Minimization of Wing Deformation in Trimmed Flight of Highly Flexible Aircraft Using Multiple Control Surfaces

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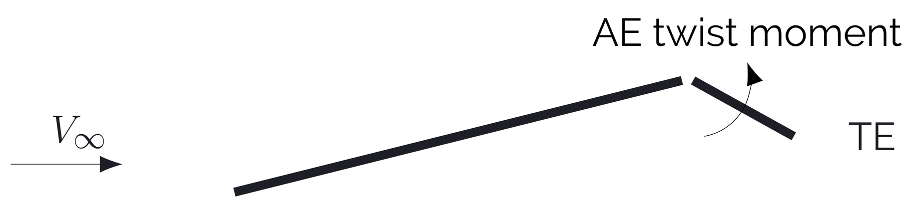
Background and Goals

- Highly flexible configurations undergo very large deformations in flight
- This introduces geometric structural nonlinearities - requires complex nonlinear modeling
- Can the deformations at trimmed flight be minimized to within linear modeling limits?
- In this study - minimization of trimmed flight deformations to user-specified limits via the use of redundant control surfaces on the leading and trailing edges of the wing

Active Aeroelastic Wing Technology

- An approach to overcome control surface efficiency problems in flexible wings
- Conventional approach:



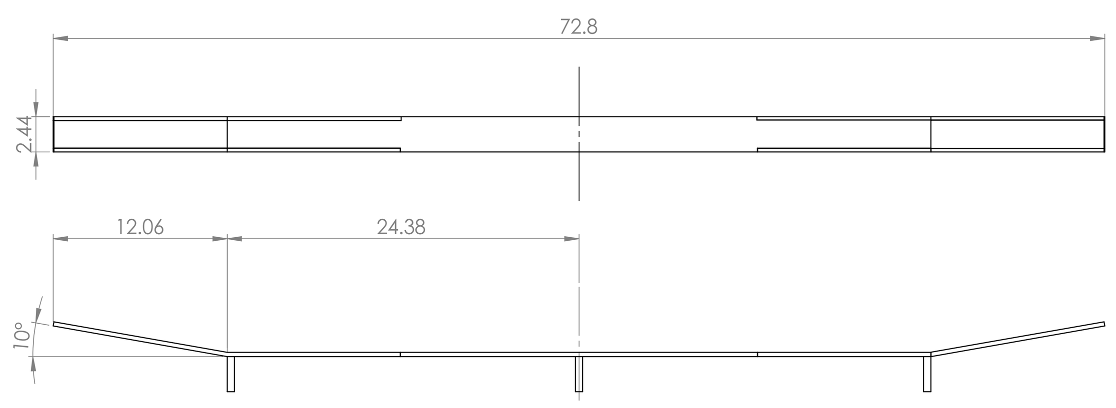
- AAW approach:

- Allows extra control over wing shape
- Flexibility is favorable instead of detrimental

Trim Optimization

- AAW uses redundant control surfaces - infinite number of solutions - optimization is possible
- Trim optimization is solved using linear programming - allows the solution of linear objective and constraints problems
- Optimization algorithm being used is the popular simplex method
- Optimization function: Weighted sum, user-specified cost function for the various trim variables
- Wing deformation is constrained to be bounded by a maximum value set by the user

Numerical Example

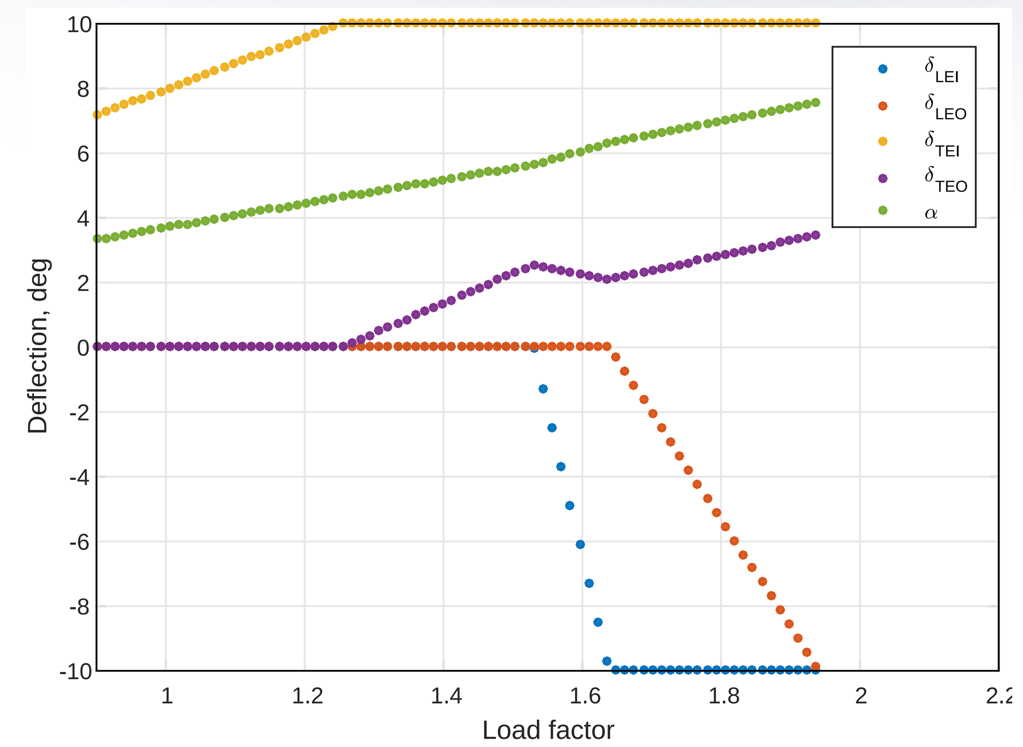


- Hale type flexible flying wing
- Five trim variables:
  1. Leading edge inboard (LEI)
  2. Leading edge outboard (LEO)
  3. Trailing edge inboard (TEI)
  4. Trailing edge outboard (TEO)
  5. Angle of attack (α)
- Panel based aerodynamic model in ZAERO
- Structural FE model is realized in NASTRAN
- Trimmed at varying load factors and dyn. pressures
- Optimization parameters:
  - Control surface travel limits: $-10°$ to $10°$
  - AOA limits: $-8°$ to $8°$
  - Relative cost: LEI: 1, LEO: 2, TEI: 3, TEO: 4, AOA: 2
  - Maximum first bending modal displacement allowed: $|\xi_4|^{\max} = 10$ (wingtip displacement of ~1 m)

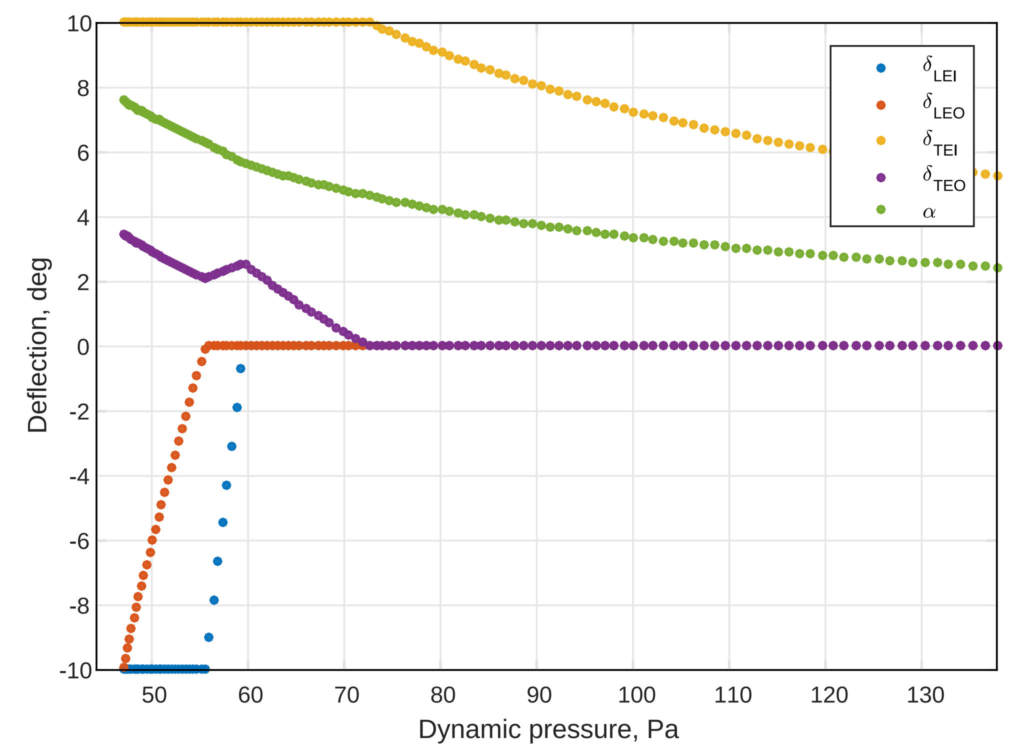
Results

Two sub-cases were examined:

1. Fixed dynamic pressure (SL, cruise), varying load factor:



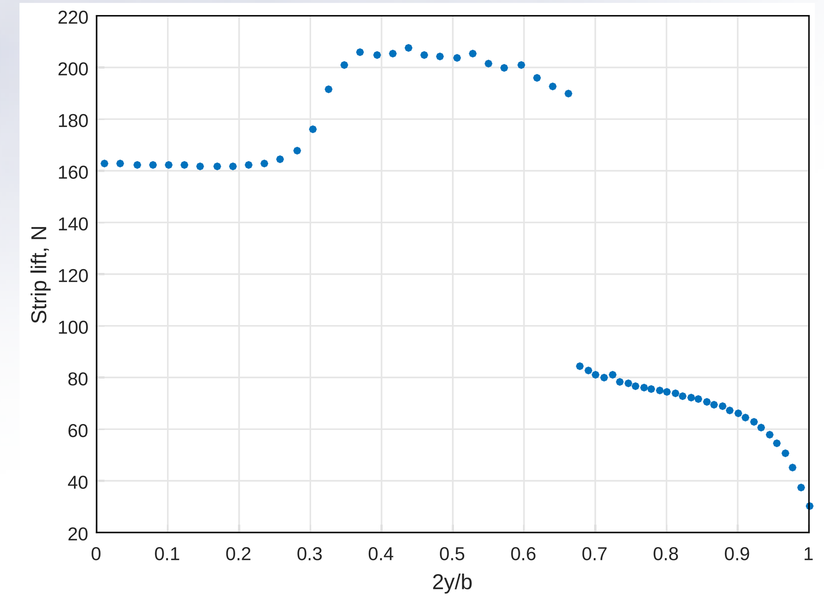
2. Fixed load factor $n = 1$, varying dynamic pressure:



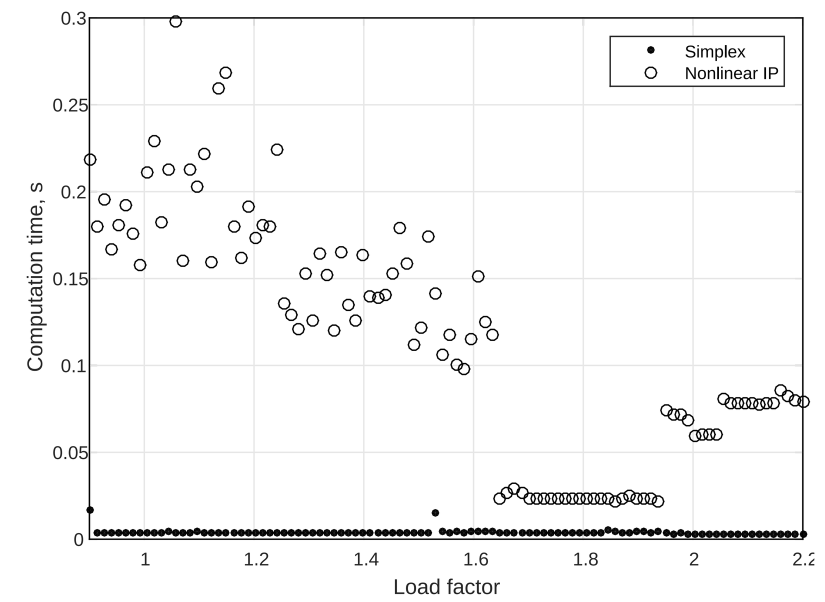
Actual wing shape during flight, n=1.9:

- Deformed wing without a constraint on $\xi_4^{\max}$
- Deformed wing with a constraint on $\xi_4^{\max}$
- Undeformed wing

Strip lift distribution along the wingspan, $n = 1.9$:



Simplex computation times compared with nonlinear interior point, n=1.9:



Conclusions

- Trim optimization can trim to a specific maneuver while reducing wing deformation to user-set limits
- Different costs can be placed on trim variables
- Ensures small deformation - no need for geometrically nonlinear structural modeling
- Employs flexibility to the structure's benefit
- Fast computation time

Forthcoming Research

- Solving the dynamic problem: Optimal load control for minimizing deformation during gust encounter