

Updating High-Order Aeroservoelastic Models from Low-Order System Identification Results

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- Aeroservoelastic Models
 - Many modes are needed to verify airworthiness criteria
 - Models often based on relatively low-fidelity models
 - Can show significant differences from tests
 - Need methods to update these complex models based on test data
- System Identification
 - Commonly used to improve rigid aircraft models
 - Always requires significant simplifying assumptions
 - Simplifications are more significant for aeroservoelasticity
- A method is needed to link these two approaches



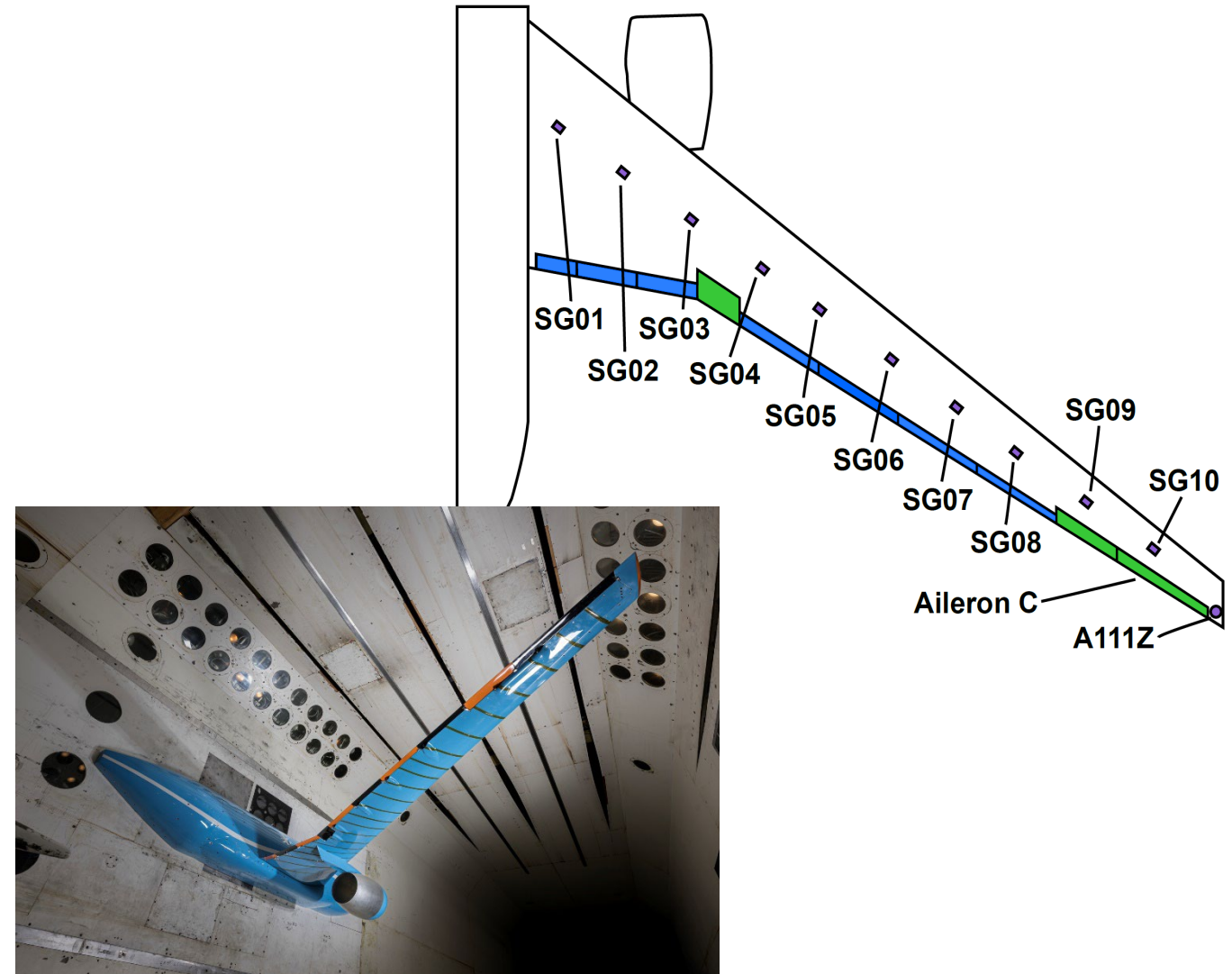
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Integrated Adaptive Wing Technology Maturation (IAWTM) Experiment



- Tested in Transonic Dynamics Tunnel (TDT) at the NASA Langley Research Center (LaRC) in Hampton, VA in July and August of 2024
- To study control of the structure to improve efficiency and reduce loads
- Up to Mach of 0.8 and dynamic pressure of 200 psf
- Using a test condition
 - Mach 0.7
 - Dynamic pressure 110 psf
- 10 Control Surfaces
 - Only Aileron C being used here
 - Using log sweep from 0.1 to 20 Hz
- 10 Strain gauges being used for updating

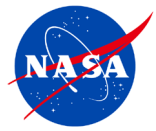


Credit: NASA/Mark Knopp

- High-order model
 - Many structural modes
 - Includes control surface modes
 - Unsteady aerodynamics
 - More suitable for many aeroelastic analyses
 - Unsuitable for model updating
 - 1,000s of different parameters
- Low-order model
 - More suitable for system identification
 - 10s of parameters
 - Quasi-steady aerodynamics
 - Small number of structural modes
- Both models are needed
 - Need a way to translate coefficients between models

$$\begin{aligned} [-\mathbf{M}\omega^2 + \mathbf{C}i\omega + \mathbf{K} - \bar{q}\mathbf{Q}(k)]\{\mathbf{q}\} &= [\mathbf{B}]\{\mathbf{u}\} \\ \{\mathbf{z}\} &= [\mathbf{\Phi}]\{\mathbf{q}\} \end{aligned}$$

$$\begin{aligned} [-\hat{\mathbf{M}}\omega^2 + (\hat{\mathbf{C}} - \bar{q}\hat{\mathbf{Q}}^1)i\omega + (\hat{\mathbf{K}} - \bar{q}\hat{\mathbf{Q}}^0)]\{\hat{\mathbf{q}}\} &= [\bar{q}\hat{\mathbf{Q}}^b]\{\mathbf{u}\} \\ \{\mathbf{z}\} &= [\hat{\mathbf{\Phi}}]\{\hat{\mathbf{q}}\} \end{aligned}$$

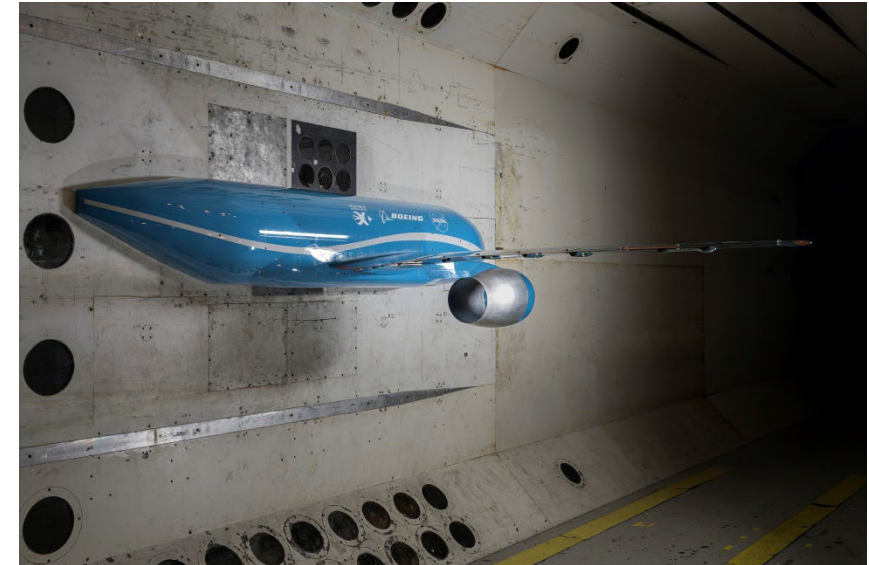


Method: Simplifying the Model

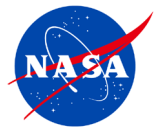


- Model reduction to create a low-order model from the high-order model
- Separate system into retained and deleted modes
 - Retaining
 - Wing first vertical bending
 - Vehicle pitch
 - Wing second vertical bending
 - Vehicle and nacelle pitch
 - Nacelle side bending
- Select a reference frequency
 - Low-order and high-order will match exactly
 - Frequency response should be close for other frequencies
 - The reference frequency can be significant
 - For IAWTM it is not
 - Using zero frequency (steady state) for matching
- Dynamic condensation, extended to include inputs and outputs
 - Solve for frequency response of deleted modes at reference frequency
 - Used to replace the influence of deleted modes on retained modes

- Dynamic condensation applied separately to unsteady aerodynamics
- Quasi-steady aerodynamics
 - Use unsteady aerodynamics at reference frequency
 - Real part of aerodynamics are steady coefficients
 - Divide imaginary part by frequency to get quasi-steady coefficients
- Model simplification is one way
- Ratio of low-order to high-order coefficients
 - Used to compare coefficients between models
 - Can be used to go from low-order to high-order
 - Multiply to go from high-order to low-order
 - Divide to go from low-order to high-order



Credit: NASA/Mark Knopp



Results: Model Updates



- Baseline models based on doublet lattice aerodynamics
 - Data here is Mach 0.7
- Using preliminary model updates
 - Updating 10 coefficients
 - The updates are of limited quality
 - They are reasonable and demonstrate the current method
- Quasi-maximum likelihood (quasi-filter-error) method to update
 - Applied in frequency domain
 - Considers sensor and process noise
 - State estimate corrects for sensor noise
 - Like a Kalman filter
 - Only uses data at a single time/frequency

Coefficients Updated

First bending due to first bending displacement*
Vehicle pitch due to vehicle pitch displacement
Second bending due to second bending displacement
Vehicle pitch due to vehicle pitch rate
Second bending due to second bending rate
First bending due to Aileron C
Vehicle pitch due to Aileron C
Second bending due to Aileron C*
Nacelle pitch due to Aileron C
Nacelle side due to Aileron C

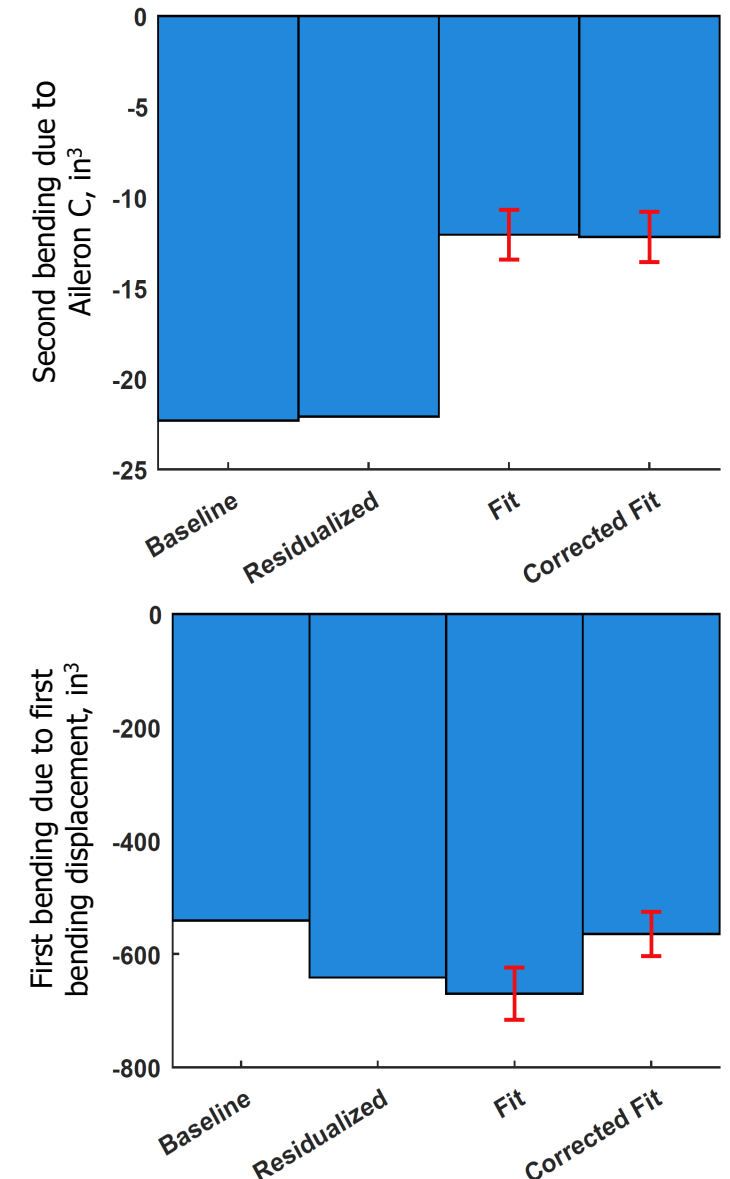
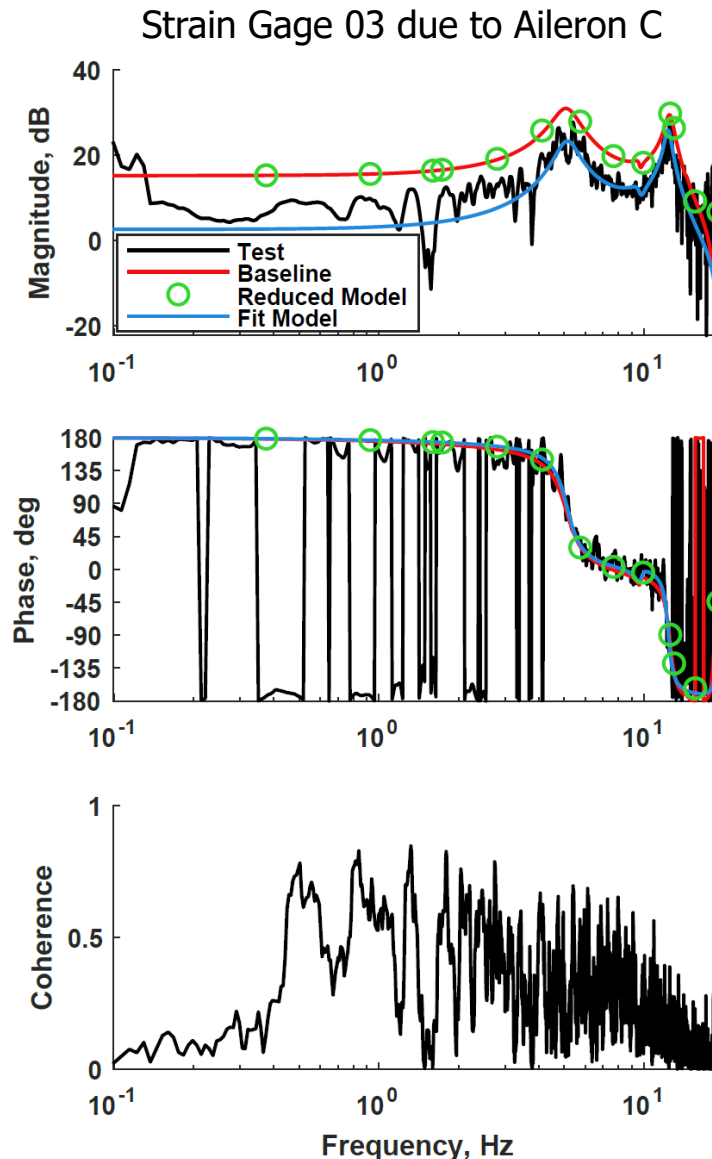
* Indicates coefficients discussed in this presentation



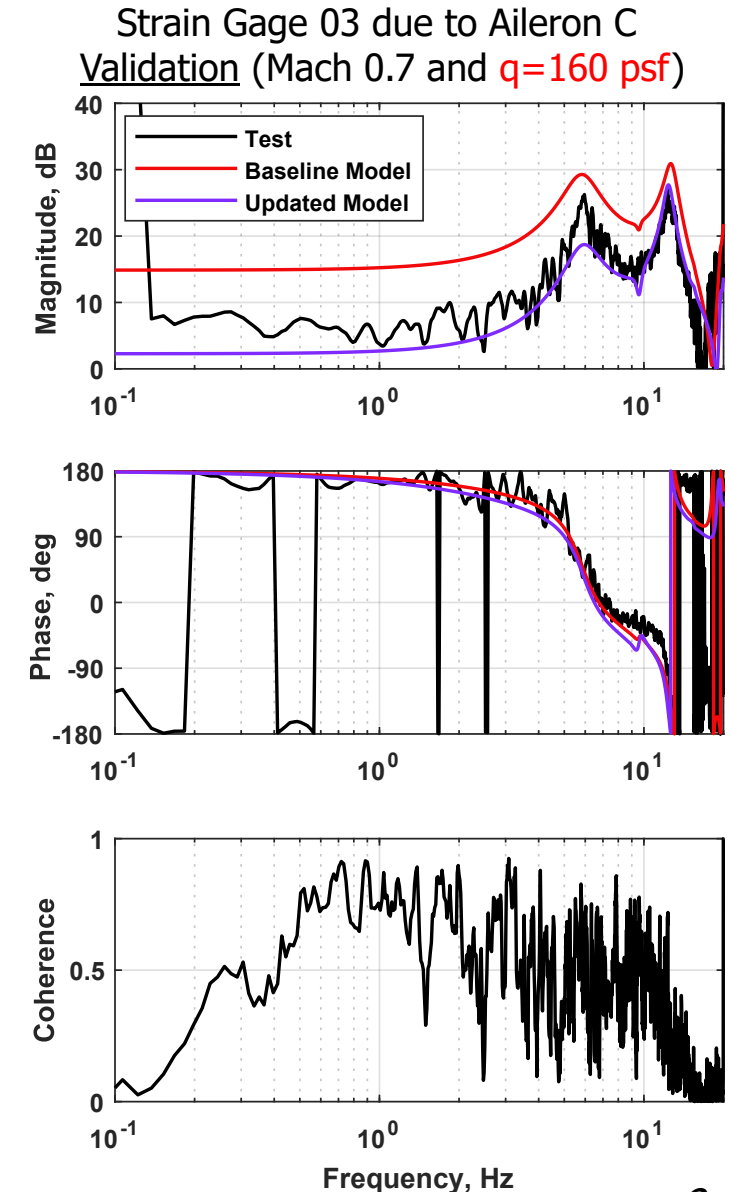
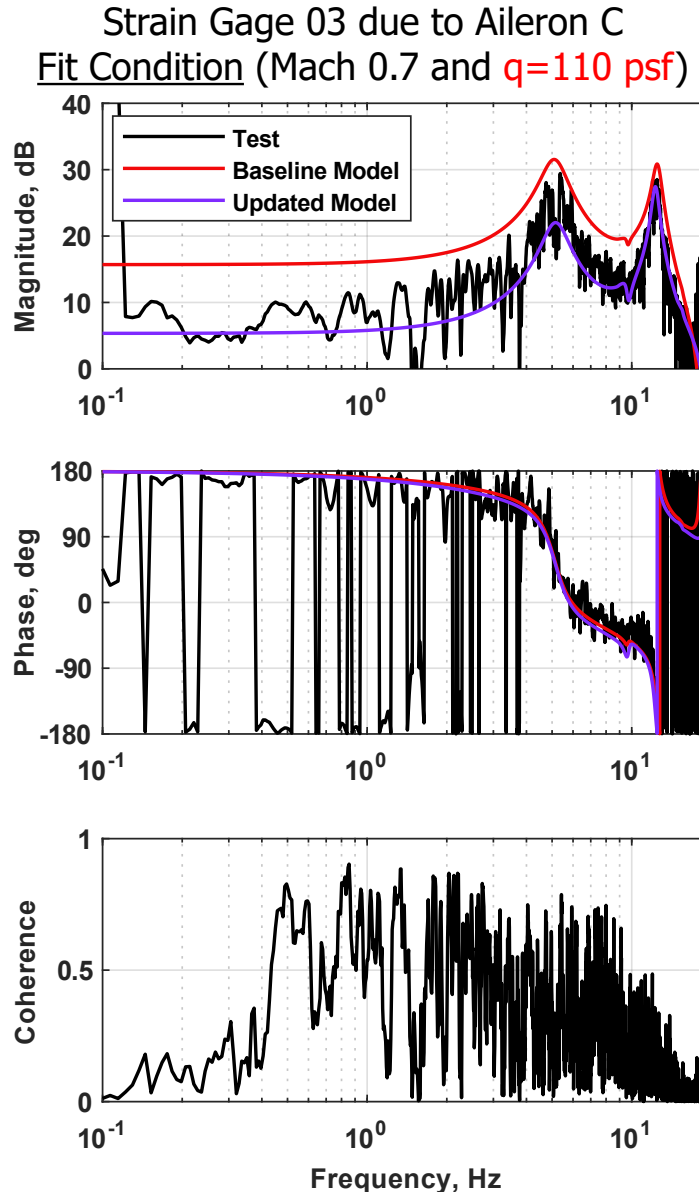
Updated Parameters



- Reduced model matches well to baseline (high-order)
- Fit model (low-order) matches test
 - Test does have relatively low coherence due to turbulence
- Second bending due to Aileron C coefficient
 - Baseline show large error relative to test
 - Low-order model is very close to high-order model
- First bending due to first bending displacement coefficient
 - Significant difference between baseline and fit coefficient
 - Very small difference between baseline and corrected fit
 - If the fit were not corrected, it would introduce more error than the baseline model.



- Updated parameters are applied to High-order model
- Updated model improves fit to test data
- Higher dynamic pressure used as validation case
 - Fit of updated model is better than baseline
 - Fit isn't as good as lower dynamic pressure
 - Errors may be due to limitations in model fitting, rather than application to high-order model



- Creating relationship between high-order (aeroelastic analysis) models and low-order (system identification) models
 - Model reduction gives one direction from high-order to low order
 - Look at ratio of coefficients to allow both directions
- Method applied to IAWTM test data
 - Able to improve the fit of the high-order model relative to the baseline model
 - Omitting the contributions of higher-order modes would cause fit model to have larger errors than the baseline



Credit: NASA/Mark Knopp