



# Leveraging a Doublet Lattice Correction Method to Expedite Linearized Frequency-Domain Optimizations in MPhys



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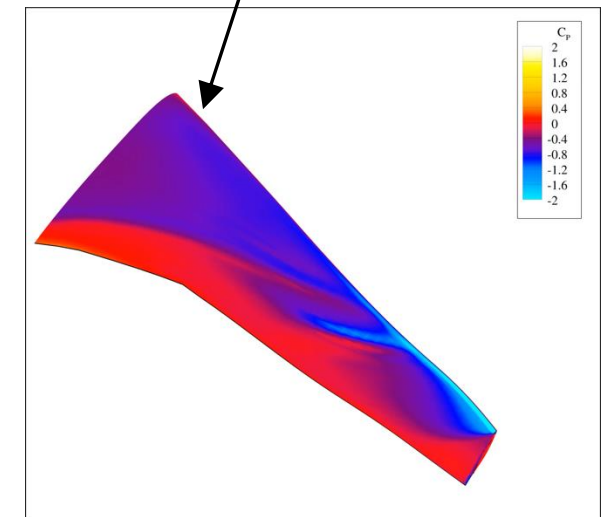
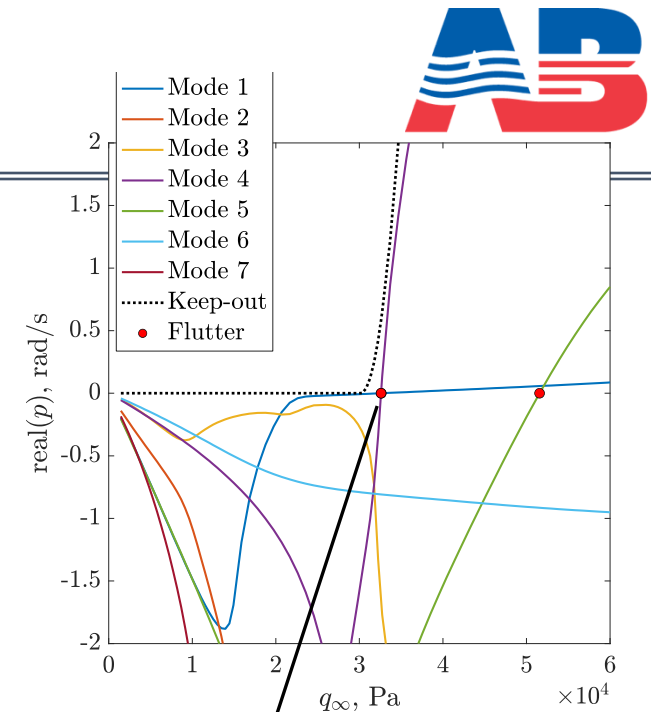


# Objective

- Gradient-based flutter- and gust-constrained optimizations have been demonstrated with FUN3D's Linearized Frequency Domain (LFD) solver
  - Implemented with the MPhys library for OpenMDAO, which seeks to standardize interfaces between solvers
  - More tractable than time-domain, but still very time-consuming to compute responses+derivatives



- Corrections to Doublet Lattice Method (DLM) have long been used to improve accuracy of DLM while not incurring cost of full CFD analysis
- Current work seeks to leverage a DLM correction method to help speed up search for LFD optimum



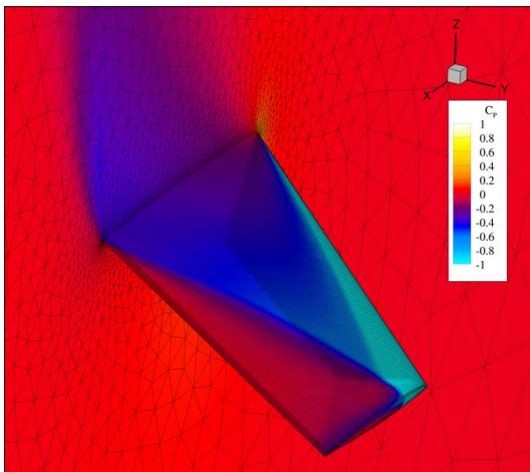
CRM optimization with LFD  
required weeks+ (IFASD 2024)



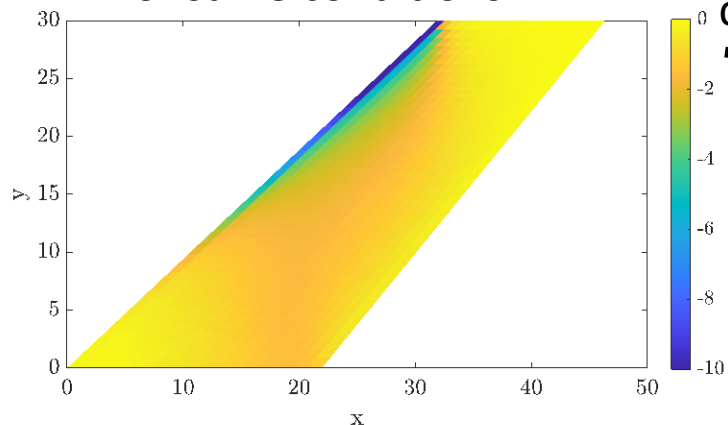
# Illustration of Correction Procedure



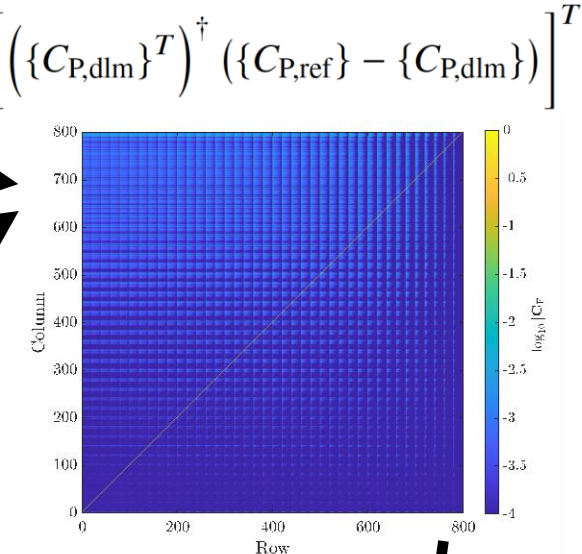
Compute steady CFD



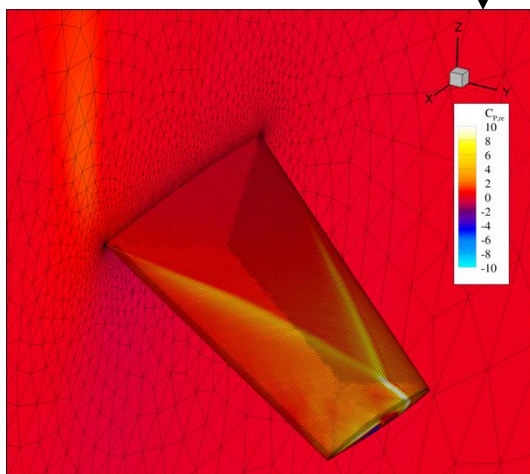
Compute DLM pressures  
for same conditions



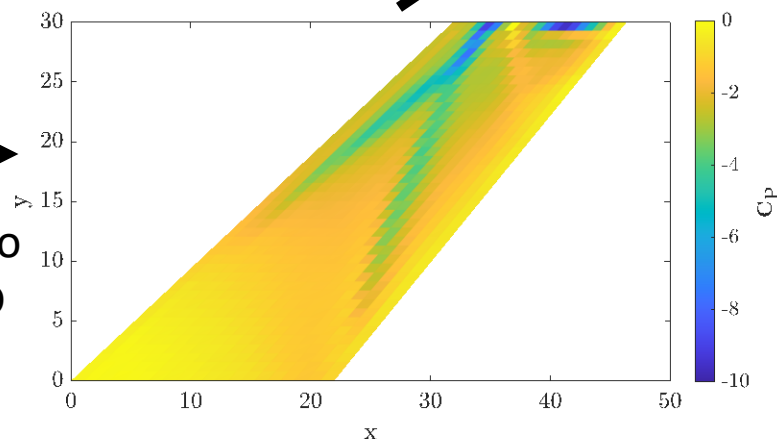
Diagonally-dominant  
correction matrix  $[C_F] = [I] + \left[ \left( \{C_{P,dlm}\}^T \right)^\dagger \left( \{C_{P,ref}\} - \{C_{P,dlm}\} \right) \right]^T$



LFD for N modes  
and/or pitching



Project LFD loads onto  
DLM panels via MELD



Pre-multiply AIC to get  
corrected Cp, GAFs (Q) for  
arbitrary modes, frequencies

$$\{C_P\} = [C_F] [AIC]^{-1} \{w\}$$
$$[Q_{ss}] = [S] \{C_P\}$$

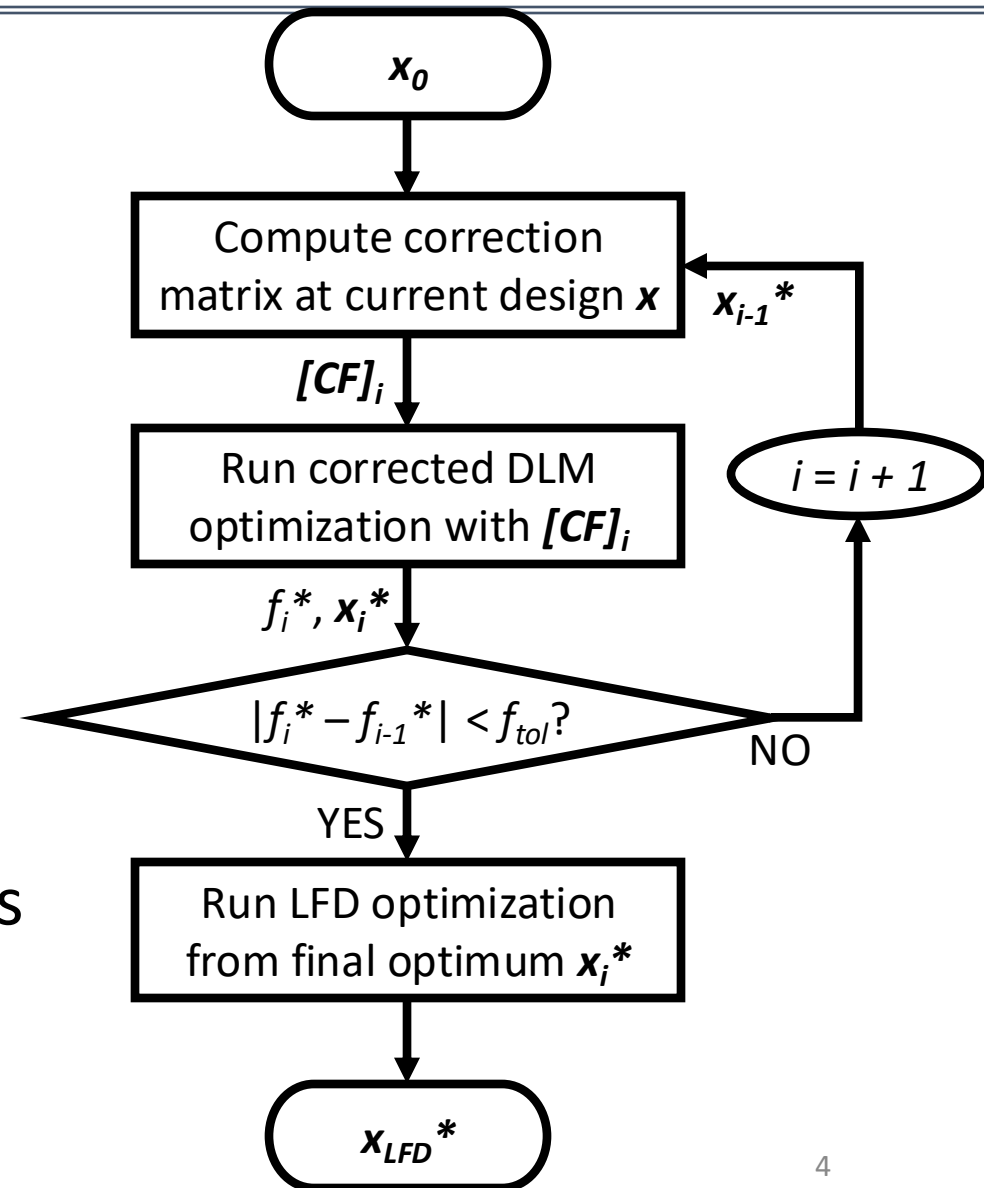
Optionally, repeat for  
N frequencies



# Sub-optimization Approach



- Corrected DLM sub-optimizations are iteratively performed, each with a new, frozen correction matrix
  - Each correction from LFD is expensive, so we want to limit them as much as possible
  - DLM evaluations are much cheaper, on the order of seconds rather than hours
- Goal is to obtain design close to LFD optimum, so that LFD optimization requires much fewer iterations

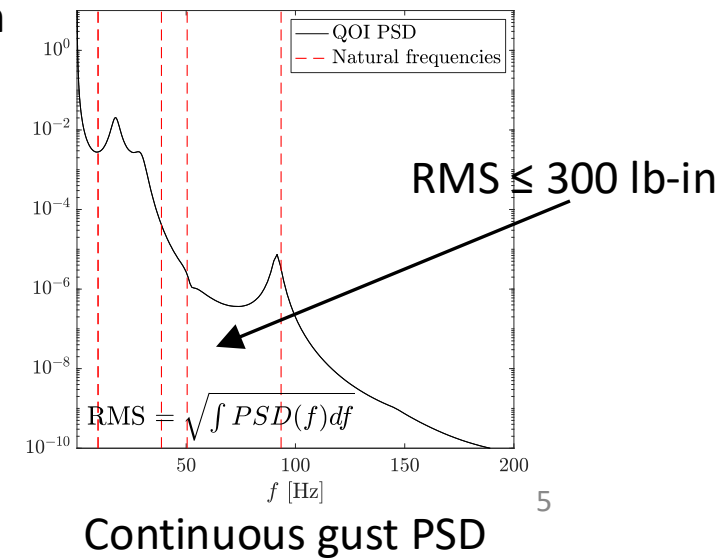
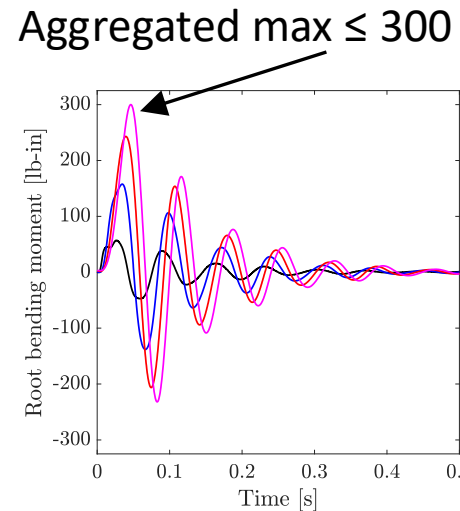
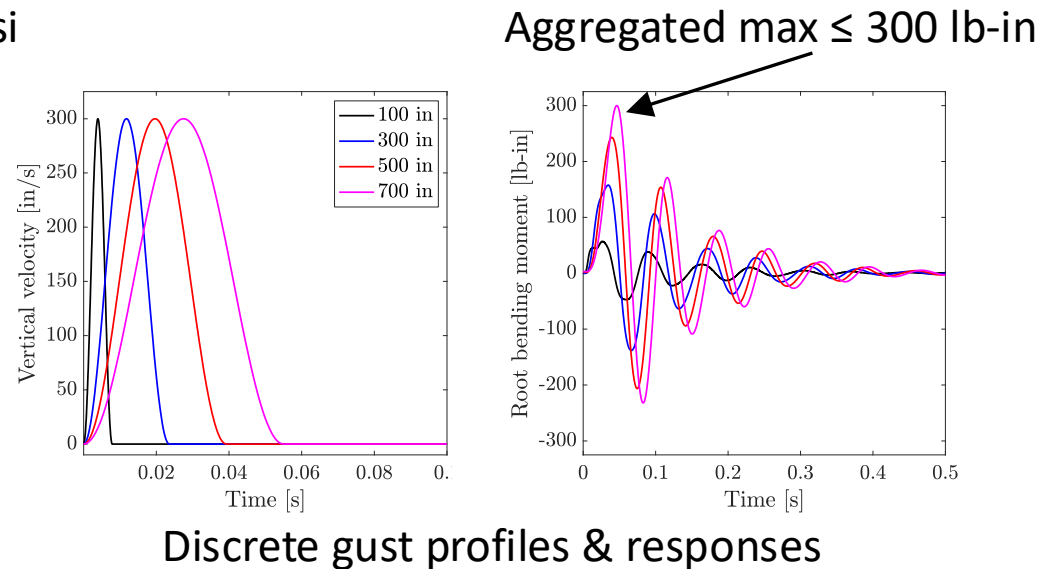
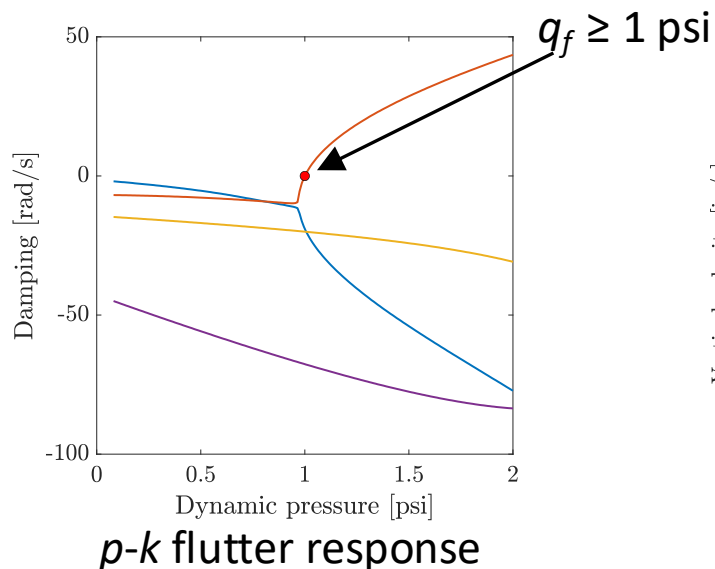
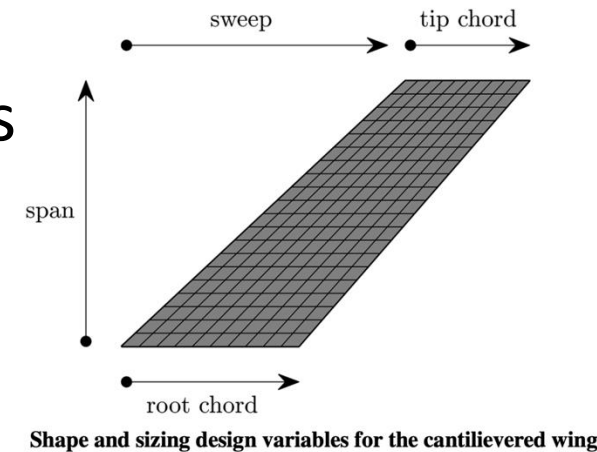




# AGARD 445.6 Wing Optimization Problem



- Minimize mass subject to area, flutter, & gust constraints
  - 100 thickness + 4 planform design variables
  - Mach 0.95, 6 degree angle of attack
- Minimum flutter onset dynamic pressure
- Maximum gust-induced root bending moment (cont. and disc.)





# Optimization Cases Performed

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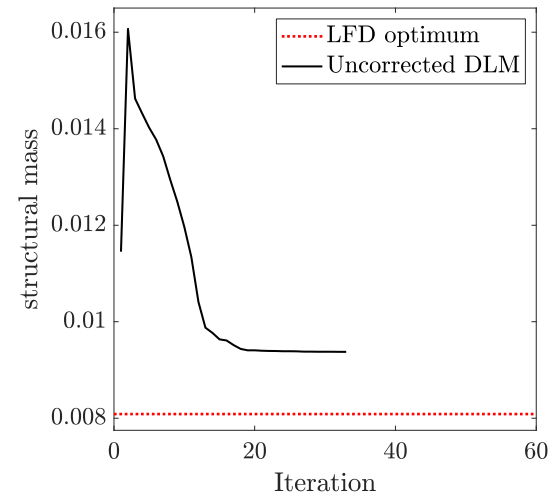
- Flutter-constrained with steady pitching
- Flutter-constrained with pitching+all modes, subset of frequencies
- Flutter- and gust-constrained with all modes, frequencies, fixed shape
- Flutter- and gust-constrained with all modes, frequencies, variable planform



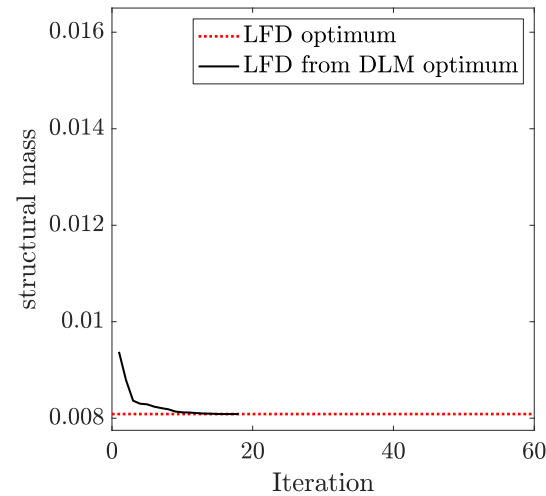
# DLM Convergence with Flutter Only



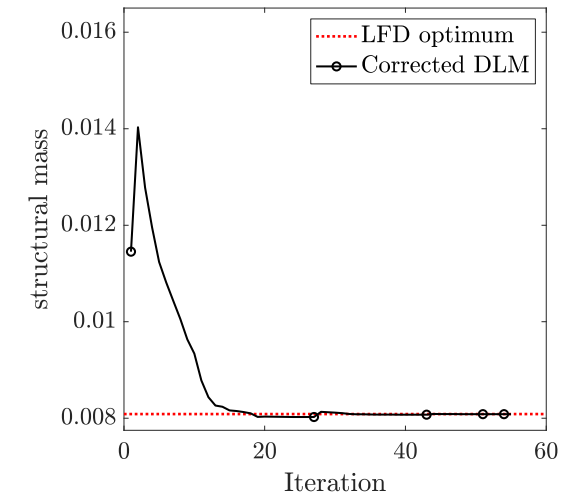
Uncorrected DLM



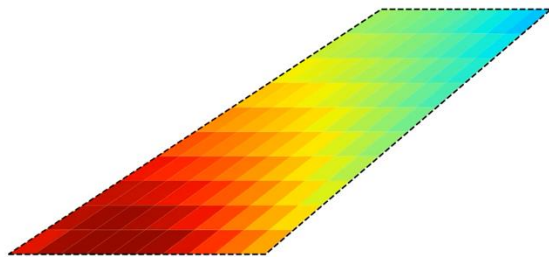
LFD from DLM optimum



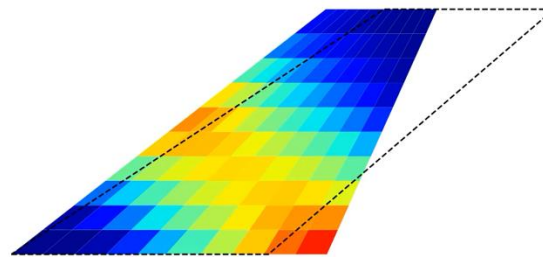
Corrected DLM (from baseline)



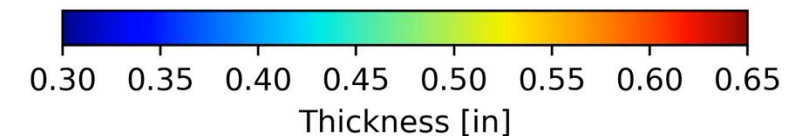
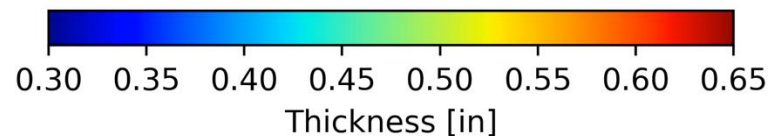
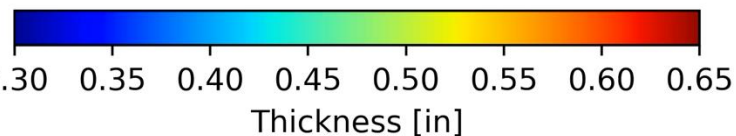
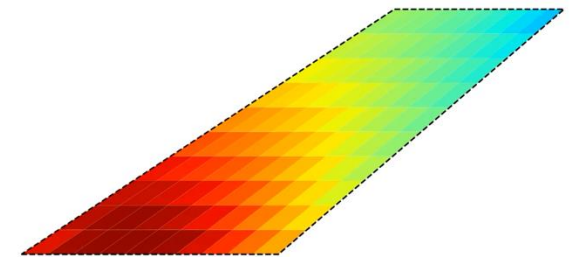
Iteration 0 - DLM



Iteration 0 - LFD



Iteration 0 - DLM

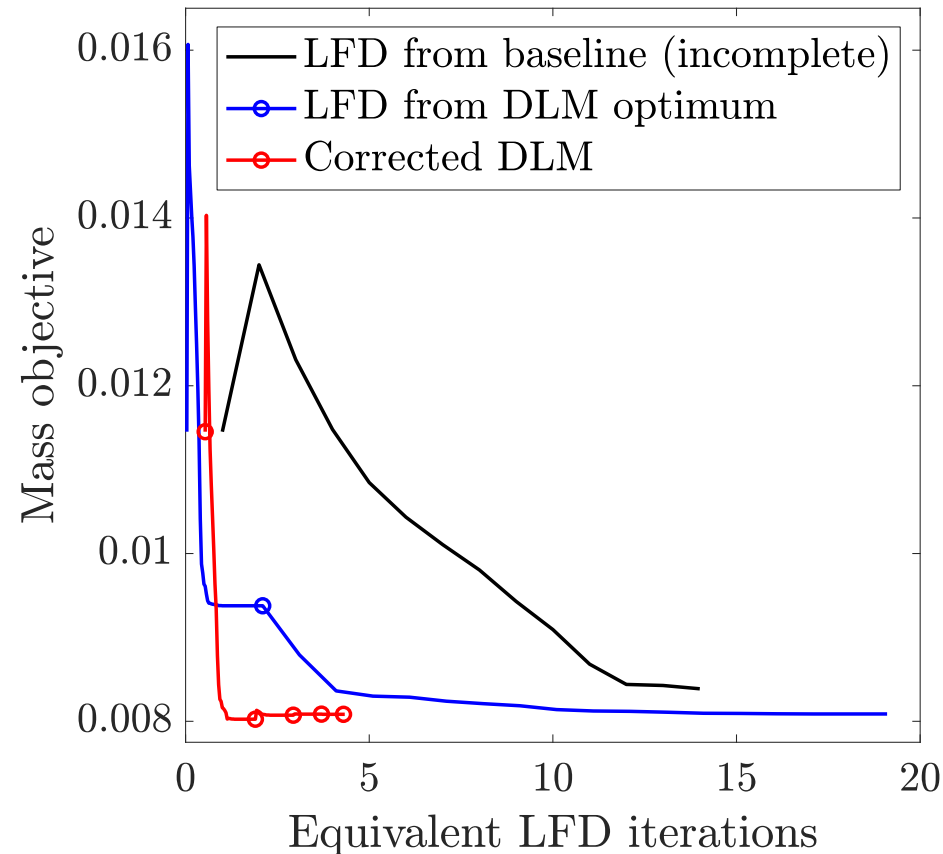




# Estimated Wall Time Savings, Flutter Only



- Relative to wall time, correction procedure (red) reaches LFD optimum in handful of equivalent LFD optimization iterations
  - Compared to 10s needed for full LFD optimization

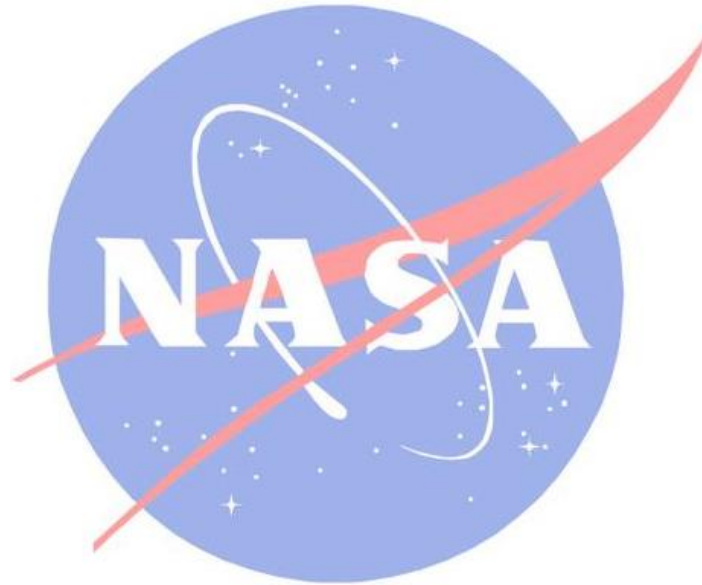




# Conclusion



- A DLM correction procedure has been developed with OpenMDAO/MPhys to help minimize the cost for an LFD optimization
  - Full, diagonally-dominant matrix from one or more modes, frequencies
  - Demonstrated on both flutter and gust constraints, but only one flutter case was shown here for brevity
- The current approach performs a handful of corrected DLM sub-optimizations, each with a fixed correction matrix, before performing an LFD optimization from the final design
- The method shows promise for structural sizing, but there are inherent limitations with shape design variables due to the planar nature of DLM
  - Alternative is to recompute correction matrix each iteration, which would be much more costly



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