at 0.6 span

![Cp vs x/c plot for CASE 3](image)
CASE 3 (M 0.85, AOA 5°, R-134A) - STATIC ANALYSIS

Cp at 0.6 span

- SST
- SA
- Exp. lo
- Exp. up
CASE 3 (M 0.85, AOA 5°, R-134A) - STATIC ANALYSIS

• Mesh effect

Cp at 0.6 span (SST)  

Cp at 0.6 span (SA)
CASE 3 (M 0.85, AOA 5°, R-134A) - STATIC ANALYSIS

- Mesh effect

Cp at 0.6 span (SST)  
Cp at 0.6 span (SA)
CASE 3 (M 0.85, AOA 5°, R-134A) - STATIC ANALYSIS

- Mesh effect

Cp at 0.6 span (SST)  
Cp at 0.6 span (SA)
CASE 3 (M 0.85, AOA 5°, R-134A) - FORCED EXCITATION, 10HZ

- SST (and SA) turbulence model
- dt=2e-4 sec -> 500 time steps in a cycle
- Snapshots every 10 time steps -> 50 snapshots in a cycle
- 18 cycles simulated
CASE 3 (M 0.85, AOA 5°, R-134A) - FORCED EXCITATION, 10HZ

Upper Surface $C_p/\theta$ Transfer Function

Lower Surface $C_p/\theta$ Transfer Function
CASE 3 (M 0.85, AOA 5°, R-134A) - FORCED EXCITATION, 10HZ

Upper Surface -Cp during a cycle
TF Magnitude, and phase shift region

AoA, and -Cp at various chord locations

$$k = \frac{2\pi fb}{V} = 0.09$$
SUMMARY

- Good prediction of WT results for the static, forced, and flutter experiments, in attached and mildly separated cases (Cases 1 and 2)
- Under massively separated flow conditions (Case 3) commonly used turbulence model cannot accurately predict the complex flow physics
- Yet simulations of forced excitation response (and flutter?) are feasible, offering reasonable accuracy
- Some sensitivity to computational parameters (convergence)
- Little sensitivity to mesh
- Lack CFD-based flutter prediction capability